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The WINNER II Air Interface: Refined multiple access concepts

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Abstract:

This deliverable aims at refining the definition of suitable multiple access schemes for the WINNER system concept. Simulations of WINNER I candidate multiple access schemes have been carried out in different evaluation scenarios defined by the Concept Group scenarios. Based on the insights from these simulations, reference design of multiple access schemes for frequency-adaptive and non-frequency adaptive transmission in uplink and in downlink are proposed. Investigations on the benefit of a Direct Access Channel in the uplink and further work on integration of Space Division Multiple Access are reported. Co-existence and adaptation mechanisms of the multiple access solutions are also discussed. In addition, an initial concept for multicast and broadcast support is described. Finally, the MAC layer from WINNER I is evolved, and protocol mechanisms needed to achieve an adaptive MAC layer with low protocol overhead are discussed.

Keyword list:

Multiple Access, Medium Access Control, adaptive TDMA/OFDMA, B-IFDMA, B-EFDMA, SDMA, DAC, Multicast and Broadcast.

Executive Summary

This deliverable aims at refining the understanding and to define suitable multiple access schemes for the WINNER system concept. Simulations of WINNER I candidate multiple access schemes have been carried out in different evaluation scenarios defined by the Concept Group scenarios. Based on the insights from these simulations, reference design of multiple access schemes for frequency-adaptive and non-frequency adaptive transmission in uplink and in downlink are proposed for the evolved WINNER system concept.

The multiple access scheme for frequency adaptive transmission is chunk based TDMA/OFDMA, and it is integrated in a MAC architecture that enables large multi-user scheduling gains to be obtained together with link adaptation gains using strong FEC coding for large channel coding gains. The design of the multiple access schemes for non-frequency adaptive transmission enables intra-chunk sleep mode, low power amplifier backoff in the user terminal, large frequency diversity gains and low addressing overhead. The schemes are denoted B-IFDMA in the uplink and B-EFDMA in the downlink.

The above multiple access schemes for scheduled transmission are based on a short frame duration, which enables frequency-adaptive transmission at vehicular speeds and fast retransmissions, to obtain reliable links also for delay critical services. As an alternative access mode, a solution for a direct access channel (DAC) is investigated and compared to a scheduled uplink channel. It is shown that there is a delay advantage of a DAC channel, which could be useful in the system, especially for small uplink packets.

The different multiple access schemes have to co-exist in the system and means for co-existence, selection and switching between multiple access schemes are discussed. The conclusion on co-existence is to frequency multiplex the different multiple access schemes, except in low bandwidth deployment scenarios. In such scenarios, time-multiplexing could be favourable, especially in case of a low carrier frequency deployment.

The current status of the work on integration of Space Division Multiple Access is also reported. In principle, all the considered multiple access schemes can be combined with SDMA if base stations/relay nodes and/or user terminals are equipped with multiple antennas. However, spatial sub-channels are only virtual channels. Their orthogonality depends on the spatial correlation among the channels of the users in the multi-user scenario. Using SDMA in unfavourable conditions, i.e., when spatial sub-channels are not close to orthogonal, may result in excessive co-channel interference and degraded performance. SDMA algorithms are therefore required to cope with this issue and multiplex data streams only on sub-channels that are sufficiently uncorrelated.

Sub-optimal frequency/time/space strategies with good complexity-performance trade-offs are proposed and discussed. Most of these correspond to dividing the problem into sub-problems; a bi-dimensional frequency/time resource allocation and spatial grouping. Depending on the order of the two steps, two strategies are identified denoted User Grouping and User Selection. The properties of the approaches are discussed in the context of availability and quality of long-term and short-term Channel State Information (CSI) and Channel Quality Indicator (CQI).

Initial concept for multicast and broadcast support is discussed. Here, means to obtain macro-diversity gains by coordinated scheduling in a Relay Enhanced Cell (REC) and in clusters of cooperating RECs are identified as both feasible and important, but a detailed concept proposal is for further study. We also report on the work on impact of spectrum sharing for multiple access and investigations on receiver side interference mitigation techniques. Furthermore, an overview of the current status of the work towards a flexible MAC layer is given. Here, the concept of Frame Descriptor Tables (FDT) is identified as a promising tool to concurrently obtain adaptivity and low protocol overhead in the MAC layer.

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List of Acronyms and Abbreviations

ACPR	Adjacent Channel Power Ratio
AP	Access Point: Denotes either a base station (BS) or a relay node (RN)
ARQ	Automatic Repeat reQuest
AWGN	Additive White Gaussian Noise
BCH	BroadCast Channel
B-EFDMA	Block Equidistant Frequency Division Multiple Access
BER	Bit Error Rate
B-IFDMA	Block Interleaved Frequency Division Multiple Access
BLAST	Bell labs LAyered Space Time
BLER	BLock Error Rate
BPSK	Binary Phase Shift Keying
BS	Base Station
CA	Control signalling for frequency Adaptive transmission
CC	Convolutional Codes or Chase Combining
CDF	Cumulative Distribution Function
CDMA	Code Division Multiple Access
CG	Concept Group
CN	Control signalling for Non-frequency adaptive transmission
CP	Cyclic Prefix
CQI	Channel Quality Indicator
CRC	Cyclic Redundancy Check
CSI	Channel State Information
CSMA/CD	Carrier Sensing Multiple Access with Collision Detection
DAC	Direct Access Channel
DFT	Discrete Fourier Transform
DL	DownLink
DoA	Direction of Arrival
EXRR	EXhaustive Round Robin
FCH	Frame CHannel
FDD	Frequency Division Duplex
FD	Frame Descriptor
FDMA	Frequency Division Multiple Access
FDT	Frame Descriptor Tables
FEC	Forward Error Correction
FER	Frame Error Rate
FFT	Fast Fourier Transform
FH	Frequency Hopping
FRN	Fixed Relay Node
FSS	Fixed Satellite Services
FSU	Flexible Spectrum Usage
GoB	Grid of Beams
GMC	Generalised Multi-Carrier
HARQ	Hybrid Automatic Repeat reQuest
HPA	High Power Amplifier
IFDMA	Interleaved Frequency Division Multiple Access
IP	Internet Protocol
IRC	Interference Rejection Combining
ISD	Inter-Site Distance
ISI	Inter-Symbol Interference
ITU	International Telecommunication Union
LA	Local Area
LDPC	Low-Density Parity-Check Codes
LNA	Low Noise Amplifier
LOS	Line Of Sight
MA	In this report: Multiple Access. In other deliverables it also denotes Metropolitan Area
MC-CDMA	Multi-Carrier Code Division Multiple Access
MCS	Modulation and Coding Scheme
MAC	Media Access Control
MIMO	Multiple Input Multiple Output
MISO	Multiple Input Single Output
MRC	Maximum Ratio Combining
MSE	Mean Square Error
MT	Mobile Terminal
NLOS	Non Line Of Sight
NMSE	Normalized Mean Square Error

OFDM	Orthogonal Frequency Division Multiplexing
OFDMA	Orthogonal Frequency Division Multiple Access
PA	Power Amplifier
PAPR	Peak to Average Power Ratio
PARC	Per Antenna Rate Control
PDU	Protocol Data Unit
PER	Packet Error Rate
PF	Proportional Fair
PHY	Physical Layer
PLM	Physical Layer Mode
PUPC	Per-User Power Constraint
QAM	Quadrature Amplitude Modulation
QoS	Quality of Service
QPSK	Quadrature Phase Shift Keying
RAC	Random Access Channel
RAN	Radio Access Network
REC	Relay Enhanced Cell
RF	Radio Frequency
RLC	Radio Link Control
RN	Relay Node
RR	Round Robin
RS	Resource Scheduler
RTU	ReTransmission Unit
RUT	Relay User Terminal
SAP	Service Access Point
SAR	Specific Absorption Rate
SBS	Score Based Scheduling
S&C	Sharing and Co-excistence
SDMA	Space Division Multiple Access
SIC	Successive Interference Cancellation
SINR	Signal to Interference and Noise Ratio
SNR	Signal to Noise Ratio
SISO	Single-Input Single-Output
SM	Serial-Modulated
TBCH	Transport Broadcast Channel
TCC	Transport Common Control Channel
TCP	Transmission Control Protocol
TDAC	Transport Direct Access Channel
TDC	Transport Data Channel
TDD	Time Division Duplex
TDMA	Time Division Multiple Access
TPCH	Transport Paging Channel
TRAC	Transport Random Access Channel
UE	User Equipment
UL	UpLink
UMTS	Universal Mobile Telecommunications System
UT	User Terminal
VIC	Virtual Connection Identifier
VoIP	Voice over IP
WA	Wide Area
WCDMA	Wideband Code Division Multiple Access
WLAN	Wireless Local Area Network
ZF	Zero-Forcing

1. Introduction

The WINNER system is being developed to provide users with high quality wireless services. It should support users in various environments who use terminals with different capabilities and it should further support a cost-efficient deployment. Such ambitions place high requirements on the radio system. For instance, supporting a stationary indoor user who is surfing the web using a laptop poses very different requirements on the system compared to providing wireless access to a user travelling by high speed in a car.

In WINNER, these challenges are addressed by the design of the radio system based on a single radio access technology that may be adapted to a large range of scenarios. The built-in adaptivity puts requirements on basically all parts of the radio interface, from the physical layer and upwards. The high degree of adaptivity of the WINNER system affects not only single links but also the multiple access (MA) scheme(s) and the MAC protocols.

The WINNER architecture is unified and yet flexible enough to handle deployments from wide area coverage to high capacity hot spots. The WINNER radio interface presents a unified set of services to higher layers, yet includes some specific parts that provide the required flexibility.

To provide flexibility and convergence in a structured way, the concept of *modes* was introduced in WINNER I, see e.g. [WIND210]. A *physical layer mode (PLM)* can be defined where there is a significant impact (discontinuity in adaptation) of PHY functionality on the radio interface concept. Two PLMs have been defined [WIND210]:

- **Frequency division duplex (FDD)** transmission, performed over paired bands and supporting half-duplex FDD terminals.
- **Time division duplex (TDD)** transmission over unpaired band.

Although any PLM can be configured for any kind of deployment, the FDD mode is evaluated primarily in wide-area cellular deployment scenarios, using frequency bands of different width. The TDD PLM is primarily evaluated in metropolitan and local-area deployment scenarios.

A *system mode* represents a specific combination of physical layer modes and MAC modes (Section 8.3 of [WIND76]). All higher layer functions are designed to be mode-independent (generic) and form the unified interface of the WINNER system. There are three MAC modes within the concept:

- **FDD cellular MAC**
- **TDD cellular MAC**
- **MAC for peer-to-peer transmission**, at present designed using the TDD physical layer mode

The combinations of PHY and MAC modes thus define three WINNER system modes, and parameterisations within modes provide further flexibility and adaptability. A flexible multi-mode protocol architecture is discussed in [WIND35]. It enables efficient interworking between different system modes. The basic idea is to define mode-specific protocols only when really needed.

The focus in this deliverable is on refined understanding of the performance of the candidate multiple access (MA) schemes that were considered during WINNER I, identifying their applicability in different scenarios and to discuss co-existence and adaptive selection of promoted MA schemes. In some cases, the adaptation may be performed with the goal to enhance the transmission quality over a single link, e.g., by improving the reliability of the data transfer or increase the data rate. Adaptation may further be executed e.g. to enhance the spectral efficiency or the energy efficiency of the network and can be performed in time, frequency, or in space. For instance the network may have to react upon temporal changes in the traffic load, the user distribution, or the interference.

With adaptive selection of MA scheme, we mean methods and procedures that determine which MA scheme should be used for a specific user flow. This assignment can be adapted on a superframe time scale. Since the multiple access adaptation is a procedure that can affect several user flows and typically will be based on relatively stable input variables, such as network load user distributions, it is foreseen that the multiple access adaptation is performed rather infrequently.

Depending on the required data rates of all users within the cell, time and frequency resources can be allocated adaptively to these different MA schemes by a resource control unit. Similarly, the adaptation can be performed in space as a way to configure the transmission in cells of different types and with different capabilities. If possible, the adaptation of multiple access schemes should be coordinated between cells to enable a mitigation of intercell interference, especially in lower loaded scenarios where not all resources are needed. However, the system should be operational even if such coordination is not possible.

This deliverable summarizes the current state in the MA identification and co-existence & adaptation development within WINNER II. It identifies the most promising MA schemes for the WINNER reference design as input to the Concept Group deliverables [WIN2D6133], [WIN2D6134] and [WIN2D6135]. The outline of the deliverable as follows,

- In chapter 1 we introduce the chunk based WINNER MAC architecture along with the superframe concept and scheduling architecture.
- In chapter 2 we make a review of the WINNER I candidate MA schemes.
- In chapter 3, we discuss the proposed multiple access concepts for the uplink and
- in chapter 4 we discuss the proposed multiple access concepts for the downlink.
- In chapter 5, we continue with discussing co-existence of MA schemes and their selection and switching criteria.
- In chapter 6 we discuss briefly some aspects of spectrum sharing, and
- finally in chapter 7, we briefly discuss some supporting MAC control functions for the multiple access concept. Further work on specific MAC protocols is required, and some supporting MAC protocol techniques are discussed in section 7.2 and Appendix C.

The detailed results of design investigations and performance comparisons are presented in the Appendices. In Appendix A, we show the recent simulation results for some of the MA schemes considered, which complement the studies during WINNER I, reported especially in [WIND26], [WIND24] and [WIND210]. In Appendix B we present, in more detail than in chapter 3 and 4, the proposed new multiple access schemes B-IFDMA and B-EFDMA for the non-frequency adaptive uplink and downlink within the reference design of the WINNER system concept. These schemes are motivated by the insights gained from the simulation results in Appendix A and WINNER I along with investigations on sleep mode and power amplifier backoff requirements for user terminals. Finally, Appendix C discusses the Frame Descriptor Table Concept that will be useful in the upcoming design of the MAC protocols based on the proposed Multiple Access schemes in this deliverable.

1.1 Chunk and Frame Structure

The physical layer of the WINNER radio interface uses generalised multi-carrier (GMC) [WIND210] as the transmission format, as this technique enables flexible switching between different forms of multi-carrier and (frequency-domain generated) serial modulation. GMC configured as standard cyclic-prefix (CP) OFDM is the preferred option for the downlink as well as uplink transmission when terminal power consumption is not a limiting factor. For other cases, GMC configured as serial modulation may be the preferred option in the uplink.

The basic time-frequency unit for resource partitioning is denoted a *chunk*. It is chosen in such a way that it experiences essentially flat fading in its time-frequency extent also in largely frequency selective channels and for users at vehicular speeds. Thus, its extent in frequency and time is small, Figure 1-1a), and consists of a rectangular time-frequency area, which contains payload symbols and pilot symbols. It may also contain control symbols that are placed within the chunks to minimise feedback delay (in-chunk control signalling). The number of offered payload bits per chunk depends on the utilised modulation-coding formats, and on the chunk sizes. The number of offered payload bits per chunk layer can be adjusted to the estimated SINR, by dynamically adjusting the modulation and coding formats. In the WINNER design, the frame duration is furthermore made short to ensure a low transmission delay over the radio interface. This enables a fast channel quality measurement and resource allocation cycle.

In transmission using multiple antennas, the time-frequency resource defined by the chunk may be re-used by spatial multiplexing. A *chunk layer* represents a discretized spatial dimension, Figure 1-1b).

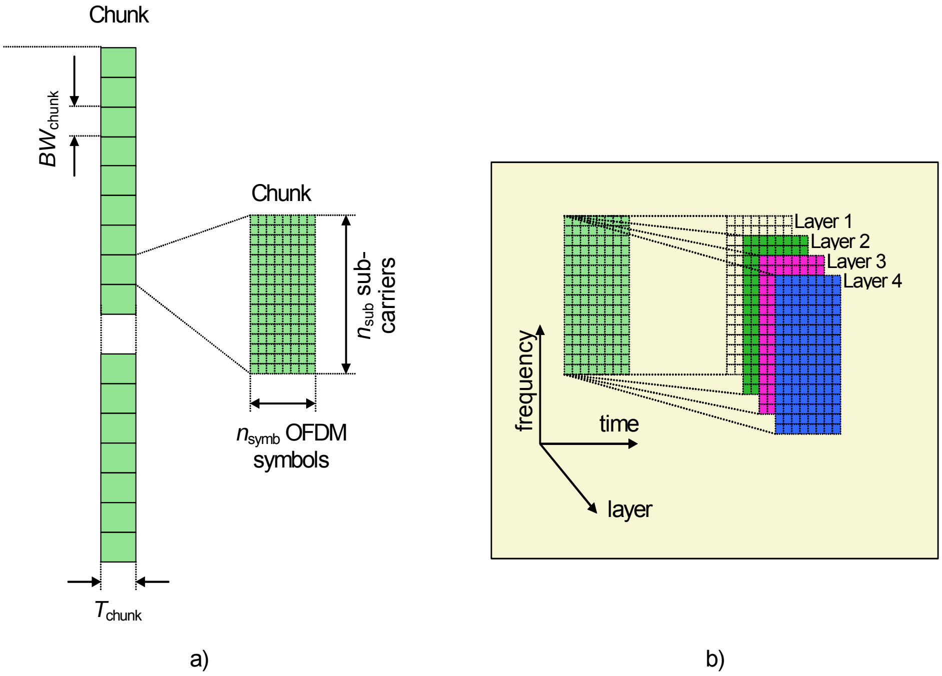

Figure 1-1: a) Multi--carrier Downlink physical channel structure and chunks. b) Chunk layers obtained by spatial re-use.

Chunks are pre-assigned in each Access Point (AP) for use with different GMC settings. This setup is dynamically adjustable on a super-frame timescale, based on e.g. flow type, terminal capabilities and channel quality. In addition, the antenna resources are dynamically configured based on a generic processing chain for different spatial processing techniques based on the available chunk layers, see [WIND210] chapter B.2. They can be used differently for different flows to/from a user terminal. The current WINNER II numerology for the baseline design, which has been used in early (2006) simulations for refinement towards a final reference system design, is defined in [WIN2D6131]. It is also presented in Appendix A.

For scheduled flows, chunks can be allocated for either *frequency-adaptive* or *non-frequency adaptive* transmission. In frequency-adaptive transmission, resource allocation and link adaptation relies on accurate channel quality information (CQI) and adapts towards the small-scale fading of the channel. These chunks are envisioned to carry in-chunk pilot and control signals, since the accuracy of the channel quality information depends on a fast control loop.

The link adaptation per chunk in frequency adaptive transmission provides link adaptation gains, and investigations on the best way to perform the link adaptation in the chunk based system concept, especially for larger FEC blocks, is discussed in [WIN2D222]. In addition, with frequency-adaptive transmission, the Resource Scheduler in the MAC layer has the possibility to allocate each chunk to the user that can utilize it best, under QoS and fairness constraints. This provides potentially large multi-user scheduling gains, as illustrated by the simulation results of Appendix A.

Non-frequency adaptive transmissions are used whenever frequency-adaptive transmission is infeasible. In non-frequency adaptive transmission, the link adaptation is used over all chunks for a flow during the frame duration. The selection and switching criteria between frequency-adaptive and non-frequency adaptive transmission is under investigation and the current status is reported in this deliverable.

1.2 Superframe Structure

The chunks and chunk layers are pre-assigned to different types of data flows, on a super-frame time scale, see Figure 1-2. They are then used in a flexible way to optimise the transmission performance.

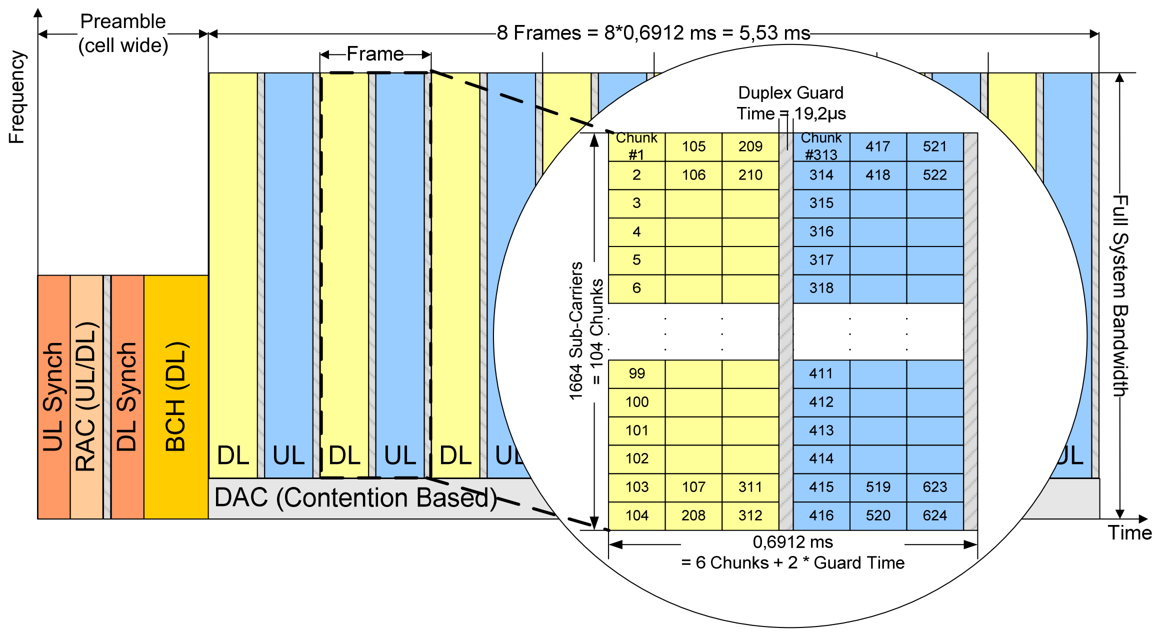

Figure 1-2: Superframe example (from [WIND210], numbers are subject to change) with eight TDD frames and asymmetry 1:1, a preamble containing a broadcast channel (BCH) and synchronization pilots, and a set of frequencies reserved for contention based peer-to-peer communication. The frame for TDD cellular transmission with its chunk-based substructure (from [WIND210], numbers are subject to change) has been enlarged.

1.3 The MAC Architecture

The MAC layer of WINNER II is based on the design of WINNER phase 1, presented in [WIND210], [WIND35] and [WIND76]. The first outline of the WINNER II design is given in [WIN26138] and is summarized in Section 7.1.

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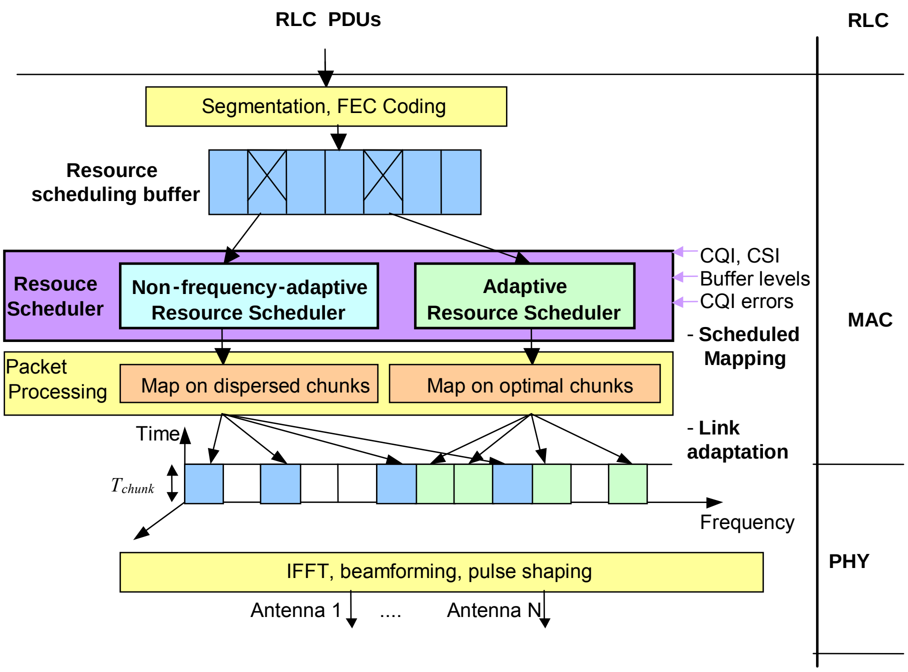

Figure 1-3: MAC flow control of scheduled downlink flows

The WINNER MAC layer organizes the transmissions of all data flows within one relay-enhanced cells. The data flows are handled individually and are associated with different transport channels. In the physical layer, transmissions associated with different transport channels are performed within different parts of the WINNER super-frame that is exemplified in Figure 1-2. Contention-based uplink RAC transmission as well as downlink system broadcasts (BCH channel) utilize the super-frame preamble. A contention-based uplink DAC channel uses a fixed frequency allocation within the main part of the superframe, see section 2.5. The largest part of the super-frame is organized into *frames* and it is reserved for *scheduled traffic,* defined by the Transport Data Channel (TDC). This includes frequency-adaptive uplinks and downlinks, non-frequency adaptive uplinks and downlinks, multicast and broadcast downlink transmissions as well as their associated control signaling.

The flow control architecture in Figure 1-3 uses the coding and link adaptation approaches that were studied in [WIN2D222] and maps flows onto transmission resource units that are prescribed by the Multiple Access schemes discussed in the present report. It illustrates the downlink transmission of Radio link control (RLC) protocol data units (PDUs) that are to use scheduled transmission. Packets that belong to flows which use the RLC acknowledged mode (Section 5.5 of [WIN2D6138]) have been segmented or concatenated by the RLC layer into segments, for which end-to-end ARQ is performed. Within the MAC layer, these segments are denoted ***retransmission units*** (RTUs). The same segments are used also by the MAC-controlled Hybrid ARQ mechanism (HARQ), which performs retransmission over one hop. The MAC layer adds a retransmission sequence number to RTUs for flows that use HARQ. Chase combining (retransmission of the whole RTU) and various Incremental Redundancy schemes (transmission of additional redundant bits) are special cases of the considered HARQ schemes.

After attachment of a MAC flow address, a segment number and an optional checksum (CRC), these RTUs are optionally FEC encoded with an *outer code*. They are then punctured and bit-interleaved, to form one or several (outer) code blocks, which are denoted ***FEC blocks***. In the baseline designs and in the reference designs described in Chapter 5 of [WIN2D6135], a RTU can be segmented into one or several FEC blocks, of pre-determined size. In an envisioned proof-of-concept implementation example of the reference design, the FEC blocks of scheduled flows are queued per flow in a *resource-scheduling buffer*. Its queues are drained with bit-level granularity. One buffer exists in each BS and RN and, for uplink traffic, also in each UT.

The scheduled bits are mapped onto the physical channel resource units. This mapping may use adaptive modulation only, or it may use both adaptive modulation and an optional chunk-specific coding (an *inner code*).

For each buffer, a ***resource scheduler*** determines which queues are to be drained, and to what extent. The resource scheduler optimises the allocation of physical channel resources under constraints, such as interference avoidance, power allocation constraints and (for some types of flows) hard delay constraints. The resource scheduler works on a time-scale of the *slot* (the uplink or downlink part of the frame in TDD, a half-frame in FDD). It is implemented within the MAC layer of the BS where it controls BS-to-UT and BS-to-RN links, and in the RN, where it controls RN-to-UT links. Since frequency-adaptive transmission is feasible up to a limiting velocity (around 70 km/h) or down to a certain average user SINR [WIND24], [SFS+05], the resource scheduler performs frequency-adaptive scheduling when feasible. Otherwise non-frequency-adaptive scheduling is used; the scheduled bits are then mapped onto sub-carriers in well-dispersed chunks and/or chunk layers.

The designs outlined in Chapter 3 and Chapter 4 aim at attaining a very short delay over the air interface. In the transmission control systems, a scheduling computation delay of max. 0.1 ms has been assumed. The computation delay for channel quality or state prediction is likewise assumed to be max. 0.1 ms. Regarding the delay of ACK/NACK for (link) retransmission, we have to add the delay of decoding.

The over-all problem is then essentially a scheduling problem, where bits from different flows are to be mapped onto sets *of time-frequency–spatial resource units,* whose characteristics are pre-determined and whose location within the super-frame is know.

The key questions to be answered on the following pages are: what are these resource units, and what types of flows should be mapped onto what types of units?

2. Overview of Considered Multiple Access Schemes

In this chapter, the multiple access schemes currently considered for the WINNER RAN are introduced. The baseline selection of MA schemes is based on an assessment of candidate schemes performed mainly during WINNER phase 1, where for each transmission mode, suitable schemes were identified in [WIND210]. A summary of results and conclusions from WINNER phase 1 can be found in Section 3.1.6 of [WIND210] and it has been reproduced here for convenience in Appendix A.1.

The primary MA schemes have been refined and/or complemented by alternative schemes in WINNERII. The suitability of the alternative schemes for certain transmission situations (e.g., low or high load situations) has been demonstrated by simulation results.

After an introduction of each of the considered WINNER MA schemes, different variants of SDMA are described which can be combined with the other MA schemes to introduce a further dimension of user separation. Furthermore, the contention-based DAC uplink channel, which needs a specialized MA method, is presented. Finally, the problem of selection and adaptation of MA schemes are introduced.

2.1 Chunk- or Symbol-based TDMA/OFDMA

To combine the envisaged spectrally efficient OFDM (or, in its generalized form, GMC) modulation scheme in WINNER with a MA method based on the assignment of subcarrier groups seems a natural choice and will lead to an easy implementation. The combination of OFDMA with a TDMA component provides a large amount of MA and resource assignment flexibility with only little additional complexity required. The granularity of resource assignment is determined by the chunk dimensions (number of subcarriers and OFDM symbols per chunk).

Therefore, in frequency-adaptive transmission on the WINNER downlinks and uplinks**,** chunk-based TDMA/OFDMA is the primary multiple access scheme of WINNER phase 1 [WIND210]. The data flows are mapped exclusively onto individual chunks (or chunk layers for MIMO transmission). The spectral efficiency of a wide-area cellular system under full load, employing half-duplex FDD and chunk-based TDMA/OFDMA was estimated at 1.2 bit/s/Hz/cell ([WIND78] B.2.1.2.1) for a SISO system with convolutional coding and HARQ with chase combining.

Variation and adaptation possibilities within the TDMA/OFDMA scheme include the adaptive assignment of chunks to users, depending on their fading profile, data rate, and quality constraints, as well as a reallocation of frequency-adaptive and non-frequency-adaptive chunks depending on the available CSI feedback for the active mobile stations in the current cell. The accuracy of CSI feedbacks depends, e.g. on the velocities of mobile stations, and on the warm-up phase of quality predictors.

A possibility for obtaining a finer granularity in the assignment of radio resources is to drop the chunk-based partitioning in the time direction and assign resources on an *OFDM symbol basis*. The subcarriers assigned to one user will then probably still exhibit chunk granularity but they can be more widely spread across the available spectrum, thereby providing enhanced frequency diversity for non-frequency adaptive transmissions. Stricter timing constraints are required on the uplink to avoid intersymbol interference if the assignment is made on an OFDM symbol basis. In non-frequency-adaptive uplinks, symbol-based TDMA/OFDMA has been chosen as the primary multiple access scheme in WINNER phase 1 but alternatives were found in phase 2 (see section 2.3).

2.2 Multi-Carrier Code Division Multiple Access (MC-CDMA)

If the chunk resource unit is to be shared by multiple users, this can be accomplished by applying spreading codes in the time and/or frequency domain. In the latter case, each user symbol is spread across a number of subchannels equal to the employed spreading factor. This variant of MA is called MC-CDMA. In WINNER phase 1, the assumption was to employ spreading and code-multiplexing only within chunks to minimise non-orthogonality of the received signals.

In MC-CDMA, frequency diversity is exploited by spreading the data symbols across subcarriers. This additional diversity becomes especially important for small packets that would otherwise utilize only a narrow frequency band. Accurate CSI information is not essential in this scheme, and it appears to be suitable especially for non-frequency-adaptive downlinks. MC-CDMA was identified as the primary multiple access scheme for this transmission mode in WINNER phase 1. In a fully loaded cell, the spectral efficiency of this scheme was shown to be approximately 0.75 bit/s/Hz/cell in SISO transmissions [WIND78] under multipath conditions that partly destroy the orthogonality of different signals. If only a single user is present, the reduced interference leads to an improved spectral efficiency of 3.25 bit/s/Hz/cell (SISO) and 4.3 bit/s/Hz/cell (2x2 MIMO) [WIND78].

A preliminary result in Section 7 of [WIND26] indicated that for non-frequency adaptive transmission, MC-CDMA exhibits inferior performance relative to OFDMA regarding cell throughput in fully loaded cells, due to the multiple access interference within cells. In low-load situations, MC-CDMA performed better than OFDMA due to its improved rejection of inter-cell interference.

2.3 DFT-precoded OFDMA with Blockwise or Interleaved subcarrier allocation

DFT-precoded OFDMA has been investigated as an alternative to symbol-based TDMA/OFDMA in non-frequency-adaptive uplinks. DFT-precoded OFDMA is a combined modulation and multiple access method that can be described as an equivalent single-carrier modulation scheme, with either ***frequency-hopped subcarrier blocks*** or ***equidistant interleaved subcarriers***. The latter variant is called IFDMA and was shown to be superior to symbol-based TDMA/OFDMA especially when a lower number of subbands is assigned to each user. All variants of DFT-precoded OFDMA can be designed to generate signals with lower envelope variation than normal OFDM.

Table 2-1 gives an overview of different DFT-precoded OFDMA schemes.

Table 2-1: Variants of DFT-precoded OFDMA schemes

Variant of DFT precoded OFDM scheme	subcarrier allocation	frequency hopping	number of sub-carriers per user
DFT-Block-OFDMA/TDMA	blockwise	no	subset
FH-DFT-Block-OFDMA/TDMA	blockwise	yes	subset
IFDMA/TDMA	interleaved	no	subset
FH-IFDMA/TDMA	interleaved	yes	subset
DFT-OFDM/TDMA	blockwise	no	all

The low envelope variation and increased frequency diversity offered by DFT-precoded schemes such as IFDMA may be beneficial for the overall cell throughput, and can provide a larger cell range. As compared to OFDM, a gain of 2 dB with respect to power backoff is attained by IFDMA, according to [WIND210], section G.7.1. However, regarding frequency diversity, it should be noted that for specific system setups, other sources of diversity (e.g., spatial or polarization diversity) may be available. The gain from added frequency diversity will then become less prominent.

In Appendix A, a detailed comparison of different DFT precoded OFDMA schemes is presented. The candidate schemes are DFT precoded OFDMA/TDMA with (possibly frequency-hopped) blockwise or interleaved subcarrier allocation. To summarize the results of this analysis, it was found that

- In a wide area scenario due to their higher frequency diversity gains IFDMA/TDMA and FH-DFT-Block-OFDMA/TDMA outperform DFT-Block-OFDMA/TDMA significantly. This gain was still observed for the MISO case and is also expected for MIMO transmission.
- Compared to FH-DFT-Block-OFDMA/TDMA, the IFDMA/TDMA scheme provides a lower pilot symbol overhead for channel.estimation.
- Compared to (FH)-DFT-Block-OFDMA/TDMA, IFDMA/TDMA provides a lower computational complexity as well as lower envelope variations.

One drawback of IFDMA is its higher sensitivity to carrier frequency offsets (e.g., caused by Doppler effects or oscillator imperfections) compared to DFT-Block-OFDMA/TDMA. However, these offsets can be estimated at the base station and reported to the mobile stations where they can be precompensated.

The main conclusion from these investigations is that IFDMA/TDMA can be regarded as an interesting option for candidate for non-frequency adaptive transmission in the uplink.

2.4 Space Division Multiple Access (SDMA)

In principle, all the multiple access methods that were described above can be combined with spatial separation or combination techniques if base stations and/or user terminals are equipped with multiple antennas. The WINNER requirements and design targets defined in phase 1 [WIND210], e.g. the required spectral efficiency, cannot actually be attained without spatial diversity, and spatial reuse gains enabled by spatial multiplexing or Space Division Multiple Access (SDMA). While FDMA and TDMA exhibit a number of similarities, SDMA differs significantly because a perfect spatial separation of users can in general not be guaranteed. The number of available spatial channels (layers) depends on the rank of the channel matrix and therefore on the environment and on the number of transmit and receive antennas. The system performance can hence be optimised by properly selecting the groups of users sharing time-frequency resources through SDMA. The complexity of calculating the optimum solution of this three-dimensional resource allocation (including the multiple access) problem becomes unfeasibly high already for relatively small number of users and chunks. Therefore, a separated approach is recommended which combines a bi-dimensional time/frequency resource allocation with a separated SDMA accommodation of user-groups. According to the order in which the two steps are carried out, different sub-optimal solutions can be distinguished. The design of the SDMA component depends on the characteristics of the transmission scenario, especially the availability and accuracy of CSI and the user distribution within the service area.

A deeper discussion addressing the quality and type of the available CSI, is given in Section 3.3. We briefly anticipate here that the following SDMA strategies can be distinguished:

- **Short-term SDMA** that relies on short-term CSI, so that precoding methods that cancel or minimise the interference among beams can be applied;
- **Long-term SDMA** is based on long-term channel characteristics, such as the users' spatial correlation properties;
- **Opportunistic SDMA** relies only on short term CQI on a given grid of beams, which can be selected randomly or be predefined.

A further classification can be given according to the kind of beamforming strategy applied. More specifically, since the power distribution in the network is defined by the transmitter, a classification in terms of beamforming strategy is based in the following on the way the antenna weights of the transmitter are generated[1] and their adaptivity:

- **Non-adaptive antenna schemes:** The antenna weights are not adapted, with the exception that antennas can be turned on and off, e.g. as in PARC and BLAST.
- **Fixed scheduled fixed beams:** A predefined set of fixed beams, each defined by a fixed set of antenna weights, are scheduled in a fixed cyclic manner. The allocation of time/frequency resources (chunks) per beam may or may not be accomplished in an adaptive way, e.g. according to the varying service demands within the beams and the users' spatial correlation properties. A periodic scheduling allows relatively simple tracking of users and channel statistics. A non-cyclic scheduling allows, however, more demanding beams, e.g., serving a hot spot, occur multiple times within one period.
- **Adaptively scheduled fixed beams:** Fixed sets of beams are scheduled to optimize the system according to given criteria, e.g. maximum capacity, coverage, etc., and adaptively with respect to the distribution of the user and channel characteristics, e.g., spatial distribution, speed, required services etc. Fixed sets of beams imply a number of interesting properties. UL and DL experience the same beamforming leading to a feedback reduction. Moreover, if the assignment of chunks to a beam is fixed, or only slowly adapted, new algorithms to minimize inter-cell interference become feasible.
- **Adaptive beams:** The antenna weights are adapted and are not selected from a fixed set. Examples are Eigenbeamforming and weighting for space-time (pre)coding. These schemes approach optimality from an information theoretical point of view. The disadvantage, especially for the most advanced schemes, is the need of high quality short term CSI feedback and therefore the sensitivity to channel estimation errors and the cost of the feedback channel. Much simpler approaches outperform the optimized ones if the feedback requirements dominate the cost function.

The two classifications are not independent. One may form a matrix of possible alternatives, of which

[1] Note that focus on the transmitter is necessary make the classification unambiguous. BLAST is an example where the transmitter is non-adaptive but the receiver weights the receive antenna signals.

some are more natural combinations than others. Short-term SDMA relies on the use of adaptive beams, while opportunistic SDMA is based on adaptively scheduled fixed beams. Long-term SDMA can be based on fixed scheduled fixed beams, adaptively scheduled fixed beams or adaptive beams.

2.5 Uplink Direct Access Channel (DAC)

In uplinks, the main share of the traffic is expected to be carried over scheduled channels that are coordinated by the base station (network). Scheduled channels may be characterized as conflict-free and transmissions must be preceded by a scheduling request message transmitted from the user terminal to the base station. After receiving the scheduling request, the base station assigns (grants) resources to the user terminal. In the WINNER system, scheduled transmission may be frequency-adaptive or non frequency adaptive.

Scheduled transmission, once up and running, may provide highly efficient data transfer but because of the request-grant phase it is also associated with a relatively high access delay. For small data packets (that are transmitted rather infrequently), accordingly, the access delay may constitute a relatively large part of the packet delay. This type of traffic may hence be better served by a contention-based channel, in which packets are transmitted without any prior handshake with the base station.

In WINNER, the uplink direct access channel (DAC) provides the possibility of contention-based uplink data transfer. Resources for the DAC are frequency multiplexed with resources for scheduled channels, as illustrated in Figure 1-2 depicting the WINNER TDD super-frame structure.

2.6 Requirements on Multiple Access Schemes for the WINNER System

In the sections above, we have introduced several MA schemes as candidates for the WINNER system. The adaptivity of the WINNER system implies that there will be a need for multiple MA schemes in the system concept. This calls for identification and integration of co-existence and selection criteria of MA schemes into the MAC design. These issues are further discussed in chapter 5.

The appropriateness of the MA scheme(s) for the WINNER system is mainly due to properties of the multiple transmissions themselves (DL/UL, frequency-adaptive/non-frequency-adaptive transmission), which depend on factors like:

- *CSI adequacy and availability*,
- *Required control signaling overhead in downlinks and reporting overhead in uplinks,*
- *traffic structure and statistical properties*,
- network load
- *deployment scenario (wide/metropolitan/local area), available radio bandwidth.*
- temporal, spectral and spatial structure of the received interference,
- temporal, spectral and spatial structure of the generated interference,
- *robustness against propagation delays and Doppler spread*,
- *terminal capabilities*.

The effects of the conditions marked in italics are targeted in this deliverable. The influence of the last two factors are discussed below, while the other factors are discussed in Section 5.2.

2.6.1 Robustness of MA Schemes Against Propagation Delays and Doppler Spread

Due to the transmission channel, the received radio signals will be subject to variability in the time and frequency domains, and a general aspect of radio transmission especially over a larger distance is the propagation delay. Because of the different distances of user terminals to the access point, their individual delays vary. The difference in distance can reach several kilometres, depending on the cell size. This is important especially for MA schemes that contain a TDMA component with the granularity of one OFDM symbol.

On the downlink, this delay variation is not critical because each user terminal receives the multiple signals of the access point with the same delay, maintaining the proper time separation of signals for different users. On the uplink, the users' synchronized transmit signals are received with different delays and could therefore be received partly out of the designated symbol interval. If, for example, the difference in distance between two user terminals is 1 km, the delay difference amounts to approximately 3.3 µs – this shift in propagation time results in inter-symbol interference if no countermeasures are taken.[2] The use of a timing advance for uplink transmissions is a well-known remedy. Methods for timing estimation and adjustment in OFDM systems are discussed in Appendix B.4.1 of [WIND210].

Another aspect of propagation delay is the possible violation of TDD duplexing order by remote synchronized cells. Normally, all cells follow the same duplex order. But due to the propagation delay, the downlink signals of remote cells may interfere with uplink signals of a central cell and vice versa. This may pose intercell interference challenges especially in metropolitan scenarios where the TDD mode will be primarily used (local area deployments are characterized by isolated cells).

The duplexing distance in the TDD superframe is 19.2 µs, corresponding to a propagation distance of 5760 m. For the presently considered cell layout in metropolitan area scenarios, this duplex interference can be completely neglected.[3]

The time dispersion can be further characterized by the channel impulse response. The WINNER 1 channel model for urban environments (C2) and NLOS propagation was established with maximum impulse response duration of only 1.47 µs [WIND54]. With the current WINNER FDD guard time dimensioning, the inter-symbol interference among OFDM symbols can thus be neglected for the C2 channel model.

In some propagation scenarios, especially in wide area deployments, the combination of propagation delays and long channel impulse responses can nevertheless result in inter-symbol interference between different users on the uplink. Multiple access schemes that assign longer periods of subsequent symbols to one user (e.g. using a chunk-based instead of a symbol-based TDMA component) reduce the interference power from this kind of interference.

Moving user terminals subject to multipath propagation are the main cause of dispersion in frequency. The resulting Doppler spectrum is determined by the angles and attenuation factors of the different propagation paths. Although a single dominant frequency offset may be cancelled out by the frequency tracking filter of the receiver, the Doppler spread is typically centred at the original frequency and extends symmetrically to both positive and negative frequency shifts - an example is the Jakes spectrum which results from an infinite number of propagation paths. At a carrier frequency of f = 3.9 GHz and a high terminal speed of, e.g. v = 100 m/s = 360 km/h, the maximum Doppler frequency $f_m = \frac{vf}{c}$ is approximately 1300 Hz. Compared to the FDD subcarrier distance of 39062.5 Hz, this means that only a small power fraction of each subcarrier will be smeared over to neighbouring carriers (a detailed calculation of inter-carrier interference should take into account the power spectral densities of the transmitted signal and the Doppler spectrum).

Generally, all multiple access schemes that exhibit a fine granularity of subcarrier assignment may avoid inter-carrier interference by leaving certain subcarriers unused in lower load situations.

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[2] According to the current WINNER FDD chunk dimensioning, each OFDM symbol has duration 25.6 µs plus a cyclic prefix/guard time of 3.2 µs. Therefore, propagation delays representing a distance up to a little less than 1 km do not interfere with the useful part of the neighbouring OFDM symbols originating from a different user terminal. For TDD transmissions in Metropolitan or Local Areas, the cyclic prefix is only 1.28 µs, so that distance differences from 384 m may pose interference on the OFDM symbols. Even for lower delay differences, the channel impulse response duration and interference within cyclic prefixes may cause performance degradations.

[3] Following the Manhattan Grid scenario in Figure 3.2 of [WIND6131], the minimum distance of base stations of the t-th tier is $d = \sqrt{2}t(s+b)$ where s is the width of streets and b the width of building blocks. The default settings are s = 30 m and b = 200 m. This means that the signals of tiers 18 and beyond would cause this kind of duplexing interference. Note, however, that the signals of tier 18 are each attenuated by a factor of $(1/36)^{\gamma}$ = 54.5 dB (compared to a transmitter with equal power, located within the central cell at half the minimum distance to the first tier base stations, and given an attenuation exponent of γ = 3.5), and can therefore be neglected.

2.6.2 Terminal Capabilities

The employment and adaptation possibilities of the described multiple access schemes depend on the capabilities of the user terminals that are active in the current cell. Terminal requirements for WINNER are described, e.g., in [WIND6111]. The most prominent terminal capabilities relevant for identification of appropriate multiple access schemes are listed here:

- **Transmit Power:** Especially in Wide Area deployments, the maximum transmit power may limit the cell size. The *short-term peak power* determines the short-term maximum data rate in the uplink, while the *long-term average transmit power* determines the maximal long-term average uplink data rate. The long-term averages are determined by regulations ([WIN2D6111]) and heat dissipation constraints. The short-term peak power may be larger than a certain agreed maximum average transmit power. However, there will certainly be a peak power limit imposed by the power amplifiers of the mobile transmitter. Transmission techniques that generate a high signal envelope variation in the uplink (i.e., the envisioned OFDMA-based MA schemes) will cause a need to limit the average output power due to this peak power constraint. In a situation where this limit is below the limit that would otherwise be imposed by regulations or heat dissipation constraints, it will affect the attainable average uplink data rate. In such situations, the use of transmission schemes that generate low envelope variations will increase the attainable transmission range or data rate .
- **Number and type of Antennas:** The WINNER I assumption is that all terminals should be equipped with at least two antennas to reach the WINNER performance requirements. If these two antennas are spatially separated, this facilitates the employment of additional SDMA components in multiple access and the re-use of time-frequency resources. If the antennas are used for polarization diversity, an SDMA configuration with a smaller number of subchannels will have to be used in certain cases.
- **Support for Multiple Access Schemes:** With respect to multiple access, modulation and coding, it is conceivable that not all terminals will support all possible schemes. For example, some terminals may not (or only) support DFT-precoded multiple access. Furthermore, certain MIMO techniques like the Space-Time Block Coding for DFT precoded OFDMA may only be implemented in a subset of active user terminals. Unrestricted adaptation towards these schemes then becomes impossible in the current cell or SDMA beam. A new grouping of users through forced handover or rearrangement of SDMA beams may resolve the problem.
- **Duplex Schemes:** Not all terminals may support both FDD and TDD. Depending on the future spectrum situation, this could pose severe restrictions on the coverage area for these terminals. However, since the MA schemes discussed here are not TDD or FDD-mode specific, this has little influence the identification of appropriate multiple access schemes.

2.7 Power Control

2.7.1 Uplink

In contrast to spread spectrum systems with uplinks based on low-correlated channelization sequences, the WINNER system concept is based on orthogonality among user signals. Under ideal assumptions like perfect synchronization, infinite dynamic range in the BS receiver, unlimited granularity in link adaptation etc, it would be beneficial to let the UT transmit with full power in the uplink. This is under the assumption that the user will get enough resources from the scheduler to use the power in an efficient way to combat the small scale fading in case of non-frequency adaptive transmission and to obtain essential coding gains. But the UT is actually normally energy limited by its energy source, typically a battery, and thus power efficiency techniques for the UT are important. This topic is addressed w.r.t. power amplifier efficiency and micro-sleep mode in Appendix B.

The base station has a finite dynamic range in its receiver and the digital baseband implementation relies on a finite number of quantization levels. In addition, due to e.g. Doppler spread, pulse shaping and inaccuracies in frequency synchronization, users are not perfectly orthogonal in the frequency domain. In the time domain there are inaccuracies in synchronization and excessive delay spread could introduce certain interference among users if a TDMA component is introduced. In the spatial domain, we have other-user interference from other beams in the cell, i.e. other chunk layers, and in a multi-cell scenario we have co-channel interference from other cell tiers.

For the above reasons, it could be expected that there should be an upper limit on the allowed UT transmit power spectral density per chunk layer also in an OFDM based cellular system. Its purpose would be to limit various types of interference on the transmissions from other users. The strategy could be open loop based, where the user estimates the channel gain over an averaging time window, or it could be closed loop based trying to track a target value on e.g. SINR per chunk as seen at the BS. The estimation and tracking loop is not expected to follow the small-scale fading, but only the path loss and shadow fading.

From WINNER I, there is no power control strategy outlined in the system concept, and in this deliverable there are different assumptions made in the simulations in Appendix A. Thus, an uplink power control strategy for the WINNER System Concept remains to be developed.

2.7.2 Downlink

In the downlink, the orthogonality among the users is better than in the uplink, but there are still different channel gains to different users. The default assumption for the power control in the downlink is to adapt to the different user channels by link adaptation using adaptive modulation and coding, while the transmit power is regarded as constant unless there are specific restrictions in certain chunks and chunk layers due to e.g. interference avoidance techniques and spectrum sharing.

2.8 Impact of Relaying

In order to allow for cost efficient and flexible system deployment, relaying is considered as one of the key technologies under investigation in WINNER. Relaying can be used to increase the coverage area of base stations, increase the capacity, and cover shadowed areas. Cells where relays are introduced are referred to as Relay Enhanced Cells (REC). In principle an arbitrary number of relays can be deployed between base station and user terminal. However the current WINNER concept is primarily designed for two hop communication, i.e. one relay between base station and user terminal. Relays are assumed to have a fixed location. They are decode-and-forward Layer 2 relay nodes, which essentially control their own sub-cells within the REC.

Relays are usually connected to their serving base station by a fixed LOS link, containing the aggregate flows currently transmitted/received by the RN, and using potentially a significant fraction of the chunk resources. It is generally agreed that it is advantageous to use narrow and fixed beams in both directions of the relay link, thereby avoiding interference to and from other signals in the current cell. The channel characteristics of the relay link are more or less stationary, i.e., very good channel knowledge can be assumed at the BS and RN. Furthermore, constraints on the signal envelope variations and complexity constraints are not as strict as for user terminals.

Other types of relay nodes can be considered, which are less complex and cheaper. In these cases the links with the relays would be less reliable, and resemble more the link between base station and terminal

Relaying can be supported by the following multiple access-related functions and techniques:

Resource partitioning divides the resources within a super-frame. The resource partitioning divides the bandwidth over different access types (contention versus scheduled traffic), between frequency-adaptive and non-frequency adaptive transmissions and between UT transmissions and relay links ([WIND210], section C.1.1). Hierarchical or distributed resource partioning within the relay-enhanced cell is favoured to limit the required signalling overhead [WIND35],[WIN2D351]. In general TDD systems, the propagation delays may cause inter-symbol interference (ISI) between relays when transmitting in the same time slot in the downlink. In uplinks, mobile terminals transmitting to the base station could interfere with mobile terminals transmitting to the relays. With the presently assumed TDD numerology and cell small sizes, such delays pose rather small problems.

Spatial domain solutions: SDMA and beamforming solutions may be used to exploit spatial diversity between different areas covered by relay nodes as discussed in Section 4.3. SDMA techniques will mainly be used to optimize the performance of two-hop RECs. The main challenge when applying SDMA for relay links is the identification of other links that can be used simultaneously in the spatial domain. Independent beams may be identified to the different relay stations or to groups of relay stations depending on their separation in the spatial domain.

3. Multiple Access in Uplink

3.1 Frequency-adaptive Scheduled Uplink Flows

The multiple access scheme for frequency-adaptive uplinks remains unchanged from WINNER phase 1: Chunk-based **TDMA/OFDMA** is used in both FDD and TDD modes. The same scheme is used for downlinks; see section 4.1.

Chunk-based TDMA/OFDMA means that flows are mapped onto individual chunk layers. The mapping is exclusive within the cells, i.e. each chunk layer carries data from only one flow. Individual link adaptation is used within each chunk layer, based on the predicted SINR that will be perceived within that particular chunk layer for that particular user, at the time when the transmission will occur. Chunks are designed to work well for adaptive transmission. The chunk has to be sized so that the channel variability is limited within it. Therefore, one set of link adaptation parameters can be used within the whole chunk with only little performance degradation, relative to a case with perfectly time- and frequency invariant channel gains within each chunk.

Fast control loops for FDD and TDD, that enable frequency-adaptive uplink transmission also at vehicular velocities, have been proposed in Section 3.1 of [WIND24]. The uplink control is based on a request for transmission in frame *j-2*. If granted, the transmission is scheduled and prepared during frame *j-1* and is then performed in the uplink slot of frame *j* (section C.1.5 of [WIND210]). The total delay from request to reception is 2.5 frames, or around 1.7 ms, over one hop.

A reference design for the frequency-adaptive transmission scheme has been outlined in Section 5 of [WIN2D6135]. Briefly, it is based on using of retransmission units (RTU) that can have one of a few allowed sizes. Each RTU is encoded with a strong outer code, and then mapped onto several chunk layers that use individual link adaptation parameters. Adaptive modulation and adjustment of the code puncturing is used for the link adaptation, but chunk-specific inner coding is not used in the present reference design. Chase combining is suggested as the reference retransmission scheme.

The resource scheduler at the BS/RN controls the uplink transmission in frame *j*, by using downlink control signalling during frame *j-1*. The type of signalling, and its overhead, is discussed in Section 5.2.3 of [WIN2D6135]. It is assumed to require 6 symbols to control an uplink chunk within the following uplink frame. This represents a control overhead of 6/96 = 6.3% in the FDD mode and 6/80 = 7.5% in the TDD mode.

The prediction of the properties of TDD uplinks can be based on prediction of the downlinks. Predictors would then be placed in the user terminals and predict the downlink channel (and the interference level, to the extent possible), based on downlink pilots. The CQI prediction reports would then be transmitted to the resource scheduler at the BS/UT, using appropriate compression and subsampling techniques (see Section 3.1.4 of [WIND24].) With compression, the required compound feedback data rate is not high, around 0.50/*s* bits for each CQI value, where the integer *s* represents a subsampling factor in time.[4]

In the case of frequency-adaptive *FDD uplinks,* channel reciprocity cannot be used for estimating or predicting the instantaneous uplink channel/CQI based on downlink pilots. Therefore *all* potential users that compete for a set of FDD uplink resources have to send pilots over *all* these resources with sufficient rate in time and sampling rate in frequency, in chunks that are at present used for payload traffic as well as in all other potentially useful chunk. Only then can all potential uplink channels from all active user terminals be predicted by the BS/RN so that the resource scheduler at the BS/RN can determine the appropriate user allocation and link adaptation for each uplink chunk. This problem was considered in Section 3.1 of [WIND24] where the use of superposed (overlapping) uplink pilots was suggested to limit the required pilot overhead, which might otherwise grow towards 100% if the number of competing users

[4] Results from Section 3.1.4.4 in [WIND24]. The factor s is inversely proportional to the UT velocity v and to the carrier frequency f. At v = 50 km/h and f = 5 GHz, s=2 is adequate when using the source coding scheme investigated in Section 3.1.4.4 of [WIND24]. As an approximation formula, we may then use, s = Int[500/vf], where v is scaled in km/h and f in GHz. This gives, for example. s = 15 at 10 km/h and 3.4 GHz carrier.

is large. Furthermore, the use of Kalman estimation was proposed as a solution to the problem of estimating and predicting the time-varying and frequency-selective channels from the multiple users with maximal accuracy. Further work on such frequency-adaptive uplinks is ongoing.

As an alternative option for the multi-user adaptive uplink, a serial modulated time- (but not frequency-) adaptive TDMA solution has been investigated. This option was investigated in [WIND210] Appendix G.4.1. It is in Appendix A4.1.6 of this report compared to an adaptive TDMA/OFDMA uplink with non-perfect frequency alignment. The conclusion of this study, using a rather narrow system bandwidth, is that the adaptive TDMA/OFDMA uplink is better than using serial modulated TDMA and that the difference is expected to be even larger in a wider system bandwidth. This is due to the channel averaging effect of a serial modulated signal within a TDMA slot that spans the whole bandwidth. This severely limits the attainable multi-user scheduling gains.

3.2 Non-frequency Adaptive Scheduled Uplink Flows

This section motivates and outlines a new baseline and reference design for multiple access for non-frequency adaptively scheduled uplink flows: *B-IFDMA*. Further details are provided in Appendix B.

The non-frequency adaptive uplink relies on diversity and transmissions are adapted according to long-term channel fluctuations. To avoid frequent packet errors due to deep signal fades or interference peaks, diversity techniques are applied. Spatial, frequency, and time diversity can be used to limit the signal fading and additional interference diversity may be achieved by means of frequency hopping. The short WINNER transmission times (chunk durations), results in limited time diversity, although Hybrid ARQ techniques could potentially help to mitigate fading and (bursty) interference. Spatial diversity may be available in many but not necessary all scenarios. This implies that a multiple access scheme design *exploiting frequency diversity* is desirable. Power limited cell edge users may furthermore benefit from a signal with low envelope fluctuations, which favours *DFT precoded* transmission techniques.

I Appendix A, different uplink alternatives are evaluated in the wide area scenario accounting for pilot overhead, frequency diversity, power efficiency, and computational complexity. Interference diversity is not considered. IFDMA/TDMA is here identified as the most promising scheme for non frequency adaptive uplink transmission, due to the high degree of frequency diversity, low signal PAPR, and reasonable pilot overhead. Accordingly, for non frequency adaptive transmission IFDMA/TDMA is the selected working assumption from these simulation results.

However, the investigations on sleep mode in Appendix B show that there is a large gain for the UT power efficiency if intra-chunk sleep mode is supported, i.e. the UT is given the possibility to enter sleep mode during a fraction of the chunk duration. The power savings in the UT due to lower power amplifier backoff requirements and intra-chunk sleep mode are essentially of the same kind, i.e. they can be both used for longer battery usage time, lower component costs and less cooling problems, which also enables a smaller form factor of the UT.

This calls for a trade-off between the low-envelope variation characteristics of IFDMA and the larger intra-chunk sleep mode gains in OFDM-symbol based DFT-precoded FDMA/TDMA schemes. At the same time, the high frequency-diversity gains which are characteristic of IFDMA should be maintained. The proposed multiple access scheme called ***Block Interleaved Frequency Division Multiple Access (B-IFDMA)*** defined in Appendix B is motivated by the above considerations. B-IFDMA can be used in FDD as well as in TDD, and is proposed for all the deployment scenarios.

The key idea is to design a scheme that trades a small loss in envelope variation (relative to IFDMA) against a large gain in the effectiveness of intra-chunk micro-sleep for saving terminal power. This is done by localizing the transmission in a rather small duration of the chunk, so that the transmitter may be turned off during the remaining chunk duration. From the analysis in Appendix B it seems very likely that the intra-chunk sleep mode gains can be made larger than the loss in power amplifier backoff. We then obtain a scheme that has *all* the features that have been identified as desirable for uplink multiple access using non-frequency adaptive transmission.

The idea is realized by letting each UT use a block of several IFDMA signals, which utilize a few adjacent subcarriers. Instead of single subcarriers that are regularly spaced in frequency, we thus use small blocks of subcarriers that are regularly spaced in frequency. The transmission interval is correspondingly shortened in time, relative to IFDMA, which uses the whole chunk duration. In the proposed baseline scheme for evaluation, the block size is ***4 subcarriers by 3 OFDM symbols***, in both the

FDD and the TDD mode. Of the 12 time-frequency symbols within a block, one is a known pilot that is used for channel estimation to enable coherent detection.

Figure 3-1 exemplifies the uplink working assumption for a bandwidth comprising eight chunks out of which four are allocated for non frequency adaptive transmission (and the remaining four are used e.g. for frequency-adaptive transmission). In the picture, a chunk comprises four blocks in frequency and five blocks in time. (This could represent a TDD uplink slot at 1:1 asymmetry, if we remove the old chunk boundaries in time and use one chunk duration = one slot = 15 OFDM symbols.) In the left example two users are allocated four regularly spaced blocks. The transmission of user 1 and user 2 are orthogonal and the regular sub-carrier allocation assures a low signal envelope variations, although they are not as low as for single-subcarrier based IFDMA. In the right-hand example, the same two users are assigned twice as many resources to enhance the offered data rate. User 1 is assigned eight sub-carriers during the same OFDM symbol. In this case the transmission comprises resources corresponding to eight IFDMA signals. The final output signal could either be constructed as the sum of eight separately precoded IFDMA signals or as a signal in which all used sub-carriers are jointly precoded. Both options increase the signal envelope variation, but the results in Appendix B indicate that the latter alternative is beneficial. User 2, on the other hand, is assigned four sub-carriers on two consecutive block durations (6 OFDM symbols). Here, the envelope variation becomes smaller but the transmission time is doubled, which affects the power saving possibilities (the intra-chunk sleep mode).

Transmission scheduling for non-frequency adaptive transmission is, typically, performed without consideration of the short-term variation of the channel quality. Scheduling decisions may instead be based on e.g. queue lengths, fairness, and user classes. Adaptive modulation and coding may be used on a slow basis accounting for e.g. the average SINR. Moreover, for the cases when pre-coded OFDM transmission is used, e.g. in the form of IFDMA, frequency adaptation is precluded. In comparison to the frequency adaptive transmission described in section 3.1, the non-frequency adaptive transmission hence provides limited adaptivity and no multi-user scheduling gains. On the other hand, the transmission is designed to be robust against time dispersion and fading and the feedback and signalling overhead is considerably lower. Means for improved interference diversity is identified as an important further study.

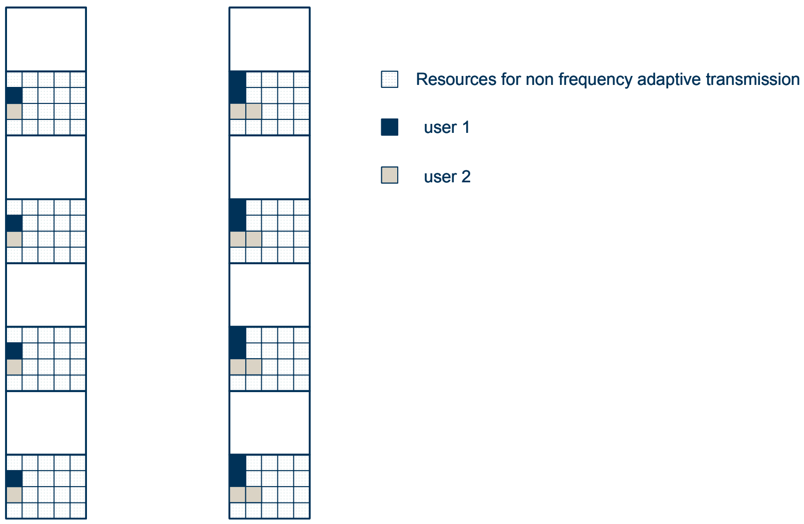


Figure 3-1: Two example of resource usage for non-frequency adaptive uplink transmissions. Time is in the horizontal direction, frequency in the vertical. The large dotted areas are chunks and the small squares represent blocks. Pilots for channel estimation are included in each block.

The required control signalling consists of an uplink request during frame *j-1*, the transmission of allocation information in the following downlink slot, followed by the transmission during the uplink slot of frame *j*. The total transmission delay over the air interface (excluding the decoding delay) is 3 slots or 1.5 frames, or 1.0 ms. over one hop. This is one frame less than was assumed for the frequency-adaptive transmission. The transmission requests are themselves transmitted as short packets by non-frequency adaptive transmission, in a part of the resource pool held free from the scheduled payload traffic. The downlink control information is transmitted by downlink non-frequency adaptive transmission, using the B-EFDMA scheme outlined in Section 4.2 below.

3.3 Direct Access Channel[5]

Many mobile data applications require frequent transfer of packets on the uplink. Some of them, including terminal emulation, credit card verification, or transmission of acknowledgments for downlink TCP packets, tolerate little delay, and typically have small packet payloads. This section presents a contention-based MAC for Direct Access Channel (DAC) on the uplink. By taking advantage of the availability of multiple receive antennas at the base station (BS) the resulting DAC delivers short packets with very small delay, and it achieves quite high spectral efficiency. The DAC design is applicable in networks using TDD or FDD.

With a traditional contention-based MAC protocol (e.g. slotted Aloha), terminals schedule transmissions autonomously from the BS, and packets may be transferred with very little delay; however, whenever more than one terminal transmit simultaneously on the same slot; a collision occurs (i.e. no packets get received by the BS). Consequently, the maximum throughput of slotted Aloha is limited to 0.36 packets/slot. With slotted Aloha, as long as the offered load is well below 0.36 packets/slot, the packets experience very short delay. Unfortunately, the resulting throughput with slotted Aloha (in terms of the number of correctly delivered packets per slot) is quite low, and this leads to quite low spectral efficiency. Over wired-line channels, CSMA/CD MAC protocols are frequently used (e.g. Ethernet) to achieve very short packet delays with quite high spectral efficiencies. It is well known that CSMA/CD performs well only when the terminals can detect idle or collision periods quickly (e.g. within a tenth of the slot duration). Due to the hidden node problem in a wireless environment, the functionality for carrier sensing and collision detection must be provided by broadcasting, on the DL, the status (busy/idle) of the uplink DAC. Unfortunately, this broadcasting approach adds at least a few slot delays to detection of idle or collisions on the DAC; hence, CSMA/CD is not well suited for use over wireless channels with very short packet delay target (e.g. packet delay target of the order of one slot duration).

With multiple receive antennas and spatial division multiplexing techniques, the BS can simultaneously receive multiple packets transmitted on the same slot and on the same sub-carriers. This is typically referred to as multi-packet reception. For example, if the BS is capable of receiving two packets simultaneously, the maximum throughput with slotted Aloha protocol can be shown to be 0.86 packets/slot. More generally, the physical-layer can be configured such that as long as the number of simultaneously transmitting terminals on the DAC is less than or equal to M, the packet from every transmitting terminal will be received correctly with probability Pc.

To achieve error-free packet transmission over the DAC channel, one can use a simple stop-and-go ARQ scheme with exponential back off, and a fixed-delay, positive acknowledgment. A terminal that is not waiting for an acknowledgment to a previously transmitted packet can transmit a not-yet-acknowledged packet on any slot on the DAC. If this packet is correctly received at the BS, an acknowledgment will be sent on the downlink with a fixed delay relative to when this packet was transmitted. If an acknowledgment is not received at the expected time following the transmission of the packet on the DAC, the mobile assumes that the packet was involved in a collision, and it performs exponential back off. After a terminal transmits a packet on the DAC, and before the expected arrival of the acknowledgment for this packet, this terminal does not transmit anything on the DAC.

For both TDD and FDD modes, the slot size used on the DAC is T_{chunk}. Each mobile will be assigned a unique Virtual Connection Identifier (VIC) by the network before it is allowed to use the DAC, and each mobile includes its VIC in every packet it transmits on the DAC.

To enable multi-packet reception at the BS, the following is included:

- i) slow power control,
- ii) single-user, MMSE receiver at the BS,
- iii) slow rate control, and
- iv) channel estimation/user-detection pilots.

Referring to Figure 3-2, the signal transmitted by the *m*-th mobile on the DAC is slow power controlled such that at the BS, the spectral density of the signal received from this mobile (averaged over all frequencies) is fixed at *P0* W/Hz. Note that this slow power control does not compensate for fast fading

5 This section is based on work by Kambiz Zangi (kambiz.zangi@ericsson.com). It has been adjusted to fit into the WINNER II framework.

effects. Prior to joining the DAC, the *m*-th mobile is assigned a pilot pattern by the network, and each transmission by this mobile on the DAC will include this pilot pattern. On each uplink frame, the BS will use this pilot to detect whether a packet was transmitted by the *m*-th mobile, and if so, to estimate the channel between the mobile and the BS antennas. For each mobile transmitting on the DAC, the BS will use a single-user MMSE receiver to generate soft values for the bits transmitted by the mobile.
The data rate on the DAC may be determined by the base station and may, e.g., be based on the SINR that is possible to receive at the base station and the desired probability of correct packet reception Pc. The receiver SINR may, in turn, be estimated accounting for the received signal power spectral density (P0), the combined thermal noise and other-cell interference (N0+I0) measured at the base stations, the number of simultaneously transmitting terminals (M) and the number of receive antennas at the base station (N). Note that all mobiles will transmit the same number of information bits in each frame of the DAC.

Performance evaluations in Section A.4.1.3 indicate that in comparison to a pure scheduled uplink access, a hybrid uplink scheme combining scheduled access with a contention-based DAC may reduce the packet delays on the uplink. Thanks to short round-trip times, however, the scheduled access in itself provides already low packet delays. Further studies are needed to identify possible scenarios in which the very low packet delays provided by the DAC channel are beneficial.

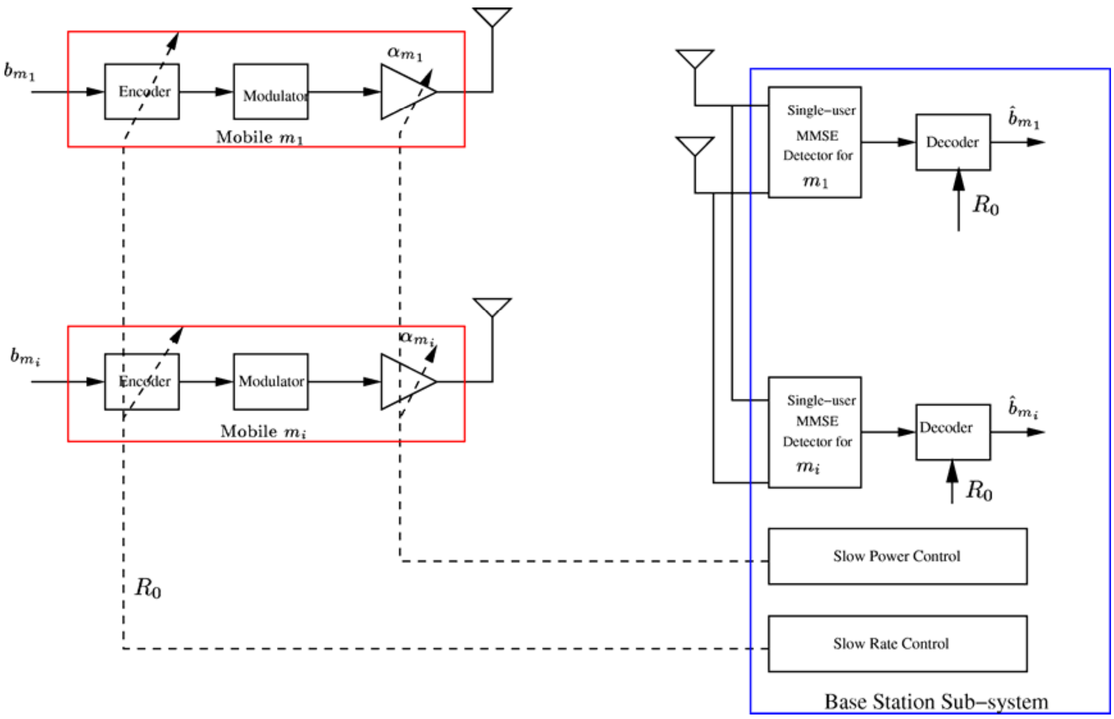


Figure 3-2: Terminal transmitters and a base station receiver.

3.4 Integration of Space Division Multiple Access in Uplinks

A typical WINNER deployment is foreseen to comprise multi-antenna base stations and terminals. Multiple antennas at the transmitter and at the receiver side may be used to achieve diversity, directivity or multiplexing gains. In uplinks, multi antenna base stations may facilitate increased robustness to fading and interference (spatial diversity) and spatial multiplexing. Spatial multiplexing may be realized in two forms. In the first variant, a single user terminal transmits multiple streams on the same time-frequency resource (chunk). This requires that the terminal is equipped with multiple transmit antennas, it may increase peak data rates and it is sometimes referred to as single user MIMO (SU-MIMO). In the second alternative, multiple user terminals are scheduled for transmission on the same time-frequency resource. This may be referred to as uplink SDMA or multi-user MIMO (MU-MIMO). Uplink SDMA may provide increased (average) user data rates.

With SDMA, a user (on average) obtains access to the channel more frequently. Moreover, for uplink SDMA, the total available transmit power increases with the number of user terminals scheduled for transmission. For the same reason, scheduling multiple users for simultaneous transmission may also lead to an increased interference. Uplink SDMA requires that the downlink signalling message transmitted from the base station to the user terminals supports (is large enough to allocate) multiple users that are scheduled on the same chunk. Moreover, the used uplink pilot patterns must be designed such that reliable channel estimation is possible also when multiple users in the same cell transmit using the same chunk. To achieve good performance, proper scheduling and link adaptation algorithms are needed as well.

In Section A.4.1.4 of Appendix A, the performance of uplink SDMA is evaluated in a multi-cell base coverage urban scenario, using a 5 MHz transmission bandwidth. One, two, or four randomly selected users are scheduled for transmission on the same chunk. Base stations are equipped with four antenna elements per sector and IRC is used to suppress (intra-cell and inter-cell) interference. Furthermore, the performance with and without successive interference cancellation (SIC) at the receiver is evaluated. The results indicate that in the studied scenario, SDMA reduced the post-receiver SINR and hence the instantaneous data rates. Average data rates are still improved, however, since users get access to the channel more frequently. Without SIC, the average cell throughout increases from around 11 Mbps/cell to 19 Mbps/cell when going from one to four simultaneously scheduled users. With four scheduled users, SIC at the base station provides an additional throughput improvement of 20 %.

4. Multiple Access in Downlink

4.1 Frequency-adaptive Scheduled Downlink Flows

The multiple access scheme for frequency-adaptive downlinks remains unchanged from WINNER I, since it has worked well, and no investigations have found any better alternative. Thus, frequency-adaptive transmission uses chunk-based **TDMA/OFDMA**, in both FDD and TDD modes. See Figure 4-1 for an illustration.

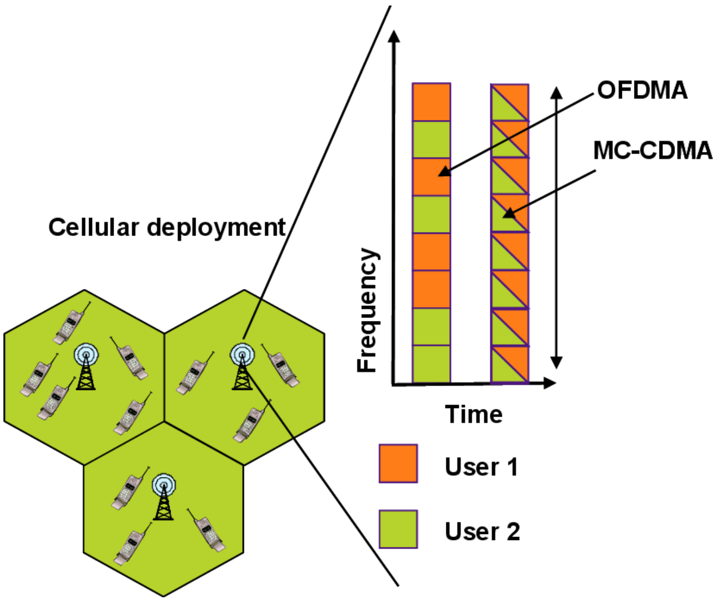


Figure 4-1: Illustration of multiple access schemes. The TDMA/OFDMA scheme (left-hand alternative) represents exclusive allocation of chunk layers to flows.

A control loop for frequency-adaptive transmission has been described in detail for the SISO case in Section 3.1 of [WIND24] and it is also summarized in Section 3.4.2 of [WIN2D222]. A very short delay over the air interface has been targeted. A transmission can be initiated during the downlink slot of frame *j-1* and then be performed during the downlink slot of frame *j*. If the whole RTU is transmitted within the slot, this corresponds to a delay (excluding decoding) of 1.5 frames, or 1.0 ms. A detailed reference design for frequency-adaptive transmission is presented in Section 5 of [WIN2D6135]. It was outlined very briefly in Section 3.1 above.

Since the resource scheduler is positioned at the BS or the RN, the control of both the downlink and the uplink flows to/from the UT require the use of downlink control information. The downlink transmission in frame *j*, is prepared by using a small amount of downlink control signalling during frame *j-1*. The main downlink control signalling then follows during frame *j*. It is performed simultaneously with the payload transmission to reduce delays. The type of signalling, and its overhead, is discussed in Section 5.2.3 of [WIN2D6135]. It is assumed to require 6 symbols in frame *j* to control a downlink chunk. This represents a control overhead of 6/96 = 6.3% in the FDD mode and 6/80 = 7.5% in the TDD mode.

The placement of the channel predictor depends on the duplex scheme and on the link direction:

- In FDD downlinks, channel predictors must be placed in the user terminals and an uplink feedback channel is used to transmit the prediction reports to the resource scheduler.

- In TDD, the channel reciprocity could be used to co-locate schedulers and channel predictors, at the BS/RN. These predictors could estimate the uplink channels and use this for predicting also the downlinks. The need for feedback CQI reporting with its associated overhead would be avoided. However, this solution has the same complication that was obtained with FDD uplinks (discussed in Section 3.1): It would require *all* user terminals that take part in the competition to transmit uplink pilots within *all* resources for which they compete. 20 uplink users, each sending 4 pilot symbols per chunk, would consume 100% of each TDD uplink chunk for pilots only. A limit must therefore be placed on the number of users participating in the competition for a set of resources. In addition, the use of overlapping (superposed) uplink pilots can limit the overhead, at the price of a higher computational complexity of the channel predictor.

- Alternatively, due to the TDD channel reciprocity, frequency adaptive TDD uplinks as well as downlinks can be designed with channel predictors that are located in the UT´s. The predictors can then work on downlink pilots. This method does not required individual pilots for each channel to each UT. Its pilot overhead thus does not grow with the number of competing users. This scheme requires a channel quality feedback over the uplink which, can be argued, is a smaller problem than requiring individual pilots for each user. This type of frequency-adaptive TDD downlink and uplink solution was presented in Section 3.1 of [WIN1D24]. It was discussed briefly in Section 3.1 above.

A design for TDD downlinks and uplinks in which channel predictors are placed in the UTs and that works on downlink pilots is proposed as the *reference design for frequency-adaptive TDD systems*.

4.2 Non-frequency adaptive Scheduled Downlink Flows

This section motivates and outlines a new baseline and reference design for multiple access for non-frequency adaptively scheduled downlink flows: *B-EFDMA*. Further details are provided in Appendix B.

The multiple access scheme for the non-frequency adaptive downlink is mainly derived from the insights from the discussion on the non-frequency adaptive uplink discussed in section 3.2. The baseline assumptions for non-frequency adaptive downlinks in the WINNER I System Concept were described in [WIND210]. Here, MC-CDMA with chunk localized code-multiplexing was the framework for flow-multiplexing over the chunks assigned for non-frequency adaptive transmission. The reason to restrict the code-multiplexing within chunks only was to limit the degree of non-orthogonality of the flows to different users, given that the channel gain is essentially flat in time and frequency within a chunk.

Orthogonal MA schemes such as OFDM-symbol based TDMA or subcarrier based FDMA allocation were seen as special cases of this MC-CDMA scheme. All these flow-multiplexing strategies were investigated in [WIND210], and the overall conclusion in [WIND210] Section 3.1.6 was that the difference between their performances is rather small. In Appendix B it is argued that intra-chunk sleep mode is almost as beneficial for the UT in receive mode as in transmit mode, and a structured allocation pattern is beneficial for keeping low control information overhead also in the downlink. In addition, a similar allocation structure in downlink as in uplink is beneficial for low system complexity and HW implementation complexity. Furthermore, a scheme that preserves orthogonality between the resources that are allocated to downlink flows (no use of code multiplexing) will simplify the design of joint (turbo) iterative channel estimation and decoding schemes at the receiver, which have been shown to significantly boost the performance. The conclusion is that the primary candidate for the downlink is a scheme similar to the B-IFDMA uplink proposal. As compared to MC-CDMA with code multiplexing, such a scheme would attain essentially the same frequency diversity.

However, in the downlink the access point has to transmit a sum of adaptive and non-frequency adaptive flows over the entire system bandwidth, where some users are close to the access point and can use high order modulation. Thus, there seems to be no performance or power saving advantage in using a DFT-precoding per flow in the downlink. (Use of a DFT-precoding common to all subcarriers would destroy the frequency adaptation and cannot be used.)

Thus, the DFT-precoding assumed in B-IFDMA is of no use in the downlink. To highlight this difference, the multiple access scheme for the non-frequency adaptive downlink is called ***Block Equidistant Frequency Division Multiple Access (B-EFDMA)***. It is the same as for the uplink, except the missing DFT-precoding. Please see Appendix B for further discussions. B-EFDMA can be used in FDD as well as in TDD, and is proposed for all the deployment scenarios wide area, metropolitan area and local area.

This similarity between the B-IFDMA and B-EFDMA schemes simplifies and unifies the multiple access schemes for uplinks and downlinks. The addressing and control signalling for the non-frequency adaptive transmission is thereby simplified considerably. The block sizes proposed for evaluation studies are the same as in uplinks, ***4 subcarriers by 3 OFDM symbols***. One out of the 12 time-frequency symbols of a block is a pilot.

Downlink control signalling, that controls the downlink as well as uplink transmission will be organized as allocation tables that are themselves transmitted by non-frequency adaptive transmission. They are placed within a set of B-EFDMA blocks that are transmitted in the early part of the downlink slot of a frame. This minimizes delays in the control feedback loop and maximizes the possibility for using terminal micro-sleep/hibernation during the remainder of the frame. The downlink control signalling contains allocation tables for the non-frequency adaptive downlink as well as for the corresponding uplink. In the envisioned downlink transmission scheme, the scheduling is determined late during frame *j-1* and the transmission, including the allocation table, is then performed during the downlink slot of in frame *j*. The delay over the air interface between the arrival of a segment to the MAC layer and the reception is then 1-1.5 frames, or 0.7-1.0 ms, depending on if the downlink slot is located in the early or in the late part of the frame.

4.3 Multicasting and Broadcasting Support

The design being developed to support multicast transmission aims to enable *efficient* multicasting in downlinks of the FDD as well as the TDD modes, to offer *reliable* multicast and also support *broadcasts* to arbitrary users. These functions should be well integrated into the WINNER transmission philosophy; they should not constitute a separate system that is grafted onto WINNER.

The design of WINNER multicast transmission techniques has to handle several issues:

1. For a multicast transmission to multiple users within an area, the properties of the worst-located user will determine the properties of the modulation, code rate and power allocation. Multicasting is more efficient than separate unicast transmissions to a group of more than 2-3 users [BH05]. However a radio transmission that is designed to be received simultaneously by several users tends to require significant transmission resources per data packet: It has to be adjusted to the user with worst channel.
2. A possible way to alleviate the first problem is to utilize cooperative macro-diversity transmission, from multiple RNs within a relay-enhanced cell, and perhaps also from multiple base-stations of relay-enhanced cells closest to a given receiver. The question then arises how to organize and control such coordinated transmissions, in a WINNER concept that has so far not been designed to support coordinated transmission from multiple base stations.
3. The multicast transmissions should be integrated with the present multi-antenna schemes. Some schemes are well suited for multicast, others are not.

Three techniques with different levels of complexity will be outlined below. None of them can yet be proposed as a reference design, since neither scheme has so far been assessed.

1. A baseline scheme that uses transmission from one BS/RN.
2. An extended scheme that uses cooperative transmission within a REC.
3. An advanced scheme that uses cooperative transmission within small groups of RECs.

Reliable multicasting can be included in all three schemes.

4.3.1 Concepts and Definitions

Let us introduce and discuss a few useful concepts:

IP multicast refers to the routing of multicast IP messages. It must be supported by WINNER, but it does not, in itself, require any special multicast radio transmission techniques.

WINNER multicast service provision or ***multicast transmission***. A set of MAC mechanisms and physical layer technique that are aimed at improving the spectral efficiency of downlink transmissions that are intended for several receivers within a cell or a cluster of cells, who are to receive the same message. The flow setup and set of WINNER-global UT addresses that specify the group of receivers is managed and updated by one gateway logical node (GW_{LN}) [WIN2D6138]. Multicast transmissions may originate from outside the WINNER RAN or from within the RAN (an UT transmits IP multicast messages, a GW_{LN} then distributes these messages to recipients inside and outside the WINNER RAN). Multicast transmission may utilize either multicast flows (see below) or unicast flows, in different parts of the RAN.

WINNER broadcast service provision or ***broadcast transmission***. A transmission technique intended for messages that could potentially be received by all terminals within a prescribed geographical area. The MAC layer of a BS/RN is not made aware of the properties of any user terminals that receive the broadcasted message. The system may however require the terminals to subscribe to a particular broadcast flow at the service level. This transmission technique will be designed as a special case of the WINNER multicast service provision. (It should not be confused with the TBCH Transport Broadcast Channel [WIN2D6138] that uses the superframe preamble to transmit WINNER system generated broadcast information.)

WINNER reliable multicast service provision. A RLC and MAC layer functionality that enables link ARQ and end-to-end ARQ by individual receivers of WINNER multicast transmissions.

Coordinated transmission area. A relay-enhanced cell, or a cluster of relay-enhanced cells, in which the transmission of downlink multicast flows (see below) can be coordinated. This coordination is controlled by the MAC layer of one of the involved base station, the ***coordinating BS***.

Multicast flow. A flow that is handled in a special way by the WINNER MAC for transmission to multiple destinations (a ***multicast user group*** within a coordinated transmission area).

4.3.2 Outline of the Baseline Design

The general description below applies also to the extended and advanced (cooperative) transmission schemes.

A flow to be handed by the WINNER multicast/broadcast service provisions is set up by one GW_{LN}.

- If it is to be handled by the WINNER multicast service provision, then a set of (global) UT addresses related to the recipients is specified and updated by the GW_{LN}.
- If it is to be handled as a WINNER broadcast transmission, then the packet flow is set up as unicast flows within all relevant relay-enhanced cells. The unicast address is earmarked as being used for a broadcast message.

The flow is then set up within each coordinated transmission area in which there is a potential recipient:

- If the flow is handled by the WINNER *multicast service provision*, and if there are *at least m recipient* users within the coordinated transmission area, then the flow is set up as a ***multicast flow***. For such flows, non-frequency adaptive transmission is used. The link adaptation is adjusted to the path loss and shadow fading of the worst UT in the multicast user group, taking the transmission technique (from single base station, cooperative between BS and RN, or cooperative between multiple BSs and RNs) into account. For one multicast service, several multicast user groups, each with a separate multicast flow, may be set up within the coordinated transmission area. These groups may e.g. be assembled based on similar SINRs or similar spatial characteristics. The utility of such sub-grouping remains to be investigated.
- If a multicast flow is handled by the WINNER reliable multicast service provision, then the RLC layer handles the end-to-end ARQ mechanism (and the segmentation). A main candidate mechanism is to use individual ARQ for each user. Unicasting is then used for the retransmissions.
- If the flow is handled by the WINNER *multicast service provision* and there are *at most m-1 recipient* users within the coordinated transmission area, then up to *m-1* separate ***unicast flows*** are set up, to be handled in the normal way either by frequency-adaptive or non-frequency adaptive transmission. Reliability is handled as usual for unicast transmissions.

- If the flow is handled by the WINNER *broadcast service provision* and is designated to be active within a coordinated transmission area, then *one virtual user* is defined to be located in a bad transmission environment (at the cell border) of the area and to have a basic receiver with not-too-advanced features. A ***unicast flow*** is set up, using non-frequency adaptive transmission, with link adaptation parameters adjusted for this intended virtual user terminal. A local MAC address is used that distinguishes this transmission as a broadcast message. Reliable transmission is not supported.

In the baseline transmission technique, coordinated transmission is not performed and the coordinated transmission area just corresponds to the cell, or the sub-cell controlled by a RN.

The limiting number of flows m remains open for further study and it depends on many factors. A fixed number m = 2 or 3 can be used as a simplifying first assumption. A refined design should make the parameter m dependent on the location of the users in question, in relation to the BSs and the RNs. In general, when a number of recipients of a multicast service provisions are served by individual unicast flows and their number within the coordinated transmission area is increased, the result of a cost-benefit analysis should determine if the whole transmission scheme should switch to using a multicast flow instead. Likewise, when a number of recipients of a multicast service provision are served by a multicast flow, and their number is reduced, the result of a cost-benefit analysis could result in a switch to the use of individual unicast flows. This mechanism is a part of the adaptation of multiple access schemes within the MAC layer, which is surveyed in section 5.2.

4.3.3 REC-Coordinated and Multi-Cell Coordinated Macro-Diversity Transmission

Cooperative (coordinated simultaneous) downlink transmission is advantageous for multicasting: It converts potential interference into useful signal power. As for unicast cooperative transmission, we obtain macro-diversity gains. For multicast flows with at least two active users within the range of two access points, we have two additional advantages:

- In contrast to cooperative transmission for unicast flows, coordination of multicast messages to the multiple recipients from two access points requires *no extra user-plane backbone traffic.*
- It also requires *no extra radio resource use*: These packets would have had to be transmitted from each of the access points anyway. The potential penalty of cooperative transmission/relaying (having to use additional transmission resources that could potentially have been used beneficially for another purpose) therefore does not arise.

In relay-enhanced cells, some of the mechanisms that are at present studied for cooperative relaying could thus, with advantage, be used for multicast flows. This would represent the *extended scheme*. Here, the BS may take over the scheduling for the resources in question for the BS-to UT transmission as well as for all RN-to-UT transmissions of the multicast flow. The resource schedulers at the RNs would then be bypassed, but would receive the BS scheduling commands as constraints on the scheduling of other downlink flows from RNs to UTs.

We may go one step further and coordinate the transmission from small clusters of cells. The coordinated transmission would then be controlled by the MAC in one coordinating BS. The intent is that the non-frequency adaptive transmission of a retransmission unit (RTU) from different base stations/relay nodes is performed simultaneously, using the same time-frequency transmission resources. The transmission can thus be combined coherently in the physical layer at reception. This would represent the *advanced scheme*.

Note that it is important for the efficiency of these schemes that the transmission from different access points uses the same time-frequency resources. If it used different transmission resources, relying on soft combining of the FEC blocks after reception, we would still obtain a diversity gain, but we would have needed to use multiple and different resources from different BS/RN for the transmission. When one BS/RN transmits, the other BS/RNs would either create interference or would have to be forced not to transmit during those time-frequency resources. Either of these alternatives decreases the transmission efficiency, as compared to simultaneous and tightly coordinated transmission.

The use of tightly coordinated transmission from multiple BS is new to the WINNER concept and it encounters two potential obstacles:

1. The delay difference due to propagation delays between the involved access points should not be too large. Otherwise, inter-symbol interference and also inter-carrier interference would be generated. Therefore, coordinated transmission between base stations is likely to be most efficient in the WINNER RAN if performed within *small* clusters of cells.
2. The tight coordination of non-frequency adaptive transmission from multiple MACs at multiple BS by a coordinating BS would require BS-to-BS coordination on a short time-scale that has not been discussed up to this point; an implicit basic assumption in the WINNER design so far has been that within-cell coordination is fast, but inter-cell coordination proceeds over a significantly slower time-scale.

Coordinated downlink transmission of a multicast flow in a small cluster of cells could potentially proceed as follows:

- Within each cluster, the multicast user group is defined by a cluster-local set of (global) UT addresses. This address set is managed and updated by the coordinating BS.
- The packets of the flow are distributed to all BS/RN within the cluster and segmented in identical fashion.
- The MAC layer at the coordinating BS schedules multicast flows to be transmitted in frame j already during frame $j-n$ (where the integer $n > 1$ is not yet specified).
- This scheduling decision is then reported to the other BS/RN in the cluster, via BS-to-BS links and the relay links. It forms a constraint on the scheduling that is performed during frame $j-1$ of the other downlink traffic to be transmitted over these access points during frame j.
- If the multicast flow in question is handled by the WINNER reliable multicast service provision, then the RLC layer at the coordinating BS handles the end-to-end ARQ mechanism (and the segmentation). A main candidate mechanism is to use individual ARQ for each user, with a retransmission buffers located at the coordinating BS. Unicasting via the nearest BS/UT is then used for the retransmissions. Acks/Nacks are forwarded to the coordinating BS over the BS-to-BS link.

A special problem for coordinating multicast transmissions over multiple cells is how such transmissions are to be integrated with the frequency reuse partitioning/interference avoidance schemes that operate between neighbouring cells.

Assume that a frequency set 1 is used with frequency reuse 1 close to base stations, while another frequency set 2 is used with reuse factor 3 closer to the cell borders[6]. To simplify, we may assume that the coordinated transmission areas consists of three cells, that correspond to the reuse-3 group of the frequency set 2. Thus, all frequencies are used in all the areas. One could then evaluate two possible alternatives for the frequency allocation used for coordinated multicasting:

2. Use the frequency set 1 for coordinated multicast transmission.
3. Use the frequency set 2 for coordinated multicast transmission.

These two alternatives are under present study. Using alternative 1, a receiver close the border of the coordinated transmission area could encounter a low SINR, despite the use of coordinated transmission. On the positive side, this alternative would produce no added interference in the neighbouring areas, unless the bandwidth of the frequency set 1 needs to be enlarged and the frequency set 2 is reduced, to accommodate the multicast traffic over the set 1.

Compared to alternative 1, the alternative 2 would generate a good SINR also for users at the area border. However, it would generate additional interference in neighbouring coordinated transmission areas.

4.3.4 Multi-antenna Broadcast Transmission

Use of beamforming would decrease the size of the multicast groups and would thus decrease the over-all effectiveness of multicasting. In particular, it seems problematic and unnecessary to combine adaptive beamforming with multicasting.

[6] One of the two baseline reuse partitioning assumptions for future studies that will be described in [WIN2D6137].

The most natural combination, and the alternative suggested as a baseline approach, is to use a linear dispersion code (space-frequency coding), i.e. a diversity transmission scheme, for multicast flows and for broadcast transmissions.

4.4 Integration of Space Division Multiple Access in Downlinks

The use of transmit- and receive antenna arrays is known to be a promising solution to enhance system performance, either by increasing link reliability through spatial diversity or by boosting throughput through spatial multiplexing, or both. With spatial multiplexing, multiple data streams are transmitted over the same chunk being separated in space. This leads to higher resource reuse levels and potentially to huge capacity gains, as classically known from [ITU8F1015E]. If the multiplexed data streams are intended to different users in a multi-user scenario, Space Division Multiple Access (SDMA) is configured.

As anticipated in Section 2.4, the stream separation is realized by beamforming, e.g., by adequately weighting the signals transmitted by each element of the antenna array in order to establish virtual channels, namely spatial sub-channels. More specifically, if a BS is equipped with a transmit antenna array with M_T elements and each of the K active user terminals are equipped with a different number of receive antennas yielding a total number of receive antennas M_R, then at most $M=min\ (M_T, M_R)$ data streams can be supported.

The weights associated with an antenna array, i.e. the so-called beamforming vector, are determined based on the available CSI or CQI. A classification in terms of the available CSI then becomes useful. A possible, but by no way complete, classification corresponds to:

- Short-term CSI: in this case, an accurate estimate of the channel impulse response is assumed to be available at transmitter and receiver.
- Long-term CSI: in this case, the channel impulse response is only partially known at transmitter, for example, in terms of first and/or second order channel statistics, i.e. in terms of Direction of Arrival and/or channel covariance matrix.
- Short term CQI: a measure of the channel gain, e.g. the received SINR, is available at the transmitter but no knowledge of the channel spatial structure is assumed.
- Long term CQI: only the average channel gain reflecting the slow fading due to the path-loss and shadowing is available at the transmitter.

The performance and applicability of spatial multiplexing techniques strongly depend on the amount and quality of the available CSI. For example, techniques like eigenprecoding can be applied if short-term CSI is available, but become less efficient when only long-term CSI is available [PNG03] [Cal04]. On the other hand, techniques like opportunistic beamforming require only short term CQI such as the perceived SINR [PNG03] [Cal04].

For multiple access schemes such as FDMA and TDMA, radio channels are essentially orthogonal. For SDMA, however, spatial sub-channels are only virtual channels. Their orthogonality depends on the spatial correlation among the channels of the users in the multi-user scenario. Using SDMA in unfavourable conditions, i.e., when spatial sub-channels are not close to orthogonal, may result in excessive co-channel interference and degraded performance. SDMA algorithms are then required to cope with this issue and multiplex data streams only on sub-channels that are sufficiently uncorrelated.

As introduced in Section 2.4, different SDMA approaches can be distinguished on the basis of the specific beamforming techniques they rely on as well as on the basis of the amount and quality of CSI required at the transmitter. In this section, we will use the classification based on the type of required CSI, while indicating for each SDMA approach the kind of beamforming technique usually adopted. The following SDMA approaches can be distinguished:

- **Short-term SDMA**, if short-term CSI is available and employed. In this case, MU MIMO precoding techniques are implemented which are based on adaptive beams (cf. Section 2.4), e.g., MMSE (minimum mean square error) or successive MMSE beamforming or Regularised Block Diagonalisation (cf. [WIN2D341]). This approach enables to cancel or minimize the interference experienced among different transmit beams.
- **Long-term SDMA**, if only long-term CSI can be used, in the form, e.g., of a channel covariance matrix, then the MU MIMO precoding can be based on the users' equivalent channels derived from the long-term CSI as explained in [WIN2D341].
- **Reduced Feedback SDMA**, if only partial (e.g. highly quantized) short term CQI is available at the BS in a DL scenario, multi-user diversity can still be leveraged to achieve high spectral

efficiency, using opportunistic scheduling algorithms. These rely on adaptively scheduled fixed or randomly generated beams (cf. Section 2.4), referred to as SDMA-based GoB in [WIN2D341].

Depending on the considered transmission scenario, i.e. wide, metropolitan and local area, one or the other of the above SDMA strategies is most suitable. Moreover, even within a certain scenario, depending on the UT location and its velocity within the cell as well as on the current cell load, the users can experience different and variable channel and interference conditions. As a consequence, different SDMA techniques may have to be adaptively selected.

Mobile stations with favourable transmission conditions, e.g. close to the base station and with low to moderate mobility, can usually profit from an accurate estimate of the channel characteristics, i.e. short-term CSI. For these short-term SDMA in the form of multi-user precoding can be become conceivable also in a wide area urban scenario in order to enhance the throughput. For higher velocity users, on the other hand, the short term CSI might not be accurate, or, in case of densely populated cells, a too high signalling overhead might be required for UL CSI feedback. In these situations, long-term SDMA based on long-term channel characteristics, e.g. the dominant eigenvector of the channel covariance matrix, becomes preferable. Long-term SDMA is typically based on user-grouping strategies according to the user's spatial correlation properties over the whole bandwidth. The actual instantaneous variation of the users' spatial correlation may in some cases limits the attainable SDMA gain, as, e.g., in the C2 channel model, characterized by a quite large angular spread. However, the situation in which the channel angular spread at the BS is so large that no dominant channel direction can be identified for each user is not expected to happen in a WA scenario, in which the BS antenna array is typically located above roof top and angular spread should be low (this is at least confirmed by two measurements, in Århus and Stockholm). With such small angular spread, long-term SDMA is envisaged to be the most promising strategy for WA scenario. Otherwise, i.e. with large angular spread and short term CSI not affordable, SDMA based GoB represents a viable solution since it still exploits the short-term statistical variations of the best channel directions and interference.

In the reminder of this section, we will first introduce in Section 4.4.1 the problem of three-dimensional resource allocation in time, frequency and space domain with reference to DL transmission[7]. In Section 4.4.2, we will focus on two sub-optimal adaptive allocation strategies and discuss the results of a comparative assessment carried out under the assumption of short-term CSI, in terms of achievable data rate and user fairness as well as required computational complexity. In Section 4.4.3, a solution for the case of long- term SDMA is proposed.

[7] Since in this earlier phase of the project, no model for inter-cell interference has been agreed and for a large number of interferers the assumption of Gaussian interference becomes more and more accurate [WIND27] our description of the problem will consider only the links belonging to one cell.

4.4.1 Modelling of the Three Dimensional Resource Allocation Problem

Let us assume that a BS is equipped with M_T antennas, K users within the cell are active and are equipped with a total number of receiving antennas. M_R. Let N_c be the number of chunks to be assigned. On each chunk up to M spatial sub-channels can be accommodated. The total search space for the optimum resource allocation is composed of $2^{Nc \cdot M}$ possible allocations.[8] Additionally, the optimum beamforming vectors and the power assigned to each allocated spatial sub-channel have to be determined. The optimization problem becomes combinatorial and finding an optimum solution can be practically infeasible even for a relatively small number of users and chunks. The problem is even more complex when different modulation/coding formats $c_{r,n}$ can be selected from a finite set of size C, so yielding $C^{Nc \cdot M}$ possible allocations.

Sub-optimal frequency/time/space strategies with good complexity-performance trade-offs have recently been proposed in the literature [Wil06], [FGH05], [ZL05] cf. [WIN2D341]), which can keep the computational costs acceptable. These correspond to dividing the problem into sub-problems:

- A bi-dimensional frequency/time resource allocation.
- SDMA grouping.

According to the order of the two steps, the following strategies can be recognized:

- **User Grouping:** users or spatial sub-channels are firstly organized in clusters according to their channel correlation properties in order to identify SDMA groups. There are two possible approaches for this. The first one is that of building groups of correlated users, which are uncorrelated to each other and can thus share the time-frequency resources in an SDMA fashion. Each chunk layer is then exclusively allocated to one SDMA group The spatially correlated users within each group have then to be separated through FDMA and/or TDMA. If short term CQI is available, frequency adaptive FDMA/TDMA can be applied within each group. The second one is that of building groups of uncorrelated users. Different users within the group can then be allocated to different spatial layers within the chunk.
- **User Selection:** the frequency/time resource allocation is performed first by selecting the optimum chunk for an initial user or spatial sub-channel under the assumption of single-user transmission. Then, other spatially compatible sub-channels are selected to build a local SDMA group on the considered chunk.

According to this definition, the user grouping strategy relies on the spatial correlation properties of the users over the whole bandwidth. Hence, it can rely only on long term CSI and it is retained to be a suitable strategy for long–term SDMA. In Section 4.4.3, it is shown how the user-grouping approach finds a convenient application in the resource partitioning among the different RNs of a relay-enhanced cell.

On the other hand, since, it does not take into account the possible frequency selective behaviour of the users' spatial correlation properties, it is the opinion of the authors that, when short term CSI is available and hence short-term beam adaptation can be performed, the user selection strategy should be preferred. The use of the user-selection based on a combination of long-term CSI and short-term CQI has been proposed in [WIN2D341] for the long-term SDMA wide area case. Once the SDMA group has been built on each specific chunk, the transmit antenna weights are optimized according to long-term eigenbeamforming criteria to minimize the mutual interference between the selected users.

However, a combination of user-grouping and user-selection is envisaged to be more efficient. This has been investigated in [WIN2D341] under the assumption of short-term CSI. According to this combined approach, in a first step, groups of uncorrelated users are built, which are allowed to overlap, and, in a second step, the user-selection is carried out over the predetermined user-groups. This implies a reduction of the search space for the user-selection and hence a significant decrease in complexity, while maintaining almost the same spectral efficiency since the overlapping of the user-groups allows a large number of possible spatial multiplexing cases. In section 4.4.2, an alternative method to user-selection for the second step is proposed, which allows to jointly carry out time/frequency and space allocation. It

[8] If no water-filling power allocation over the chunks is used, we may fix the power allocation per chunk and per user (per-user power constraint, PUPC). Then, the allocations to different chunks can be optimised independently, in case a throughput-related performance criterion is used. The complexity of the scheduling, link adaptation and spatial assignment is then reduced drastically, to a comparison of $Nc\ 2^M$ possibilities

represents an extension of the greedy method presented in [RPS+06] for single-carrier SDMA. Results of a comparative assessment reported in detail in A.3.1.3 are also discussed.

4.4.2 Short Term SDMA

The aim of adaptive resource allocation is to optimize the system performance by proper bit loading over all K users and N_c chunks, which in turn determines the power loading $P_{k,n}$, $k = 1, \ldots, K$, $n = 1, \ldots, N_c$. Two main optimization criteria can be used: minimize the total transmit power under the constraint of minimum data rate or maximize the total data rate under the constraint of maximum transmit power. Here, we aim at the maximization of the total data rate, while considering a constraint on the power per chunk indicated as Per Chunk Power Constraint (PCPC), i.e.

$$\max \sum_{k,n} r_{k,n} \text{ s.t. } \sum_{k} P_{k,n} \le P_{chunk} \quad \forall n \text{, with } P_{chunk} = P_{tot} / N_c \text{ ,} \tag{4.1}$$

where $r_{k,n}$ indicates the rate and the power allocated to the k-th user of the n-th chunk, respectively.
With the proposed per-chunk power constraint the total power available at the transmitter is equally distributed over the whole bandwidth. This makes the inter-cell interference predictable and it is advantageous for inter-cell interference management.

Differently from orthogonal multiple-access schemes like FDMA, in case of SDMA, the SINR of one user, and, hence, $P_{k,n}$, depends not only on its own channel but also on the allocation of the other users, i.e. on the effective channel gain, that depends in turn on the assumed beamforming technique.

It follows that the optimization problem (4.1) represents an integer programming problem whose optimum solution would require unfeasible computational effort. In A.3.1.3 a sub-optimal solution, referred to as joint FDMA/SDMA is briefly presented. It consists in a greedy algorithm in which time, frequency and spatial allocation are carried out jointly. In each iteration only the rate of the user who experiences the minimum cost is increased by a given amount on the corresponding chunk as depicted in Figure 4-2. The cost function is defined as the power increase required not only to guarantee the user with the given rate increase but required also to compensate the loss in effective channel gain experienced by the co-located users. To take into account different user service priorities, this is weighted by a proper priority value, so yielding a proportional fairness allocation strategy.

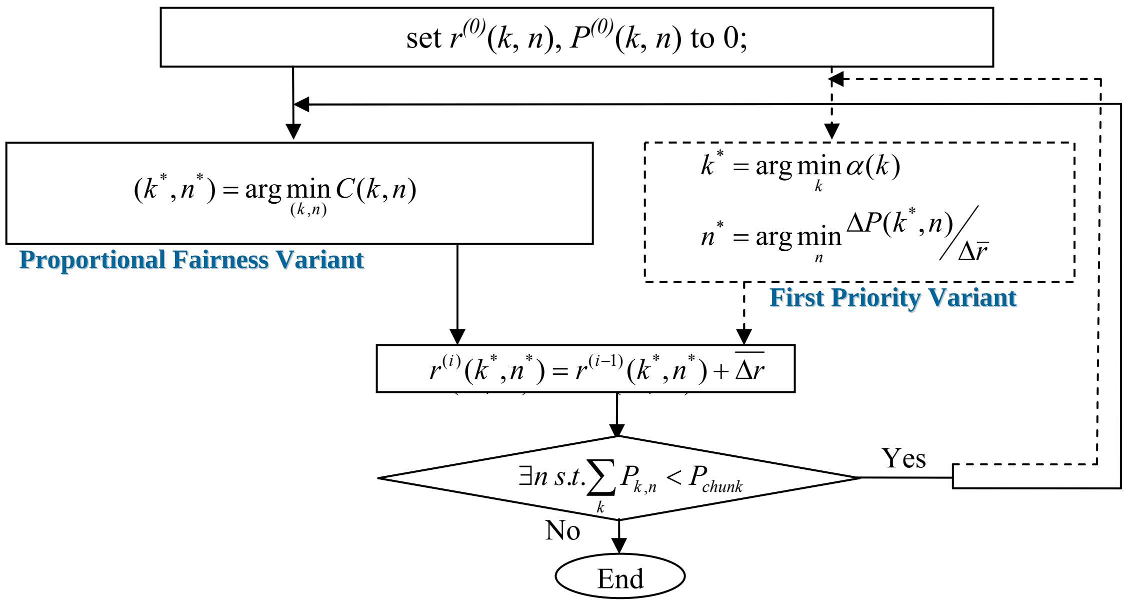


Figure 4-2: Greedy algorithm for joint FDMA/SDMA resource allocation

The expected advantages of this approach are the following:

- a high degree of freedom is guaranteed in sharing the power among co-located users over one chunk,
- at each iteration both the frequency and spatial dimension are exploited in selecting the best fitting user.

An alternative joint FDMA/SDMA method in which the additional constraint that the power per chunk has to be equally shared among the co-located users, indicated as Per User Power Constraint (PUPC), is also considered for comparison in A.3.1.3. For both methods, alternatively, a first-priority allocation strategy can be considered, as shown in Figure 4-2 and detailed in A.3.1.3. Both methods are compared with a user-selection approach with PUPC, denoted also as disjoint FDMA/SDMA, in which all chunks are considered sequentially either according to first priority or proportional fairness strategy and proportional fairness strategy is used to build the SDMA group on each chunk after selecting the first user.

From simulation results in A.3.1.3, it can be concluded that the greedy algorithm for joint FDMA/SDMA under PCPC attains a good trade-off between rate and fairness.

4.4.3 Long Term SDMA

Since User Grouping relies on the channel correlation properties of the users, i.e. on long-term CSI, it is retained to be a suitable strategy for long–term SDMA. In particular, the approach of building groups of correlated users which are uncorrelated to each other can find a convenient application for the resource partitioning among different access points, see below.

The use of the user-selection approach based on a combination of long-term CSI and short-term CQI has been proposed in [WIN2D341] for the long-term SDMA wide area case. Once the SDMA group has been built on each specific chunk, the transmit antenna weights are optimized according to long-term eigenbeamforming criteria to minimize the mutual interference between the selected users.

Since long-term SDMA for intra-cell resource scheduling is extensively dealt with in [WIN2D341], in this section, we will discuss its application for the resource partitioning among different APS, with reference in particular to the RNs of a relay enhanced cells. Further results on this can be found in [WIN2D351].

4.4.3.1 SDMA for Relay Enhanced Cells

In relay enhanced cells (REC), besides the resources allocated for the relay links between the BS and the RNs, the resource partitioning function located at the MAC control plane at the BS dynamically assigns a part of the chunks exclusively for transmission between RNs and UTs, a part for direct transmission between BS and UTs and a part for sharing between the RNs and the BS. Each chunk can be reserved either for a single RN or for a group of RNs that create little mutual interference.

In this section, a strategy is proposed that enables a dynamic sharing of chunks in the spatial domain by different RNs, or APs in general (when the BS to UTs connections are assumed to share the chunk with RN to UTs connections), by exploiting beamforming and the user-grouping approach described above.

The crucial point of this strategy is the identification of spatially compatible links. For this purpose, in a first step, the BS groups the UT links affiliated to each RN into a low number of groups according to their direction of arrival (DoA) in such a way that UT links within the same group are spatially correlated. During actual transmission, the RN does not necessarily steer its multiple antenna array so to direct a beam in the DoA of the served UT, but it can adopt another transmit strategy, i.e. based on more accurate short-term channel state information, if available. Nevertheless, since UTs within the same group are spatially correlated, they will generate similar interference to other sub-cells. In this way, the BS identifies a set of long term logical beams at each RN. Hereafter, the term "beam" is also used to refer to such a group of spatially correlated users

In a second step, the BS selects the beams from different RNs within its REC, which are sufficiently spatially uncorrelated, so that they can share the same chunks in spatial domain without generating too high inter-beam interference. A metric based on inter-user interference has been designed in order to evaluate the quality of an allocation of multiple beams sharing the same resources. For example, with reference to Figure 4-3, the groups of beams with the same pattern and color are allowed to share a chunk. It is to be noted that the beam configuration is not necessarily as regular as in Figure 4-3. The beam configuration can be flexibly decided by the BS on a long term basis, e.g., a super frame basis, in such a way to minimize the intra-REC interference, while taking into account users and traffic distribution within the REC. Groups of beams can be partially overlapping, i.e. a beam can belong to more than one group. Provided that information on the allocation in adjacent RECs is available, also the inter-cell interference can be considered in forming the beams and deciding then on their resource sharing.

In order to assess the performance of the proposed strategy for dynamic spatial domain resource partitioning among different APs in a REC, a baseline case has been defined, according to which the sub-cell of each RN is sub-divided into fixed sectors and fixed sets of spatially uncorrelated sectors from different sub-cells are allowed to share the same chunks in the spatial domain. The proposed strategy has been evaluated in comparison to a modified baseline case in which the sets of spatially compatible sectors of different sub-cells are dynamically identified. Simulation results are reported in Section A.3.1.4 in terms of total cell throughput versus both user throughput and number of active users.

It can be inferred that a quite significant cell throughput gain can be achieved through the proposed strategy due to the higher flexibility in grouping the user links, which is expected to be most beneficial in case of non-uniform traffic distributions. Moreover, an even larger gain is to be expected with respect to the baseline case, in which the grouping of the sectors is also fixed. Furthermore, it can be derived that the proposed strategy is also more robust in case of densely populated RECs.

Several issues arise for the application of the proposed strategy, which are subject of further investigations and partially already addressed in the upcoming deliverable [WIN2D341]. These include, e.g.,

- The identification of groups of spatially correlated users, i.e. the construction of the beams (the algorithm proposed in [FGH05] has been employed for the case reported in Section A.3.1.4)
- The UT to AP (RN or BS) affiliation procedure, which may take into account interference patterns and load balancing between beams (this is simply based on the total channel capacity over the two hops for the case in the section A.3.1.4;
- The identification of spatially uncorrelated beams (the decision on beam grouping has been assumed to be based on the maximum inter-user interference for the case in the section A.3.1.4);
- The development of a suitable MAC protocol (cf. Section 7.)
- The development of an efficient strategy for partitioning of resources between the second hops, i.e. the beams, and the first hops to guarantee that the amount of traffic they can serve is as balanced as possible. A strategy is proposed in [WIN2D351].

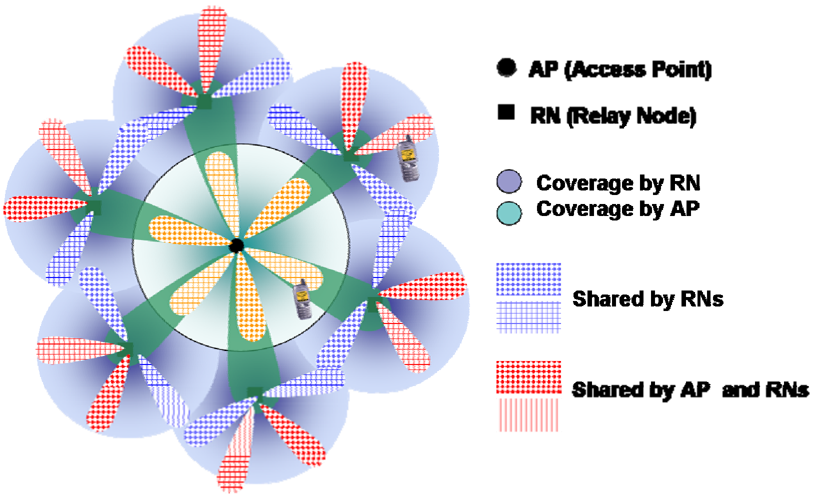


Figure 4-3: Example of beam pattern configuration for the RNs of one REC (AP means BS in the figure).

5. Co-existence and Adaptive Selection of Multiple Access Schemes

A major issue regarding the scalability of the WINNER system is the need to adapt to different available bandwidths. Hereafter, we discuss how this impacts the selection of the transmission mode, frequency-adaptive or non-frequency adaptive, and of the multiple access scheme as well as the coexistence between different modes and MA schemes.

5.1 Co-existence of Multiple Access Schemes

For the scheduled channels we have two different basic transmission methods, frequency adaptive and non-frequency adaptive transmission. Both of these methods benefit from a large resource pool with independent fading statistics. Non-frequency adaptive transmission needs the independent resources to combat the small-scale fading by diversity combining techniques. Frequency adaptive transmission benefit from independent resources to minimize the service outage probability for semi-static users and to enable large multi-user diversity gains. In addition, there is a contention-based Direct Access Channel in the uplink.

5.1.1 Multiplexing Strategies for Multiple Access Schemes

Resources for frequency adaptive and non-frequency adaptive transmissions may be multiplexed in time, frequency or space. The possibilities of time and frequency multiplexing are illustrated in Figure 5-1.

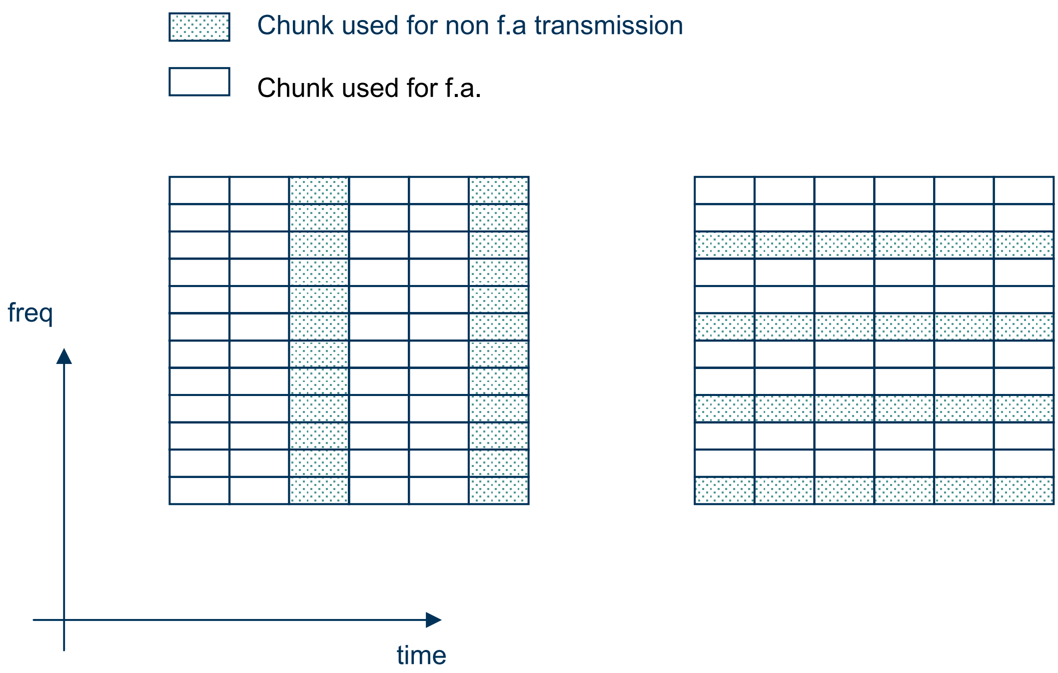


Figure 5-1: Time and frequency multiplexing of resources used for frequency adaptive and non-frequency adaptive transmission.

- Spatial multiplexing of MA schemes is both possible and useful at least in certain grid of beam scenarios[9]. The re-configuration has to be slowly changing and transmitted in the cell-wide broadcast channel of the superframe. In more general MIMO scenarios, the usefulness is less clear due to the less orthogonality of the spatial channels over time, but this is for further study.
- Frequency multiplexing is beneficial if the system bandwidth is large enough to obtain enough frequency diversity in each MA scheme, since it support low delays over the air interface. However, the efficiency of frequency multiplexing of resources for frequency adaptive and non-

[9] E.g. outside a shopping mall area; one beam could be serving the shopping mall with a lot of semi-static users that can use adaptive transmission and another beam could serve the users in the direction of the close by highway where a lot of users are fast moving, and they thus have to use non-frequency adaptive transmission.

frequency adaptive transmissions declines with the available frequency bandwidth, because the time diversity over subsequent frames is typically very small and cannot compensate.

- Time multiplexing is straightforward, and in a system that has access to a relatively narrow transmission bandwidth or that is subject to constraints by frequency reuse schemes or spectrum sharing, it may be more difficult to achieve an efficient frequency multiplexing. Time multiplexing may further limit the power consumption in the UTs, since it provides more possibility for the UT to enter inter-chunk sleep mode, see Appendix B.2. The drawback is that it implies a higher delay over a hop and it has lower granularity compared to frequency multiplexing.

Short delay over the WINNER RAN is set to be one of the most important goals, enabling (H)ARQ and two-hop relaying also for delay-sensitive flows for reliability, support of real-time services, high TCP throughput and good coverage. In addition, most deployment scenarios are targeting a rather wider system bandwidth. For these reasons, chunk based *frequency multiplexing* is the most reasonable way to multiplex different MA schemes, and ***the default reference design is to frequency multiplex resources for frequency adaptive and non-frequency adaptive transmission***.

In addition, in the current super-frame design, resources for scheduled uplink transmission are frequency multiplexed with resources assigned to the uplink direct access channel. The contention-based channel is assigned a set of consecutive chunks in the lower part of the uplink bandwidth. The investigations on the DAC channel in Appendix A indicates that it is important to continuously maintain a rather low load in the DAC channel to maintain the low delay property of this channel.

However, a special consideration has to be taken for narrowband deployment, especially if a frequency reuse factor larger than 1 is used in parts of the cell. If this deployment scenario uses a low carrier frequency it can enable single-hop deployment, i.e. without relay nodes. This would enable time-multiplexing of frequency adaptive and non-frequency adaptive transmission modes. Depending on the carrier frequency, this may imply a larger or smaller maximum speed for the users using frequency adaptive transmission, because the performance of the channel predictors depends on the prediction horizon in number of travelled wavelengths during the time of the feedback loop, see e.g. [WIND26] section 6.1.1. Thus, ***for deployment with low system bandwidth and low carrier frequency, the reference design is to time multiplex resources for frequency adaptive and non-frequency adaptive transmission***.

In order to identify conditions in which case this choice could reveal to be critical, assume that the useful system bandwidths for Wide Area scenarios ranges from (1.25)/2.5 MHz to 40 MHz per uplink/downlink. With the currently assumed physical chunk size of 312,5 kHz in the FDD mode, we get (4)/8 to 128 chunks in the frequency domain per uplink/downlink. Moreover, we observe that some of these chunks must be reserved for the DAC channel, some will get constraints due to frequency reuse partitioning for inter-cell interference avoidance and some may be needed for spectrum sharing guards to other legacy systems in specific geographical areas. Moreover, we assume that a frequency reuse scheme is used that applies a frequency reuse factor 1 in the inner part of the cells and a reuse factor of 3 only in the outer parts. It follows that in a narrowband deployment scenario, e.g. of 1.25 MHz, with frequency reuse 3 in the outer part[10] of the cells and one chunk for the DAC channel, we have used all 4 chunks along the frequency axis, i.e. there is no space for more than one MA scheme in the outer part of a specific cell. In this case, time-multiplexing of the frequency adaptive and non-frequency adaptive schemes becomes preferable. This is under the assumption that the narrowband deployments are made e.g. in re-farmed low carrier frequency bands and relay nodes are not deployed (BS range is not a limiting factor), so that delays induced by time-multiplexing would not represent a concern.

5.1.2 Constraints on Multiplexing of Multiple Access Schemes

The fraction of resources used for the different MA schemes needs to be updated according to the demand in the network, and the allocation must be distributed to the nodes in the cell. E.g., the frequency adaptive transmission relies on fast quality based scheduling and accurate link adaptation. To accomplish uplink frequency domain scheduling, at least in an FDD network in which the uplink and the downlink channels are not reciprocal, all UTs must regularly transmit reference symbols (pilots) over the entire frequency band. If resources assigned to frequency adaptive and non frequency adaptive transmission are frequency multiplexed, the pilot pattern of the UTs should preferably reflect the current MA resource assignment (to

[10] The baseline reuse partitioning assumption from [WIN2D6137].

avoid excessive pilot overhead). The resource assignment is determined by the base station (network) and UTs must hence be informed in which chunks to transmit reference symbols.

Moreover, if macro diversity is used for multicasting and broadcasting, i.e., that the same information is transmitted by several base stations, it may be beneficial to coordinate the resource usage in neighbouring cells. Such coordinated usage of resources among base stations was discussed in section 4.3.3. It places additional constraints on the resource partitioning: the used set of chunks must be available for use at all the participating access points.

5.2 Adaptive Selection of Multiple Access Schemes

In the previous sections, we have primarily discussed the MA schemes that are most suitable for frequency-adaptive transmission and non-frequency adaptive transmission of scheduled flows. Within a super-frame, different sets of chunks are pre-allocated for each of the two modes. These sets are fixed within the whole super-frame, but may be changed between super-frames.

The selection of MA scheme for a particular flow is made at the flow set-up, but switching of MA schemes can be made for ongoing flows, on a super-frame time scale, if needed. Here we present criteria and mechanisms for the selection and the possibly later switching of the MA scheme for a flow.

During handover to other cells, there are cases when switching is needed. This re-negotiation has to be made as part of the handover process. For intra-mode handover between cells, it should be possible to use similar selection and switching criteria as discussed here. MA scheme adaptation in inter-mode handover situations (between the cellular TDD, cellular FDD and Peer-to-peer modes) is for further study and should be an integrated part of the development of the overall handover algorithm in WINNER.

The selection criterion for use of the uplink *direct access channel* (DAC) is that a flow should require an extremely low delay, *lower* than that the 1.0 ms delay that is attainable by non-frequency adaptively scheduled uplinks, and that such a low delay can actually be *obtained* over the DAC, with its presently allocated bandwidth. Candidate types of flows are those with small and infrequently arriving uplink packets. Uplink flows that contain short measurement messages to higher layers are possible candidates. However, it is at the moment unclear if there are any flow types at all that fulfil the conditions.

We below focus on the selection between frequency-adaptive and non-frequency adaptive transmission and the selection of SDMA type for scheduled flows.

5.2.1 Preselection Criteria and Switching Criteria for Scheduled Flows

The initial selection of MA scheme for a flow is based on two sets of criteria, preselection criteria and switching criteria. The *preselection criteria* are rather static. They are determined by the capability and the configuration of the infrastructures (BS and RNs), the spectrum constraints and the UT capabilities and their distribution in the cell. They do not rely on measurements. The *switching criteria* are instead more related to parameters that change dynamically within the cell and for the flow. They are monitored and later used for possible switching of MA schemes for already established flows.

The list of preselection criteria considered at present is given below.

- Flow type (defined by a flow descriptor from the Service Level Controller, SLC)
- Next hop node type (BS, RN or UT)
- UT capability (from e.g. UT ID database)
- Chunk resources and their current constraints
- Cell load

For example, relay links are characterized by good semi-static channel conditions, antenna directivity gains and large more or less continuous data transfer rate due aggregation of many user flows served by the RN. This calls for selecting frequency adaptive transmission, while keeping the CQI update rate and hence the feedback and pilot overhead rather low.

The set of switching criteria considered at present is:

- CSI/CQI quality, as measured by the estimation/prediction Normalized Mean Square Error (NMSE)

- Terminal velocity (e.g. based on Doppler spread or on GPS/Galileo measurements)
- Average SINR
- Downlink SINR, which determines the reliability of downlink control information
- The number of recipients of a multicast transmission (see section 4.3.2).

The use of one of the preselection criteria and all of the switching criteria listed above is illustrated below in the determination of the use of frequency-adaptive versus non-frequency adaptive transmission for a newly set-up scheduled flow to/from a UT. The choice is based on evaluating the following three factors:

- **The reliability of the downlink control information**. Frequency-adaptive transmission requires significant control overhead. To keep the overhead reasonable, a very low modulation and code rate cannot be used for the control information. The reference design uses 4-QAM rate ½ convolutional coding for the downlink control information that controls both the uplink and downlink frequency-adaptive transmission. These control bits have to be received with sufficiently low error probability. This places a limit of around **5 dB** for the downlink SINR. At lower downlink SINRs, the non-frequency adaptive transmission, which has a lower control overhead and can thus afford to use a more secure control transmission, should be used.

- **The reliability of the chunk-wise predicted SINR**. The attainable performance of channel predictors and the required prediction accuracy were studied in [WIND24]. These investigations used no outer coding and performed link adaptation by adaptive modulation combined with chunk-wise (inner) convolutional coding. Under these conditions, the frequency-adaptive transmission was for vehicular users shown to be feasible at 5 GHz carrier frequencies, if a fast adaptation control loop was used (see Section 3.1 of [WIND24] and [SFS+05]). It was shown to be feasible up to a limiting velocity (up to 70 km/h) that depends on the average user SINR. Outside of this feasible SINR plus terminal velocity range, the non-frequency adaptive transmission has to be used. (The limiting velocity is inversely proportional to the carrier frequency. It also depends on the predictor implementation and the pilot symbol density.)

- **The properties of the flows**.
  - Frequency-adaptive transmission is mostly used for a multicast service provisioning, unless very few users are within the cell/coordinated transmission area. See Section 4.3.2 above.
  - The frequency-adaptive transmission requires channel predictors to have updated predictions of sufficient accuracy, based on pilots within a sufficiently long past time window. Streaming and file downloads with regularly arriving packets are well suited for using frequency-adaptive transmission, with continuously running channel predictors, However, for flows with rare or very irregularly arriving packets, the overhead required for having channel predictions updated and ready for use is likely to negate the gains obtainable by the frequency-adaptive transmission. Here, only extrapolation of instantaneous channel CQI can still be used, but it provides sufficient accuracy only at pedestrian velocities, see Figure 3.7 of [WIND24].

I general, the principles for selecting between frequency-adaptive or non-frequency adaptive transmission over one hop can be summarized by the following sequence that is executed each time a new scheduled flow is set up within a relay-enhanced cell:

1. *Pre-selection phase*: If the properties of the transmitting node, the receiving node or the present resource partitioning exclude the use of frequency-adaptive transmission, then use non-frequency adaptive transmission. Stop.
2. If the flow is to be handled as a multicast flow or is a broadcast transmission, then non-frequency adaptive transmission is used. Stop.
3. If the average downlink SINR for the user is below 5 dB, then non-frequency adaptive transmission is used. Stop.
4. Determine the feasibility of using channel prediction, based on the expected characteristics of the newly set-up flow. Take the overhead due to explicit uplink SINR feedback signalling in the case of FDD downlinks into account and also the transmit power overhead required (e.g. for uplink pilots) in case of FDD uplinks.
5. Determine if the estimated channel prediction accuracy is sufficient for frequency adaptive transmission, using curves such as Figures 3.3-3.7 in [WIND24] and a threshold of the

normalized complex channel prediction MSE. If it is, use frequency adaptive transmission, if not, use non-frequency adaptive transmission.

The choice of using a multicast flow or unicast flows for a multicast transmission was discussed in general terms at the end of section 4.3.2, but this choice has not yet been investigated and no detailed decision algorithm has been constructed. In Section 4.3.2, the number *max 2 users within the coordinated transmission area* was provisionally suggested as the upper limit for using unicast flows for multicast transmissions In metropolitan and local area situations, more users are likely to be able to use frequency-adaptive transmission, which has much larger spectral efficiency than non-frequency adaptive transmission. Thus, the switching threshold for number of users in the unicast/multicast transport format will depend on the deployment scenario and is expected to be larger in the metropolitan area and local area scenarios than in the wide area scenario.

The influence of the downlink control overhead and the prediction accuracy factors are at present rather well characterized, but they still need to be quantified in more realistic simulation settings. The effect of the properties of the flow on the balance between adaptation gain and pilot and reporting overhead remains to be further studied.

After flow setup, the scheduling architecture presented in [WIN2D222] section 2 enables switching between frequency-adaptive and non-frequency adaptive transmission of ongoing flows also during transmission of incremental redundancy in the context of HARQ. This property relies on the strategy to perform outer coding before resource scheduling as discussed in [WIN2D222] section 5.4.6.

5.2.2 Adaptive Selection of SDMA Strategy

Mobile stations with favourable transmission conditions, e.g. close to the base station and with low to moderate mobility, can usually profit from an accurate estimate of the channel characteristics, i.e. short-term CSI. For these ***short-term SDMA*** in the form of multi-user precoding can be become conceivable not only for the local area and metropolitan area scenarios but also in a wide area urban scenario in order to enhance the throughput.

For higher velocity users, on the other hand, the short term CSI might not be accurate, or, in case of densely populated cells, a too high signalling overhead might be required for UL CSI feedback. In these situations, long-term SDMA based on long-term channel characteristics, e.g. the dominant eigenvector of the channel covariance matrix, becomes preferable. As discussed in Section 4.4, long-term SDMA is typically based on user-grouping strategies according to the user's spatial correlation properties over the whole bandwidth. The actual instantaneous variation of the users' spatial correlation may limit in some cases the achievable SDMA gain, as, e.g., in the C2 channel model, characterized by a quite large angular spread. However, the situation in which the channel angular spread at the BS is so large that no dominant channel direction can be identified for each user is not expected to happen in a WA scenario, in which the BS antenna array is typically located above roof top and angular spread should be low (this is at least confirmed by two measurements, in Århus and Stockholm). With such small angular spread, ***long-term SDMA*** is envisaged to be the most promising strategy for the WA scenario.

Otherwise, i.e. with large angular spread and short term CSI not affordable, SDMA based GoB represents a viable solution since it still exploits the short-term statistical variations of the best channel directions and interference.

6. Impact of Spectrum sharing

6.1 Scenarios

Two Spectrum Sharing mechanisms are distinguished**, Flexible Spectrum Usage** (FSU) and **Sharing and Co-existence** (S&C). The fist is implemented by a function called **spectrum assignment** and deals with spectrum sharing between WINNER RANs, and the latter is implemented by a function called **(Inter-system) spectrum sharing** and deals with spectrum sharing between WINNER RANs and RANs from other radio systems [KOL+07].

The different modes of the WINNER system introduce different constraints for spectrum sharing. In the FDD mode, mainly separation in the frequency domain is of importance. For TDD both frequency and time separation are important. Additional gains for both modes can be achieved when supporting separation in the spatial domain, by for example applying SDMA or beamforming techniques.

Inter-system sharing

Multiple access concepts that can be used to address inter-system sharing include: definition of control channels between the systems, reduction of interference introduced to the target system by adapting the transmit power, modifying the used bandwidth (avoiding certain bands and using scalable bandwidths) and using beamforming. Additionally the WINNER system could be made robust against interference by using more robust coding and modulation. Furthermore in some cases advanced scheduling can be applied.

One particularly interesting use case is spectrum sharing between the WINNER system and Fixed Satellite Services (FSS) which would open up frequency bands in the 3.4-5GHz range [ITU-R06]. WINNER also targets these bands for its system deployment. Here interference avoidance schemes can be applied, including beamforming, reduced transmission power, and inter-system signalling schemes.

Intra-system sharing

If all the participating networks are **synchronized**, then very small or no guards would be needed between the allocations to different RANs. This provides high spectral efficiency and also large flexibility for the spectrum sharing. Further very flexible resource partitioning schemes can be used allowing for varying allocation within the same bandwidth for the different systems.

If **unsynchronized** inter-network operation is assumed between WINNER RANs that are to share a common spectrum, then guard frequency bands have to be introduced. These guard bands have to be of similar widths as those that are used between a WINNER and a non-WINNER RAN. The size of the guard bands in the frequency domain depends on the permitted Adjacent Channel Power Ratio (ACPR), which is defined via the spectrum mask.

6.2 Multiple Access and MAC Functional Tools

Multiple access and MAC level functionality that enables flexible spectrum usage include

- a super-frame structure that allows operation over fragmented bandwidths (i.e. bandwidths that are not continuous over time or space),
- chunks that can be assigned in a flexible manner within these super-frames (e.g. adaptive transmission within OFDMA),
- appropriate communication channels (including over-the-air communication between base stations),
- and the above mention synchronization.

In WINNER phase I, several functions relevant to flexible spectrum usage and sharing have been included at the Medium Access Control level, in particular Resource Partitioning, the Constraint Processor, and the MAC Control feedback [WIND210].

Spatial techniques: Using simple beam forming schemes and up to 8 antenna elements in the base station about 20 dB damping is achievable. Beamforming can be used to reduce interference between WINNER and a satellite system as follows: Avoid beaming in the direction of the satellite station, placement of attenuation poles on the satellite’s stations main lobe (and possibly side lobes) and use of advanced design procedures and algorithms. For a further discussion and preliminary simulation results, please see Appendix A of [WIN2D341].

Scalability of bandwidth allocation: The bandwidth supported by the WINNER system is scalable over a wide range. Current evaluation scenarios are for 2x50 MHz FDD and 100 MHz TDD, but significantly smaller bandwidth will also be supported. Flexible use of bandwidths will enable various spectrum sharing scenarios.

Resource Partitioning: Resource portioning prepares the structure of the next super frame, and allocates spectrum to relays, adaptive and non-adaptive flows. Resource partitioning between cells must be performed with guard chunks because of non-orthogonality introduced by time delays. Inter-system resource partitioning requires synchronization.

Advanced signalling schemes: Signalling schemes between WINNER and other systems (such as the aforementioned satellite systems) will enable flexible adaptation to varying interference scenarios. Exchanged information may consist of exclusion zones, spatial exclusion directions, maximum power levels, and bandwidths.

6.3 Spectrum Mask

When sharing the spectrum within the WINNER system or between WINNER systems and other radio technologies, the susceptibility to interference, and interference caused to other systems is of importance for the system performance. In order to investigate how close in the frequency domain these systems can be operated the adjacent channel power and the generated noise are important parameters determining the power mask within which the transmitted energy of the system has to remain.

During WINNER phase I a spectrum mask for the WINNER system has been derived [WIND25]. The power mask is based on the noise floor and the Adjacent Channel Power Ratio (ACPR). The far-limit points follow from the noise floor, bandwidth and maximum Tx power, and because of this they are different for the base stations and the terminals. The transition part of the mask is formed according to non-linear effects of the transmitter (mainly Power Amplifier non-linearities), while satisfying requirements from the ACPR and the noise floor. The more ACPR suppression required, the more complex and costly the implementation becomes. Therefore, it is desirable to achieve more relaxed ACPR boundaries [SG01]. As a reference, the value for 802.11a is 25 dB and for WCDMA 33 dB. The difference to 802.11a is because WLAN is not a cellular system.

The spectrum mask used in WINNER phase I is in general still valid for WINNER phase II. The spectrum mask is flat over the desired bandwidth of the signal (A), and then there is a sharp fall-off of the mask down to (B), the beginning of the adjacent channel. A frequency shoulder due to non-linear effects in the transceiver (e.g. Power Amplifier) is located between (B) and (D). According to preliminary PA simulations, a transition in the slope of the output spectrum in the spectrum shoulder occurs at an offset of approximately one bandwidth (C). The slope is assumed about 15 dB/bandwidth first, and then 19 dB/bandwidth. After transition point (D) the PA spectrum crosses the noise floor. The values for the spectrum mask for a bandwidth of 100 MHz, FFT size of 2048 (1664 used subcarriers), and a cyclic prefix size of 2.5 μs is presented in Table 6-1. A maximum output power of +24 dBm for the mobile terminal and +46 dBm for the base station is assumed.

Table 6-1 Transition points of the spectrum mask for base station and mobile terminal [WIND25].

Mask Point	Frequency offset,	Spectrum value	Comment
A	51.2 MHz (BS WB) 51.2 MHz (UT WB)	0 dBc	In the middle of channels
B	60.8 MHz (BS WB) 60.8 MHz (UT WB)	-39 dBc (AP WB) -33 dBc (MT WB)	Beginning of the adjacent channel; satisfies ACPR criterion.
C	83.2 MHz (BS WB) 83.2 MHz (UT WB)	-44 dBc (AP WB) -38 dBc (MT WB)	Spectrum slope transition point.
D	155 MHz (BS WB) 116 MHz (UT WB)	-64.3 dBc (AP WB) -47.3 dBc (MT WB)	Simulated PA spectrum slope hits noise floor.

The shape of the spectrum mask is determined by two types of processes; here we refer to them as linear and non-linear. The **linear processes** reduce the spectrum regrowth due to the transmitted pulse shape; techniques that may be applied here are pulse shaping, time domain windowing, and frequency domain filtering. The **non-linear processes** influence the spectrum regrowth due to non-linear phenomena and components, and can be influenced for example by the power amplifier characteristics (choice of the PA), amplifier backoff, and the pre-distortion filtering.

Although pulse shaping helps in reducing the bandwidth of the signal (out of band side lobes) and as such is needed to obtain a steep enough fall-off of the spectrum mask, it does not have a strong effect on reducing the spectral re-growth. This is dominated by the non-linear effects introduced by the the power amplifier. Frequency windowing was shown to slightly reduce the spectral re-growth for serial modulation (such as IFDMA), but has no effect on OFDMA.

When the OFDM symbols are extended with a couple of samples the out of band radiation is already reduced significantly to levels below the noise introduced by the amplifier. Using smoothening over more than a couple of samples therefore does not reduce the spectral regrowth further. Assuming a FFT size of 2048 and a symbol length of 20 µs would result in a sampling rate of 2048 / 20µs = 102.4 MHz and a sampling time of 9.7ns. In this case using 10 samples would result in a transition time of roughly 100 ns, using 25 samples would result in a transition time of 250ns for the time domain windowing. These values are relatively small compared to the currently considered cyclic prefix times. As a comparison, in WLAN 802.11a windows are extended and smoothened with transition time of 0.1µs [IEEE802a].

7. Supporting MAC Schemes

7.1 WINNER II MAC Layer

The WINNER I MAC layer was summarized in chapter 3 and Appendix C of [WIND210] and in [WIND76]. Relaying aspects were also discussed in [WIND35]. A brief overview of some of its main features have been given in Chapter 1. While the WINNER I MAC work focused on the control structures for the physical layer, WINNER II refines this work and will also outline MAC protocols for cellular transmission. We here provide a very brief outline of the MAC layer itself. Section 7.1.2 points to control functions within the MAC layers that will have the responsibility to execute or support the various multiple access control and optmimization problems that have been presented in the previous sections. Section 7.1.3 summarizes the transmission timing results of previous sections and also outlines the targeted retransmission delays.

7.1.1 Overview

The MAC layer of WINNER II is essentially based on the WINNER I design, and a snapshot of its current state of development is provided in Section 5.6 of the Intermediate WINNER II concept [WIN2D6138]. Figure 7-1 below shows the over-all WINNER radio interface structure.

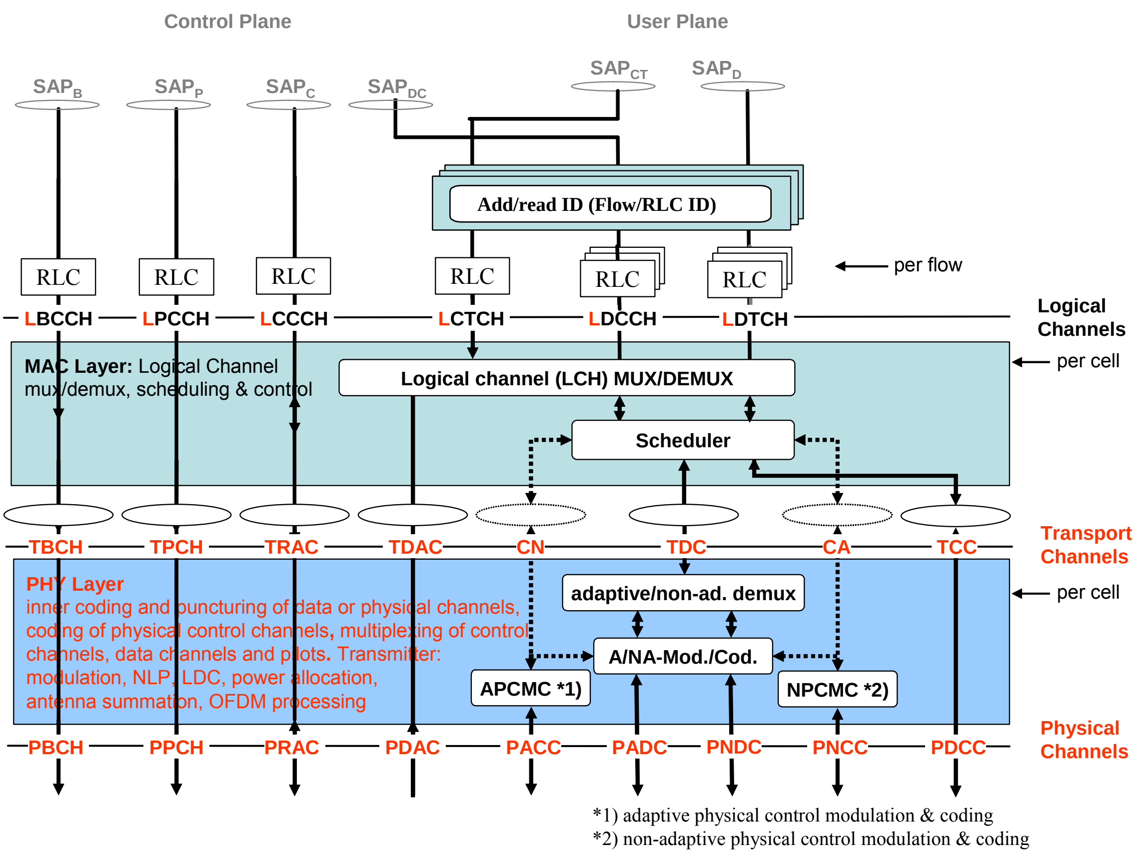


Figure 7-1: Radio Interface Protocol architecture (network side)

Some recent additions to the design are highlighted below.

- The MAC layer is embedded in the WINNER II protocol architecture, which is described in [WIN2D6138] and illustrated by Figure 7-1.
- Forwarding of messages in relay nodes will be added (Section 5.4.2.1 of [WIN2D351]).

- For scheduled flows, specific reference designs for the frequency-adaptive as well as the non-frequency adaptive transmission have been defined; see Chapter 5 of [WIN2D6135].
- For the downlink control signalling (the allocation tables) that supports non-frequency adaptive transmission, as well as for the information that defines the resource partitioning within a super-frame, the technique of frame descriptor tables will be used. It is described in Section 7.2 below and in Appendix C.1.

The same set of layers (PHY, MAC and RLC) is available in all communicating parties, i.e. at the terminal- and the network side, although for simplicity reasons only the network side is shown in Figure 7-1. It illustrates separate protocol instances as rectangles while vertical lines are used to show how data units pass through the structure. **Service access points (SAP)** (ovals) are interfaces between adjacent layers. The Service Access Points describe what kind of services each layer provides to the next higher layer and their properties are modeled by **channels**. The channels can be represented by structured memory addresses whose fields specify the information that is to be transferred. This information is intended to be received by a peer protocol entity at the receiving end. It is transmitted by the lower layer and will then be available to the peer layer at the receiving end. For example, the MAC layer at the BS uses transport channels to communicate with the MAC layer at a RN or a UT.

Inter-layer control-signaling is also required e.g. for submitting the physical resources and MCS that the MAC scheduler has selected for transmission of a flow to the PHY, and the information needs to be passed to the corresponding layer. This inter-layer-communication is modeled by using **associated signaling.** In contrast to channels, the associated control signaling is passed to a layer within the *same* logical node and not to a corresponding layer in a peer entity. Associated signaling is passed over **Control Access Points** and they are drawn with dotted lines in the figure above.

Channels subdivide into logical, transport and physical channels where

- Logical channels
  - Define services offered to higher layers by the MAC, and are used by these higher layer protocols for communication between peers
  - Logical channels describe what type of information is transferred, e.g. one-to-one, one-to-many, user-data, control-data
  - Logical channels provide flow identification
- Transport channels
  - Define services offered by the PHY layer to MAC, and are used by MAC protocols that define the communication between MAC peers.
  - describe *how* the information is transferred, e.g. random access, direct access, data channel
- Physical channels
  - Are defined as the interface between different PHY layer instances
  - describe *where* the information is transferred in the frame and *how it is transferred physically.*

The “physical channels” represent detailed physical layer descriptions of the corresponding transmission. Note that in contrast to legacy systems, the physical channels describe not only *how* the information is transferred but also *where* within the super-frame it is transferred.

The transport channels and their definition are still under development. A preliminary set of transport channels is defined below:

Transport Broadcast Channel (TBCH) is a downlink channel for broadcasting system information, etc., to all terminals inside the cells coverage area.

Transport Paging Channel (TPCH) is a downlink channel used for broadcast of paging information into an entire cell.

Transport Random Access Channel (TRAC) is a contention-based uplink channel for initial access to the network.

Transport Direct Access Channel (TDAC) is a contention-based uplink channel for user-data transfer, which has been discussed in sections 2.5 and 3.3.

Transport Data Channel (TDC) is a channel for point-to-point and point-to-multipoint communication. It describes the RTUs that are handled by scheduled transmission.

Transport Common Control Channel (TCC) is a control channel for point-to-point and point-to-multipoint communication. It is used for distributing resource partitioning information from BS to RN and UT, and from RN to UT.

The associated signalling between MAC and PHY are defined as

Control signaling for non-frequency adaptive transmission (CN) carries the associated signaling for control of the non-frequency adaptive transmission, in downlinks as well as uplinks.

Control signaling for frequency adaptive transmission (CA) carries the associated signaling for control of the frequency adaptive transmission, in downlinks as well as uplinks.

7.1.2 Control Functions

As in WINNER I, the MAC layer for FDD and TDD cellular transmission includes a set of control functions, illustrated in Figure 3.3 of [WIND210] and described in its Appendix C.1. We here briefly relate these functions to the multiple access control tasks that have been discussed on the preceding pages.

Resource partitioning. Provides the layout within the super-frame in time, frequency and possibly also spatial dimension (beam) of the chunks that are to be used for frequency-adaptive scheduled transmission, non-frequency adaptive scheduled transmission and contention-based uplink transmission. This layout is constant within the super-frame. The SDMA scheme for relay-enhanced cells of section 4.4.3.1 is a possible component of the over-all resource partitioning scheme.

Constraint processor. Combines constraints on the use of chunks and chunk layers. These constraints arise from interference between user terminals, interference avoidance scheduling/reuse partitioning with neighboring cells and spectrum sharing between operators (Section 6.1). The constraints have a spatial dimension, and thus provide inputs to the decision on how to use SDMA. They also provide constraints on the resource scheduling.

Spatial scheme controller. Assigns an appropriate multi-antenna spatial transmission scheme to each flow. This assignment has to be performed in coordination with the decision on how, and to what extent, SDMA will be used within the cell. Detailed principles for its function are presented in Appendix B of [WIN2D341].

Flow setup and termination. Includes the initial selection of multiple access schemes, including the selection of DAC versus scheduled transmission for uplinks and the choice of frequency-adaptive versus non-frequency adaptive transmission for scheduled flows, discussed in Section 5.2.1.

Flow state controller. This set of functions control the FEC coding/decoding of packets and controls the active/semi-active/passive state of flows. It can also be given the task of monitoring the appropriateness of using frequency-adaptive or non-frequency adaptive transmission for a scheduled flow, and make a re-assignment if this is required.

Resource Scheduler. Optimizes the total transmission of multiple flows over one hop. Performs the frequency-adaptive and non-frequency adaptive scheduling. Also determines the link adaptation parameters as well as the uplink slow power control strategy. As described in sections C.1.6 and C.1.7 of [WIND210], the Resource Scheduler includes as its first algorithmic step the spatial user grouping, which is a key component of SDMA schemes (Section 2.4 and 4.4).

Proof-of concept designs of all these control functions are needed for properly assessing the performance of the multiple access schemes that have been proposed in this report.

7.1.3 Transmission and Retransmission Delays

The timing of the transmission control loops for frequency adaptive and non-frequency adaptive transmission have been outlined in Sections 3.1, 3.2, 4.1 and 4.2. The target is to attain a very short delay over the air interface.

In the transmission control systems, a scheduling computation delay of max. 0.1 ms has been assumed. The computation delay for channel quality or state prediction is likewise assumed to be max. 0.1 ms.

Regarding the delay of ACK/NACK for (link) retransmission, we have to add the delay of decoding. The results of Table B-2 of Appendix B in [WIND210] show that a delay of below one clock cycle per decoded bit is attainable, with appropriate parallel implementations of LDPC and DBTC decoders. For example, the assumed FEC block sizes of max. 1200 bits, this corresponds to less than 6 µs when 200 MHz of the total clock cycles are allocated to decoding. We below allow the total *receiver processing delay to use up to one slot (345.6 µs).* Decoding of FEC blocks of size up to 1520 bytes should require less than 60 µs, so this provides ample time also for iterative turbo decoding /channel estimation.

In the TDD Physical layer mode, frames comprise an UL slot followed by a DL slot. In the FDD mode, half-duplex terminals are assigned to one of two groups. Group 1 transmits in the downlink in the first slot of the frame and in the uplink in the latter slot. Group 2 transmits/receives in the opposite way. ([WIND210], section C.1.2).

For either case, let "UL *i*" and "DL *i*" denote the uplink/downlink slots of frame number *i*, respectively The timing of the transmission over one hop, outlined in Sections 3.1, 3.2, 4.1 and 4.2 is summarized by Table 7-1. In the tables below, it is assumed that in half-duplex FDD as well as TDD, a DL slot precedes an UL slot within the frame.

Table 7-1: Transmission plus decoding delays

	Transmit request	Predict. update Scheduling, DL control	Trans-mission	Decoding of RTU	1-hop delay incl. decoding (frames)	1-hop delay (ms)
Frequency-adaptive **uplink**	UL *j-2*	UL, DL *j-1*, DL *j*	UL *j*	DL *j+1*	3.0	2.1
Non-frequency adaptive **uplink**	UL *j-1*	DL *j*	UL *j*	DL *j+1*	2.0	1.4
Frequency-adaptive **downlink**		DL *j-1*, DL *j*	DL *j*	UL *j*	2.0	1.4
Non-frequency adaptive **downlink**		*j-1*, DL *j*	DL *j*	UL *j*	2.0	1.4

The attainable delays involved in a retransmission are summarized by Table 7-2 below.

Table 7-2: Retransmission delays

	FEC block received	ACK/NACK transmission	Retransmission	Retransmission delay (frames)	Retransmission delay (ms)
Downlink	DL *j*	UL *j+1*	DL *j+2*	2.0	1.4
Uplink	UL *j*	DL *j+2*	UL *j+2*	2.0	1.4

The following examples illustrate the range of attainable delays over the air interface.

Example 1. Consider a downlink transmission over two hops (BS-RN-UT) in TDD. The BS-RN relay link transmission is initiated during slot DL *j-1* and executed in slot DL *j*. Decoding is finalized during slot UL *j*. Simultaneously with the decoding, the forwarding/scheduling is prepared for the next hop over the RN-UT link. An ACK/NACK is transmitted over the reverse RN-BS relay link during slot UL *i+1*. Transmission over the RN-BS link is performed during slot DL *i+1*, with decoding completed at the UT during slot UL *i+1*. (We here assume that the forwarding and queuing at the MAC layer within a RN does not induce any extra delay.) The transmission over two hops thus requires in total 6 slots or 3 frames, with total delay 2.1 ms. (In the FDD mode with relay nodes, the timing becomes somewhat different, see

Figure 30 in [WIN2D6133]. Note, however, that the decoding delay is not taken into account in that figure, and that slots are denoted as MAC frames.)

Example 2: A one-hop downlink transmission is performed for a 576 byte TCP-IP packet that is segmented into four 1200 bit RTUs. These four blocks are transmitted over subsequent frames *k,k+1,k+2,k+3, k+4*). In the baseline design, [WIN2D6137], at most one non-retransmission RTU per flow is allowed per frame. One of the blocks encounters a transmission error and has to be retransmitted once. The retransmission is given high priority and is executed simultaneously with a normal RTU transmission. The transmission starts during frame *k-1* and error-free transmission would be completed in frame *k+4*, with the last ACK arriving in frame *k+6*.

If the first or the second block has to be retransmitted once, then the retransmission will arrive during frame *k+3* or *k+4*, respectively so no extra IP-packet delay will be incurred. If the third or fourth block is erroneous, an extra delay of one or two frames, respectively, is caused.

If all four RTUs can be transmitted in the same frame, using a more advanced N-Channel Stop-and Wait protocol, then this would reduce the delay for error-free transmission +decoding to 2 frames, or 1.4 ms.

7.2 Frame Descriptor Tables

Assuming a centrally controlled, frame based reservation scheme, as proposed for the WINNER MAC, the concept of Frame Descriptor Tables (FDT) (see Appendix C.1) helps to reduce signalling overhead by eliminating redundant description of frame contents across frames. This is done by caching the description of frame contents in mobile stations/relay nodes and referencing a certain description by transmitting an associated ID. This can be seen as a way to merge the concepts of frame based resource reservation and the reservation of TDMA channels in order to take advantage of the merits of both concepts The analysis and simulative assessment of the concept (see Appendix C.1) show the positive effects this concept can have on signalling overhead. The results show that with this concept a reduction of overhead and establishment of TDMA channels using a MAC protocol employing a frame based reservation is feasible and promising.

When examining multi-hop solutions for frame based MAC protocols it becomes obvious that this reduction will get even more important. A drawback of the multi-hop MAC protocol, which will be an integrated part of the WINNER system design, is the fact that control signalling is needed for each hop. This results in an increasing overhead with an increasing number of hops. With the help of FDTs this overhead can be kept small. Considering a multi-hop solution that establishes fixed or even partly fixed connections for the relaying of data, implementing the concept of FDT in such a realisation of a MAC protocol is even more interesting. In a typical multi-hop scenario there is a BS that serves several UTs as well as one or more FRNs, which in turn serve Relay User Terminals (RUT) attached to them. The traffic generated by the RUTs can be multiplexed onto one, or at least less number of connections from the FRN to the BS and vice versa. These connections have a more or less fixed resource requirement that can be almost perfectly described using an FDT. Instead of describing this long-standing and slowly changing connection every frame, it can be described using an FDT. This provides an easy means to ensure a minimum bandwidth allotted to the FRN as well as saving overhead and thus enabling the allocation of more resources to the UTs attached to the BS directly. There are additional advantages of the fixed allocation of resources. In the case of UL connections usually a station has to send a resource request, which has to be processed by the BS. At the earliest in the next frame resources can be allocated. This step can be omitted using the method of establishing a fixed TDMA channel. Moreover in [EKW06] it is shown that in a multi cellular environment, the quality of the interference estimation has a big impact on the gain attained with the frequency adaptive scheduling scheme. As long lasting connections help to improve the interference estimation they are a promising means to attain the possible improvements.

As discussed in section C.1.7, there are various possibilities to apply FDTs in the WINNER context. The relevance has to be analysed from case to case but at least the establishment of TDMA channels for relaying and the reduction of overhead introduced by the resource partitioning information and the allocation table content seem to be a promising way to improve the WINNER system performance.

7.3 Control Signalling for Adaptive MA Selection

One challenge of supporting more than one MA scheme is the need for a flexible data structure for e.g. signalling of the resource allocation. Naturally different MA schemes will request for different and/or differently sized data fields within control signals, which induces that in a common data structure there have to be fields for all parameters of all supported MA schemes. There are two possibilities to overcome this drawback. Firstly one could try to design the describing fields in such a way that they are able to contain different information depending on the applied MA scheme as shown in Figure 7-2.

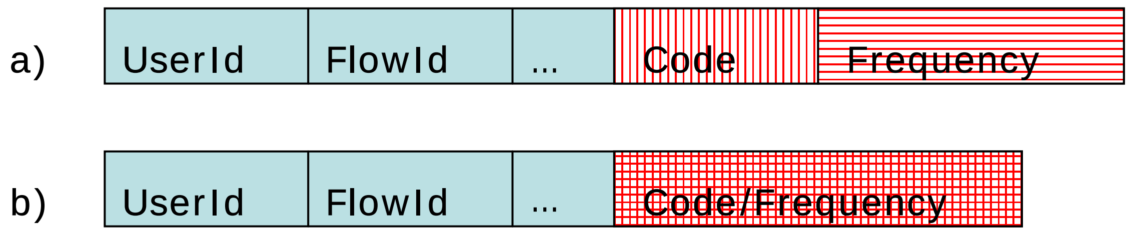


Figure 7-2: Adaptable control information structure

Figure 7-2 a) shows an exemplary data structure for resource allocation with fields for code and frequency information. If not both information is needed at the same time, i.e. each MA scheme only requests one of both information, the data structure can be designed as shown in Figure 7-2 b). Here the relevant field is able to contain code or frequency information.

This approach still has the disadvantage that the most challenging scheme in the sense of requiring the highest amount of signalling information will define at least the number of required fields and their size. Therefore another approach seems to be promising. The proceeding is based on splitting the control signals into a fixed and a dynamic part. This separation allows for a highly scalable control signalling.

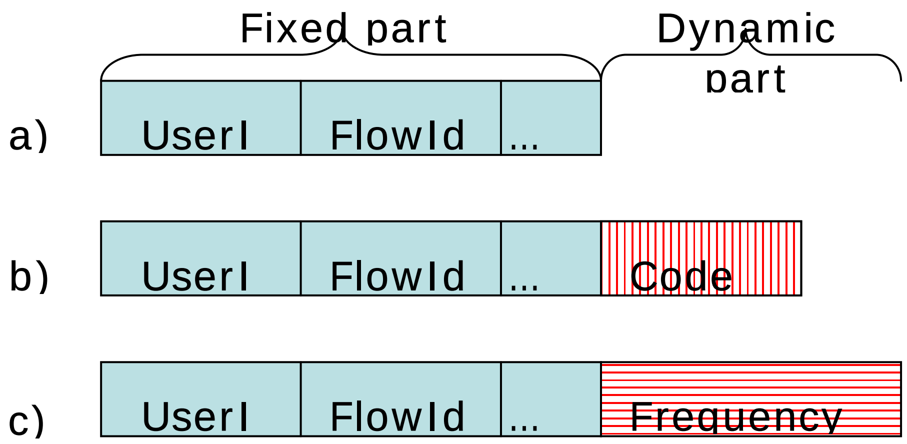


Figure 7-3: Exemplary split resource allocation control information

As seen from Figure 7-3, the fixed part of the control signal comprises the data fields required by all MA schemes. The additional fields, which are MA scheme specific, are attached to the fixed part accordingly to the need. Of course the fixed part needs to have a field that specifies the upcoming dynamic part to realize this proceeding. This approach would allow for even more scalability when the MAC will support the feature of online updates; i.e. the controlling entity (typically BS/RN) transmits the way the receivers have to interpret the dynamic part of the data structure. Thus it would be easily possible to enable the system to integrate e.g. another MA scheme not recognized during the first specification of the system at a later stage without having the need for a complete redesign of the data structures.

It is worth to be mentioned that the concepts in this paragraph are described in reference to the adaptability of MA schemes but are by far not limited to it. They will show their usefulness in various other contexts. Figure C-20 for example, shows the concept of split control signal information for the BCH. Inside the fixed part a pointer references to the dynamic part which is distributed over several chunks in this example.

8. Conclusions

The overall goal of this deliverable was to refine the understanding and definition of suitable multiple access schemes for the WINNER system concept. We started by introducing the chunk based WINNER MAC architecture along with the superframe concept and scheduling architecture. We continued with a review of the WINNER I candidate MA schemes, and then we discussed the proposed multiple access concepts for the uplink and for the downlink respectively based on the insights from investigations in the appendices. We proceeded with discussing co-existence of the different multiple access schemes and their selection and switching criteria. Some aspects of spectrum sharing were then addressed in, and finally we discussed the evolved MAC layer design and some supporting MAC control functions for the multiple access concept that are useful in the further work of the MAC layer design. The detailed results of design investigations and performance comparisons were presented in the appendices.

To summarize:

- The reference multiple access scheme for frequency-adaptive transmission remains chunk-based TDMA/OFMDA, i.e. exclusive allocation of chunk layers to flows based on short term CQI per chunk layer. It is integrated in a MAC architecture that enables large multi-user scheduling gains to be obtained together with link adaptation gains based on individual link adaptation within chunk layers using strong FEC coding for large channel coding gains.
- The reference multiple access schemes for non-frequency adaptive transmission in uplinks and downlinks are denoted B-IFDMA and B-EFDMA, respectively. They are closely related to each other, the difference is a DFT precoding step in B-IFDMA. They enable intra-chunk sleep mode, low power amplifier backoff in the user terminal, large frequency diversity gains and low addressing overhead. Their performance gains in terms of user terminal power efficiency are assessed. Due to their similarity with IFDMA and chunk-based MC-CDMA, their expected spectral efficiency can be derived from the IFDMA and chunk based MC-CDMA simulations in Appendix A, but simulations of the schemes are needed to find optimal parameterization of e.g. the block size and the allocation strategies taking MAC protocols and multiple antenna solutions into account.
- The multiple access schemes for scheduled transmission are based on a short frame duration, which enables frequency-adaptive transmission at vehicular speeds and fast retransmissions, to obtain reliable links also for delay critical services. But as an alternative access mode for the uplink, a solution for a direct access channel (DAC) based on multi-antenna reception was investigated and compared to a scheduled uplink channel. There is a delay advantage of a DAC channel, which could be useful in the system, especially for small uplink packets.
- For the SDMA downlink, two adaptive allocation strategies were discussed and a comparative assessment was carried out under the assumption of short-term CSI. In addition, a solution for the case of long-term SDMA was proposed. For the uplink, the studies indicate that SDMA reduces the post-receiver SINR and hence the instantaneous data rates. However, average data rates are still improved, since users get access to the channel more frequently. Using Successive Interference Cancellation (SIC) at the base station provides an additional throughput improvement. The integration of SDMA is an ongoing topic for further study.
- Means for co-existence, selection and switching between multiple access schemes were discussed. The conclusion on co-existence is to frequency multiplex the different multiple access schemes, except in low bandwidth deployment scenarios. In such scenarios, time-multiplexing could be favourable, especially in case of a low carrier frequency deployment.
- Initial concept for multicast and broadcast support was discussed. Here, means to obtain macro-diversity gains by coordinated scheduling in a Relay Enhanced Cell (REC) and in clusters of cooperating RECs were identified as both feasible and important, but a detailed concept proposal is for further study.
- The work towards a complete MAC layer proposal was taken forward and means for designing an adaptive MAC layer with low protocol overhead were discussed. Here, the concept of Frame Descriptor Tables (FDT) was identified as a promising tool. Further work on the definition of the MAC layer is a topic for the rest of WINNER II.

Appendix A. Performance of WINNER I Candidate Multiple Access Schemes

A.1 Review of WINNER I Multiple Access Simulations

Multiple access and related problems was studied within WINNER phase 1 in the reports [WIND26], [WIND24] and [WIND210].

- [WIND26], Assessment of Multiple Access Technologies, in October 2004 gave an overview of the candidate MA schemes and assessed their advantages and drawbacks individually.
- [WIND24], Assessment of Adaptive Transmission Technologies, in February 2005 presented detailed control feedback loop designs for predictive frequency adaptive transmission in TDMA/OFDMA downlinks and uplinks, in both the cellular FDD and the cellular TDD mode.
- [WIND210] in December 2005 presented the WINNER I multiple access proposal and contained several simulation studies that compared variants within the over-all MA framework.

The following summary was made in Section 3.1.6 of [WIND210] of simulation and assessment results relevant for selection of multiple access schemes that had been performed within WINNER phase 1. (Underlined words have been added.)

"For the case of *frequency-adaptive transmission* a gain was, not surprisingly, found when concentrating the transmitted packets to individual chunks, instead of spreading them out over the slot. Spreading them out over all frequencies by e.g. MC-CDMA or TDMA would *average away* the channel variability. Lowering the cannel variability reduces potential multi-user scheduling gains. In Appendix G.4.1 of [WIND210] (single-carrier) TDMA that allocates the whole 20 MHz band to only one user is found to result in a reduced multi-user scheduling gain. See also Section 3.1.5.3 in [WIND24] where OFMD-based TDMA was compared to TDMA/OFDMA.

The chunk sizes have been designed to be appropriate for the transmission scenarios used, with reasonably flat channels within chunks. Therefore, as shown in Appendix G.4.3 of [WIND210], very little can be gained by *sharing chunk layers between flows* if the throughput is to be maximised. As shown in Appendix G.1.4 of [WIND210] and Section 3.3 of [WIND24], chunk sharing can be of advantage in a special case: There are many flows that have the very strict delay requirements and a guaranteed throughput in each slot (0.34 ms). While such delay constraints are extreme for user data, they are applicable for retransmissions and for time-critical control information. Appropriate transmission schemes for these will be studied in WINNER II.

For *non-frequency adaptive transmission*, Appendix G.4.2 of [WIND210] illustrates the improved performance obtained by partitioning the transmission over a set of resources whose channels have high diversity. As noted above, different methods can be used: MC-CDMA, symbol-based TDMA or subcarrier-based OFDMA. The performance differences between them were investigated and were found to be rather small. Of these schemes, MC-CDMA provides the highest diversity. In Appendix G.1.1 of [WIND210], it is concluded that MC-CDMA outperformed OFDMA in terms of cell throughput for all considered loads and scheduling algorithms. In Appendix G.1.2 of [WIND210], MC-CDMA provides some advantage while in Appendix G.1.3 of [WIND210], OFDMA is found to provide slightly superior performance. Explanations for these differences are discussed in Section 5.3.3 of [WIND210].

None of the so far performed investigations added the effect of spatial diversity schemes. It can be expected that the additional use of spatial diversity will lessen the requirement for frequency diversity. This would simplify the resource partitioning problem (Appendix C.1.1 of [WIND210]), that includes selecting appropriate sets of chunks for adaptive and non-frequency adaptive transmission.**"**

The assessment studies of WINNER II have taken these conclusions as a starting point, to provide further background information for the refined MA schemes and the MA adaptation studies.

A.2 Simulation Assumptions

This section provides the set of simulation assumptions which are considered to reinforce the MA concepts described in this deliverable.

Table A-1 summarizes the different simulator classes identified in [WIN2D6131] and typical assessment parameters to evaluate the multiple access concepts.

Table A-1: Classification of different simulator types

	Class I Protocol Level Simulator	**Class II System Level Simulator**	**Class III System Level Simulator**	**Class IV Link Level Simulator**
Categorisation	Pure protocol simulator	Dynamic system behaviour, Continuous evolution	Snap-shot/Quasi-static based SLS	Link level simulator
Basic characteristics	Detailed modelling of protocols (state buffers, etc.)	Dynamic change of user behaviour (# of users, locations, velocity, birth-and-death)	Fixed position of users (fast fading in one snap-shot with considering Doppler)	
Radio channel	Path loss Shadowing	Path loss Shadowing Complete WINNER channel model (fast fading + spatial channel property)	Path loss Shadowing Complete WINNER channel model (fast fading + spatial channel property) within snap-shot	Complete WINNER channel model (fast fading + spatial channel property) within snap-shot
Cell configuration	Multi-cell			Single-cell
Number of links in a cell	Multiple			Single (Multiple)
Interference	Inter-cell interference			Intra-cell interference
Traffic data	Statistics on IP level		Statistics on MAC-SAP	Continuous transmission with full buffer
Typical Output	• Network throughput, e.g., TCP throughput • Delay • Fairness	• System throughput • Call/packet blocking/dropping rate • Delay • Fairness	• System throughput • Delay • Fairness	• Link budget • Link performance curves, e.g., BER/BLER/FER/PER vs. Eb/No

As stated in [WIN2D6131] considered **test scenarios** comprise of **application scenario assumptions** and the specific **system assumptions**.

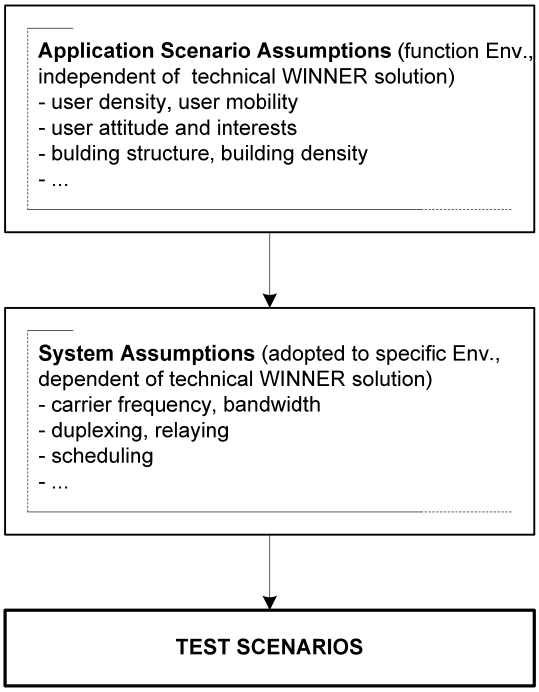


Figure A-1: Development of test scenarios.

A.2.1 Scenario Assumptions

Application scenarios describe the relevant characteristics of a selection of environments where a WINNER system will be operated. "Environment" means here that the description is independent from the technical solution WINNER provides, but refers only to the external characteristics that cannot be changed by WINNER. The prioritized test scenarios are divided into 3 groups which are derived from the deployment scenarios:

- **base coverage urban:** an urban macro-cellular scenario using the FDD physical layer mode, a carrier frequency of 3.7 GHz / 3.95 GHz, and 2 x 50 MHz bandwidth. This is applicable for **Wide Area (WA)** scenario.
- **microcellular:** an urban micro-cellular scenario, a sub scenario of **Metropolitan Area (MA)**, using the TDD physical layer mode and 100 MHz bandwidth at 3.95 GHz.
- **indoor:** an indoor hotspot scenario using the TDD physical layer mode and 100 MHz bandwidth at 5 GHz. This is a **Local Area (LA)** scenario.

Couple of base line assumptions to provide sufficient information for simulations are given in the following tables.

Table A-2: Application scenario assumptions (environment specific)

	Base Coverage Urban (WA)	**Microcellular (MA)**	**Indoor (LA)**
Environment characteristics	Two-dimensional without topographic details	Two-dimensional regular grid of buildings ("Manhattan grid")	One floor of a building with regular grid of rooms and corridors, three dimensional
		Number of buildings: 11 x 11 Building block size: 200x200m Street width: 30 m	Number of rooms: 40 Rooms size: 10x10x3m Number of corridors: 2 Corridor size: 100x5x3m

	Base Coverage Urban (WA)	**Microcellular (MA)**	**Indoor (LA)**
User distribution model (at simulation startup)	• Number of users is a variable parameter • All users are uniformly distributed in the entire *area*	• Number of users is a variable parameter • All users are uniformly distributed in the *streets*	• Number of users is a variable parameter • 90% of users are uniformly distributed in *rooms* and 10% of users are uniformly distributed in *corridors*
User mobility model (class III and IV)	• Fixed and identical speed $\|v\|$ of all UTs • $\|v\| \in \{3, 50, 120\text{km/h}\}$ $\angle v = \theta_v \sim U(0^o,360^o)$	• Fixed and identical speed $\|v\|$ of all UTs • $\|v\| \in \{3, 50\text{km/h}\}$ $\angle v$: UTs only move along the streets they are in. Direction is random and both directions are equally probable	• Fixed and identical speed $\|v\|$ of all UTs • $\|v\| \in \{0, 5\text{km/h}\}$ $\angle v = \theta_v \sim U(0^o,360^o)$
User traffic model (class III)	Single traffic flow per user; Full queue per user or alternatively Number of data packets of size K bits is drawn from a random distribution for each queue at the beginning of each snapshot. No new data packets arrive during a snapshot. The packets in each queue have a linearly increasing expiration date representing an equidistant arrival time		

[WIND54] describes WINNER MIMO channel models for link and system level simulations. Link level is defined for a single communication link whereas system level is defined for multi communication links and base stations. The prioritized scenarios are: Scenario A1 for indoor small office environments, Scenario B1 for microcell urban environment, Scenario B5 for hotspot LOS stationary wireless feeder and Scenario C2 for Metropolitan ubiquitous coverage in macrocell urban environment. The other additional Scenario C1 is part of the WINNER channel model for macrocell suburban environment. These are summarised in Table A-3. These models have been basically developed during phase I with some extensions regarding path loss modelling for different BS antenna heights and carrier frequencies during beginning of phase II. These models naturally depend on the selected frequencies.

Table A-3: Channel modelling parameters

		Base Coverage Urban (WA)	**Microcellular (MA)**	**Indoor (LA)**
channel model BS↔MT		C2[11]/(C1)	B1	A1
channel model BS↔RN		30% B5a (LOS) 70% B5f (NLOS)	B5c	n.a.
channel model RN↔MT		C2	B1	n.a.
Correlation of large scale par	between sectors of different sites	No		
	between sectors of same sites	Full, i.e. use identical large scale parameters for all sectors		
	between UTs of same site	Distance dependent		
Correlation of small scale parameters between sectors of same site		Partly full, i.e. use identical small scale parameters except the sub path-phases which are redrawn randomly.		
noise power spectral density		-174dBm/Hz		

[11] For WA, the WINNER channel model C2 has highest priority. Channel model C1 might optionally be considered.

For detailed parameter descriptions of these channel models refer to [WIND54].

Performance Requirements
As defined in [WIN2D6111], within WINNER the 95%-ile is used. Although no strict one-to-one mapping of the 95%-ile to coverage area is possible, it can be regarded as the target that will be exceeded in the main service area of a site, whereas the remaining 5% represent disfavoured situations, such as users in heavy shadowing at the cell edge. The satisfied user criterion for phase II is thus defined as 95% of the users have an average active session throughput greater or equal than 2 Mbps. A session is considered active from the time the first packet of a packet call enters the transmit buffer until the last packet of a packet call has been successfully received.

A.2.2 System Assumptions

The baseline system assumptions reflect, as stated in [WIN2D6131], the current status of the simulation tools within the WINNER consortium. These are minimal configurations which do not correspond to any particular future WINNER implementation. The main purpose is to form a basis for relative comparisons and thereby assessing the added benefit of new features. The baseline system assumptions further serve to assess the status of the simulation tools, to assist in planning and coordination of simulation campaigns, and to form the basis for prioritization of future development of simulators.

Table A-4: System assumptions (deployment specific)

		Base Coverage Urban (WA)	**Microcellular (MA)**	**Indoor (LA)**
General	duplexing (asymmetry)	FDD (1:1)	TDD (1:1)	TDD (1:1)
	carrier frequency f_c	3.95 DL/3.7 UL	3.95 GHz	5.0 GHz
	channel bandwidth	2 x 50 MHz	100 MHz	100 MHz
	Deployment (see Figures 3.1 – 3.3 in [WIN2D6131])	cellular, hexagonal layout	cellular, Manhattan grid lay-out [UMTS 30.03]	isolated site[12], regular room layout [UMTS 30.03]
	frequency reuse	1 → no fixed resource partitioning[13]		n.a.
base station	location/height[14]	Above rooftop, 25m	Below rooftop, 10 m	3m
	max. transmit power per sector	46dBm = 39.81W	37dBm = 5.012W	21dBm = 125.9mW
	inter site distance	1km	follows from fig. 3.2 in [WIN2D6131] and Table A-2	n.a.
	number of sectors	3	1	1 sector[15]
	number of antennas per sector	4	8	8
	antenna configuration (per sector)	Linear array ||||	Cross polarized linear array X X X X	Cross polarized linear array X X X X
	antenna element spacing	$0.5\lambda=0.5c/f_c$ (f_c =DL carrier frequency, c=speed of light)		

[12] The Local area CG considers isolated cell for link level simulation but consider deployment based on a couple of cells for radio resource management strategies (e.g. to evaluate coordination mechanisms between BSs).

[13] It is understood that it would lead to pessimistic results without smart intercell interference cancellation techniques, currently under investigation in the project. Higher frequency reuse may be used for specific evaluations.

[14] This information is only informative since it is inherent to channel model

[15] For Indoor, a single sector with a maximum number of 24 antennas (organized in a triangular or circular array) is the preferred choice that allows to meet the requirement. However, simplified assumption could be considered for the baseline system.

		Base Coverage Urban (WA)	Microcellular (MA)	Indoor (LA)
	azimuth antenna element pattern	$A(\theta) = -\min\left[12\left(\frac{\theta}{\theta_{3dB}}\right)^2, A_m\right]$ [dB] A_m= 20, θ_{3dB}= 70° (A_m= 23, θ_{3dB}= 35° for 6 sector site)		A_m= 12, θ_{3dB}= 70°
	elevation antenna gain	14dBi		
	receiver noise figure	5dB		
user terminal	height[2]	1.5m		
	transmit power	24dBm = 251.2mW		21dBm = 125.9mW
	number of antennas	2		
	antenna configuration	dual cross polarized antennas: X		
	azimuth antenna element pattern	$A(\theta) = 1$		
	elevation antenna gain	0dBi		
	receiver noise figure	7dB		

Table A-5 summarizes the OFDM/GMC parameters which are completely described by the triple, subcarrier distance, guard interval length and number of used subcarriers.

Table A-5: OFDM/GMC parameters

	Base Coverage Urban (WA)	Microcellular (MA)	Indoor (LA)
Subcarrier distance Δf	39062.5Hz	48828.125 Hz	
Useful symbol duration T_N	25.6μs	20.48μs	
Guard interval T_G	3.2μs	1.28μs	
Total symbol duration	28.8μs	21.76μs	
used subcarriers	[-512:512]	[-832:832]	

The frame and superframe structure for the baseline system implementation is depicted in Figure A-2. The corresponding parameters are listed in listed in Table A-6 and Table A-7, respectively. Note that Figure A-2 reflects the TDD case with respect to the frame structure (superframe parameters are identical). In case of FDD, i.e. base coverage urban scenario, each "frame" consists of two downlink (or uplink) chunks.

Table A-6: Frame parameters

	Base Coverage Urban (WA)	Microcellular (MA)	Indoor (LA)
Overall frame length	0.6912 ms		
Number of OFDM symbols per frame	24	30	
Chunk dimension in symbols x subcarriers	12 x 8 =96	5 x 16 = 80	
Pilot and signalling overhead per chunk in # of resource elements	19	15	
Number of chunks per frame in time and frequency direction	2 x 128	6 x 104	
Duplex guard time	0μs	2 x 19.2μs	

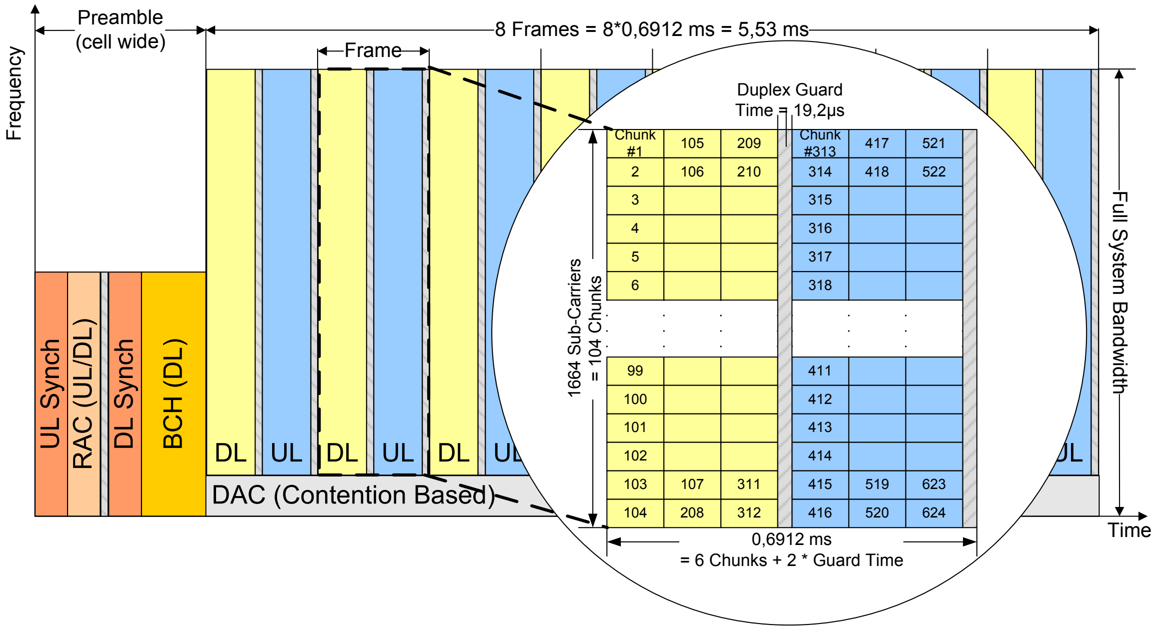


Figure A-2: Sketch of superframe structure (holds for both FDD and TDD scenarios) and frame structure (holds only for microcellular and indoor test scenarios).

The resource allocation in WINNER happens in chunks (time-frequency tiles). The size of the chunk is selected so that it would be within the coherence time and coherence frequency of the propagation channel. With FDD the chunk size is 12 symbols x 8 subcarriers which corresponds to 345.6 µs x 312.5 kHz. With TDD the chunk size is 5 symbols x 16 subcarriers corresponding to 108.8 µs x 781.2 kHz. With FDD the chunk duration spans half of a frame whereas the chunk duration in TDD spans only one sixth. A duplex guard of 19.2 µs is taken into account for TDD providing sufficient time to switch between transmission and reception.

Table A-7: Superframe parameters

payload length = DAC length		8 frames = 5,5296ms
Preamble	UL Synch	3 OFDM symbols
	RAC (UL/DL)	2 OFDM symbols
	Guard time	1 OFDM symbol
	DL Synch	4 OFDM symbols
	BCH (DL)	4 OFDM symbols
	Subcarrier reuse factor	7

The pilot and signalling overhead are given for the evaluation of a realistic throughput, in order not to avoid to scale down the simulation results for taking into account the overhead. The considered superframe consists of 8 succeeding frames preceded by a preamble part. The estimated length of the preamble part is specified in Table A-7.

The next table shows details of the convolutional codes and their puncturing pattern for respective code rates.

Table A-8: Code details for convolutional codes

generator polynom	Rate	puncturing pattern
G_1=561 G_2=753	R=1/2	$\begin{bmatrix}11111111\\11111111\end{bmatrix}$
	R=2/3	$\begin{bmatrix}11011111\\10110110\end{bmatrix}$
	R=4/5	$\begin{bmatrix}11011111\\00110100\end{bmatrix}$
	R=8/9	$\begin{bmatrix}11011111\\00100100\end{bmatrix}$

generator polynom	rate	puncturing pattern
G_1=575 G_2=623 G_3=727	R=1/3	$\begin{bmatrix}11111111\\11111111\\11111111\end{bmatrix}$
	R=1/2	$\begin{bmatrix}11111111\\10001111\\01110000\end{bmatrix}$
	R=2/3	$\begin{bmatrix}11011101\\10000111\\00110000\end{bmatrix}$
	R=4/5	$\begin{bmatrix}11011001\\10000110\\00110000\end{bmatrix}$
	R=8/9	$\begin{bmatrix}11001001\\10000110\\00110000\end{bmatrix}$

A.3 Downlink Simulation Results

A.3.1 Wide Area

A.3.1.1 Adaptive versus non-Adaptive Frequency Allocation

In order to answer the question, how much system performance gain could be achieved in DL for the fast/slow adaptive vs. non-adaptive frequency assignment (subcarrier assignment), couple of system level simulations have been carried out.

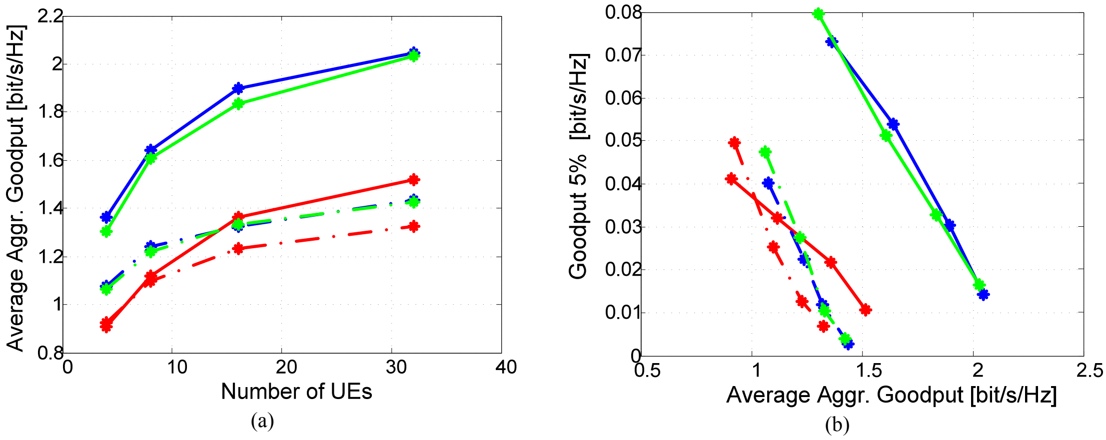
Table A-9: Deviated simulation assumption parameters

OFDM parameters	336 subcarriers used
User Mobility	|v| € {0, 50, 200} km/h
User traffic model	416 bits per packet
Scheduling	sliding window length for SBS is 8
Frame model	16 MAC frames per snapshot and minimum of 4 snapshots for each MT
overhead per chunk (# of REs)	18

Figure A-3 depicts the results where the CSI-update period is varied for fixed beam Score Based Scheduling (SBS) using WA channel model C2. Two types of subcarrier allocation were examined, chunk/block (blk) and interleaved (int) allocation while keeping the no. of OFDM symbols to the fixed value 12. In order to provide sufficient frequency diversity, the equidistant subcarriers for interleaved assignment are distributed over the total available bandwidth and the non-adaptive frequency assignment per user is considered. The delay between channel measurement and usage of this information for chunk adaptation processing is termed here as CSI update rate. According to the basic simulation assumptions it is set to 1 MAC frame.

As expected, the average system's aggregate goodput for chunk/block based resource allocation decreases up to 50% with an increase in terminals velocity, here from 0 to 200 km/h. Even very high adaptive rates (CSI updates every MAC frame) don't bring a significant improvement for velocities over 50km/h. For the considered scenario and terminal's velocity greater than 50km/h, CSI update period above 5.53ms doesn't lead to any performance improvement (comparing Figure A-3 c and d).

According to performance requirements, the satisfied user criterion is defined as 95% of users have an average throughput greater than or equal to 2Mbps, in normalised form 0.04 bits/s/Hz. Since for these simulations only 336 subcarriers are used, the average throughput is 0.013 bits/s/Hz. Thus 5% of users don't satisfy this requirement.



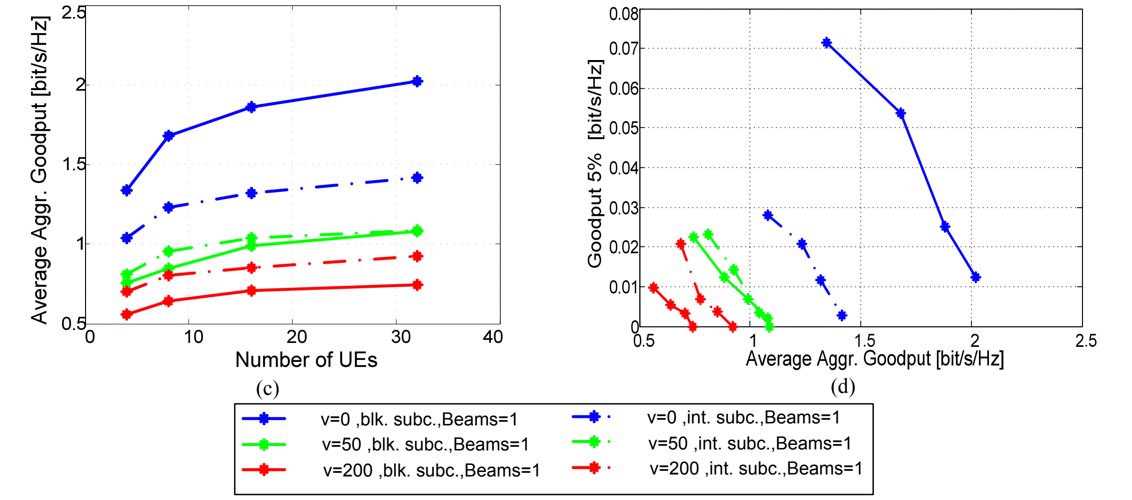


Figure A-3: Average aggregate system goodput comparison for adaptive (chunk) and non-adaptive (interleaved) frequency allocation at different terminal velocities, CSI update (a, b) rate 1 and (c,d) rate 8.

Compared to chunk/block based assignment, interleaved frequency assignment achieves better results for increase in terminals velocity and increase in CSI update period. The same effect has also been noted for increase in fixed beam count per sector.

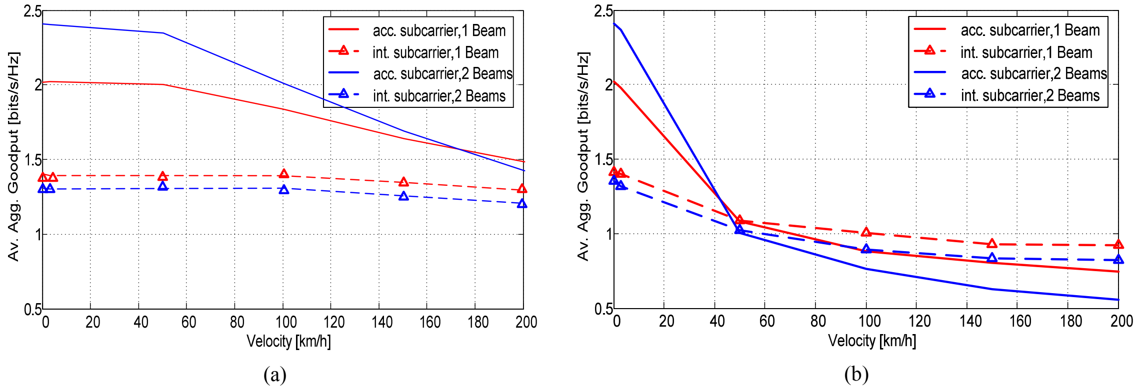


Figure A-4: Average aggregate system goodput vs. terminal velocity for adaptive and non-adaptive frequency allocation, CSI update (a) rate 1 and (b) rate 8.

It can be concluded, that chunk based frequency allocation is preferable for lower terminal velocities (<50kmh) and for higher CSI update rates (<2.7ms). Otherwise, interleaved frequency assigned allocation is the best option.

A.3.1.2 Adaptive versus non-Adaptive Frequency Allocation – Impact of User Speed

Simulations in this subsection are supposed to evaluate the impact of user speed over the system performance of frequency adaptive and frequency non-adaptive resource allocation schemes. HARQ was taken into account. Detailed inter-cell interference was simulated from the closest 10 sites over 19 simulated (according to C2 channel model), while the interference generated by the other sites was modeled as additive Gaussian noise. OFDMA-TDMA is the simulated multiple access scheme for frequency adaptive allocation with Score Based (SB) scheduling, as proposed in [WIND6131]. MC-CMDA, as described in Section 2.2, is the selected multiple access scheme for frequency non-adaptive allocation with Round Robin (RR) scheduling.

In this set of simulations, the most important deviated simulation assumptions are the channel bandwidth, the OFDM parameters, and chunk size, while the frame structure is still chunk-based as in the baseline. Deviated simulation parameters are reported in Table A.10.

Table A-10: Deviated simulation assumption parameters (OFDMA)

	Base Coverage Urban (WA)	**FT Scenario**
	General	
Channel Bandwidth	2 x 50 MHz	2 x 10 MHz
number of antennas per sector at BS	4	1, 2
UT antenna configuration	dual cross polarized antennas: X	Linear 0.5λ
	OFDM parameters	
Subcarrier distance Δf	39062.5Hz	15000Hz
Useful symbol duration T_N	25.6μs	66.43μs
Guard interval T_G	3.2μs	4.69μs
Total symbol duration	28.8μs	71.39μs
used subcarriers	[-512:512]	FFT size = 1024, 600 used
	Slot and chunk parameters	
Overall frame length	0.6912 ms	1 ms (2 slots of 0.5 ms)
Number of OFDM symbols per frame	24	14
Chunk dimension in symbols x subcarriers	12 x 8 = 96	7 x 25 = 175
Chunk dimension in x subcarriers	345.6μs x 312.5kHz	500μs x 375 kHz
Pilot and signalling overhead per chunk in # of resource elements	19	15
Number of chunks per frame in time and frequency direction	2 x 128	2 x 24

In simulations we have considered a MIMO Alamouti scheme with 2 transmit and 2 receive antennas, and also a scheme with receive diversity (rxDiv) with one antenna at the BS and 2 at the UE. We notice that the UE antenna configuration is linear and with an antenna separation of 0.5λ. However, the antenna correlation at the UE side is still very small, less that 0.05, due to the large angular spread (53°) at the UT, as assumed by the C2 model. This correlation is hence comparable to the one of the dual cross polarized antennas. Other simulation parameters are reported in Table A.11.

Channel predictors at the BS are not used in these simulations, but the CSI is reported at each MAC frame (1 ms) and an additional delay of one slot (0.5 ms) is considered for scheduler processing. This means that at the scheduling instant the CSI is 1.5 ms old. This in fact can have an impact on the scheduler performance, above all for frequency adaptive scheduling and high UT's speeds [WIND24].

Table A-11: Other simulation assumptions

Parameter description	**Value**
Cellular Layout	19 tri-sectored sites, accurate interference from 10 closest sites
Total number of users	48
Simultaneous active user	8
Window length for SB	30 slots (= 15 ms)
Link to System Interface	Effective Exponential SNR mapping (not WINNER's one)
Traffic model	Full queue
CSI measurement interval at UT	1 frame = 1 ms
CSI update rate	1 frame = 1 ms
HARQ	Chase Combining
Max number transmissions per packet	1 + 5 retransmissions
Parallel HARQ processes	5

The MCSs used in the simulation are reported in Table A.12, the selected coding scheme is duo-binary turbo coding: each packet is coded and modulated into 480 complex symbols, which occupies 3 chunks belonging to the same slot (half of MAC frame) of 0.5 ms. Hence we suppose that the scheduler always allocates to each active user a fixed number X of chunks (in our case $X = 3$). In the following we describe how the link adaptation was performed. Let N_{tot} be the total number of subcarriers used for data transmission and $chunk_{freq}$ be the number of subcarrier per chunk (in our case $N_{tot} = 600$ and $chunk_{freq} = 25$). We suppose that in the system there are 48 users waiting for service, but only $K_u = \frac{N_{tot}}{chunk_{freq}.X}$ user can tranmit: the values considered in our setting give $K_u = 8$ active user per slot.

In **frequency adaptive OFDMA/TDMA**, the scheduler selects the K_u scheduled users and assigns the corresponding X chunks in a fair way based on their respective channel qualities, according to the selected algorithm (in our simulation a Score Based scheduler is used). This requires an increased feedback using one SINR value per chunk for each active user. Link-adaptation is then performed explicitly by the base-station after chunk allocation. The chosen MCS index is based on the effective SINR on the allocated set of chunks. Consequently, the MCS and the chunk allocation has to be signalled to each scheduled mobile. Resource allocation in our simulations is performed through the following steps:

1) The scheduler selects $K_u = \frac{N_{tot}}{chunk_{freq}.X}$ users for the next slot based on their average SINR over the whole bandwidth, according to the predefined algorithm (in our simulation campaign we used here a Score Based algorithm).
2) The K_u selected users order their $\frac{N_c}{chunk_{freq}}$ chunks with decreasing SINR.
3) The users select their preferred chunks (1st position in their list) in a round-robin manner. Each selected chunk is removed from the chunk lists of the other users. The selection process is repeated until all chunks are allocated or each selected user is allocated a maximum X chunks.
4) Link adaptation is performed for each user on its X selected chunks.

If link adaptation is not successful (no suitable MCS is found) for a user, the lowest MCS is used and the user is allowed to transmit.

Table A-12: MCS set used in the simulations

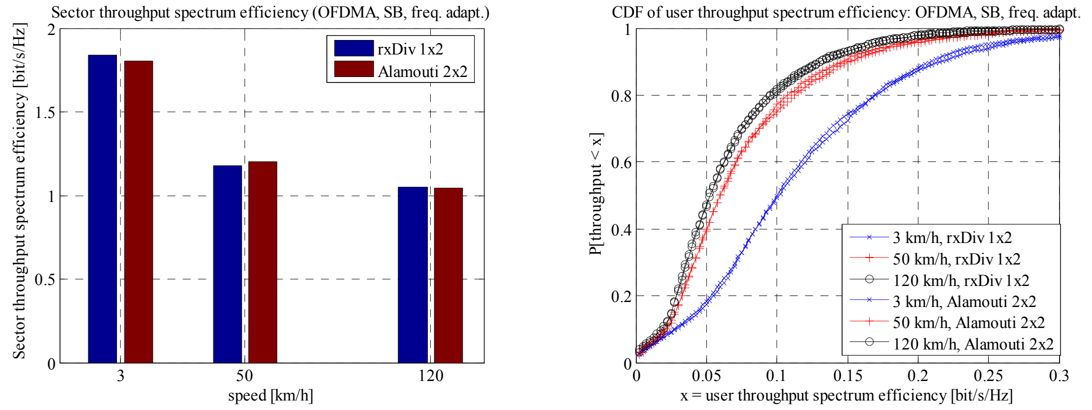
Modulation		QPSK			16QAM		64QAM	
Channel Code Rate		1/3	½	3/4	1/2	3/4	1/2	3/4
Information bits per packet (one packet is sent over 3 chunks)		318	480	720	960	1440	1440	2160
Spectral efficiency (bit/s/Hz)		0.106	0.768	1.152	1.536	2.304	2.304	3.456
Bit rate (Mbit/s)	per packet (3 chunks)	0.636	0.96	1.44	1.92	2.88	2.88	4.32
	total (24 chunks)	5.088	7.68	11.52	15.36	23.04	23.04	34.56

In the case of MC-CMDA, 8 users are active and one spreading code is assigned to each one of them (spreading factor = 8).

For **non-frequency adaptive MC-CDMA**, the whole system bandwidth is shared among all scheduled users. The users' signals are here separated using spreading with orthogonal Walsh-Hadamard Codes. In general, in WINNER baseline, spreading can be performed in two dimensions time and frequency but only within each chunk, in order to avoid interference among the different codes (users). In our simulation setting, a spreading factor of SF = 8 is used to accommodate 8 simultaneous users, as in the frequency adaptive DL mode. Users share the whole bandwidth and each complex symbol is spread in 4 adjacent sub-carriers and 2 successive OFDM symbols.

For non-frequency adaptive MC-CDMA, scheduling is performed according to the selected algorithm (Round Robin in our simulations) which takes as input the average SINR of the users over the whole bandwidth. Hence, only limited feedback from the mobile is required: the average SINR or the index of the best suited MCS. Since only an average measure of the channel quality is provided, scheduling can take place also after link adaptation. In fact, in this case link adaptation is just assigning to the scheduled user the best suited MCS corresponding to its average SINR.

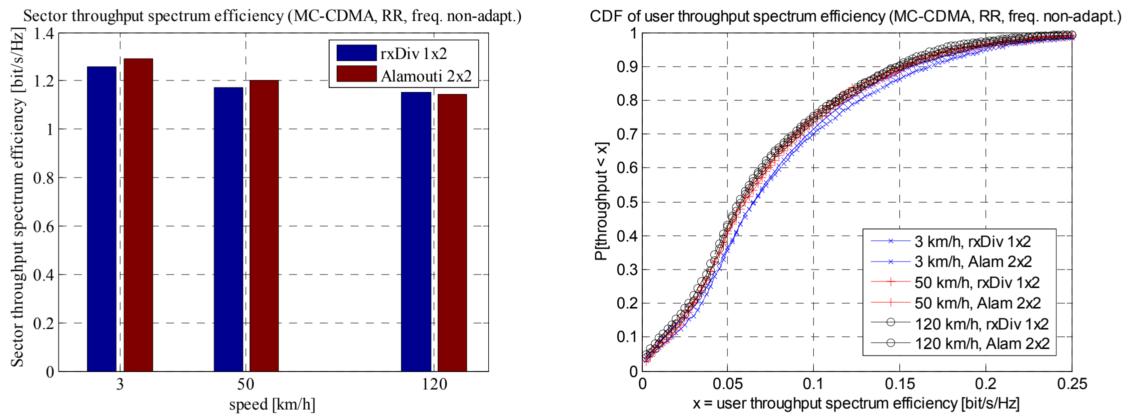
In the final part of our simulations, we have also considered **frequency non-adaptive OFDMA/TDMA**, in which the chunks of the $K_u = \frac{N_{tot}}{chunk_{freq} .X}$ selected users are simply interleaved in frequency to provide a diversity gain for the channel decoder. This chunk allocation can be pre-defined and signalled in advance to the mobile. Just as for MC-CDMA, scheduling can take place after link adaptation and is based on a single channel quality value.



(a) (b)

Figure A-5: Adaptive frequency allocation, OFDMA/TDMA, Score Based scheduling: sector throughput spectrum efficiency [bit/s/Hz] for as a function of UT speed (a); cumulative distribution function of user throughput efficiency (b).

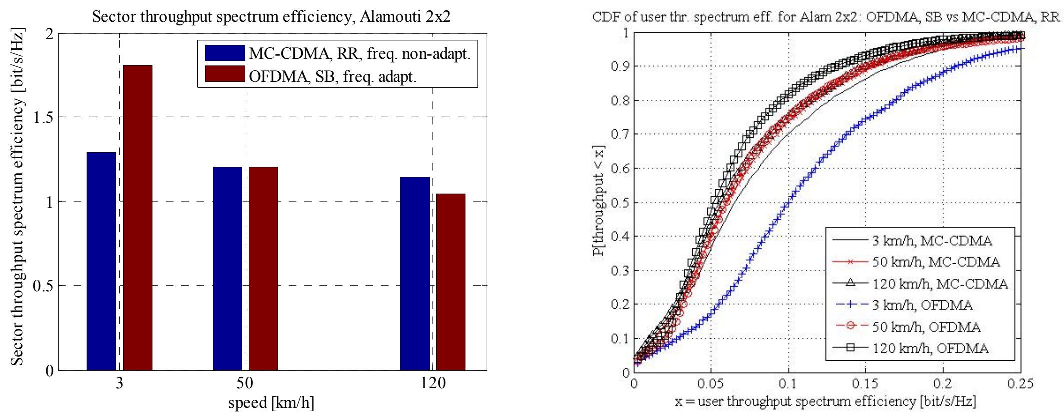
In Figure A-5, the sector throughput spectrum efficiency [bit/s/Hz] and the cumulative distribution function of user throughput efficiency are presented for adaptive frequency allocation, OFDMA/TDMA and SB scheduling, as a function of UT's speed. The performance of the Alamouti scheme with 2 transmit and receive antennas is drawn and, for reference, the performance of a system with one transmit antenna and 2 antennas at the UT (with maximum ratio combining) is presented for reference. As it can be seen in the figure, the performance of the two schemes is substantially equivalent; in fact the Alamouti scheme sometimes suffers from a small loss in performance. This is due to the fact that transmit diversity reduces channel variations in frequency, which is not beneficial to frequency adaptive resource allocation. It is then beneficial to use the transmit antennas (at the BS) for SDMA rather than for transmit diversity. The impact of UT's speed on sector throughput spectrum efficiency is important, even if better robustness is to be expected if good channel predictors are used at the BS. The performance loss is about 33% from 3 km/h to 50 km/h, while it is of 42% from 3 km/h to 120 km/h (10% from 50 to 120 km/h). The degradation is less severe from medium (50 km/h) to high (120 km/h) UT speeds, than from low to medium UT speeds. The user throughput spectrum efficiency has the same behaviour (Figure A-6 b)): performance quickly degrades from 3 to 50 km/h. Alamouti and receives diversity schemes substantially achieve the same performance.



(a) (b)

Figure A-6: Non-adaptive frequency allocation, MC-CDMA, Round Robin scheduling: sector throughput spectrum efficiency [bit/s/Hz] for as a function of UT speed (a); cumulative distribution function of user throughput efficiency (b).

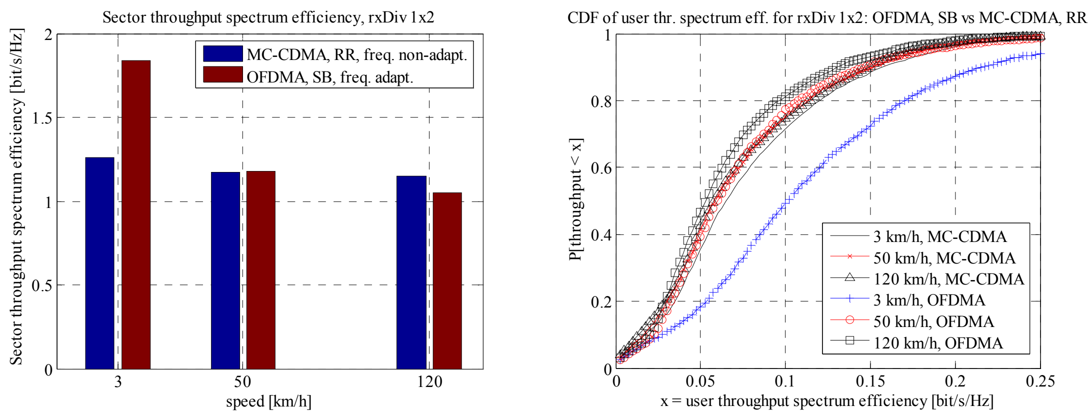
The same analysis was carried out in the case of frequency non-adaptive MC-CDMA (see Figure A-7). The Alamouti scheme seems to be better than receive diversity only at low and medium speeds (+2.5% and 2.2% at 3 and 50 km/h), while a small loss of 0.7% is shown at 120 km/h. The MC-CDMA with frequency non-adaptive scheduling (Round Robin) is much more robust to user speed variations. The Alamouti scheme performance loss is 7% from 3 to 50 km/h and 5% from 50 to 120 km/h. The user throughput spectrum efficiency is robust to user speed variations too (see Figure A-7 b)).



(a) (b)

Figure A-7: MIMO Alamouti 2x2 scheme for frequency adaptive and non-adaptive allocation: sector throughput spectrum efficiency [bit/s/Hz] for as a function of UT speed (a); cumulative distribution function of user throughput efficiency (b).

We reported in Figure A-7 the results of the Alamouti 2x2 scheme for OFDMA and MC-CDMA. OFDMA with frequency adaptive Score Based scheduling is to be preferred at low speed (< 50km/h), while MC-CDMA with frequency non-adaptive Round Robin scheduling is more advantageous for higher speed, from a sector throughout perspective. From a user throughput perspective OFDMA is better than MC-CDMA at low speeds too. However, this comparison is unfair for the frequency adaptive OFDMA, since, as we have seen, the Alamouti scheme penalizes its sector throughput.



(a) (b)

Figure A-8: Receive diversity 1x2 scheme for frequency adaptive and non-adaptive allocation: sector throughput spectrum efficiency [bit/s/Hz] for as a function of UT speed (a); cumulative distribution function of user throughput efficiency (b).

In Figure A-8 we report results for the more fair case of receive diversity (one antenna at the BS and 2 antennas at the UT, maximum ration combining is used at the receiver side). The conclusions are the same as in the MIMO Alamouti case: OFDMA with frequency adaptive Score Based scheduling is to be preferred at low speed (< 50km/h), at 50 km/h there is a substantial equivalence of the two MA schemes. This is true also for the cumulative distribution function (CDF) of the user throughput spectrum efficiency. An interesting consideration can be done for users at the cell edge, as can be seen in Figure A-8 b), for CDF values in between 0.05 and 0.2. To explain the behaviour of the curves in Figure A-8 b) and better illustrate our discussion we report in Figure A-9 the dependence of user throughput versus distance in case of receive diversity 1x2 for frequency adaptive OFDMA and frequency non-adaptive MC-CDMA.

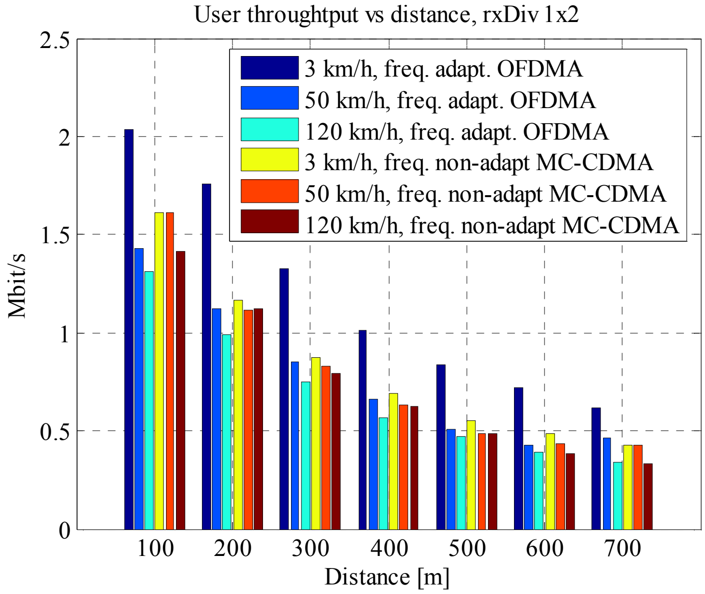


Figure A-9: Receive diversity 1x2 scheme for frequency adaptive (SB) and non-adaptive (RR) allocation: user throughput as a function of the distance.

As previously observed, at low UT speed, OFDMA/TDMA is to be preferred for all the users of the cell (at the cell centre or the cell edge). With increasing UT speed, the average user throughput of users close to the BS in OFDMA/TDMA case is worse than in MC-CDMA case, while at the cell edge the two schemes surprisingly achieve similar performance. This same behaviour was observed in the case of MIMO Alamouti scheme, but is not due to transmit diversity, since it is also present in the case of receive diversity only. This effect is neither to be ascribed to burst-like interference, since the whole bandwidth is affected by un-rejected inter-cell interference in the two case.

A possible explanation of the bad performance of OFDMA/TDMA close to the BS, already at 50 km/h is that, for users close to the cell centre using a frequency adaptive SB scheduler, the imperfect CSI available at the transmitter leads to bad selection of the high rate MCS. It is hence definitely preferable to use MC-CDMA for users close to the BS, already at 50 km/h (if no channel predictor is available). However, for users at the cell edge, with bad channel conditions, the frequency adaptive SB scheduler has performance (average user throughput) equivalent to the frequency non-adaptive RR scheduler. This is probably due to the fact that at the cell border the selected MCS have low rate, so that possible erroneous link adaptation choices have minor impact. In this way, the (small) scheduling gain of the SB scheduler manages to provide performance analogous to the simpler RR scheduler. It is also to be noticed that the use of a SB scheduler in the case of frequency non-adaptive MC-CDMA will probably lead to better performance than the RR one, hence stating the superiority of the MC-CDMA at the cell edge too (but further simulation are needed).

Finally we have also compared the frequency non-adaptive MC-CDMA to a frequency non-adaptive OFDMA in which each user receives packets over three regularly distributed chunks. As it can be seen in Table 13, MC-CDMA always offers better sector throughput spectrum efficiency than frequency non-adaptive OFDMA. This is due to the fact that in the OFDMA case, each user experiences less channel diversity than in the MC-CDMA case. This result extend to the MIMO Alamouti case the conclusion reported in Appendix G.1.1 in [WIND210]: in non-frequency adaptive allocation, MC-CDMA outperforms OFDMA in terms of cell throughput.

Table A-13: Sector throughput spectrum efficiency in bit/s/Hz of frequency non-adaptive MC-CDMA and OFDMA (over 3 regularly distributed chunks): MIMO 2x2 Alamouti scheme.

MA	3 km/h	50 km/h	120 km/h
MC-CDMA	1.2901	1.2002	1.1428
OFDMA	1.2248	1.0644	1.0282

Let us comment about the impact of deviated simulation assumptions on WINNER performance.

The channel maximum time spread of the C2 channel model is about $T_{s,max}$ = 1.4 μs, which yields a coherence bandwidth of about $B_{coh} = 1/T_{s,max}$ = 714 kHz. The chunk frequency extension in our scenario is 20% bigger than the one in WINNER baseline and is much smaller than B_{coh}. Hence, the basic assumption of quasi-constant channel frequency response inside a chunk holds in our scenario too. In WINNER scenario, C2 channel model, the total frequency diversity can be roughly estimated to 50 MHz / B_{coh} = 70. In our scenario the channel bandwidth is equal to 10 MHz which yields a frequency diversity degree equal to 14. However, at PHY level, the performance of two codes with the same coding gain and different diversity gain becomes very similar for diversity degrees higher than 8-10. Hence, we can conclude that the total frequency diversity of the channel will not impact in a sensible way on user performance (while, obviously, the absolute value of the sector throughput depends on the channel bandwidth).

In these simulations the impact of user speed on performance is also investigated. The maximal speed we took into account is 120 km/h, which corresponds to a coherence time of about 4.5 ms. In this case too, the chunk duration (0.5 ms in our scenario) is well under the coherence time threshold and the hypothesis of constant channel inside a chunk is valid in the temporal domain. The chunk duration in our scenario is about 43% bigger than the one of the WINNER baseline. If the time delay unit of the CSI report is the slot duration, for fixed speed, the WINNER system will probably be more robust against performance degradation caused by high user speed, due to its finest temporal granularity.

Overhead impacts on the absolute spectral efficiency values given by simulation (overhead is < 10 % in our case, while it is about 20% in WINNER). However this parameter should not impact the relative behaviour of the schemes we have investigated.

We can conclude that, the WINNER system behaviour in the WA scenario for OFDMA and MC-CDMA can qualitatively be predicted by using the deviated assumptions too. Absolute values of the throughput of WINNER system can not be deduced from our simulations, but conclusions based on comparative analysis of the simulation results can definitely be extended to the WINNER WA scenario.

Let us briefly summarize the presented results. In case of Alamouti 2x2 scheme or simpler 1x2 receiver diversity, our simulations indicate that it is better to switch from OFDMA/TDMA with frequency adaptive Score Based Scheduler to MC-CDMA with frequency non-adaptive Round Robin scheduler for a user terminal speed of about 50 km/h. Both considered MA schemes are the ones proposed in WINNER simulation assumption baseline. This result holds true under the assumption that quick CSI update is available at the transmitter (1.5 ms delay from the generation of the channel and its use in the BS), but without advanced channel predictors. We have also showed that, even if at UT speed of 50 km/h the sector throughput is substantially the same with frequency adaptive OFDMA/TDMA and frequency non-adaptive MC-CDMA, the average user throughput distribution with respect to the distance from the BS changes. For users close to the BS it is better to use MC-CDMA, while for user at the cell border OFDMA achieve a slight gain. Even at high speeds (120 km/h), OFDMA performance copes with MC-CDMA performance at the cell border. The introduction of better performing scheduling algorithms (e.g. Score Based) instead of Round Robin for frequency non-adaptive MC-CDMA should lead to some improvement.

A.3.1.3 Short-Term SDMA

Three-dimensional Resource Allocation or joint FDMA/SDMA

The algorithm starts with the assignment to all users of a null rate on all available chunks by setting the individual power allocation to zero, i.e. $r_{k,n}^{(0)} = 0$ and $P_{k,n}^{(0)} = 0$. In each iteration, then, for each user over each chunk a certain cost function is evaluated corresponding to the increase of the user data rate of a given $\Delta\bar{r}$ and on that chunk only the rate of the user k^* experiencing the minimum cost is increased on the corresponding chunk n^*, i.e. $(k^*, n^*) = \arg\min_{(k,n)} C(k,n),$ where $C(k,n)$ represents the cost for granting a rate increase for user *k* on chunk *n*, defined as

$$C(k,n) = \alpha_k \frac{\Delta P(k,n)}{\Delta\bar{r}}.$$

Note that $\Delta P(k,n)$ represents the power needed not only to grant the user *k* the rate increase $\Delta\bar{r}$, but also to compensate the possible decrease of effective channel gain of already allocated users on this chunk. α_k represents a priority value assigned to user *k*, which can be defined as $\alpha_k = \frac{A_k + \varepsilon}{R_k}$,

where $A_k = \sum_n r_{k,n}$ is the current data rate of user *k*, R_k the actual rate requirement and *ε* is a small positive regularization term that guarantees *α* to be larger than zero. In other words, α_k is a measure of how well the user has met its data rate requirement. A user with a small α_k will be favoured because it requires a higher data rate increase. Hence, this allocation strategy represents a proportional fairness approach. The algorithms ends till no more allocation is possible under the given power constraint.

An alternative approach, referred to as first priority, can be that of sorting the users according to their priority in descending order and then increase the data rate of the first user over the chunk which requires the least power increase, i.e.

$$k^* = \arg\min_k \alpha(k)$$

$$n^* = \arg\min_n \Delta P(k^*, n) / \Delta\bar{r}$$

In some situations, in addition to the per chunk power constraint, it might be desirable for users allocated to the same chunk to equally share the power on that chunk. We refer to this as per-chunk-per-user power constraint, i.e. the maximisation problem becomes the following

$$\max \sum_{k,n} r_{k,n} \text{ s.t. } P(k,n) = \begin{cases} P_{chunk} / |\Psi_n|, k \in \Psi_n \\ 0, k \notin \Psi_n \end{cases}$$

where Ψ_n represents the set of co-located users over chunk *n* and $|\cdot|$ its cardinality. In this case, the proposed greedy algorithm can be applied as follows. The algorithm starts by setting $\Psi_n^{(0)} = \emptyset$, $\forall n$. In each iteration, the pair of user k^* and chunk n^* is chosen that minimizes the cost function $C(k,n)$, now expressed as

$$C(k,n) = \frac{P_{chunk}}{\sum_{j \in \Psi_n^{(i-1)} \cup \{k\}} \frac{r_{j,n}}{\alpha_j}},$$

where $r_{j,n}$ represents the data rate achievable by user *j* over chunk *n* under the assumption that $\Psi_{n^*}^{(i)} = \Psi_{n^*}^{(i-1)} \cup \{k^*\}$ and power assignment equal to $P_{chunk} / |\Psi_n|$ and the priority value α_j is calculated as explained above. Note that if , for the additional user *k*, the cost function in the *i*-th iteration becomes higher than in the iteration *i-1*, then selecting user *k* for chunk *n* will not be considered. The algorithm ends when for all chunks it is not possible to add one more user without increasing the cost function.
Similar to the approach for the optimization problem under per-chunk power constraint, both the first priority and the proportional fairness allocation strategies can be used.

User Selection or disjoint FDMA/SDMA

With user selection, radio resources are defined in the frequency/time plane. By processing each chunk at a time, a reduction in the total number of possible allocations from $2^{N_c \cdot M_R}$ to $N_c \cdot 2^{M_R}$ is achieved and the radio resource allocation becomes non-combinatorial over the resources.
If it is further assumed that initially the frequency/time resource allocation is performed under single-user transmission, e.g., by assigning the best fitting chunk resource to the highest priority spatial sub-channel, then only $N_c \cdot M_R$ possible allocations have to be considered in a first step. This assumption simplifies the beamforming processing since a single sub-channel is considered as well as the application of frequency/time allocation algorithms, such as those in [SOB+06] [ZHC05], which are usually designed for the case of one user per resource. After determining the first spatial sub-channel on a certain chunk, other spatial sub-channels can be selected in a second step to build an SDMA group and share that chunk

in space. In this case, there are 2^{M_R-1} possible groups of spatial sub-channels per radio resource, totalizing $N_c \cdot M_R \cdot 2^{M_R-1}$ possible allocations.

After allocating one radio resource r to an SDMA group, priorities can be updated taking into account this allocation so that QoS can be efficiently handled. In spite of sub-optimality, this strategy has the following advantages:

- Reduced complexity, since frequency/time resources are sequentially allocated.
- Multi-user and frequency/time diversity, since the best fitting frequency/time resource is allocated to the highest priority spatial sub-channel during the first step.
- Performance lower-bounded by single-user transmission, since extra sub-channels are only added if they are spatially compatible, i.e., if they are close to orthogonal.
- Efficient priority management due to sequential frequency/time resource allocation.

In spite of reducing the overall number of possible resource allocation from $2^{R \cdot N}$ to $R \cdot N \cdot 2^{N-1}$, User Selection still requires an (almost) exhaustive search to build an SDMA group for each resource. This approach is still unfeasible for large values of N (or K). To simplify the SDMA grouping task and avoid exhaustive searches, sub-optimal greedy algorithms can be employed. Such algorithms are usually based on heuristic rules that limit the number of groups to be evaluated. Comparisons to determine whether an SDMA group is better than another are done using a suitable grouping efficiency metric, whose design is guided by the targets of the optimization problem.

Two variants of the user selection approach are considered in the simulation analysis below. In the first, the first allocation is carried out according to a first priority strategy, i.e. the user k^* with the highest priority is selected and allocated to the chunk n^*, where it can achieve the highest rate $r_{k^*,n}$. In the second, the pair of user and chunk (k^*, n^*) is selected, that maximizes the performance in a proportional fair way, i.e. $\left(k^*, n^*\right) = \arg\max_{k,n} \frac{r_{k,n}}{\alpha_k}$.

All other allocations on the considered chunk are performed then in both variants according to a proportional fairness strategy. After building an SDMA group on that chunk, for choosing the next chunk to be considered, the first priority strategy and the proportional fairness strategy are used in the first and the second variant, respectively, upon a proper update of the priority values.

Comparative Assessment of Joint and Disjoint FDMA/SDMA

In this section, the performance and the complexity of the different resource allocation approaches described above is assessed. For the sake of clearness, hereafter we indicate simply with a letter each specific approach, as follows: A-PF and A-fp indicate the joint FDMA/SDMA with per-chunk power constraint (PCPC) and with proportional fairness (PF) and first priority (fp) allocation strategy, respectively; B-PF and B-fp indicate the joint FDMA/SDMA with per-user power constraint (PUPC) and with PF and fp allocation strategy, respectively. Finally, C denotes the disjoint approach with PUPC.

A single sector has been considered in the simulation with 8 uniformly distributed users. The channel model C2 NLOS has been assumed and the BS and the UT are equipped with 4 and 2 antennas respectively. Moreover, short-term CSI and ZF beamforming are assumed.

A. Achievable Data Rate and Fairness

The average SNR of user k is defined as $P_{\text{chunk}} E\{|h_{k,n,m}|^2\}/\sigma^2$, where $E\{|h_{k,n,m}|^2\}$ is the average gain of the channel at all receive antennas over all chunks. In the simulations, same average SNR and same data rate requirement R_k are assumed for all users. Simulation results are reported here in terms of average data rate as well as fairness as a function of average SNR. To measure the fairness we adopt the Jain's index $F(x)$. In case of K users competing for some resource x, this index is given by:

$$F(x) = \frac{\left(\sum_k x_k\right)^2}{K\left(\sum_k x_k^2\right)}$$

It is equals to 1 when all users get the same amount of resource and tends to $1/K$ for fully unfair cases. In this investigation x_k indicates the k–th user data rate normalized with respect to its data requirement R_k.

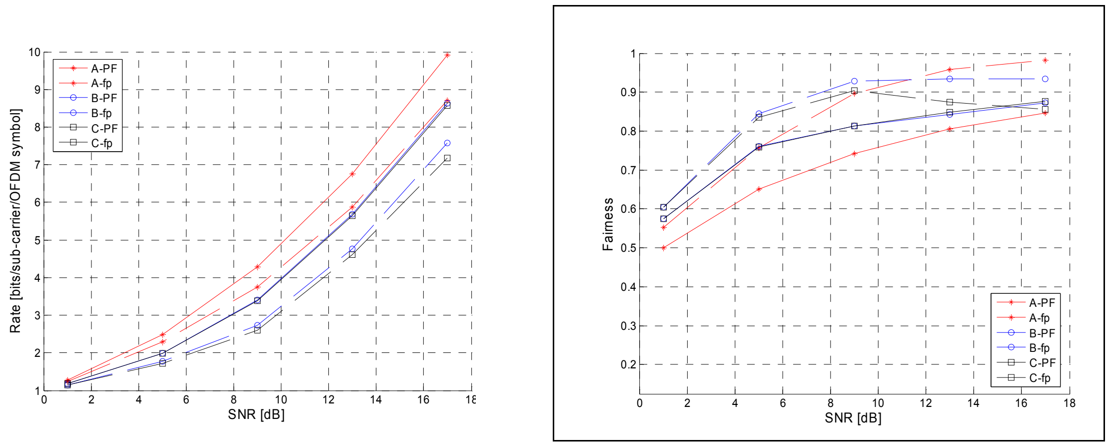


Figure A-10: Comparison in terms of sum rate and fairness.

Figure A-10 shows the comparison between the different approaches, by considering both the proportional fairness and the first priority strategy, in terms of achievable data rate and fairness. It can be inferred that a much higher data rate is achievable through approach A (red curves) because of the higher degree of freedom in sharing the power per chunk among the co-located users. Moreover, as reasonably expected, the proportional fairness strategy (solid curves) yields in general higher average data rate, but the first priority strategy guarantees a much higher level of fairness among users. Furthermore, it can be derived that under proportional fairness strategy and PUPC Joint 3D is not advantageous with respect to the user-selection approach. From this comparison, it can be concluded that the approach A-fp (dashed red curves with stars) achieves the best compromise between rate and fairness.

B. Complexity

The complexity of the considered resource allocation comes from two folds: one is the computation of effective channel; the other is the effort to compute the cost function and find the minimum, which is measured by the number of comparisons. Since at most M_t users can be allocated to the same chunk, for all approaches, the times of effective gain computation are $\sum_{i=0}^{N_c M_t - 1\sim}(K-i) \sim O(N_c K M_t)$.

For approach A, a fixed rate Δr is increased in each iteration. Hence, the number of iterations increases with the average SNR and decreases with increasing Δr, and so does the the number of comparisons. In the following, we will focus on the complexity of different approaches under PUPC.

For approach B, one user is allocated to one chunk in each iteration, and so there are at most $M_t N_c$ iterations. In case of approach B-PF, in the i-th iteration, there are $(KN_c + 1 - \text{i})$ possible allocations, therefore totally $\sum_{i=1}^{N_c M_t}(KN_c - i) \sim O(N_c^2 K M_t)$ comparisons are required to find the best one. In case of approach B-fp, in the i-th iteration, firstly the user k^* with highest priority is selected through $(K-1)$ comparisons, and then the best chunk is chosen from those on which user k^* has not been allocated. In average, there are $(i-1)/K$ chunks that have been allocated to each user, and so to select the best chunk for user k^* requires $\left(N_c - \frac{i-1}{K} - 1\right)$ comparisons. Therefore, it totally requires $\sum_{i=1}^{N_c M_t}\left((K-1) + \left(N_c - \frac{i-1}{K} - 1\right)\right)$ $\sim O(N_c^2 M_t)$comparisons.

For approach C, in i-th iteration to first find the best chunk for the user with highest priority requires $((K-1)+(N_c - i))$ comparisons, and then for the selected chunk $\sum_{i=2}^{M_t}(K-i)$ comparisons are required to perform adaptive SDMA on it. Hence, the total number of comparisons is $\sum_{i=1}^{N_c}(K-1+N_c-i) + N_c \sum_{i=2}^{M_t}(K-i) \sim O(N_c^2)$.

The complexity for different approaches is summarized in Table A-14. As we can see, disjoint approach C requires much less number of comparisons than joint approaches, but the complexity of joint approach can be significantly reduced with first priority strategy. Nevertheless, one should keep in mind that the calculation of effective channel gain, which includes matrix inversion, represents the largest part of the computation effort.

Table A-14: Number of comparisons for different approaches

Number of Comparisons		
B-PF	B-fp	C
$O(N_c^2 K M_t)$	$O(N_c^2 M_t)$	$O(N_c^2)$

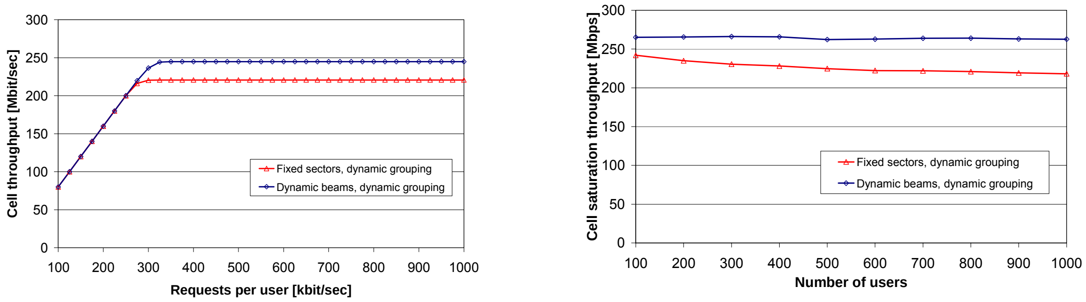
A.3.1.4 SDMA for Relay Enhanced Cells

In this section, the performance of the strategy proposed in Section 4.4.3.1 that enables dynamic beam generation and dynamic resource sharing are reported and compared with the conventional approach, i.e. fixed sectorisation. In case of fixed sectorisation, users are assigned to proper sectors which are pre-determined regardless of the user and traffic distributions. Sectors that undergo low inter-sector interference can be grouped together so as to share the chunks in spatial domain. Although the sectorization is fixed, the grouping of sectors can be dynamically carried out by the BS according to current interference levels and traffic load. In the proposed strategy, the BS dynamically groups spatially correlated users into virtual beams and then allows beams with low interference to share the chunks by dynamic beam grouping.

Table A-15: Simulation Assumptions.

System Parameters	
Scenario	WINNER Basic Coverage Urban
Channel Model	RN/AP-UT: C2 (only path-loss and shadowing) AP-RN: LoS
Bandwidth	100 MHz
Number of RNs per cell	6
BS Transmission Power	46dBm
RN transmission Power	40 dBm
Number of Users	Variable (100 -1000)
User Distribution	Uniform

Simulation results obtained under the assumptions of Table A-15 are reported in Figure A-11 in terms of total cell throughput versus both user traffic load and number of active users.



(a) (b)

Figure A-11: Cell throughput achievable through dynamic spatial resource sharing in RECs.

From Figure A-11 (a), it can be inferred that a quite significant cell throughput gain can be achieved through the proposed strategy due to the higher flexibility in grouping the user links, which is expected to be most beneficial in case of non-uniform traffic distributions. Moreover, an even larger gain is to be expected with respect to the baseline case, in which the grouping of the sectors is also fixed. From Figure A-11 (b), it can be derived that the proposed strategy is also more robust in case of densely populated RECs.

A.3.2 Metropolitan Area

Simulation assumptions	B1 channel model, LOS and NLOS 8 MAC frames per snapshot
Cell layout	Manhattan grid with 230 meter building size and street width 20 meters
Number of users	40 per cell
Modulation and coding	- Modulation: BPSK, QPSK, 16-QAM, 64-QAM - CC 1/3, 2/3, 8/9 - independent coding of each retransmission segment - chunk-based link adaptation in TDMA/FDMA, no power control
CSI and it's feedback	perfect CSI at the receiver, CSI at the transmitter delayed by 1 MAC frame
Overhead	Chunk's overhead: 17.5% (14 out of 80 symbols) in TDMA/FDMA, duplex time
Other differences	Omni-directional antennas, 4 antennas at UT, no ARQ, perfect estimation and synchronization, interference generated by 18 BS

19 Base Stations located within Manhattan grid of buildings have been examined in the Metropolitan Area scenario. The cell radius has been selected equal to 500 meters. Implemented scheduler algorithms allocate resource elements of each MAC frame to the data flows of 8 users. Four scheduling algorithms have been considered: Round Robin, maximum SNR, Fair Rate and version of Fair Rate scheduler with simplified algorithm. Each resource element is coded independently and fills one chunk. A very simple link adaptation based on the chunks' average SNR value with only 5 combinations of possible code-rate and modulation has been applied.

The presented throughput averages are the averages of scheduled resources and actually transmitting users. Not scheduled users are not considered. Which means, that users unable to transmit due to the bad channel conditions do not affect (lower) averages.

Figure A-12 below shows the average user's throughput plotted versus the distance between the BS and MT for considered scheduling algorithms. All simulation results have been obtained using older pathloss models. Application of the updated models increases pathloss for the NLOS channels, decreasing average users' and cell's throughput at the same time.

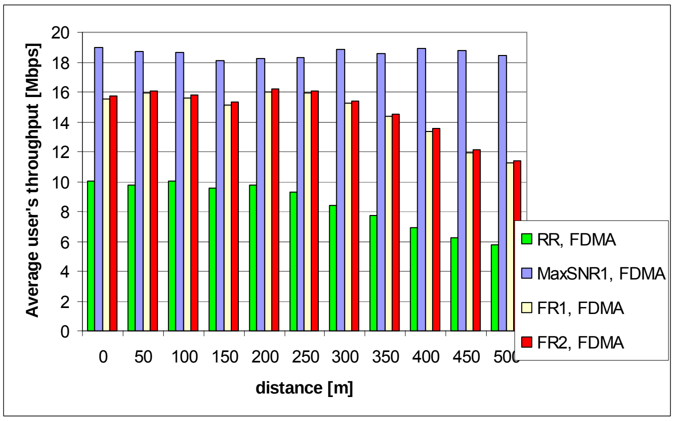


Figure A-12 Average user's throughput vs. distance between BS and UT

The average cell's throughput is the highest for the maximum SNR scheduling (148 Mbps), lower for the Fair Rate scheduling (119 Mbps) and the lowest for the Round Robin scheduling (68 Mbps). All presented throughput values include overhead reserved for signalling and pilots within chunks and duplex time between slots in frame. Super frame overhead was not considered.

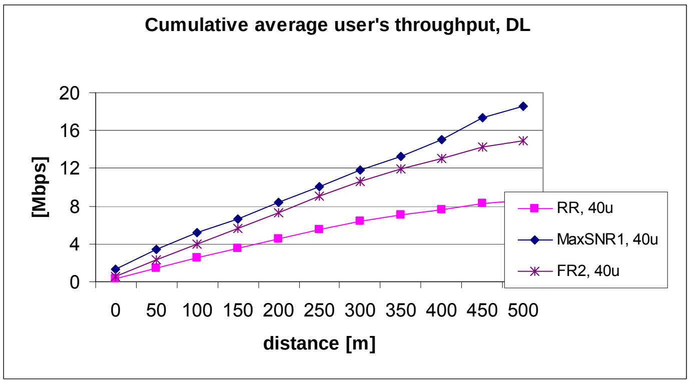


Figure A-13. Cumulative distribution of average user's average throughput normalized to the scheduled user's spatial density for TDMA/FDMA shown as a function of distance

Cumulative distribution of the average user's throughput is shown in Figure A-13. This figure presents impact of the users located at given distance from the BS on the average throughput. Total average throughput can be read for the maximum distance (500 meters in this case). The highest average throughput per user is offered by the MaxSNR scheduling algorithm. A low probability of scheduling users at the cell's edges is the disadvantage of the MaxSNR schedulers. Additionally, any given user that is "stuck" in bad channel conditions will not be served by the MaxSNR schedulers.

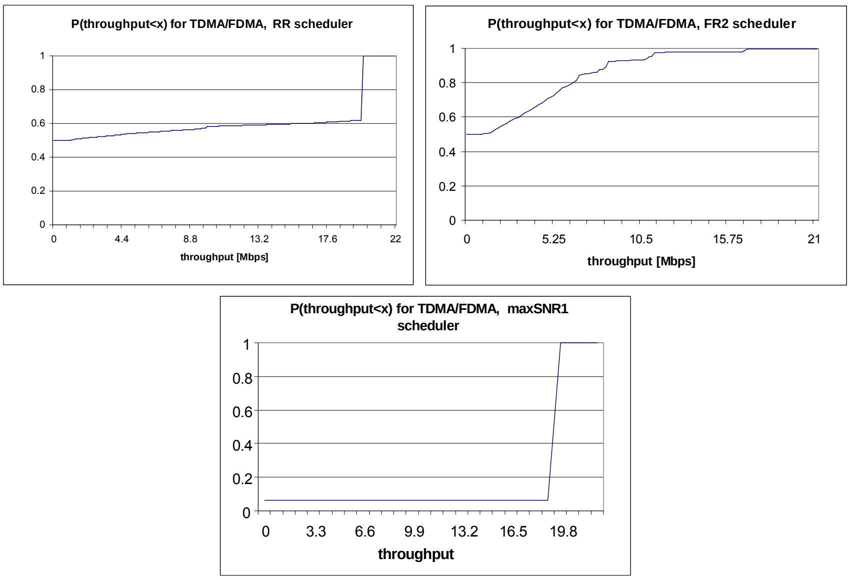


Figure A-14. Cumulative probabilities of achieved users' throughputs

The figures presented above show the cumulative probabilities of the achieved users' throughputs. The more concave curve, the higher throughput is attainable and a lower fraction of users will achieve given throughput. One can observe, that about 50% of users are unable to transmit even with the lowest modulation order and highest coding rate (1/3) when scheduled using RR and FR algorithm. In case of the maxSNR1 algorithm, only users with the highest SNR are considered and even then more than 5% of them is unable to transmit.

A.3.3 Local Area

Simulation assumptions from Phase 1	Local Area (A1) LOS and NLOS, SISO channel models 8 MAC frames per snapshot
Number of users	40 and 80 per cell
Modulation and coding	- Modulation: BPSK, QPSK, 16-QAM, 64-QAM - CC 1/3, 2/3, 8/9 with tail - independent coding of each retransmission segment - chunk-based link adaptation in TDMA/FDMA, no power control
CSI and it's feedback	perfect CSI at the receiver, CSI at the transmitter delayed by 1 MAC frame
Overhead	Chunk's overhead: 17.5% (14 out of 80 symbols) in TDMA/FDMA, tail of CC, duplex time

Implemented scheduler algorithms allocate resource elements of each MAC frame to the data flows of 8 users. Two implemented versions of the maximum throughput scheduler differ with a localization of the maximum SNR scheduling algorithm. The first version, denoted as MaxSNR1, allocates equal number of resources to each of 8 users with the highest SNR, while the second version, denoted as MaxSNR2, allocates users on the equal time sharing base, and resources are distributed according to the maximum rate sharing principle (to the user with the maximum SNR. Round Robin and Fair Rate scheduling algorithms have been implemented as well.

Each resource element is coded independently and fills one chunk in the TDMA/FDMA. A very simple link adaptation based on the average SNR value has been applied. Reference curves have been obtained in simulations of packets in the AWGN channel. Packets' lengths have been selected to match the length of coded packets with the size of the retransmission segment for different coding rates.

Many of the figures presented below show the average user's throughput plotted versus the distance between the BS and MT or its distributions. The presented throughput averages are the averages of scheduled resources and actually transmitting users. Not scheduled users are not considered. Not scheduled users are not considered. Because of lower mobile terminal's transmission power and antenna gain, the uplink transmission is characterized with lower SNR values. However, as it will be shown, for low cell's radii the uplink and downlink throughputs are comparable because the terminal's power budget is sufficient to support the highest data rate transmission nevertheless.

Impact of the coding tail on the average throughput

Powerful coding schemes like Turbo or LDPC Codes approach the channel capacity but require quite long code-word. On the other hand, Convolutional Codes can provide satisfactory BER for lower code block length. In the TDMA/FDMA mode, in least favorable conditions and assuming a signaling overhead equal to 14 symbols, one chunk can carry only 22 information bits (CC rate 1/3, BPSK modulation). In such case, application of a tail would create an additional overhead equal to about 30% of the encoded block length. One could consider application of CC with tailbiting or without tail, however both solutions have their own disadvantages such as much higher decoding complexity (64 times higher for constraint length 7 code) or loss of coding gain. Simulations shown that application of tail produces an average overhead equal to 2% of the throughput for the DL and 3% for the UL. The difference between DL and UL is caused by higher Path Loss in the UL and thus lower average throughput.

Table A-16. Ratio of the average throughput in system where CCs without tail and with tail were applied, TDMA/FDMA with Round Robin scheduling

Distance [m]	DL	UL	Distance [m]	DL	UL
0	1.017	1.017	60	1.020	1.035
10	1.017	1.017	70	1.023	1.042
20	1.017	1.018	80	1.026	1.051
30	1.017	1.021	90	1.030	1.060
40	1.018	1.028	100	1.033	1.068
cell's average				1.023	1.037

Figure A-15 shows the distribution of average users' throughput obtained in a cell with 100 meter radius, using Round Robin scheduler, and 40 or 80 allocated users in the downlink and uplink. One can observe that the average user's throughput drops significantly with the distance, and due to the higher pathloss, the uplink throughput is lower than that of the downlink transmission by about 45%-50% at the cell's edges.

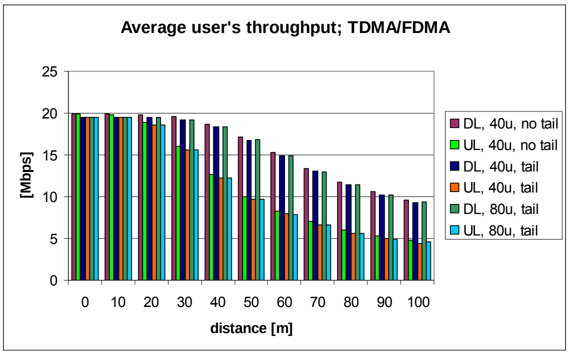


Figure A-15. Average user's throughput vs. distance for cells with 40 and 80 users; coding with and without tail, Round Robin scheduling

One can notice that there is almost no difference between the uplink and downlink users' average throughput for the distances between the MT and BS up to about 20 meters (regardless the number of users and tail presence). This is a consequence of the sufficient power budget and transmission with 64-QAM modulation at the highest coding rate.

Comparison of different schedulers

Average cell's throughput

The average cell's throughputs obtained with the Round Robin scheduler are summarized in Table A-17. One can observe that the number of users does not have significant impact on the average cell's throughput. Such results have been obtained also for the other scheduling algorithms which allocate users on the equal time sharing base.

Table A-17. Average cell's throughput, Round Robin scheduling (CC with tail)

system	radius 100m, 40 users [Mbps]	radius 100m, 80 users [Mbps]
DL TDMA/FDMA	116.31	116.13
UL TDMA/FDMA	71.38	71.12

The MaxSNR1 scheduling algorithm adaptively selects the scheduled users and thus allows to increase the overall cell's throughput (155.7 Mbps in the DL and 147.8 Mbps in the UL for 40 users and 156.1 Mbps and 155.5 Mbps for 80 users respectively). However, as shown in Figure A-16, the scheduled users are not distributed uniformly within a cell (in comparison with fair time based allocation of users). Fair time sharing results in a linear increase of the scheduled users distribution versus the distance (regardless the number of allocated users), while the maximum rate sharing causes that proportionally more scheduled users are located closer to the BS. Average cell's throughput obtained using MaxSNR2 scheduling was only slightly lower than that for the MaxSNR1 scheduler for the DL transmission. In the UL the average cell's throughput exceeded 142Mbps.

The average cell's throughput for the Fair Rate scheduler was equal 125.3 Mbps in the DL and 64Mbps in the UL.

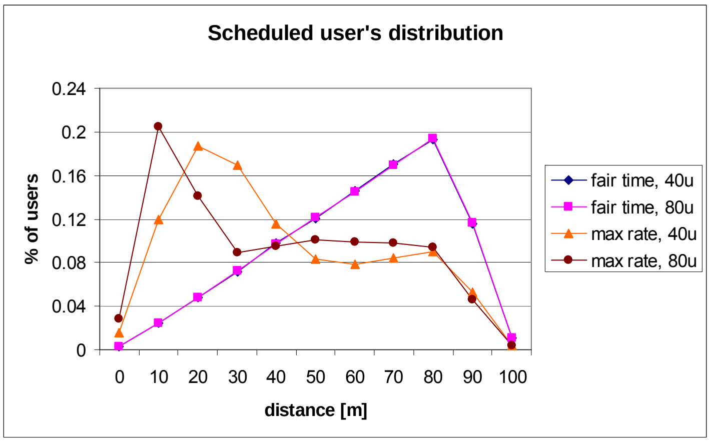


Figure A-16. Distribution of scheduled users vs. distance for two types of user's scheduling: fair time sharing and maximum rate sharing; 40 and 80 users allocated

Figures presented below show the average user's throughput plotted versus the distance between the BS and MT. All presented throughput averages are the averages of actually scheduled resources and users. Not scheduled users, or scheduled but without allocated retransmission segments are not considered.

Figure A-17 shows the average throughputs obtained for the MaxSNR1 and MaxSNR2 scheduling algorithms in a cell with 100 meter radius and 40 allocated users. The MaxSNR2 algorithm allocate retransmission segments to the user with the highest SNR, thus the average user's throughput drastically decreases with distance. Additionally, most of the theoretically scheduled users are not served at all, because their SNR is too low. Appropriate probabilities of achieved user's rates will be shown in the next section. The MaxSNR1 scheduling algorithm allocates a equal number of resources to the users with the highest SNR (and thus throughput) and can support high instantaneous data rates for all users. However, the probability of good channel conditions decreases with the distance from the BS and the resulting distribution of served users is concentrated around the BS, as was shown in Figure A-16. It means that users located further from the BS must wait statistically longer until they experience good channel conditions and are scheduled. Some of the resultant long-term distribution of the average user's throughput obtained by superposition of the average user's throughput distributions and the users distribution are shown in Figure A-20.

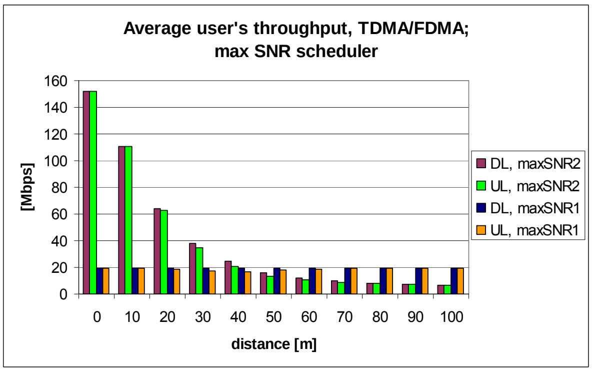


Figure A-17. Average user's throughput vs. distance for the MaxSNR schedulers, 40 users allocated

The results obtained for the TDMA/FDMA, MaxSNR1 scheduler and a different number of users are shown in Figure A-17. One can observe, that the average throughput drops for the middle range of users' distances from the BS for lower number of allocated users (40), especially for lower average SNRs (in the UL transmission or for longer cell's radii). An increase of the number of users allows to improve user's average throughput and the overall cell's throughput.

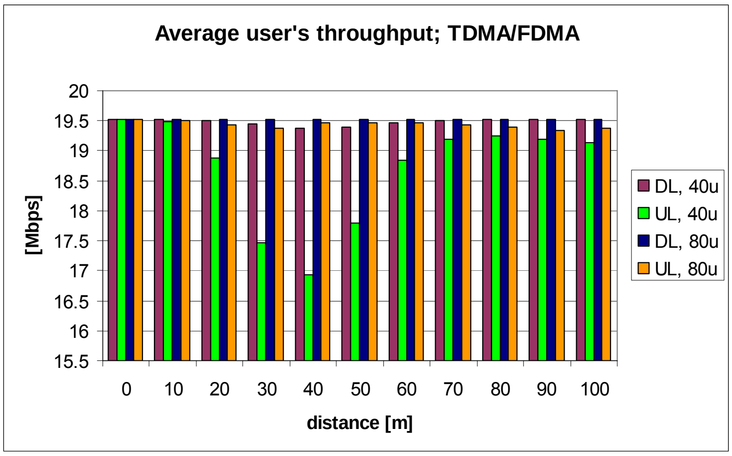


Figure A-18 Average user's throughput vs. distance for the MaxSNR1 scheduler, 40 and 80 allocated users

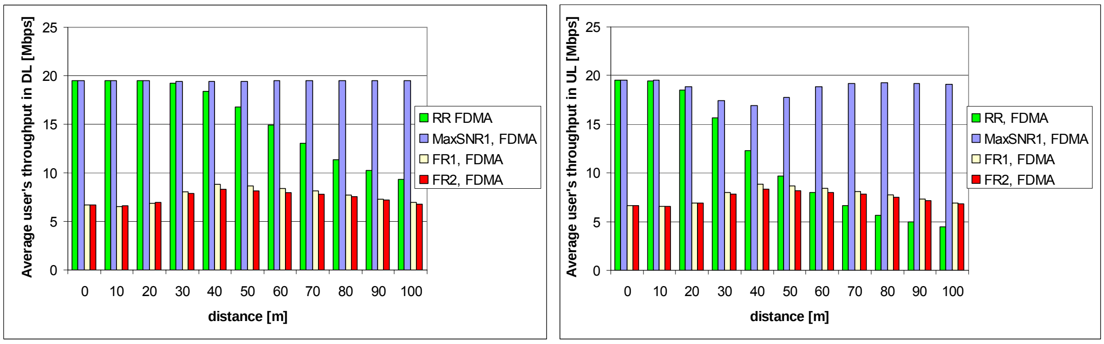


Figure A-19. Comparison of average user's throughput for different schedulers, 40 allocated users

Cumulative distribution of the average user's throughput is shown in Figure A-20. The higher throughput, the better, the more linear curve, the more uniform distribution of the average throughput vs. distance. This figure presents impact of the users located at given distance from the BS on the average throughput. Total average throughput can be read for the maximum distance (100 meters in this case).

The highest average throughput per user is offered by the MaxSNR1 scheduling algorithm. A low probability of scheduling the users at the cell's edges is the disadvantage of the MaxSNR schedulers. Additionally, any given user that is "stuck" in bad channel conditions will not be served by the MaxSNR schedulers. As one can observe, the results obtained with the maximum ratio sharing of available resources (MaxSNR2) and selecting users on the maximum SNR base (MaxSNR1) are comparable in the long term, because of the same channel statistics. However, the latter one is a little more efficient.

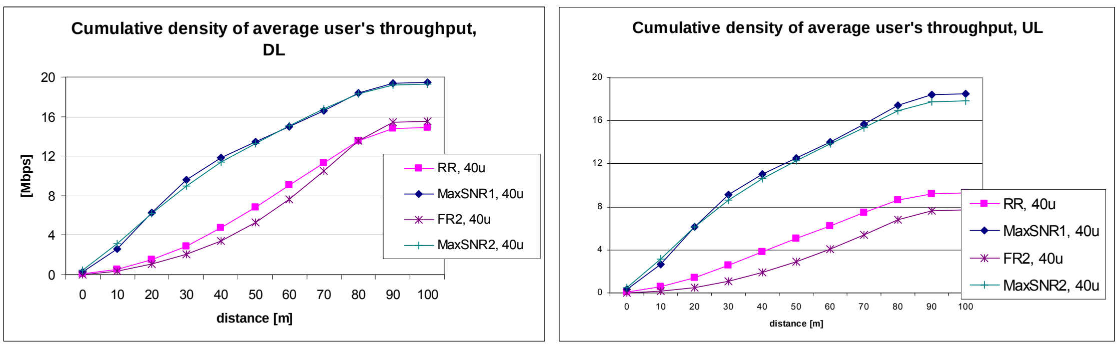


Figure A-20. Cumulative distribution of average user's average throughput normalized to the scheduled user's spatial density for TDMA/FDMA for the UL and DL shown as a function of distance

The figures presented below show the cumulative probabilities of the achieved users' throughputs. Due to the fact that all scheduled users are considered, there is about 87% probability that user's throughput is lower or equal to zero for the MaxSNR2 scheduling algorithm. The more concave curve, the better, meaning that a lower fraction of users will achieve not higher throughput.

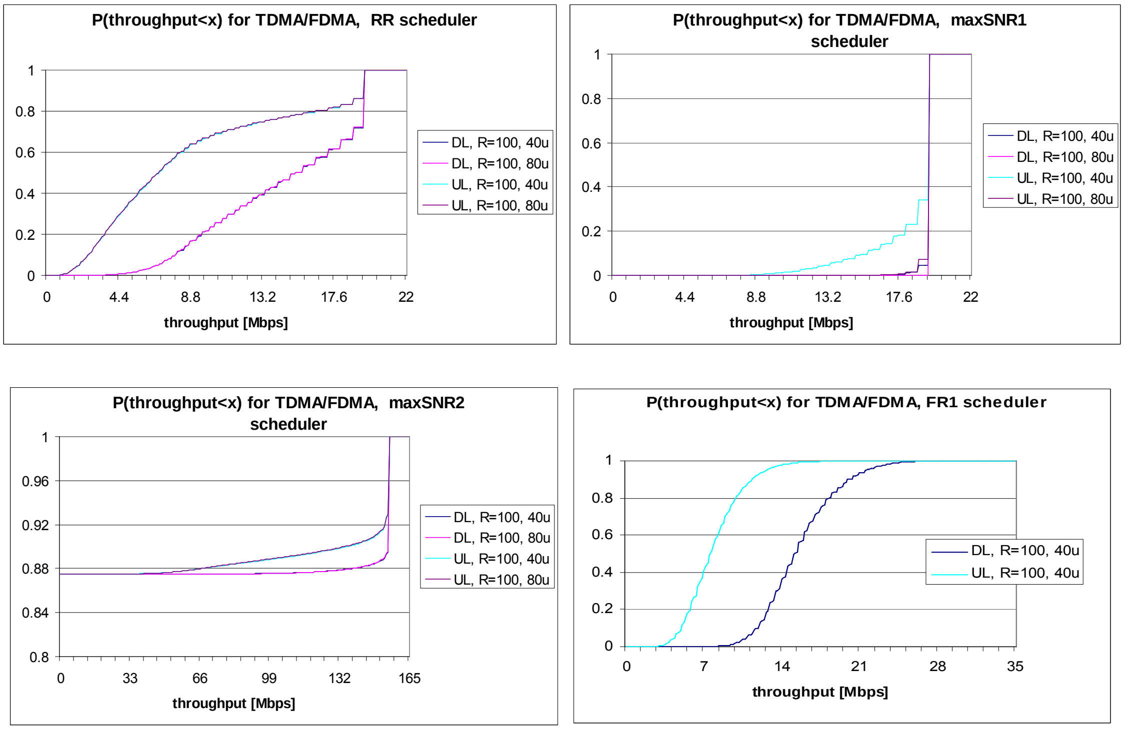


Figure A-21. Cumulative probabilities of achieved users' throughputs

Not surprisingly, the users in larger cells have lower throughputs, also the UL offers lower throughputs than the DL.

The non-adaptive scheduling ensures that each user obtains the same number of resources, and since the user's throughput depends on the channel statistics, each user at any given location achieves (in average) the same throughput. The Round Robin scheduler ensures fair access to resource elements and equal time between scheduling each user's flows. The maximum SNR schedulers maximize the users' and cell's throughput, but distribute it unfairly between users. More optimum is the MaxSNR1 algorithm. It provides the highest average cell's throughput and the highest average user's throughput normalized to scheduled users density. However, the users more distant from the BS experience a lower probability of being scheduled and any given user that is "stuck" in bad channel condition will not be served.
There is a small difference between the uplink and downlink users' average throughputs for distances between the MT and BS up to about 20 meters. This is a consequence of a sufficient power budget and transmission using 64-QAM modulation at the highest coding rate. However, for larger distances, the average throughput in the uplink transmission is significantly lower than that in the downlink transmission.

A.4 Uplink Simulation Results

A.4.1 Wide Area

A.4.1.1 Comparison of Multiple Access Schemes for the Non-Frequency Adaptive Uplink

In this section, a comparison of different candidate MA schemes for frequency non-adaptive uplink transmission in the Wide Area scenario is performed. The considered schemes are

- LFDMA/TDMA: DFT precoded OFDMA/TDMA with blockwise subcarrier allocation, also denoted as Localized Frequency Division Multiple Access with TDMA component.
- IFDMA/TDMA: DFT precoded OFDMA/TDMA with interleaved subcarrier allocation, also denoted as Interleaved Frequency Division Multiple Access with TDMA component.
- FH-LFDMA/TDMA: DFT precoded OFDMA/TDMA with blockwise subcarrier allocation and frequency hopping performed with blocks of subcarriers per OFDM symbol.

For the TDMA component, according to [WIND210], the minimum possible TDMA slot length is assumed to be equal to the length of one OFDM symbol.

Frequency diversity

For LFDMA/TDMA, transmission is restricted on a localized portion of bandwidth. For high data rates in a Wide Area scenario, for LFDMA/TDMA the portion of bandwidth is large compared to the coherence bandwidth of the channel. In this case, the scheme provides sufficient frequency diversity and, thus, good performance. For moderate to low data rates the amount of frequency diversity exploited by LFDMA/TDMA depends on the design of the TDMA component. The frequency diversity can be increased by assignment of the minimum possible number of consecutive TDMA slots and by increasing the time intervals inbetween blocks of consecutive TDMA slots assigned to a specific user since in this case for a given data rate the portion of bandwidth used for transmission is increased. The minimum possible number of TDMA slots assigned to a specific user within a block is one in the SISO case and two in the MIMO case with Alamouti Space-Time Coding. The length of the intervals between blocks of consecutive TDMA slots is limited by the maximum delay of the WINNER air interface which is < 2ms [WIND210], i.e. a delay of at most 2 frames is required.

For IFDMA/TDMA, the signals are spread over the total available bandwidth. Similar to LFDMA/TDMA, for IFDMA/TDMA the number of subcarriers assigned can be also increased by reducing the number of consecutive TDMA slots in a block and by increasing the intervals between blocks of TDMA slots assigned to a specific user. In Figure A-22 the simulation results for LFDMA/TDMA, FH-LFDMA/TDMA and IFDMA/TDMA are shown. The simulation parameters correspond to the simulation assumptions for the Base Coverage Wide Area Scenario described in Appendix A.2. In addition, QPSK modulation and as coding scheme a rate ½ convolutional code with decoder based on the Bahl-Cocke-Jelinek-Raviv (BCJR) algorithm, cf. [BCJR74], has been used. As multiple antenna scheme for MISO transmission an Alamouti Space-Time Block Code has been applied. It is assumed that all TDMA slots within one superframe are assigned to a specific user. Thus, a data rate of 1.25 Mbps (5 Mbps) corresponds to a number of 32 (128) subcarriers assigned to a specific user. Coding and bit interleaving is applied per chunk.

From Figure A-22 it can be deduced that due to the spreading of the subcarriers over the total available bandwidth for IFDMA/TDMA a diversity order of 4-5 can be obtained whereas for LFDMA/TDMA the diversity order is 2-3 depending on the data rate and on the use of single or multiple antenna transmission.

In Table A-18 the SNR requirements for the different MA schemes at a BER of 10^{-3} are summarized. It is shown that IFDMA/TDMA significantly outperforms LFDMA/TDMA due to its higher frequency diversity. For data rate services that require a lower number of subcarriers than 32, the frequency diversity gains of IFDMA/TDMA compared to LFDMA/TDMA are expected to be even higher. From Table A-18 it can be deduced that compared to the SISO case, the performance gains of IFDMA/TDMA for MISO are lower but still considerable.

The amount of frequency diversity exploited by LFDMA/TDMA can be increased by applying frequency hopping (FH). However, in order to achieve a good performance a large number of consecutive TDMA slots has to be assigned to a specific user since for FH exploitation of diversity is realized by coding and interleaving over several hops and the amount of diversity that is exploited increases with an increasing number of hops. For the current simulations coding and interleaving over 12 hops, i.e., one chunk is assumed. As shown in Figure A-22, for the given interleaving depth the diversity order of FH-LFDMA/TDMA is slightly lower than for IFDMA. From Table A-18 follows that the performance of FH-LFDMA/TDMA is slightly lower compared to IFDMA/TDMA but considerably higher compared to LFDMA/TDMA.

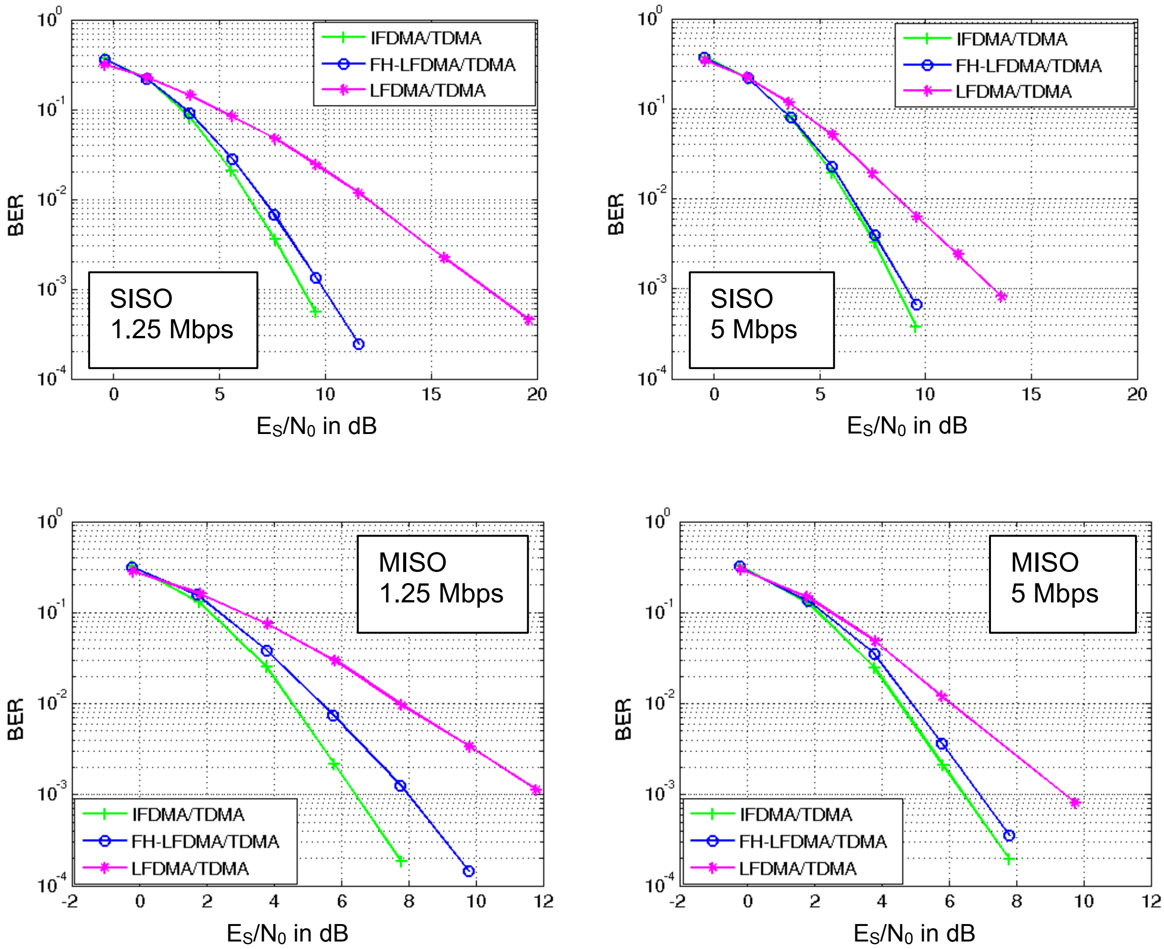


Figure A-22. Performance results for SISO and MISO transmission of LFDMA/TDMA, FH-LFDMA/TDMA and IFDMA/TDMA in a Wide Area scenario for different data rates

Table A-18. SNR requirements for different MA schemes at a BER of 10^{-3}

# Antennas (Tx, Rx)	Data rates in Mbps (all TDMA slots in a superframe assigned to one user)	IFDMA/TDMA	FH-LFDMA/TDMA	LFDMA/TDMA
		Es/N0 in dB		
SISO	1.25	9	9.9	17.5
	5	8.4	9.2	13
MISO (2,1)	1.25	6.4	8	12
	5	6.4	6.9	9.3

Overhead for channel estimation

The overhead for pilot symbols required for channel estimation can be expressed as amount of energy that has to be spent additionally for transmission of each information bit. In other words, due to pilot symbol overhead a higher amount of energy per bit has to be spent in order to achieve the same bit error rate. This additional energy per bit can be directly compared to the performance gains from Table A-18.

The overhead depends on the number of consecutive TDMA slots assigned to a specific user. Since, compared to the dimensions of an OFDM symbol, the coherence time for, e.g., 70 km/h is large, a high number of consecutive TDMA slots would provide the possibility of interpolation of the channel estimates in time and, thus, significantly reduce the required overhead. The lower the number of consecutive TDMA slots assigned, the higher the overhead, cf. Table A.4.1.1.4.

For IFDMA/TDMA, in general, in the SISO case at least two consecutive TDMA slots have to be assigned to a specific user whereas for LFDMA/TDMA assignment of one TDMA slot is possible. The reason for that is that as long as the distance of two subcarriers belonging to a specific user in frequency direction is larger than a fraction of the coherence bandwidth B_c (typically $B_c/5$, cf. [KaF03]) for each carrier one pilot symbol is required. Thus, in case of IFDMA/TDMA the first TDMA slot is used exclusively for pilot transmission. Equivalently, in the MIMO case with Alamouti Space-Time Coding for IFDMA/TDMA at least 4 consecutive TDMA slots instead of at least two required for LFDMA/TDMA have to be assigned since due to the Alamouti scheme the first two TDMA slots are used exclusively for pilot symbol transmission.

Also for LFDMA/TDMA, a short TDMA slot length leads to a high overhead since the distance of the pilot symbols in frequency direction (typically $B_c/5$, cf. [KaF03]) is in the order of magnitude of a few subcarrier bandwidths, cf. Table A-19. For the smallest possible number of TDMA slots the additional energy per bit due to pilot symbol overhead for the given parameters is 3 dB.

In general, for FH-LFDMA/TDMA interpolation in time direction is not possible, thus the overhead for channel estimation is high, cf. Table A-19. It is similar to the overhead for LFDMA with smallest possible number of consecutive TDMA slots assigned to a specific user.

The pilot symbol overhead required for channel estimation at a data rate of 5 Mbps and 1.25Mbps is summarized in Table A-19 for different numbers of consecutive TDMA slots. It is assumed that the interval between blocks of consecutive TDMA slots is one frame.

Table A-19. Overhead at 5 Mbps and 1.25 Mbps

	LFDMA/TDMA	FH-LFDMA/TDMA	IFDMA/TDMA
Minimum possible number of consecutive TDMA slots assigned to a specific user (e.g., SISO: 2 for IFDMA/TDMA, 1 for LFDMA/TDMA and 2 for FH-LFDMA/TDMA)	3 dB	3 dB	3 dB
12 consecutive TDMA slots assigned to a specific user	0.38 dB	3 dB	0.18 dB

Power efficiency and power consumption

The power efficiency of a mobile terminal plays an important role for the choice of the MA scheme. For a good power efficiency a low PAPR is essential. Comparison of IFDMA/TDMA and LFDMA/TDMA shows that even for realistic pulse shaping and higher order modulation schemes such as 64QAM, both schemes have a significantly lower PAPR compared to OFDMA/TDMA [MLG06]. Moreover, IFDMA/TDMA provides a lower PAPR compared to LFDMA/TDMA [MLG06], cf. Table A.4.1.1.4. E.g., for 8-PSK (64QAM) the PAPR of IFDMA/TDMA is 3.3 dB (1.6 dB) lower than for LFDMA/TDMA.

A possibility to save battery power at the terminal is switching into sleep mode after transmission. The efficiency of the sleep mode depends on the design of the TDMA component. The lower the number of consecutive TDMA slots within one block and the longer the intervals between blocks of TDMA slots assigned to a specific user, the longer the sleep time and, thus, the lower the power consumption of the terminal. However, assignment of a low number of consecutive TDMA slots increases the channel estimation overhead.

Since IFDMA/TDMA requires a minimum number of TDMA slots within a block which is double the number of TDMA slots for LFDMA/TDMA, the efficiency of micro sleep is expected to be higher for LFDMA/TDMA. However, for long intervals, e.g., one superframe, between blocks of TDMA slots assigned to a certain user, which are desirable in order to increase the efficiency of micro sleep in general and in order to increase the frequency diversity, the efficiency of micro sleep for both schemes converges, cf. Table A.4.1.1.4.

Computational Complexity

The computational complexity for signal processing of all schemes is similar to OFDMA/TDMA. However, at the transmitter side, IFDMA/TDMA provides the possibility of efficient implementation by compression, repetition and subsequent phase rotation with further reduced computational effort [SDS98]. Let N denote the number of subcarriers in the system, K the number of users and Q the number of subcarriers assigned to a specific user. Further on it is assumed that N, K and Q are powers of 2. Omitting the computational effort for subcarrier mapping, for LFDMA/TDMA $1/2Q\mathrm{ld}(Q)$ complex multiplications resulting from the DFT precoding and $1/2N\mathrm{ld}(N)$ complex multiplications resulting from an N-point IDFT for OFDMA modulation are required. For IFDMA/TDMA, the computational effort is given by the effort for user specific phase rotation, i.e., by one complex multiplication for each of the $KQ=N$ elements of the K-fold repetition of the Q data symbols within each block [FKC05]. The computational complexity is summarized in Table A 1.1.1.3.

Table A-20. Computational complexity for signal generation in number of complex multiplications

		LFDMA/TDMA	IFDMA/TDMA
Data rate (all TDMA slots within a superframe assigned to one user)	**5 Mbps**	5344	1024
	1.25 Mbps	5200	1024

Impact of scalability in bandwidth

For a smaller system bandwidth the amount of frequency diversity that can be exploited by IFDMA/TDMA and FH-LFDMA/TDMA decreases. In Figure A-23 the performance of IFDMA/TDMA with 16 subcarriers per user spread over different bandwidths is shown. As a reference, also the performance for LFDMA/TDMA with 16 subcarriers is shown. According to the parameters described in Appendix A.2, for LFDMA/TDMA a block of 16 subcarriers uses a bandwidth of 640 kHz. The simulation parameters correspond to the parameters for Base Coverage Wide Area, cf. Appendix A.2. QPSK modulation, a rate ½ convolutional code with BCJR decoder and single antenna transmission is assumed.

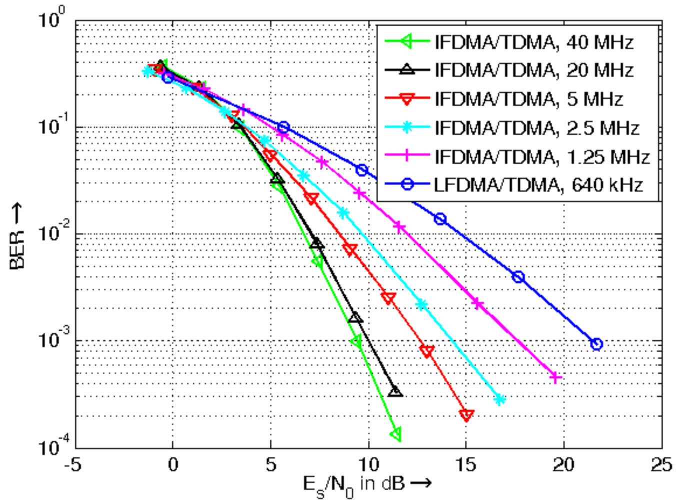


Figure A-23. Performance results for SISO transmission of IFDMA/TDMA for different bandwidths and for LFDMA/TDMA as reference, 16 subcarriers per user

From Figure A-23 it can be deduced that the performance of IFDMA/TDMA for spreading of the subcarriers over 20 MHz is similar to spreading over 40 MHz. A reduction of the bandwidth of the IFDMA/TDMA signal to 5 MHz causes a significant performance degradation. However, for the given parameters IFDMA/TDMA spread over 1.25 MHz still provides a significant performance gain compared to LFDMA/TDMA with the same number of subcarriers, cf. Figure A-23. In general, the performance of FH-LFDMA/TDMA is expected to show similar degradations dependent on the considered bandwidth as shown for IFDMA/TDMA whereas for a given number of subcarriers the performance of LFDMA/TDMA is expected to be independent of the system bandwidth since for LFDMA/TDMA transmission is restricted to a localized portion of the system bandwidth.

Conclusion

The properties of the different MA schemes are summarized and compared in Table 4.1.1.4. As a result, FH-LFDMA/TDMA provides slightly lower performance compared to IFDMA/TDMA. At the same time, a high number of consecutive TDMA slots is required and, thus, the efficiency of the micro sleep mode is lower compared to LFDMA/TDMA. Moreover, interpolation of the channel estimates in time is not possible and, thus, the channel estimation overhead is high. Already for short intervals between blocks of consecutive TDMA slots assigned to a specific user, IFDMA/TDMA provides, on the one hand, significant performance gains compared to LFDMA/TDMA due to higher frequency diversity especially for moderate to low data rates. On the other hand, the efficiency of the micro sleep mode for LFDMA/TDMA is higher due to a lower possible number of consecutive TDMA slots assigned to a specific user. As long as the gains due to higher frequency diversity and lower PAPR correspond to a higher saving of transmit energy than that enabled by LFDMA/TDMA due to its higher efficiency of the micro sleep mode, IFDMA/TDMA turns out to be the most promising scheme for frequency non-adaptive uplink transmission. However, a solution to combine the advantages of IFDMA/TDMA and higher efficiency for micro sleep mode at the expense of a slightly decreased PAPR is given by assignment of the sum of a few IFDMA/TDMA signals to a specific user such that interpolation in frequency is enabled. The resulting scheme is denoted as Block-IFDMA/TDMA (B-IFDMA/TDMA) throughout this deliverable. For B-IFDMA/TDMA the minimum possible number of TDMA slots is equal to the minimum possible number of TDMA slots for LFDMA/TDMA. Thus, B-IFDMA/TDMA, on the one hand, maintains the advantages of IFDMA/TDMA and, on the other hand, provides the same power efficiency for micro sleep as LFDMA/TDMA.

Table A-21. Comparison Matrix

<table>
<tr><th>Assessments</th><th>IFDMA/TDMA</th><th>FH-LFDMA/TDMA</th><th>LFDMA/TDMA</th></tr>
<tr><td>Frequency diversity</td><td>High</td><td>High</td><td>Decreases with decreasing data rate</td></tr>
<tr><td rowspan="2">Pilot Overhead</td><td>High for low number of consecutive TDMA slots (higher than for LFDMA/TDMA)</td><td rowspan="2">High since number of consecutive TDMA slots assigned to a specific user has to be high</td><td>High for low number of consecutive TDMA slots</td></tr>
<tr><td>Low for high number of consecutive TDMA slots</td><td>Low for higher number of consecutive TDMA slots</td></tr>
<tr><td>PAPR</td><td>Low</td><td>Medium</td><td>Medium</td></tr>
<tr><td rowspan="2">Micro sleep</td><td>Lower efficiency than for LFDMA/TDMA due to higher minimum possible number of consecutive TDMA slots for short intervals between blocks of consecutive TDMA slots assigned to a certain user</td><td rowspan="2">Low efficiency since number of consecutive TDMA slots assigned to a specific user has to be high</td><td>High efficiency for short intervals between blocks of consecutive TDMA slots assigned to a certain user</td></tr>
<tr><td>High efficiency for long intervals between blocks of consecutive TDMA slots assigned to a certain user</td><td>High efficiency for long intervals between blocks of consecutive TDMA slots assigned to a certain user</td></tr>
<tr><td>Complexity</td><td>Lowest due to efficient implementation by compression and repetition</td><td>Low</td><td>Low</td></tr>
<tr><td>Overall Ranking</td><td>1</td><td>3</td><td>2</td></tr>
</table>

A.4.1.2 Time Division Multiple Access (TDMA) vs. Frequency Division Multiple Access (FDMA) comparison for non-frequency adaptive DFT-block-OFDMA/TDMA

In this section we report first investigations on DFT-block-OFDMA/TDMA with non-frequency adaptive scheduling, in which the TDMA time-scale unit is the chunk duration. Even if the MA scheme of WINNER baseline is DFT-block-OFDMA/TDMA based on OFDM symbol time-scale, we think that these preliminary results are worth reporting.

The simulation parameters used in this study case differ from WINNER baseline parameters. However, the obtained comparative trends are of interest in the WINNER WA scenario too. In fact, in our scenario, the channel can be considered constant inside a chunk both in frequency and in time, thus fulfilling WINNER basic design assumption.

The results are based on dynamic system level simulations including fast fading channel model. Proportional Fair Scheduler and Chase Combining Hybrid ARQ with synchronous stop-and-wait H-ARQ processes are implemented. Link adaptation is based on Channel Quality Indicator (a measure of one user radio link quality averaged over the entire bandwidth); hence, the Proportional Fair scheduler does not use per-chunk CSI and then, the algorithm is not frequency adaptive. CQI is measured and reported every slot.

The system level simulation methodology can be summarized as follows: users are uniformly dropped over a network of 19 tri-sectored sites (57 sectors) with inter-site distance equal to 500 m. The average number of users per sector used during simulation is 4, 10 and 16. At each slot (i.e. chunk duration, assumed to be equal to 0.5 ms), the multi-path channel is updated according to the Jakes' channel model, the traffic is updated, and all the MAC mechanisms are simulated. Concerning the link to system level simulation interface, the signal-to-interference ratio of one received packet is computed taking into account the interference produced by users in other cells on each sub-carrier and for each OFDM symbol of the packet.

The goal of this study case is to perform a comparison between FDMA and TDMA access for an UL OFDM cellular system with frequency non-adaptive scheduling.

- In TDMA (with chunk duration granularity) only one user is allowed to transmit during one slot of 0.5ms. The frequency non-adaptive Proportional Fair scheduler selects the active user based on the channel quality indicator of the average channel condition over the whole bandwidth.
- In FDMA, several users are allowed to transmit during one sub-frame. In this case too, the average CQI is used by the scheduler, so that the implemented scheduler is not a frequency adaptive scheduler.

First results seem to state the superiority of FDMA in UL for DFT-block-OFDMA/TDMA, with respect to the generated sector throughput spectrum efficiency. This is due to the fact that in TDMA allocation, for each slot at most $P_{t,max}$ is transmitted in the sector (where $P_{t,max}$ is the maximum UT transmit power equal to 21 dBm), while, in FDMA allocation, when N users have been selected for transmission, N times $P_{t,max}$ is transmitted in the sector for each slot. Simulations state that, in FDMA allocation, the loss due to the inter-cell interference generated by the neighbouring users is smaller than the gain obtained by the growing number of active UTs communicating at maximum transmit power.
These trends need to be investigated in a fully-compliant WINNER WA scenario. They indicate a possible superiority of frequency chunk-based allocation in UL over classical chunk-based TDMA allocation. These first results indicate also that possible interesting gains can be obtained in case of frequency allocation of the resources even without a scheduler which uses a precise CSI for each chunk.

A.4.1.3 System Performance With and Without DAC

In this section, we compare the performance of two uplink MA schemes: 1) a pure reservation-based MAC, and 2) a hybrid, reservation-based and contention-based MAC, where the contention-based part is implemented as a DAC. This comparison will highlight the impact of having (or not having) a DAC.

The physical-layer on the uplink was assumed to be OFDM with cyclic prefix (see Table A-22 for more details of the simulated physical layer). We considered an FDD system with a nominal bandwidth of 20 MHz on the uplink. 8 OFDM symbols form one uplink frame, and each chunk is 16 sub-carriers by 8 OFDM symbols. The packet error probability is determined using a mutual information based link-to-system interface.

Each terminal generates on average 5 packets per second with exponential inter-arrival distribution (i.e. Poisson process). To examine the packet delay experienced by packets with different size payload, half the generated packets have a 1500-byte payload, and other half have a 100-byte payload.

Table A-22: Common Parameters for Both Simulated MACs

No. sub-carriers	1024
Sub-carrier BW	15 kHz
Base Rx Antennas	4
Freq. Reuse	1/1
Sectors/cell	3
T_{gurad}	4 µs
Base Noise Figure	2.3 dB
inter-siet distance	1 km
Frame duration	0.56 ms
Max UT transmit power	21 dBm
ARQ	Instant, no soft combining
Base Height	30 m
UT Height	1.5 m
Path loss exponent	-3.5
Path loss constant	-29.0 dB
Total simulated cells	21

Uplink Simulation Results for a Pure Scheduled-based MAC

With the pure scheduled-based MAC on the uplink, traffic packets are generated for each mobile (according to a Poisson process), and they enter the transmit buffer of the terminal. Each terminal with a non-empty transmit buffer can request uplink resources (i.e. chunks) from its serving cell. Each request consists of a number of desired frames and a fixed number of chunks desired on each of these frames. Six parallel request channels are available in each cell, and each mobile picks one of these channels randomly for making each of its requests. Each request channel is modelled as a slotted Aloha channel: if one and only one request is made on a given request channel, this request gets through to the serving cell; otherwise, no request gets through on this channel. Once the request gets to the BS, the BS will assign the requested number of chunks/frames to the mobile among the earliest chunks that have not yet been assigned to other terminals. Note that with this MAC, the base can assign multiple terminals on the same uplink frame (on non-overlapping frequencies). Slow power control (compensating for path loss and shadowing) is employed by all transmitting mobiles such that the average received SNR on the scheduled channel (SNR_SCH) is 3.5 dB, where average SNR_SCH is defined as SNR_SCH = Prx/(I0+N0), and Prx is the average received power spectral density, I0 is the average other cell interference power spectral density, and N0 is the thermal noise power spectral density. Offline, link-level simulations were performed to determine the coding and modulation resulting in the highest throughput at various values of SNR_SCH. Lastly, we assume that there is a 3 frame minimum delay between the time a terminal transmits a request for uplink resources and the time this mobile receives its assignment of resources on the downlink.

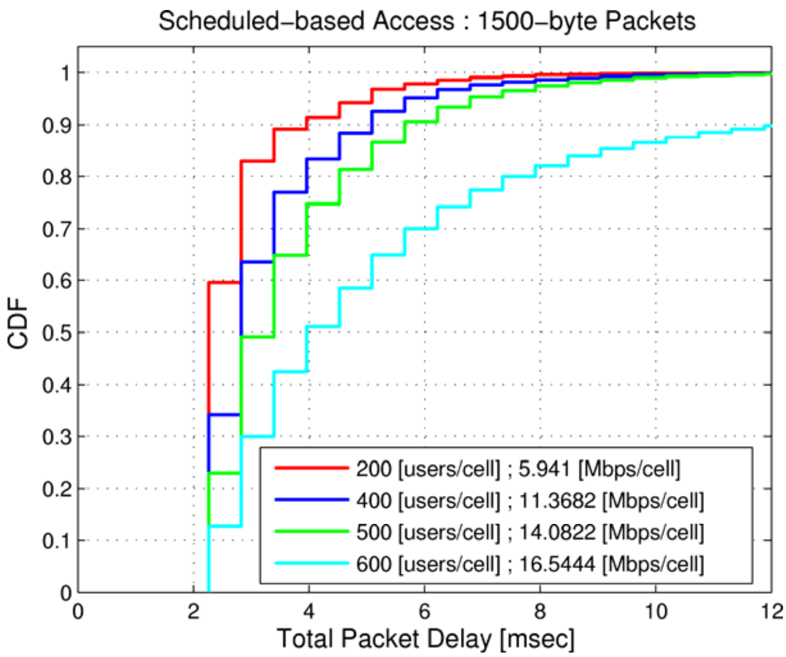


Figure A-24: 1500-byte Packets without DAC

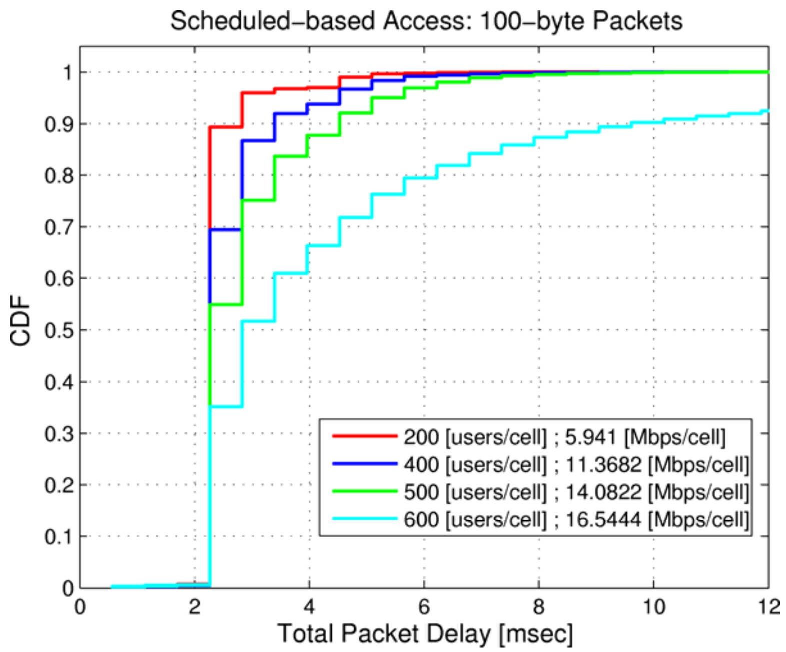


Figure A-25: 100-byte Packets without DAC

For various number of users per cell (200, 400, 500, and 600), the CDF of packet delay using the pure scheduled-based MAC is depicted in Figure A-24 and Figure A-25. Both Figure A-24 and Figure A-25 correspond to a system with a pure scheduled-based MAC on the uplink. In Figure A-24, we have plotted the CDF of the delay experienced by 1500-byte packets. In Figure A-25, we have plotted the CDF of the delay experienced by the 100-byte packets. In the simulations, packets of both sizes were simultaneously generated.

Uplink Simulations for a Hybrid Reservation-based/Contention-based MAC

With this hybrid MAC, the uplink bandwidth in each cell is divided in two contiguous, non-overlapping parts. Approximately 88% of the uplink bandwidth is set aside for scheduled-based access, and the remaining 12% of the uplink bandwidth is set aside for the DAC (with a contention-based MAC).

The hybrid system further contains four parallel request channels, and these channels are used by terminals to request resources for transmission on the scheduled part of the uplink. Each request channel is again modelled as slotted Aloha. A mobile with a non-empty transmission buffer decides autonomously whether to transmit immediately on the DAC or to send a request on one of the request channels and waits for assigned resources on the scheduled part. To make this decision, each mobile with non-empty transmission buffer containing B bits will compute the time it would take it to transmit these B bits using the DAC (assuming no collisions), and if this time is less than or equal to a pre-specified threshold, it will transmit using the DAC. Otherwise, if the computed time for transmission of these B bits using the DAC is more than the pre-determined threshold, the mobile will send a request and will wait for an assignment.

Slow power control (compensating for path loss and shadowing) is employed by all mobiles that transmit on the DAC such that the average received SNR on the DAC (SNR_DAC) is 5.0 dB. Off-line, link-level simulations were performed to determine the coding and modulation resulting in the highest throughput at various SNR_DAC such that if less than or equal to four terminals simultaneously transmit on the DAC, all their packets will be received with high probability.

Lastly, on frames that no terminal is scheduled (i.e. the scheduled part of the bandwidth is idle in a given frame), the bandwidth of the DAC is extended to the entire available bandwidth (i.e. all 1024 sub-carriers). Consequently, with low number of user per cell, many terminals can transmit their 1500-byte packets over the extended DAC. However, with a large number of users per cell, it is very rare that there will be no scheduled user on any given frame; hence, almost all 1500-byte packets will be transmitted using the scheduled MAC (over the part of bandwidth set aside for scheduled access).

For various number of users per cell (200, 400, 500, and 600), the CDF of packet delay using the hybrid MAC is illustrated in Figure A-26 and Figure A-27. In Figure A-26, we have plotted the CDF of the delay experienced by 1500-byte packets. In Figure A-27, we have plotted the CDF of the delay experienced by the 100-byte packets. In the simulations, packets of both sizes were simultaneously generated.

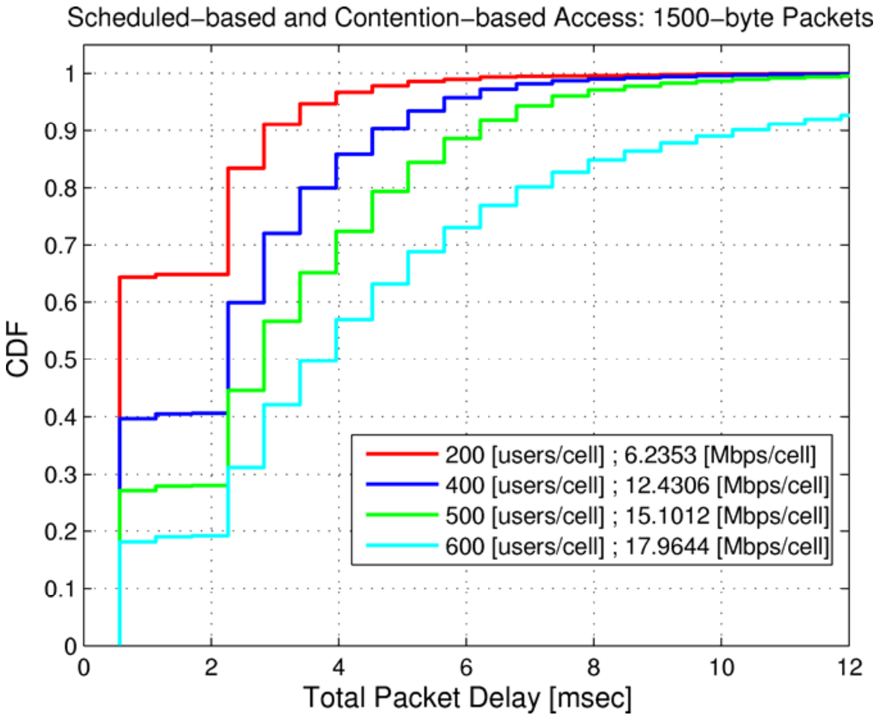


Figure A-26: 1500-byte Packet with DAC.

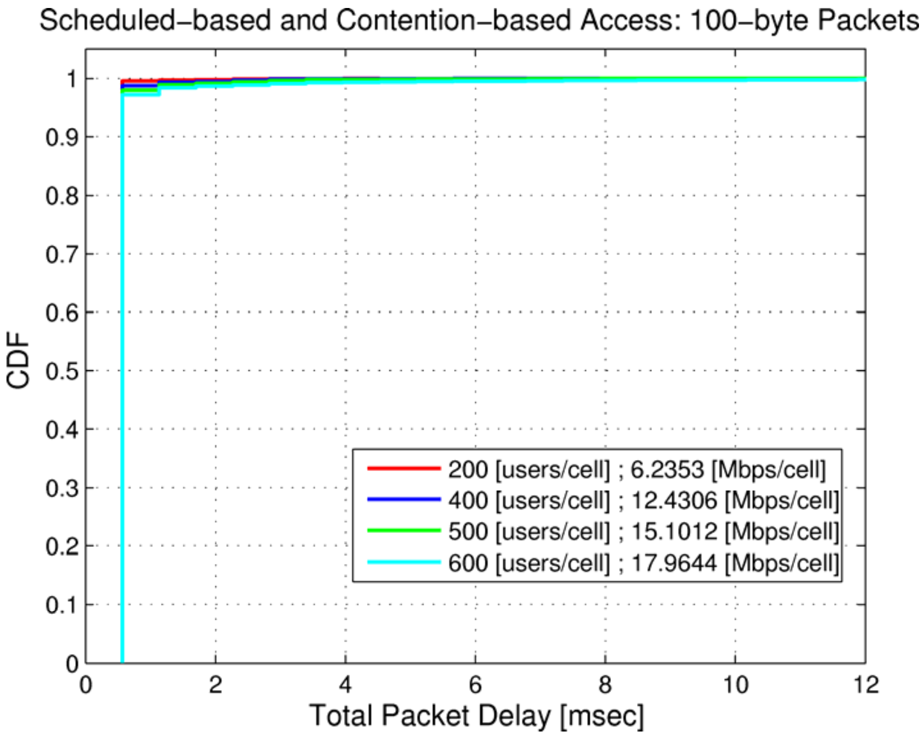


Figure A-27: 100-byte Packets with DAC.

Remarks on Simulations for Uplink MA

The impact of having a DAC on the delay experienced by large-sized packets (e.g. 1500-byte packets) can be seen by comparing Figure A-24 and Figure A-26. Focusing on the case with large number of users per cell (e.g. 600users/cell), we see that without a DAC (Figure A-24) 90% of packets experience a delay of less than 12 ms; however, with a DAC (Figure A-26) 90% of packets experience a delay of less than 11ms. Focusing on the case with a small number of users per cell (e.g. 200users/cell), we see that without a DAC (Figure A-24) 65% of packets experience a delay less than 3ms; however, with a DAC (Figure A-26) 65% of packets experience a delay of only 0.5ms. We conclude for packets with large-sized payload, the additional of DAC reduces the delay slightly at high loads, and reduces the delay significantly at low loads.

The impact of having a DAC on the delay experienced by small-sized packets (e.g. 100-byte packets) can be seen by comparing Figure A-25 and Figure A-27. Focusing on the case with large number of users per cell (e.g. 600 users/cell), we see that without a DAC (Figure A-25) 90% of packets experience a delay of less than 10 ms; however, with a DAC (Figure A-27) 90% of packets experience a delay of less than 0.5ms. Focusing on the case with a small number of users per cell (e.g. 200users/cell), we see that without a DAC (Fig. 2) 90% of packets experience a delay less than 2.2ms; however, with a DAC (Figure A-27) 90% of packets experience a delay of only 0.5ms. We conclude for packets with small-sized payload, the additional of DAC reduces the delay significantly at all loads (factor of 4 reductions in delay at low loads, and a factor of 30 reductions in delay at high loads).

The simulations results indicate that a hybrid uplink MAC consisting of a scheduled part and a contention-based part (where the contention-based part is implemented as a DAC with multi-packet reception capability) can significantly reduce the delay for small-sized packets on the uplink. Mobiles data applications generating intermittent small packets, including terminal emulation, credit card verification, or transmission of acknowledgments for downlink TCP packets, should benefit greatly from the addition of a multi-packet DAC.

A.4.1.4 Uplink SDMA

A non frequency adaptive uplink based on OFDM/TDMA is evaluated in the base coverage urban scenario. In order to assess the potential of uplink SDMA, the TDMA scheduling is complemented by a SDMA component by scheduling multiple users per cell for simultaneous transmission. this is sometimes also referred to as multi-user MIMO (MU-MIMO). Performance is compared for an inter-site distance of 1000 m and the base station receiver is equipped with four antenna elements separated ten wavelengths. User terminals transmit using as single receive antenna. The uplink transmission bandwidth is 5 MHz (8 chunks with 16 sub-carriers per chunk), i.e., the bandwidth of the considered network is scaled-down in comparison to the 40 MHz transmission bandwidth that is the default assumptions in the base coverage urban scenario.

In the considered scenario, one, two or four randomly selected users per cell are scheduled for transmission and interference rejection combining is used at the base station receiver to suppress intra-cell and inter-cell interference. Moreover, successive interference cancellation (SIC) after channel decoding is considered as an optional feature at the base station. With SIC, the signal associated with already decoded packets is regenerated and subtracted from the received signal. Here, the decoding order is selected randomly (but determined prior to the link adaptation). In the basic scenario all terminals transmit using the maximum output power. As an alternative, a SNR-based open loop power control scheme is also evaluated. In the latter case, the terminal output power is selected based on the estimated pathloss between transmitter and receiver and the noise level at the base station. The considered SNR-target equals 20 dB.

Figure A-28 depicts the distribution of the user post-receiver SINR (geometrically) averaged over all sub-carriers and all transmission attempts. Without SIC, the SINR decreases with around 4 dB when going from one to two simultaneously scheduled users and when going from two to four users the SINR is reduced by 5-6 dB. SIC provides a performance improvement when two or more users per sector are scheduled for simultaneous transmission. With two scheduled user, SIC provides an improvement of approximately 1 dB. The corresponding figure when four users are scheduled is around 2 dB.

Figure A-29 depicts the distributions of the user active radio link rates, i.e., the data rate when scheduled for transmission (averaged over all transmission attempts). Because of the additional interference introduced by SDMA, the instantaneous data rates decrease with the number of scheduled users. For example, the median figure decreases from 9.5 Mbps to 5.8 Mbps when going from one to two scheduled users (no SIC). With four simultaneously scheduled users the median figure reads 2.3 Mbps. Note, however, that even though the instantaneous data rate decreases the average rate may be improved since each user gets access to the channel more frequently. This is visualized in Figure A-30 that depicts the average uplink sector throughput as a function of the number of scheduled users per cell. With no power control and without SIC, the throughput is around 11 Mbps/sector, 16 Mbps/sector and 19 Mbps/sector, respectively, i.e., in this example the average throughput increases with the number of SDMA users. SIC provides a throughput improvement of 5 % and 20 % with two and four scheduled users, respectively. Transmitting using the SNR-based open loop power control provides approximately the same throughput as without power control.

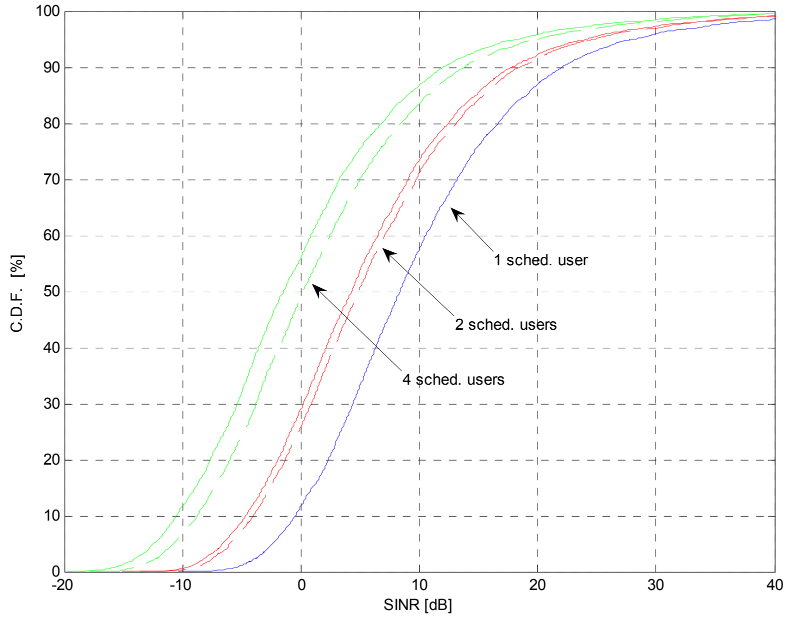


Figure A-28: Post-receiver SINR for 1, 2, and 4 scheduled users. Power control is not used. Performance without (-) and with (--) SIC is depicted.

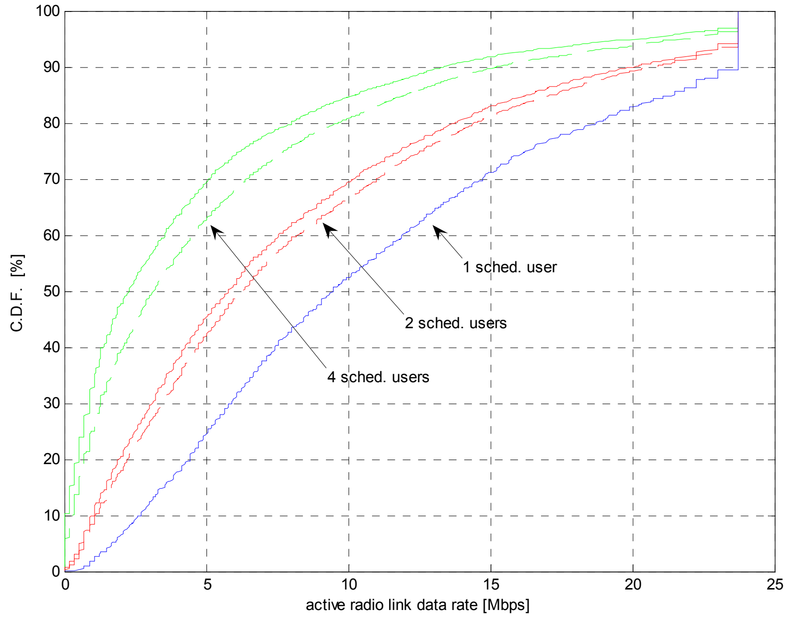


Figure A-29: Distribution of the active radio link data rates with 1, 2, and 4 SDMA users without (-) and with (--) SIC. Power control is not used.

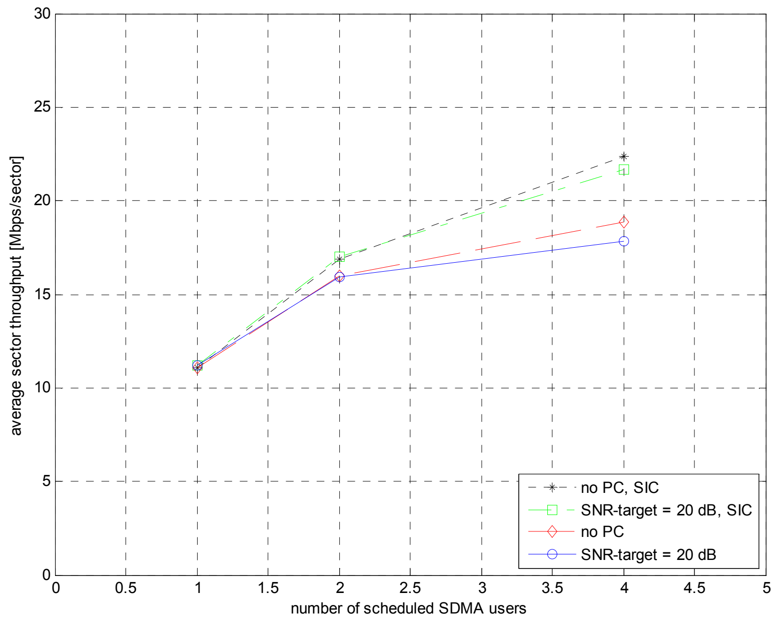


Figure A-30: Average uplink sector throughput.

A.4.1.5 Performance of Adaptive TDMA/OFDMA Uplink with Carrier Frequency Offsets

Simulation Assumptions	
Simulator	Multi-link
Scenario	Wide area, single-cell, SISO, long-term power control
Channel modelling	ITU-IV Channel A, average user speed 50 km/h, perfect channel prediction and estimation. Not perfect frequency alignment among users.
MCS	Uncoded: BPSK, 4QAM, 8PSK, 16QAM, 32CrossQAM, 64QAM, 128CrossQAM and 256QAM
Uplink spectrum	1.9 GHz carrier frequency and 5 MHz bandwidth
OFDM parameters	Symbols and cyclic prefix of length 100μs and 11μs respectively, with subcarrier spacing 10 kHz.
Chunk size	0.667 ms times 200 kHz, which gives 120 symbols, 6 symbols of length 111μs on each of the 20 subcarriers. Out of the 120 symbols, 12 are for training and downlink control, leaving 108 payload symbols.
Frame size	Each chunk individually allocated to the users.

Performance results for an adaptive TDMA/OFDMA uplink are provided. These results are not obtained with the WINNER parameters, but the results have a general value by showing the performance of an adaptive TDMA/OFDMA uplink under non-perfect frequency alignment. This uplink performs multi-user frequency adaptive scheduling to the small scale fading for the individual users and also link adaptation of the scheduled users. The aim of the investigation is to show the sensitivity to frequency offsets among the different uplink users in the form of the penalty in multi-user diversity gains that can be obtained as a function of frequency offsets. The simulation results presented is a review of the results in [WOS06], where an analytical model of the impact of frequency offsets is derived and assessed by simulations. Below we show a summary of the results in [WOS06].

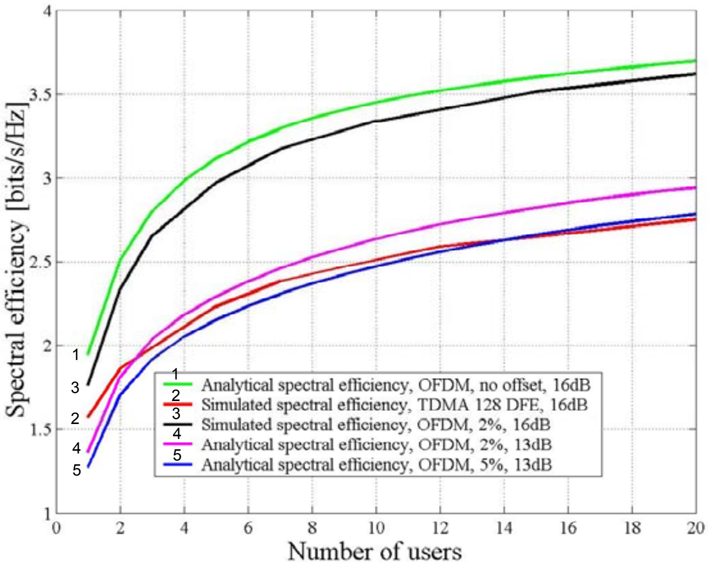


Figure A-31: Performance of the Adaptive Uplink under different frequency offsets as a fraction of the subcarrier spacing. As a comparison, the results of the adaptive TDMA uplink presented in [WIND210] section G4.1 is also shown.

The curves at average user SINR 13 dB with 2-5% frequency offsets are comparable to the simulated spectral efficiency of the adaptive single-carrier TDMA uplink with decision-feedback frequency-domain equalizer at 16 dB as shown in [WIND210] section G4.1. This 3 dB difference provides a margin for the power back-off value when comparing an OFDM-based uplink and a single-carrier adaptive uplink. Note that the difference is expected to be even larger in a wider system bandwidth than the 5 MHz assumed in this study.

A.5 Interference Suppression Techniques

A.5.1 Introduction

Smart usage of multiple antennas at the transmitter and at the receiver side is seen as one of the key technologies of the WINNER concept. The design of a configurable transmitter, which may be used to achieve directivity, diversity or multiplexing, started in [WIND2.7]. and was elaborated on in [WIND210]. The latest design of the generic transmitter is described in [WIND3.4.1].. The transmitter allows e.g. for segmentation of flows into several data blocks that are separately channel coded. Such segmentation enables, in turn, the use of techniques like per antenna rate control and per stream rate control, PARC and PSRC, respectively.

To efficiently exploit the capabilities and the flexibility of the generic (multi antenna) transmitter the corresponding receiving entities must typically be equipped with several receive antennas. Multiple receive antennas are e.g. required for efficient spatial multiplexing and may further be used to improve the diversity or the robustness to interference. Moreover, for schemes like PARC or PSRC successive interference cancellation (SIC) after channel decoding may be used at the receiver side to improve decoding performance. The gains of multi-antenna receivers and SIC were e.g. discussed in [WIND2.7] and [WIND2.10].

The gains of multi antenna receivers were discussed and assessed e.g. in Appendix G of [WIND2.10]. The following sections extend the discussion of [WIND210] and presents evaluation results derived using assumptions based on the updated WINNER concept proposal.

A.5.2 Multi-antenna Receivers for Interference Suppression in OFDM Networks

One possible means to enhance the radio network performance is to equip the radio receivers with multiple antennas. Since the radio channels (from a transmit antenna) to the receive antennas tend to fade differently multi antenna receivers provide diversity – both for the signal of interest and for the interference. With appropriate selection of the antenna combining weights, accounting for e.g. the radio channel, the interference power and the spatial colouring of the interference, such multi antenna receivers may provide increased robustness to both fading and interference. This, in turn, may improve the radio network coverage, capacity and user data rates.

Maximum ratio combining (MRC) and interference rejection combining (IRC) are two well-known combining schemes. With MRC the combining weights are selected accounting for the radio channel (of the desired signal), the noise power and the interference power at the different receive antennas. IRC, sometimes also referred to as optimal combining [Win84] or minimum mean square error (MMSE) combining, determines the combining weights based on the channel and the (spatial) noise and interference covariance matrix, i.e., not only the interference power but also the spatial colouring of the interference is considered.

A way of increasing the peak data rates is the use of multi-stream MIMO transmission. One such scheme is per antenna rate control, for which one channel encoded block is transmitted from each antenna. At the receiver side multiple antennas may be used for interference suppression and the receiver performance may be further enhanced by successive interference cancellation. With SIC, the signals associated with already decoded code blocks are regenerated and subtracted from the received signal.

A.5.2.1 Evaluation Assumptions

The potential performance gains of using multi antenna receivers for interference suppression are here assessed by means of computer simulations of a non frequency adaptive OFDM/TDMA network. The simulation assumptions are based on the base coverage urban scenario parameters as specified in [WIND6.13.1]. The studied deployment comprises 19 sites, each with three sectors per site. The downlink evaluations assume, for single stream transmission, a single base station transmit antenna and one, two, or four terminal receive antennas. The terminal antennas are separated half a wavelength and MRC or IRC is employed on a per sub-carrier basis. For dual stream transmission with PARC the base station transmits two streams from two transmit antennas that are separated ten wavelengths. Terminals have two or four receive antennas and IRC is used. The performance of dual stream transmission is studied both for the case when the terminal employs successive interference cancellation (after channel decoding) or not. The uplink evaluations assume a single terminal transmit antenna and one, two, or four base station receive antennas. The antenna separation at the base station is either half a wavelength or ten wavelengths.

Round robin TDMA scheduling is used in both uplink and downlink, i.e., in each frame a single user per sector is assigned to the entire bandwidth. The transport format (modulation scheme and channel code rate) is selected to maximize the expected throughput. There are three available modulation schemes (QPSK, 16QAM, and 64QAM) and six different channel code rates (1/10, 1/3, 1/2, 2/3, 3/4, and 8/9), i.e., in total there are 18 different transport formats. Accordingly, the peak data rates equal 189.6 Mbps and 379.3 Mbps for single and dual stream transmission, respectively.

The simulations assume perfect channel and interference estimation at the receiver. Similarly, channel quality measurement errors and delays are not accounted for. The OFDM transmission is further modelled as perfectly orthogonal and any potential inter-symbol or inter-carrier interference caused by channel time dispersion exceeding the cyclic prefix is not considered. Overhead, such as e.g. reference symbols (pilots) for channel and interference estimation or protocol headers are neither accounted for.

The used performance measures are the post receiver SINR, the active radio link data rate and the average sector throughput. The first two may be described as user centric performance measures while the last is focused on the system performance. The post receiver SINR is the symbol SINR after antenna combining (geometrically) averaged over all symbols in the frame (code block). The active radio link data rate is the user data rate when scheduled for transmission averaged over all transmission attempts. The average throughput, here measured in Mbps/sector, is calculated as the number of correctly received bits in relation to simulation time and the number of sectors. To assess how the performance depends on the network cell size, the average sector throughput is plotted as a function of the inter-site distance (ISD).

A.5.2.2 Numerical Results: Downlink Single-stream Transmission

The left plot in Figure A-32 depicts the post receiver SINR of an interference limited network (inter-site distance 500 m). The number of receive antennas at the terminal are one or two and MRC or IRC is used. Dual antenna reception with MRC enhances the average SINR by around 3 dB for basically all users and IRC gives an additional improvement of approximately 2 dB. The right plot in Figure A-32 shows the corresponding distribution in a network that is largely noise limited (inter-site distance 2000 m). The gain of going from one to two receive antennas with MRC is similar to what was observed in the interference limited network, i.e., around 3 dB. Since the studied deployment is limited by noise rather than interference, the gain of IRC in comparison to MRC is small.

The impact on system performance, here measured by the average sector throughput, is indicated by the results in Figure A-33. Figure A-33depicts the downlink average sector throughput as a function of the inter-site distance for one, two, and four terminal receive antennas using MRC or IRC. With a single receive antenna the sector throughput reaches around 40 Mbps/sector for a network comprising small cells (interference limited deployment), which corresponds to around 1 bps/Hz/sector. Introducing terminals with dual receive antennas using MRC increases the average throughput by 30-40 % in deployments with small cells while the gain is 50-60 % in large cell deployments. IRC improves the throughput in interference limited deployments by additionally 15-20 % but provides no additional gain in noise limited deployments.

If terminals are equipped with four receive antennas the throughput may be further enhanced. When using MRC, the gain is around 35 % for small cells when increasing the number of receive antennas from two to four. In large cell deployments the corresponding gain is around 50 %. Furthermore, IRC with four antennas gives a gain of 35 % compared to MRC with four antennas in interference limited deployments. Compared to a single receive antenna, IRC with four receive antennas accordingly provides a throughput improvement of more than 150 %.

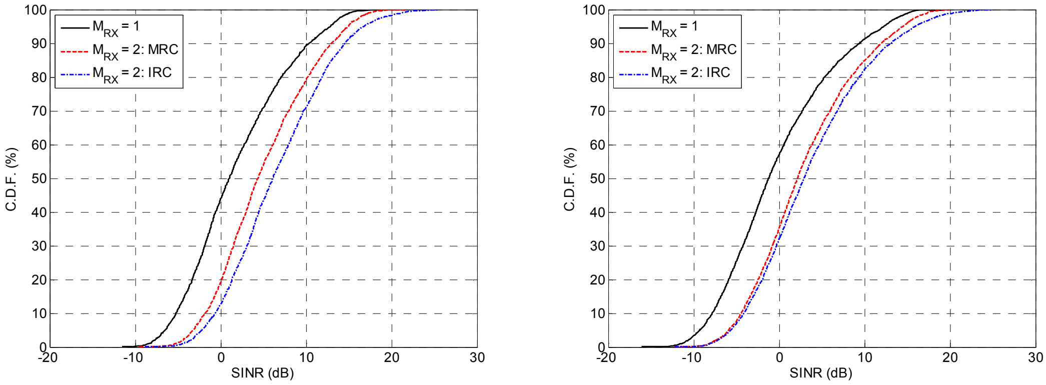


Figure A-32: Post receiver SINR distributions in an interference limited network (left) and a noise limited network (right). The mobile terminals are equipped with different number of receive antennas (1, 2, and 4) and MRC or IRC is used.

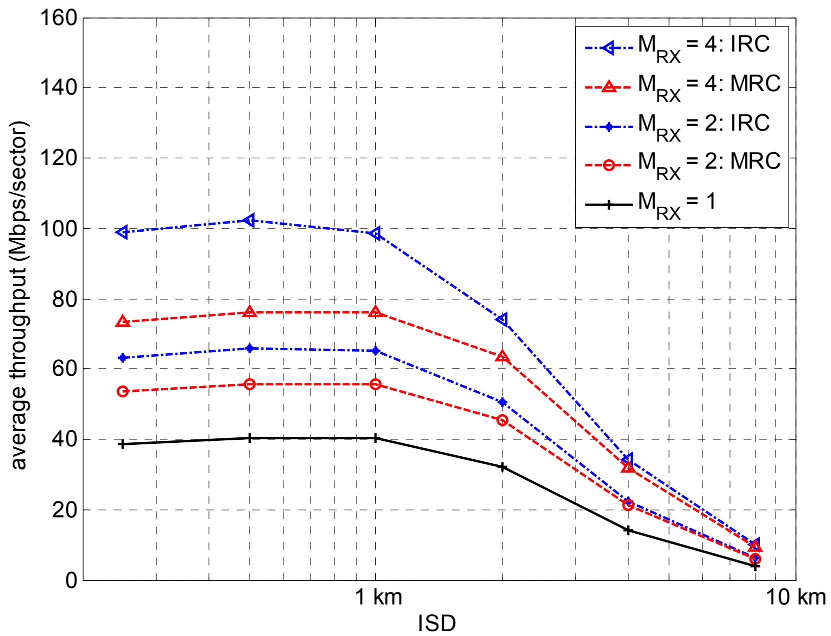


Figure A-33: Downlink average sector throughput as a function of the inter-site distance for different number of receive antennas (1, 2, and 4) and for different combining schemes (MRC and IRC).

A.5.2.3 Numerical Results: Downlink Dual-stream Transmission

Multi-stream MIMO transmission is a possible means to enhance the data rates in a radio network. Figure A-34 depicts the distribution of the active radio link data rates in a network where dual stream transmission with PARC is employed. From each of the two transmit antennas the base station transmits one channel coded packet using all available sub-carriers. The multi antenna terminals employ IRC to suppress (intra-cell and inter-cell) interference and both the case with and without successive interference cancellation is considered. As a reference, the data rate distribution for single stream transmission with the same number of receive antennas is included as well.

The left plot of Figure A-34 depicts the distributions in case terminals are equipped with two receive antennas while the right plot shows the corresponding distributions for terminals using four receive antennas. A comparison of the rates of single stream transmission and dual stream transmission without SIC in the two receive antennas case indicates that in the studied scenario dual stream transmission may only improve the data rates for a very small fraction of the users. A majority of the users are actually better off if single-stream transmission is employed. The reason is that dual stream transmission introduces intra-cell interference and it also changes the characteristics of the inter-cell interference. Limiting the analyses to the strongest interfering base station, which for many users largely determines the character of the experienced interference, one may notice that the inter-cell interference now originates from two sources (antennas) rather than one. Moreover, the interference suppression must now not only account for inter-cell interference but also the introduced intra-cell interference. With successive interference cancellation employed at the receiver side, a relatively small fraction of the users may increase their data rates while the remaining fraction of the users gets a marginally reduced data rate.

Four antenna terminal receivers without SIC in combination with dual stream transmission offers performance comparable to single stream transmission, as illustrated in Figure A-34. Roughly 70 % of the users get a slightly reduced data rate while the remaining part of the users gets improved data rates. With SIC, the performance of dual stream transmission improves even further and a large fraction of the users get higher data rates compared to single stream transmission. Moreover, for single stream transmission, a small fraction of the users reach the peak data rate and are hence modulation limited.

Figure A-35, furthermore, depicts the downlink average sector throughput for single stream and dual stream transmission with two (left) and four (right) terminal receive antennas, respectively. Dual stream transmission is analyzed with and without SIC in the terminal receivers. With two receive antennas, dual stream transmission without SIC reaches a lower average throughput compared to the corresponding network in which single-stream transmission is used. Dual stream transmission with SIC, however, achieves the highest throughput. With four receive antennas the throughput when using single stream transmission is similar to what is achieved with dual stream transmission without SIC while dual stream transmission with SIC provides the highest throughput.

The results in Figure A-34 and Figure A-35 indicate that multi-stream transmission, here exemplified by dual stream transmission with PARC, may be a way to increase data rates and throughput in the downlink of a radio network. It may, however, come at a cost of reduced data rates to low percentile users. With sufficient interference suppression capabilities, e.g. in the form of sufficiently many receive antennas, SIC, or a combination thereof, the data rates to high percentile users and the average throughput may however be increased without any significant reduction of low percentile data rates.

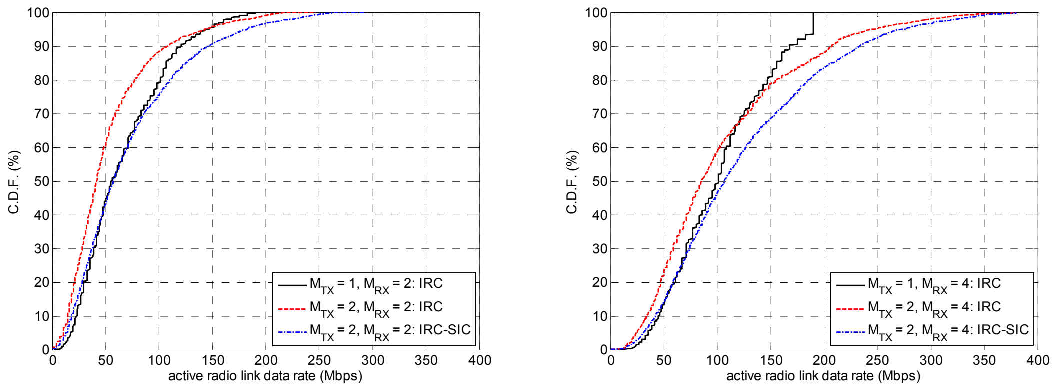


Figure A-34: Active radio link data rate distributions with two (left) and four (right) terminal receive antennas, respectively.

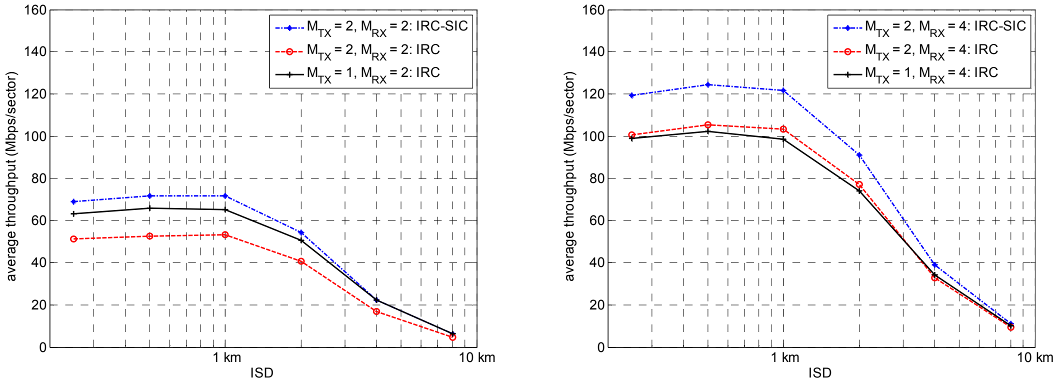


Figure A-35: Average downlink sector throughput with two (left) and four (right) terminal receive antennas as a function of the site-to-site distance.

A.5.2.4 Numerical Results: Uplink

Like in the downlink, the uplink performance may be improved by using multi antenna receivers. Considering the relatively small angular spread at the base station (compared to the corresponding angular spread at the mobile station), receive antennas separated half a wavelength does not necessarily provide sufficient diversity, however, since the fading from a transmit antenna to the different receive antennas tend to be similar. Therefore an antenna separation of ten wavelengths at the base station is studied as well as the default separation of half a wavelength. Like in the downlink round robin TDMA scheduling is used, which implies that a terminal, when scheduled for transmission, utilizes the entire transmission bandwidth. In a wide-area scenario, in which many mobile terminals are located far from the base station and experience high signal attenuation, this is not necessarily an efficient solution since many terminals are power limited. An alternative solution would be to simultaneously schedule and frequency multiplex several users per sector. Compared to pure TDMA scheduling, such a network would probably be interference limited and show higher spectrum efficiency.

Figure A-36 depicts the uplink post receiver SINR in a network where base stations are equipped with two and four receive antennas. IRC is used and the antenna separation is half a wavelength and ten wavelengths. The results indicate that two receive antennas with IRC improves the SINR by around 4-5 dB. With four receive antennas the SINR is improved by almost 10 dB compared to a single receive antenna. The SINR distributions are only slightly influenced by changing the antenna separation from half a wavelength to ten wavelengths. Further work may be needed to provide more information on how the base station antenna separation influences performance.

The uplink average sector throughput is depicted in Figure A-37. For small cells and a single receive antenna the throughput reaches around 35 Mbps, i.e., 0.9 bps/Hz/sector. This is only slightly below the corresponding downlink figure. With more receive antennas performance is improved and for small cells the larger antenna separation of ten wavelengths is beneficial.

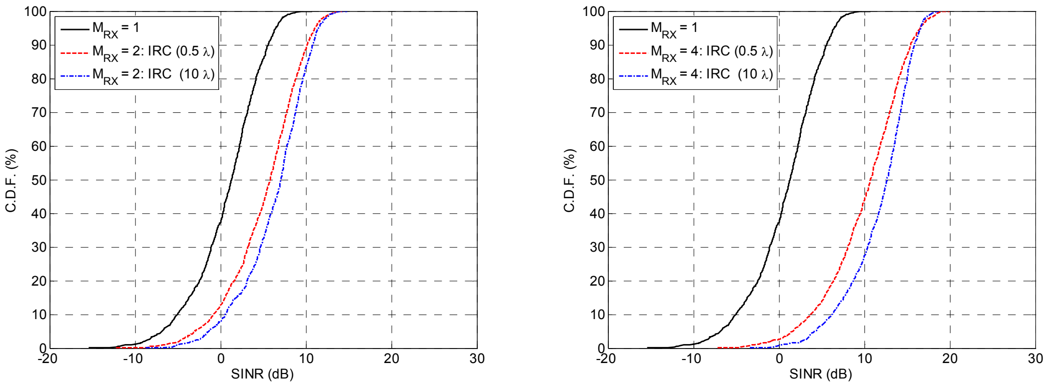


Figure A-36: Post receiver SINR in a multi-cell deployment with different number of base station antennas (1, 2, and 4) and different antenna separations (0.5 and 10 wavelengths). IRC is used and the inter-site distance is 250 m.

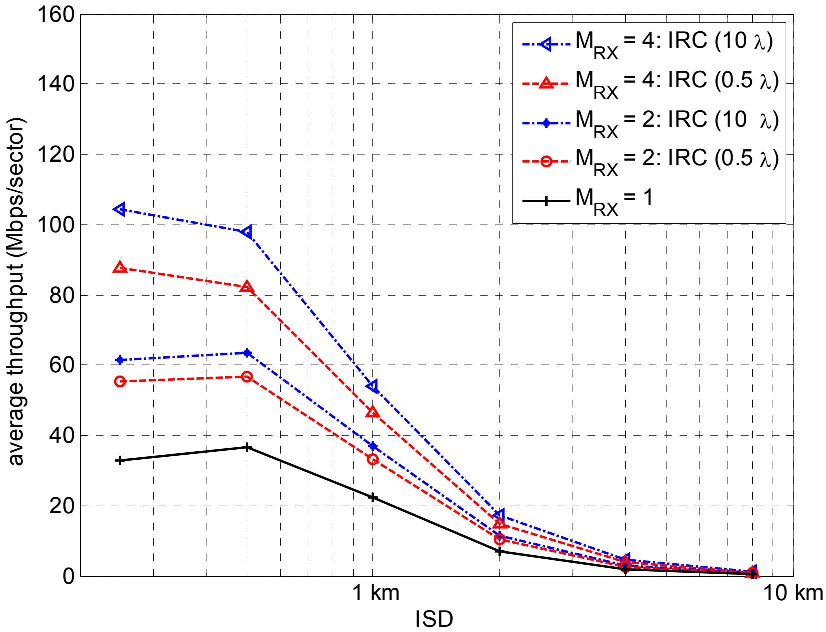


Figure A-37: Average sector throughput as a function of the inter-site distance for different number of receive antennas (1, 2, and 4) and for different antenna separations (0.5 and 10 wavelengths). IRC is the used combining scheme.

A.5.3 Interference Suppression Enablers

The results in section A.5.2 indicate that multi antenna receivers may be an efficient means to enhance both uplink and downlink performance in cellular networks. The gain increases with the number of receive antennas and in interference limited deployments IRC may provide substantial gains in comparison to MRC. In practice, the achievable gain may be limited by several factors. Firstly, the form factor of the receivers, especially in the downlink, may limit the number of receive antennas that could be used. An often mentioned assumption is that small handsets may have room for two antennas while laptops may be equipped with four antennas. A base station could probably be equipped with up to eight or even sixteen antenna elements per sector.

Second, the interference suppression gain depends on that accurate estimates of the channel and interference are available at the receiver. Typically, such estimates are achieved from reference symbols or pilots that are transmitted together with the data, which implies that this information can be achieved at a cost in terms of overhead. Pilots for channel estimation are needed for data demodulation and it should be possible to use the same reference symbols also for interference estimation. Section 3.2 of [WIND2.10] outlines a possible WINNER pilot design pattern for channel estimation where a scattered pilot grid is used for OFDM transmission. Interference estimates may here be derived as a by-product of the channel estimation (using the residual as an estimate of the interference). The design of a scattered pilot is further discussed in [WIND3.4.1] and the overhead of such a design is estimated to be within 2 % to 5 % per spatial stream. [WIND3.4.1] further discusses and evaluates different pilot designs accounting for the cross-correlation between pilots in neighboring cells. The analysis identifies two pilot designs with particularly good performance. In the first design, the pilot positions in different cells are dissimilar. In the second design, different sectors of the same site use the same pilot positions but orthogonal training sequences and different sites use dissimilar pilot positions.

Appendix B. Multiple Access Schemes for Reference Design in Non-Frequency Adaptive Transmission

B.1 Introduction

With non-frequency-adaptive allocation, bits from each flow are allocated onto sets of chunks that are dispersed in frequency and/or space. Forward Error Correction (FEC) coding and interleaving are used to combat the small-scale frequency selective fading. Link adaptation may be performed with respect to shadow fading, but not with respect to frequency-selective fading, i.e. the same modulation and coding is used in all frequency and spatial resources allocated to the flow in a frame slot (i.e. chunks and chunk layers), but the resource scheduling is fast both for adaptive and non-frequency adaptive flows, with around 1 ms minimum delay over the radio interface.

Non-frequency adaptive transmission mode is required for control signalling and is also used for point-to-multipoint transmission in multicasting and broadcasting. It offers a robust option for scheduled flows and it serves as a fallback solution for adaptive scheduling, since adaptive transmission becomes less reliable below a certain SINR threshold and above a certain user terminal velocity. Non-frequency adaptive transmission could also be used in an initial startup phase for adaptive flows before channel prediction is reliable enough, however recent results in chapter A3.1.3 indicates that adaptive transmission could be competitive also when working on channel estimates only. The spectral efficiency of the system is lower when the flow has to be allocated to non-frequency adaptive transmission than if the flow could have been allocated for adaptive transmission, due to the chunk-wise link adaptation and also the multi-user diversity gains.

In the baseline assumptions for non-frequency adaptive downlinks in the WINNER I System Concept described in [WIND210], MC-CDMA with chunk localized code-multiplexing was the framework for flow-multiplexing over the chunks assigned for non-frequency adaptive transmission, see Figure B-1. The reason to restrict the code-multiplexing to be within chunks only, was to limit the degree of non-orthogonality of the flows to different users, taking advantage of the chunk property that the channel gain is essentially flat in time and frequency. Orthogonal signalling such as OFDM-symbol based TDMA or subcarrier based FDMA allocation were seen as special cases of this MC-CDMA scheme with chunk localized code-multiplexing. The performance differences between these flow multiplexing strategies were investigated in [WIND210], and the overall conclusion in [WIND210] section 3.1.6 was that the difference between these flow multiplexing strategies within the chunks were found to be rather small.

In the baseline assumptions for non-frequency adaptive uplinks in the WINNER I System Concept described in [WIND210], OFDM-symbol based TDMA/OFDMA allocation was assumed with no code-multiplexing to avoid the complexity of multi-user detection in the receiver, see Figure B-1. Either pure OFDM or DFT-precoded OFDM resulting in serial modulation were allowed, i.e. Generalized Multi-Carrier modulation (GMC). For the serially modulated uplink, DFT-precoded FDMA/TDMA was envisioned, e.g. DFT-precoded block OFDMA or IFDMA. Compared to chunk-based OFDMA/TDMA, these schemes provide increased frequency diversity and resources of shorter duration. The shorter time duration (mapping on individual OFDM symbols/GMC slots) also provides increased opportunities for terminals to go into power-saving micro-sleep intervals.

None of the investigations in [WIND210] added the effect of spatial diversity schemes in the multiple access investigations, but it was expected that the additional use of spatial diversity will lessen the requirement for frequency diversity. The gain with spatial diversity has been studied in Appendix A.4 for IFDMA and Alamouti space-time coding. The general conclusion could be to use spatial diversity as much as possible, because it is easier to share the frequency domain than to share the spatial domain. In particular, with spatial diversity gains the resource partitioning problem that includes selecting appropriate sets of chunks for adaptive and non-frequency adaptive transmission would be simplified.

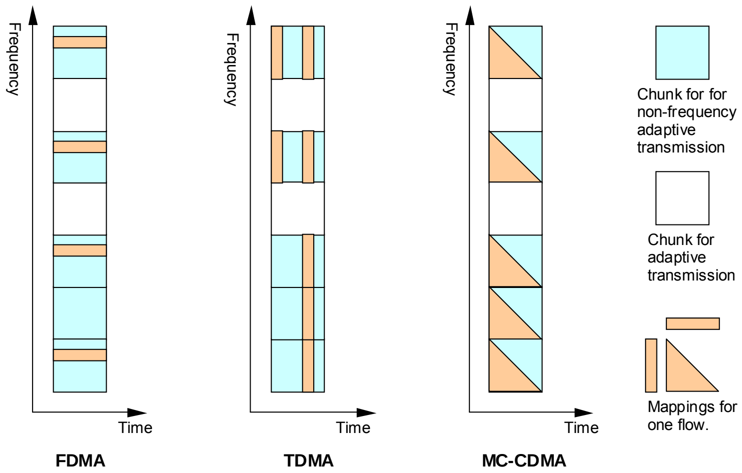


Figure B-1: Illustration of the different flow mapping strategies onto chunks as considered in WINNER I [WIND210].

Frequency synchronization for the uplink users could be a potential problem, but in [WIND210], it was shown that frequency offset errors among UTs can be suppressed to around 1% of the subcarrier spacing by the UL-DL synchronisation scheme outlined in [WIND210] Appendix B.4.1 and investigated also in [WIND23]. Thus, an OFDM based uplink scheme is feasible both for adaptive transmission and non-frequency adaptive transmission. The degradation for an adaptive TDMA/OFDMA uplink due to frequency offsets was quantified in Appendix A and shown to be modest for carrier frequency offsets up to 2%. However, even with a carrier frequency offset as high as 5% of the subcarrier spacing, the result still outperforms the adaptive single-carrier TDMA system investigated in [WIND210] Appendix G.4.1.Since the performance gain was found to be small between the different options from WINNER I for the non-frequency adaptive downlink, there has been a focus on the non-frequency adaptive uplink in the work towards this deliverable. Even though spatial diversity is seen as the primary source for diversity due to the simplification in resource partitioning, the system has to be possible to deploy in scenarios were low spatial diversity is available, e.g. in non-rich scattering environments. In section A4.1, a comparison is made between the different options in the DFT-precoded multi-user uplink. The conclusion is that IFDMA is the best candidate, especially due to its capability to take advantage of a large frequency diversity in the channel without the need for a large pilot overhead, since compared to frequency hopping, interpolation of the channel state in time is made possible. This comparison study did not quantify the sleep mode gains, but such an attempt is performed in section B.2 below.

B.2 Power Saving Sleep Mode in User Terminals

B.2.1 Introduction

A significant part of the power consumption in a user terminal is due to the transceiver chain. Typically, the transceiver can be in (at least) five different modes [HS00]:

- Off mode
- Sleep mode
- Idle mode
- Receive mode
- Transmit mode

Each of these consumes different power levels from the energy source in the user terminal, sorted in increasing order in the list. The transmit mode consumes most energy, but according to the numbers given in [HS00] for a WaveLan modem, the difference in Transmit, Receive and Idle mode is rather small, see Table 1 in [HS00]. On the other hand, the energy savings while entering Sleep mode could be substantial. In [HS00], savings of 16.0 dB for Transmit mode->Sleep mode, 15.85 dB for Receive mode->Sleep mode and 15.8 dB for Idle mode->Sleep mode are reported based on measurements. An important insight from this study is that:

- Sleep mode is almost as important for the downlink as for the uplink as seen from the user terminal

The important parameters that affect the energy consumption in the UT due to the wireless interface are:

- The power consumption in the different modes
- The switching time between the different operational modes

A study on sleep mode aspects for UTs in the WINNER system concept has been carried out in the work towards this deliverable on multiple access schemes. In the chunk based WINNER system concept, we have to make a distinction between intra-chunk sleep mode and inter-chunk sleep mode:

- In intra-chunk sleep mode, the UT is given the possibility to enter sleep mode in a fraction of the chunk duration
- In inter-chunk sleep mode, the UT is given the possibility to enter sleep mode in the full duration of a chunk

B.2.2 Inter-chunk Sleep Mode

Inter-chunk sleep mode support relies on the MAC protocol and the Resource Scheduler being designed in such a way that it enables the UT not to listen to all chunk durations in a superframe. The extent of the possibility for inter-chunk sleep mode depends e.g. on the QoS requirements of the active flows to/from the UT, the acceptable latency for flow setup and other control signalling, and the requirements on network synchronization with the UT. These protocols are expected to be rather independent of the multiple access scheme used within the chunks and thus these protocols have not been in the focus sofar in the work towards this deliverable, which focus on the multiple access solutions. In the continued work, also inter-chunk sleep mode investigations will be carried out as an integral part of the overall MAC design based on the proposed multiple access solutions in this document.

B.2.3 Intra-chunk Sleep Mode

Intra-chunk sleep mode has been the focus sofar, because the analysis gives important input to the design and selection of appropriate multiple access schemes in the different scenarios. The feasibility and expected gains of intra-chunk sleep mode are investigated below.

In the WINNER system concept, resources are allocated based on the chunk concept. For adaptive transmission, an entire chunk is allocated uniquely to one flow. Adaptive transmission will typically be used for large volumes of data transmission to/from the UT in situations with good channel conditions for the UT, and it enables a large increase in the system capacity due to the gains in link adaptation and multi-user diversity gains, which could be very important for high cell load situations. The full chunk allocation in adaptive transmission makes intra-chunk sleep mode impossible, but inter-chunk sleep mode will be possible with a penalty on the maximum UT speed at a given SINR, because the channel quality indicator per chunk (CQI) from the channel predictors will be less reliable in this case.

In non-frequency adaptive transmission on the other hand, we need to allocate the user flow over multiple chunks in the frequency domain and/or multiple spatial chunk layers in order to collect diversity enough for robust links. But, using multiple chunks/chunk layers in the duration of a chunk would in general imply a too large resource for a user flow. Thus, we need to allocate multiple flows per chunk and we have the option to do this in an intra-chunk TDMA fashion, which enables the possibility to enter sleep mode inside a chunk during some of the OFDM symbols in the chunk.

Assume the user is scheduled every possible chunk time (every FDD slot in full duplex and every second slot in half duplex). In order to maintain the same data rate for the user in case of a TDMA component is introduced within the chunk duration, there must be more parallel payload bits transmitted. This means that the instantaneous RF transmit power has to be comparable larger over these OFDM symbols in the TDMA slot within the chunk (unless diversity gains can be obtained by the parallel transmission), but the average RF transmit power averaged over the chunk duration will be the same.

If we assume that this average RF transmit power averaged over the chunk duration (345.6 μs in current FDD numerology) is the measure for dimensioning the system w.r.t. to range of the cell, requirements on the absorption rate in the human body, e.g. Specific Absorption Rate value (SAR), and the transceiver of the UT, there is no penalty in introducing an intra-chunk TDMA component. The basic questions regarding intra-chunk sleep mode then becomes how fast the UT can enter and leave different sleep mode states and the associated power savings in the UT.

B.2.3.1 Feasibility of Intra-chunk Sleep Mode

A problem to assess the feasibility and possible gains of intra-chunk sleep mode is the lack of performance data in the open literature, and manufacturers of handheld devices are not happy to reveal all their secrets in hardware design. In addition, we have to make a forecast of the possibilities a few years from now. A case study based on the hardware characteristics w.r.t. state transition times and power savings of a WaveLan modem reported in [HS00] and input on switching times from one mobile phone manufacturer within the project is carried out below.

The WaveLAN system is based on Direct Sequence Spread Spectrum with 11 chips per symbol and 2 Mb/s symbol rate, which gives 22 MHz of channel bandwidth. Thus, the system bandwidth is comparable to the WINNER 2x20 MHz FDD mode. In [HS00], the following switching times are reported:

- "10 bytes" to enter Sleep mode and "63 bytes" to wake up in Idle mode. With the 2 Mbit/s interface, this means 40 μs and 250 μs respectively for the go-to-sleep and wake-up times.

In the current WINNER FDD design, the chunk size is 345.6 μs consisting of 12 OFDM symbols of duration 28.80 μs. With the above transition times, we would need 250+28.80+40 = 318.80 μs for the sequence wake-up -> send/receive -> go-to-sleep, and there would be 26.8 μs or ***7.8 %*** sleep time of a chunk duration. If we can assume double as fast transition times for a 2x40 MHz capable UT, the UT could be in sleep mode during 171.8 μs or ***50%*** of the slot time.
Thus, already from these conservative assumptions intra-chunk sleep mode is feasible in a fraction of a chunk duration while being allocated to transmit or receive, if the Multiple Access scheme support this. A more up-to-date indication of what is possible is the following input from an RF engineer at a mobile phone company in the project:

- Hibernation mode: switching off/on PA, LNA, and other selected parts of RF (and possibly baseband) is possible to do within ***a few microseconds***. On Tx side the limiting factor is the spurious emissions created by switching off the PA. Thus, the spectrum mask and allowed adjacent channel interference levels define the minimum switching time.
- Sleep mode: i.e. switching off/on also the synthesizer makes the switching off/on time to be in the order of ***a few hundred microseconds***.
- Deep sleep mode: i.e. switch off/on also the clock - then the switching off/on time is on the order of ***a few milliseconds***.

The relative power saving between these different alternatives depend naturally on the relative power consumption of different entities. A fair assumption is that we need pretty linear Power Amplifier in the UT, which means that the power consumption of the Power Amplifier may be dominating the power consumption in the transmit chain. Then, already Hibernation mode would bring significant power savings. On the receiver side, the power consumption is defined by how large fraction of time the receiver chain has to be on.

From the above figures, Hibernation is definitely possible. In fact, it seems possible to go to sleep or wake up from Hibernation in (less than) one OFDM symbol duration (being 28.80 µs long). The possibility for Sleep mode seems to be similar as for the WaveLan example in [HS00], i.e. maybe in the order of 50% of the chunk duration, as discussed above.

B.2.3.2 Expected Gains of Intra-chunk Sleep Mode

The following figures on power consumption of the WaveLan modem in [HS00] for different power saving modes were reported based on measurements:

- Power off: 0 mW
- Sleep mode: 35 mW
- Idle mode: 1325 mW
- Receive mode: 1345 mW
- Transmit mode: 1380 mW

With the switching times discussed above for the 22 MHz WaveLan system, and if there is no need to be awake for other reasons in the chunk, this would give a power difference of (0.078*35+0.922*1380)/1380=0.924=***-0.34 dB*** when the UT is transmitting, and a little less when it is receiving, assuming the UT is allocated only one OFDM symbol per chunk.
But as discussed above, if we can assume double as fast transition times for a 2x40 MHz capable UT, the UT could be in sleep mode during ***50%*** of the slot time, and this would lead to a power difference of (0.5*35+0.5*1380)/1380=0.513=***-2.9 dB*** when transmitting and little less when receiving.

Assuming the same power saving for the Hibernation mode, as defined above, at least in transmit mode ***the power saving potential is even larger***, since the switching can be performed on the order of the duration of an OFDM symbol.

B.2.4 Conclusion

From the analysis above, we conclude that intra-chunk sleep mode is both feasible and that there are large gains in energy savings to be made by the UT, *both while transmitting and while receiving*. The energy saving is of the same kind as for a UT using a low envelope signal; it can be used for longer usage time, cheaper components and smaller form factor of the UT due to smaller heat dissipation in the UT. With the assumptions in the analysis, the power savings averaged over the chunk duration could be several dBs, depending on the UT design and the number of OFDM symbols that the UT can be in sleep mode. This analysis is an important input to the proposal of multiple access schemes for the reference design for the non-frequency adaptive uplink and downlink as described below and included also in deliverable [WIN2D6133].

B.3 Impact of Power Amplifier Backoff

B.3.1 Introduction

We cannot expect to use the low envelope variation property of a serial modulated uplink signal to increase the cell size, because the cell size is determined by the satisfied user criterion [WIN2D6111], which can be translated into an average receiver SINR at the access point, and is upper bounded by the average RF transmit power in the UT. But the maximum transmit power is likely limited not by the power amplifier technology as such, but rather the regulations of absorption rate in the human body or similar measures. The possibility to generate a larger instantaneous RF transmit power could possibly be used for instantaneous larger power on e.g. pilot signals and small packets, as long as the transmit power constraint is fulfilled over the averaging window in time. Thus, it may be used to make network synchronization on various levels more robust.

The investigations on sleep mode in section B.2 shows that there is a large gain for the UT power efficiency if intra-chunk sleep mode is supported, i.e. the UT is given the possibility to enter sleep mode in a fraction of the chunk duration. The power savings in the UT due to low power amplifier backoff requirements and intra-chunk sleep mode are essentially of the same kind, i.e. they can be used for longer battery usage time, lower component costs and less cooling problems, which also enables a smaller form factor of the UT.

This calls for a trade-off between the low-envelope variation characteristics of IFDMA and the larger intra-chunk sleep mode gains in DFT-precoded OFDM symbol based TDMA. In [WIND22] chapter 4.2, investigations were made on multi-band transmission and its penality on power backoff. The investigation was made by investigating the required power amplifier backoff needed to fulfil a spectrum mask using a realistic model of a non-linear amplifier. The conclusion was that there is a rather small penalty in using a multi-bandwidth DFT-precoded signal. Since IFDMA is a serial modulation signal with low envelope variations, summing a few IFDMA signals could potentially lead to a modest penalty in power amplifier backoff requirements.

OFDMA can obtain the same diversity gains as IFDMA, but there is a penalty on power amplifier backoff. The less restrictions on subcarrier allocation is in principle useful as a flexibility in resource allocation among users, but it also implies a larger addressing overhead compared to a structured allocation as IFDMA, where it is enough to signal e.g. the lowest subcarrier and the subcarrier distance to be used for a flow.

B.3.2 Power Backoff Requirements

Minimizing the power backoff required for high power amplifiers (HPAs) is very important in terms of cost and battery recharging intervals, especially for mobile terminals. Backoff from the maximum available HPA power is necessary to avoid nonlinear distortion of the HPA output signal. Even modest amounts of nonlinear distortion can cause the transmitted spectrum to exceed the allowed bounds imposed by a spectral mask; larger amounts of nonlinear distortion will also cause distortion and BER performance degradation of the received signal. Large required backoff lowers amplifier efficiency and increases the maximum output power required from the HPA, thus increasing its cost, and battery drain.

The minimum required power backoff depends on several factors:

- The distribution of the transmitted signals' amplitude; i.e. its dynamic range. A large dynamic range implies larger minimum to maximum amplitude swings and hence larger backoff to minimize distortion. A commonly used, but not necessarily very useful, criterion is "peak to average power ratio" (PAPR).
- The nonlinear input-output characteristic of the HPA. In this study, we use the Rapp model for amplitude to amplitude conversion, which is considered reasonably typical for solid state power amplifiers. The model has one parameter, p, whose value we choose to be 2; this results in an input-output characteristic which has a visible nonlinearity below the saturated output.
- The power spectrum mask to which the HPA output power spectrum must be confined. It is determined by consideration of allowed power leakage into adjacent users' spectral allocations. In this study we use the spectral mask that was derived for WINNER narrowband mobile terminal outputs in [WIN1D2.5], scaled to the used wide area signal bandwidths of 40 MHz and 10 Mhz.

In general, different nonlinearity characteristics and spectral masks will change the absolute values of backoffs for different types of signals, but would not be expected to change the relative values.

Various OFDMA and DFT-precoded OFDMA signals transmitted through a Rapp model nonlinearity with p=2 were simulated, and their resulting average output power spectra were measured. For each signal, the average power was adjusted by trial and error so that the power spectrum barely grazed the spectral mask. Then the difference between that average power and the saturated output power from the nonlinearity was the signal's required power backoff.

B.3.2.1 Wideband Signals (40 MHz Used Bandwidth)

An IFDMA signal can be generated by DFT-precoding, and then distributing the DFT components sequentially at uniform frequency intervals. After an inverse DFT, the resulting time domain signal can easily be shown to be equivalent to a spread spectrum serial-modulated (SM) signal. SM signals are well known to have lower dynamic range, and lower required backoff than corresponding OFDMA signals, which would be formed in exactly the same way, but without the DFT precoding step. The figure below shows an IFDMA signal in the frequency domain. It occupies 32 subcarriers spaced at intervals of 32 subcarriers. For an inter-subcarrier spacing of 39.0625 KHz, its occupied bandwidth is exactly 40 MHz. Each of the used subcarriers can be considered to be a "chunk" whose width is 1 subcarrier.

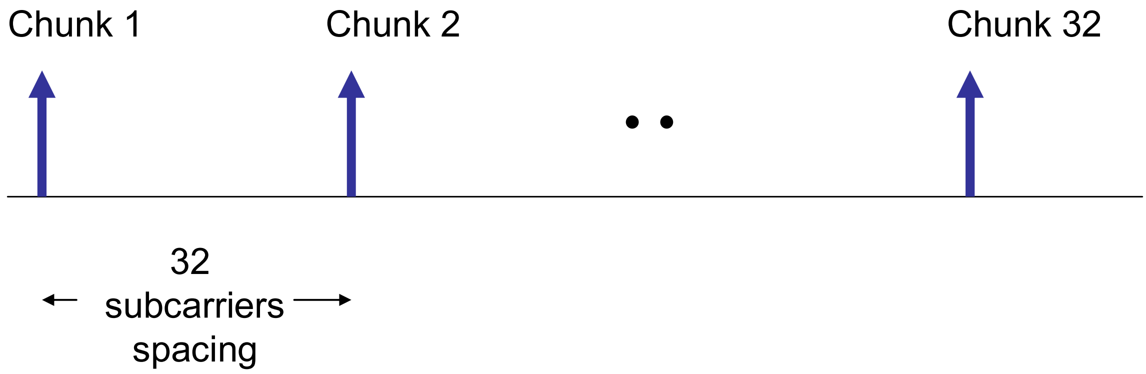


Figure B-2: Frequency domain illustration of an IFDMA signal with 32 subcarriers spaced at 32-subcarrier intervals.

For the wide area scenario, this signal would convey 32 X 12=384 coded symbols during the 12 OFDM symbols constituting a slot (not counting pilots and control symbols). If the terminal is to go into sleep mode for 3/4 of the slot, then to maintain the same data rate while occupying only 3 OFDM symbols, the data rate in each OFDM symbol must be increased by a factor of 4. Such a signal, with the same bandwidth and frequency diversity as the above IFDMA signal, is shown in the frequency domain below.

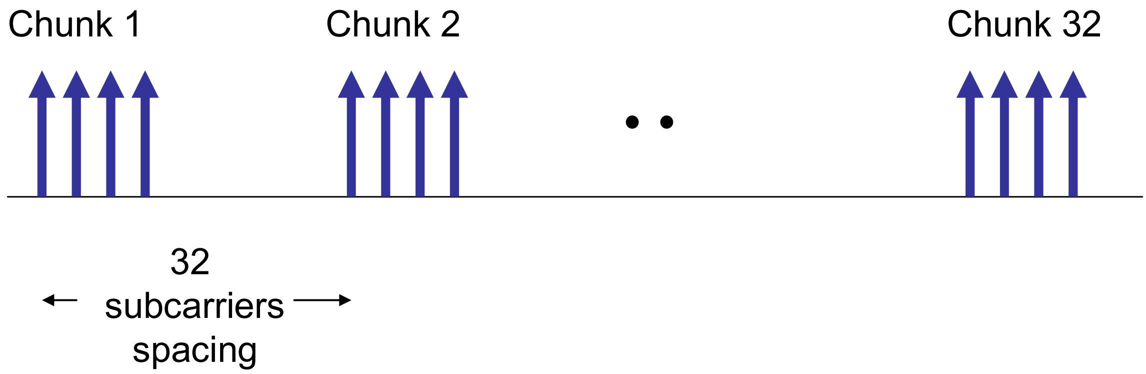


Figure B-3: Frequency domain illustration of a signal with 128 subcarriers and chunk width=4, with chunks spaced at 32-subcarrier intervals.

It is formed by precoding the original coded data symbols with a DFT, and distributing the resulting frequency domain components sequentially to the frequencies shown, and then transforming to the time domain with an inverse DFT. Now each "chunk" consists of 4 adjacent subcarriers. This DFT-precoded OFDMA signal is in general not a pure SM signal, but as will be seen, it has more favourable backoff requirements than a comparable OFDMA signal, which would be formed in the same way, without the DFT precoding step.

The figure below shows the power spectra and spectral mask for the IFDMA signal and the equivalent OFDMA signal, with their respective power backoffs that just satisfy the spectral mask.

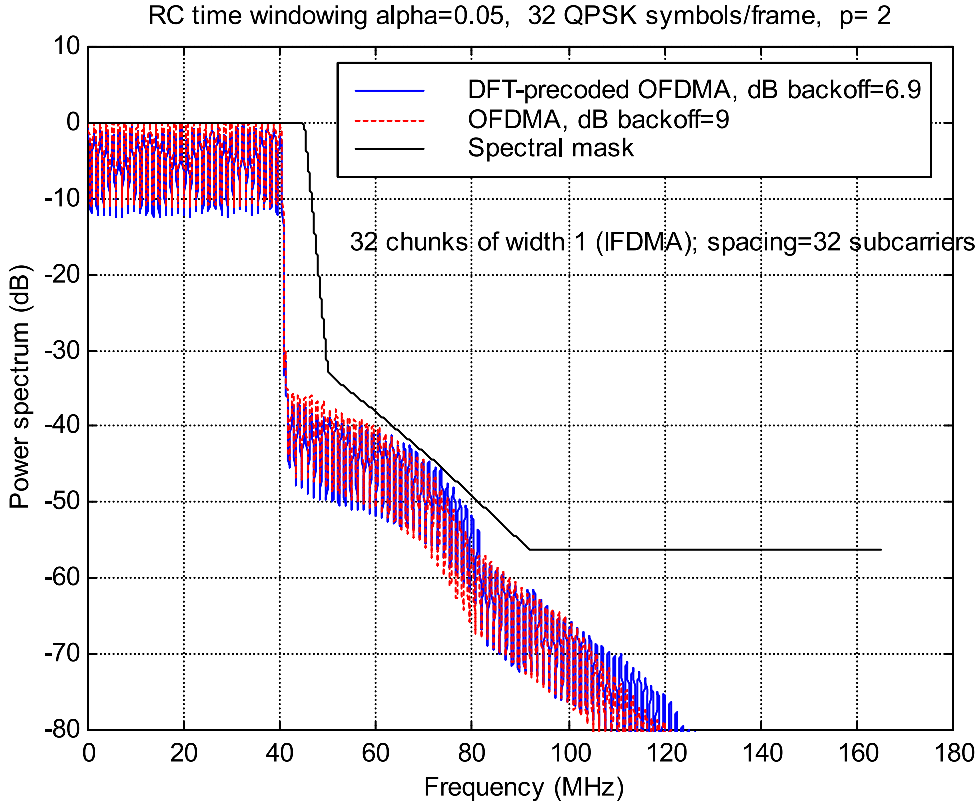


Figure B-4: HPA output power spectra for OFDMA and DFT-precoded OFDMA signals corresponding to IFDMA with 40 MHz nominal bandwidth. HPA has Rapp model nonlinearity with parameter p=2.

Note that the IFDMA signal requires 2.1 dB lower power backoff than the OFDMA signal to satisfy the spectral mask.

The backoff requirements for the chunk size=4 signal are shown in the figure below. The power backoff for the OFDMA signal remains unchanged, the DFT-precoded OFDMA signal's power backoff is increased by about 0.2 dB, but it is still 1.9 dB below that of the OFDMA signal.

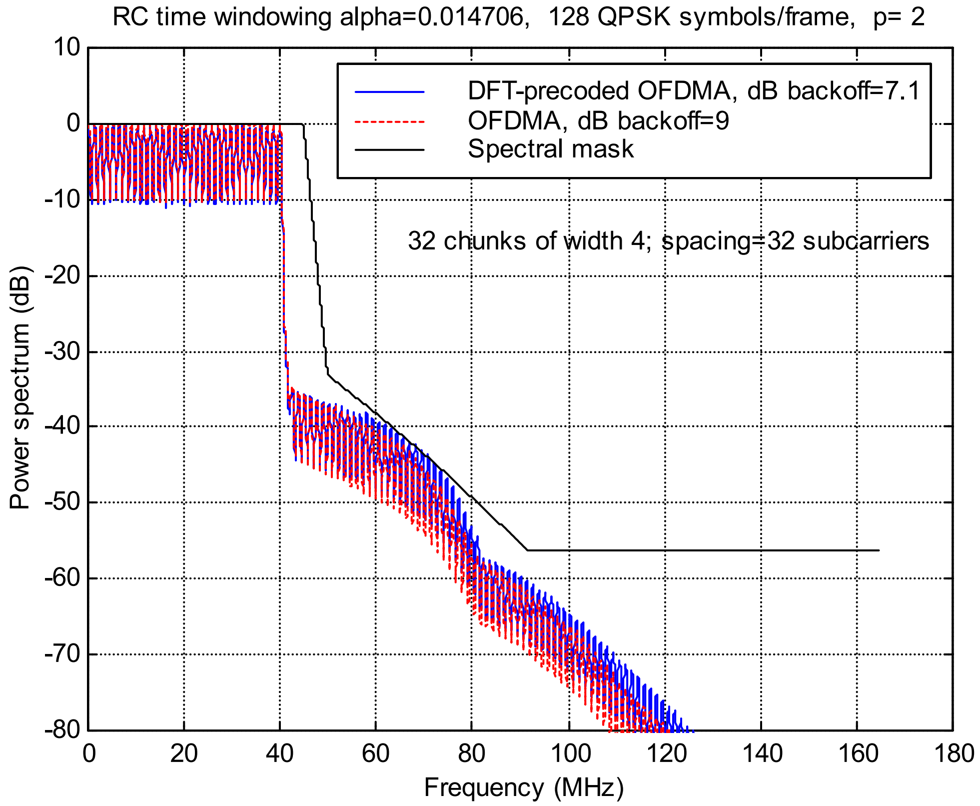


Figure B-5: HPA output power spectra for OFDMA and DFT-precoded OFDMA signals with chunk width=4 and with 40 MHz nominal bandwidth. HPA has Rapp model nonlinearity with parameter p=2.

B.3.2.2 Narrowband Signals (10 MHz Used Bandwidth)

The same tests were applied for signals with only 8 chunks instead of 32, so that the bandwidth is 10 MHz instead of 40 MHz. The figures for chunk widths of 1 (IFDMA) and 4 are shown below. The backoffs are slightly different from the wideband case, but the relative rankings remain the same.

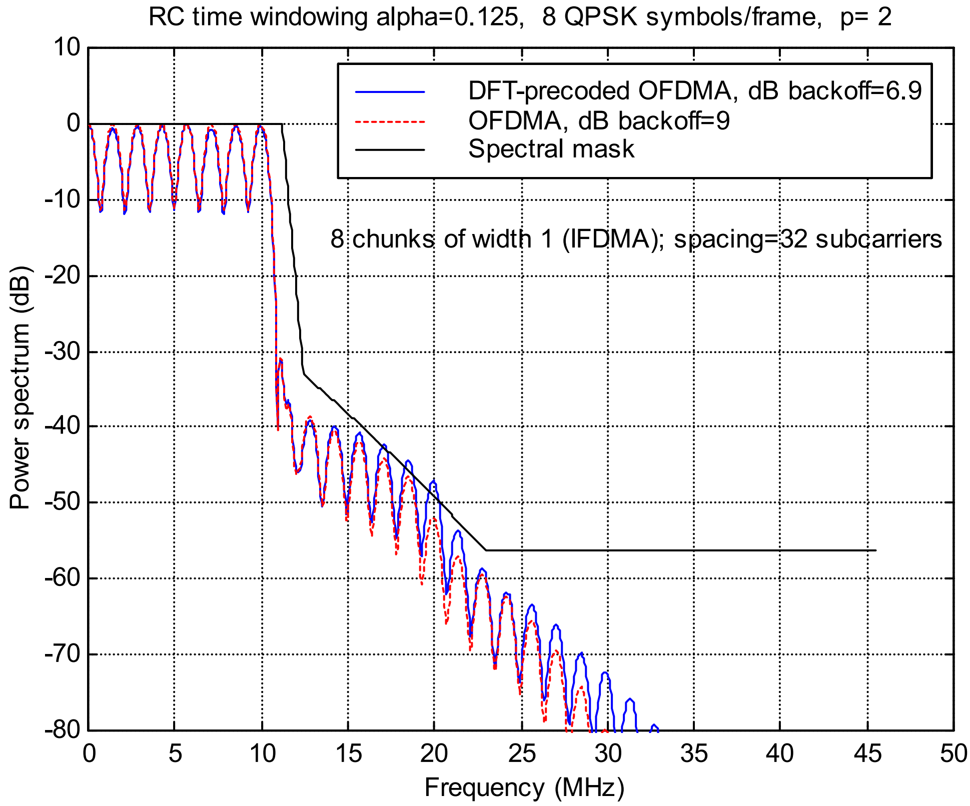


Figure B-6: HPA output power spectra for OFDMA and DFT-precoded OFDMA signals corresponding to IFDMA with 10 MHz nominal bandwidth. HPA has Rapp model nonlinearity with parameter p=2.

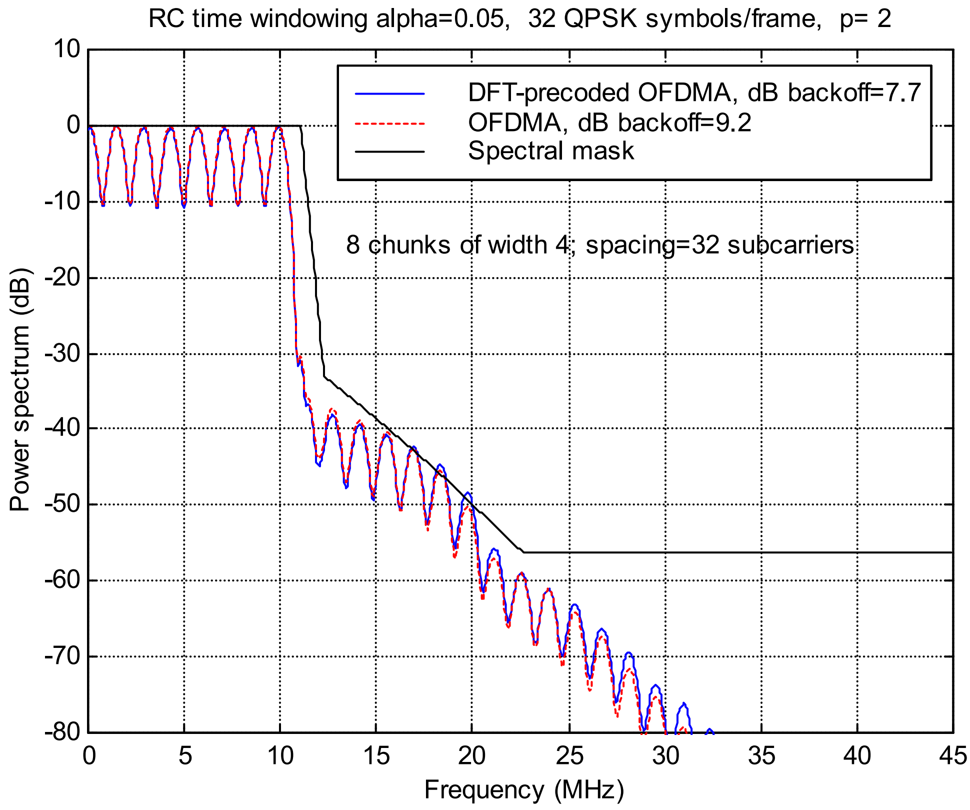


Figure B-7: HPA output power spectra for OFDMA and DFT-precoded OFDMA signals with chunk width=4 and with 10 MHz nominal bandwidth. HPA has Rapp model nonlinearity with parameter p=2.

A possible alternative signal arrangement in the 10 MHz case with only 3 of the 12 OFDM symbols active is 4 separate frequency-interleaved IFDMA signals making up an active OFDM symbol. This is illustrated in the frequency domain below. The used bandwidth and frequency diversity is similar to that of the narrowband DFT-precoded OFDMA case.

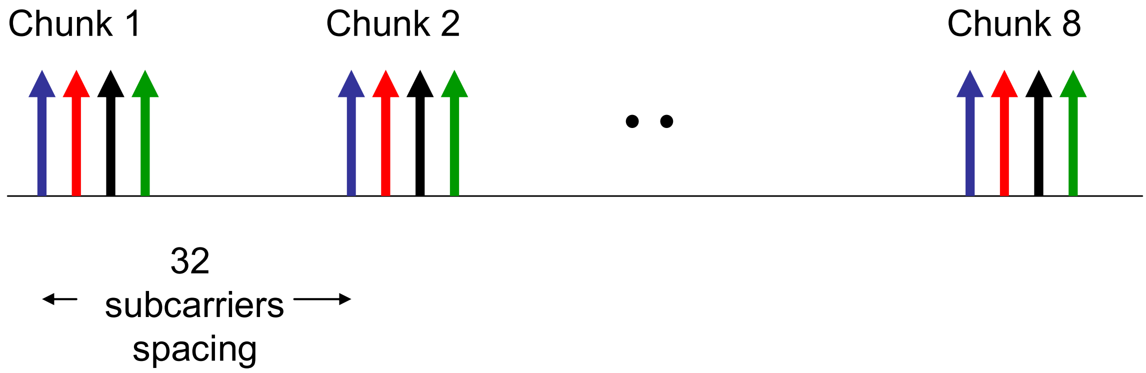


Figure B-8: Frequency domain illustration of a signal with 128 subcarriers, consisting of 4 frequency-interleaved IFDMA signals, each with 8 subcarriers, and with subcarriers at 32-subcarrier intervals.

The spectra for this arrangement and for the equivalent OFDMA signal without DFT precoding and frequency-interleaving, is shown below.

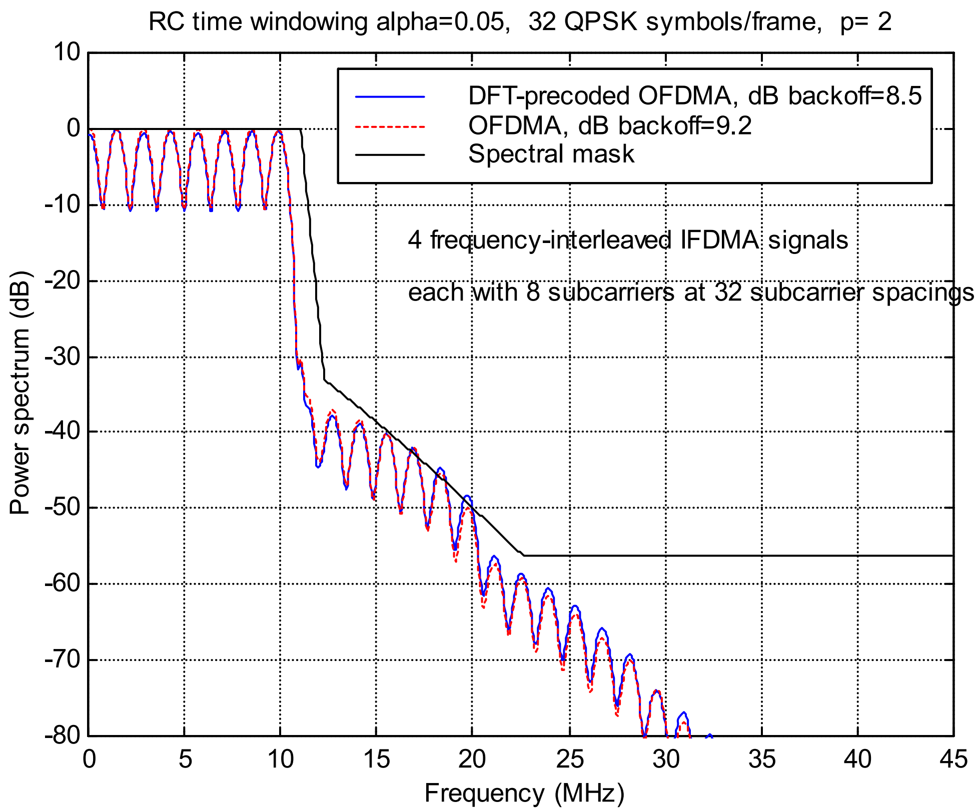


Figure B-9: HPA output power spectra for OFDMA and for 4 frequency-interleaved IFDMA signals with 10 MHz nominal bandwidth. HPA has Rapp model nonlinearity with parameter p=2.

In this case the interleaved IFDMA signal still have lower backoff requirement that the equivalent OFDMA signal, but the difference is much reduced. It is therefore evident that the DFT_precoding scheme is superior to the interleaved IFDMA scheme in terms of power backoff requirements.

B.3.2.3 Summary of Results

The resulting backoff requirements in the investigated scenarios are summarized in the table below.

Table B-1: Summary of backoff requirements

Required power backoff for OFDMA (dB)	IFDMA/DFT-precoded OFDMA schemes	Required power backoff for IFDMA/DFT-precoded OFDMA schemes (dB)	Power backoff difference between OFDMA and DFT-precoded OFDMA (dB)
9.0	IFDMA with 8 subcarriers (10 MHz bandwidth)	6.9	**2.1**
9.2	DFT-precoded OFDMA with 8 chunks of width 4 (10 MHz bandwidth)	7.7	**1.5**
9.0	IFDMA with 32 subcarriers (40 MHz bandwidth)	6.9	**2.1**
9.0	DFT-precoded OFDMA with 32 chunks of width 4 (40 MHz bandwidth)	7.1	**1.9**
9.2	4 frequency-interleaved IFDMA signals with 8 subcarriers each (10 MHz bandwidth)	8.5	**0.7**

To summarize the results:

- Pure IFDMA has slightly lower backoff requirements than DFT- precoded OFDMA with chunk size 4: 0.2 dB compared to IFDMA for the 40 MHz case and 0.6 dB for 10 MHz case.
- Using DFT-precoded OFDMA with chunk size 4 requires 0.8 dB less power backoff than 4 frequency-interleaved IFDMA signals.
- Therefore, DFT-precoded OFDMA is preferable compared to summing 4 frequency-interleaved IFDMA signals.

B.3.3 Conclusion

From the investigations in this chapter, we can conclude that it is possible to design a multi-bandwidth signal based on equidistant contiguous subcarrier blocks with low envelope variations and consequently low power amplifier backoff requirements, by performing one common DFT precoding over the entire sequence of equidistant subcarrier block allocation. It is possible to sum a few IFDMA signals and obtain a lower power amplifier backoff requirement than for a non-DFT precoded signal, as e.g. OFDMA, but a common DFT precoding seems to be the best method.

B.4 Definition of the Multiple Access Schemes for Non-frequency Adaptive Transmission

Below we outline the design of the proposed reference design for the non-frequency adaptive uplink and downlink that is motivated by the above investigations and considerations.

B.4.1 Reference Design for Uplink - Block Interleaved Frequency Division Multiple Access (B-IFDMA)

Assumptions on key requirements on the multiple access scheme for the non-frequency adaptive uplink:

- Large frequency diversity gains are important in certain scenarios where not enough spatial diversity is available (low scattering environment or few antennas in deployment)
- Low envelope fluctuations are useful for cell edge UTs in the uplink
- Intra-chunk sleep mode is both feasible and the gains are larger than for maintaining a strict low envelope signal
- A resource unit per chunk time of similar size as for adaptive transmission is reasonable in order to keep low addressing overhead and efficiently support small packets

Proposed reference design of the multiple access scheme for the non-frequency adaptive uplink is called Block Interleaved Frequency Division Multiple Access (B-IFDMA), and it is outlined below. It aims to maximize frequency diversity, to enable micro-sleep within chunks and to simultaneously enable low envelope variations of transmitted uplink signals.

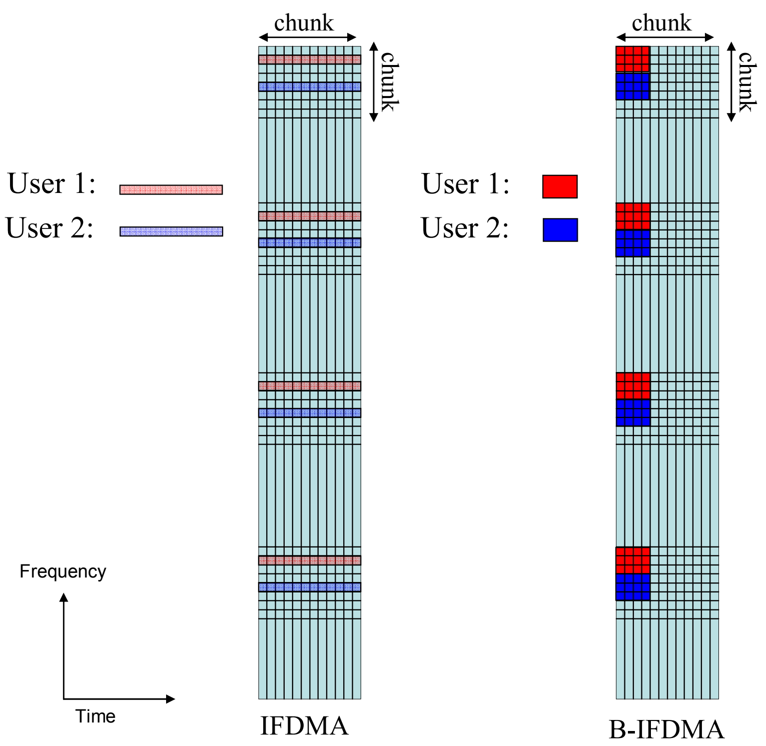


Figure B-10: Example of B-IFDMA based on current FDD chunk size. Note that the appropriate block size is to be determined.

In Figure B-10, B-IFDMA is illustrated in comparison with IFDMA. In B-IFDMA, equidistant blocks of subcarriers in contiguous OFDM symbols are allocated in a chunk duration (slot in FDD). DFT-precoding is performed to make the envelope variation of the transmitted signal low. The same amount of data carrying OFDM subcarrier symbols are allocated in B-IFDMA as in IFDMA to a flow in a chunk duration (equals a frame slot in the current FDD assumptions). By allocating a block of adjacent subcarriers within a chunk, the pilot overhead should be the same as for IFDMA since the chunk is essentially frequency flat. The block based subcarrier allocation also offers the same frequency diversity as IFDMA and a smaller sensitivity to frequency offsets among the uplink UTs compared to IFDMA. The equidistant block allocation in B-IFDMA gives the same advantage and drawback as in IFDMA; it limits the flexibility for the resource allocation, but it enables a smaller resource addressing overhead. B-IFDMA can be used in FDD as well as in TDD, and is proposed for all the deployment scenarios wide area, metropolitan area and local area.

Using the current FDD numerology as an example, in IFDMA a subcarrier in equidistant chunks of all 12 OFDM symbols of a chunk duration are used. The assumption in the IFDMA simulations in Appendix A is to use one subcarrier every 4th chunk in the frequency domain to enable use of uncorrelated frequency resources. In B-IFDMA, a few adjacent subcarriers are used and only a fraction of the OFDM symbols in a chunk. This enables the UT to enter sleep mode in a fraction of the chunk duration.

The appropriate size of the blocks is to be investigated further. The assumption in Figure B-10 is to use a block size of 3 subcarriers times 4 OFDM symbols. Using an even number of OFDM symbols enables use of Alamouti space-time coding and using equidistant blocks each of 3 subcarriers give a power amplifier backoff penalty smaller than 1dB, see section B.3.2, and at the same time enables the UT to be in sleep mode for more than half of the chunk duration. Note that an update of the chunk size in FDD would be needed if the block size 3 subcarriers times 4 OFDM symbols is adopted. Another option would be to use 4 subcarriers times 3 OFDM symbols. This case was investigated in the evaluations of required power amplifier backoff penality, and the degradation was shown to be rather small. If Alamouti is to be used in this case, it has to be done in the frequency-space domain instead of the time-space domain. An open question here is the impact of the DFT precoding step in B-IFDMA, which has not yet been investigated.

This power amplifier backoff penalty is more than compensated for by the enabled intra-chunk sleep mode opportunity, which could enable power savings of several dBs, as discussed in section B.2.3. On the other hand, with the current FDD chunk size a block size of 4 subcarriers and 3 OFDM symbols would fit better, but the appropriate block size should be considered in the overall numerology of the FDD frame definition, which should take into account also the space needed for control signals in the chunks.

Note that B-IFDMA does not define the resource unit per chunk duration (FDD slot) based on the chunk size, but rather as a function of the block size, repetition distance and bandwidth allocated for non-frequency adaptive transmission. The chunk concept is however still useful; it defines the common resource unit for resource allocation between adaptive and non-frequency adaptive transmission and resource partitioning between access points in case effective frequency reuse distance larger than one is used. Furthermore, it is a common entity for channel estimation due to its property of being essentially flat in time and frequency.

B-IFDMA can be seen as a sum of a few IFDMA signals with a TDMA component within the chunk duration. However, as shown in section B.3.2, summing a few IFDMA signals is not the best method to generate the B-IFDMA signal. These nvestigations indicate that it may be favourable w.r.t. signal envelope variations to perform one DFT over all assigned equidistant blocks.

Since more than one OFDM symbols is still used per chunk, B-IFDMA also enables some degrees of frequency hopping within an FEC block to mitigate narrowband interference, but that would need extra pilots for channel estimation as discussed in section A4.1 in the context of frequency-hopping in localized FDMA/TDMA, and would lead to a lower throughput.

B.4.2 Reference Design for Downlink - Block Equidistant Frequency Division Multiple Access (B-EFDMA)

The multiple access scheme proposed as reference design for the non-frequency adaptive downlink is mainly derived from the insights in the uplink. Recall that the studies in WINNER I [WIND210] did not show significant differences in the performance among the different flow multiplexing strategies within the chunks. We argued above that intra-chunk sleep mode is almost as beneficial for the UT in receive mode as in transmit mode. The following requirements were identified as important on the appropriate multiples access scheme for the non-frequency adaptive downlink:

- Intra-chunk sleep mode is almost as beneficial for receive mode as for transmission mode
- A structured allocation pattern is beneficial for keeping low control information overhead

- Similar allocation structure in downlink as in uplink is beneficial for low system complexity and HW implementation

In the downlink the access point has to transmit a sum of adaptive and non-frequency adaptive flows over the entire system bandwidth, where some users are close to the access point and can use high order modulation. Thus, there seems to be no advantage to use a DFT-precoding per flow of the non-frequency adaptive downlink flows (a common DFT-precoding would destroy the frequency adaptation and cannot be used).
Thus, the DFT-precoding assumed in B-IFDMA is of no use in the downlink and to highlight this difference, the multiple access scheme for the non-frequency adaptive downlink is called Block Equidistant Frequency Division Multiple Access (B-EFDMA) and it is the same as for the uplink except the missing DFT-precoding. B-EFDMA can be used in FDD as well as in TDD, and is proposed for all the deployment scenarios wide area, metropolitan area and local area.
This similarity between the B-IFDMA and B-EFDMA schemes simplifies and unifies the multiple access schemes for uplinks and downlinks. The addressing and control signalling for the non-frequency adaptive transmission is thereby simplified considerably. Downlink control signalling, that controls the downlink as well as uplink transmission will be organized as an allocation table that is placed within the first OFDM symbol of the downlink slot of the frame. This choice is made to minimize delays in the control feedback loop and maximize the possibility for using terminal micro-sleep/hibernation during the remainder of the frame.

B.4.3 Scalability of the B-IFDMA and B-EFDMA Schemes

In B-IFDMA and B-EFDMA, higher flow data rates can be assigned for the non-frequency adaptive users in three different ways, not considering the possibility of spatial multiplexing, as outlined below in Figure B-11. Lower rate users can of course be accommodated by being scheduled in less slots.

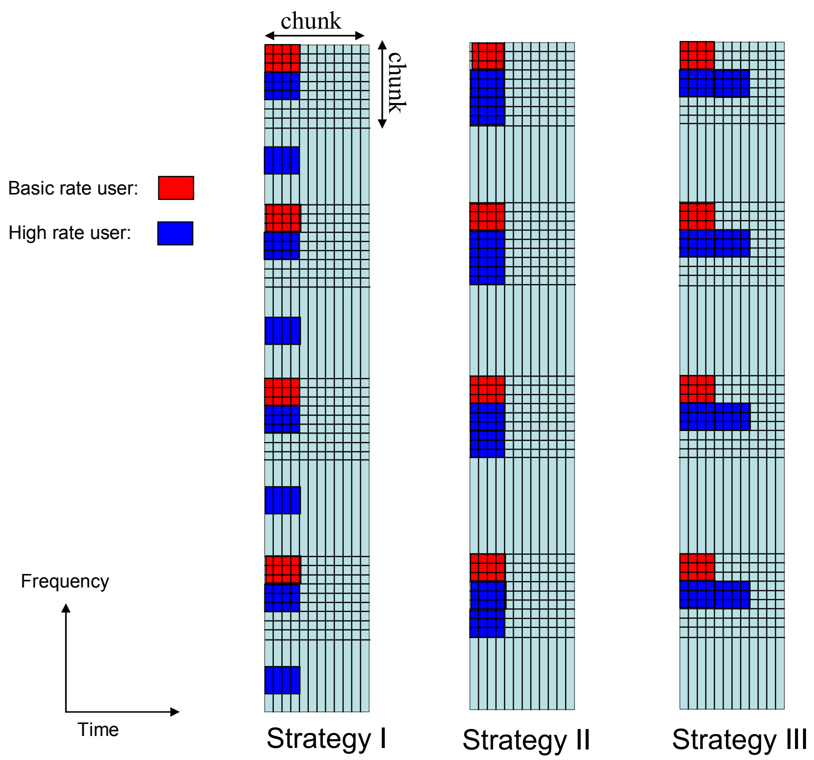


Figure B-11: Illustration of flexible resource allocation in B-IFDMA and B-EFDMA. Note that the appropriate block size is to be determined.

Allocation strategies:

- I: Assign subcarrier blocks with smaller spacing if they are not already occupied. But a too small block separation would give less frequency diversity. This strategy could however still be feasible to accommodate large enough rates in a low-bandwidth deployment scenario with rich spatial diversity. The assumption in the IFDMA simulations in Appendix A is to use 32 subcarrier spacing which means to use one subcarrier in every 4th chunk and the subcarrier distance with the current FDD numerology would be about 1.25 MHz, which is larger than the coherence bandwidth in the wide area scenario. With 2x40 MHz allocated to non-frequency adaptive flows, 32 blocks can be allocated to a flow in each chunk duration with 32 subcarrier spacing between the block centers. It seems that roughly 2x10 MHz bandwidth is needed to be allocated to non-frequency adaptive flows in order to get a diversity order of 10 from the frequency domain. Further results on scalability of results are under preparation for the IFDMA uplink investigations.
- II: Assign more subcarrier blocks in the frequency direction within the chunk. That would give less frequency diversity than in strategy I and larger envelope variations which leads to larger backoff penalty unless the power amplifier is of high quality class, but it preserves large intra-chunk sleep mode possibility. This could be the preferred option for high-end UTs like laptops, and could also be an option for UTs being close to the access point were higher order modulation is used, which already increases the power backoff requirement. The backoff penalty with serial higher order modulation is currently under investigation.
- III: Assign more subcarrier blocks in the time direction within the chunk. That would give less frequency diversity than in strategy I, but the low envelope characteristics of the signal is maintained, at the cost of less possibility for intra-chunk sleep mode. This could be useful for low-end UTs that cannot take advantage of the intra-chunk sleep mode possibility due to more simple control electronics.

Option III above could also be used for the basic rate assignment in situations where severe narrowband interference is a problem in a cell. The resource scheduler could allocate resources according to option III, i.e. an aggregate of two or three B-IFDMA/B-EFDMA resources in the chunk time direction, but with correspondingly larger repetition distance between the blocks. This enables more frequency hopping per chunk at the cost of intra-chunk sleep mode and larger pilot overhead for channel estimation. However, other interference mitigation methods might be more preferable such as incremental redundancy in a Hybrid ARQ scheme, especially for less delay critical flows.

It is expected that the in-chunk control information will be located in the first OFDM symbol of the chunk, so to maximize the in-chunk sleep mode possibility, UTs requesting for intra-chunk sleep mode possibility should be allocated B-IFDMA/B-EFDMA resources early in the uplink/downlink frames. The allocation policy in the BS could be slowly updated in the superframe preamble and UT specific preferences could be negotiated during UT-BS association procedure and refined during flow setup.

Note that the structured resource allocation in B-IFDMA and B-EFDMA is very beneficial for maintaining a low addressing overhead, compared to e.g. OFDMA. It is enough to signal e.g. the lowest subcarrier and the subcarrier distance to be used for a flow. In fact, the subcarrier distance could be predefined to certain given values as different rates on a superframe time scale (e.g the Basic rate in Figure B-11 above), and only an index is needed to signal during flow setup. On the other hand, other highly adaptable allocation strategies could also be supported, but that can make handover more difficult and also make resource allocation for macro-diversity from cooperating access points in the downlink in e.g. multicasting more difficult.

B.5 Conclusions

The reference multiple access schemes for non-frequency adaptive transmission in uplinks and downlinks are denoted B-IFDMA and B-EFDMA, respectively. They are closely related to each other and have been presented and motivated in this Appendix. Their feasibility and performance gains w.r.t user terminal efficiency were assessed. Due to their similarity with IFDMA and chunk-based MC-CDMA, their expected spectral efficiency can be derived from the IFDMA and the chunk based MC-CDMA simulations in Appendix A and [WIND210].

Appendix C. Supporting MAC schemes

C.1 Frame Descriptor Table Concept

C.1.1 Introduction

The WINNER air interface requires the implementation of a new and more efficient MAC protocol which is capable of multi-hop and supports QoS. The reservation of the resource “radio channel” prior to the initiation of transmission is a prerequisite for the support of QoS. It can be done in different ways. Two promising approaches are the reservation of the medium on a per-frame basis as applied in many QoS supporting MAC protocols e.g. 802.11e [80211IEEE04],[MCHKW03], 802.16a [80216aIEEE03], HiperLAN/2 [H2ETSI99] and the establishment of TDMA channels as utilized in W-CHAMB [Xu02]. The Frame Descriptor Table (FDT) concept [KEF05], [KEFW06a] effectively combines the merits of both approaches by enabling the establishment of fixed TDMA channels in a frame based protocol and moreover improves the multi-hop performance by reducing the control information signalling. An analytical and simulative performance evaluation has been made in order to predict the behaviour of a system realizing resource reservation by using the FDT concept. This appendix presents a generic description of the FDT concept, which can be applied in the WINNER MAC. A numerical evaluation of the FDT scheme is made based on the HiperLAN/2 MAC awaiting finalization of the WINNER MAC design. The main characteristics potentially influencing the concept will also be part of the WINNER and most future MAC protocols with a frame structure as basis of the resource allocation. There seem to be various possibilities to apply the concept of FDTs in the WINNER context (see section C.1.7). The relevance has to be analysed from case to case but at least the establishment of TDMA channels for relaying and the reduction of overhead introduced by the resource partitioning information and the allocation table content seem to be a promising way to improve the WINNER system performance.

The remainder of this chapter is organized as follows: section C.1.2 presents the most important characteristics of the MAC protocol the evaluations are based on. With the help of this MAC protocol the general concept of FDT is explained. Section C.1.3 describes the potentials of applying the FDT concept in a multi-hop scenario. The scenario used for assessment of the concept is presented in section C.1.4 before the analytical assessment is presented in section C.1.5 and the simulation results are discussed in section C.1.6. The applicability of the concept in the WINNER context is analyzed in section C.1.7 before a summary of the results and findings concludes the chapter with section C.1.8. The results presented in this chapter have been published on behalf of the WINNER project in [KEFW06b],[KEFW06c],[KEFW06d],[KEFW06e].

C.1.2 General Description

The FDT concept and different kinds of its application are presented in a detailed fashion in [KEF05]. Here we only briefly describe the protocol which is used to apply the FDT concept for the assessment presented in the latter sections. Additionally we shortly wrap up the FDT concept in a general way.

C.1.2.1 MAC Protocol

To derive the FDT concept we assume a MAC protocol performing the resource allocation on a per frame basis. The available radio resources, i.e. the medium to be used for communication, are supposed to be fixed in the frequency domain and therefore only allocable in the time domain from frame to frame (Time Division Multiple Access (TDMA)) [Wal02]. The adaptation of the concept to a system based on a combination of TDMA with Frequency Division Multiple Access (FDMA) [Wal02] or even Code Division Multiple Access (CDMA) [Wal02] is straightforward. The medium access is controlled by a master terminal. The logical relation of a data exchange between master and slave and vice versa is called a connection. There can be more than one connection established between the master and one slave. A frame is composed of a broadcast phase, a downlink (DL) phase, an uplink (UL) phase, and a phase for random access (see Figure C-1). During the broadcast phase the controlling master terminal sends out at least a Broadcast Channel (BCH) and a table of contents inside the Frame Channel (FCH). Inside the BCH information about the controlling terminal, the length of the FCH, and other information irrelevant in this scope are transferred. The FCH consists of Information Elements (IE) each describing one connection of the following UL and DL phases. The IEs specify for each connection among other things the transmission direction (DL/UL), the starting point of transmission in the frame, the transmission duration and the sender as well as the receiver. During the DL and UL phases user data and additional control information are sent from the master terminal to the slave terminals and vice versa.

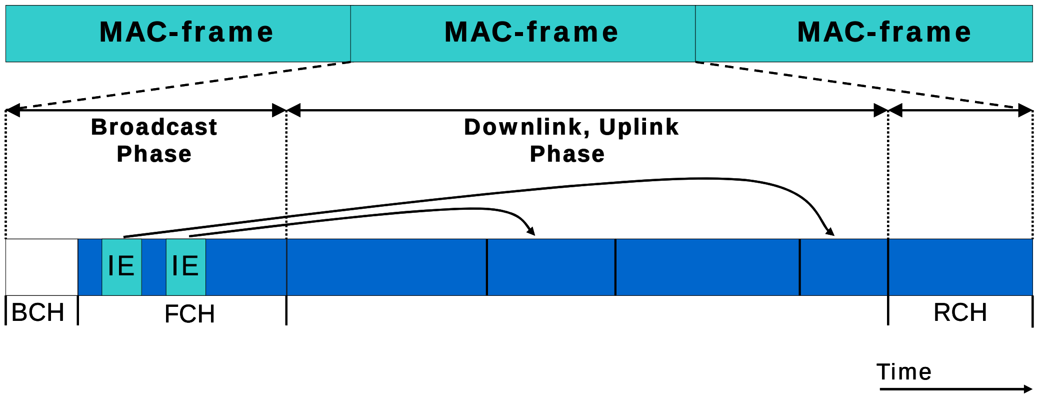


Figure C-1: Basic MAC Frame structure

A specific part of the UL phase is reserved for contention based random access in the Random Channel (RCH). The slotted RCH is primarily used for association of the slave terminals to the master terminal. The number of slots available is announced by the master inside the BCH. As mentioned before the concept of FDTs is able to work on different frame layouts and similar protocol behaviours as well. This is just an exemplary design of a MAC protocol which can benefit from the FDT concept presented in the following section.

C.1.2.2 Frame Descriptor Table

There are several ways to employ the concept of FDTs (see [KEF05]). Based on the MAC protocol presented in the section before, in the following the general concept is outlined.
First of all we introduce the Frame Descriptor (FD). It contains IEs which describe the frame layout, i.e. the contents of the UL and DL phase. It differs from an FCH in that it is not transmitted every frame, but only in certain intervals. Additionally each FD transmitted has a unique ID. Each slave terminal maintains an FDT where all announced FDs are stored indexed by their ID. With the help of the ID an FD can be referred to by the master in one of the following frames. The slaves can look up the content of the FD by consulting their FDT with the help of the ID. If there is a certain periodicity in the communication needs of a particular service (e.g. VoIP) the master terminal can easily adapt to these needs by referring to two or more FDs in an alternating fashion.
One advantage of this concept is the resulting decrease in overhead. The description of the frame layout is coded and can be simply communicated to the slaves by transmitting a number. In the following we assume the ID of the FD used during a certain frame is included in its BCH. To ease the understanding of the FDT concept we give two specific examples of its application:

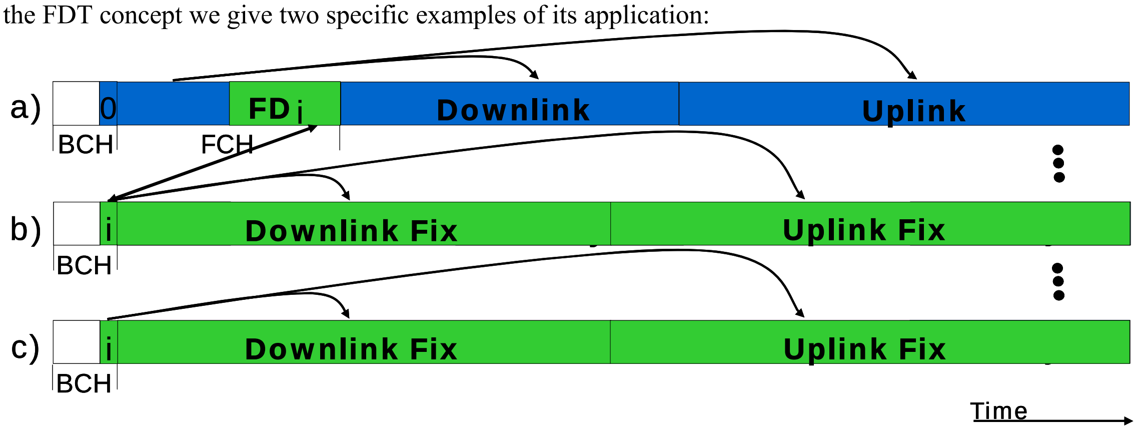


Figure C-2: FD describing a Static Frame

The plainest case of the use of an FD is the description of a static frame completely with the help of an FD. In that case the FCH is substituted by specifying the identifier of an FD. The referenced FD has to be communicated to the slave terminals beforehand. This possibility of applying the FDT concept and the way to announce the FD to the slave terminals is illustrated in Figure C-2.
Inside the BCH a field is reserved for announcing the ID of the FD which describes the current frame. If the value in this field is 0 (see Figure C-2a)), no FD but an FCH describing the current frame is expected. For the purpose of introducing a new FD_i the master terminal sets the identifier in the BCH to 0. The following FCH then contains the description of the current frame, as well as the new FD with ID equal i

(see Figure C-2a) which is to be stored in the FDT in each slave terminal. Each time the master wants to reuse this FD it announces the ID (i) in the BCH as illustrated in Figure C-2b and Figure C-2c.

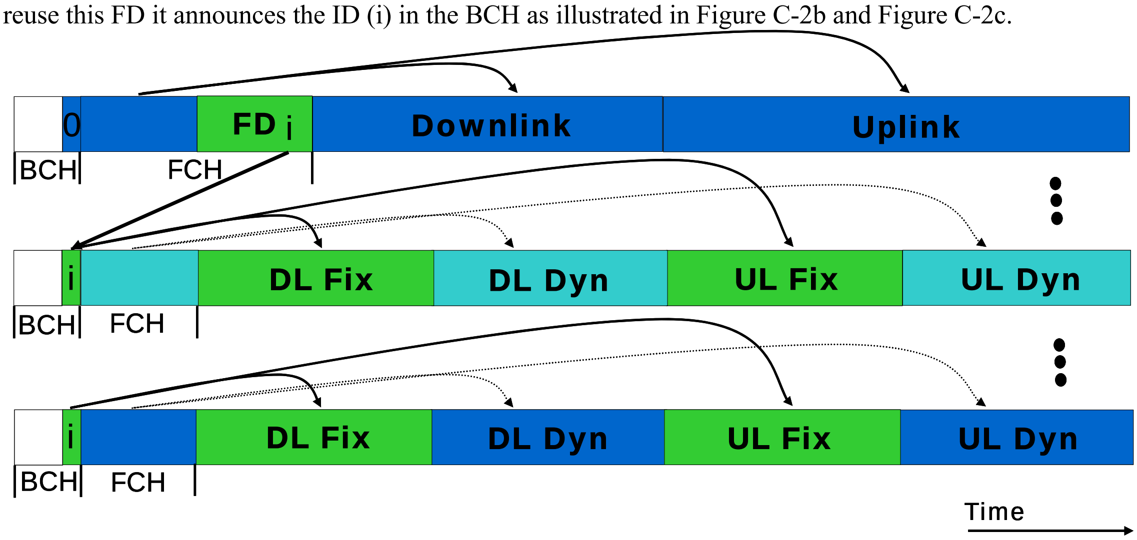


Figure C-3: Description of Fixed and Dynamic Portions

In some cases a connection only needs few resources infrequently. Reservation of resources for a prolonged period of time would therefore be very inefficient. To easily accommodate such needs without having to change the layout of the frame and having to transmit a new FD, a dynamic portion is included in the frame. As shown in Figure C-3b, the FD describes the fixed portions of the UL and DL. This information only has to be transmitted once (cp. Figure C-3a). In the subsequent frames this description is referred to by the ID of the FD given in the BCH. In addition to these fixed portions, there are dynamic portions of UL and DL which are described within the FCH. As can be seen from Figure C-3b and Figure C-3c the content of the dynamic parts of the frame are changing while the fixed parts correspond to the description of the FD_i.

C.1.3 FDT in Multi-hop

As explained in the section before the concept of FDTs allows for a reduction of overhead by decreasing the amount of signalling. When examining multi-hop solutions for frame based MAC protocols [EWP04], [SPI03] it becomes obvious that this reduction will get even more important. A drawback of the multi-hop MAC protocol is the fact that control signalling is needed for each hop. This results in an increasing overhead with an increasing number of hops. With the help of the FDTs this overhead can be kept small. Considering a multi-hop solution which establishes fixed or even partly fixed connections for the relaying of data, implementing the concept of FDT in such MAC protocols is even more interesting.
In a typical multi-hop scenario there is a master serving several slaves. At least one of the slaves, the relay, on his part acts as a master for several remote slaves. The traffic used by the remote slaves can be multiplexed onto one single connection from the relay to the master and vice versa. This connection has a more or less fixed resource requirement. Instead of describing this long standing and slowly changing connection every frame, it can be described using an FD. This provides an easy means to ensure a minimum bandwidth allotted to the relay as well as saving overhead and thus enabling the allocation of more resources to the slaves attached to the master directly. There is an additional advantage of the fixed allocation of resources on the UL connection. Usually a station has to send a resource request which has to be processed by the master. At the earliest in the next frame resources can be allocated. This step can be omitted using this method of establishing a fixed TDMA channel.

C.1.4 Scenario

In this section we present the scenarios on which the assessments of the FDT concept are based. Two scenarios, one for single hop and one for multi-hop are employed.

C.1.4.1 Single Hop Scenario

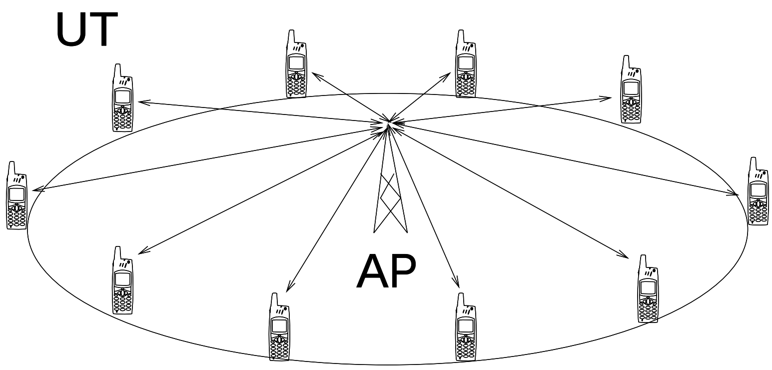


Figure C-4: Single hop scenario

The scenario used for single-hop analysis is shown in Figure C-4. It consists of one Access Point (AP) representing the master serving 10 User Terminals (UT) representing the slaves. Each of these UT has one UL and one DL connection. All connections have the same load. The BS controls a MAC frame with a length of 2ms.

C.1.4.2 Multi-Hop Scenario

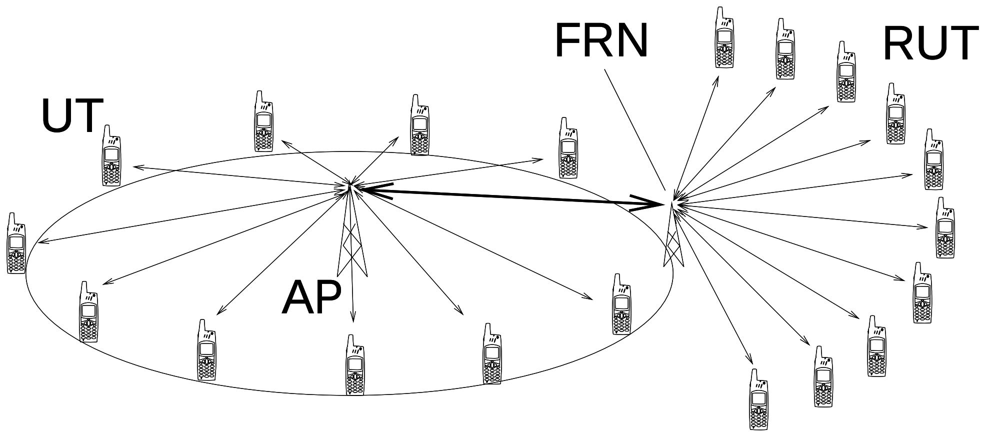


Figure C-5: Frame-by-frame multi-hop scenario

The multi-hop scenario used for the analysis of the concept is shown in Figure C-5. It consists of a BS representing the master, UTs representing the slaves and one Fixed Relay Node (FRN). The FRN acts as a slave from the BS point of view and as a master from the associated Remote User Terminals (RUT) point of view. There are 10 UTs attached directly to the AP. Attached to the FRN are another 10 RUTs, with the same load as the ones in the BS cell. On the first hop between BS and FRN all data targeted from the BS to the RUTs and vice versa are multiplexed onto a single bidirectional connection. The FRN processes its MAC frame alternately with the BS MAC frame. Each frame has a length of 2ms. I.e. the frame interval for BS and FRN is 4ms each.

C.1.5 Analysis of Potential Savings in Signalling Overhead

In this section the signalling overhead and the savings of the FDT concept are calculated. The analysis is realized on the basis of the data structures and parameters as specified in [H2ETSI99], [H2ETSI01]. The calculations presented in this section are based on the analysis presented in [Ess04] and [Het01].
First the overhead necessary in a single hop scenario is calculated. The signalling necessary for two hop operations using the frame-in-frame technique presented in [Ess04] is calculated afterwards. This technique differs from the one described in section C.1.4.2 and is briefly explained in section C.1.5.2. For both scenarios the amount of signalling of the conventional method is compared to the amount of signalling using the FDT technique.

C.1.5.1 Analysis of Overhead in a Single Hop Scenario

For the organization of the data transmission in a single hop scenario the following capacity must be reserved (according to [Het01]and [Ess04]):

$$L_{Orga} = L_{BCH} + L_{FCH} + L_{ACH} + L_{RCH} + L_{DL} + L_{UL} + L_{TTA} \quad (1)$$

L_{Orga} is given in Orthogonal Frequency Division Multiplexing (OFDM) symbols. The different components L_{Orga} contains are the OFDM symbols needed for the organization of the associated control channels. The Access feedback Channel (ACH) is transmitted by the BS/FRN at the end of the broadcast phase to inform the UT/RUT about the success of receptions during the RCH of the previous MAC frame. For more details see [H2ETSI99]. L_{TTA} equals the time necessary for the transceiver to switch from transmission to reception and vice versa given in OFDM symbols accordingly.

Since a MAC frame according to [H2ETSI01] has a total of 500 OFDM symbols, the number of free symbols available for payload within a frame can be calculated as:

$$L_{Payload} = 500 - L_{Orga} \quad (2)$$

In Figure C-6 the number of free symbols is plotted versus the number of stations in the radio coverage of a BS for two different scheduling approaches.

The following assumptions are made in the calculation: The number of active bidirectional connections per UT and frame is $n_{bi\text{-}con} = 1$. That means the minimum number of active connections per frame is one UL and one DL. For this calculation Automatic Repeat Request (ARQ) acknowledges are not considered. The number of RCH slots is $n_{RCH\text{-}Slots} = 1$.

Using exhaustive round robin (EXRR) it is assumed that each terminal has enough data in its queue to fill a whole frame. This means that each frame contains one bidirectional connection (so in fact one UL and one DL connection), no matter how many stations are in the cell. This results in an amount of overhead (~7% of the frame) that can be regarded as the lower limit. As can be seen from Figure C-6 the overhead is independent of the number of stations in a cell.

Round robin scheduling serves all connections equally and integrates the same fraction of each into the frame. With a growing number of stations in a cell, consequently the number of connections scheduled in one frame increases. This results in an increase in overhead. Applying round robin for 10 stations almost 30% of the frame is occupied by overhead. This overhead consists of signalling overhead resulting from IEs transmitted in the FCH as well as PHY overhead resulting from preambles preceding every DL respectively UL transmission.

The results of round robin with FDT show that the overhead can be reduced significantly. Serving 10 stations the reduction of overhead is greater than 10% of the whole frame. The FDT technique eliminates the signalling that has to take place in the FCH. The PHY overhead induced by the preambles depends on the number of transmissions scheduled in a frame. This explains the slow but steady fall of the result.

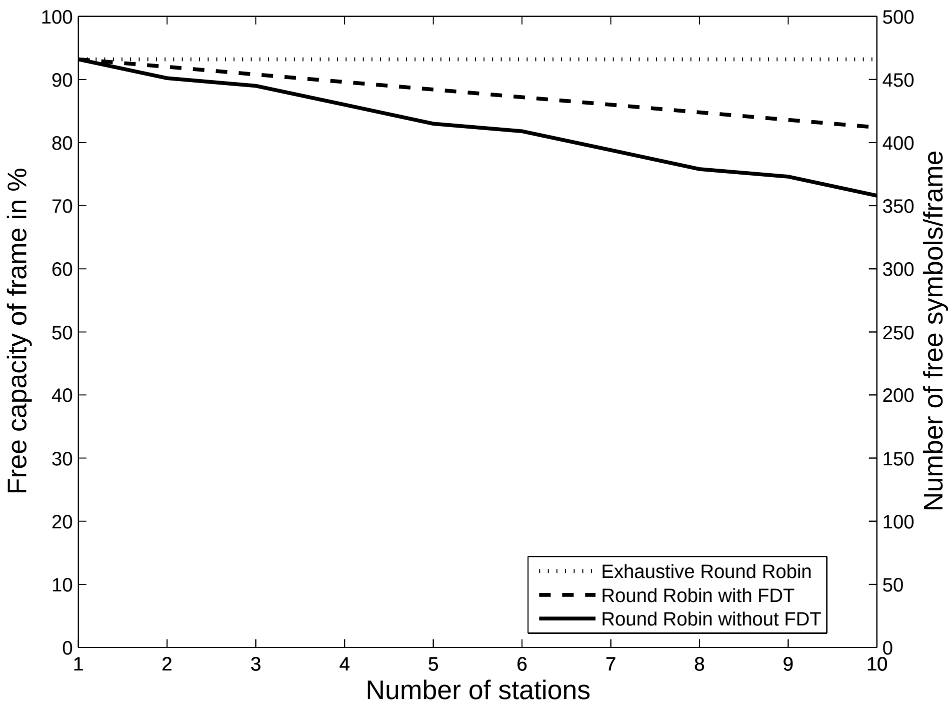


Figure C-6: Comparison of free symbols in a MAC frame

C.1.5.2 Analysis of Overhead in a Frame-in-Frame Multi-hop Scenario

The Frame-in-Frame multi-hop concept proposed in [Ess04] is another example of the possible savings using FDT. In short this concept proposes inserting a complete forwarding frame with broadcast, uplink and downlink phase into the regular BS controlled MAC frame. This inner frame could be used for communication of the BS with a FRN which in turn passes information to RUTs associated with the FRN. A BS can reach n_{UT} UTs and n_{FRN} FRNs on the first hop. The FRNs serve n_{RUT} RUTs each on the second hop. Thus, the total number of connections to RUTs results in:

$$n_{RUT-ges} = n_{RUT} \cdot n_{FRN} \quad (3)$$

Each UT or RUT has $n_{bi\text{-}con}$ bidirectional connections, for which resources are scheduled in each frame if requested. FRNs are only used as relays. If they have connections on their own, they have to be accounted for as separate UTs.

Assuming all connections are scheduled within one frame (EXRR) the number of symbols necessary for handling the signalling of the system with relaying concept can be calculated:

$$\begin{aligned} L_{Orga} &= L_{BCH} + L_{FCH} + L_{ACH} + L_{RCH} + L_{DL} + L_{UL} \\ &+ L_{TTA} + L_{F-BCH} + L_{F-FCH} + L_{F-ACH} + L_{F-RCH} \\ &+ L_{F-DL} + L_{F-UL} + L_{F-TTA} \end{aligned} \quad (4)$$

The index F refers to the forwarding frame. Since a MAC frame has a total of 500 OFDM symbols, in a two hop scenario a total of

$$L_{Payload} = 500 - L_{Orga} \quad (5)$$

symbols are available for transferring user data.

In Figure C-7 the amount of free symbols in a MAC frame is plotted versus the number of stations present in a multi-hop scenario. The scenario consists of one AP, one FRN and a variable number of UTs/RUTs. The number of stations ($n_{Station} = n_{UT} + n_{RUT}$) is increased in such a way that the number of UTs is $n_{UT} = \lceil n_{Station} / 2 \rceil$ and the number of RUTs is $n_{RUT} = \lfloor n_{Station} / 2 \rfloor$. This, and the fact that a new set of IEs is necessary for every three connections explains the irregular run of the curve displaying the number of free slots using round robin scheduling without FDTs.

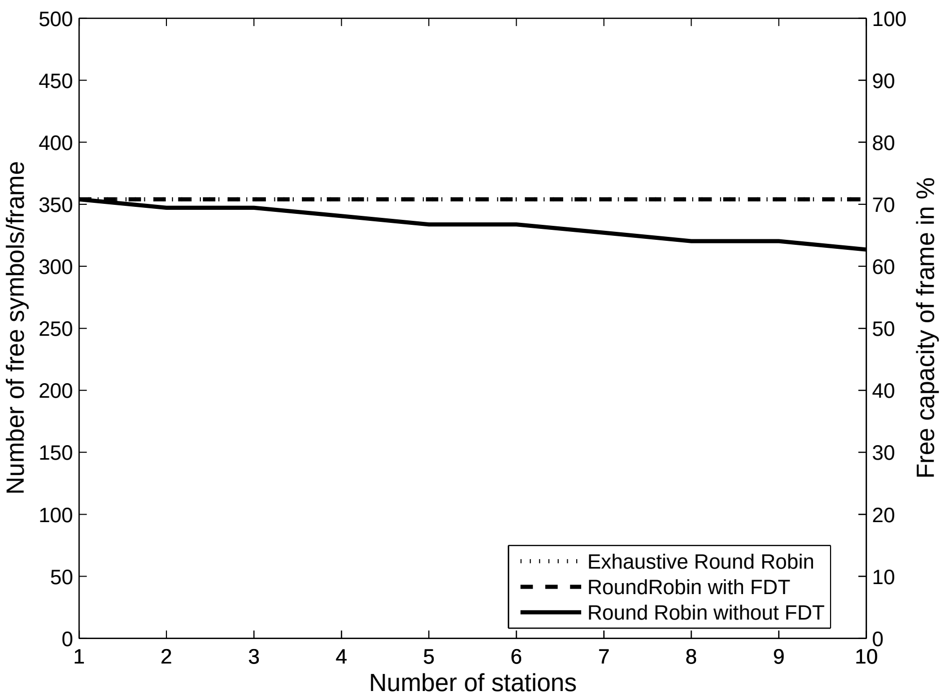


Figure C-7: Comparison of free symbols in a MAC frame in the case of multi-hop

Examination of Figure C-7 reveals that the amount of signalling necessary to realize multi-hop operation is substantial. The amount of free symbols available in each frame can drop to less than 50%. This amount of signalling overhead can be reduced significantly by applying the FDT technique. Again, the difference between the results for FDT and the application of EXRR is a result of the amount of PHY overhead necessary for preambles preceding each transmission.

C.1.6 Simulation Results

In this section the results obtained by event driven stochastic simulations are presented. Since the main objective of these simulations is to compare the effects caused by the use of FDTs, the absolute throughput values are not important. Therefore in all results given the traffic load is scaled to the percentage of the maximum transferable bit rate which depends on the applied modulation and coding scheme. The amount of the frame available and used for transmission of user data is given as percentage of the whole frame. Results showing delays are based on a maximum transferable bit rate of 9 Mbps. All the simulation results presented in the following were obtained assuming an ideal channel. This means no packets were lost due to interference or other causes. The load generator creates packets of size 48 byte and follows a Poisson distribution. The length of the MAC queue for packets coming from higher layers in each terminal is limited to 1000 packets. All parameters of the MAC and PHY are chosen as specified in [H2ETSI99] and [H2ETSI01].

C.1.6.1 Single Hop

1) Variable Frequency of FDT Changes

In the first simulation runs performed within the scope of this work one FD is kept within the FDT for a fixed period of several frames. After this period elapses a new FD is calculated and sent out by the BS to the UTs. These substitute the old entry in their FDT for this newly received FD. The efficiency of the concept scales up with the number of stored FDs in the FDT. To get an impression of the potential of the concept and to ease the understanding of the results we have chosen this basic approach of implementing it. Applying the FDT concept in particular this way is a trade-of between flexibility and overhead. If the layout of the frame is kept unchanged for too long, the needs of a connection scheduled within the FD may have changed and resources may be allocated unnecessarily. If the FD is changed too often, the efficiency is reduced. In order to find out which frequency for changing the FD is reasonable, simulations have been carried out with the results presented in Figure C-8, which shows the system throughput vs. the system load depending on the interval between changes of FD.
The system changing the FD in every frame (pure round robin (RR)) is the first to be overloaded. What should be mentioned is the fact that there is no additional overhead because of the use of the FDT concept. The results are exactly the same as for pure RR scheduling without the use of FDs.
The longer the time between two changes of an FD, the less signalling is needed. Thus the throughput increases with increasing intervals between changes of an FD. But another fact becomes apparent when examining Figure C-8. The rate of gain in overhead is getting smaller with increasing intervals between FD changes. This becomes intuitively clear when imagining the same amount of signalling being spread out over an increasing interval. The gain is growing logarithmically. The upper limit of this development (Interval between changes of FD $i \rightarrow \infty$) converges to the maximum capacity of 70.4% calculated in [KEFW06a]. On the basis of this result the interval for changing the FD is set to 5 frames for the other simulations executed in the course of this work.

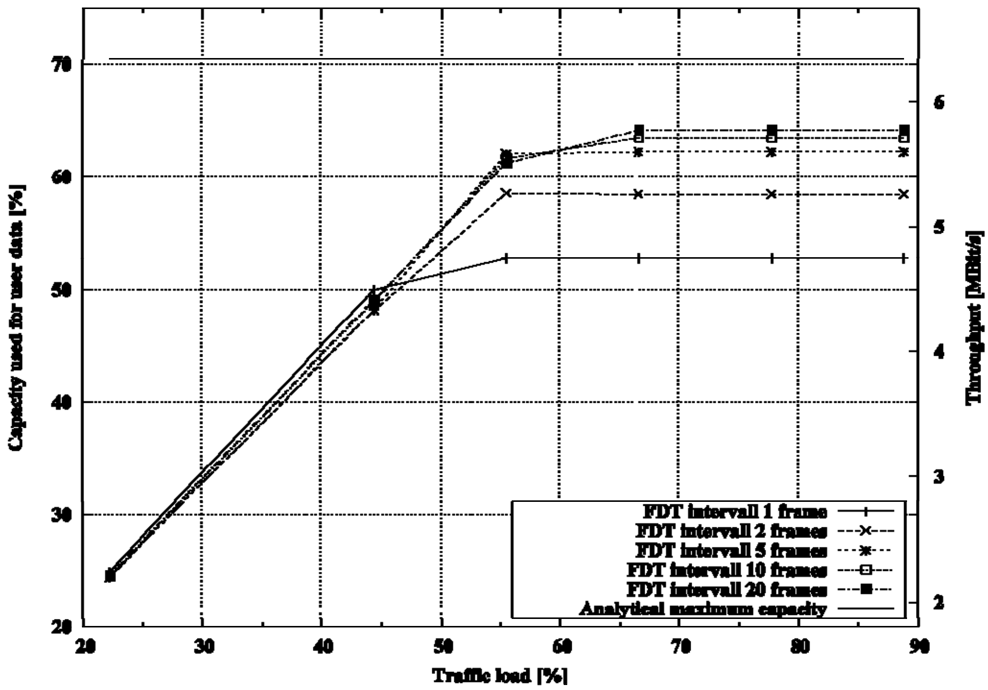


Figure C-8: Throughput vs. System Load depending on interval between changes of FD

2) StaticFDT

First of all we will discuss the influence of the introduced concept on the delay of data packets above the MAC layer. To explain the impact of applying the FDT concept we will compare the probability density function of the downlink delay versus the load using Round Robin scheduling (RR) with and without applying the FDT concept. The delays of the scenario given in section C.1.4.1 were measured in an identical setting with and without application of the FDT concept.
The concerning curves can be found in Figure C-9 for the case without FDT respectively in Figure C-10 for the case with FDT.

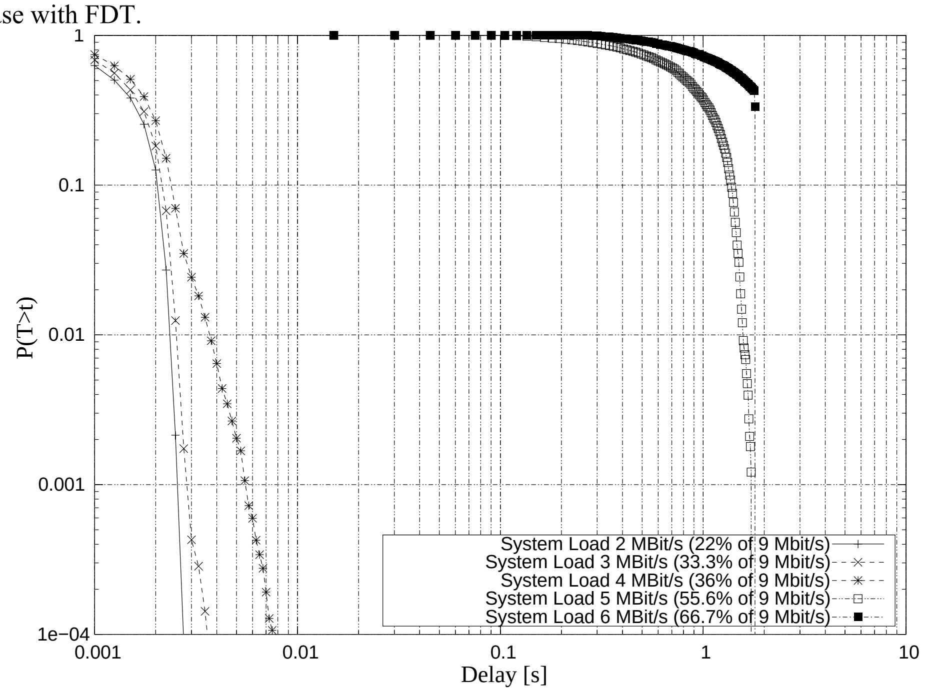


Figure C-9: Pdf of downlink delay vs Load using Round Robin scheduling without FDT

Figure C-9 shows that for all levels of system load (from 22% up to 66,7%) the delay with at least a probability of 99,9% is very close to a maximum delay which increases from below 3ms for a load of 22% up to below 3s for a load of 66,7%. Thus it can be concluded that the MAC protocol is able to support Quality of Service (QoS). Of course the achievable level of QoS is depending on the amount of load the system has to support.

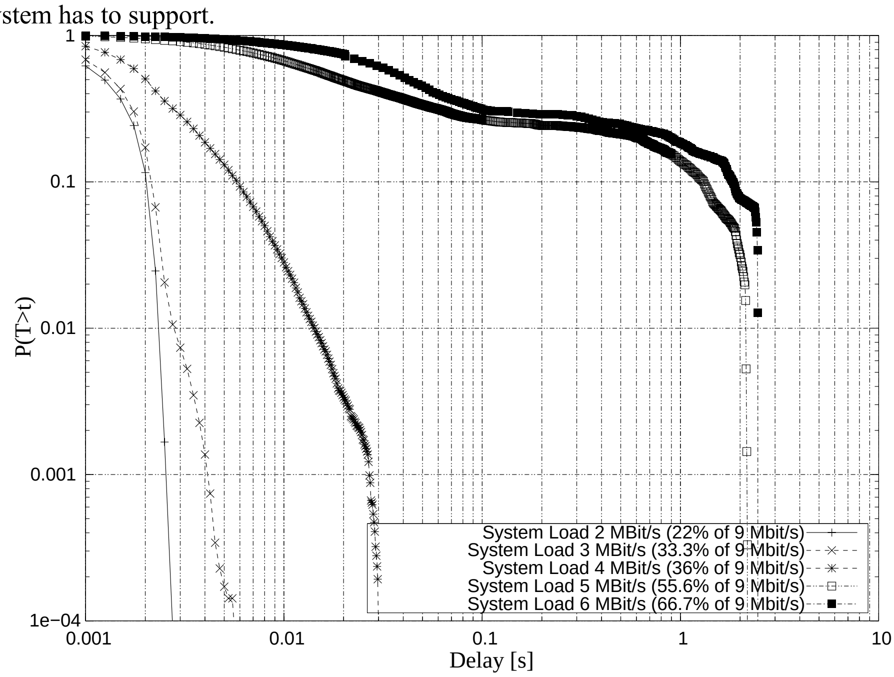


Figure C-10: Pdf of downlink delay vs Load using Round Robin scheduling with FDT

Comparing the results to the ones achieved when applying the FDT concept presented in Fig. 13 one can see that in particular in the case of medium (36%) and high (more than 50%) load the maximum delays increase stronger. The reasons are the simplified simulation assumptions to allow only one changing FD. This leads to a situation in which resources are allocated in the FD for connections which do not have packets in the queues to be transmitted. The worst case assumption of poisson traffic even aggravates the situation as the packets drop into the MAC queues extremely bursty. By allowing the use of more than one FD, multiple FDs could be announced each adapted for different situations regarding the fill level of the MAC queues. But even with the worst case assumptions made within this work a positive effect can be seen looking at the high load curves presented in Figure C-10. By applying the FDT concept the probability of achieving delays reduced by a factor of 100 is about 30% higher compared to the pure RR curves given in Figure C-9.

In Figure C-11 the throughput is plotted versus the traffic load for the simulations with and without FDT. As can be seen the utilization of the frame at low loads is better using RR scheduling without FDT. This is because at low loads the assignment of resources for a duration of, in this case, 5 frames tends to waste resources by assigning them to connections which do not need them right now. These resources are used more efficiently if the assignment takes place every frame. This disadvantage is more than compensated by the saving of overhead at higher loads.

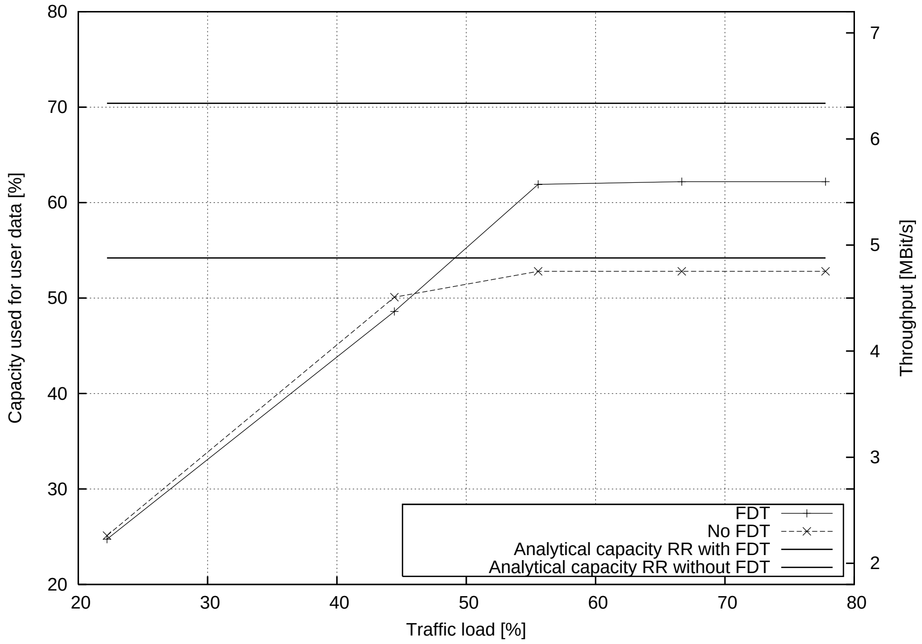


Figure C-11: Throughput vs Load using Round Robin scheduling with and without FDT

In keeping with the calculations presented in[KEFW06a], the maximum percentage of a frame used for transmission of user data with 20 connections (10 UL and 10 DL) using the RR scheduling method and polling is between 50% and 55%. The analytical capacity (see [KEFW06a]) for RR scheduling of 54.2% is not quite reached due to imperfect scheduling in the simulator. With the use of FDT this percentage can be raised to between 60% and 65%. This is less than the 70% presented in [KEFW06a]. The reason for this discrepancy is the fact that the periodical transmission of the FD has not been included into the calculations. In this simulation it takes place every 5 frames.

3) Description of Frames with Dynamic Portions

The usage of the FDT concept is not limited to describing whole frames. As shown in section C.1.2.2 the FD can be used to describe parts of a frame as well. This enables the use of different scheduling algorithms within one frame. The effects of such a usage with respect to the throughput are shown in Figure C-12. The scenario for this simulation is the same as before.
The scheduling strategy used has an impact on the overhead necessary for MAC and PHY operation. Because of this the achievable throughput of the system depends on the scheduling algorithm used. The most signalling is needed when using pure RR scheduling (no FDT, RR). This results in the lowest throughput as can be seen from Figure C-12. Less than 55% of the frame capacity can be utilized for user data.
In this simulation series two strategies using the FDT concept are examined as well. One of them uses half of the frame for transmitting data using connections which have been described in FDs. The other half of the frame is described by a regular FCH using RR scheduling (FDT, RR).

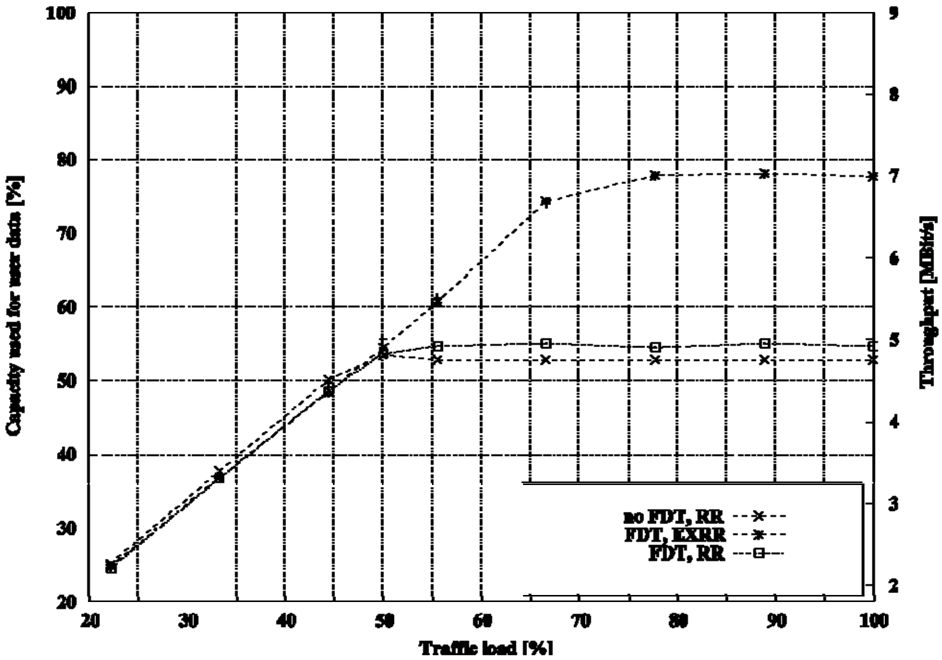


Figure C-12: Throughput vs. System Load depending on scheduling algorithm

The resulting throughput is not increased significantly. This is because a lot of the overhead necessary in RR scheduling comes from preambles of the exemplarily assumed PHY [H2ETSI01]. But the FDT concept lessens the signalling overhead of the MAC layer.
This becomes obvious when examining the last curve describing the run of the third variation of scheduling examined here (FDT, EXRR). This time, the half of the frame which is described by the FCH is scheduled using Exhaustive Round Robin (EXRR). The part described by the FD is scheduled using RR. This is the most effective alternative in terms of throughput. The FCH is very short, since it only has to describe a single connection or two. The FD which describes a lot of connections using RR scheduling only has to be transmitted every 5 frames. This results in a capacity used for user data of nearly 80% of the frame capacity. Thus this strategy outperforms both others by providing about 25% more frame capacity for user data.

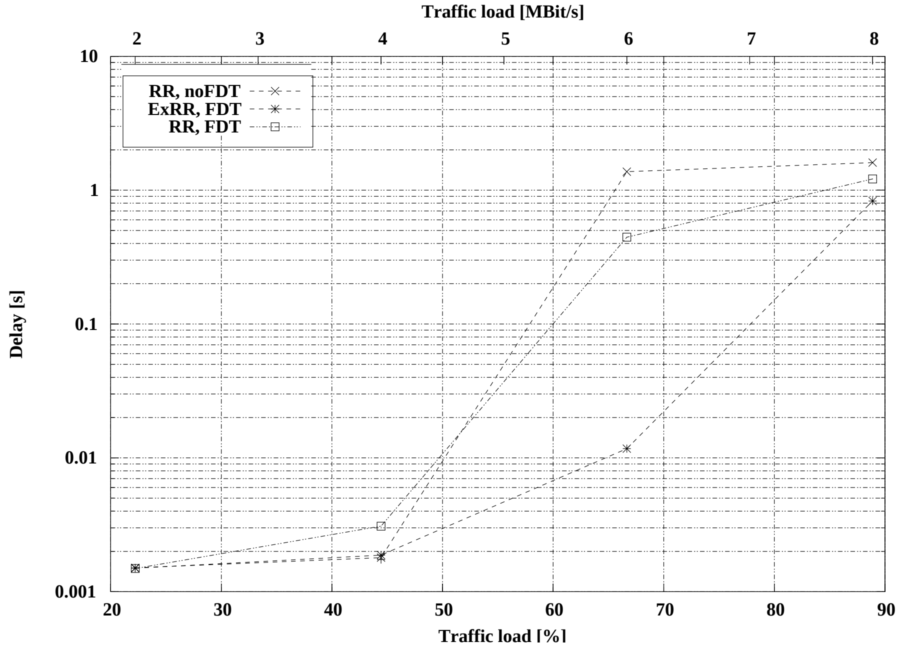


Figure C-13: Mean downlink delay vs. System Load depending on scheduling algorithm

The performance of the delay is influenced as well by the usage of FDs as can be seen in Figure C-13 showing the downlink mean delay versus the system load depending on the scheduling algorithm.

At a certain amount of traffic load [%] the delay is increasing rapidly. Like it was the case for the throughput, the strategy applying a combination of FDT concept together with EXRR outperforms the others significantly in terms of mean delay.
The performance of the combination of RR together with the FDT concept shows higher mean delays for low traffic up to 50% compared to pure RR. In exchange it outperforms pure RR at higher loads. The reason is that for low loads the static resource allocation of the FDT can be outperformed by the dynamic of the RR whereas at higher loads the FDT concept reduces the signalling overhead in such a way that the gained capacity helps to reduce the mean delay.

C.1.6.2 Multi-Hop

In order to show the merits of the FDT concept, the system throughput and delay of the scenario given in section C.1.4.2 was measured in an identical setting without (see section 1)) and with (see section 2)) application of the FDT concept.

1) Without FDT

In the first simulation a round robin scheduling over all connections is performed without using FDTs. The resulting throughput vs. the traffic load is shown in Figure C-14 and Figure C-15.

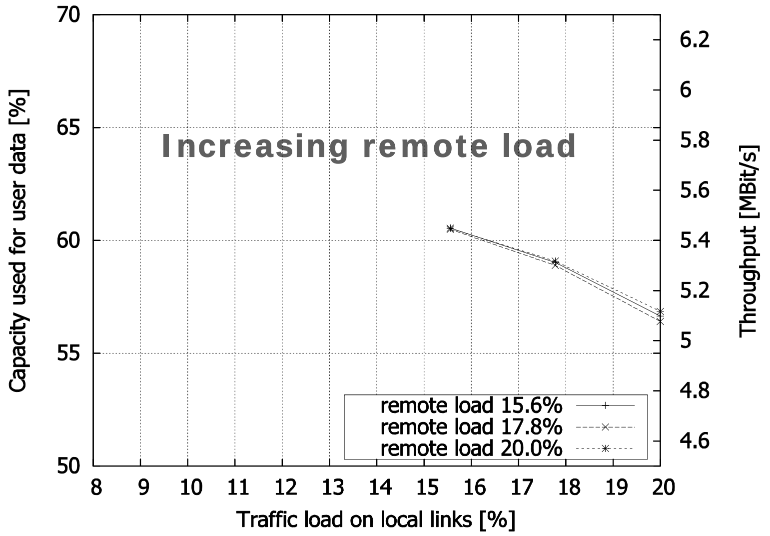


Figure C-14: Throughput without FDT - rising load on local connections

Figure C-14 shows the throughput of the whole system versus increasing load on the local links. As can be seen, the throughput of the system is actually reduced with higher load. This can be explained by the fact that with low load on the local links the main throughput is generated by the highly loaded connection from the BS to the FRN. The relay connection is heavily overloaded and packets are discarded. If the load on the local UTs is increased, it is spread across more connections. Scheduling more connections in one frame increases the overhead. Thus the overall throughput of the system is reduced.

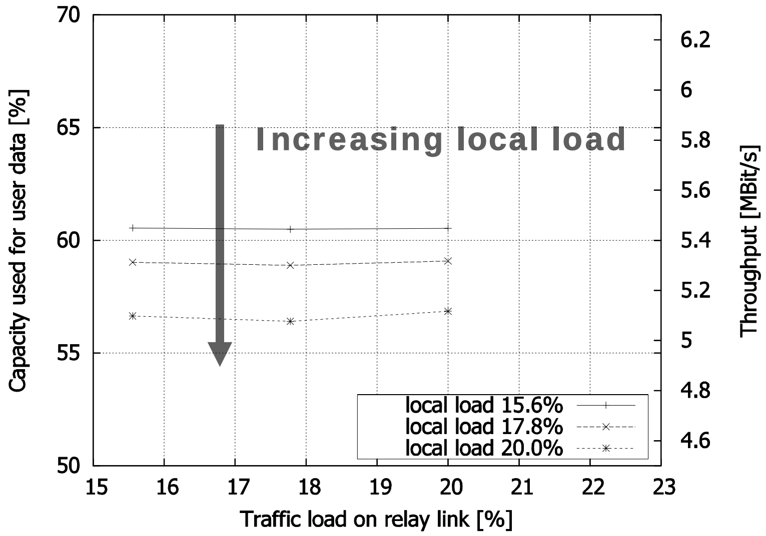


Figure C-15: Throughput without FDT - rising load on relay connection

The fact that the connection from the BS to the FRN is in overload becomes clear from Figure C-15. Here the same data is displayed but this time the throughput is plotted vs. the load of the relay connection. The char parameter is the load on the local UTs. As can be seen, the throughput of the system does not change when increasing the load on the relay connection. It is already overloaded.

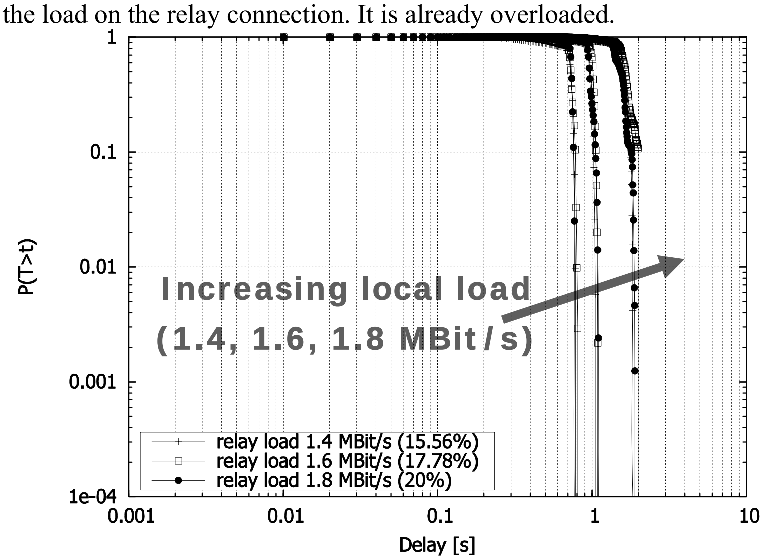


Figure C-16: Downlink end-to-end delay without FDT

This becomes apparent as well when examining Figure C-16 in which the end-to-end DL delay of the connection from the BS to the RUT is shown. As can be seen, the delay of the two-hop connection solely depends on the load generated by the local UTs. The delay is in the order of magnitude of one second. This is another proof of the overload condition of this link.

2) With FDT

The situation described above is clearly a very unbalanced one. Because of the round robin scheduling the one connection serving the FRN is not able to request as many resources as would be necessary. An FDT can be used to establish a channel of fixed capacity between the BS and the FRN. This ensures the connection serving the FRN obtain a certain amount of resources which does not depend on the load imposed by the local UTs and moreover reduces the amount of signalling during the broadcast phase.
This has been done in the following simulation. Half of the frame has been reserved for the transmission of data described by an FDT. This section of the frame is used for transmissions to and from the FRN. The throughput of the relay connection and the local connections are shown in Figure C-17 and Figure C-18.

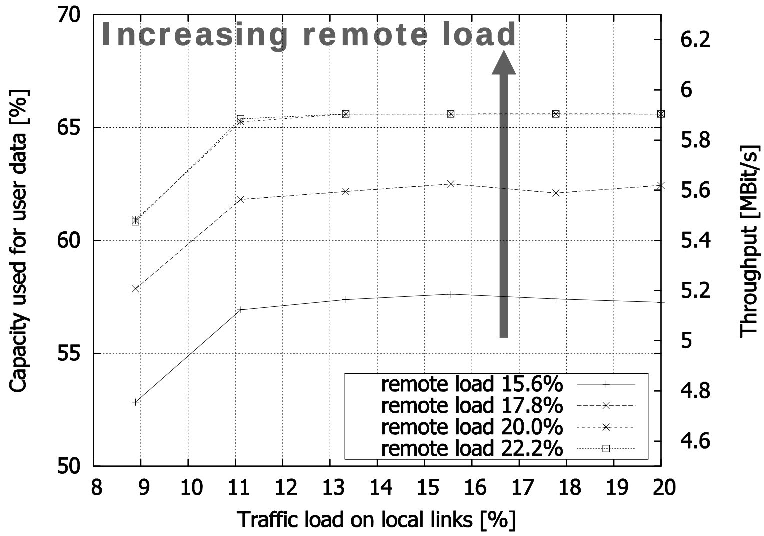


Figure C-17: Throughput with FDT - rising load on local connections

As above, the throughput of the whole system is plotted vs. the load on the local connections in Figure C-17. This time, the connections from the BS to the local UTs and vice versa are overloaded earlier. There is now only half a frame for them to be scheduled in. The other half is reserved for the connection to and from the FRN. As can be seen the total throughput is increased from around 60% without FDT to around 65% with the use of FDT.

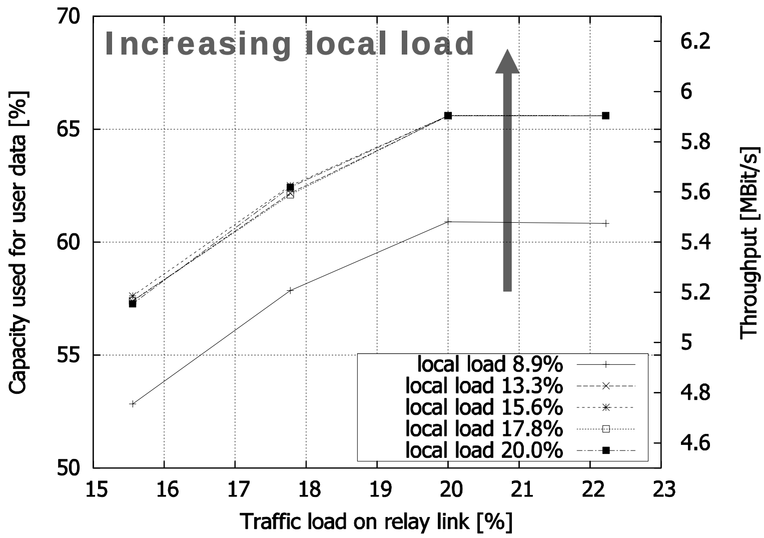


Figure C-18: Throughput with FDT - rising load on relay connection

In Figure C-18 we can see that using FDTs has an immense impact on the system throughput when increasing the traffic load on the relay link. In contrast to the behavior without FDT (see Fig. 18) the system throughput increases up to a traffic load of about 20 % where the system starts to be saturated. This characteristic is independent of the load on the local links.

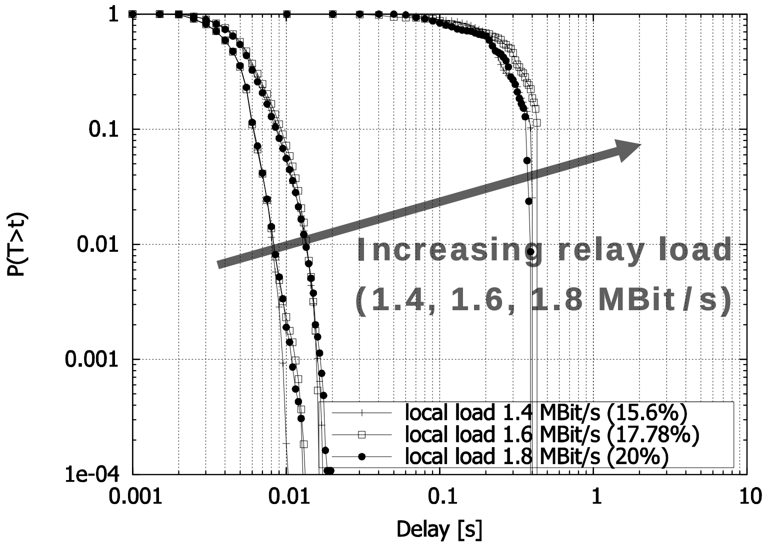


Figure C-19: Downlink end-to-end delay with FDT

The end to end delay of the relay connection in downlink direction is shown in Figure C-19. It becomes clear that the delay of the relay link does not depend on the load on the local connections anymore. It rises strictly with the load on the relay link. This is the expected behaviour, since the same amount of resources are provided for the relay link, no matter how much load there is on the connections to local UTs. Moreover it can be seen that the delay compared to Figure C-16 could be reduced dramatically.

C.1.7 Applicability in the WINNER Context

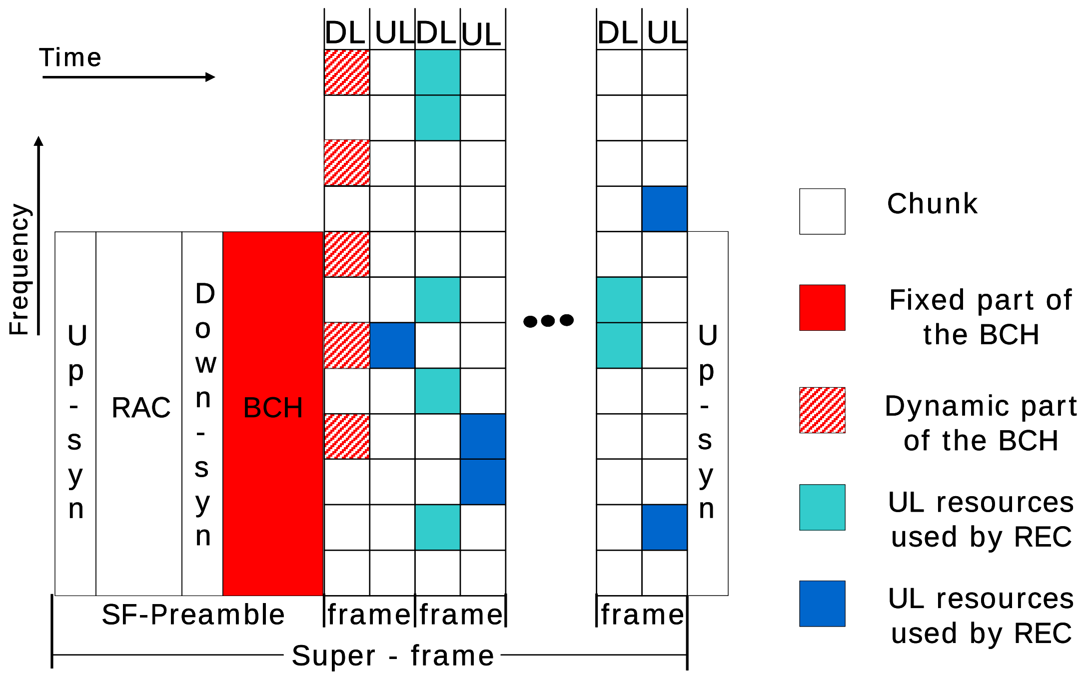


Figure C-20: Splitted BCH Information

The concept of FDTs is applicable to different kind of information that is transmitted from a central controller to associated receivers.
With respect to the WINNER system there will be several control signals needed that have to be transmitted by the BS/RN in the downlink. In all cases where these signals show some kind of redundancy in principle it is feasible to analyse the relevance of applying the FDT concept.

A prerequisite is that the information is split in a fixed part and a dynamic part where the fixed part at least contains some kind of pointer or index referring to the dynamic part. This is exemplary shown in Figure C-20 for the BCH in the WINNER system. In this particular case it seems to be an option to keep the continual overhead introduced by the BCH at a minimum by putting parts of the information necessary to be transmitted from time to time into a dynamic part. Inside the fixed part a pointer references to the dynamic part which is distributed over several chunks in this example.

For two kind of information it is obvious that the positive effects shown in the previous sections will be similar for the WINNER system:

1. Resource Partitioning information:
   The WINNER system design so far foresees that the resource partitioning information is transmitted inside the BCH. It seems likely that this information will not have to be updated from Superframe to Superframe. Therefore as explained in the example before and shown in Figure C-20 this information could be of relevance for the FDT concept.

2. Resource allocation information for:
   a. Non-frequency adaptive scheduled transmissions
      Until now it is not decided where and how often the resource allocation information for the non-frequency adaptive scheduling transmissions will be transmitted. But anyway the information will be needed in a similar way as the FCH in the MAC protocol (see section C.1.2.1) which is used as a basis for the assessment in the previous sections.

   b. Frequency adaptive scheduled transmissions:
      So far the system design proposes to transmit the resource allocation related information of each scheduled chunk inside the chunk itself. But however it could make sense to remove for example the indexing of the station which should send/receive within the corresponding chunk into an allocation table as well similar to the structure of the FCH described in section C.1.2.1. This would then easily allow applying the FDT concept to that information, too.

As seen in the previous sections, establishing TDMA channels per connection needs little signalling with rising load. Signalling is necessary only for the establishment of connections. The ratio of signalling to user data is especially favourable for connections that, once established, are used for a long time.
Multi-hop operations, which are planned to be an integrated part in the WINNER system, can exploit this by establishing connections multiplexing the traffic of several other terminals.
Moreover in [EKW06] it is shown that in a multi cellular environment the quality of the interference estimation has a big impact on the gain which is achievable with the frequency adaptive scheduling scheme. As long lasting connections help to improve the interference estimation they are a promising means to attain the possible improvements.

C.1.8 Conclusion

The results given within this chapter emphasize the relevance of the concept of Frame Descriptor Tables. It has shown to be a promising way of minimizing the need for resources necessary for the transmission of control information in wireless mobile radio systems.
Describing the layout of a whole frame with the help of FDs the probability of achieving delays reduced by a factor of 100 is about 30% higher compared to pure RR. The throughput saturates at significantly higher loads and provides about 10% more frame capacity to be used for user data.
By introducing dynamic portions described by the FCH in addition to the part described by the FD the combination of FDT concept together with EXRR scheduling shows the potential of the FDT concept both in terms of enhanced throughput as well as in terms of reduced mean delay.
Multi-hop solutions for frame based MAC protocols have the drawback of implicating additional overhead introduced by control information to be signalled for each hop. With the help of the FDTs this overhead can be kept small.
The simulation results for multi-hop show an increased system throughput. A larger scenario with an increased number of relays would benefit even more from the application of the concept. The reduced end-to-end delays presented in addition reflect the advantages of having fixed TDMA channels for the connection between master and relay station which can be easily established when using FDTs.

As discussed in section C.1.7 there seem to be various possibilities to apply the concept of FDTs in the WINNER context. The relevance has to be analysed from case to case but at least the establishment of TDMA channels for relaying and the reduction of overhead introduced by the resource partitioning information and the allocation table content seem to be a promising way to improve the WINNER system performance.

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