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WINNER System Concept Description

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Abstract:

The objective of this deliverable is to provide a comprehensive and consistent overview on the WINNER system concept work at the end of the first project phase. Concepts investigated in various WINNER work packages have been harmonized and integrated into the WINNER system concept which is described within this deliverable. To illustrate the WINNER system architecture a formal descriptive approach has been chosen based on Unified Modelling Language 2.0. By using state diagrams the external behaviour of each service provided by a certain protocol layer is illustrated. Furthermore, technical details are given on the internal structure of WINNER protocol layers, whenever they provide useful hints on the overall understanding of the concept.

Keyword list:

WINNER System Concept, Protocol Architecture, IP Convergence, Radio Link Control, Medium Access Control, Physical Layer, Radio Interface Concept, Modes, Physical Deployment Characteristics

Executive Summary

This document presents the overall framework for the integration of results from WINNER Phase I and is complemented by the technical deliverables and the upcoming documents on system performance and complexity. It forms the base for the remaining work in Phase I and for Phase II of WINNER.

The integration of the various concepts and technologies investigated in the WINNER work packages into one coherent concept is a challenging task that requires a clearly structured approach. The result of the chosen system engineering approach is presented in this document. It is based on a UML2.0 – like notation that structures the concept into services provided by the following protocol layers: IP–Convergence, Radio Link Control, Medium Access Control and Physical Layer.

The "IP-convergence layer (IPC-layer)" provides the interface towards IP-based networks and is the top-level WINNER protocol layer. It is thus the layer which keeps all the RAN-internal complexity away from the IP-based infrastructure. The IPC's User Plane receives IP packets from the user of the WINNER RAN, maps them into flows and performs header compression and decompression. Flows of one user are treated independently, allowing individual transmission according to their specific quality-of-service requirements. This capability ensures that all packets travelling through the WINNER RAN are treated effectively and consistently regardless of where or how they originate. The IPC Control Plane is responsible for RAN association functions as well as for macro-mobility (IP level mobility).

The "Radio Link Control layer (RLC-layer)" provides reliable packet transfer over the air-interface. It also performs confidentiality protection and packet prioritisation in order to meet the QoS goals. Unlike the existing technologies, the RLC User Plane provides only one single packet transfer service towards the upper layer (IPC-layer). In that way, the details of the layer are not visible to the upper layer. The RLC User Plane is also responsible for maintaining the QoS of the different flows in the RAN. It monitors, conditions and schedules the flows by the service level controller. The traffic of each flow is conditioned to ensure that it complies with the corresponding profile definition; in particular the defined maximum traffic rate. This can be achieved through delaying (shaping) or dropping (policing) packets. The RLC Control Plane takes care of flow establishment and release, location services, load, spectrum and micro-mobility (mobility within the WINNER RAN) control. One of the WINNER RLC Control Plane advantages is that it handles the handover process per flow rather than per User Terminal. Therefore, a UT might send/receive traffic over different cells and routes that match best the requirements of the specific flow. Additionally, it includes functionalities for coordinated spectrum sharing with other radio access networks using the same radio access technology as well as for spectrum sharing with other radio access technologies. Finally, unlike in existing systems, admission control is not responsible for only admitting a new flow, or handover an existing flow to a new cell but selecting the best cell among a group of candidate cells that are nominated by the micro mobility functionality.

The "Medium Access Control layer (MAC layer)" enables the effective usage of the radio spectrum by adapting the transmission as best as possible to the actual radio propagation conditions and user requirements. Adaptive transmission is integrated into the design, on all time-scales. Up to moderate vehicular velocities, link adaptation and scheduling can be performed with fine granularity in the frequency domain (OFDMA/TDMA). This enables multi-user scheduling gains to be obtained. For higher velocities, the transmission adapts to the shadow fading. On a larger time-scale, the resource partitioning can adapt to the traffic demand over different transport channels. The MAC enables fast transmission and very low re-transmission delays over the radio interface. These properties are the key to attaining high spectral efficiency via adaptive schemes and reliable communication through efficient re-transmission. Furthermore, the MAC layer is designed for efficient support of multi-antenna transmission from the beginning. The multi-antenna processing can be adjusted in a very flexible way per flow, to obtain an appropriate balance between obtaining multiplexing gains to boost throughput, achieving robustness via diversity transmission, and obtaining SDMA gains by transmitting different flows over different spatial channels.

The "Physical layer (PHY-layer)" handles the physical transmission of chunks, measurements and control signalling directly related to the radio interface. It offers different transfer services for adaptive and non-frequency–adaptive transmission, direct transmission between user terminals, random access and control transmission. Towards higher layers, it reports measurements from user terminals required by the MAC and the RLC layers. The PHY layer transmission chain implements OFDM transmission in the downlink and GMC in the uplink which includes OFDM transmission and frequency-domain generated serial modulation as special cases. The multi-antenna concept is a generic architecture that aims at performing multi-user spatial domain link adaptation, based on the following basic components: (linear) dispersion codes, directive transmission (beamforming), per stream rate control, and multi-user precoding. This

architecture allows fostering spatial processing gains in flexible combinations as required by different scenarios, i.e. different combinations of physical layer mode, link direction, transport channel type, deployment, propagation conditions, cell load, traffic type, BS antenna configuration, and terminal capabilities. It therefore embeds different spatial processing algorithms into a common framework.

Beside the detailed description of the protocol layers mentioned above, this deliverable discusses the WINNER logical node architecture. The main goal of the logical node architecture model is to assist in grouping functions, between which there may be a need for defining open interfaces. Furthermore, this is complemented by exemplary physical deployments that are characterised with respect to cell ranges in different environments. Finally, an update on the definition of WINNER System and Physical Layer (PLM) Modes is given. The introduction of modes is seen as an appropriate means to cope with the wide variety of anticipated WINNER deployments. Currently two PLMs namely for the FDD and TDD duplex method seem necessary.

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List of Acronyms and Abbreviations

ACSLN	Access Control Server Logical Node
ARLN	Access Router Logical Node
ARS	Adaptive Resource Scheduling
BCH	Broadcast Channel
BER	Bit Error Rate
BS	(Physical) Base Station
BSLN	Base Station Logical Node
CAPEX	Capital Expenditure
CC	Convolutional Code
CDC	Common Data Channel
CDMA	Code Division Multiple Access
CL	Convergence Layer
CP	Cyclic Prefix, Control Plane
CQI	Channel Quality Indicator
CRC	Cyclic Redundancy Check
CSI	Channel State Information
DAC	Direct Access Channel
DEC	Decoding
DECT	Digital Enhanced Cordless Telecommunications
DIV	Diversity
DL	Downlink
FDD	Frequency Division Duplex
FDT	Frame Descriptor Table
FEC	Forward Error Correction
FFT	Fast Fourier Transform
GI	Guard-Period Insertion
GMC	Generalised Multicarrier Transmission
HO	Handover
ICE	Iterative Channel Estimation
ID	Identifier
IFDMA	Interleaved Frequency Division Multiple Access
IFFT	Inverse Fast Fourier Transform
IP	Internet Protocol
IPC	IP Convergence Layer
ISO	International Organization for Standardization
ITU	International Telecommunication Union
LAN	Local Area Network
LDC	Linear Dispersion Code
LDPCC	Low Density Parity Check Codes
LN	Logical Node
LT	Long-Term
LVO	Location-based Vertical Handover
MAC	Medium Access Control Layer
MIMO	Multiple-Input Multiple-Output
MOD	Modulation
M-PSK	M-ary Phase Shift Keying
M-QAM	M-ary Quadrature Amplitude Modulation

MSE	Mean Square Error
NRS	Non-frequency-adaptive Resource Scheduling
OFDM	Orthogonal Frequency Division Multiplex
OFDMA	Orthogonal Frequency Division Multiple Access
OPEX	Operative Expenditures
OSI	Open Systems Interconnection
P2P	Peer-to-Peer
PARC	Per-Antenna Rate Control
PCCC	Parallel Concatenated Convolutional Codes
PDU	Protocol Data Unit
PER	Packet Error Rate
PHY	Physical Layer
PLM	Physical Layer Mode
PMP	Point-to-Multi-Point
PSAP	Provided Service Access Point
PSRC	Per-Stream Rate Control
QoS	Quality of Service
RAC	Random Access Channel
RAN	Radio Access Network
RANGLN	Radio Access Network Gateway Logical Node
RAP	(Physical) Radio Access Point
RAT	Radio Access Technology
RAT	Radio Access Technology
REC	Relay Enhanced Cell
RLC	Radio Link Control Layer
RN	(Physical) Relay Node
RNLN	Relay Node Logical Node
RRM	Radio Resource Management
RS	Resource Scheduler
RSB	Resource Scheduling Buffer
RTU	Re-transmission Unit
SDMA	Space Division Multiple Access
SDU	Service Data Unit
SF	Superframe
SINR	Signal-to-Interference plus Noise Ratio
SLC	Service Level Controller
SLCB	Service Level Control Buffer
SMMSE	Successive Minimum Mean Square Error
SMUX	Spatial Multiplexing
SNR	Signal-to-Noise Ratio
SRRM	Specific RRM
ST	Short-Term
STF-EQ	Space Time Frequency Demapping and Equalizing
STFM	Space Time Frequency Mapping and Modulation
STFP	Space Time Frequency Processing
TDC	Targeted Data Channel
TDD	Time Division Duplex
TDMA	Time Division Multiple Access
TF	Time Frequency

TFC	Transport Format Control
UL	Uplink
UML	Unified Modeling Language
UP	User Plane
UT	User Terminal
UTLN	User Terminal Logical Node
WLAN	Wireless Local Area Network
WWI	Wireless World Initiative

1. Introduction

The present document describes the WINNER system concept at the end of Phase I of the WINNER project. The system concept is the result of the technical work within the project, integrating the technical concepts and solutions that have been developed by the technical work packages into one coherent concept. It serves as a framework for the project that helps to identify required functionalities, structures them into a system model and aligns the interfaces between them. The system concept explains the role of all functionalities, their behaviour and chosen technical solution, and the interplay between the functionalities. By referencing the technical background for the chosen technologies, the document serves as a directory to the deliverables provided by other technical work packages of the project. It provides also the basis for future work in Phase II of the project.

This work has been conducted by work package 7 with intensive cooperation and support from the technical work packages in the framework of the cross – work package group "System Concept"

The document starts with a terminology chapter 2 that provides a set of definitions that are crucial for a clear understanding of the concept. These have been agreed upon and are consistently used within the project. Chapter 3 briefly summarises the WINNER vision and baseline assumptions.

The main innovations of the concept are briefly summarised in chapter 4 to provide the reader with a short overview of the main innovative conceptual ideas of WINNER. References to the chapters within this document which detail the innovations are given.

The core of the document is the functional description in chapter 5. It has been developed following a top-down approach that structures the concept into a set of services. "Service" in this context means a particular functionality that is offered by a system layer towards the layers above and not a service in the sense of user service, e.g. voice transmission service. Services are structured by grouping them in the system layers IP – Convergence, Radio Link Control, Medium Access Control and Physical Layer, which are further divided into User and Control Plane. The services are further broken down into service components, which are not directly visible to other layers. This service specification has been described applying use – case and state diagrams in a UML2.0 like notation.

The top-level behaviour of the services is described by means of state-machines and external trigger messages, here denoted as service primitives. These describe the interface and the communication between the system layers but also between service components of the same layer.

The result of this work is a set of more than 100 UML diagrams. In order to restrict the number of pages of this document to a comprehensive level, only the main – level diagrams have been included and detailed diagrams have been transferred into text. The diagrams presented within this document have been chosen such, that emphasise is given to the external behaviour of a layer, which is observed by the layer above, i.e. by the user of the service described. Details of the functions are only given where needed to understand the concept or solve a pre-requisite for the approach by an innovative solution. For further details, the interested reader is referred to other WINNER documents.

The following chapter 6 maps the services to logical network elements of the WINNER RAN and presents an architectural view of the WINNER concept. Then, an investigation of the relation between achievable cell sizes at different carrier frequencies and required user – data rate based on link budget calculations is presented in chapter 7. Single – hop deployment cell ranges are compared with ranges of a simple multi-hop scheme in 4 scenarios in order to analyse application areas and technical prerequisites for multi-hop deployments.

The WINNER radio interface is assumed to operate in different modes to serve different environments, e.g. rural or urban scenario, or usage scenarios in an optimal way. To enable this, the idea of system modes is emphasised in chapter 8. To support these WINNER system- or physical layer modes a "Reference Protocol Architecture" has been developed to provide means to generalize the radio interface to the higher layers and to allow a smooth interworking between the different modes.

Finally, conclusions are derived in chapter 9.

2. Definitions

2.1 General

Mode	**-**	Specific combinations of algorithm assignations or ranges of algorithm assignations may be referred to as "Modes". The two main considered physical layer modes (PLM) are based on, and denoted, FDD and TDD. A System mode is a PL mode combined with MAC and RLC assignations.
Radio Access Technology	**RAT**	The radio access technology (RAT) is the air interface that is used to allow the link between User Terminal and Base Station or Relay Node of the RAN. This includes also multi-hop/relaying elements. The WINNER RAT can be derived into several Physical Layer Modes.
Deployment Concept		The term “Deployment Concept” describes network element types and their functions (i.e. logical network elements), (a) how these network element types are linked in a network topology, (b) how logical network elements are mapped onto physical network elements and (c) where physical network elements are deployed according to the radio propagation scenarios for which the deployment concept is applicable.

2.2 Physical Network Elements

Physical Network Element		A physical network element denotes a physically existing device in the RAN that incorporates certain functionality, thereby representing one or possibly even more logical network nodes.
(Physical) Base station	**BS**	A stationary physical network element serving relay nodes or user terminals via its radio access capabilities. Base stations are interconnected with network elements belonging to the RAN. A physical base station contains one or more base station logical nodes.
User terminal	**UT**	A physical network element used by the end user to access a service or set of services.
(Physical) Relay node	**RN**	A physical network element serving other RN or UT in a given geographical area via its radio access capabilities. It is wirelessly connected to a base station, another relay node and/or a user terminal and forwards data packets between these network elements.
Heterogeneous Relay Node		A heterogeneous relay node is a relay node that uses different radio access technologies (or different modes of the same RAT) using common or different sets of transmission resources (e.g. RF channels) for its links (BS-RN, RN-RN, RN-UT). The radio access technologies that a heterogeneous relay incorporates can be different modes of the same RAT (i.e. in the WINNER context), one WINNER RAT-mode and another (possibly legacy) RAT, or two (legacy) RATs, where the latter case is not in the WINNER scope of research.
Homogeneous Relay Node		A homogeneous relay node is a relay node that uses the same radio access technology and mode in a common set of transmission resources (e.g. RF channels) for its entire links (BS-RN, RN-RN, RN-UT).
(Physical) Radio access point	**RAP**	A physical network element in the radio access network responsible for radio transmission and reception to or from the user terminal via its radio access capabilities. A RAP can be either a relay node or a base station.
Access System		The access system is used to connect the WINNER user terminals to the base station either directly or via relay nodes. The elements

		of the access system are the WINNER base stations and the WINNER relay nodes.
Feeder System		The feeder system is the transport system used to feed the base stations. The distinctive characteristic compared to the access system is that WINNER users shouldn't connect to this network directly. The transmission technology used by the feeder system could be wireless or wired and is irrelevant and transparent for the final user.
Site	**-**	A site is defined as the physical co-location of base station hardware serving a set of antennas. Users may be connected to a site either directly or through relay nodes

2.3 Logical Nodes

Logical Node	**LN**	A Logical Node is defined by the service (or group of services) it provides towards other nodes and the service (or group of services) it requires from other nodes. Identical Logical Nodes terminate an identical set of protocols and provide/require the same group of services. One physical element can comprise one or several LNs."
Base Station Logical Node	**BS_{LN}**	A logical node terminating the transport network layer protocols on the network side as well as the radio protocols on the UT and RN side. It contains a single MAC entity corresponding to a single cell, and it manages the logical relay nodes connected to it.
Relay Node Logical Node	**RN_{LN}**	A logical network node with relaying capabilities that is wirelessly connected to a BS_{LN}, UT_{LN} or another RN_{LN}. Like the BS_{LN} it terminates the radio protocols (MAC and PHY) on the UT side as well as on the BS side and, in case of more than two hops, also on the RN side. The RN_{LN} does not terminate the transport network layer protocols. It contains a single MAC entity corresponding to a single cell.
User Terminal Logical Node	**UT_{LN}**	A logical node comprising all functionality necessary for it to communicate directly with another UT_{LN} or the RAP.
Radio Access Network Gateway	**$RANG_{LN}$**	A logical node terminating the RLC-UP protocols.
Access Control Server	**ACS_{LN}**	A logical network node that controls the access to the radio interface resources. It terminates Control Plane protocols of the RLC.
Access Router Logical Node	**AR_{LN}**	A logical IP layer node that performs the tasks attributed to an Access Router as defined in relevant IETF specifications. In the WINNER architecture the AR_{LN} contains all functionalities of the IP Convergence Layer (CL).
Cooperative RRM	**CoopRRM**	The CoopRRM will be responsible for the decision making process of the cooperation mechanisms (handover, admission control and QoS management) and is foreseen to be physically located outside of the involved RANs.
Radio Access Network	**RAN**	The WINNER RAN comprises $BS_{LN,}$ $RN_{LN,}$ $RANG_{LN,}$ $ACS_{LN,}$ AR_{LN}

2.4 Links, Flows, Cells and Handovers

Link	**-**	A link is a radio connection between two physical network elements of the WINNER access system. It subdivides into relay link between radio access points and the user link between the user terminal and the radio access point.
Flow	**-**	A flow is a packet stream from one source to one or several destinations, classified by QoS requirements, source and destination(s)

Cell	**-**	A cell is defined by the geographical coverage area of its broadcast channel. A cell uses a single PLM on a particular carrier frequency.
Base station serving area or Relay enhanced cell	**REC**	The geographical area covered by the broadcast channels of cells whose resources are managed by a single base-station and its connected relay nodes.
Multi-Homing (Multi – RAN Transmission)	**-**	Multi-homing means that a UT is associated to more than one RAN simultaneously.
Multi-Mode-Transmission	**-**	Multi-mode-Transmission means that a UT is connected by more than one link to different cells of one WINNER RAN. These cells use either different WINNER PLM or the same mode at different carrier frequencies.
Handover	**HO**	A Handover is a change in the set of links between a RAP and a UT. This includes a hard “switch” from one cell to another, moving into and out of a multi-mode-transmission and a changing of the links used for multi-mode-transmission
Intra-system HO	**-**	Intra-system HO is a handover between two different radio cells within the same system, with the same or different radio mode. It subdivides further into Inter-mode HO, Inter-cell HO and Inter-frequency HO. The term horizontal handover is equivalent to intra-system handover.
Inter-mode HO	**-**	Inter-mode is a intra-system-handover between WINNER cells operating in different system modes (FDD, TDD and P2P).
Intra-mode HO	**-**	Intra-mode is a intra-system-handover between WINNER cells operating in the same system mode (FDD, TDD and P2P).
Inter-cell HO	**-**	Inter-cell HO is a intra-mode-handover between WINNER cells operating in the same system mode at the same frequency.
Inter-frequency HO	**-**	Inter-frequency HO is an intra-mode handover between WINNER cells operating in the same system mode but at different frequencies.
Inter-system HO	**-**	Inter-system handover: An inter-system handover is a handover between two different radio systems e.g. WINNER <->WLAN, UMTS <->GSM. Two subcategories are distinguished: inter-system handover of radio networks belonging to the same operator and inter-system handover of radio networks belonging to different operators. The term vertical handover is equivalent to inter-system handover.

2.5 Transport Channels

Transport channels		Transport channels have in the WINNER system been defined as the User Plane interface between the RLC and the MAC.
Broadcast Channel	**BCH**	For control information to all terminals within a cell.
Random Access Channel	**RAC**	Contention based random access channel, for initial access to master device
Direct Access Channel	**DAC**	Contention based direct access channel
Common Data Channel	**CDC**	Scheduled transport channel for point-to-multipoint communication
Targeted Data Channel	**TDC**	Scheduled transport channel for point-to-point communication
Protocol Data Unit	**PDU**	Output from a protocol layer
Service Data Unit	**SDU**	Input to a (protocol) layer. A packet in a transport channel is a MAC SDU and a RLC PDU

2.6 MAC and PHY-specific Terms

Service level controller	**SLC**	Service level controller in RLC User Plane
Resource scheduler	**RS**	MAC User Plane. Controls the resource mapping onto PHY channels
Service level control buffer	**SLCB**	Flow queuing in RLC layer for scheduled flows. The SLCB contains MAC SDUs.
Resource scheduling buffer	**RSB**	Per-flow queuing in MAC layer for scheduled flows. Each RSB contains one queue per active flow and one RS controls it. A RSB contains coded segments of MAC SDUs, denoted FEC blocks
Cyclic Redundancy Check	**CRC**	Code sequence added to re-transmission units
MAC Re-transmission unit	**RTU**	Retransmitted individually by link ARQ for scheduled flows and DAC. Formed by (a segment of) a MAC SDU +CRC code+ segment number
FEC block		Coded transmission block with whole or part of an RTU as payload. Content of RSB.
Adaptive resource scheduling	**ARS**	Uses channel quality or state info. at the transmitter
Non-frequency-adaptive resource scheduling	**NRS**	
Chunk		Basic resource unit on radio channel. A time-frequency resource consisting of nsub adjacent subcarriers and nsymb consecutive OFDM symbols with chunk duration Tchunk
Chunk layer		Chunk within one spatial channel (layer). There are Qc layers in the cell.
Generalised Multicarrier Transmission	**GMC**	Has OFDM and frequency-domain based serial modulation as special cases. See [WIND21] and [WIND23].
Slot		Time interval for uplink or downlink transmission in half-duplex FDD and in TDD.
Frame		Time-frequency-spatial resource unit. The frame duration in time covers one uplink slot and one downlink slot in half duplex FDD and TDD transmission.
Superframe	**SF**	Time-frequency-spatial unit on the physical channel. Contains resources for all transport channels and control signalling, and includes main synchronization pilot symbols. Consists of preamble followed by a number of frames.
Resource mapping		Mapping of FEC blocks onto SF preamble and chunk layers.

2.7 Spectrum related Terms

Coexistence		The concurrent operation of different services or RANs in the same or in adjacent frequency bands without causing degradation to any service, with emphasis on the indicated limitations in terms of, e.g., frequency separation, physical separation, and transmission powers.
Sharing		The use of a same frequency band by different RANs or services, either with coordination or possibly without any coordination between the systems, with emphasis on the spectrum access schemes and methods.
Dedicated Spectrum		Spectrum is available for a single deployment of the WINNER based RAN (e.g. similar to current GSM bands).
Single system shared spectrum		Spectrum is available for WINNER only, but multiple independent deployments are possible in the same bands (e.g.

	similar to current DECT bands).
Open shared spectrum	Spectrum can be used by WINNER (one or more deployments) and also other systems (e.g. similar to ISM bands).

3. Vision

The goal of WINNER is to define a ubiquitous radio access system concept, capable of providing the connectivity required to enable the long-term vision of the "Wireless World". This vision has at its heart the idea of user centricity – new technologies are not introduced just because they exist, but because they address the users' needs and desires.

In order to address the goal of WINNER within this vision, the following general assumptions form the guiding principles towards a WINNER system concept:

- WINNER will develop a single new ubiquitous radio access system concept whose parameters can be scalable or adapted to a comprehensive range of mobile communication scenarios from short-range to wide-area.
- The ubiquitous radio access system concept will provide terrestrial communications, but not including BAN and PAN elements.
- The ubiquitous radio access system concept will be self-contained, allowing WINNER to target the chosen requirements without the need for interworking with other systems.
- Where other systems are available (including BAN/PAN, as well as, for example, evolved 3G and WLAN), cooperation, interworking and infrastructure reuse may be used for mutual benefit. The WINNER concept will fit into a multi access structure allowing an "Always Best Connected" solution.
- First deployment expected at the earliest in 2010, widespread from 2015.
- The WINNER RAN should provide significant benefit to users, manufacturers, providers and any potential actors compared to alternative technologies, such as evolved 3G or WLAN systems. Examples of benefit might include cost, performance, and ease of use or ubiquity of service availability.
- Requirements will be further developed which relate to the expected stakeholder experiences. E.g. from the end user perspective, continuous & ubiquitous link throughput, delay and negotiable quality of service.
- WINNER develops a single Radio Access Network (RAN)
- The WINNER RAN is further based on one WINNER Radio Access Technology (RAT). The WINNER RAT may provide different modes to come up with a flexible solution for different scenarios and propagation conditions.
- The ubiquitous radio access system concept will be scalable in terms of service requirements, capacity-per-area-unit and stepwise increasing complexity and related performance.

Details about WINNER requirements can be found in [WIND71].

4. Innovations

The WINNER system concept is designed to support and integrate a large number of innovative features. These features are summarized below and references are given to the following chapters explaining the technical details.

4.1 Physical and MAC Layer

A radio interface based on self-organised synchronisation

The basic radio-interface, and its superframe, is designed to accommodate self-organised synchronisation not only of user terminals, but also of base stations and relay nodes that may belong to different operators. This enables an improved spectral efficiency in two ways: it makes large guard bands unnecessary and it enables interference-avoidance scheduling between cells and relay nodes on a fine granularity in time, space and frequency (see 5.5.4.1).

Integration of transmitters with single-carrier waveforms with OFDM transmission

While OFDM is the primary choice for downlinks, the proposed framework for uplink transmission is GMC (generalised multicarrier). Within this framework (see 5.5.1.4), transmissions that have single-carrier waveforms (frequency domain based serial modulation) can be generated within a multicarrier transmitter by per- forming an extra FFT operation. This is of interest to minimize the peak-to-average power ratio of the transmitted signal, which is important in uplinks from power constrained terminals. The uplink GMC framework enables transmitters that use OFDM to co-exist with others that use serial modulation. They may share a common frequency range and take part in the above mentioned self-organised synchronisation loop.

Enabling technologies for adaptive transmission

Work within the WINNER project has shown the feasibility of two other key enabling technologies for adaptive transmission:

- The use of channel prediction (see 5.5.4.3) and the short control loop delays enable adaptive allocation for terminals that move at vehicular velocities, with sufficient accuracy, even at 5 GHz carrier frequencies.
- Compression techniques (chapter 5.5.4.4) radically reduce the feedback control data rates required in such adaptation control loops to acceptable levels.
- The concept of Frame Descriptor Tables (FDTs) introduced is a promising means to mitigate the need for resources necessary to transmit control information in wireless mobile radio systems of the next generation. MAC protocols using a frame based reservation scheme have an inherent necessity to inform associated stations about the resources they have been scheduled for. When the control information is designed to describe the whole frame layout in each frame, this result in a high percentage of control data compared to user data to be transferred. The general idea of the concept of FDTs is the “coding” of control information to reduce the amount of data to be sent.

As a result, adaptive transmission can be performed in a wide variety of situations.

However, non-frequency adaptive allocation is implemented as an important fallback alternative for situations and types of flows where adaptive transmission is infeasible. Examples include terminals at very high speeds (where channel prediction is unreliable) and multicast flows. The non-frequency adaptive transmission averages over the frequency-selective fading, but still adapts to the shadow fading, on a slower time-scale.

Low radio interface delay

The design is optimised for very low transmission delays over the radio interface (around 1ms over one hop). This makes it possible to use hybrid ARQ for most types of services and packet flows, also delay-sensitive ones. Retransmission at lower layers is an effective tool for stabilising the quality of the transmission channel as perceived by higher layers. The detrimental effects of transmission errors on higher layer protocols such as TCP can then be reduced.

Multi-antenna transmission that is adaptively tuned per flow

A flexible multi-antenna transmission scheme has been proposed (see 5.4.2.1 and 5.5.1.5), that includes diversity-based methods, multiplexing and beamforming as special cases. The scheme is selected per flow; this means that two flows to/from the same terminal may use the available antenna resources at the transmitter and receiver in different ways: An adaptively allocated flow may e.g. use multiplexing to boost the performance while a non-frequency adaptively allocated flow may use a diversity scheme (space-time-frequency coding) to reduce the probability of transmission errors.

Aspects of spatial processing solution (chapter 5.5.1.5)

- Spatial multi-user link adaptation is used as integrated part of the WINNER system concept. A multi-user spatial link adaptation concept has been developed that is scalable with respect to the channel state information at the transmitter, adapts to a wide range of operational scenarios by fostering spatial diversity, spatial multiplexing, SDMA, and enhanced interference management techniques in variable combinations.
- It is the first time that non-linear precoding techniques are integrated into a wireless system design.
- Successive Minimum Mean Square Error (SMMSE) including SDMA is a novel linear multi-user precoding technique developed within WINNER.

Self-Organising Radio Resource Management

A single frequency network, where all cells can access all radio resources brings the challenge of co-channel interference control. One method requires communication among base stations (BSs) to exchange information. However this requires large overheads in both the hardware (e.g. cable connections) and software (protocols, signalling, etc). Self-Organising Radio Resource Mangement has neither a central controller nor direct communication between BSs. Each BS independently makes its own decision on resource management. The BS and the user terminal (UT) cooperate in the resource allocations. They measure and estimate the possible SINR values on all available subcarriers, and select the ones with highest SINR. This is done independently in each BS-UT link.

4.2 Protocols and Resources

Multi-mode protocol stack and Mode Convergence Manager

To enable ubiquitous broadband service in a wide variety of scenarios, the WINNER air interface concept envisages multiple modes of operation (further described in chapter 8).

As part of the work on deployment and system concepts performed in WINNER Phase I, a reference model for the implementation of a flexible protocol stack has been developed.

Key aspects of the reference model are:

- a separation of the protocol functionality into mode-specific parts and parts that all modes have in common (mode independent parts),
- an interworking structure enabling to provide mode-specific behaviour of the protocol software through combination and parameteriztion of mode-specific and mode-independent functions and
- managing functions to control the above mentioned combination and parameterization.

As a result, the reference model allows for:

- cooperation and coexistence of different air interface modes, to enable an easy implementation of multi-mode devices and efficient switching between modes and
- an improved and efficient design process, where commonalities between modes can be identified and exploited and design overhead can be kept low.

This efficient integration of multiple modes is termed "*Modes Convergence*". Devices with a protocol software conforming to this modes convergence reference model will dynamically adapt to different WINNER modes, which gives them maximum flexibility and reduces the complexity overhead compared to "conventional" multi-mode devices (e.g. combined 3G / GSM handsets).

The dynamic adaptation to certain modes and the handling of the protocol software is enabled by the so-called *Modes Convergence Manager*, under which the set of managing functions can be understood that is necessary to achieve mode-specific behaviour of the protocol software and coordinated operation of multiple modes. The Managing functions can be logically divided into functions controlling single protocol layers (Layer-X Modes Convergence Manager) and functions controlling the entire protocol stack (Stack Modes Convergence Manager).

Re-transmission protocols

The introduction of intermediate or relay nodes means that new challenging problems need to be solved to ensure reliable information transfer over an entire multi-hop chain. Novel re-transmission schemes with elaborated status reporting mechanisms have been proposed such that the sender (source) can distinguish between intermediate node and final (destination) receiver status. When compared to prior-art schemes, these protocols allow re-use of protocol state information, lowered number of unnecessary re-transmissions, and reduced overhead. Further description can be found in chapter 5.3.2 and [WIND32].

Two layerered scheduling, namely service level controller and resource scheduling

The *Service Level Controller (SLC)* (see 5.3.2.1.3) is foreseen to have the overall responsibility for adjusting inter-flow fairness, assuring the fulfilment of service level contract agreements and total delay constraints. It may perform by requesting resources from several BSs that may utilise different WINNER modes working on a slower time scale and may allocate resources belonging to several modes/base stations. As buffer management and traffic policing could impose constrains on the service level controller, they could be located at the same node. All packets are then forwarded to the SLC cache and are treated by the resource scheduler RS which schedules them based on channel state and queuing time.

Multi-Mode transmission

Efficient multi-mode operation requires algorithms for the selection of one or several modes to serve a particular flow/user. The mode selection could run on different time scales depending on whether it is done per call or session (slow selection), per packet (fast selection), or triggered by non-traffic related events like changes in radio conditions (mode re-selection). This is carried out by the micro-mobility control (described in chapter 5.3.3.3)

More frequent mode selection will lead to larger potential capacity and quality gains (through exploitation of “mode-selection diversity”), but can increase signalling load. In some cases mode selection will require user interaction or be dictated by an application (also referred to as slow selection or even re-selection).

Packet based system design: flow concept

The WINNER RAN has been developed to be a packet based system right from the beginning. For example, there are no radio bearers or long term radio channel allocations, like in traditional cellular systems which have been designed, first and foremost, for circuit-switched voice traffic. In the WINNER concept, radio resources are allocated dynamically whenever there are packets to be transmitted. Instead of a radio bearer, WINNER utilizes the concept of a flow that is internal to the RAN (i.e. it is not assumed that the flow would be established above the WINNER RAN). The User Plane of the top – system layer IP – convergence receives IP packets from the user of the WINNER RAN, maps them into flows and performs header compression and decompression. Different flows of one user are treated independently, allowing indidvidual transmission according to their specific quality-of-service requirements.

Spectrum sharing

It is the first time a wireless system design includes RRM functionalities for coordinated spectrum sharing with other radio access networks using the same radio access technology as well as for spectrum sharing with other radio access technologies. The functionalities (details can be found in 5.3.3.5) include:

- Spectrum sharing with other RATs; Functionalities for controlling the emissions of WINNER transmissions and hence avoiding interference towards legacy systems will form part of the system concept. Varying coordination capabilities from simple beacon to complex negotiation can be taken into account after the other RATs are identified. These novel functionalities allow making more efficient use of the spectrum while ensuring co-existence of heterogeneous systems in the same frequency band.
- Spectrum sharing with other WINNER RANs. This provides flexibility in the spectrum assignments that supports:
    1. gradual, step-by-step deployment of WINNER RANs as well as the deployment of different sizes of WINNER RANs and
    2. spectrum assignment adaptation to the changes in the networks traffic load, ranging in time scale from slowly changing market shares to rapid & local differences on the traffic load and, hence, intensifying the use of spectrum

4.3 Deployment Concepts and Architecture

Establishment of Layer-2 Relay as an integral part of the system concept

Multi-Hop relaying of user data represents an integral part of the WINNER system concept. The relaying functionality is envisaged to be performed on layer 2 according to the ISO/OSI reference model, Therefore the WINNER radio network deployment concept is based on Relay Enhanced Cells (RECs), which are formed out of one BS and its connected Relay Nodes (RN), which provide a key aspect of the WINNER system. Thereby the integration of relay nodes does not rule out the possibility of deploying WINNER nodes in a conventional single-hop deployment concept. The application of RECs for ubiquitous radio access in wide area and local area/metropolitan scenarios allows for a radio network deployment concept that is:

- flexible due to:
  1. the capability to set up RNs on demand and
  2. the higher freedom of placement as no direct backbone connection is required, but only power supply.
- fast, as no wired infrastructure has to be deployed for the RNs and
- cost efficient:
  1. as no direct connection to the fixed network is required, neither by wire nor by other radio links (extra HW cost – CAPEX) and
  2. little maintenance is required due to self-organisation of relay nodes (OPEX).

RNs in the radio network deployment allow for a variety of network optimisations. RECs can be designed to:

- enlarge the coverage range of one BS,
- increase the capacity at the cell border of a given BS cell,
- balance the available capacity per area element,
- reduce the required transmission power and emitted interference and
- cover areas otherwise uncovered due to shadowing.

From a protocol point of view, the relay node is designed so that it appears to the UT such as a BS, which allows keeping the UT complexity low. The coordinated resource partitioning between BSs and RNs allows for optimising the mutual interference situation, both inside one REC and between RECs.

Scalable architecture

A desirable property for a ubiquitous radio system is scalability as the number of possible deployment scenarios is large and the range of supported data rates is wide. The radio protocol architecture is therefore based on a clear distinction between User Plane and Control Plane protocols that may be located in separate physical or logical nodes. In that way, functions that deal with user data and network control may have independent evolution and scalability.

A flexible node architecture model (see chapter 6) is also proposed that aims to support a large variety of deployment scenarios while still keeping the number of logical nodes and interfaces at a manageable level. Segmentation and reassembly strategies have been proposed that can handle variable sized (upper layer) packets over a wide range of data rates.

4.4 Co-operation

Cooperation with legacy RANs

To exploit the installed base of wireless systems and to allow the gradual introduction of WINNER networks WINNER RRM enables the inter-working of multiple RANs, including legacy RANs, and operators (domains). Current RRM solutions consider primarily a single Radio Access Network (RAN) owned by a single instance.

In addition to the intra-RAN cooperation mechanisms, the WINNER RRM architecture supports new inter-RAN cooperation mechanisms: mobility management including handover, admission control, congestion/load control and QoS-based management. These are described in [WIND41].

The logical nodes in charge of these co-operations are the specific RRM (SRRMw) for co-operation between WINNER modes; and CoopRRM for co-operation between WINNER and legacy RANs). The CoopRRM is no inside the WINNER system whereas the SRRMw is part of the RLC Control Plane (chapter 5.3.3). Full details can be found in [WIND43]

Location Based Inter-System Handover

It is foreseen that in future the wireless terminal will be able to use different wireless systems. However, the new association of the terminal can only be initiated if respective information about the status of the destination network is available, currently the terminal itself synchronize and take measurements in the destination network, but this complexity and time consuming task will be increased even more in the case of multi-RAN terminals. In Location Based Vertical Handover (LVO) the terminals timely and autonomously perform measurements and send a status report (measurements and location) to a central repository (Hybrid Information System) of the system they are connected. A terminal in a foreign network could quickly and efficiently anticipate the link condition using the measurements in the target cell adopting measurements of a nearby-located terminal connected to the target system. Again further description is contained in [WIND43].

Use of Advance Triggers

Besides traditional physical-based layer 2 triggers (signal strength, interference level, BER, PER, etc.), advanced higher layer triggers (QoS violation, location, service availability, load condition, buffer occupation, etc.) will be used by the cooperation mechanisms. These are part of the RLC (chapter 5.3).

5. Functional Architecture

This chapter describes the functionalities within a WINNER RAN in a service-oriented way. This follows a top-down system engineering approach [Lep05] adopted partly by WP7 in the description of the system architecture. In this approach the system services and their users are first identified. The external behaviour of the services is then described by way of state-machines (service specification phase). Next the services are broken into service components and the execution logic and usage of other service is described, again with state machines (service decomposition). These two phases lead into a functional architecture where the functionalities are broken into a hierarchical structure with behavioral description, without addressing the distribution of the functionalities into logical system nodes. Only in the third phase, service distribution, the functionalities are placed in the system nodes. The advantages of this approach, when fully adopted, are much improved control over system complexity and reduced development time.

This chapter shows how the system services are placed in system layers and what kind of services the lower layers offer to the layers above. Implementation of the services is touched only at the level that is necessary for understanding the functional flow. Note that the distribution of service components over the network elements is not addressed in this chapter. The protocol architecture descriptions in [WIND31] and [WIND32] represent this distributed implementation of service components.

The system layers consist of services. Each service has a set of users that typically are served in the layers above (but not necessarily). The service to the users is offered through service primitives. These are signals that are visible in the *Provided Service Access Point (PSAP)* of the service. They describe the communication between the user and the service. It is worth mentioning, that this type of communication (between the user and the service) is different from the communication between protocol peer entities where two parties at the same level are communicating with each other. For the same reason, the functional architecture and its system layers should not be confused with the notion of protocol architecture and protocol layers (which represent the distributed implementation of the service components).

In the following description, the external behaviour of the services (the exchange of service primitives between the user and the service) are described by way of PSAP state machines. The notation used in this document follows loosely UML2.0 notation, with some simplifications and modifications in order to keep the notation compact and informal. The state machine notation is shown in Figure 5-1. Each state machine contains a single entry point, where the execution starts. The red state transition arrows describe the flow of execution between states. These should not be confused with information flow. It is possible to mark the transition with a trigger event that causes the transition. This can either be an arriving signal (blue arrow towards the transition line) or some other trigger event (red text in brackets). The state transition can also contain an action, which is typically sending a signal (a blue arrow away from the transition). The sources of the triggering signals, i.e. the users of the service, are shown in the grey boxes above or below the state machine. The single state symbol denotes a state where nothing, other than waiting a trigger, is performed. A composite state is a collection of states and tasks, which perform a certain function. A task symbol can be used for a simple function, e.g. assigning a variable. Finally, the state machine can contain multiple exit symbols, which can be marked with a name.

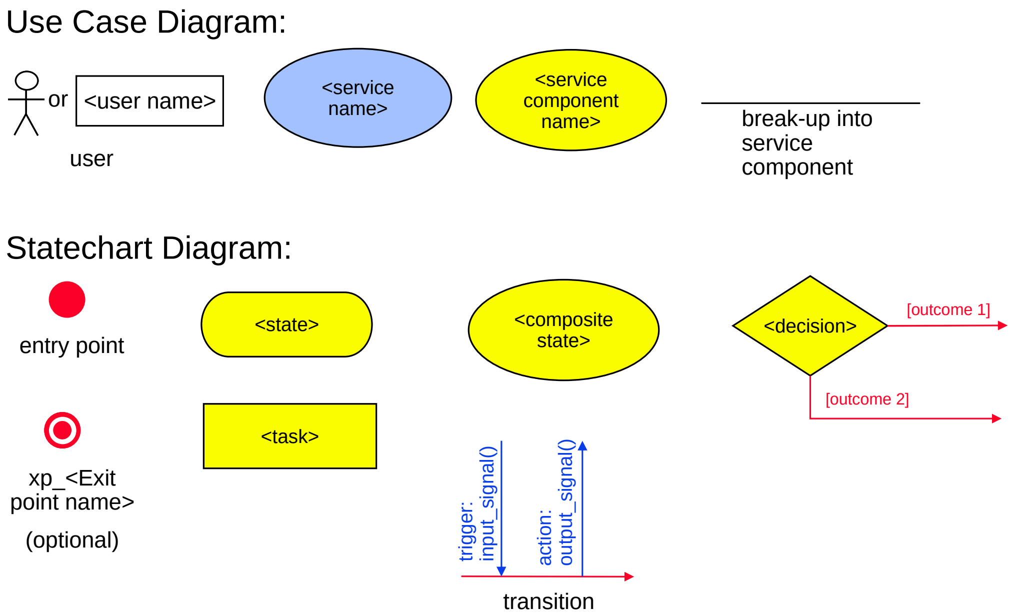

Figure 5-1: The symbols used in the service specification figures in this chapter

Often a service needs to be broken into parallel service components, for each of which the PSAP state machine is then presented. The break-up of a service into the service components is described using modified UML Use Case Diagrams. In these diagrams, the service components (yellow bubbles) are connected to the service (blue bubble) by black solid lines.

The service structure shown in this document follows the outcome of service specification work done in WP7 and other WPs. The internal UML-style document that resulted from this work is too big to be included in this document.

5.1 Overview

The WINNER concept consists of four system layers (see Figure 5-2). The layers are further divided into User Plane (UP) and Control Plane (CP). Those services that need to operate on individual data units (IP packets or lower layer PDUs) have been placed in the UP. The CP services operate on longer time scales and control the operation of the UP services by way of control signalling.

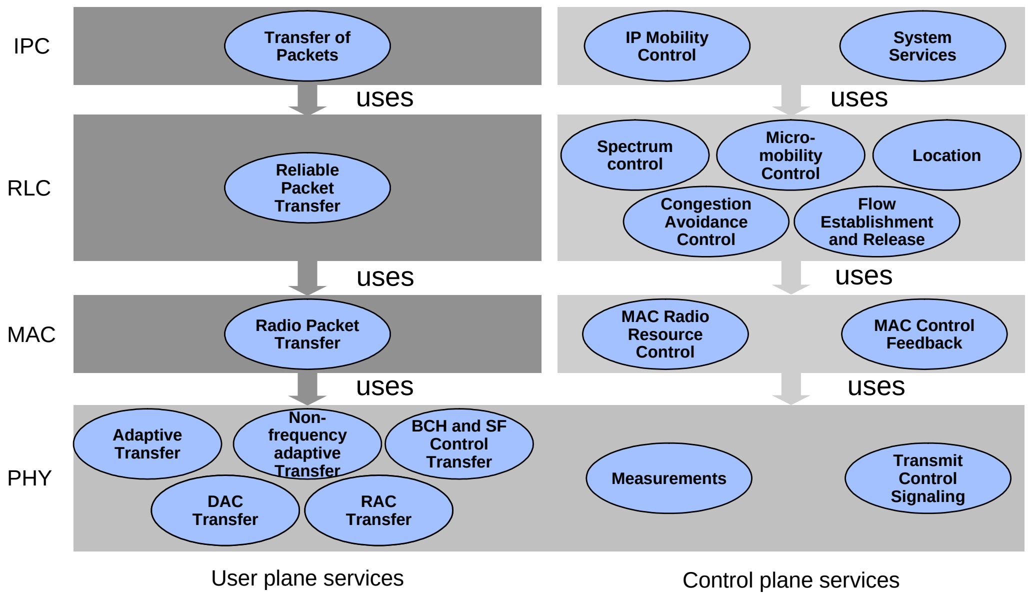

Figure 5-2: The layers and services of WINNER

The rough functional role of each layer is as follows:

IP Convergence (IPC) Layer

The UP of the IPC layer receives IP packets from the user of the WINNER RAN, maps them into flows and performs header compression and decompression. The CP is responsible for RAN association functions as well as macro-mobility (IP level mobility).

Radio Link Control (RLC) Layer

The UP of the RLC Layer provides reliable packet transfer over the air-interface. It also performs confidentiality protection and packet prioritization in order to meet the QoS goals. The CP takes care of flow establishment and release, location services, load, spectrum and micro-mobility control.

Medium Access Control (MAC) Layer

The MAC UP provides the service "Radio Packet Transfer", i.e. transmission and reception over the radio interface of packets. An important part of this service is the scheduling of packets over the radio interface. The Control Plane provides the "MAC Radio Resource Control" service, i.e. acceptance and execution of control messages from higher layers that specify required transmission parameters and boundary conditions. Furthermore it implements "MAC Control Feedback", i.e. messaging that supports the flow control, the QoS control and the spectrum assignment and other functions at the RLC layer.

Physical (PHY) Layer

The PHY layer handles the physical transmission of chunks and measurements and control signalling directly related to the radio interface. The PHY layer is not separated into UP and CP since it is assumed that all control functionality for the PHY layer resided within the CP of the MAC layer.

5.2 IP Convergence Layer

5.2.1 Overview

The IPC layer services and their users are shown in Figure 5-3. The grey boxes on top denote the users, whereas the blue bubbles are the services. The blue lines show the usage relationships. IP Layer_U and IP Layer_C in front of the user names denote that the users are located in IP Layer User and Control Planes, respectively (external to WINNER RAN). In chapter 5.2.3.1.1 we refer to an entity called *CoopRRM*. CoopRRM refers to the Cooperative RRM entity that controls the usage of different radio access networks (see chapter 5 of [WIND43]).

This description of the IP Convergence Layer should be understood as a proposal how the WINNER RAN connects to an IP network. It is foreseen that many of the functionalities now included in the IPC layer will be developed further outside WINNER, for example, in the WWI project Ambient Networks [AN].

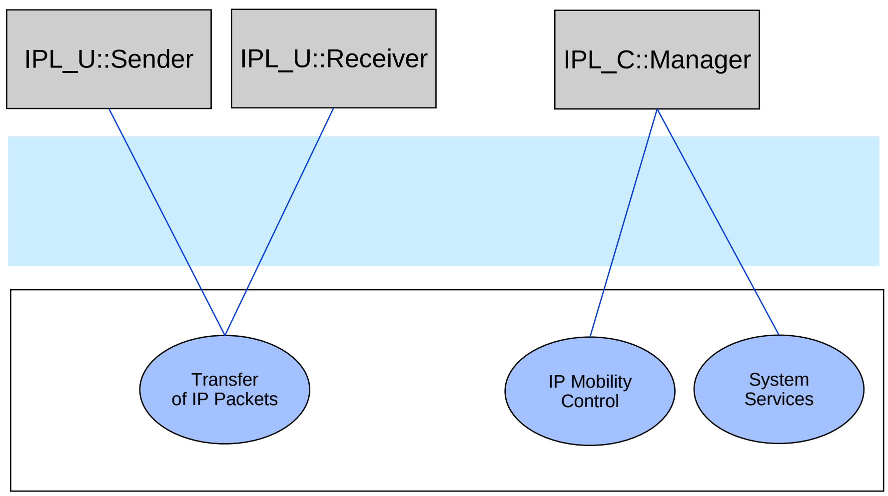

Figure 5-3: The users and services of the IP Convergence Layer

5.2.1.1 Advantages compared to existing technologies

WINNER RAN has been developed to be a packet based system right from the beginning. For example, there are no radio bearers or long term radio channel allocations, like in traditional cellular systems which have been designed, first and foremost, for circuit-switched voice traffic. In the WINNER concept, radio resources are allocated dynamically whenever there are packets to be transmitted. Instead of a radio bearer, WINNER utilizes the concept of a flow that is internal to the RAN (i.e. it is not assumed that the flow would be established above the WINNER RAN). When an IP Packet arrives to the WINNER RAN, the IPC layer associates it with a WINNER flow, based on the information in the IP packet header. The information about the flow is stored in the flow context. If a suitable flow does not exist, a new flow is initiated. For such a packet that does not require a flow, a default flow is used without header compression. This capability ensures that all packets travelling through the WINNER RAN are treated effectively and consistently regardless of where or how they originate. The only requirement is that the IP header has information of the service class, or that it can be induced from the IP header.

5.2.2 User Plane Services

5.2.2.1 Transfer of IP Packets

The IPC layer has only one UP service, *Transfer of IP Packets*. It breaks into two service components, *Send IP Packet* and *Receive IP Packet*, as shown in Figure 5-4, depending on whether the IPC layer is sending or receiving, packet over the WINNER RAN, respectively. There is one instance of this service for each UT, i.e. the service is UT-specific.

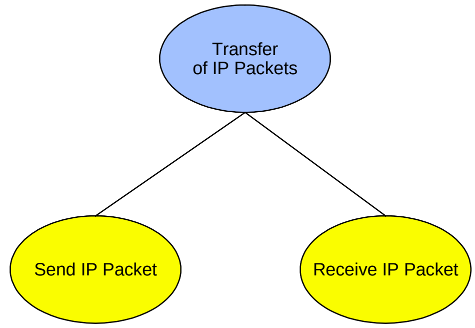

Figure 5-4: The service components of the IPC layer UP service Transfer of IP Packets

5.2.2.1.1 Send IP Packet

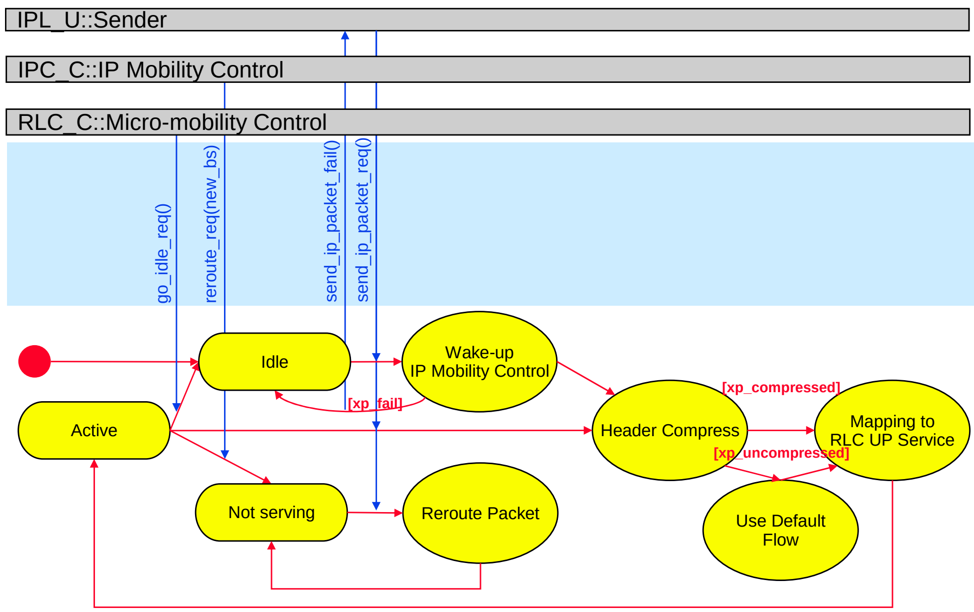

Figure 5-5: The external behaviour and execution logic of the Send IP Packet service component shown as a PSAP state machine

The PSAP state machine of *Send IP Packet* is shown in Figure 5-5. The service component has three users: the *Sender* entity outside WINNER RAN (e.g. above IPC in the terminal stack), *IP Mobility Control* in the IPC layer and *Micro-mobility Control* in the RLC Layer. The two mobility related CP services control the behaviour of *Send IP Packet* through specific service primitives. Note that entities within or under the IPC layer can also act as users and request/trigger actions.

Idle: When an instance of this service is created, it goes to an *Idle* state. This state corresponds to the situation where there is no traffic between the UT and the network and there is no need for *IP Mobility Control* to track the UT with an accuracy of a single cell. Only arrival of a new PDU from *Sender* triggers transition from this state.

***Wake-up IP Mobility Control*:** This returns idle-state *IP Mobility Control* to active state by sending it a wake-up signal when a packet is received from higher layers. If, for some reason, the wake-up is not possible, *Sender* is notified by a failure signal. *Sender* is not signalled by the User Plane of the RLC Layer whether the IP packet was successfully sent or not.

Header Compress: The availability of a suitable flow is checked based on the information in the IP header. If a suitable flow exists, the header is compressed using the flow ID and the execution returns via exit point *xp_compressed*. If no suitable flow exists, a new flow is requested from *Flow Establishment and Release* service on the RLC Layer. At the same time a flow context is established. The flow context is internal to the WINNER RAN and holds flow ID, source and destination addresses, service profile information, and internal routing data. For some packets establishment of a new flow may be inefficient. For such cases, no compression is done and the execution returns via *xp_uncompressed.*

Use Default Flow: The IP packet is mapped to a default flow that always exists between a given UT and the network.

Mapping to RLC UP Services: Here the decision is made which RLC service to use for sending the packet. The IP packet is then sent to RLC for further processing.

Activ: This is the state where *Send IP Packet* normally waits for new packets to arrive from IP Layer. There are three possible triggers from this state: (1) Arrival of a new packet triggers transition to *Header Compress*. (2) The signal *go_idle_req* from RLC *Micro-mobility Control* triggers transition to the *Idle* state. This happens after a passive period exeeding a certain length as decided by *Micro-mobility Control.* (3) The signal *reroute_req* from *Macro-mobility Control* triggers transition to *Not Serving* state.

Not Serving: This state is entered after handover, where the old access point stops serving a UT. Packets that still arrive need to be re-routed to the new access point. The state is only present in an access point.

Reroute Packet: In this composite state the packet is re-routed to a new access point after handover.

5.2.2.1.2 Receive IP Packet

The *Receive IP Packet* service component is depicted in Figure 5-6. The functionality is much simpler than in the sending side as there is no need to track the mobility state.

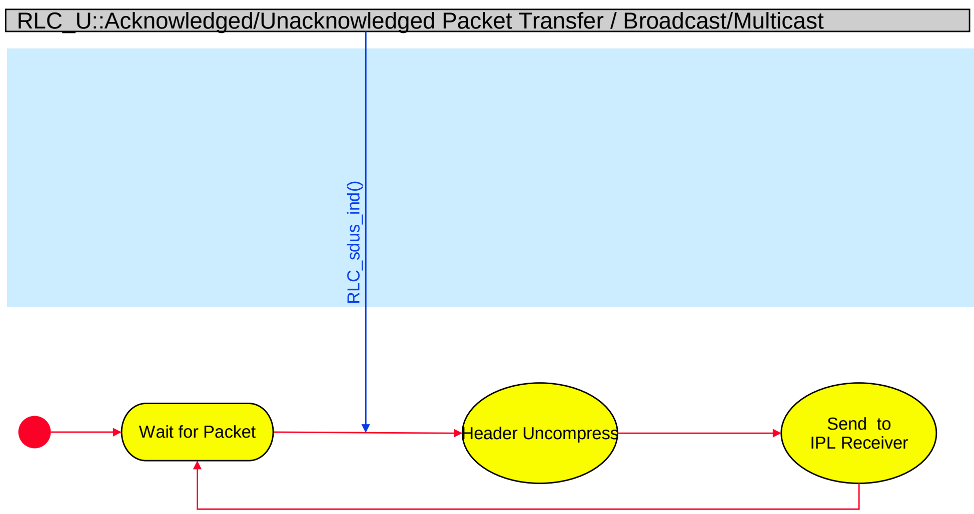

Figure 5-6: PSAP communication of the Receive IP Packet service component

Header Uncompress: The IP header is regenerated based on the flow ID and the flow context information. RLC encapsulation is removed (e.g. flow ID). If the default flow is used, only the RLC encapsulation is removed (no header compression was applied by *Send IP Packet*).

Send to IP Layer Receiver: In the composite state the packet is moved to IP Layer.

5.2.3 Control Plane Services

5.2.3.1 IP Mobility Control

IP Mobility Control consists of two service components, *Macro-mobility Control*, which takes care of network access and IP mobility in network connected operation, and *Ad-hoc Connection Control* (Figure 5-7).

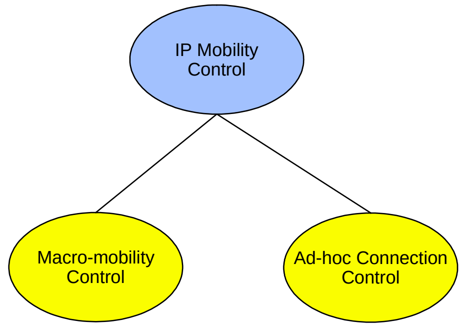

Figure 5-7: Components of the IPC layer CP service IP Mobility Control

5.2.3.1.1 Macro-mobility Control

The external behaviour and main execution logic of *Macro-mobility Control* is shown in Figure 5-8. The states and composite states are explained below.

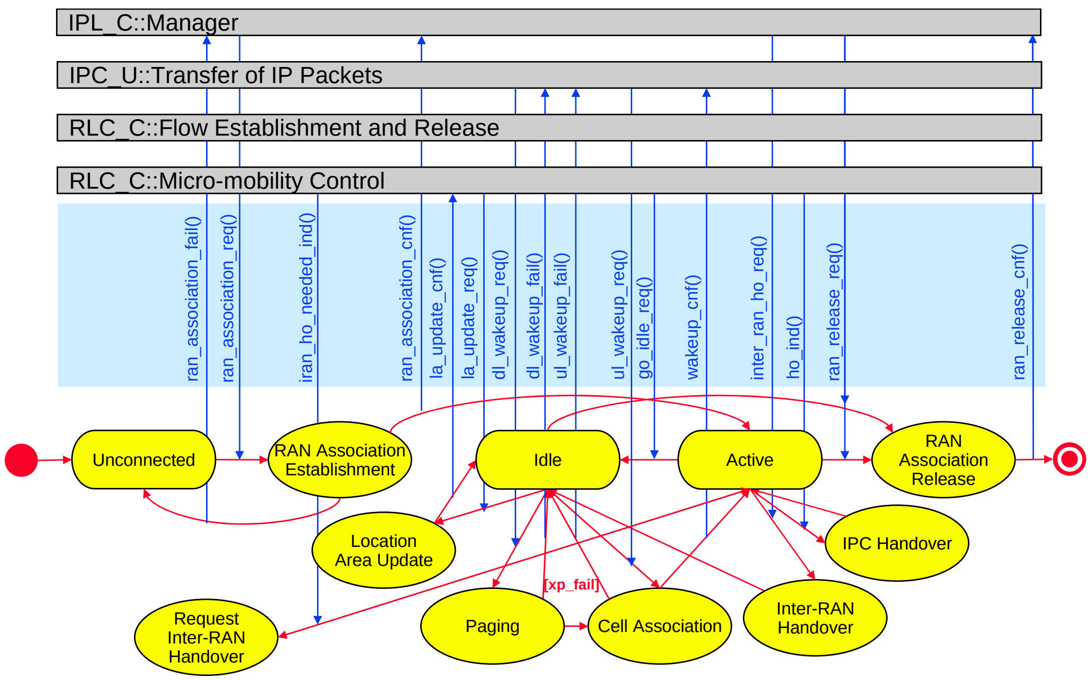

Figure 5-8: Users and the PSAP state machine of the IPC layer service component Macro-mobility Control

Unconnected: This state is entered in start-up. Only a *ran_association_req* signal from *CoopRRM* external to the WINNER RAN triggers transition from this state.

RAN Association Establishment: This composite state associates a single UT to the WINNER RAN. It consists of initial access, network and UT authentication, authorization, user policy establishment and charging initiation. After successful completion, the execution transfers to state *Active.*

Active: In this state *Macro-mobility Control* accepts triggers to initiate various activities. Typically the triggers are related to handover and originate from the RLC Layer, where the need for handover is first recognized.

IPC Handover: The IPC Handover is triggered by handover indication from the RLC Layer. It consists of a routing table update and global binding update, if needed. These operations are not performed if the handover does not affect IP routing.

Request Inter-Ran Handover: A request from RLC *Micro-mobility Control* triggers entry to this composite state, where the IPC layer requests the IP Layer *CoopRRM* entity to initiate handover to another RAN.

Inter-RAN Handover: When the IP Layer *Manager* is ready for handover, it triggers entry to this composite state. *Inter-RAN Handover* consists of moving the flow context information to IP Layer and returning any unsent packets to the IP Layer UP. After inter-RAN HO, the execution returns to the idle state, i.e. the RAN association still remains. This allows the UT to be connected to multiple RANs simultaneously (multi-homing).

Idle: *Macro-mobility Control* enters *Idle* state upon request from RLC *Micro-mobility Control.* In this state the location of the UT is not tracked with the accuracy of a single cell. Cell association and paging (in downlink) are needed to start communication.

Location Area Update: This is triggered by RLC *Micro-mobility Control* when it notices that the location area has changed. The location area defines where (by which base stations) paging is done in the WINNER RAN.

Paging: Paging is triggered by *Transfer of IP Packets* whenever a packet needs to be sent over the WINNER RAN but the location of the user is not known (*Idle* state). Paging locates the user with the accuracy of a single cell. It is implemented by a request to *MAC Control Feedback* service.

Cell Association: In *Idle* state, there is no association between the UT and the network. *Cell Association* operates by sending a request to RLC *Micro-mobility Control.*

RAN Association Release: This composite state is entered by request from IP Layer *CoopRRM*. After the UT is released from the RAN, *Macro-mobility Control* dies.

There is one instance of *Macro-mobility Control per UT lwithin each RAN the* UT is associated to (in the multi-homing case, UT can be associated to multiple RANs).. .

5.2.3.1.2 Ad-hoc Connection Control

Ad-hoc Connection Control (see Figure 5-9) manages the ad-hoc networking (direct communication) between two UTs. Ad-hoc networking between higher numbers of nodes is not yet supported, nor does this description include the functionality of UTs operating as gateways or relays. There is one instance of this service component for each UT.

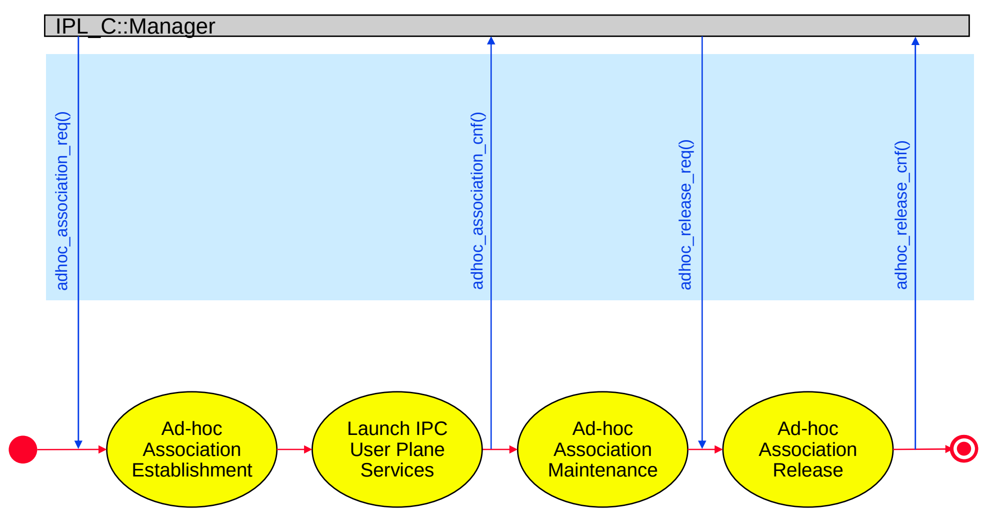

Figure 5-9: PSAP communication of the IP Mobility Control service component Ad-hoc Connection Control.

Ad-hoc Association Establishment: This composite state is entered upon the reception of adhoc_association_req() from *the CoopRRM* on IP Layer Control Plane. In this case it has to be understood that the request comes from the *CoopRRM entity* in the UT. Association establishment consists of four phases. In the inquiry phase, the UT that attempts to initiate communication requests the address of the responding party. In authentication phase, both parties are authenticated. In association phase, the radio identifiers are assigned and security keys are distributed. Finally, in capability discovery phase, the parties discover the communication capabilities of the corresponding party.

Ad-hoc Association Maintenance: This composite state launches the services in the lower layers that are necessary to maintain the ad-hoc communication.

Ad-hoc Association Release: The context information related to the ad-hoc link is flushed by both parties.

5.2.3.2 System Services

The IPC layer service *System Services* consists of only one service component, *Network Detection* (see Figure 5-10). It is used by the *CoopRRM* entity on IP Layer Control Plane. It is used to collect information about the WINNER networks that the UT could attempt to associate with.

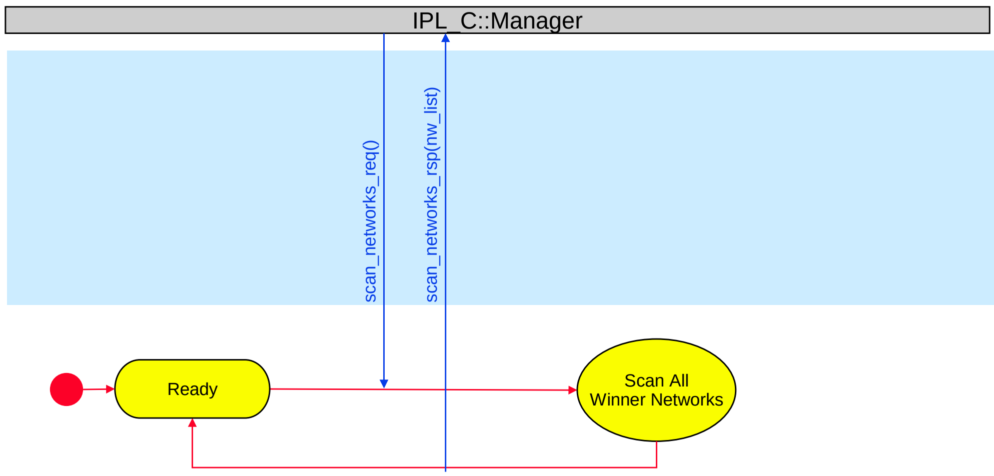

Figure 5-10: PSAP communication of the service component Network Detection.

Scan All WINNER Networks: This composite state uses MAC of WINNER to scan the WINNER networks (by receiving their system broadcast signals).

5.3 Radio Link Control Layer

5.3.1 Overview

The RLC Layer services and their users are shown in Figure 5-11. The grey boxes on top denote the users, whereas the blue bubbles are the services. The blue lines show the usage relationships. IPC_U and IPC_C in front of the user names denote that the users are located in the IPC layer's User and Control Planes, respectively.

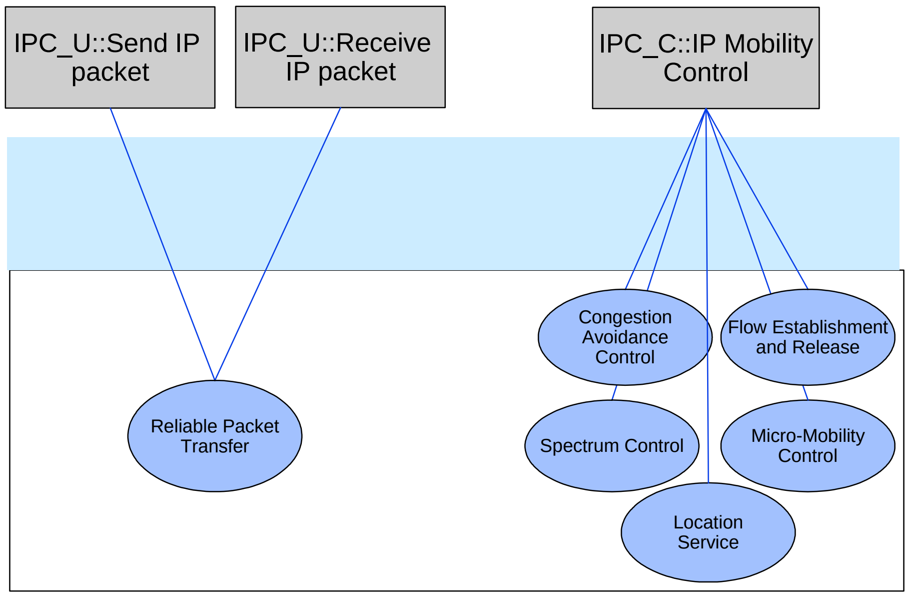

Figure 5-11: The users and services of the Radio Link Control Layer

5.3.1.1 Advantages compared to existing technologies

One of the WINNER RLC Control Plane advantages is that it handles the handover process per flow rather than per UT. Therefore, a UT might send/receive traffic over different cells and routes that match best the requirements of the specific flow. Additionally, it includes functionalities for coordinated spectrum sharing with other radio access networks using the same radio access technology as well as for spectrum sharing with other radio access technologies. Finally, unlike in existing systems, admission control is not responsible for only admitting a new or handover flow to a new cell but selecting the best cell among a group of candidate cells that are nominated by the micro mobility functionality.

A shortcoming of existing technologies is that the User Plane typically segments the incoming upper layer packets into fixed sized segments where the lowest supported data rate determines the segment size. In other words, the (fixed) segment size has to be small enough such that it can carry a small amount of data over a physical layer resource unit with the lowest supported data rate. A scalability problem however arises, since these fixed (and small) sized segments introduce large overhead as soon as high data rates are supported. The RLC User Plane is therefore aimed handle non-segmented upper layer packets.

Unlike the existing technologies, the User Plane provides only one single packet transfer service towards the upper layer. In that way, the details of the layer are not visible to the upper layer. This is advantageous since the upper layer does not need to make the decision on how the problem of transfer reliability should be actually solved.

5.3.2 User Plane Services

An important issue that needs to be taken into account is that the radio interface is solely based on packet transfer. Even though packet transfer is an efficient method for sharing communication resources among multiple users there is also a downside. Usually the underlying network introduces plenty of uncertainties that generally impair the information transfer reliability. Scheduling functions, re-transmission protocols and (dynamic) routing schemes are examples of functionalities that change the packet transmission and reception order. Similarly, re-transmission ambiguities, signalling errors, and unreliable feedback channels results in spurious re-transmissions and residual errors. Out-of-order delivery, duplicates, and lost packets are therefore typical error events that occur in this type of communication systems. A problem arises, since these events also degrade the upper layer protocol or user perceived communication quality. The purpose of the User Plane service *Reliable Packet Transfer* is to help this problem.

5.3.2.1 Reliable Packet Transfer

The problem of reliable information transfer essentially boils down to the questions how the sender and receiver buffers are handled, and how the receiver should process the packets before they are delivered to the upper layer. A fundamental requirement for this service is that the sender and receiver sides (and their buffers) can exchange control and status information. As different users may have different requirements on the communication quality, the level of transfer reliability should be also adjustable, i.e. the layer should be configurable with respect to its actions on observed error events. Some (upper layer) users may, indeed, tolerate certain type of errors more than others, e.g. residual errors, and therefore all error events should not necessarily always result in similar kind of actions.

The reliable packet transfer service is composed of three components; *Send*, *Receive* and *Service Level Controller (SLC)* as illustrated in Figure 5-12. Moreover, the *Flow Establishment and Release* service in the RLC Control Plane is responsible to configure the *Send* and *Receive* components as soon as the flow is established. The purpose of this configuration is to determine e.g. whether a feedback channel should be established between the communicating parties or not. In the following, the different components and their interactions with other components and services are explained in more detail.

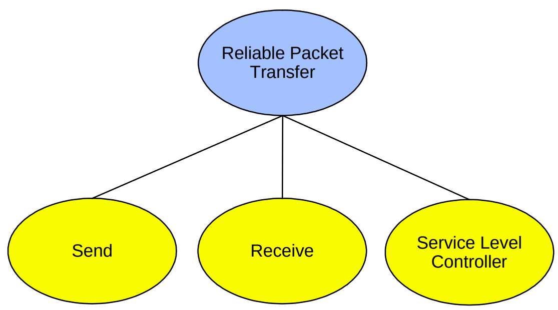

Figure 5-12 Components of the Reliable Packet Transfer service.

5.3.2.1.1 Send

The *Send* component has following users; *Transfer of IP Packets* service of the IPC layer User Plane, *Service Level Controller*, *Flow Establishment and Release,* and the *Receive* component. The initial state of the machine is denoted as *Ready* state. Service primitives and internal timers trigger transition to other states.

Ready: Incoming packet from the *Transfer of IP Packets* triggers transition to a state *New Packet Arrival*. Indication from the *Service Level Controller* to forward a packet to the lower layer triggers a transition to the state *Transfer of Packet to Lower Layer*. If the layer is configured to support re-transmissions, status report from the *Receive* component (and/or expired optional re-transmission timer) triggers a transition to the state *Buffer Content Updating* and similarly expired status polling timer triggers a transition to the state *Status Polling*. Finally, request from the *Flow Establishment and Release* triggers a transition to the *Flow Release* state.

New Packet Arrival: Assign a sequence number and insert the packet into the sender buffer. If the layer is configured to support re-transmissions, the packet is also inserted into a re-transmission buffer. Return to the *Ready* state.

Transfer of Packet to Lower Layer: Cipher the packet and forward it to the lower layer. Return to the *Ready* state.

Flow Release: Forward all unsent packets to the upper layer, flush the sender buffer, send a flush message to the receiving side, and terminate the process.

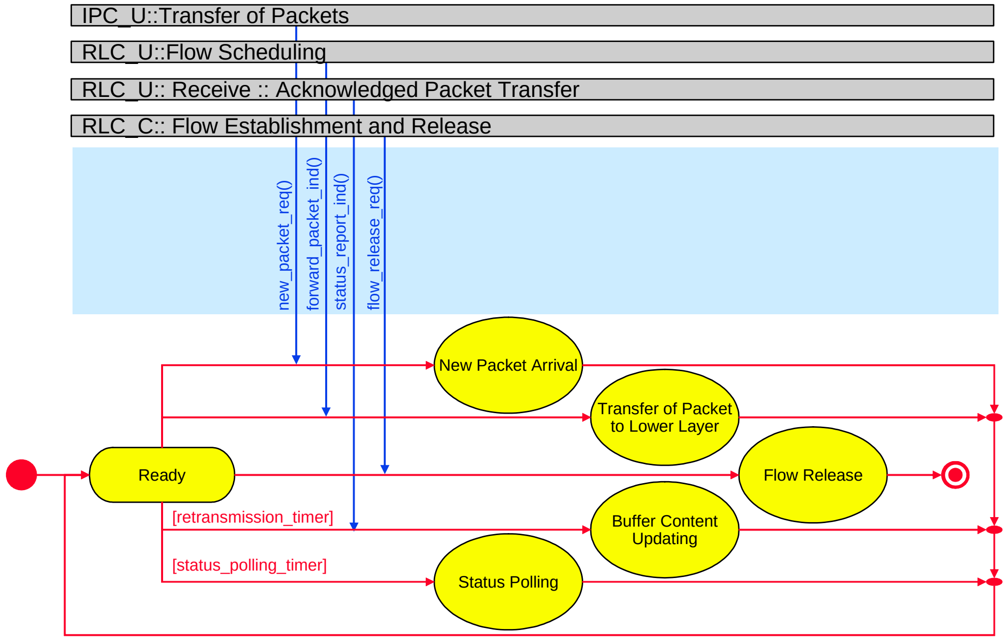

Figure 5-13 PSAP state-machine of the Reliable Packet Transfer service Send component

Buffer Content Updating (Optional): Release acknowledged packets from the re-transmission buffer. Move the rest of the re-transmission buffer content to the sender buffer. (Reset the optional re-transmission timer). Return to the *Ready* state.

Status Polling (Optional): Poll the receive status, i.e. send a request for a status report, and return to the *Ready* state**.**

5.3.2.1.2 Receive

The PSAP state machine of the *Receive* component is illustrated in Figure 5-14 and the states are described below. The state-machine starts (again) from a state that is denoted as *Ready* state. The upper layer service *Transfer of IP Packets* uses the service component. Observe that this description is a simple example that clarifies the functional flow and therefore all protocol related problems such as stalling avoidance, status reporting and window handling are not explained in detail.

Ready: Packet delivery from the lower (MAC) layer triggers a transition to the *Reception of Packet from Lower Layer* state.

Reception of Packet from Lower Layer: Decipher the received packet. If the packet is a status-reporting request, continue at the state *Status Reporting*. Otherwise, insert the packet in the receiver buffer according to its sequence number. If the sequence number is outside of the receiver window, discard the packet. If the packet is the leading edge of the receiver window, advance the window and deliver the packet to the upper layer. If re-transmissions are supported, update the status report. Return back to the *Ready* state.

Status Reporting: Generate a status report packet and return to the *Ready* state.

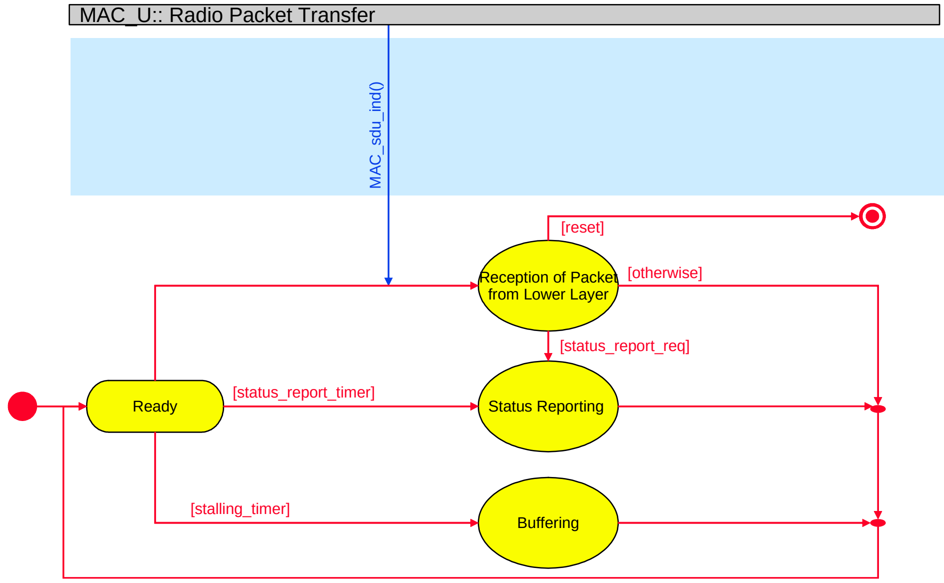

Figure 5-14: PSAP state-machine of the Reliable Packet Transfer service Receive component

5.3.2.1.3 Service Level Controller

Unlike the above-described components of the packet transfer service, the SLC is specific for a population of users (that is still at this stage of the project unspecified but it could be for example the population within one cell or sector). The SLC provides means to allocate network resources to the traffic associated with the different applications and end-user services (i.e. not radio interface services). The service differentiation is exercised through three different (and parallel) service components, namely, *Flow Conditioning*, *Flow Queuing* and *Flow Scheduling*. The SLC also comprises a *flow monitoring* service component to provide feedback on e.g. load predictions (see Figure 5-16).

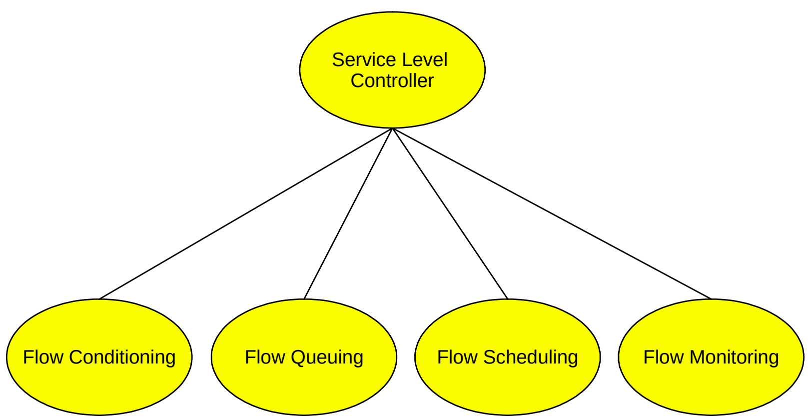

Figure 5-15: Components of the Service Level controller

In WINNER, a concept of differentiated services is adopted. In that concept, traffic from one or more service(s) can be classified into a single service class. A network operator then controls the allocation of network resources per service class through profile definitions. An example of such a profile is the triplet <*priority, minimum bit rate, maximum bit rate*> that is associated with the traffic aggregate of a specific service class. Moreover, all traffic carried by the WINNER RAN is associated with a flow (corresponds to the triplet <*source (within the RAN), destination (within the RAN), service class*>) and every packet entering the WINNER RAN is marked with a corresponding *flowID*. The flow association is performed by the *Flow Establishment and Release* service in the RLC Control Plane whereas the packet marking procedure is performed by the *Send IP Packet* service in the IPC layer in the User Plane (for more details on these functions, please see the corresponding chapters).

Flow Conditioning: The traffic of each flow is conditioned to ensure that it complies with the corresponding profile definition; in particular the defined maximum traffic rate. This can be achieved through delaying (shaping) or dropping (policing) packets. Optionally, packets may also be marked as conforming or non-conforming in relation to the service class profile. The latter marking can then be used by the flow queuing function described below to preferentially drop non-conforming packets, or to let them pass when capacity is available. The goal of traffic conditioning is to protect the network against any kind of persistent congestion and traffic overflow situations. This could be the result of misbehaving, i.e., non-rate-adaptive applications, or of Denial-of-Service attacks. To be able to perform these actions the flow conditioning needs input from *Flow Establishment and Release* on *flowID* and the corresponding service class.

Flow Queuing: Although flow queuing performs a rather simple function, it is an essential component of service differentiation. In WINNER, it is assumed that separate queues are allocated for each flow. Packets in respective queue may get dropped during transient phases of congestion. However, with proper network dimensioning, the dropping of conforming packets should be an exception. Still, a considerable fraction of non-conforming packets can enter the packet queues explained above. If capacity is available, those packets will be forwarded to ensure high network utilization. Otherwise, such packets need to be dropped in order to fulfil the minimum bit-rate requirements of the different service classes. Active queue management schemes are widely used already today in packet routers to control the packet dropping per queue. The choice of the right queue management scheme and its configuration used per service class could be part of the mentioned profile definitions. To be able to perform these actions the flow conditioning needs input from *Flow Establishment and Release* on *flowID* and the corresponding service class.

Flow Scheduling: As in D3.1[1] [WIND31] and D3.2 [WIND32], the basic hypothesis for the scheduling architecture will be that scheduling is partitioned into two levels (although combined integrated solutions may also be envisioned and is not prevented by the proposed scheduling architecture), namely flow scheduling (residing at the RLC layer) and resource scheduling (residing in at the MAC layer).[2]

Flow scheduling may be considered as management between flows and determines the order in which PDUs will be forwarded to the SLC cache buffer residing at the MAC layer and works on a time scale characterised by the packet arrival rates. The scheduler takes inter-flow fairness, service class profiles as well as moving average statistics about the SLC cache contents (mainly used as an indication of the current serving rate) into account in its decisions.[3]

The *flow scheduling* controls the resource scheduler and the interaction between these two schedulers is assumed to work as follows. The *flow scheduling* should ensure that a sufficient amount of packets are residing in the SLC cache to enable high multi-user gains (i.e. based on predictions about the current rate the *flow scheduling* aims at keeping the overall SLC cache content at some predetermined level, e.g. corresponding to what (on average) may be transmitted within 5 ms). At the same time, the resource scheduler must guarantee that it will (to the furthest extent possible) transmit the packets in the SLC cache within a small amount of time, e.g., in less than 10 ms. Otherwise, the resource scheduler could create head-of-line blocking and too much delay. Effectively, this means that the ultimate decision about if and when (within a few ms timeframe) a packet is transmitted lies with the *flow scheduling* since the resource scheduler sooner or later has to schedule the packets assigned to it. This also means that service classes are transparent to the resource scheduler. Nevertheless, (if deemed necessary) the resource scheduler may also be made aware of the service classes (or at least some priorities of the different flows) to support work-conserving packet preemption (i.e. that a higher priority packet can preempt the transmission of a lower priority packet destined for the same node) as well as to give preferential treatment of e.g. network control signalling packets.

The guiding principle here has been to keep the interface between the *flow scheduling* and resource scheduler as simple as possible. The performance of the proposed scheme needs to be thoroughly investigated. If more elaborate signalling between SLC and RS is found to be required, this should be introduced at a later stage.

---

[1] N.B. Some terminologies have been altered as compared to D3.1: what was denoted packet scheduling in D3.1 is now denoted flow scheduling, while the channel dependent resource allocation of D3.1 will be denoted resource scheduling.

[2] Motivations for this split may be found in D3.2 [WIND32].

[3] At high system load, load control (and potentially also admission control) may influence flow scheduling by requesting it to adjust the rate of flows belonging to a specific service class.

The current assumption is that the previously described scheme holds both for the uplink and downlink direction (under the assumption that resources are granted per flow and not per UT in the uplink direction). The only difference between the uplink and the downlink scheduler is that for the uplink scheduler, the required control communication is carried out of band.

To be able to perform these actions the *flow scheduling* needs input from *Flow Establishment and Release* on *flowID* and the corresponding service class as well as feedback from *MAC Radio Resource Control* on the content of the SLC cache.

Figure 5-16 gives an example (with *N* flows) of how the different functionalities for service differentiation described in this chapter could be implemented in the downlink.

Flow Monitoring: The main aim for flow monitoring is to (as the name suggests) monitor the flow and provide feedback on flow traffic predictions to any other function that may require this information (e.g. *Congestion Avoidance Control*). In addition, flow monitoring may invoke other functions based on the performed measurements e.g. it may invoke *Flow Establishment and Release* when flows have been inactive for an extended period of time and it may invoke *Congestion Avoidance Control* when flow targets have not been met during some predetermined period of time.

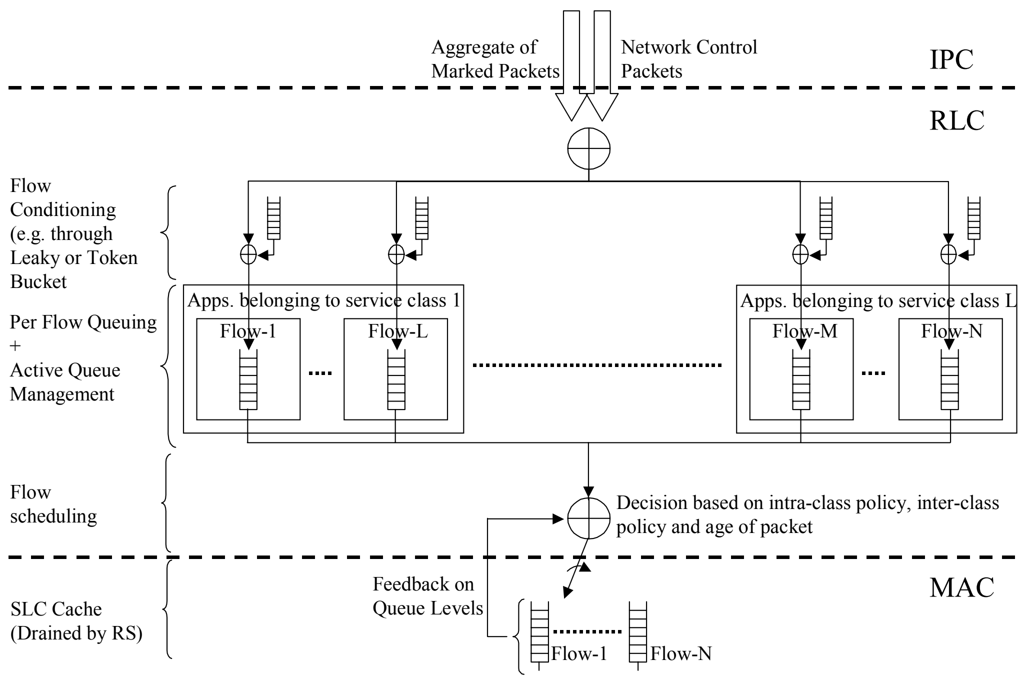

Figure 5-16 Example of flow conditioning, flow queuing and flow scheduling.

5.3.3 Control Plane Services

5.3.3.1 Location Service

The *Location Service* consists of one service component, the *Calculate Location*, which is responsible for geographically positioning the UT based on measurements information (see Figure 5-17).

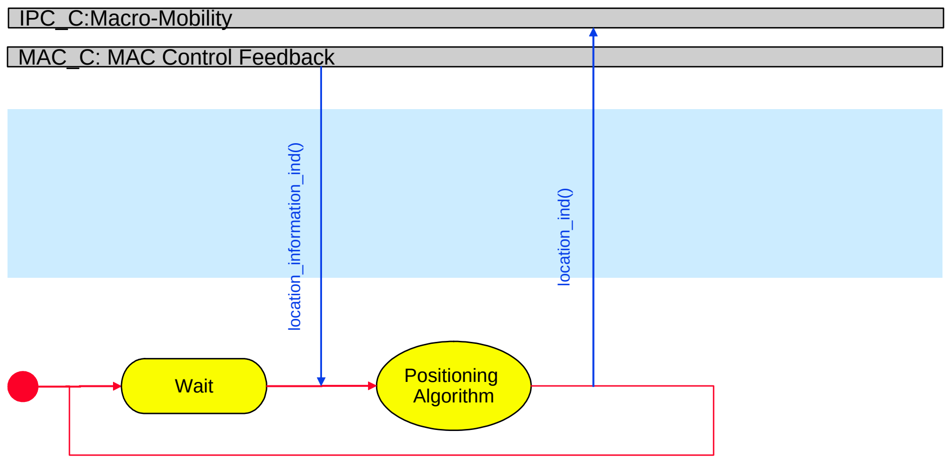

Figure 5-17: The external behaviour and execution logic of Calculate Location

5.3.3.2 Congestion Avoidance Control

The *Congestion Avoidance Control* service consists of three service components, the *Admission Control* service component which is responsible for admitting a new or handed over flow to a cell based on resource availability, the *Pro-active Routing* service component which takes care of the updating of the routing table for Point to Multi-Point (PMP) structures and the *Load Control* service component which monitors periodically (and/or by polling) the load per cell and re-distributes it in case of a overload situation (see Figure 5-18). A PMP structure is obtained by combining a linear deployment of RNs from a logical viewpoint, along different branches and last hop connections towards the UT around each RN. It is simplified, with respect to a generic PMP model, in that the connection pattern to be handled by each RN is limited by the constraint that each RN is connected to two other RNs at most. On the other hand, several RN can be connected to the BS, originating several branches. A multiplicity of UT can be handled by each RN in the last-hop [WIND34].

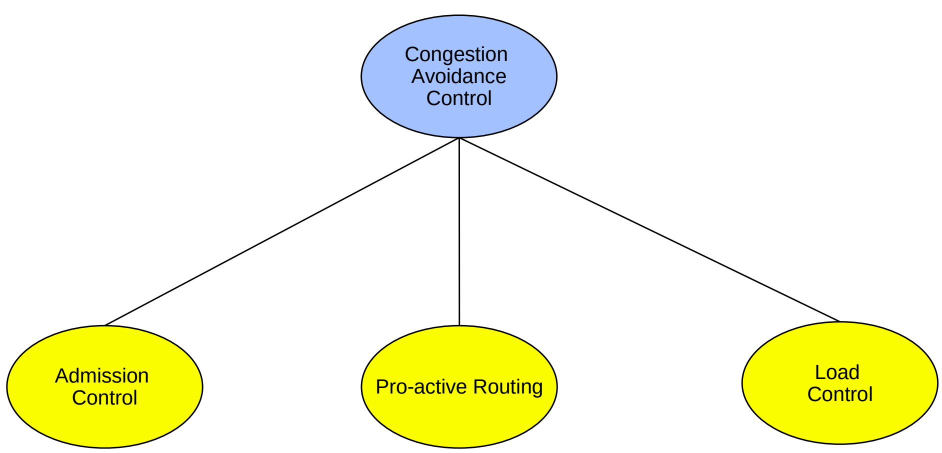

Figure 5-18: Components of the RLC layer CP service Congestion Avoidance Control

5.3.3.2.1 Admission control

The external behaviour and main execution logic of the *Admission Control* is shown in Figure 5-19. The states and composite states are explained below.

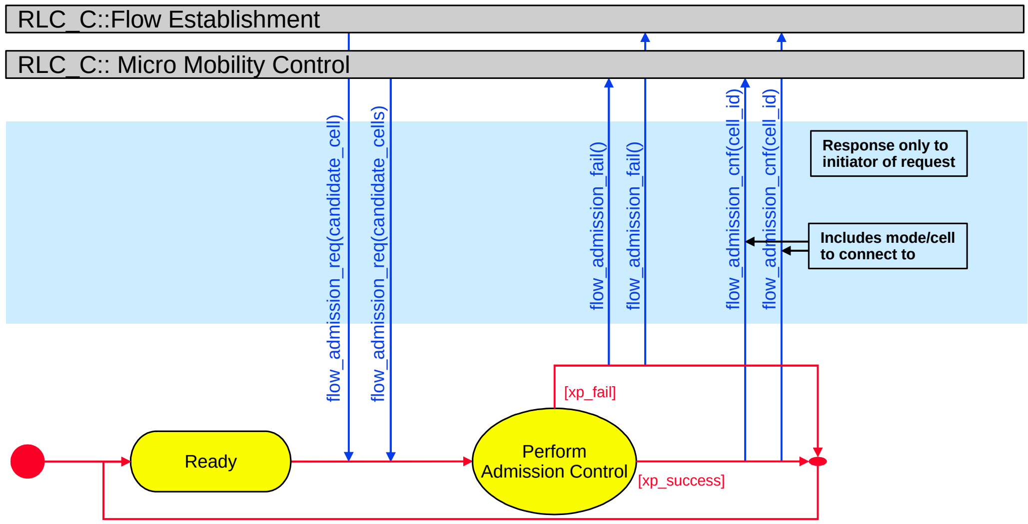

Figure 5-19: The external behaviour and execution logic of Admission Control

Ready: In this state the *Admission Control* is waiting for admission requests either from the *Flow Establishment* entity (new flows) or the *Micro-Mobility* entity (flows that need to be handed over).

Perform Admission Control: In this composite state the candidate cells as well as the decision to admit a flow or not is taken. This decision is based on information such as load prediction, statistics of current flows, resource restrictions and physical layer measurements. In particular it is assumed that flow statistics will include:

- throughput per flow, in previous superframe,
- time-frequency-spatial resource use per flow,
- spare capacity within cell in previous superframe,
- path loss estimate and
- interference estimates.

In case of limited resources in the candidate cells, a number of different actions may be taken (in close cooperation with *Load Control*), such as:

- reduce requests for connection/flow in question and/or for lower priority flows,
- resource re-partitioning,
- lower load in (interference from) neighbouring cells,
- handover flows (cell/mode/RAN),
- drop flows.

5.3.3.2.2 Pro-active Routing

The external behaviour and main execution logic of the *Pro-active Routing* is shown in Figure 5-20. The states and composite states are explained below.

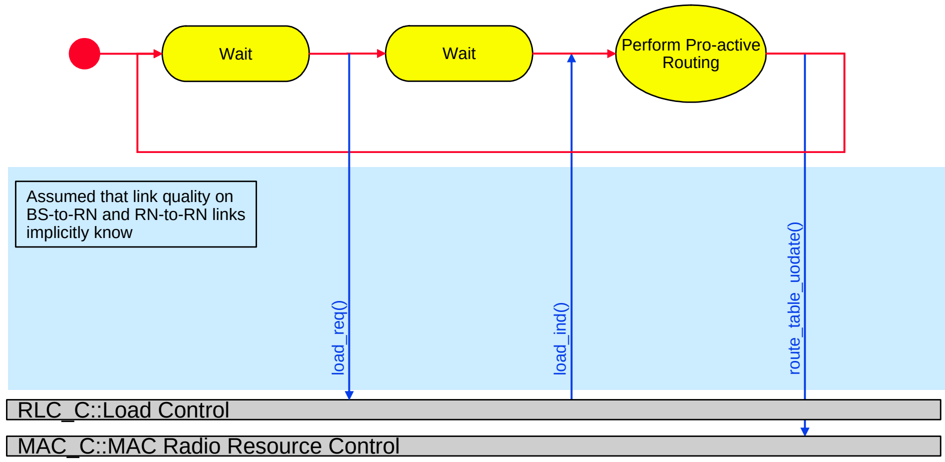

Figure 5-20: The external behaviour and execution logic of Pro-active Routing

Wait: *Pro-active Routing* is an infrequent service that takes place periodically for PMP structures. In this state the service is waiting for a timer to expire and send a request for current load information.

Perform Pro-active Routing: Upon, reception of such information from the *Load Control* service, it re-calculates the BS-to-RN and RN-to-RN routes (the link quality is assumed to be known) and updates the routing table. Note that this function is related to the routing of a group of flows (that are using the BS-to-RN and RN-to-RN routes) rather than to the independent routing per flow..

5.3.3.2.3 Load control

The external behaviour and main execution logic of *Load Control* is shown in Figure 5-21. The states and composite states are explained below.

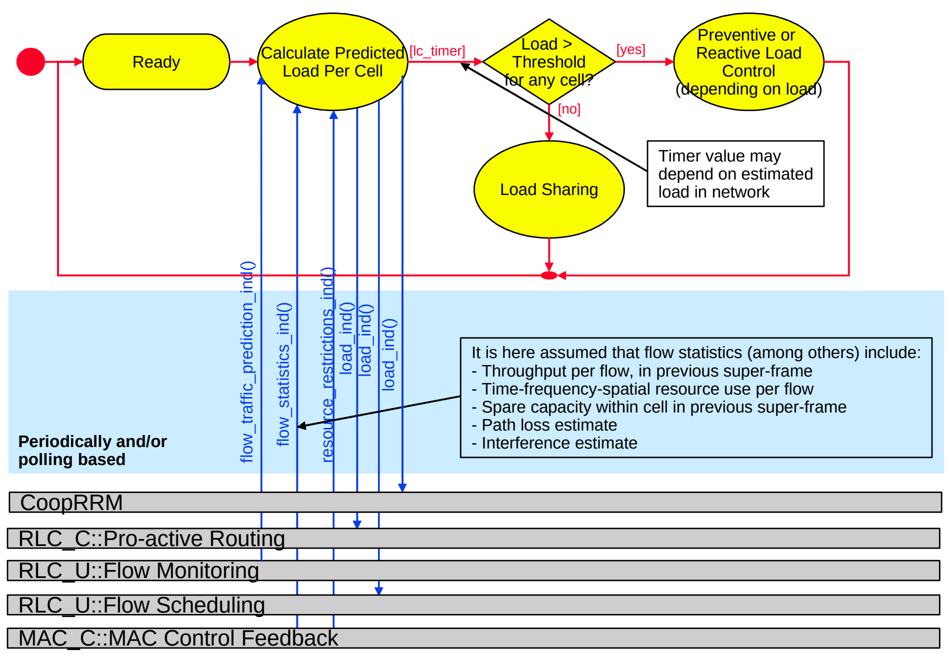

Figure 5-21: The external behaviour and execution logic of Load Control

Ready: The service is ready to receive information from other services.

Calculate Predicted Load Per Cell: This composite state calculates the predicted load per cell based on information such as load prediction, statistics of current flows and resource restrictions. It then sends this information to the *Flow Scheduling* and *Pro-active Routing* services as well as to the *CoopRRM* entity that is responsible for the cooperation between WINNER and legacy RANs. Additionally, a timer is triggered whose value may depend on estimated load within the network. Upon the expiration of the timer, the load per cell is assessed. If it is greater than a given threshold then *Preventive* or *Reactive Load Control* is activated. Otherwise, the *Load Sharing* is executed.

Preventive or Reactive Load Control: The aim herein is to ensure that the system is in stable state. In particular:

- The Preventive Load Control takes care so that the network does not get overloaded and remains stable and attempts to improve the system performance by distributing users/sessions/resources among cells/sectors.
- The Reactive Load Control attempts to bring the load back to stable regions as fast as possible

Potential actions for a “congested cell” are taken. Examples are:

- interaction with the *Service Level Controller* and restriction of incoming traffic,
- denial of new flow requests,
- change of TDD asymmetry factor,
- reduction of requests (e.g. bit rates) for flows (within limits as specified in the flow QoS specification),
- attainment of more resources by resource re-partitioning or lower load in (interference from) neighbouring cells,
- handover of flows to another cell/mode/RAN and
- dropping of flow(s).

Depending on these actions, indications are then sent to the corresponding services.

Load Sharing: *Load Sharing* is a function whose purpose is to distribute the load (the offered traffic) and/or resources between “resource owners” (BSs and RNs) such that the resources are efficiently utilised. Potential actions include:

- resource re-partitioning,
- handover of flows (cell/mode/RAN) and
- change of TDD asymmetry factor.

These actions should be prioritised and considered according to this prioritisation (action and rate of action relates to estimated load). Depending on these actions, indications are then sent to the corresponding services.

5.3.3.3 Micro Mobility Control

The *Micro Mobility Control* consists of one service component, the *Micro Mobility*, which is responsible for cell selection and handover. The external behaviour and main execution logic of the *Micro Mobility* is shown in Figure 5-22. The states and composite states are explained below.

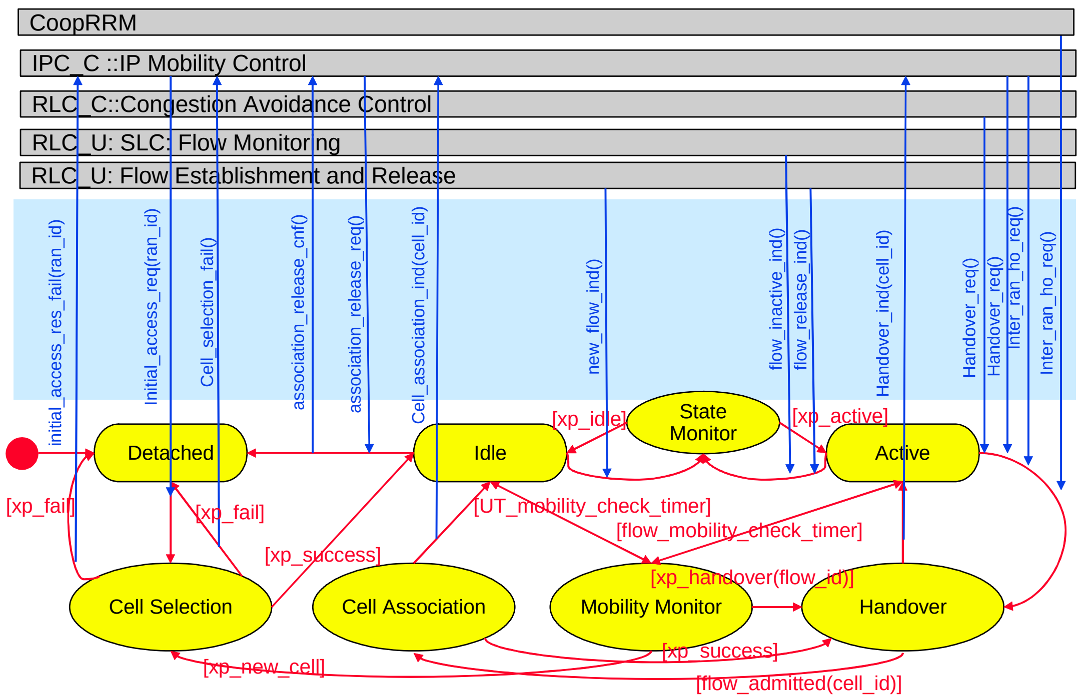

Figure 5-22: The users and the PSAP state machine of Micro-Mobility

Detached: This is the state at start up. The transition from this state is triggered by the *IP Mobility Control* entity with an initial access request.

Idle: In this state the UT is not transmitting/receiving traffic. After the UT_mobility_check_timer is expired the Mobility Monitor composite state checks whether cell selection needs to be performed. The transition to the *Detached* state takes place upon a request for RAN association release by the *IP Mobility Control*.

Active: In this state the UT has active flows and therefore handover per flow is performed when required. The handover can be triggered either by the *Mobility Monitor* composite state, the *Congestion Avoidance* entity, the *IP Mobility Control* or by the *CoopRRM* entity.

State Monitor: This composite state is responsible for the transition between *Idle* and *Active* states by monitoring whether a UT has any active flows. It is triggered by the *Flow Establishment and Release* when a flow is established or released and by *Flow Monitoring* service component (SLC) when an existing flow becomes inactive.

Mobility Monitor: This composite state is responsible for monitoring periodically (UT_mobility_check_timer from the *Idle* state and flow_mobility_check_timer from the *Active* state) whether there is a need for a cell selection (UT has no established flows) or flow handover (UT has active flows). Then within this composite state and based on measurements and statistics on the current cell from the *MAC Control Feedback* and *Congestion Avoidance Control*, respectively, a decision for cell selection or flow handover is taken in case a trigger is activated.

Cell Selection: This composite state is responsible for selecting the best available cell for UT upon initial access and when the UT has no active flows. In case of a failure in acquiring a cell, then an initial_access_res_fail or cell_selection_fail message is sent to the *IP Mobility Control* if it happens during initial access or normal operation, respectively. Additionally, the UT goes to the *Detached* state. In case of a successful cell acquisition the UT goes to the *Idle* state. During cell selection the UT requests measurements and statistics from the *MAC Control Feedback* and *Congestion Avoidance Control* respectively on the neighbouring cells. It then ranks these cells and decides on the best candidate. It then requests for permission to camp on this cell. If successful it sends a location update to the *IP Mobility Control* entity.

Handover: In this composite state the handover of individual flow(s) is executed. Based on measurements and statistics from the *MAC Control Feedback* and *Congestion Avoidance Control* on the neighbouring cells, a candidate cell is selected. An admission request is then sent to the *Admission Control* entity. If accepted cell association is performed and then the handover is completed by transferring the flow context, resending the buffered packets and updating the routing table. After the handover is completed the UT returns to the *Active* state and sends a handover indication with the cell id to the *IP Mobility Control*.

Cell Association: This composite state is responsible for registering with the new cell after a handover flow is admitted and setting up the resources required by the flow by sending an association request to the MAC. It then sends a cell_association_ind message to the *IP Mobility Control* entity.

5.3.3.4 Flow Establishment and Release

The *Flow Establishment and Release* service is responsible for setting up and releasing flows. The external behaviour and main execution logic of the *Flow Establishment and Release* service is shown in Figure 5-23. The states and composite states are explained below.

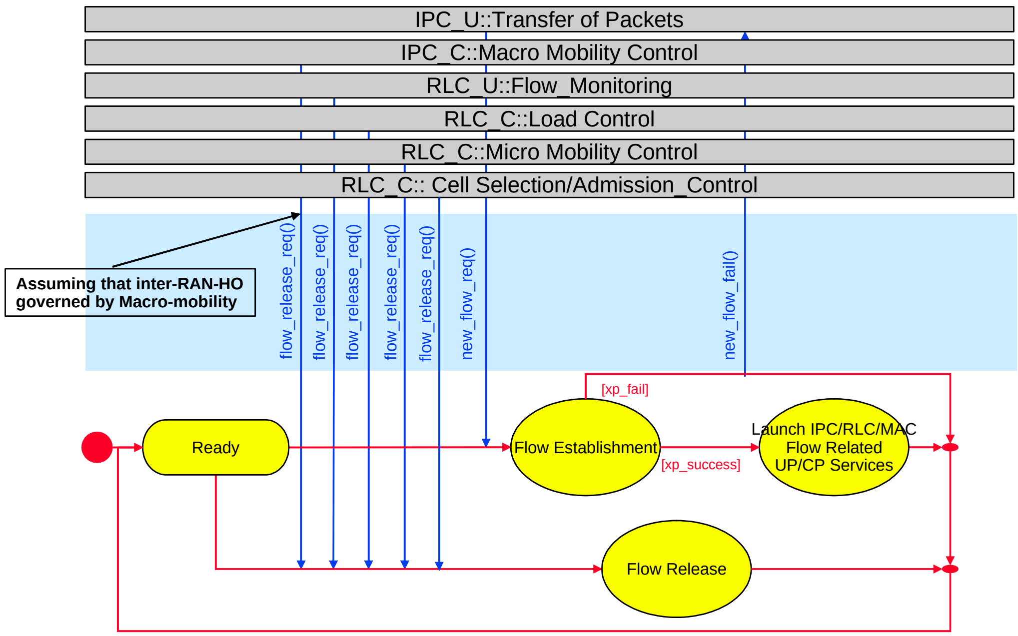

Figure 5-23: The users and the PSAP state machine of Flow Establishment and Release

Ready: In this state *Flow Establishment and Release* is ready to receive requests for the establishment or release of a flow.

Flow Establishment: In this composite state a request for a new flow has been received from the IPC User Plane. Following this request the Flow is classified in terms of mapping the service class to QoS targets and RLC services. It then requests admission from the *Admission Control* entity and upon acceptance the flow context is established.

Launch IPC/RLC/MAC Flow Related UP/CP Services: After a flow is established the flow context is sent to MAC/RLC/IPC user and Control Planes.

Flow Release: In this composite state the flow context is released from all layers upon a request that might be originated due to a handover (*Macro Mobility* and *Micro Mobility* entities), a QoS violation (*Flow Monitoring*) or Load re-distribution (*Load Control* entity).

5.3.3.5 Spectrum Control

Spectrum control coordinates flexible spectrum use between WINNER RANs and spectrum sharing with radio access systems using some other radio access technology (RAT). To have more tractable problems, the service is divided into two service components, *Spectrum Sharing* coordinating spectrum sharing with systems using other RAT, and *Spectrum Assignment,* providing flexible spectrum use between WINNER RANs.

5.3.3.5.1 Spectrum Sharing

Spectrum Sharing controls the access to the spectrum in frequency bands which are shared with other RATs, which are probably legacy systems (Figure 5-24). Depending on the regulatory rules governing the shared bands, different approaches to spectrum sharing are possible:

Horizontal sharing

The involved systems in the shared frequency band have equal regulatory status, i.e. no system has priority over the other(s) in accessing the spectrum.

- *Horizontal sharing without coordination*: No signalling is possible between the involved systems, as e.g. nowadays in the 2.4 GHz band for WLAN and Bluetooth. Since QoS cannot be guaranteed for any system, this possibility is not considered in further detail.
- *Horizontal sharing with coordination*: The involved systems coordinate their spectrum access based on a set of predefined rules (spectrum etiquette) that all systems adhere to. This requires capabilities for signalling or at least detection of the other systems.

Vertical sharing

In this modality, sharing is performed with clearly established priorities. The primary system has preference in accessing the spectrum and the secondary system(s) may only use the spectrum as long as they do not cause harmful interference towards the primary.

- *(1)* WINNER is the primary system: WINNER can (but is not obliged to) assist the secondary systems by signalling the free spectrum resources via its broadcast channel. Depending on the expected incentives for the WINNER operators, free spectrum could be actively created.
- *(2)* WINNER is the secondary system: WINNER has to control its emissions (from the BS and all terminals) in order to avoid interference towards the primary system. This requires considerable knowledge about the deployed primary (legacy) system.

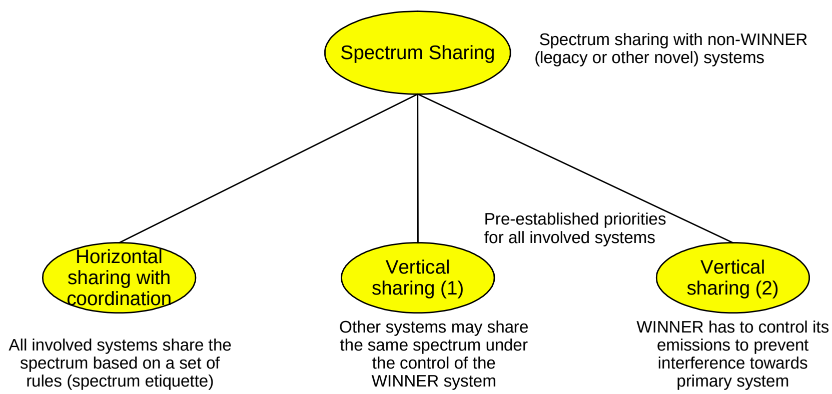

Figure 5-24: Main components of spectrum sharing

The most important and complex service component is *Vertical sharing (2)*, which controls the emissions from the WINNER system to avoid harmful interference towards legacy systems. This function first has to reliably identify the "white spaces", i.e. unused spectrum and then determines the transmit constraints of the WINNER system. The identification of the *white spaces* can be based on measurements as well as on information provided by a central radio controller or a spectrum database. Based on the available information, constraints for the transmit parameters are determined and signalled to the constraint processing function in the MAC layer. In order to avoid uncontrolled emissions, the listen-before-talk principle has to be implemented in all terminals.

5.3.3.5.2 Spectrum Assignment

Spectrum Assignment is divided further into *Long-term Spectrum Assignment* providing slowly varying spectrum assignments for large geographical areas and *Short-term Spectrum Assignment* providing short-term, local variations to the large-scale solution. The detailed implementation of these functionalities remains as an open issue, and further development will be carried out in WINNER II.

Long-term Spectrum Assignment

The service component coordinates and negotiates the spectrum assignments between multiple WINNER RANs for large geographical areas with spatial granularity of several cells (sets of cells). Spectrum assignments are updated periodically and at slow rate, that is, in time frame of several minutes. The component is distributed to all WINNER RANs. The only central unit is a central data base allowing, thus, higher layer control on spectrum assignments through spectrum priorities and fairness/cost metrics. Spectral resources assigned to the networks are divided into two categories, namely, resources assigned to a certain network with a priority, to guarantee basic operation of network, and to common pool resources. The main level functionalities of long-term spectrum assignment are shown in Figure 5-25.

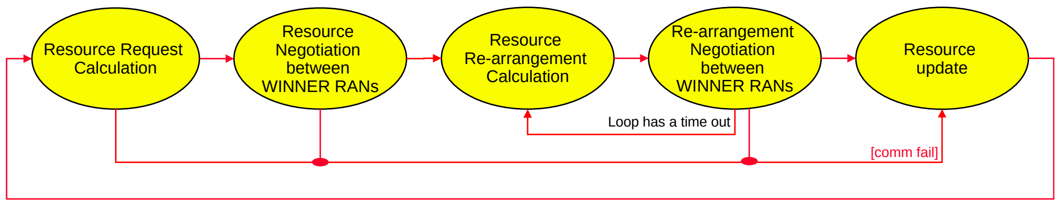

Figure 5-25: Main components of long-term spectrum assignment

Resource Request Calculation: decides the requested spectral resources for the next assignment period based on the inputs from load prediction, MAC control feedback, and spectrum sharing with systems using other RATs. Also the non-negotiable spectral resource changes (voluntary resource releases, retrievals of prioritised resources) are defined and announced to the other WINNER RANs.

Resource Negotiation between WINNER RANs: Negotiations between WINNER RANs are carried out based on the resource requests and by utilizing fairness or cost metrics. Inter-network signalling is performed either over the air or through the core network. For the over the air signalling, RAC is used through the MAC radio packet transfer service.

Resource Re-arrangement Calculation: The amount of spectral resources assigned for each RAN is fixed after the previous step. The possibilities to optimise the spectral resource assignments (by minimising inter-RAN guard bands) through the exchange of the resources with other RANs are defined.

Re-arrangement Negotiation between WINNER RANs: The resource exchanges are negotiated with other RANs.

Resource Update: functionality complies the necessary spectral resource and constraint information for MAC radio resource control, updates logs, sends updates to the central data base as well as downloads updated parameters from the data base and, if necessary, triggers short-term spectrum assignment. It also performs recovery from possible communication failures between the WINNER RANs.

Short-term Spectrum Assignment

The service component controls short-term and local, i.e., cell-specific variations to the large-scale spectrum assignments. Hence it enables faster adaptation to the local traffic load variations and geographically more accurate spectrum assignments. The assignments are performed in the time scale of seconds. Functionality requests resources from other WINNER RANs after triggered by the long-term spectrum assignment or preventive load control. In the case of a resource request from other RANs, the functionality rejects, accepts or partially accepts the request based on information from load prediction and MAC control feedback on the overlapping and neighbouring cells. Inter-network signalling is performed either over the air or through the core network. For the over the air signalling, RAC is used through the MAC radio packet transfer service. The constraint information is updated based on the decisions and sent to appropriate MAC radio resource controls.

5.4 Medium Access Control Layer for FDD and TDD

5.4.1 Overview

5.4.1.1 The MAC services and tasks

In Phase I of WINNER, the work has been focused on the following two **physical layer modes**:

- **FDD**: Transmission over paired bands, in which the terminals may use half-duplex FDD. In Phase I, this mode is evaluated in *wide-area cellular and metropolitan* deployment scenarios using two bandwidths: 20 MHz and 40 MHz.
- **TDD**: Transmission over an unpaired band, using TDD. In Phase I, this mode is evaluated in *short-range cellular* and *metropolitan* deployments and for use in *relay links*, using a contiguous 100 MHz wide band. It is also to be used as a basis for *peer-to-peer* communication.

The MAC design focuses on **three MACs**, of which the first two are presented in this chapter:

- **FDD cellular MAC**, including multiple-access, multi-hop and multi-antenna aspects.
- **TDD cellular MAC**, including multiple-access, multi-hop and multi-antenna aspects.
- **MAC for peer-to-peer transmission**, using the TDD physical layer mode.

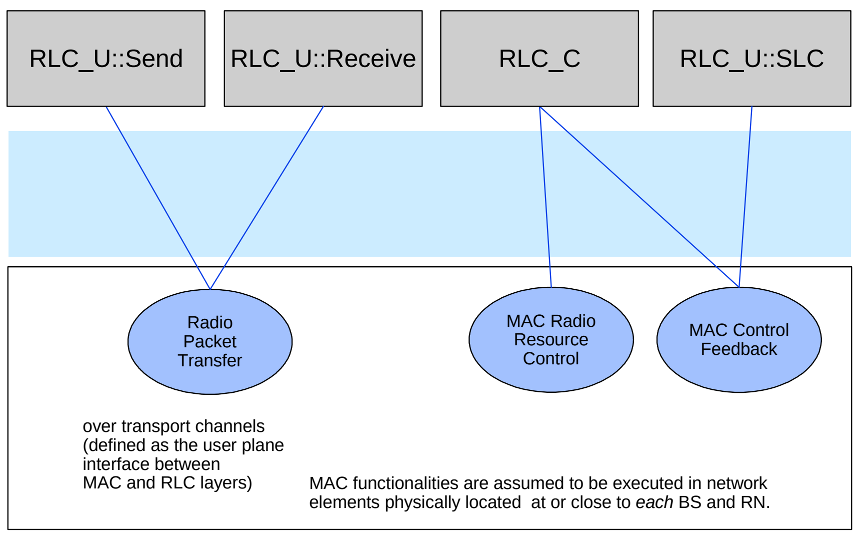

Figure 5-26: The cellular FDD and TDD MAC services, and their users at higher layers

The MAC for the FDD and the TDD modes should provide the following services to the RLC layer:

- **Radio packet transfer**, i.e. transmission and reception over the radio interface of packets belonging to any of the transport channels defined below.
- **MAC radio resource control**, i.e. acceptance and execution of control messages from higher layers that specify required transmission parameters and boundary conditions.
- **MAC control feedback**, i.e. messaging that supports the flow control, the QoS control and the spectrum assignment and other functions at the RLC layer.

Transport channels have in the WINNER system been defined to serve as the User Plane interface between the RLC and the MAC layers. The transport channels define the basic types of radio packet transfer that a MAC may provide:

- Broadcast channel (**BCH**) for broadcasting system information from RLC and higher layers to all terminals inside the coverage area of the cell,
- Contention based random access channel (**RAC**) for initial access to a BS or RN and also for BS-to-BS control signalling in TDD systems,
- Contention based direct access channel (**DAC**) for contention-based uplink data transfer,
- Common data channel (**CDC**) for scheduled point-to-multipoint communication,
- Targeted data channel (**TDC**) for scheduled point-to-point communication.

The **MAC radio resource control** and the **MAC control feedback** refers to control and feedback messaging on a rather slow time-scale of around 10 ms. These interactions can thus be performed between physically separated elements using e.g. IP traffic. Control and channel quality feedback on shorter timescales, required for executing the Radio resource control messages, is the responsibility of the MAC itself.

Execution involves control and resource allocation on two time scales:

- *Resource partitioning* and *spatial scheme control*, on a time scale of the superframe (5-10 ms): The allocation to different transport channels is adjusted on this time scale, based on the aggregated demand within each transport channel. Guard chunks for interference avoidance scheduling are also defined and re-adjusted, to enable flexible spectrum use between WINNER operators/users and adaptive interference avoidance between neighbouring cells, beams and sectors.
- *Resource scheduling* (RS) on the time scale of the frame (0.7 ms): The scheduled flows are allocated to time-frequency-spatial resources available within the superframe in one of two ways: *Adaptive* RS utilizes the frequency selective fading. This requires processing of CSI/CQI feedback from the PHY layer. *Non-frequency adaptive* RS uses a diversity-based transmission within the frame.

We give a brief overview of how the tasks are solved and of the interplay between the involved functions.

5.4.1.2 Overall architecture

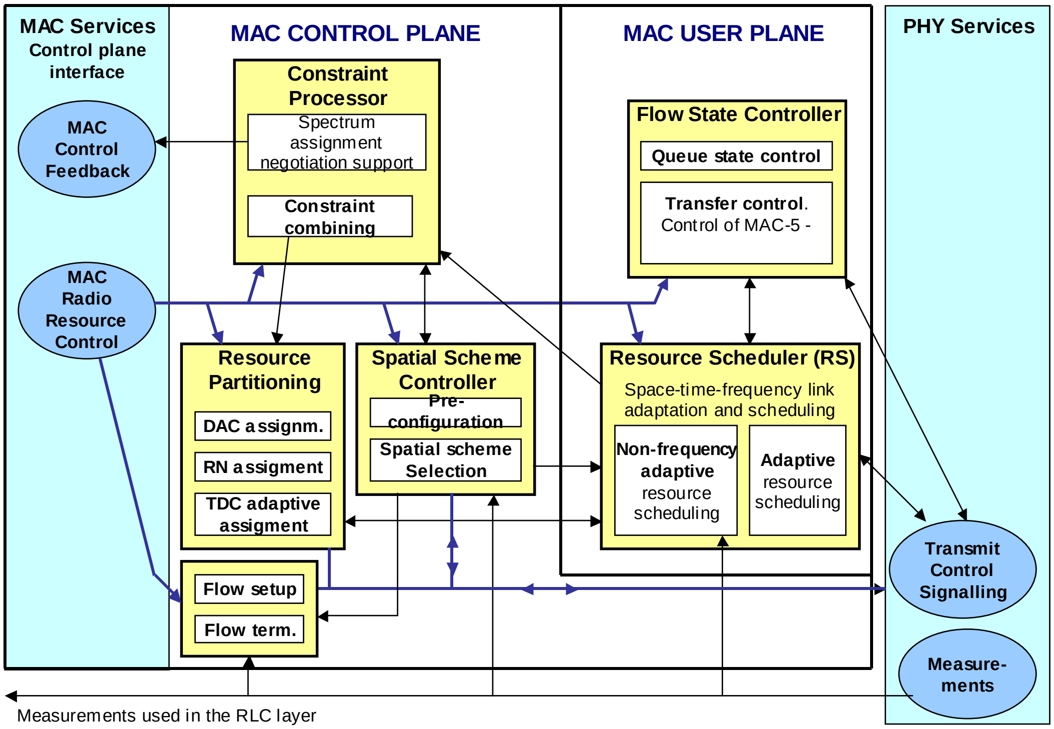

Figure 5-27: FDD and TDD cellular MAC control functions: Services and main function blocks

The MAC layer is subdivided into a Control Plane and a User Plane. The PHY layer is not subdivided in that way, since all essential control functions for the physical layer reside in the MAC. The six main MAC control function blocks are illustrated by Figure 5-27. Control functions that directly control packet transmission on a slot time-scale reside in the User Plane.

- ***Resource partitioning***. Partitions the superframe into sets used for adaptive, non-frequency adaptive and DAC transmission, as well as chunks set aside for use by RNs, BS-to-RN links and as guards for interference avoidance with respect to other cells.
- ***Spatial scheme control***. The appropriate spatial transmit scheme is determined for each flow, and it is held fixed within a superframe. The spatial scheme selection is influenced by the channel and the interference conditions. It forms input to the resource scheduling.
- ***Flow setup and termination*** performs flow context establishment and release over one hop, supervised by the RLC flow establishment and release functionalities.
- ***Constraint processor***. Combines constraints on the use of chunks and chunk layers. These arise from interference between user terminals, interference avoidance scheduling with neighbouring cells and spectrum sharing between operators. The output is in the form of chunk masks that define restricted use of the chunks of a superframe. The constraint processor also processes measurements that support the RLC spectrum assignment/negotiation.
- ***Flow state controller.*** Controls the segmentation and FEC coding/decoding of packets and monitors the states of RS queues. It also controls the active/semi-active/passive state of flows. It interacts with the RS and the packet processing functions in the User Plane.
- ***Resource scheduler (RS).*** Includes adaptive and non-frequency adaptive scheduling algorithms and control of spatial link adaptation. Power control in both uplinks and downlinks is performed under the control of the resource scheduler and is integrated into the optimization of the transmission parameters.

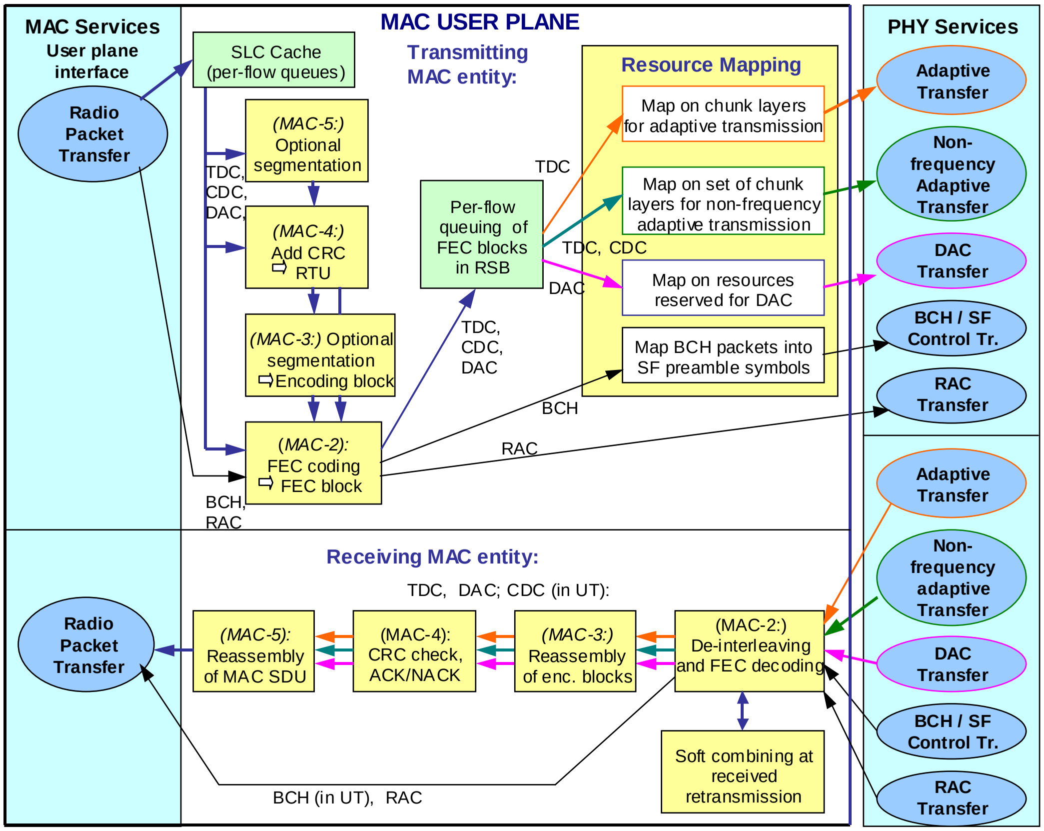

Figure 5-28: FDD and TDD cellular MAC: User Plane services and packet processing

The data flows in the User Plane, shown in Figure 5-28, are processed by three groups of functions:

- ***Transmission: Segmentation, encoding and buffering.*** The flow state controller supervises this sequence. Sub-layers MAC-1-MAC-5 have been introduced by XWP RLC for describing the different re-transmission options. A MAC SDU is drained from the SLC Cache. If it belongs to the TDC or DAC transport channels, it may be retransmitted. Re-transmission can be introduced as an option also for CDC point-to-multipoint flows. The TDC, CDC or DAC packet is optionally segmented. A CRC sequence is added, resulting in a Re-transmission unit (RTU). The RTU may optionally be segmented into *encoding blocks* that are encoded separately. Coding and interleaving results in *FEC blocks*, that are buffered in the RS buffer on the transmitter side, in one or several queues per flow. There they remain, until acknowledged or dropped. BCH and RAC-packets are transmitted in the superframe preamble, without possibility for re-transmission.
- ***Resource mapping***. At transmission, bits from TDC flows are mapped either on chunks reserved for adaptive transmission, or on the sets of chunks intended for non-frequency adaptive transmission. CDC (multicast) flows should use non-frequency adaptive transmission. DAC packets are mapped on the contention-based physical channel. For TDC and CDC, puncturing of the buffered FEC block may be performed and only a part of a FEC block may be transmitted in a scheduling round that comprises a frame. For CDC, TDC and DAC, the Resource scheduler controls the resource mapping. For the BCH, the mapping into the preamble broadcast OFDM symbols is under the control of the Resource partitioning function in the Control Plane, which has over-all control of the multiplexing and modulation of these symbols.
- ***Reception: Decoding and reassembly***. The flow state controller supervises the reception. De-interleaving and FEC decoding is first performed for received FEC blocks belonging to TDC, CDC or DAC packets, followed by the (optional) re-assembly of the RTU. Then, the re-transmission unit is optionally checked for transmission errors and a re-transmission may be requested. The MAC SDU is finally re-assembled. BCH and RAC packets are received separately in the superframe preamble and then decoded.

The MAC is designed to work in *relay-enhanced cells.* A set of RNs may be directly connected to the BS and share the spectral resources with it. Each RN is connected to one but not more BSs. Some or all UTs may communicate directly with the BS. If RNs are present, some UTs may transmit to/receive from these RNs. The MAC implemented in each RN controls those transmissions. Thus, the RNs essentially control separate sub-cells. A complete MAC layer is assumed to be implemented at each BS and also at each RN.

While both heterogeneous and homogenous relaying is under consideration, the cellular MAC design has focused on the more challenging case of homogenous relaying, where RNs and BS use the same PL mode and share spectral resources. Relaying via user terminals is not considered in case of UTs being hand-held terminals (mobile phones). The total time-frequency resources are partitioned into parts used by the BS, shared parts, and parts used by RNs. This partitioning is computed by the MAC that is implemented at the BS, and is then signalled to all RNs and UTs.

The deployment concept may also include "relay nodes" that are not part of the relay-enhanced cells. Such RNs would typically be located beyond the cell border. They would be fed by relay links but would otherwise be treated like neighbouring base station from a resource partitioning perspective. Such RNs will here simply be regarded as neighbouring base stations.

The control of *downlink flows* resides in the MAC that is implemented in the transmitting RAP. Most MAC control functions for *uplink transmissions* reside in the receiving RAP. Parts of the RLC functionality will have to be implemented at Relay nodes, to participate in the control of uplink flows.

5.4.1.3 MAC Superframe structure

The **superframe** (SF) is a time-frequency unit that contains pre-specified resources for all transport channels; Figure 5-29 illustrates its preliminary design. The preliminary WINNER SF design comprises a preamble followed by n_f frames. The proposal uses n_f = 8, resulting in superframes of approximate duration 5.6 ms. (It could be extended to e.g. 16 frames, if required). In the time direction, there are 6 chunks per frame in the TDD mode and two chunks per frame in the FDD mode, see Chapter 5.5.1. The available number of chunks in the frequency direction could vary with the geographical location. It is assumed that for both for the FDD DL and UL and for TDD, there exist frequency bands that are available everywhere. The preamble is transmitted in those commonly available bands.

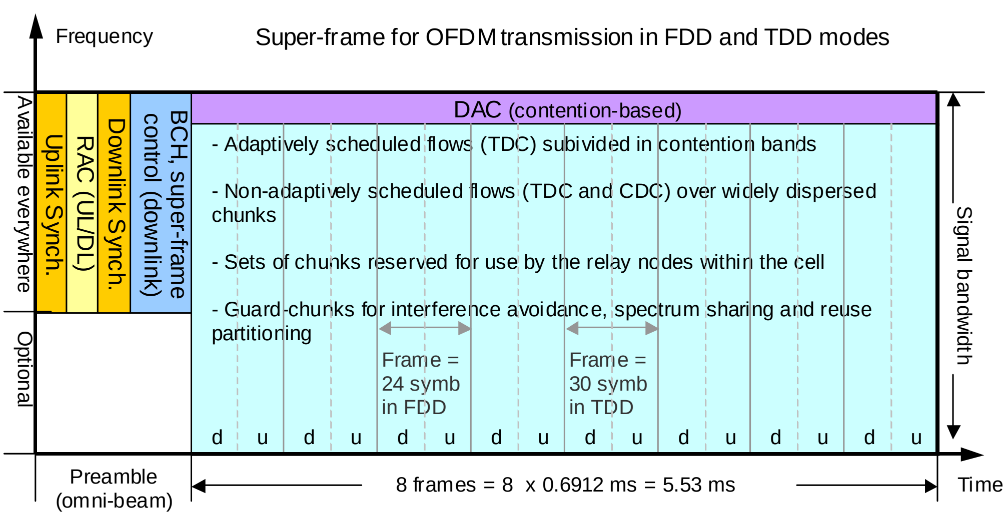

Figure 5-29: Preliminary superframe structure for both FDD and TDD physical layer modes. u = uplink transmission in TDD and d = downlink in TDD

Self-organizing synchronization of terminals and network nodes as described in [WIND23] and Chapter 5.5.4.1 can be used on a superframe basis by this design. Each superframe has the following structure:

- At the beginning of each superframe there are two synchronization slots, each consisting of three OFDM symbols. In the second slot, denoted as downlink synch, each base station/relay node transmits on two adjacent subcarriers, with the others set to zero. Each terminal recognizes the subcarrier pair on which the strongest synchronization signal is received, derives from it the information on time and frequency offset with respect to the correspondent BS/RN and synchronizes with it. In the first slot of the next superframe, the uplink synch, all terminals transmit the same synchronization signal on the two adjacent subcarriers used by the BS/RN, with which they are synchronized. From these signals the other BSs/RNs derive their relative time and frequency offsets and so indirectly get synchronized with one another in a self-organised way. These symbols are used for synchronization of terminals. They are also used for self-organizing synchronization of the base stations and relay nodes, which receive uplink synchronistion symbols from terminals at other BS, that in turn synchronise to those BS.

- In-between these synchronization slots, a short timeslot over the whole band is reserved for the contention-based random access channel (RAC). This channel enables initial access to a RN or BS. Placing the RAC and its guard time in-between the synch slots gives the RAP sufficient time to process the uplink synch signal and adjust its synchronization before transmitting the downlink synchronisation signal. The RAC time-slot is in TDD systems also used for BS-to-BS and RN-to-BS over-the-air control signalling.
- Subsequently, a set of OFDM symbols carries the **downlink preamble control transmission**. It contains the broadcast control channel (BCH) from the RLC layer. It also contains a control message that specifies the overall resource allocation used within this superframe. Adjacent BS and RN should use orthogonal time-frequency sets within this timeslot for their downlink preamble control transmission, to limit their mutual interference.

The initial timeslots described above form the **preamble** of the superframe. They are located in a part of the band available everywhere. The remainder of the superframe may use other spectral areas that are available at some locations, or to some operators, but not to others. All of these spectral regions are spanned by one FFT at the receiver. This main part of the superframe is shared by the contention-based direct access channel (DAC), the scheduled data channels CDC and TDC, and their out-of band control signaling. It also contains time-frequency-spatial resources that are not to be used due to interference avoidance constraints.

5.4.1.4 Advantages compared to existing technologies

The MAC design supports and enables several innovative features of the WINNER system:

- The superframe is designed to include self-organized synchronisation of all involved base stations, relay nodes and user-terminals.
- MACs for FDD and TDD cellular transmission enable fast transmission and very low re-transmission delays over the RI. These properties are key to attaining high spectral efficiency via adaptive schemes and reliable communication through efficient re-transmission.
- Adaptive transmission is integrated into the design, on all time-scales. Up to moderate vehicular velocities, link adaptation and scheduling can be performed with fine granularity in the frequency domain (OFDMA/TDMA). This enables multiuser scheduling gains to be obtained. For higher velocities, the transmission adapts to the shadow fading. On a superframe time-scale, the resource partitioning can adapt to the traffic demand over different transport channels.
- Multi-antenna transmission can be adjusted in a very flexible way per flow, to obtain an appropriate balance between obtaining multiplexing gains to boost throughput, achieving robustness via diversity transmission, and obtaining SDMA gains by transmitting different flows over different spatial channels.
- Operation in spectrum shared with other operators who use the same physical layer WINNER mode will be an integral part of the design. Operation in dedicated bands is seen as a special case of this situation.
- The superframe and the resource partitioning is designed to work efficiently in conjunction with inter-cell interference avoidance schemes. It is also designed for relay-enhanced cells, so that base stations and a set of relay nodes can share the total spectral resources efficiently.

5.4.2 Control Plane Services

5.4.2.1 MAC radio resource control

5.4.2.1.1 Resource partitioning and constraint combining

The problem to be solved by the **resource partitioning** is to prepare the structure of the next superframe, cf. Figure 5-29. As outlined in Chapter 5.5.1.3 the time-frequency *chunk* is the basic unit for subdividing the radio resources. The partitioning of the superframe will be performed with chunk granularity. The resource partitioning may be changed on a superframe basis, but most parameters will typically stay unchanged over longer time horizons. In TDD, one single superframe is to be defined. In FDD, separate uplink and downlink superframes are to be specified. These will normally use differing allocations.

The time-frequency resources within the next superframe are subdivided in the following sequence:

- First, all constraints on the use of chunks are updated by the ***Constraint combining*** function of the constraint processor at the BS. It receives control inputs from the RLC on restrictions due to spectrum sharing and due to interference avoidance with neighbouring base stations. These restrictions may have a spatial component and are defined in terms of *chunk-beams*[4]. The restrictions are combined into two chunk masks: 1) Chunk beams that must be avoided. 2) Chunk beams that may be used, but that are shared with neighbouring cells/other operators, and thus may contain significant interference.

The subsequent steps are performed by the ***Resource partitioning*** function that is implemented in the MAC Control Plane at the base station.

- ***DAC assignment***. A (nonzero) set of chunks is reserved for DAC (contention-based traffic). In the TDD mode, these resources may also be used for peer-to-peer traffic.
- ***RN assignment***. In cells that include relay nodes, sets of chunk beams are reserved exclusively for transmission between these RNs and UTs. Each set is reserved either for single RNs or for a group of RNs that will create little mutual interference. Furthermore, resources may be allocated for use in the relay links between BSs and RNs.
- ***TDC adaptive transmission assignment***. The remaining chunks are divided for use by adaptively and non-frequency adaptively scheduled flows, respectively. This division is based on the history of the previous traffic demand.
- The set of chunks reserved for adaptive transmission may be further divided into *competition bands*, where one stream normally uses only a single band. These competition band allocations are updated, if required.

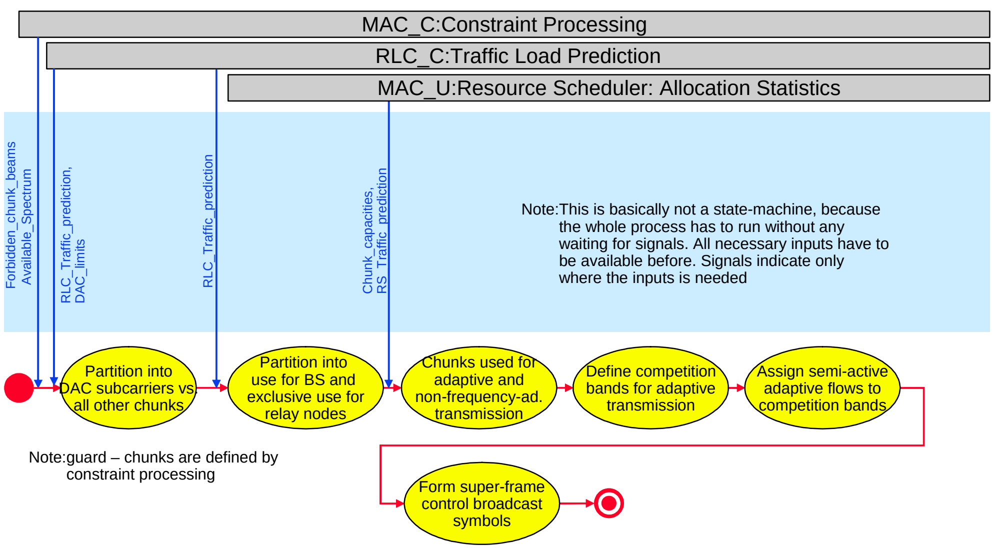

Figure 5-30: Main steps of the resource partitioning sequence, which determines the structure of the following superframe. Parts of this sequence is also executed at relay nodes

[4] In a grid-of-beams implementation, this will correspond directly to an azimuth direction. However, in general, each particular chunk-beam will correspond to a set of constraints on the spatial covariance matrix of the transmitted signal. This makes it possible to handle interference constraints for example in scenarios with local scattering around the access point or base stations with large antenna spacings.

The superframe has now been constructed. Control messages that specify the allocation are transmitted from the BS at two instances. In a case of two-hop relaying, the resource partitioning information is thereby distributed to all the participating UTs at the beginning of the following superframe:

- The RN partitioning is transmitted from the BS to the RNs in chunks that are reserved for control signaling within the present superframe.
- The remaining control information is transmitted by the BS to the UTs. This is done during the downlink control part within the preamble of the superframe being defined. In the here-considered case of two-hop relaying, it is the next superframe. Simultaneously, each RN transmits the RN assignment to the UTs under its control.

5.4.2.1.2 Flow setup and termination

New uplink and downlink flows are established by the RLC Flow establishment function. It requires the detailed set-up of a flow context over each involved hop. That flow context establishment is executed by the MAC ***flow setup*** function. Flow context release is initiated by the RLC and is executed by the MAC ***Flow termination*** function.

When a new downlink flow is established, it is given a local flow address that is unique within the cell. Its destination UT (or UTs in the case of CDC point-to-multipoint flows) is notified and a resource scheduling buffer queue is initialized.

In the FDD mode, flows to/from half-duplex terminals are assigned to one of four groups: *Group 1* transmits in the downlink the first half of the frame, and in the uplink during the latter half. *Group 2* transmits/receives in the opposite way. *Group 3* contains half-duplex terminals that have adaptable and flexible uplink and downlink transmission periods. Full-duplex terminals belong to *Group 4*.

TDC flows are initially assigned either for adaptive or for non-frequency adaptive transmission by the flow setup controller. The choice is based on the capability of the terminal, the average SINR and the velocity of the terminal, see Chapter 5.5.4.2. The choice is also affected by the potentially available spatial schemes, and their CSI and CQI requirements. The initial assignment may be changed later if the circumstances change.

5.4.2.1.3 Spatial scheme pre-configuration and selection

A base station or relay node can have one or multiple antennas. These antennas can be localized or may constitute a distributed antenna system, e.g. comprising all antenna elements within a building. A general **spatial processing scheme** for MIMO transmission and spatial domain link adaptation has been defined [WIND27]. It includes multiplexing, diversity-based transmission, fixed beamforming and adaptive beamforming as special cases. A baseline spatial scheme selection process is invoked to select an appropriate spatial transmit scheme for the newly established flow. This selection is based on the terminal capabilities, the BS antenna capabilities and the choice of adaptive and non-frequency adaptive transmission. In addition, the interference properties of other flows and their demand for spatial channels influence the decision. Also for already established flows, the spatial processing scheme can be changed by the Spatial Scheme Controller. To reduce the complexity of this process a split in two functions and temporal layering is used:

- ***Spatial scheme pre-configuration*** performs static and long-term trigger-based assignments. These assignments serve as inputs and constraints to the next step:
- ***Spatial scheme selection,*** which determines the dispersion code (degrees of spatial diversity and spatial multiplexing), the possible use of per stream rate control and the possible use of and type of precoding.

The Figure 5-31 below illustrates these functions and the different time scales at which they operate. The *static* part of the ***spatial scheme pre-configuration*** evaluates all parameters, decisions and constraints that can only be changed with an update of the basic cell configuration, including the physical layer mode, type of deployment (cellular, isolated hot spot), cell range, and the basestation (BS) antenna configuration. Furthermore mapping tables indicating the possible spatial schemes for each transport channel and terminal capability, as well as a list of possible combinations of dispersion code, PSRC, and precoding type can be generated at this stage.

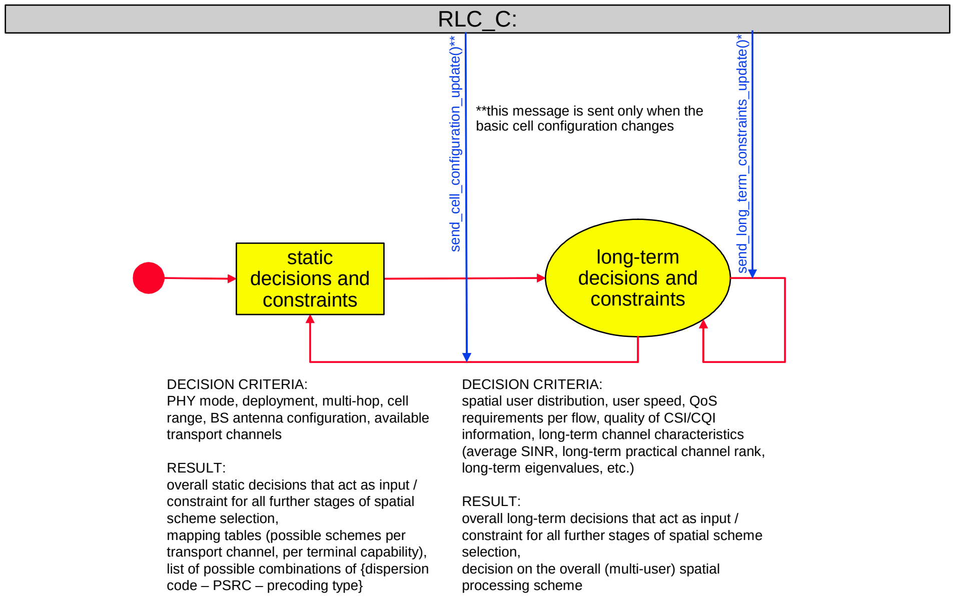

Figure 5-31: Overview of temporal layering of the MAC functionalities Spatial scheme pre-configuration and selection within the spatial scheme controller

The long-term part of the spatial scheme pre-configuration evaluates all parameters, decisions and constraints that normally change on time scales greater than one superframe or issues that cannot be decided on a per-flow basis, like the overall selection of a scheme that applies to all users of a cell (e.g., configuration of a fixed beam approach, or multi-user precoding). Slowly varying parameters include user distribution, user speed, quality of CQI/CSI information, the flows' QoS parameter, and long-term channel characteristics, like average SINR, long-term channel rank and eigenvalues. Also certain flow-specific decision will be long-term oriented, e.g. the decision between long-term and short-term spatial processing.

The ***spatial scheme selection*** considers the remaining parameters and adapts the spatial scheme per flow under the constraints set by the spatial scheme pre-configuration.

Spatial scheme selection includes the following major steps:

- ***dispersion code selection*** determines the requested number of streams used for spatial multiplexing and diversity for each flow based on the flows' requirements and the actual channel conditions. First, degrees of freedom are allocated to spatial diversity as much as required for robustness (with the goal to minimize them and considering the diversity available in frequency and time domain). Then it is checked whether the QoS requirements for particular users would require spatial multiplexing and degrees of freedom are allocated accordingly (subject of course to the channel conditions, measured e.g. by the practical channel rank). Also here the goal is to minimize spatial multiplexing to leave sufficient possibilities to benefit from SDMA.[5]
- ***PSRC (per-stream rate control) decision*** that determines whether segmentation of one flow will take place and the number of subflows. Each subflows will undergo individual link adaptation,
- ***precoding decision*** that first distinguishes between no beamforming, fixed beamforming and adaptive precoding. In the latter case it differentiates between short-term/long-term processing, whether multi-user optimisation is applied, and between linear and non-linear techniques. The type of precoding or beamforming is determined to a large extend in the spatial scheme pre-

[5] The dispersion code selection is in general a preliminary request that might be revised during the actual resource scheduling in order to perform multi-user optimization and to improve the opportunities for SDMA. A successive allocation of the spatial degrees of freedoms based on maximum increments of a target function is a promising candidate. Traditionally pure channel-dependent criteria have been used, such as maximum increments of sum-rate [TUB05, BPS+05], however the target function should also take the priorities and the individual requirements of diversity and spatial multiplexing of the flows into account.

configuration, since it depends on BS antenna configuration, deployment, cell range, transport channel type, user distribution and quality of channel knowledge. However, the number of users requesting resources and their buffer content is changing rapidly in a packet-oriented network. These parameters will also influence whether it is worth configuring adaptive precoding with all its involved measurement and feedback overhead. For adaptive processing we distinguish further between short-term (ST) and long-term (LT) processing, basically on static or long-term information used in the spatial scheme pre-configuration, such as PLM, user speed, and channel measurement quality. The latter, together with the number of active users are also important to determine whether it is worth considering multi-user optimization.

A preliminary sequencing of the decisions is illustrated by Figure 5-32 below.

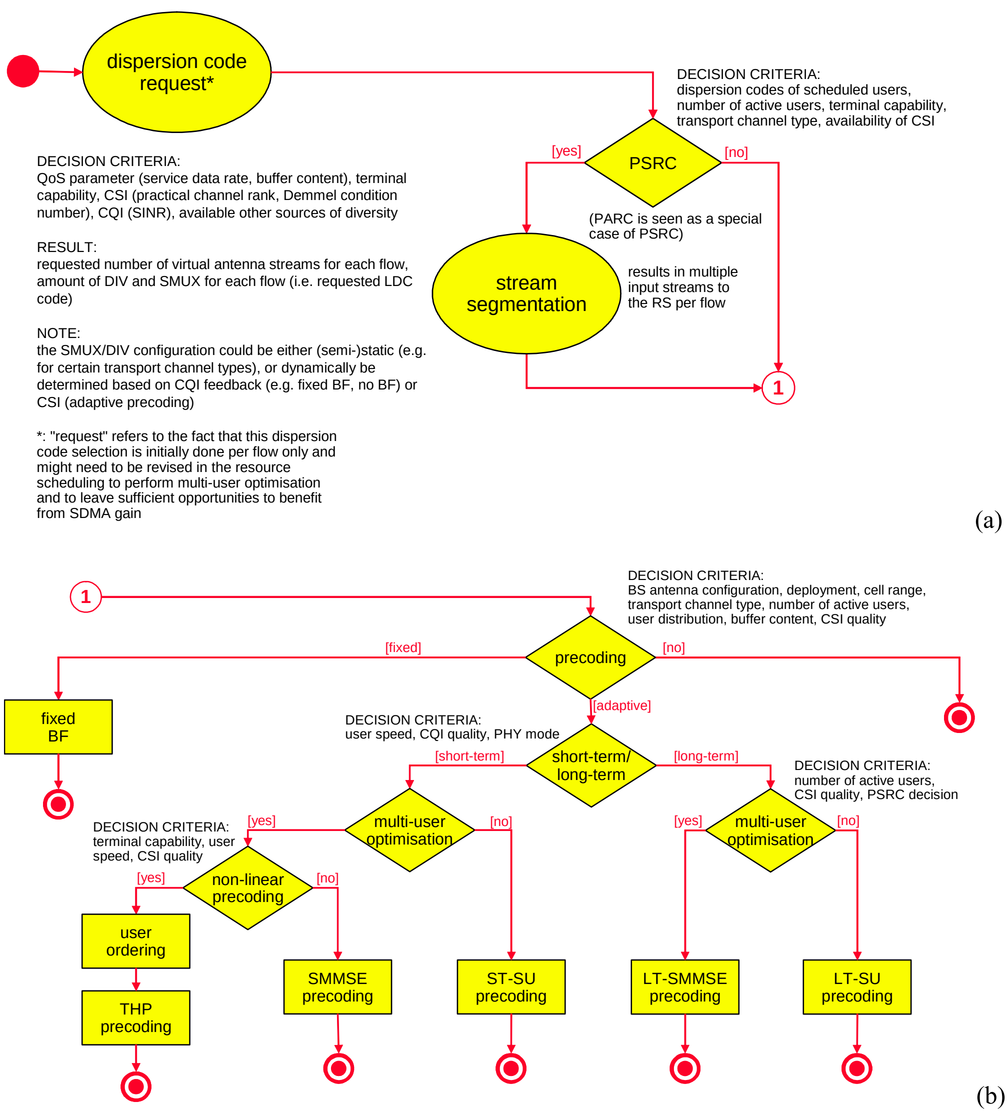

Figure 5-32: Example Algorithm for Spatial Scheme Selection.

Apart from the static and long-term input variables mentioned in the context of spatial scheme pre-configuration above, additional useful decision criteria for spatial scheme selection include:

- channel-related short-term measurements (CQI, channel rank, …)
- number of active users and their buffer content.

5.4.2.2 MAC control feedback

The definition of service primitives for the MAC Control Feedback service is driven completely by the demand for such feedback from the RLC layer and the IP Convergence layer. In principle, all outputs from the main function blocks, and even internal states of these function blocks, could be made visible to upper layers, to enable various forms of inter-layer interaction. The set of required feedback parameters is still under discussion. It includes SLC Cache levels (see below) as well as feedback on restricted resources towards *RLC::Load Control* service.

5.4.3 User Plane Services

5.4.3.1 Radio packet transfer

5.4.3.1.1 Transmission and reception

The transmission control is performed in cooperation with the Service level controller at the RLC layer. A **Service Level Controller (SLC) Cache**, with per-flow queues for all downlink TDC, CDC and DAC flows, is assumed to be implemented within each MAC at each BS and RN. For uplink flows, corresponding buffers are present at each RN and UT.

The RLC Service level controller controls the inflows to the BS SLC Cache and monitors its state. The outflow from the SLC Cache is under control of a MAC:

- For BS-to-UT downlinks and BS-to-RN relay links, the MAC at the BS controls the transmission.
- For UT-to-RN uplinks, the MAC at the RN controls the transmission.
- For UT-to-BS uplinks, the MAC at the BS controls the transmission.

Packet transmission and reception will be handled differently for the five transport channels. BCH packets and RAC packets are encoded at transmission and decoded at reception, but are not processed further by the MAC layer. TDC, CDC and DAC packets are processed by a more elaborate transmit and receive sequence that is divided into five sub-layers, as illustrated by Figure 5-28:

MAC-5: Performs optional segmentation and reassembly of MAC SDUs (i.e. RLC PDUs). MAC-5 also performs flow identification at reception.

MAC-4: Sender adds CRC, resulting in a *re-transmission unit (RTU).* Receiver checks CRC and may ask for re-transmission in case of error . The re-transmission mechanism is denoted **MAC restransmission**.

MAC-3: Sender performs optional segmentation of RTUs into *encoding blocks.* The receiver then performs reassembly of received blocks into RTUs.

MAC-2: Coding of each encoding block results in an *FEC block* (forward-error-correction coded block) that is saved in the appropriate RSB queue. The receiver decodes each FEC block. It may also perform (soft) combination with retransmitted FEC blocks. This encoding /decoding will in the following be referred to as the *outer code*.

MAC-1: Performs puncturing of FEC blocks and resource mapping onto assigned chunks. ***Resource mapping*** is a separate main function of the MAC User Plane.

The sub-layers MAC-5 – MAC-2 may all be transparent, i.e. their functions are optional. Special cases of this transmission sequence accommodate all re-transmission schemes and segmentation strategies that are at present under consideration. The design outlined above performs segmentation and encoding before the mapping onto chunks. It thus decouples the segment size used for re-transmission from the chunk size. It also decouples the code block size from the chunk size, in a practical way. These factors are also important when the WINNER air interface concept is used as a test-bed to compare and evaluate different combinations of MAC re-transmission strategies and coding schemes.

For BCH, the mapping onto superframe control symbols is controlled by the ***Resource partitioning*** function For TDC, CDC and DAC, the ***Transfer control*** function supervises both transmission and reception.

The transmission control is focused at fast transfer via the physical layer:

- For adaptively allocated TDC downlink flows, a transmission can be initiated during the downlink part of frame *j* and then be performed during the downlink slot of frame *j+1*.
- For adaptively allocated TDC uplink flows, a transmission can by requested during frame *j*, prepared and scheduled during frame *j+1* and then be performed in the uplink slot of frame *j+2*.
- For non-frequency adaptively allocated TDC and CDC downlink flows, the scheduling can be determined during frame *j*. an allocation table is transmitted in the first DL OFDM symbol of frame *j+1*. The transmission can then be performed either within frame *j+1* or during frame *j+2*.
- For non-frequency adaptively allocated TDC uplink flows, the transmission is initiated during frame *j* and is then performed in the uplink slot of frame *j+1*.

Thus, the delay from initiation of a transmission to its completion is 1.0-2.5 frames (0.7-1.7 ms) over one hop. Multi-hop transmission will add to the total delay. The roundtrip delay until a MAC re-transmission can be performed depends on the decoding delay, which is under current investigation.

The transmission of packets belonging to the different transport channels is summarized below.

TDC (downlinks and uplinks): Packets in scheduled Targeted Data Channel flows are optionally segmented and then coded, using the transmission sequence outlined above. The FEC blocks are buffered by per-flow queuing in the resource scheduling buffer. Scheduling and the subsequent mapping is then performed by either the adaptive or the non-frequency adaptive resource scheduling algorithm, depending on the assignment of the flow (Chapters 5.5.2.1 and 5.5.2.2). Thereafter, transmission proceeds using the PHY Adaptive transfer or Non-frequency adaptive transfer services. At reception, complete FEC blocks are delivered to the MAC. In *downlinks*, the MAC at the BS or RN controls the transmission. In *uplinks*, packet transmissions are initiated by UT requests. The MAC at the BS/RN with which the UT communicates controls the subsequent scheduling, transmission and re-transmission.

CDC (downlinks only): The point-to-multipoint transmission has to deal with a wide variety of channels and directions to the destination users. This complicates the adjustment of the transmission parameters and the use of beamforming. To reduce the variability, a CDC flow may be partitioned into separate copies, *targeted flows*, which are destined to specific groups (clusters) of users in different directions/within different beams. A CDC flow is processed through the MAC-5 – MAC-2 general transmission chain. The resulting FEC blocks are copied into one or several queues in the RSB, one queue for each targeted flow. Scheduling and mapping of each targeted flow then proceed by non-frequency adaptive transmission, with transmission parameters that are adjusted in a conservative way. The transmission uses the PHY Non-frequency adaptive transfer service. At reception, complete FEC blocks are delivered to the MAC, where they are decoded. Packets (MAC SDUs) are finally recombined if segmentation was used. A reliable multicast service may utilise re-transmission. The re-transmissions could be triggered by NACKs from any of the destination users of a targeted flow. Schemes that combine this mechanism with ACKs from the terminal with worst channel are also possible.

DAC (uplinks only): Contention-based transmission is potentially the best way of transmitting uplink flows that have small packets with a low packet arrival rate. When a uplink packet destined for contention-based transmission is drained from the SLC Cache at the UT, it is prepared for possible re-transmission and then coded. The same function blocks/sub-layers as for TDC and CDC transmission are used, but the parameter settings may be different. The FEC blocks are transmitted by using the PHY contention-based transfer service (Chapter 5.5.2.3). Received DAC FEC blocks are decoded and the RTUs are possibly retransmitted if an error is detected.

BCH (downlinks only): The BCH packets contain control signaling from higher layers. The range of their safe reception places an upper bound on the size of the cell. Downlink broadcast channel packets are combined with superframe control packets. They are coded but are not retransmitted. Low-rate encoding in the MAC is combined with low-rate space-time-frequency (inner) encoding is performed at the PHY layer. Transmission and reception proceeds via the PHY BCH and SF control transfer service (Chapter 5.5.2.5). Received BCH packets are decoded.

RAC (uplinks and, for TDD, BS-to-BS/RN): The Random access channel can be used for initial access to a BS or RN from UTs, e.g. after handover. At transmission, RAC packets are coded and then transmitted in the reserved time-slot of the superframe preamble in a contention-based manner. Transmission and reception proceeds via the PHY RAC transfer service (Chapter 5.5.2.4). The RAC time-slot can in TDD systems also be used for *BS-to-BS and RN-to-BS over-the-air control signaling*. A BS or RN involved in this transmission would use the RAC for transmission in a few superframes, while it listens for reception in the others.

5.4.3.1.2 Resource scheduling

The ***Resource scheduler*** determines the resource mapping for TDC and CDC flows. It utilises two scheduling algorithms:

- The ***Adaptive resource schedule****r*, used for high-performance TDC transmission.
- The ***Non-frequency adaptive resource scheduler***, used for all CDC flows and as a fallback alternative for TDC flows.

These algorithms take priorities from the RLC Service Level Controller into account, as well as the queue levels in the RSB and the SLC Cache.

- The ***adaptive resource scheduling*** and transmission uses predictions of channel quality indicators (CQI) to *utilise the small-scale and frequency-selective variations of the channel* for different terminals. The scheduler assigns a set of chunk layers (see Chapter 5.5.1.5) within the frame to each flow. After scheduling, the RSB queues are drained with bit-level resolution. The bits from each flow are mapped onto the assigned chunk layers. This mapping is exclusive in downlinks, i.e. several flows do not share a chunk layer. The transmission parameters within each chunk layer are adjusted individually through link adaptation to the frequency-selective channel of the selected user. This link adaptation may use combinations of adaptive modulation, (inner) coding that is adjusted to each chunk, and power control. The aim of the link adaptation is to provide a target SINR per bit for the FEC blocs that are coded with the (outer) FEC code. Link adaptation may be combined with spatial multiplexing, for example in the form of per-stream rate control, where different FEC blocks of one flow are mapped to different chunk layers. By selecting the best resources for each flow, multi-user scheduling gains can be realized. The scheduling algorithm should take into account the channel quality information of each user in each chunk layer, the RLC flow transmission requirements/priorities and the queue levels. Timely channel quality information requires the SINR within each chunk layer and for each candidate terminal to be predicted with relatively high accuracy. The most advanced multi-antenna transmit schemes furthermore require the whole MIMO channel gain matrix to be known at the transmitter. This is denoted full *channel state information (CSI).*
- **Non-frequency adaptive resource scheduling** and transmission is instead based on averaging strategies. Such transmission schemes are designed to combat and reduce the effect of the variability of the SINR, by interleaving, space-time-frequency coding and diversity combining. Non-frequency adaptive transmission is required when fast channel feedback is unreliable due to e.g. a high terminal velocity or a low SINR [WIND24], or when the terminal does not support adaptive transmission. It is also required for point-to-multipoint communication belonging to the common data channel (CDC) flows. The non-frequency adaptive transmission slowly adapts to the shadow fading, but it averages over the frequency selective (small-scale) fading. It requires the FEC blocks to be mapped on a set of chunks that are widely dispersed in frequency and if possible in different spatial layers, to maximize the effectiveness of the coding and interleaving.

Figure 5-33 below gives an overview of the downlink transmission of scheduled flows. Among other things, this figure illustrates that two scheduling entities control the flows, and have to cooperate. The Service level controller at the RLC layer (Chapter 5.3.2.1.3) and the Resource scheduler of the MAC. In the present design, these two scheduling entities interact in a very simple way: The SLC fills the SCL Cache, while the RS is responsible for draining it. The SCL furthermore reports priorities of each flow to the RS. The RS drains the queues and allocates the transmission resources in a way that optimizes a criterion that takes the queue levels and the priorities into account. The adaptive RS uses detailed knowledge of the available resources, the non-frequency adaptive RS has to work with more crude measurements of the average channel qualities. Existing algorithms with very low computational complexity can be used to solve the resource scheduling problem, when formulated in this way.

Adaptive transmission requires prediction of the channel quality due to the transmission control loop delay. In [WIND24] the predictability and attainable prediction accuracy is investigated as a function of the SINR and the terminal velocity. The effect of the prediction errors on the attainable adaptive transmission performance and on attainable multi-user scheduling gain was investigated. Fast adaptation control loops are a part of the WINNER design. With correspondingly low delays, adaptive transmission was found feasible at vehicular velocities at 5 GHz carrier frequencies. A SINR and velocity-dependent boundary delineates when adaptive or non-frequency adaptive transmission is the best alternative (Chapter 5.5.4.3). This decision is taken at flow setup, and may be changed later.

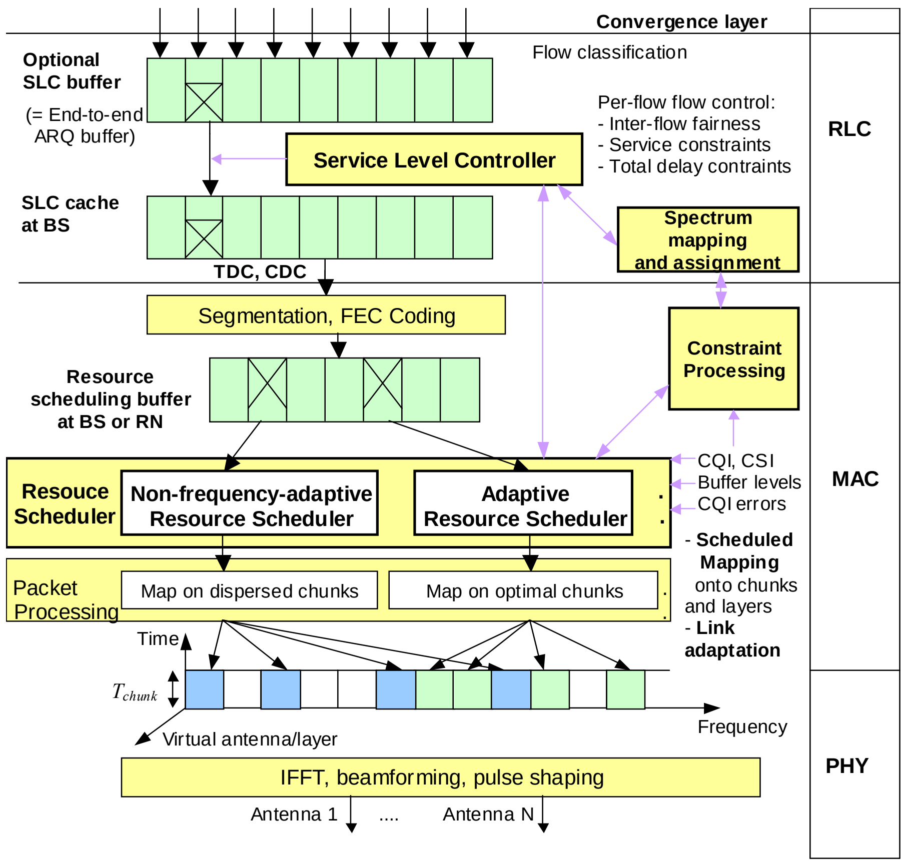

Figure 5-33: Data flows and some control functions in downlinks of the scheduled data channels

Both downlink and uplink power control is supervised by the Resource scheduler and is integrated into the optimization of the transmission parameters.

A novel framework had been developed for handling the spatial dimension of the multi-user scheduling and link adaptation problem. It integrates various SDMA (spatial division multiple access) strategies into the total solution.

As outlined by Figure 5-34 below, adaptive multi-antenna link adaptation and scheduling separated into four steps, to limit the computational complexity so that a fast feedback loop is obtained:

1. Spatial user partitioning, i.e. separation of users into spatially well separated sets.
2. Preliminary single-user link adaptation for each potential user and potential resource.
3. Channel-adaptive multi-user scheduling within the sets of spatially highly-interfering terminals, using the chunk capacities calculated in step 2. (In case of non-frequency adaptive transmission, only slow adaptation to the shadow fading is used).
4. Final link adaptation, resource mapping and transmission of the selected flows

The sequence can be iterated a few times to improve the over-all allocation.

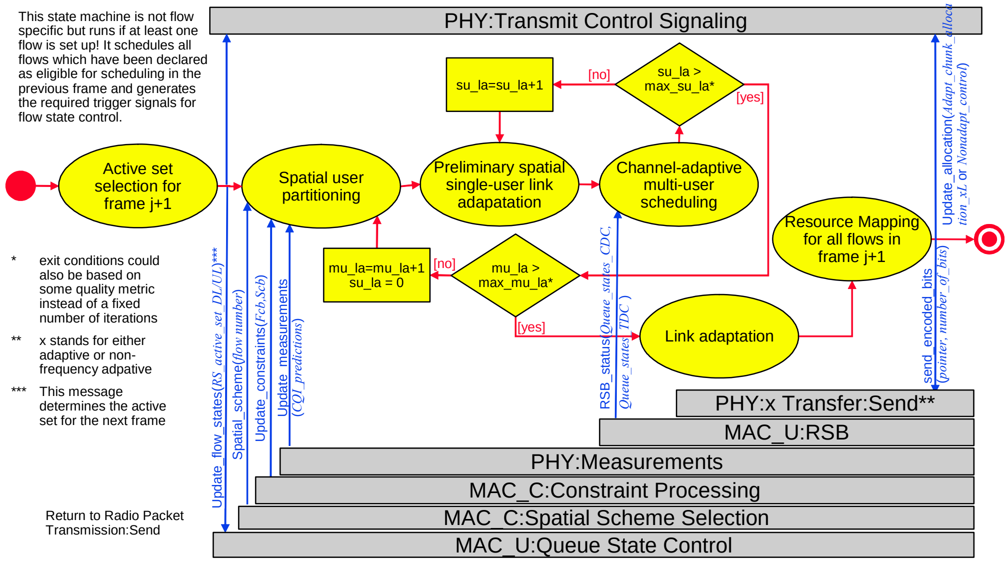

Figure 5-34: Resource scheduling sequence overview (adaptive and non-frequency adaptive)

To reflect the bursty nature of packet flows and to limit the transmission overhead, each adaptively allocated TDC flow shifts between the following states (see Figure 5-35):

- **Passive**. The flow has an empty RSB queue and no packet in the SLC Cache. Minimal transmission control signaling is required. Terminals may be in micro-sleep mode except during specified control transmission time-slots.
- **Semi-active**. This state is only used for adaptively allocated TDC flows. The flow has segments in queue, but is not eligible for scheduling during the present frame.
- **Active.** The flow is eligible for scheduling during the present frame. The full transmission control loop is up and running.

The transition between these three states and the corresponding PHY control messaging is governed by the ***Queue state control*** function within the Flow state controller and the ***active set selection*** in the RS. The queue state is updated every slot (half-frame).In cells with few flows, all flows with packets to transmit will be in the active state. In cells with many flows assigned for adaptive transmission, the access to the active state can be restricted, to limit several types of complexity and overhead: The scheduling computational complexity, the downlink control overhead, the channel prediction complexity and the CQI and CSI feedback signalling overhead.

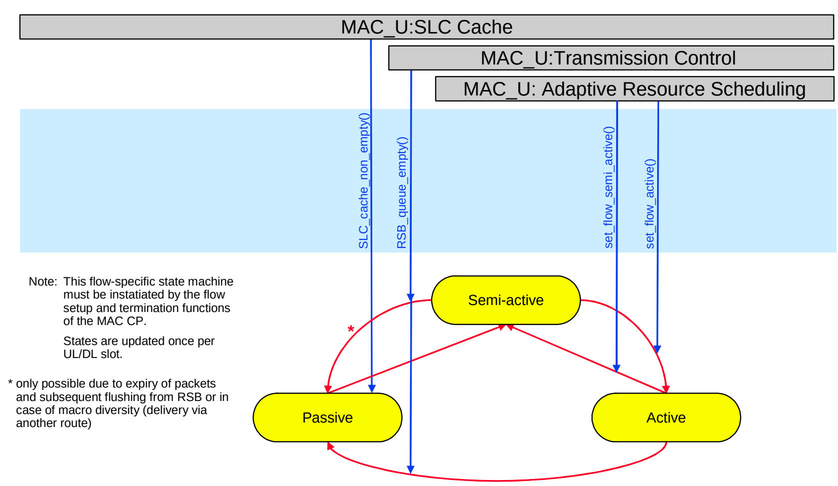

Figure 5-35: Radio Packet Transfer: Queue state control for adaptively allocated TDC flows

5.5 Physical Layer

5.5.1 Overview of the physical layer

In the physical layer of the WINNER concept, OFDM is assumed to be used in downlinks of the FDD PL mode and in both uplinks and downlinks of the TDD PLM. The baseline assumption on OFDM is classical cyclic-prefix OFDM. GMC, which contains frequency-domain based serial modulation as a special case, is assumed to be utilised in FDD uplinks, using the same OFDM parameters as for FDD downlinks. Below follows a brief summary of physical layer properties.

5.5.1.1 PHY services

The physical layer offers the following services to higher layers:

- **Adaptive transfer**: Transmission and reception of adaptively allocated FEC blocks.
- **Non-frequency adaptive transfer**: Transmission and reception of non-frequency adaptively allocated FEC blocks.
- **DAC transfer**: Contention-based transmission and reception of DAC FEC blocks over the physical resources allocated to the DAC uplink.
- **RAC transfer**: Contention-based transmission and reception of control packets over the RAC time-slot in the superframe preamble.
- **BCH and SF control transfer**: Transmission over the superframe preamble of downlink broadcast control messages from the RLC layer and of downlink control messages from the MAC that determine the structure of the following superframe.
- **Measurements**: Reports from user terminals required by the MAC and the RLC layers.
- **Transmit control signaling**. Transmission of control messages in both directions between BS/RN and user terminals for controlling the data transmission over the physical channel. Transfers signaling to/from the PHY layer at the UT.

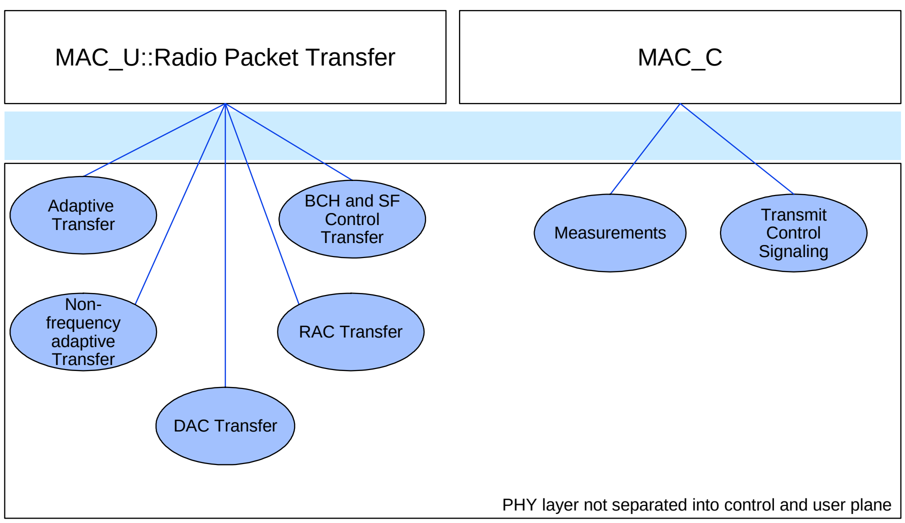

Figure 5-36: The PHY Services

The following subchapters provide an overview of the proposed physical layer, to be described in more detail in [WIND210].

5.5.1.2 Advantages compared to existing technologies

The design of the physical layer supports several of the innovative features of the WINNER concept:

- A slotted time-frequency chunk pattern is defined that can be adjusted to different propagation scenarios. The chunk durations and frame durations are short, which is a basic requirement for a low transmission delay over the air interface.
- A transmission chain is used which includes OFDM transmission and frequency-domain generated serial modulation within sets of chunks as special cases.
- Flexible spatial processing is integrated into the transmission and reception chain.
- Pilot patterns are included that support efficient synchronization, channel estimation and channel prediction for adaptive transmission.
- Channel prediction can be used to expand the possibility for using adaptive transmission to include vehicular users.
- Efficient means have been developed for compressing the channel quality information feedback required for adaptive transmission and the channel state information required for some multi-antenna schemes. These methods reduce the required feedback overhead to reasonable levels.

5.5.1.3 Chunks, chunk layers and frames

The basic time-frequency resource unit in OFDM links is denoted a **chunk**. It consists of a rectangular time-frequency area that comprises a number of subsequent OFDM symbols and a number of adjacent subcarriers. A chunk 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.

Each chunk entity comprises n_{sub} subcarriers and spans a time window of n_{symb} OFDM symbols. In transmission using multiple antennas, the time-frequency resource defined by the chunk may be re-used by spatial multiplexing. A **layer** represents the spatial dimension**.**

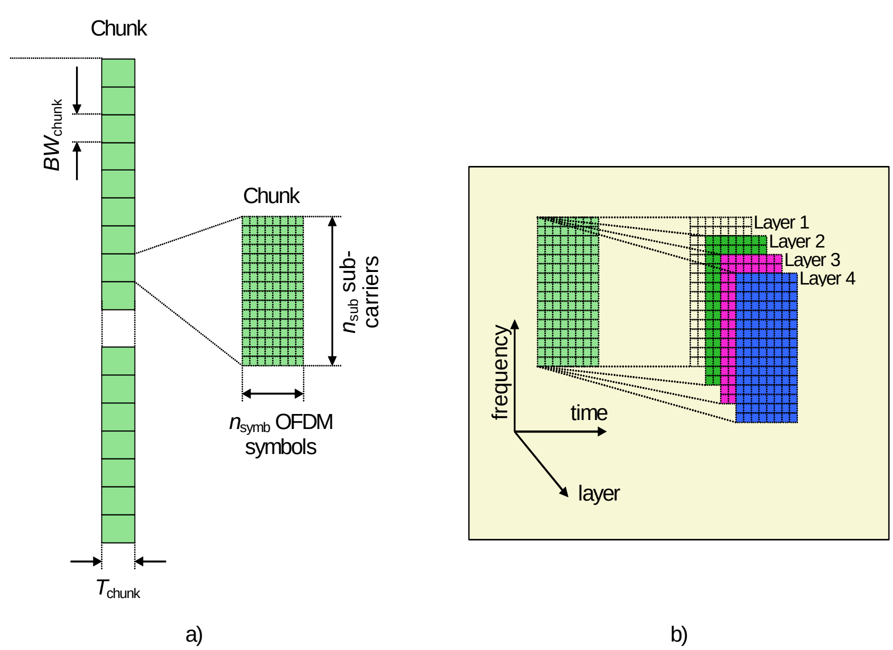

Figure 5-37: a) Multi--carrier Downlink physical channel structure. b) Layered time and frequency chunks for MIMO transmission

The first assumptions for study and simulation presented below are used for investigations during the WINNER Phase I. Note that the real WINNER system will be required to support several different configurations (parameter sets), in order to effectively adapt to differing channel conditions and fulfil the "always-best" objective. The parameters listed below are examples for such parameter settings, which can be used to study the relative merits of different techniques. The paragraphs and tables below provide an overview on the selected modulation techniques and their specific configuration, respectively. A framework for deriving appropriate parameter sets can be found in [WIND23].

- ***FDD:*** Transmission is performed over paired 20.0 MHz bands, using 512 subcarriers, of which 416 (16.25 MHz) are utilised. With 39062 Hz subcarrier spacing and 3.20 µs guard interval (1/8 OFDM symbol), the duration of OFDM symbol + guard interval is 28.80 µs. In downlinks, OFDM transmission is assumed.
- ***FDD*** wideband variant: Paired 40.0 MHz bands using FDD. Uses same parameters as above, but with 1024 subcarriers, of which 832 (32.50 MHz) are utilised.
- ***TDD:*** Transmission over a single (unpaired) band of 100 MHz. OFDM is used with 2048 subcarriers, of which 1664 (81.25 MHz) are utilised. The subcarrier spacing is 48828 Hz, the assumed guard interval is 1.28 µs (1/16 OFDM symbol) and the OFDM symbol + guard interval duration is 21.76.

In both FDD and TDD uplinks, different variants of **Generalised Multi-carrier** (**GMC)** [WIND23] [WIND29] transmission, which include conventional cyclic-prefix OFDM and frequency-domain generated serial modulation as special cases, can be applied by different terminals. All these uplink transmission are embedded in the superframe and are assumed to fine-synchronized (Chapter 5.5.4.1).

The FDD mode is mainly evaluated in *wide-area cellular* deployment, with cell radii of up to 1-2 km. The TDD mode is evaluated in the *metropolitan (short-range cellular)* and peer-to-peer scenarios but also in relay links over distances up to 1 km. Its guard times have therefore been selected shorter than for the FDD mode.

Parameter	**FDD mode (2 x 20 MHz)**	**TDD mode**	**Units/notes**
Centre frequency	5.0 DL/ 4.2 UL	5.0	GHz
Duplexing method	FDD (paired)	TDD	
FFT BW	20.0	100.0	MHz
Number of subcarriers in GMC	512	2048	Equals length of FFT
Subcarrier spacing	39062	48828	Hz
Symbol length (Excluding cyclic prefix)	25.60	20.48	µs
Cyclic prefix length	3.20	1.28	µs
Total symbol length	28.80	21.76[6]	µs
Number of subcarriers in use	416	1664	[-208:208] and [-832:832] Subcarrier 0 not used
Signal BW	16.25	81.25	MHz
Chunk size in symbols	8 x 12 = 96	16 x 5 = 80	Subcarriers x Symbols

Table 5.1: Basic transmission parameters used for simulation of GMC based systems

It should be noted that the parameters in Table 5.1 can be applied to any GMC based transmission, including frequency-domain based serial modulation.

The chunk width is set to *8 subcarriers, or 312.5 KHz* in the FDD mode adjusted for wide-area coverage and to *16 subcarriers, or 781.2 KHz* in the TDD mode mainly intended for short-range coverage. Thus, the usable 416 subcarriers in the FDD mode narrowband variant are partitioned into 52 chunks, the 832 subcarriers of the wideband variant into 104 chunks and the usable 1664 subcarriers in the TDD mode are partitioned into 104 chunks.

The radio interface delay requirement of around 1 ms stated in R3.4 of [WIND71] can be interpreted as a requirement on the slot duration of the FDD transmission, and the uplink and downlink slot lengths of the

[6] A small symbol roll-off time is here assumed to be included in the guard intervals.

TDD transmission, by the following reasoning: The shortest control loop for a transmission consists of a request, response, and transmission, i.e. a downlink/uplink/downlink or uplink/downlink/uplink transmission sequence. Each such sequence should have duration of approximately 1 ms.

The chunk durations T_{chunk} of the FDD mode will therefore be set to 12 OFDM symbols plus guard times, or 334.6 µs. The **frame** of the half-duplex FDD system consists of an uplink chunk followed by a downlink chunk, with duration $T_{frame} = 2\ T_{chunk} = 691.2$ µs.

The frame of the TDD mode consists of downlink period + duplex guard time + uplink period + duplex guard time. This frame duration is set equal to the FDD frame duration of 691.2 µs, to simplify inter-mode cooperation. The TDD chunk duration is set to 5 OFDM symbols plus guard times = 108.8 µs. The duplex guard time is set to 19.2 µs. Each TDD frame contains 6 chunks plus two duplex guard times, 6 x 108.8 + 2 x 19.2 = 691.2 µs. With asymmetry 1:1, each frame contains three downlink chunks and three uplink chunks. The downlink:uplink asymmetry ratio could be varied from 5:1 to 1:5, but for timing reasons in adaptive transmission, it should not be set larger than 2:1.

A chunk thus contains 96 symbols in the FDD mode and 80 symbols in the TDD mode, see Figure 5-38.

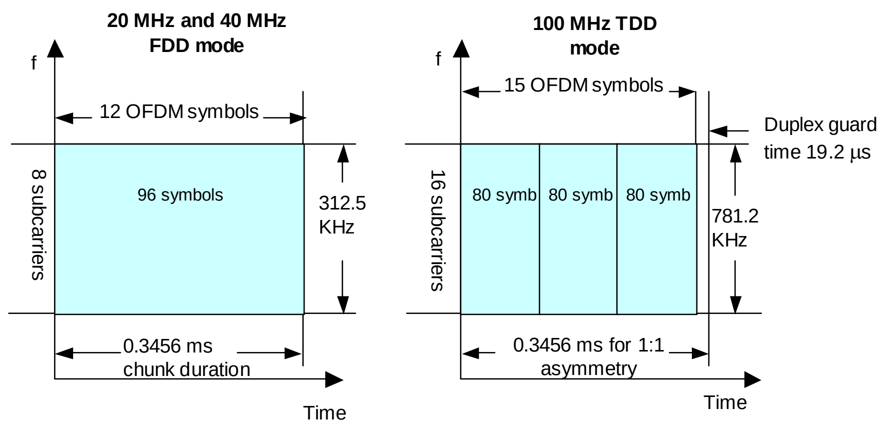

Figure 5-38: Summary of assumed chunk sizes in the two physical layer modes. The figures show a slot (half of the frame duration) in each case, assuming 1:1 TDD asymmetry

5.5.1.4 Physical layer transmission and reception: Generalised multicarrier transmission

Figure 5-39 and Figure 5-40 give a general overview of the envisaged structure for the transmitter and receiver, respectively in the WINNER system concept. The structure is the same for all cases of generalised multi-carrier transmission, requiring only appropriate configuration for some components. For OFDM transmission, the "GMC" pre-processing block in Figure 5-39 would only contain (optional) frequency domain filtering. For frequency domain generated serial modulation, it is necessary to subject the modulated symbols to a FFT *before* any frequency domain (spatial) processing, i.e., modulation has to be done *before* the formation of chunks. One option is to take a block of M modulated symbols that eventually will be turned into one or more chunks and pass it through an M-point FFT (this operation will be done in the GMC processing block of Figure 5-39). The resulting M-point complex block is now in the frequency domain, and is mapped into the specified chunk layers. The remaining processing is equivalent to that for other GMC signals, e.g. OFDM. It should be emphasised that serial modulation is only envisaged for the uplink from *individual* user terminals, i.e., will probably only require a quite basic configuration of the generic spatial processing chain described in detail in Chapter 5.5.1.5.

A proposal for the corresponding receiver structure is depicted in Figure 5-40. Feedback loops between soft-input soft-output decoder and space-time equaliser and channel estimation enable e.g. the iterative detection and channel estimation techniques detailed in [WIND21, WIND23, WIND29]. Serial modulation based transmission (time and frequency domain based single carrier, as well as IFDMA) requires an IFFT in addition to the FFT of multi-carrier based transmission, to enable frequency domain equalisation.

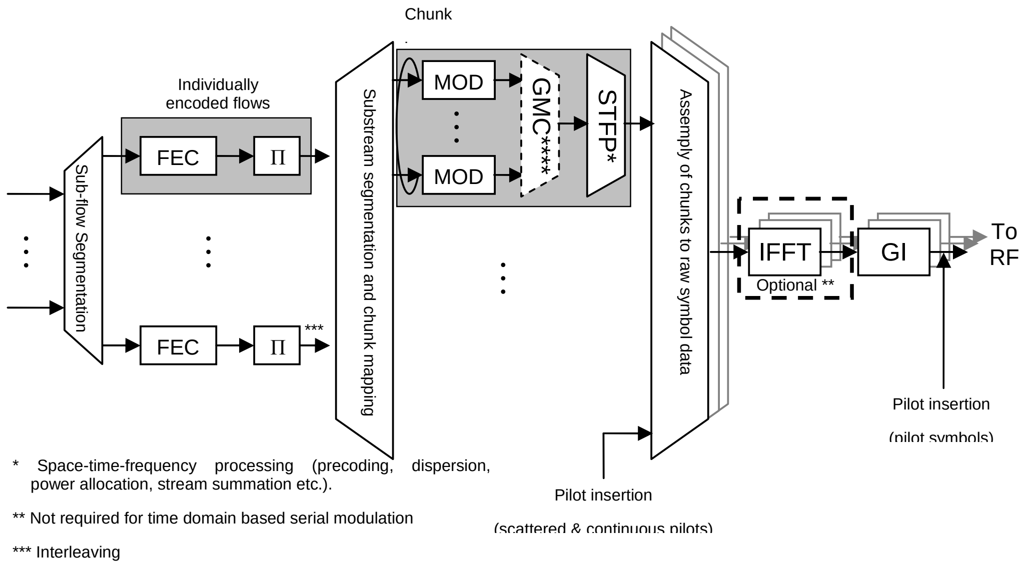

Figure 5-39: Overview of transmitter structure

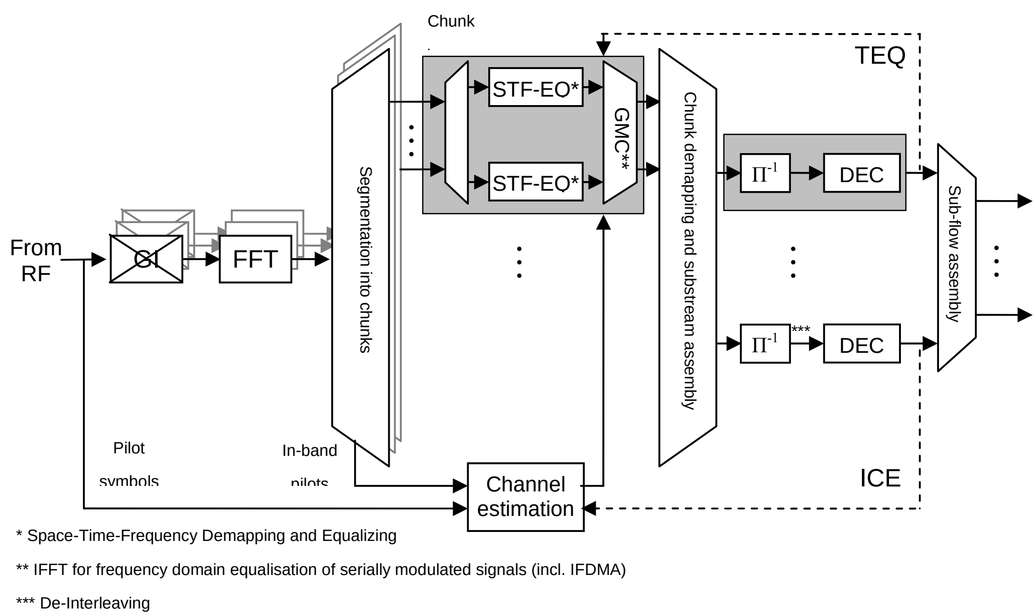

Figure 5-40: Overview of receiver structure

5.5.1.5 Spatial processing and time-frequency mapping

Spatial processing provides performance gain via spatial diversity, spatial multiplexing, SDMA, and enhanced interference management. Spatial diversity adds reliability by transmitting multiple copies of the same data over uncorrelated channels. Therefore, diversity efficiently copes with the detrimental effects of fading on the error performance. On the other hand, fading in a multi-antenna system can also be seen as a beneficial effect that can lead to a substantial increase of the achievable data rate by performing spatial multiplexing, i.e. transmitting independent data over the uncorrelated spatial channels to one user terminal. When considering a multi-user environment, the existence of multi-user diversity provides another adaptation dimension that should be exploited. A significant contribution to high spectral efficiency is interference avoidance by spatial processing, e.g. based on multi-user precoding at the transmitter in the downlink. The use of beamforming (adaptive or non-adaptive) makes it possible to schedule multiple users on the same time-frequency resource within a cell or across multiple cells, and separate them by the SDMA properties of the multi-antenna channel. When channel knowledge is available at the transmitter, it is also possible to distribute complexity between transmitter and receiver in a very flexible manner. Precoding techniques, for example, allow keeping receiver complexity low. Note that, although first investigations are based on traditional cell layouts with sectorised antennas, precoding with distributed antennas (using a central processing unit and separated radio heads) is seen as a particular deployment of the proposed WINNER multi-antenna concept that can be of additional benefit for the overall goal of an interference-avoidance radio interface concept.

The WINNER multi-antenna concept is a generic architecture that aims at performing *multi-user spatial domain link adaptation*, based on the following basic components: (Linear) dispersion codes, directive transmission (beamforming), per stream rate control, and multi-user precoding [WIND27]. This architecture allows fostering the spatial processing gains introduced above in flexible combinations as required by different scenarios, i.e. different combinations of physical layer mode, link direction, transport channel type, deployment, propagation conditions, cell load, traffic type, BS antenna configuration, and terminal capabilities. It therefore embeds different spatial processing algorithms into a common framework [DAO05].

The generic spatial processing is detailed below mainly from a downlink perspective, although many blocks may equally be used in OFDM-based uplinks.

The multi-antenna transmission scheme can be described as follows. A chunk covers n_{sub} subcarriers and n_{symb} consecutive OFDM symbols. To enable techniques such as SDMA and per stream rate control, a third dimension, referred to as a *chunk layer* is added to the chunk. The (maximum) number of layers in a chunk c, denoted Q_c, can be different for different chunks. In adaptive transmission, each layer carries data from one flow only In non-frequency adaptive transmission, code-multiplexing may be used in downlinks. The layers may stem from the different RTUs of different flows in the case of SDMA, or from the same flow in case of per stream rate control and versions of multi-level coding. Note that the number of layers in a chunk may be arbitrary in relation to the number of physical antennas, denoted M_T.

The channel encoded bits of the layers of a chunk are to be modulated and dispersed in space over the physical transmit antennas, as well as in time over the symbols and in frequency over the subcarriers of the chunk. A generic spatial processing transmitter chain accomplishing this is depicted in Figure 5-41.

The bits of Q_c layers of chunk c are first modulated onto S_c *modulated layers*. The number of modulated layers is inferior or equal to the number of chunk layers, $S_c \leq Q_c$. In the baseline implementation they are equal meaning that each chunk layer is modulated independently [DAO05]. However, for the case with multi-level coding, several chunk layers are modulated onto the same modulated layer.

The modulated layers are then subject to an optional non-linear precoding. The non-linear precoding proposed in [WIND27] is based on Tomlinson-Harashima precoding, however, the non-linear precoding block can also include more general lattice coding techniques. Such techniques allow approaching the optimal dirty paper coding, and can be used to improve the performance of a MIMO single link.

The precoded modulated layers are then dispersed onto *virtual antenna chunks* with a dispersion code. A *virtual antenna chunk* is a three-dimensional entity which spans M_T virtual transmit antennas in space, n_{symb} OFDM symbols in time, and n_{sub} subcarriers in frequency. To simplify the presentation it is assumed that the number of virtual antennas is equal to the actual number of physical antennas. If the underlying dispersion code encodes the signal over less or more dimensions, appropriate zero padding and puncturing in the spatial dimension is assumed.

Of particular interest are linear dispersion codes (LDC) [HH02]. LDC can be used to represent not only spreading, but also a large number of so-called vector and matrix modulation schemes including antenna hopping, space-time block codes (e.g., Alamouti, Diagonal-ABBA, Double-ABBA [WIND27]), and spatial multiplexing onto different number of streams. LDC can therefore allow for a flexible tradeoff between spatial diversity and multiplexing. Typically, such a linear dispersion code is assumed, but by allowing non-linear dispersion codes, also non-linear schemes such as various forms of space-time trellis-coded modulation and space-frequency turbo-coded modulation may be represented in the generic processing [WIND21, WIND23, WIND26, WIND27].[7]

[7] If some form of coding and modulation is performed by the dispersion code, the outer code is probably relatively weak and the modulator essentially bypasses the encoded bits.

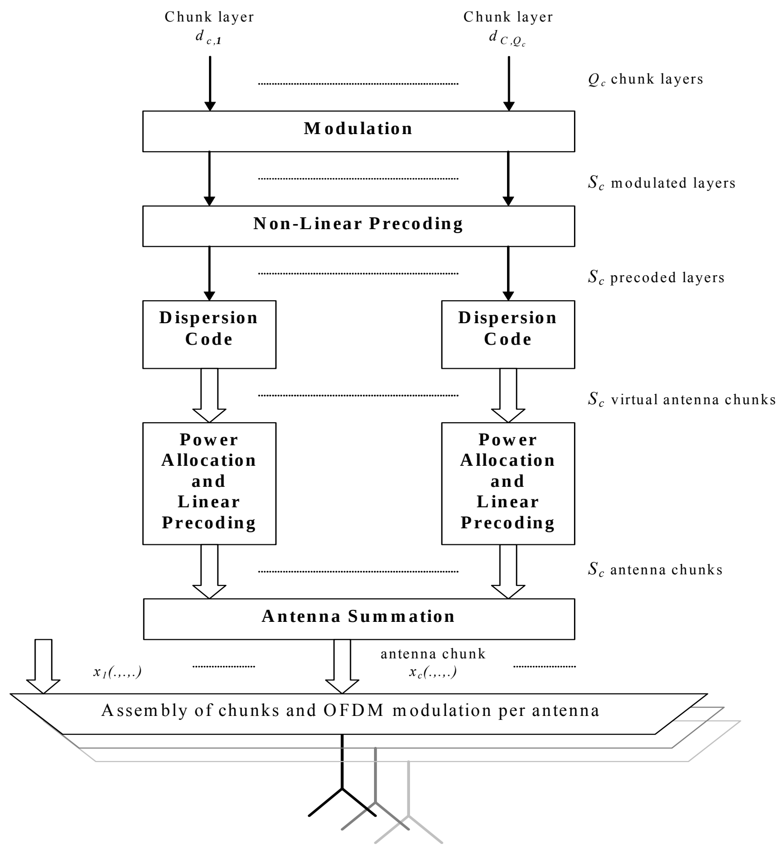

Figure 5-41: Modulation and dispersion in space, time and frequency of chunk layers

The virtual antenna chunk of each layer is then subject to power allocation and linear precoding which means that each virtual antenna chunk of each layer is mapped onto a physical *antenna chunk*. Each element of the three-dimensional antenna chunk, which spans the M_T physical transmit antennas, the n_{symb} OFDM symbols, and the n_{sub} subcarriers of the chunk, is a linear combination of the elements of the layer's virtual antenna chunk. The term linear precoding in the present context covers techniques such as closed-loop transmit diversity, beamforming based on a fixed grid of beams, beamforming based on eigenmodes, linear multi-user precoding (e.g. SMMSE), and also antenna or beam selection and hopping as well as random beamforming that may be employed by opportunistic beamforming approaches. For cases with multi-user optimisation, the linear precoding and power of virtual antenna chunks are optimised jointly.

Finally, the layers' antenna chunks are summed over the antennas to form a three-dimensional antenna chunk, which is passed to assembly and OFDM modulation per antenna.

5.5.2 PHY Services

5.5.2.1 Adaptive transfer

The *Adaptive transfer and Non-frequency adaptive transfer* services work frame-wise: They transmit one or several (punctured) FEC blocks belonging to a TDC or CDC flow, as specified by the Adaptive resource scheduler. Since the RSB queues are drained with bit-level granularity, the transmission may comprise only parts of a FEC block. In case of transmission of parts of FEC blocks, the PHY buffers the arriving bits until a complete FEC block has been received. (The block size is specified by the PHY transmit control signalling.) Then, the whole FEC block is released to the MAC.

The transmission is performed on a set of chunks within each slot allocated by the MAC resource partitioning. This set of chunks should be widely dispersed in frequency to obtain large diversity and increase the variability of the channel as experienced by each user terminal. This will increase the chances to allocate good resources to each terminal, to "ride the peaks" of the channel.

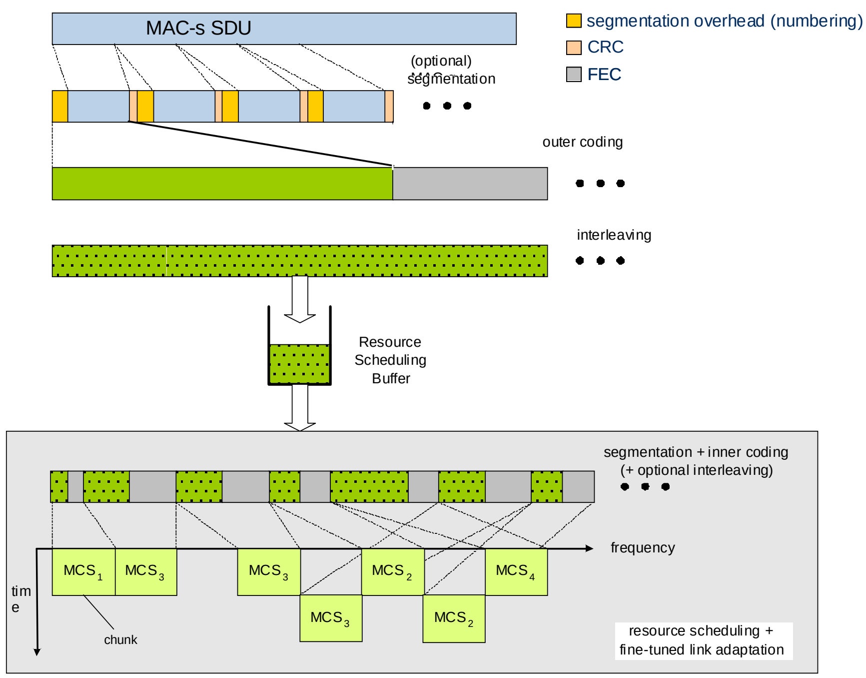

Figure 5-42: Illustration of segmentation, buffering, link adaptation and chunk mapping, when using concatenation of coding over FEC blocks and convolutional coding within individual chunks

Figure 5-42 above illustrates the mapping onto chunks, in a case where (convolutional) chunk-specific inner coding is used as a part of the link adaptation. Puncturing of the 1st FEC code (outer code) is placed in the MAC resource mapping. Coding and puncturing of a possible chunk-specific inner code is performed in PHY. The MAC controls it and all other link adaptation parameters, since the adaptive resource scheduler needs to know the precise number of bits that are mapped onto each assigned chunk.

5.5.2.1.1 Transmission and reception sequence

The transmission and reception sequence used for both adaptive transfer and for non-frequency adaptive transfer is described below.

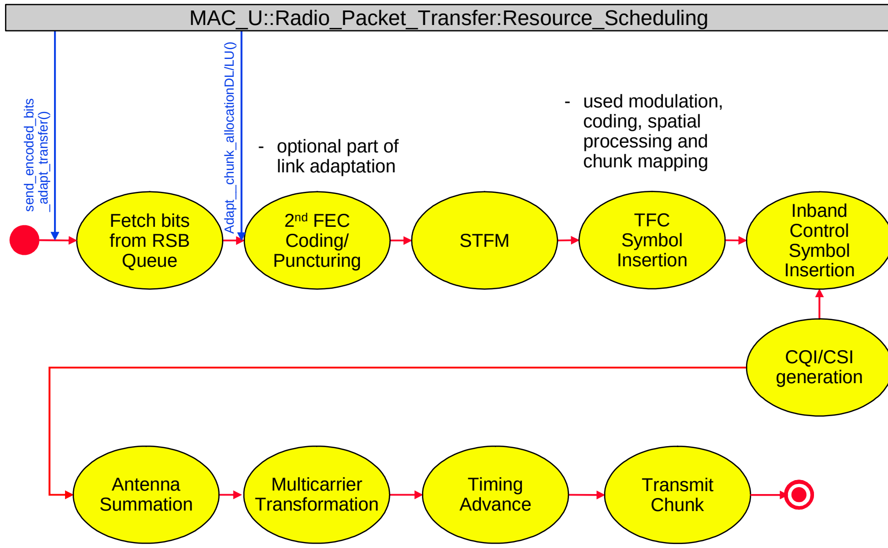

Figure 5-43: PHY Adaptive transmission

Transmission (downlinks and uplinks)

- The chunks assigned for adaptively allocated transmission are prepared. The MAC resource mapping punctures the FEC blocks of the RSB queues with flows that have been scheduled and then drains these queues with bit-level resolution.
- The PHY adaptive transfer takes over at this point, using the general transmit chain described by Figure 5-39 and Figure 5-41. Space-Time-Frequency Mapping and Modulation (STFM) is performed, and optional inner chunk-specific encoding may also be applied.
- The payload symbols are mapped onto the payload locations of the chunks assigned for adaptive transmission.
- Insertion of dedicated pilots into the chunk layers.
- In case of a downlink transmission, the control message Adapt_chunk_allocation_DL/UL is encoded, modulated and mapped onto pre-assigned control symbol positions. This message specifies what chunk layers are assigned to what flows and what link adaptation parameters (spatial processing, modulation, code type, code rate, power) are used within each chunk. The locations of these control symbols can be within the payload chunks, in a separate resource, or a combination.
- Antenna summation is performed.
- Addition of common pilots.
- Form an OFDM symbols by combining adaptively allocated parts, non-frequency allocated parts and the guard frequencies due to interference avoidance.
- For each OFDM symbol: Multicarrier transformation (IFFT) to the time domain
- Timing advance.
- Conversion to passband and transmission.

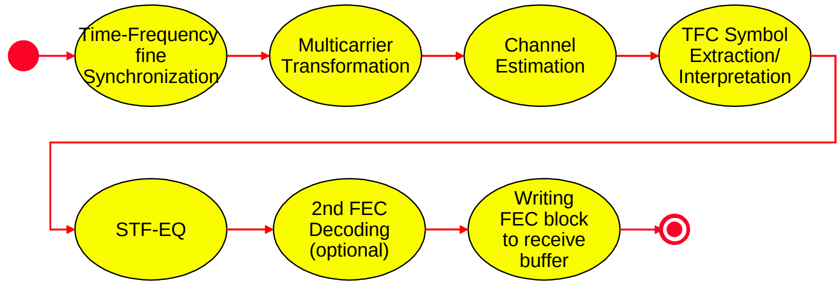

Figure 5-44 PHY reception, demodulation and decoding for adaptive transfer

Reception:

- Receive OFDM-symbol time-slot.
- Optional: fine-tune synchronization based on guard intervals and/or embedded pilots.
- Perform multi-carrier transformation (FFT).

Demodulation and decoding: (Performed after data for whole chunk-duration has been received)

- Extract received signals at all pilot symbol locations.
- Copy the received frequency-domain signals from chunks that were allocated to adaptive transmission to a separate memory, for further processing.
- In a downlink transmission, the receiver must perform coarse channel estimation that is sufficient to extract and decode the control message Adapt_chunk_allocation_DL/UL and then decode this message.
- In a downlink transmission: Read the control message. Identify what flows were transmitted, what chunks were used, what spatial schemes were used (this is known if the flow is known) and what link adaptation parameters were used in the downlink (this may be inferred implicitly).
- For each flow, perform interpolation of the channel estimate within the relevant chunks. (Optionally, this channel estimation may be iterated with detection of the payload symbols within the chunk).
- Coherent detection of the payload symbols within each chunk, based on the estimated channel. If inner coding was used, decoding is performed. Preferably soft bit outputs are provided for the outer decoding.
- If a complete FEC block has been received at the BS/RN, it is forwarded via the PHY Adaptive Reception service to the MAC. Otherwise, the (soft) bits are buffered in the PHY until a complete FEC block has been received.
- The complete FEC block is transferred to the MAC User Plane.

The transmission and reception has here been outlined for the case of standard OFDM. For a serial modulation GMC transmission, an extra FFT would have to be performed before step 3 at transmission and an extra IFFT would be performed around step 18 at reception. A still open question is the positioning for the control message and of the pilots in that case.

5.5.2.2 Non-frequency adaptive transfer

The non-frequency adaptive transfer maps flows onto sets of chunk layers that should provide large channel diversity. As in the case of adaptive transfer, these chunks should also be well dispersed over the available spectrum to maximize the available diversity. To jointly provide the maximum diversity, chunk allocations for adaptive and non-frequency adaptive transfer should be mixed in the frequency domain, rather than being given separate contiguous sub-bands.

The sequence for non-frequency adaptive transfer is formally almost identical to the sequence that was outlined above for adaptive transfer. One difference is that the control message is denoted *Nonadapt_control*. Another difference is that an inner chunk-specific code is not used: The link adaptation parameters are constant within the whole set of resources that is allocated to a flow.

The non-frequency adaptive transmission uses multiple access schemes that differ from those used for adaptive transmission. For all flows that use adaptive transmission, TDMA/OFDMA (mapping flows onto individual chunk layers, with individual rate adaptation) is used. In an averaging scheme, there is a problem in attaining sufficient frequency diversity when transmitting small packets when mapping the packets directly onto chunks. Therefore, two other schemes that increase the diversity significantly have been selected as the baseline alternatives for non-frequency adaptive transmission:

- In *downlinks*, multicarrier CDMA is used within the assigned set of chunks.
- In *uplinks* TDMA/OFDMA is used on a subcarrier basis within the assigned set of chunks.

In downlinks, spreading may thus be used to code-multiplex the flows onto sets of chunks assigned for non-frequency adaptive transmission. See the right-hand part of Figure 5-45. Orthogonal signalling (TDMA per OFDM symbol or FDMA per subcarrier) are special cases of the scheme (left-hand illustration and middle illustration in. Figure 5-45.) They may be used when this is deemed of advantage.

In uplinks, the use of code-multiplexing is avoided, which avoids the need for multi-user detection. Instead TDMA is used on an OFDM symbol basis. Several uplink flows may share one OFDM symbol (OFDMA) to improve the rate matching. See the middle part of Figure 5-45. Either OFDM or frequency-domain generated serial modulation can be used in the uplinks.

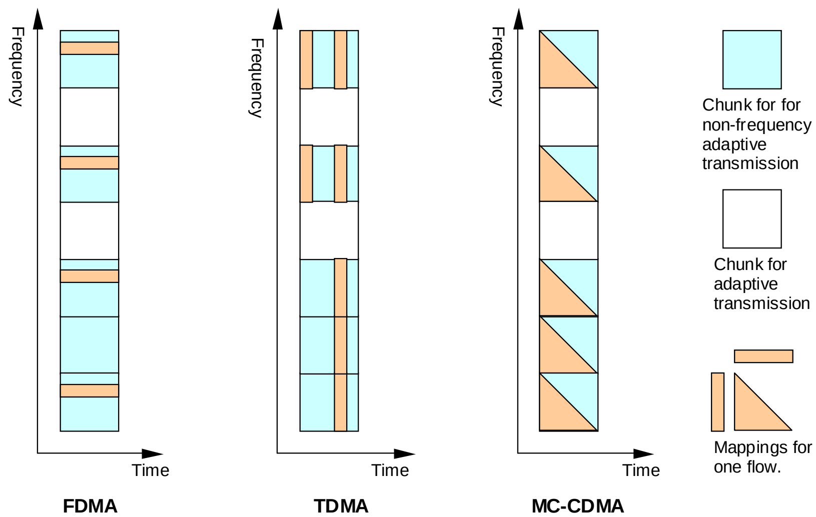

Figure 5-45: Illustration of the mapping of one flow on the chunks earmarked for non-frequency adaptive transmission when using FDMA, TDMA or MC-CDMA within the set of chunks

5.5.2.3 DAC transfer

The main current proposal for contention-based transmission is a scheme that uses carrier-sense multiple access and therefore requires a constant set of frequencies to be assigned exclusively during the whole superframe, as illustrated by Figure 5-29. The transmit and receive sequences are illustrated by Figure 5-46 and by Figure 5-47 below.

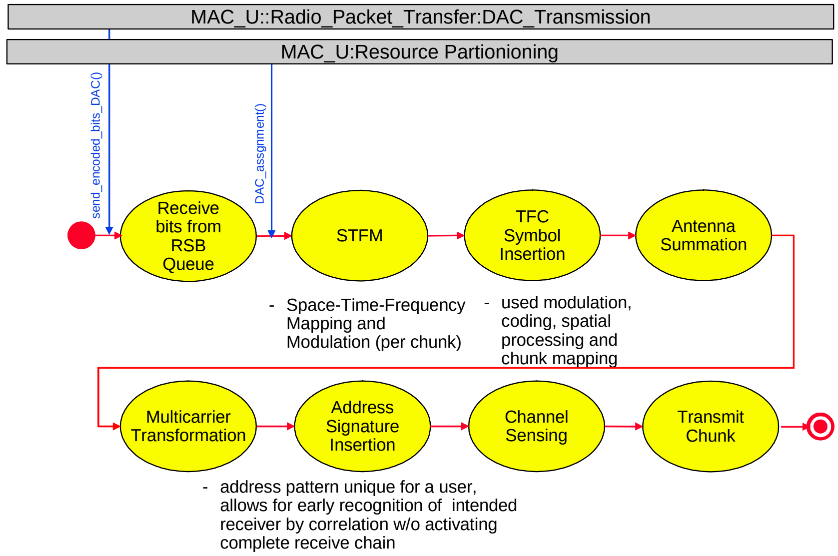

Figure 5-46: PHY DAC transmission

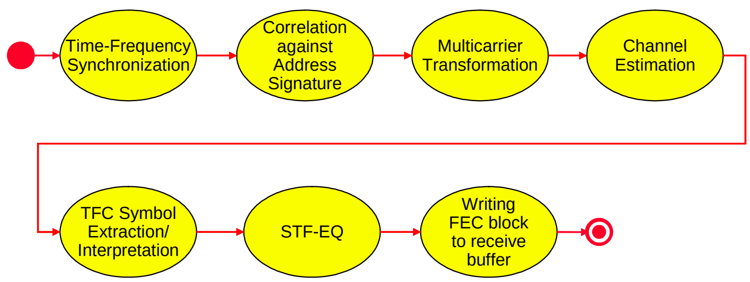

Figure 5-47: PHY DAC reception

5.5.2.4 RAC transfer

In-between the synchronization slots of the superframe preamble, a short timeslot over the whole band is reserved for the contention-based random access channel (RAC). The RAC time-slot is in TDD systems also used for BS-to-BS and RN-to-BS over-the-air control signalling. Since this channel is to be used for initial access to a master device, correct adjustment of the timing advance cannot be assumed. Therefore, the RAC time-slot has to be surrounded by guard symbol intervals. The RAC channel covers the whole preamble spectral width, since RAC transmission with badly synchronized transmitters could interfere with other transmissions that are placed at other frequencies.

The packets transmitted over the RAC channel have an address field that declares their (global) sender address and their type of transmission.

The RAC transmission and reception sequence is as follows.

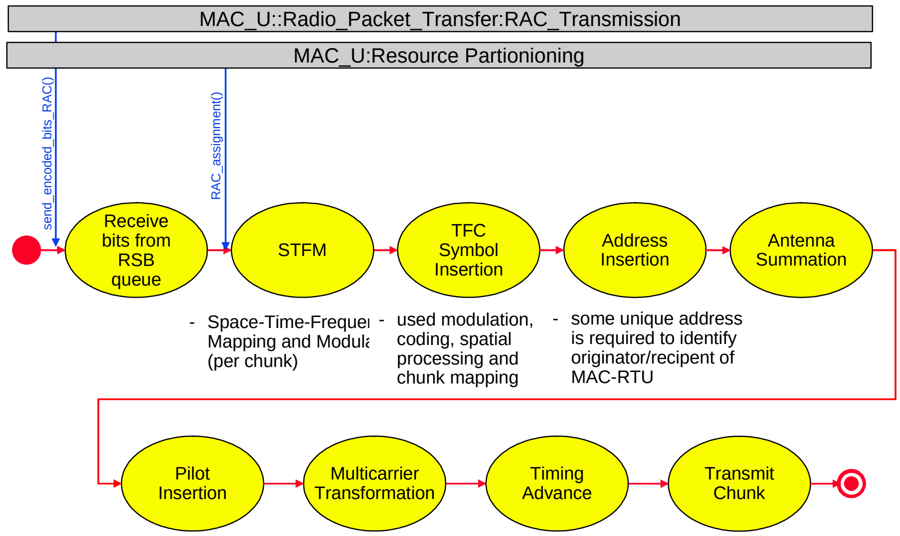

Figure 5-48: PHY RAC Transmission

Transmission (uplinks and in TDD also RAP-to-RAP over-the-air control signaling)

- RLC and MAC: To the RAC payload, a header with (global) sender address and the type of the transmission is added (the default ID of the terminal/BS/UT). The whole packet is encoded in the MAC-2 sublayer.
- Modulation is performed at the PHY layer. The FEC block is mapped onto one OFDM symbol. Since the receiver will not have knowledge of the spatial transmission scheme used, only a simple spatial transmit scheme and low-order modulation can be used.
- Add TFC (time-frequency coding) symbols that reveal the used transmit scheme (This will not be necessary if standardized transmit parameters are agreed upon in Phase II).
- Antenna summation.
- Pilots for synchronization and channel estimation are added.
- Multicarrier transformation (IFFT) of the OFDM symbol to the time domain
- Timing advance is performed (if known).
- Conversion to passband and transmission.

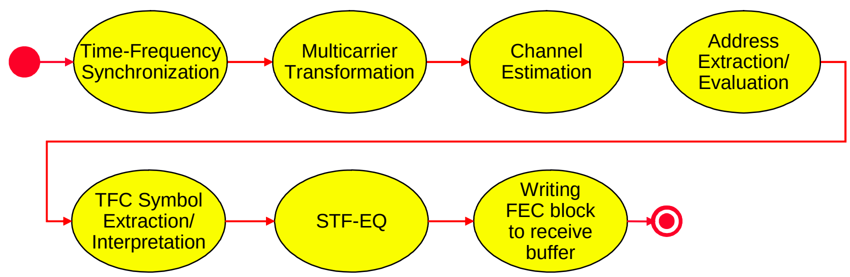

Figure 5-49: PHY RAC Reception

Reception:

- Receive OFDM-symbol time-slot plus large guard times (due to possible timing misalignment).
- Perform time-frequency synchronization.
- Perform multi-carrier transformation (FFT).

Demodulation and decoding:

- Channel estimation
- Extract and interpret TFC symbols.
- Pilot-based channel estimation.
- Coherent detection payload symbols and header symbols.
- The received FEC block is transferred to the MAC User Plane.

5.5.2.5 BCH and superframe control transfer

At the end of the superframe preamble, a set of OFDM symbols are reserved for transfer of the broadcast channel and the superframe control information to user terminals.

The range of the safe reception of this transmission is an upper bound on the distance to the cell border. Transmission from all BS and RN is assumed to be synchronized and their superframes are assumed to be aligned in time. Therefore, spectral partitioning schemes are required to reduce the interference between BCH/SF control packets transmitted from different BS/RN. Two schemes are under current discussion:

- Use of omni-directional transmission with a fixed reuse partitioning scheme for base stations, e.g. reuse 3. Use of further orthogonal time-frequency slots for the transmission by relay nodes. Low-rate space-frequency coding is used to handle the fading channel.
- Use of beamforming, where the beams from different base stations and relay nodes must be coordinated to avoid simultaneous transmission in opposing directions, to limit interference.

The transmission is performed under control of the resource partitioning function in the MAC Control Plane. The BCH and SF control transmission proceeds as follows.

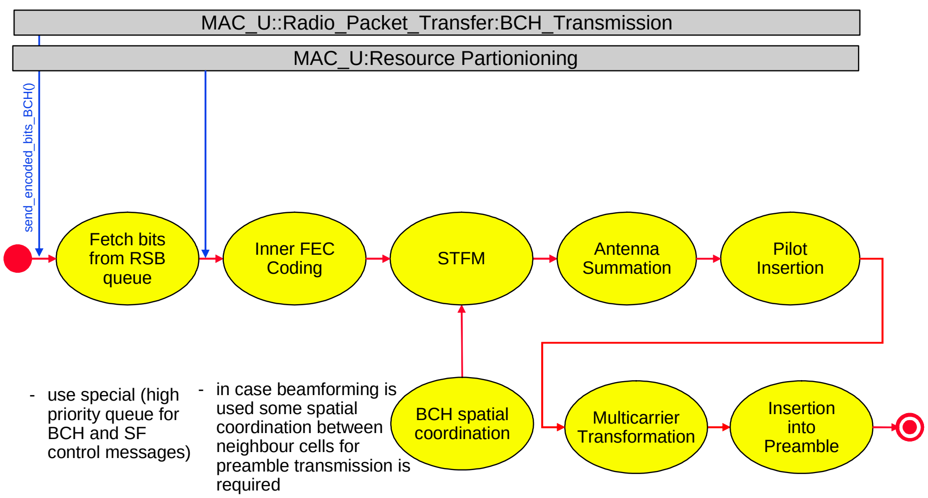

Figure 5-50: PHY BCH and superframe control transmission

Transmission (downlinks):

- The BCH payload and the superframe control payload is encoded by an outer code in MAC-2.
- (Inner) space-time-frequency modulation and encoding is then performed in the PHY layer, under supervision by the MAC.
- The encoded symbols are mapped onto a set of time-frequency resources in the preamble that are assigned by the interference avoidance scheme.
- Antenna summation
- Pilot insertion.
- Multicarrier transformation (IFFT) of the OFDM symbol to the time domain.
- Transmit in the superframe preamble.

Figure 5-51: PHY BCH and superframe control reception

Reception:

- Perform time-frequency synchronization based on embedded pilots.
- Perform multi-carrier transformation (FFT).

Demodulation and decoding:

- Pilot-based channel estimation.
- Coherent detection of the payload symbols.
- Decoding of the space-time-frequency (inner) code.
- The received FEC block is transferred to the MAC-2 sublayer for (outer) decoding.
- The superframe control information is then forwarded to the MAC Control Plane, while the decoded BCH message is forwarded to the RLC layer.

5.5.2.6 Physical Layer Measurements

The phyical layer has to provide measurements of various properties of the transmission channel to the higher layers. Depending on the quantity to be measured, results have to be delivered and updated on various time-scales. Throughout the following we distinguish between three different timescales, frame-by-frame, superframe-by-superframe and several superframes. Furthermore, some measurements may be gathered by the BS's physical layer, others may be measured at the UT and reported back to the BS or RN.

Measurements which have to be reported/updated on frame-by-frame basis:

- CQI predictions: SINR predictions of all relevant chunk layers for all relevant UTs, originating either from predictor at BS/RN or from reports from UTs. Updated on a fast time-scale.

Measurements which have to be reported/updated on superframe-by-superframe basis:

- Synch. pilot power: Measurement of preamble synch signal strength, received from several adjacent base stations.
- Frame pilot power: Measurements of received power at frame pilot locations from the current active BS, averaged over the superframe.
- Long-term spatial link adaptation measurements: Long-term channel characteristics (average SINR, long-term Demmel condition number, long-term practical channel rank, long-term eigenvalues)
- Pathloss: Path loss estimate, kept at UT, reported every superframe.

Measurements which have to be reported/updated on a basis of several superframes:

- basic link adaptation measurements (e.g. UT velocity, average SINR, terminal capabilities)

5.5.2.7 Transmit control signalling

Throughout the following, a tentative list of necessary transmit control signalling elements is given. Transmission of the superframe layout control information has furthermore been discussed in Subchapter 5.5.2.5. Resource allocation schemes for adaptive and for non-frequency adaptive transmission were discussed in Chapter 5.5.2.1 and 5.5.2.2 respectively. The exact placement and encoding of the control information has not been specified.

Superframe layout control that is transmitted in superframe preamble to UTs:

- Assignment of chunks to be used by DAC
- Assignment of chunks to be used for adaptive transmission
- Assignment of chunks to be used for non-frequency adaptive transmission
- Reservation of chunks for out-of-band control signalling
- Signalling of UL/DL asymmetry factor in case of TDD PLM

Downlink control of the adaptive transmission in both downlinks and uplinks:

- RS message describing active set eligible for transmission in next frame
- RS message describing detailed allocations of flows to chunks and link adaptation parameters. Transmitted in the same DL slot as a DL transmission. For UL transmissions, it is transmitted in preceding DL slot. Can use out-of chunk or in-chunk signaling.

Downlink control of the non-frequency adaptive transmission in downlinks and uplinks:

- RS message that for each non-frequency adaptively allocated flow gives the flow address, number of transmitted bits and the link adaptation parameters.

Superframe resource partitioning reports from BS to RN, transmitted in special chunks:

- Chunk-beams for exclusive use by relay groups g.
- Chunk-beams for non-exclusive use by relay groups g.
- Chunk-beams used in relay links to/from relay node r.

Other control information, transmitted at most once per superframe containing e.g.:

- Flow setup request
- Flow setup message
- Flow release message
- Terminal capabilities request
- Terminal capabilities message (e.g. antennas, interference rejection, memory, …)
- RS message for uplink slow power control
- Control messages originating in RLC and transmitted in MAC control ‘container’
- Message from RLC for initial connection establishment (before flow setup). Includes timing advance.
- Message from RLC for connection establishment in new cell after handover. Includes timing advance.

Service primitives associated to the signalling messages given above are of two types:

- Messages to and from the PHY layer at the UT
- Transmission of messages to/from other MAC peers at e.g. relay nodes. This type of message may be transmitted as a flow with special address and high priority over the normal transfer channels, such as adaptive or non-frequency adaptive transfer.

5.5.3 Physical Layer Implementation

5.5.3.1 Baseline spatial processing

In addition to the generic coding and chunk processing described above a lean baseline configuration is outlined that serves as basic implementation example and benchmark, see Figure 5-52. All processing is essentially two-dimensional and the mapping from two to three dimensions may then be put after the linear precoding block.

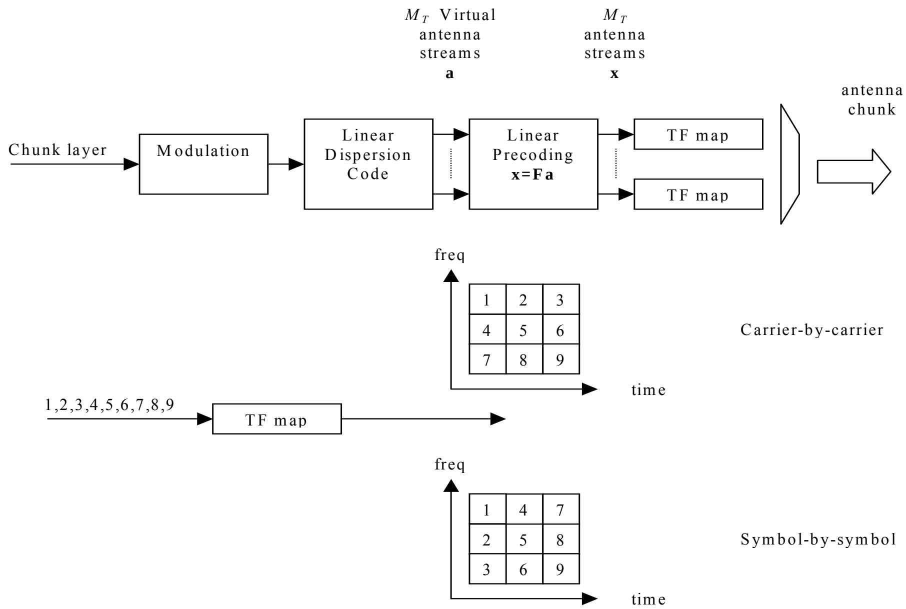

Figure 5-52: Baseline processing of a chunk layer

As a baseline it is assumed that each RTU is not segmented into several FEC blocks, but encoded as a single FEC block. The actual mapping and segmentation onto chunks is a function of the MAC resource allocation. Each chunk layer is processed independently, meaning that each modulated layer stems from a single chunk layer, which in turn stems from one RSB queue. As baseline it is assumed that non-linear precoding is not used meaning that the pre-coded layers are identical to the modulated layers. Furthermore, a linear dispersion code is used. Commonly used designs generate a set of virtual antenna streams and thus perform two-dimensional dispersion. To fill up a three-dimensional virtual antenna chunk one may consider filling the chunk subcarrier-by-subcarrier or symbol-by-symbol.

Purely spatial linear precoding is done meaning that the virtual antenna layers for a given symbol and subcarrier contribute only to the antenna layers of the same symbol and frequency. Further, the same linear combinations are used for all symbols and subcarriers in a chunk. To be a bit more specific, let $\mathbf{a}_{c,l}(t,f)$ be an $M_T\,x\,1$ column vector holding the element of the virtual antenna chunk for chunk c and layer l for symbol t and subcarrier f. Now, let $\mathbf{x}_{c,l}(t,f)$ contain the corresponding layers of the layer's antenna chunk. Then

$$\mathbf{x}_{c,l}(t,f) = \mathbf{F}_{c,l}\mathbf{a}_{c,l}(t,f),$$

where $\mathbf{F}_{c,l}$ is the precoding matrix for chunk c and layer l. Each column of the precoding matrix may be viewed as transmit weight vector for the corresponding virtual antenna stream, and thus, each virtual antenna stream use its own transmit weight vector. The power allocated to a certain layer is proportional to the Frobenius norm of the precoding matrix.

5.5.3.2 Forward error correction

Among the large number of possible options for forward error correction [WIND21], three techniques have been identified as main candidates for the WINNER system [WIND23, WIND29]: convolutional codes (CC), parallel concatenated convolutional codes (PCCC, Turbo Codes) and low-density parity-check codes (LDPCC). Details on the assessment can be found in [WIND23, WIND29].

The current working assumption is that CC will be used for short block lengths (up to a few hundred information bits) and LDPCC for larger block lengths. Duo-Binary turbo codes are considered serious candidates for a wide range of block lengths, especially medium block sizes. They will be the target of focused relative performance and complexity assessment in the remainder of Phase I. Although currently, LDPCC are still at an early stage of their development for the practical use, it is our conviction that they will be mature enough for use by the time the WINNER system will be deployed. It should be emphasised that the impact of selection of one or another FEC technique on the overall system concept is rather limited, as soft-input soft-output decoder algorithms exist for all investigated techniques, which can be regarded from the rest of the system as a “black box”. Performance and complexity will of course have a significant impact on the overall system performance and implementation feasibility, which motivates the above stated selection of techniques.

5.5.3.3 Modulation alphabets and bit mapping

Non-differential M-PSK and M-QAM modulation is proposed for the use in the WINNER system, since channel state information can be made available to the receiver at relatively low pilot overhead in all scenarios, For the wide-area scenario, modulation formats up to 64-QAM are proposed, while for short-range transmission even 256-QAM appears to be feasible.

Gray mapping is a natural choice for the bit labelling, since it facilitates the calculation of soft output at the detector, especially if the maxLogMAP approximation is used. The selection of other bit labellings such as natural labelling, D21, D23, or Anti-Gray is justified mainly in cases where iterative equalisation with a weaker outer code (CC) is envisaged, which is not the focus of the current investigations.

5.5.4 PHY Measurements support

5.5.4.1 Intra and inter-cell fine synchronisation and signal strength estimation

In [WIND21] a synchronisation method was proposed which has been assessed in [WIND23]. This enables both intra-cell and inter-cell synchronisation by assuming a cellular OFDM network, where the terminals in every cell, BSs or UTs, are allowed to receive and transmit over the whole system frequency band at the same time during synchronisation. Three phases can be distinguished for the synchronisation process:

- *Coarse synchronisation*: Responsible for aligning the superframe of all cells.
- *Fine synchronization* aims at removing the residual time and frequency offsets both between UTs within the same cell, to achieve intra-cell synchronisation, and between BSs of different cells, so obtaining inter-cell synchronisation. During this phase, data transmission will not be possible.
- *Tracking*: When the remaining time and frequency offsets do not exceed pre-set thresholds, the system is considered synchronised and data transmission is allowed. Test signals are periodically transmitted by all terminals to monitor the network synchronisation.

A solution based on utilisation of the OFDM signal cyclic prefix, without resorting to any training symbol has been suggested in [WIND23] for coarse intra-cell synchronisation.

The method summarised here enables fine synchronisation to be achieved. It has been developed for TDD systems but can be used also in FDD. It assumes the residual time and frequency offsets after coarse synchronisation to be within the OFDM symbol period and within the subcarrier spacing, respectively. It also enables the user terminals to measure the signal strength from BS and RN that are distant, since probe tones with low bandwidth and high power density are used.

Both the DL and the UL sync signals are embedded in the MAC superframe structure, see Chapter 5.4.1.3. In the DL, every BS transmits an individual sync signal and all UTs listen to all BSs in order to identify the BS received with highest amplitude and synchronise with it. In this way all UTs within a certain cell become mutually synchronised. Furthermore, all UTs within the network transmit sync signals which are in their turn received and analysed by all BSs within range. If most involved UTs are reasonably well synchronized, each BS can indirectly acquire an estimate of the time and frequency offsets with respect to other adjacent BSs and accordingly adjust its status.

Each sync signal consists of three adjacent OFDM symbols, during which each BS, in DL, transmits only on a single pair of adjacent subcarriers with the maximum power. Each BS randomly chooses the pair of subcarriers in each superframe among a set of subcarrier pairs equally spaced within the whole bandwidth and separated by guard bands to avoid interference. With the relatively large number of subcarriers currently considered, the probability of conflict among BSs in choosing the same subcarrier pair is negligible. The same subcarrier pair chosen by the (closest) BS in DL is then used by all UTs associated with that BS in UL. This guarantees that each BS can receive the sync signal from adjacent cells with sufficient power and can easily recognise it from the sync signal sent by its own UTs.

At the transmitter, the phase difference between the two adjacent subcarrier signals is zero as well as the phase difference between two adjacent OFDM symbols on a single subcarrier. Hence, the frequency and time offsets can be estimated simultaneously in the frequency domain (post FFT) as the phase rotation between two adjacent OFDM symbols on the same subcarrier and as the phase difference between two adjacent subcarriers, respectively.

It should be observed that according to this approach no additional synchronisation among UTs within one cell is carried out at the BS receiver during the UL. Thus, the performance achieved in data transmission during the UL only depends on the synchronisation accuracy obtained during the DL intra-cell synchronisation phase. Simulation results reported in [WIND23] show that within a cell, frequency synchronisation between UTs and their BS can be achieved in 20 superframes with an accuracy of about 0.5 % of the subcarrier spacing, and time synchronisation can be obtained in 10 superframes with remaining time offsets of about 8% of the guard interval. Both frequency and time synchronisation between all BSs within the cellular network can be achieved after 20 superframes, with remaining frequency offset of about 1% of the subcarrier spacing and time offset of about 10% of the guard interval, respectively.

5.5.4.2 Pilots within frames, for channel and interference measurements

Channel estimation for cyclic prefix (CP) generalised multi-carrier (GMC) signals is addressed in the WINNER deliverables [WIND21, WIND23, WIND29]. As conventional technique channel estimation by interpolation in time and frequency is considered to be an efficient solution for an OFDM-based air interface. Interference estimates, per chunk layer or averaged over chunk layers, may be obtained as by-products of the pilot-based channel estimation: The residual, i.e. the signal component that cannot be explained through the known pilots and the channel model, is used as interference estimate.

Conventional channel estimation by interpolation may still require a pilot boost and/or a significant degree of oversampling. Advanced solutions, namely adaptive filtering techniques and iterative channel estimation, aim to make a pilot boost redundant, at the expense of increased complexity [WIND29]. If an iterative receiver structure is already in place, iterative channel estimation offers a good compromise between performance and complexity; particularly, on the uplink significant performance gains are expected.

From a computational complexity point of view, both channel estimation and synchronisation are feasible, which is demonstrated by the numerous OFDM systems that are already operating today. As bandwidth efficiency is a major goal of the WINNER air interface, it is an important question how much pilot overhead is really needed to achieve reliable and accurate channel estimation and synchronisation. With the support of MIMO systems, bandwidth efficient channel estimation is becoming more critical, since transmitting several virtual antenna streams will inevitably cause a larger pilot overhead.

Different types of pilots are foreseen to be used in the WINNER system concept:

- Two short sets of ***training symbols*** (uplink and downlink) are included in the superframe preamble. They are used for synchronisation, as described in the preceding chapter.
- A scattered pilot grid is used for OFDM channel estimation and channel prediction. In [WIND29], it was shown that a scattered pilot grid could also be utilised to improve timing synchronisation accuracy. The pilot overhead is 1-2% and 3-9% per virtual antenna stream for the WINNER short-range TDD and wide-area FDD mode, respectively.
- In OFDM uplinks that use adaptive transmission, channels from many users have to be estimated and predicted in each chunk. Methods based on simultaneous pilot transmission from all candidate terminals (overlapping pilots) can then be used to limit the pilot overhead fraction in the uplink. See [WIND24] and subchapter 5.5.4.2 below.
- Pilot patterns for serial modulation in the uplink may be generated in the frequency-domain, which also allow channel estimation via interpolation in time and frequency. The exact types of patterns have not yet been determined.
- For multi-antenna transmission, a combination of dedicated pilots per flow, common pilots per cell/sector, common pilots per antenna and common pilots per beam are required for different purposes [WIND29].

Concerning the pilot symbol density within a chunk in a scattered pilot grid for a single transmit antenna, the following rules can be applied to the short-range and to the wide-area transmission SISO scenarios (based on the framework from [WIND21, WIND23]):

Wide-area case (FDD mode): In the adaptive scheduling configuration, the pilots are more sparsely inserted into the chunk as the channel condition is assumed to vary slowly enough to enable an adaptive scheduling algorithm. We deploy therefore solely 4 pilots in the chunk. In the non-adaptive mode, the channel state is supposed to vary rapidly and the pilot symbol spacing has to be smaller in time direction.

In that case, 6 to 8 pilots can be utilised, 2 in frequency direction and 3 to 4 in time direction, in order to cope with a higher mobility.

Short-range case (TDD mode): Due to better propagation conditions in the short-range case, the number of pilots in frequency direction can be constantly set to 2. In time direction, 1 pilot shall be used in the adaptive configuration while 2 may be employed in the non-adaptive mode, for reasons mentioned in the precedent paragraph for the wide-area transmission scenario.

The proposed pilot tone densities are summarised in the Table 5.2. The pilot overhead factor is defined as the ratio of the number of *data* symbols per chunk, N_{data}, to *the total* number of symbols per chunk N_{chunk}. The chunk sizes are in line with the latest OFDM system parameters for the WINNER air interface, i.e. 96 symbols in the wide-area case and 80 symbols for the short-range TDD mode.

Table 5.2: Pilot symbol overheads on chunk level

Tx mode / Pilots data	**Wide-area case FDD mode**		**Short-range case TDD mode**	
	Non adaptive	Adaptive	Non adaptive	Adaptive
Number of pilots per chunk	6 to 8	4	4	2
Pilot overhead factor N_{data}/N_{chunck}	0.9167 to 0.9375	0.9583	0.95	0.975

Extension to MIMO/OFDM:

Pilots are used for implementing certain physical layer support functions, e.g. connection setup, synchronisation, mobility support, power control, CQI measurements and most importantly channel estimation. Two types of channel estimation must be distinguished: channel estimation for data reception (where the pilots are send at the same time), and channel estimation for adaptive transmit processing based on return link feedback or measurements (where an additional extrapolation/prediction in time is required, see also Chapter 5.5.4.2). In order to realise an efficient system, the same pilots should be re-used for different support functions. Spatial processing, however, limits the potential re-use of pilots and brings along additional requirements [WIND27]. In particular we need to distinguish

- ***Dedicated pilots*** may be required if user-specific transmit processing (i.e. a user-specific adaptation of amplitude and phase) is applied to the data symbols. These pilots are subject to the same transmit processing as the data symbols and therefore allow the receiver to estimate the effective channel $\mathbf{H}_U \cdot \mathbf{f}_U$ of user U. The use of dedicated pilots for other purposes, like CQI measurements, is limited, since they contain a power allocation specific (in most of the cases) to another user.
- ***Common pilots*** have the property that they do not include user-specific transmit processing and different variants of common pilots exist, e.g., an omni-directional common pilot per sector, common pilots per antenna or per beam.

Due to the fact that common pilots can be used by several users, they are appealing for the downlink processing, since the overall energy to perform the associated functions has only to be spent once and the pilot symbols can be spread over all resources. Also they provide a basis for un-biased CQI measurements. However, certain user-specific spatial processing techniques require dedicated pilots.

Multi-user precoding techniques are assumed to impose most stringent requirement on pilot-aided channel estimation, since high accuracy prediction of the downlink channel need to be obtained based on uplink measurements. A performance degradation of 2 dB due to imperfect channel estimation requires a pilot SINR of 20 dB and channel estimator gains between 13 dB and 17 dB [WIND27, WIND29]. Furthermore a sufficient number of orthogonal pilots must be contained in the uplink transmission in order to be able to estimate several antennas and benefit from multi-user scheduling and precoding gains.

Since the requirements regarding pilot type, number of pilots and pilot SNR are varying considerably a modular and scalable MIMO-pilot design should be adopted. For example, a combination of common pilots spread out over all resources and additional dedicated pilots per chunk according to the requirements of the spatial processing scheme is conceivable.

In order to be able to estimate the channel from different antennas orthogonal pilots are required and the following principle design guidelines are possible:

- transmit pilots in frequency-multiplex (different subcarriers of one chunk),
- transmit pilots in time-multiplex (consecutively on one subcarrier),
- apply code-multiplexing across pilot symbols on different subcarriers,
- apply code-multiplexing across consecutive pilot symbols of one subcarrier.

In existing MIMO-OFDM testbeds, code-multiplexing based on Hadamard sequences on consecutive pilot symbols of one subcarrier has been used and verified [MST04, HPB04, JFH05, JHF04]. A similar design has also been proposed for fixed grid of beam techniques in WINNER (see Chapter 3.2.2.2 of [WIND27]. The pro and cons of the general design principles in the WINNER framework are for further study. Detailed discussions of the pilot overhead and implementation aspect for MIMO-OFDM are contained in [WIND29].

5.5.4.3 Channel quality prediction for adaptive transmission

Adaptive transmission always involves a closed feedback loop, and thus incurs a delay. The allocation decision will be based on outdated channel quality information. While most WINNER terminals are expected to be stationary or slowly moving, this will create a problem for faster moving terminals. It would be advantageous with a scheme that allows the vast majority of WINNER terminals, including many of those moving at vehicular velocities, to utilise adaptive transmission. The situation can be improved markedly by introducing a channel predictor. In [WIND24], it is shown that this enables prediction of the channel power at sufficient quality over time delays consistent with realizable feedback loops, at vehicular velocities and 5 GHz carrier frequencies. Adaptive transmission at vehicular velocities would *not* be possible if the present channel state is just extrapolated.

A special problem is prediction in the uplink. Since several terminals will then be in competition for the whole or a part of the bandwidth, they have to send pilots over the whole of this band. The overhead due to these pilots would increase proportionally with the number of active terminals. To prevent this overhead from becoming too large, a simultaneous transmission of the pilots, *overlapping pilots*, is preferred. This technique requires the terminals to be sufficiently well synchronised in time and frequency. It also requires estimation of a multiple-input single-output channel based on these overlapping pilots.

Channel prediction can be performed in the time-domain for the impulse response [Ekm02], [SEA01] or in the frequency domain for the channel gains. In [WIND24], frequency domain prediction is investigated. It utilises the correlation between neighbouring subcarriers, and the time-domain correlation between subsequent OFDM symbols in a state space model [SA03]. Control symbols are used in decision directed mode for improving the estimates. Figure 5-53 below shows the results, expressed in normalised prediction error MSE, as a function of the SNR from 0 dB to 25 dB and as a function of the prediction horizon scaled in wavelengths. The result is for downlink predictions for the FDD mode in cellular deployment, for a full duplex FDD terminal that listens continuously on the downlink pilots. The Urban Macro channel model was used. Note the large dependence of the performance on the SINR.

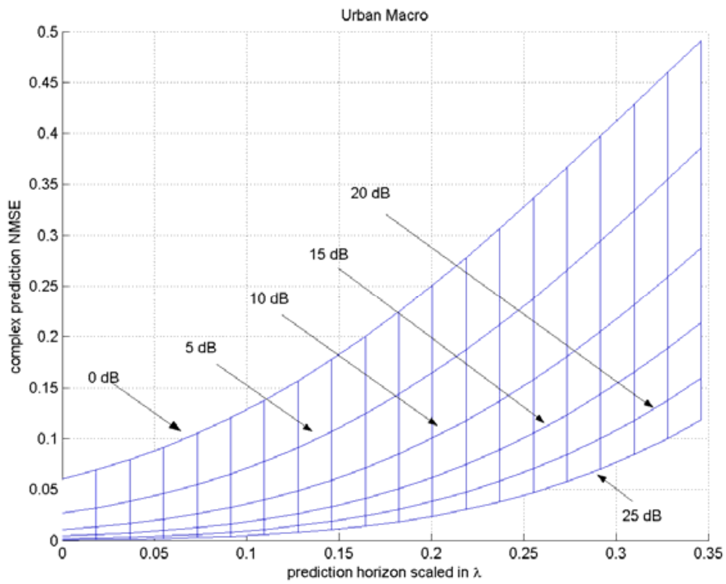

Figure 5-53: FDD downlink prediction accuracy in terms of the normalised channel prediction MSE, as a function of the prediction horizon scaled in carrier wavelengths, and as function of the SNR. Results for FDD downlink over Urban Macro channels, using a Kalman algorithm that utilises 8 subcarriers

Adaptive transmission to/from a terminal will be feasible up to a maximal velocity for a given SINR, or equivalently, down to a limiting SINR at a given velocity. For combinations of velocities and SINRs beyond such a boundary, non-frequency-adaptive transmission must be used. In [WIND24], a preliminary finding is that the normalised prediction error level 0.15 indicates the location of this boundary rather well, when using adaptive convolutional coding combined with BPSK or M-QAM. Based on this, one may calculate the approximate SNR boundaries for different velocities, different predictor designs and different designs of the adaptation feedback loops. The results in Figure 5-53 are for the adaptation loop designs presented in Chapter 3.1 of [WIND24]. For the FDD mode, it is based on downlink channel prediction 2.5 slots ahead at the terminals. In uplinks channel prediction is based on overlapping pilots, at the base station. For the short-range TDD modes, the prediction is assumed to be performed by the user terminals. (A scheme that moves the predictor to the base station is of course also possible). The required prediction horizons to the far end of the predicted chunk, scaled in the carrier wavelength λ_c at 5 GHz, are also shown in Table 5.3. For further results please see Chapter 3.1 of [WIND24] or [SFSA05].

In these examples, adaptive transmission can be expected to work in the widest variety of situations in the proposed wide-area FDD downlinks and short-range TDD downlinks, while it works in the narrowest range of circumstances in the proposed short-range TDD uplink that requires the longest prediction horizon. The case of wide-area FDD uplinks, using overlapping pilots, falls somewhere in-between. The performance deteriorates with the number of simultaneous users that transmit overlapping pilots, but this deterioration is not severe.

Table 5.3: SINR limits for cases where the accuracy limit $\tilde{\sigma}^2 = 0.15$ allows the use of adaptive transmission, exemplified for three terminal velocities for a 5 GHz carrier frequency. Also shown are required prediction horizons in carrier wavelengths. From [WIND24], Table 3.2

	30 km/h	50 km/h	70 km/h
TDD downlink (prediction horizon 2 slots)	< 0 dB (0.094 λ_c)	5 dB (0.156 λ_c)	10 dB (0.219 λ_c)
TDD uplink (prediction horizon 3 slots)	5 dB (0.150 λ_c)	15 dB (0.25 λ_c)	> 25 dB (0.35 λ_c)
FDD downlink (Figure 5-53)	< 0 dB (0.117 λ_c)	6 dB (0.195 λ_c)	12.5 dB (0.273 λ_c)

FDD uplink, 2 users in competition band	0 dB (0.117 λ_c)	7 dB (0.195 λ_c)	15 dB (0.273 λ_c)
FDD uplink, 8 users in competition band	3.5 dB (0.117 λ_c)	11 dB (0.195 λ_c)	20 dB (0.273 λ_c)

5.5.4.4 Compression of channel quality and state feedback for adaptive transmission

This chapter contains a brief summary of results from Chapter 3.1.4 in [WIND24] and Chapter O.5 in [WIND29]. Assume that one or several clients within a terminal are in competition for a sub-bandwidth of the total band comprising N chunks (one-antenna SISO transmission is assumed here). K active terminals compete for this competition band. Assume that each terminal feeds back a proposed code and modulation rate for each chunk. For a scheme with r rates, each terminal then needs to feed back $N \log_2(r)$ bits per chunk duration T_{chunk}. For K users, the required total feedback data rate is then

$$R_f = KN \log_2(r) / T_{chunk} \text{ [bit/s]}$$

For the full-band wide-area FDD downlink with N = 104 chunks and with r = 8 code and modulation rates, we would have a feedback overhead of 925 kbit/s per active user! Expressed in another way, for each chunk for which K downlink users compete, $K \log_2(r)$ feedback bits would have to be transmitted in the following uplink chunk. The FDD mode chunks of Chapter 5.5.1.3 contain 96 symbols. With around 80 non-pilot symbols per uplink chunk, K = 8 active terminals with r = 8 would consume 24/80 = 30% of the uplink bandwidth for control signaling, if one feedback bit/feedback symbol can be used on average. The situation described here is clearly unacceptable. Fortunately, there are several ways in which the required feedback rate can be reduced significantly.

The channel gains and SNRs at adjacent chunks will be highly correlated. (If they were not, the chunk widths would have been selected too wide, and we would have severe problems with channel variability within the chunks.) This correlation can be utilised to reduce the feedback rate. The channels are also correlated in time. Furthermore, it is likely that in most cells except those situated close to major roads, the large majority of terminals will not travel at vehicular speeds, but rather be stationary. For those terminals, very little feedback is required.

In Chapter 3.1.4 of [WIND24], several principles for compression are introduces and evaluated. Lossless compression of the modulation-coding rates could, for the considered ITU Vehicular A and Pedestrian A channels be performed at rates close to 0.91 bits/chunk and 0.35 bits/chunks, respectively.

Significantly lower feedback rates can be attained by using lossy compression of the SINR. This method provides the added benefits that SINR-values, not only suggested rates, are fed back. This enables the scheduler to select intelligently among users who would have suggested the same rates for a given chunk. The net effect is that lossy compression of SINR values is superior to lossless compression of suggested modulation-coding rates. It enables us to attain *both* lower feedback data rates *and* a higher performance, in terms of the attained spectral efficiency when performing multi-user scheduling. The suggested coder uses transform coding (Discrete Cosine Transform, DCT) to compress the SINR data in the frequency direction. It combines this with subsampling in the time direction to obtain a further compression due to the temporal correlation. Motivations for these design choices are discussed in [WIND24]. The resulting algorithm is summarised by Figure 5-54 and Figure 5-55 below.

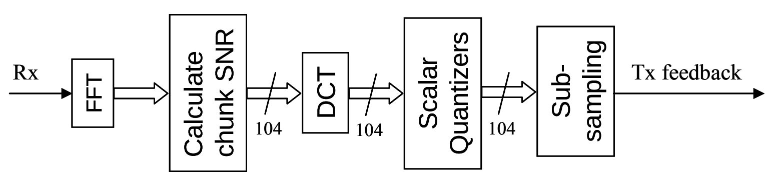

Figure 5-54: A block diagram of feedback handling in the terminal

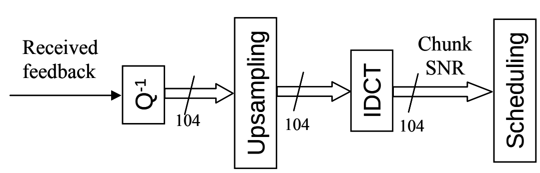

Figure 5-55: Block diagram of feedback handling at the base station

With the discussed compression of SINR predictions, only 0.25 bits/chunk are required for the Vehicular A channels and 0.12 bits/chunk for the Pedestrian A channels when all users travel at 50 km/h and the modulation-coding scheme uses $r = 8$ rates. If the mobile speed is reduced, it will be possible to further subsample the coded feedback information. For example, at 5 km/h, it would be possible to reduce the feedback information further by a factor of 10. With a feedback rate of 0.25 bits/chunk over the Vehicular A channel, we would only need 4 bits per chunk to accommodate 16 *vehicular* 50 km/h users per contention band, in addition to many more stationary users. Uplink feedback with only four 4-QAM symbols per chunk that use rate ½ coding is adequate for this.

For multiple antenna systems, the required feedback rate will of course increase proportionally with the number of virtual antenna streams for which the channel quality feedback is required. If not only real-valued channel quality SINR values, but channel state information in the form of complex-valued matrices is required, this will increase the feedback requirements quite substantially. In Appendix O.5 of [WIND29] a method is outlined that can significantly reduce the required CQI feedback by using vector quantization. An example is given for a system with four transmit antennas and one receive antennas that would need 32 bits if all four complex gains were represented by 8 bits each. With compression by vector quantization, only two bits per chunk and per user are required, at some performance loss. Especially efficient is the use of long-term (exact) CSI at the transmitter together with compressed short-term CSI feedback. The resulting feedback requirement is still high for adaptive multi-user transmission. However further reductions can be expected by utilizing the temporal correlation, as was outlined for the SISO case above.

6. Logical Node Architecture

6.1 Introduction

The main goal of the logical node architecture model is to assist in grouping functions, between which there may be a need for defining open interfaces. In particular, the logical node architecture needs to support all envisioned deployment scenarios for WINNER (as well as not yet foreseen deployment scenarios) without introducing too many logical nodes and/or interfaces. The list of Logical Nodes (LNs) presented in Chapter 6.3 are reference logical nodes. These reference LNs present the actual view of WINNER.

Definition:

"A Logical Node (LN) is defined by the service (or group of services) it provides towards other nodes (the provided service access points), the service (or group of services) it requires from other nodes.

Identical Logical Nodes terminate an identical set of protocols and provide/require the same group of services (i.e. identical service access points). One physical node can comprise one or several LNs."

A physical node instead can comprise more than one logical node, e.g. one physical node can comprise a RANG logical node and an ACS logical node. Physical nodes can be different in different physical deployment concepts.

6.2 The WINNER Logical Node Architecture

The WINNER logical nodes architecture is shown in Figure 6-1.

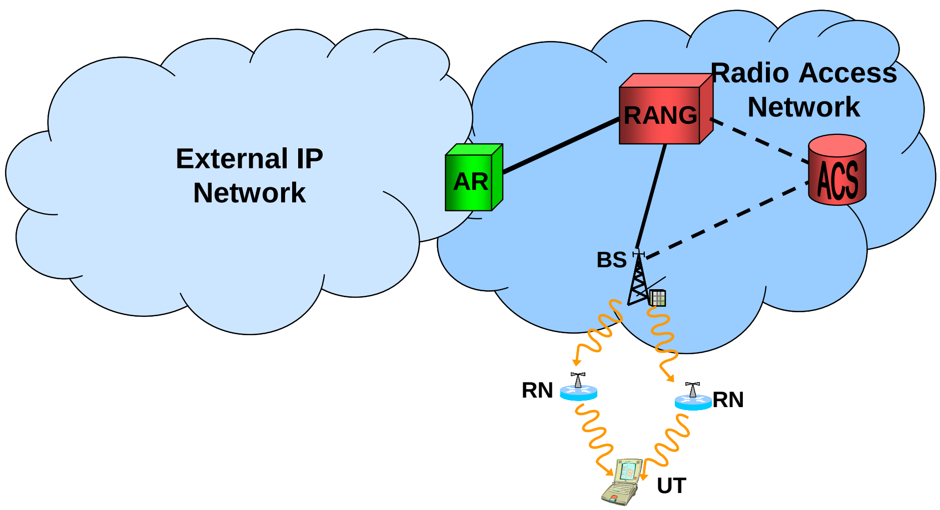

Figure 6-1: WINNER Logical Nodes Architecture

In the following the different logical nodes are explained in more detail.

6.3 WINNER Logical Nodes

User Terminal Logical Node (UT_{LN}) is a logical node comprising all functionality necessary for it to communicate directly with another UT or the network, i.e. a BS or a RN.

Base Station Logical Node (BS_{LN}) is a logical node terminating the transport network layer protocols on the network side as well as the radio protocols on the UT and RN side.

Relay Node Logical Node (RN_{LN}) is a logical network node with relaying capabilities that is wirelessly connected to a BS_{LN}, UT_{LN} and/or another RN_{LN}. Like the BS_{LN} it terminates the radio protocols (MAC and PHY) on the UT side as well as on the BS side and, in case of more than two hops, also on the RN side. The RN_{LN} further comprises all necessary functionalities to associate itself to the network (placed in the RLC-CP). To avoid unnecessary signalling between the RN_{LN} and the network the SLC functionalities are required on the uplink. Further the RN_{LN} will comprise the peer entity for the network side resource partitioning (RP) control entity in order to receive and understand the RP information coming from the central node. In case of more than two hops resource partitioning functionalities are required to control the further hops.

Another difference to a BS_{LN} is that it does not terminate the transport network layer protocols. Due to future work it might not be sufficient to classify only one RN_{LN}. The RN_{LN} may need to be further partitioned, e.g. depending on whether it is mobile or not (i.e. classified as a Fixed Relay Node (FRN_{LN}) or Mobile Relay Node (MRN_{LN})) or on what layer it performs the forwarding (e.g. classified as a RN with layer 3 routing capabilities ($RN3_{LN}$)).

Radio Access Network Gateway Logical Node ($RANG_{LN}$) is a logical network node terminating the mode independent RLC-UP protocols.

Access Control Server Logical Node (ACS_{LN}) is a logical network node that controls the access to the radio interface resources. It terminates Control Plane protocols of the RLC (and/or RRC).

Access Router Logical Node (AR_{LN}) is a logical IP layer node that performs the tasks attributed to an Access Router as defined in relevant IETF specifications. In the WINNER architecture the AR_{LN} contains all functionalities of the IP Convergence Layer (CL).

7. Reference Physical Deployment Characteristics

7.1 Introduction

This chapter's purpose is to provide basic link budget figures for a number of exemplary deployments and settings of system parameters, and to show some preliminary WINNER system deployment properties. Single- and exemplary two-hop deployments are treated in order to provide hints on the coverage gains expectable from applying relaying techniques.

It should be emphasized that these results only constitute the most basic functionality of the WINNER system, excluding more advanced antenna solutions, and also adopting rather conservative assumptions on e.g. pathloss, and indoor propagation loss. Please note that the shown analytical results are calculated for one set of parameters per scenario only, whereby the chosen parameters must not be seen as final WINNER parameters, but serve as reference for further deployment studies. Therefore, the figures presented should not be seen as final but rather as a first view of the potential basic coverage. Furthermore, we emphasise, that only the downlink (DL) has been considered.

7.2 Methodology

A simple link budget calculation method as depicted in Figure 7-1 is used for all range calculations presented throughout the following. The transmitter which transmits with a power of P_t dBm via an antenna with gain G_t produces an Effective Isotropic Radiated Power (EIRP) of Pt+G_t dBm. At the location of the receiver the EIRP is reduced by the distance dependent pathloss L_p. Some margin M_{fading} to account for shadow fading effects further reduces the perceived power at the receiver location. A receive antenna gain in turn increases the received power observed at the receive antenna connector by G_r dBm. On the other hand the receiver is subject to noise that can be viewed as a combination of thermal noise (-174 dBm/Hz) and receiver design-specific noise amplification characterised by the noise figure F_{noise}. Reliable communication below a certain error rate is only possible if the power observed at the receiver's antenna connector is at least SNR_{min} dB above the received noise. SNR_{min} depends on the chosen transmission techniques (e.g. modulation and coding scheme, spatial diversity, beamforming, etc.).

The base line SNR requirement figures are calculated by link level simulations using a 1x4 antenna configuration with MRC at the receiver side. Consequently, in case of a 4x2 system which is the basic configuration used in all range calculations, 6 dB and -3 dB beamforming gain is added at the BS and UT respectively.

For some scenarios both, outdoor and outdoor-to-indoor ranges are calculated. The only difference between these cases is an additional 20 dB penetration loss for the outdoor-to-indoor case.

The throughput assumption in the presented results lies between 5 and 50 Mbps, but peak data rates of up to 100 Mbps, and even up to several hundred Mbps with adaptive antenna solutions, can be expected in the WINNER system.

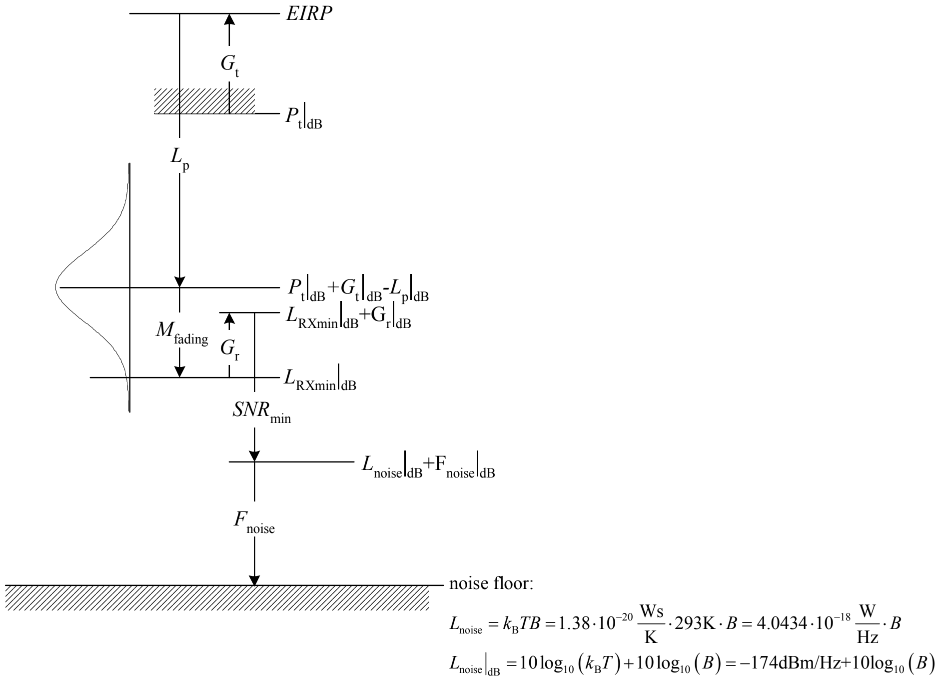

Figure 7-1: Graphical representation of the link budget calculation method as applied

7.3 Deployment Scenarios

[WIND72] contains a list of scenarios which describe the characteristics of potential deployment areas for WINNER systems. Four of these scenarios have been prioritised and are applied for the following calculations. These describe an "Indoor" case (A1), a "Hot-Spot / Hot Area" case (B1), a "Metropolitan" case (C2) and "Rural" case (D1). WP5 has developed pathloss models for these scenarios (cf. [WIND54]) under particular assumptions on physical deployment, e.g. antenna heights. These models and their area of usage are summarised in Table 7-1. The pathloss models have the following basic form:

$$PL = A\log(d) + B\ ,$$

where d is the distance between transmitter and receiver, the fitting parameter A includes the pathloss exponent parameter and B is the intercept.

The pathloss models are based on measurements at 5 GHz. For other center frequencies, the above pathloss models are modified with a frequency dependent offset term. This correction term has the following form:

$$F_{corr} = 20\log\left(\frac{f_c}{f_{ref}}\right),$$

where f_c is the considered carrier frequency and f_{ref} ist the frequency for which the pathloss model has been derived (cf. Table 7-1).

scenario		**pathloss [dB]**	**shadow fading standard deviation**	**center freque ncy [GHz]**	**applicability range**
A1	LOS	$18.7 \log_{10}(d[\text{m}]) + 46.8$	σ = 3.1 dB	5.25	3m < d < 100m
	NLOS	$36.8 \log_{10}(d[\text{m}]) + 38.8$	σ = 3.5 dB	5.25	3m < d < 100m
B1	LOS	$22.7 \log_{10}(d[\text{m}]) + 41.0$	σ = 2.3 dB	5.3	10m < d < 650m

scenario		pathloss [dB]	shadow fading standard deviation	center freque ncy [GHz]	applicability range
	NLOS	$0.096\ d_1[\mathrm{m}] + 65 + 10\ (2.8 - 0.0024\ d_1[\mathrm{m}])\ \log_{10}(d_2[\mathrm{m}])$	σ = 3.1 dB	5.3	$10\mathrm{m} < d_1 < 550\mathrm{m}$ $w/2 < d_2 < 450\mathrm{m}$ *)
C1	LOS	$23.8\ \log_{10}(d[\mathrm{m}]) + 41.6$; $40.0\ \log_{10}(d/d_{BP}) + 41.6 + 23.8\ \log_{10}(d_{BP})$ ****) +)	σ = 4.0 dB σ = 6.0 dB	1.7666	$30\ \mathrm{m} < d < d_{BP}$ $d_{BP} < d < 5\mathrm{km}$
C2	NLOS	$35.0\ \log_{10}(d[\mathrm{m}]) + 38.4$ ***)	σ = 8.0 dB	1.7666	$50\mathrm{m} < d < 5\mathrm{km}$
D1	LOS	$21.5\ \log_{10}(d[\mathrm{m}]) + 44.6$; $40.0\ \log_{10}(d/d_{BP}) + 44.6 + 21.5\ \log_{10}(d_{BP})$ ****) +)	σ = 3.5 dB σ = 6.0 dB	5.25	$30\mathrm{m} < d < d_{BP}$ $d_{BP} < d < 10\mathrm{km}$
	NLOS	$25.1\ \log_{10}(d[\mathrm{m}]) + 55.8$	σ = 8.0 dB	5.25	$30\mathrm{m} < d < 10\mathrm{km}$

Table 7-1: Pathloss models

*) w is LOS street width, d_1 is distance along main street, d_2 is distance along perpendicular street.

**) Validity beyond 1 km not confirmed by measurement data.

***) Validity beyond 2 km not confirmed by measurement data.

****) d_{BP} is the break-point distance: $d_{BP} = 4\ h_{BS}\ h_{MS} / \lambda$, where h_{BS} is antenna height at BS, h_{MS} is antenna height at MS, and λ is the wavelength. Validity beyond d_{BP} not confirmed by measurement data.

+) BS antenna heights in the measurements: C1 LOS: 11.7 m, D1: 19 – 25 m.

A shadow fading margin of $\sigma \cdot 1.64$, corresponding to a 95% probability of the shadow fading being below the margin, is assumed in all.

7.4 Baseline Physical Deployment Concepts

Two simple alternative physical deployment concepts are evaluated and compared throughout the following. In each deployment scenario a single – hop case and a multi-hop case is investigated. For both of them, the same antenna configurations are assumed at UT and BS/RN respectively. Figure 7-2 shows a picture of the antenna configurations and the names used for the respective links.

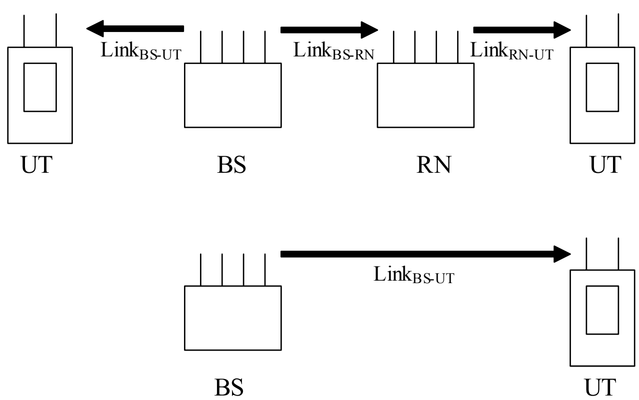

Figure 7-2: Baseline antenna configurations and definition of links

The antenna gain breaks down into the antenna element gain and the additional antenna array gain. The latter is considered as a simple beamforming gain in the link budgets. Omni-directional antennas are assumed for both single-hop and multi-hop deployments.

For each of these cases a set of carrier frequencies and bandwidths, believed to be relevant for the case in question, are chosen to calculate the associated link budgets.

7.4.1 Single-Hop Deployment

System parameters used to investigate single-hop deployments in this document are listed in Table 7-2. In general we assume non-line-of-sight conditions for single-hop, hence we used the respective NLOS models from Table 7-1. Transmission power used at the BS is scenario dependent and lies in range of 20 to 43 dBm depending on the BS antenna installation situation, i.e. in case of rural deployment we assumed antenna installation on top of an antenna mast with an installation height 19 to 25 m above ground level. For performance degradation due to channel estimation errors, we assumed a 1 dB loss in SNR. For BS antennas a realistic antenna element gain figure is 18 dB, assuming 60° 3 dB beamwidth. It is assumed that 12 dB out of this 18 dB originate from directivity in vertical orientation. Thus, since we assume omni-directional cell layouts for the range estimation, we set the antenna element gain to 12 dB. As explained earlier, the BS beamforming gain is assumed as 6 dB since the underlying link-level investigations assumed a 1x4 antenna configuration, but we assume 4 BS antennas. Correspondingly, at the UT side we assume -3 dB beamforming gain due to the fact, that at maximum we consider two antennas at the UT and not 4, as assumed for the link-level results. The total antenna gains on the link between BS and RN are the sum of the antenna element gains and beamforming gains of both BS and UT. All relevant system parameters are summarized in Table 7-2 below.

Parameter	**value**
channel model	NLOS
BS Tx power [dBm]	scenario dependent
channel estimation degradation [dB]	1
BS antenna element gain [dBi]	12
BS beamforming gain [dB]	6
UT antenna element gain[dBi]	0
UT beamforming gain[dB]	-3
UT receiver noise figure [dB]	9
interference margin [dB]	0 (for isolated cell scenarios) 3 or 4 (for continuous coverage)
shadowing margin [dB]	$\sigma \cdot 1.64$

Table 7-2: Single - Hop parameters

7.4.2 Multi-Hop Deployments

For the multi-hop cases, a deployment with one central base station serving 3 relay nodes has been defined as a reference deployment. It should be noted that this reference deployment is only one example of a multi-hop deployment and therefore care should be taken when making general conclusions based on this case.

The basic assumption is that each relay node is capable to transmit the same link data rate to the UT as in the single-hop case. The available bandwidth B has to be distributed between the base station and the relay nodes. We assume that the same spectral resource is used for the BS-RN links by exploiting spatial separability (SDMA). However, in order to keep interference between BS-UT and RN-UT links manageable, we assume separate spectral resources for these links. The overall bandwidth B is thus partitioned as follows:

$$B = 3\,B_{\text{RN-UT}} + 1\,B_{\text{BS-UT}} + 1\,B_{\text{BS-RN}}$$

With the same bandwidth for the link from BS to UT as for the link between RN and UT we get:

$$B_{\text{RN-UT}} = B_{\text{BS-UT}} = B_{\text{UT}}$$

$$B = 4\,B_{\text{UT}} + 1\,B_{\text{BS-RN}}$$

The BS has to transmit with link data rate to the UT in its own cell within the bandwidth B_{UT} and towards all relays within $B_{BS\text{-}RN}$, assuming that $B_{BS\text{-}RN}$ can be reused due to spatial processing. Figure 7-3 depicts these relations by one example with a link data rate of d = 10Mbps at a bandwidth of B = 10MHz.

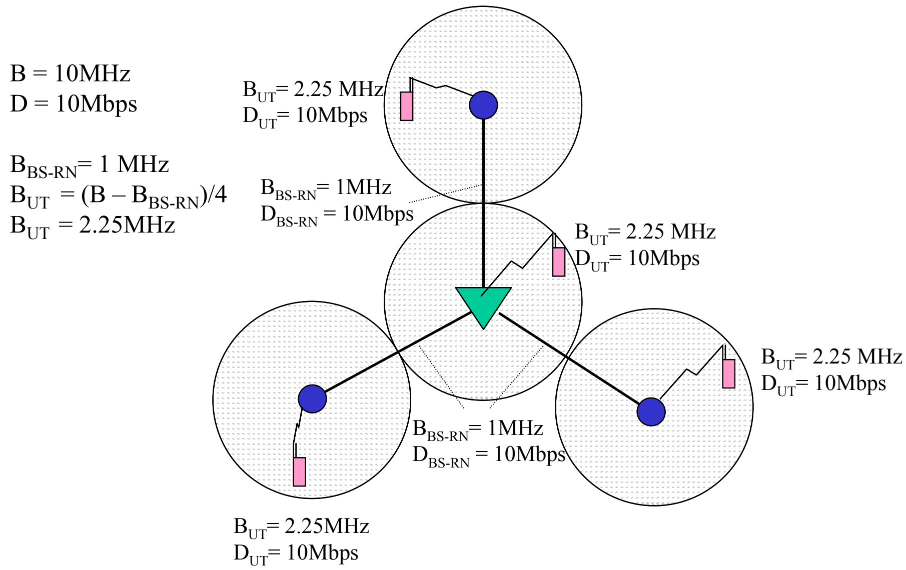

Figure 7-3: Bandwidth and throughput distribution between RNs and BS example

The required bandwidth for the 1st hop $B_{BS\text{-}RN}$ is calculated by applying the highest possible modulation and coding scheme under the condition that the required SNR results in a range higher than the sum of BS-UT and RN-UT ranges[8]. Under the used assumptions of line-of-sight propagation between BS and RN in all deployments, this means in practice that the highest modulation can always be used. Table 7-3 lists the minimum required bandwidth necessary to reach the anticipated data rate assuming 64QAM and rate 8/9 coding.

link data rate [Mbps]	required bandwidth ($B_{BS\text{-}RN}$) [MHz]
5	3.125
10	6.25
20	12.5
50	31.25
100	62.5

Table 7-3: Required bandwidth for first hop, to satisfy link data rates as in single-hop case for the two-hop scenario as depicted in Figure 7-3 (transmission with 64 QAM and rate 8/9 coding at 20dB SNR assumed)

System parameters for the multi-hop deployment scenario are summarized in Table 7-4. The beamforming gains take into account the number of antennas at UT, RN and BS compared to the baseline configuration with one transmit antenna at the base station and 4 receive antenna at the UT. On the BS–RN link, the RN makes use of 4 Rx–antennas, resulting in an Rx–beamforming gain of 0dB.

The total antenna gains on the BS–RN link is the sum of the BS and RN antenna element gains, beamforming gains of the BS and Rx beamforming gain of the RN. The total antenna gains on the RN–UT links is the sum of the RN and UT antenna element gains, Tx beamforming gains of the RN and beamforming gain of the UT. As the RN is assumed to be a cheaper, less complex device than the BS, the

[8] this is generally the case in all considered scenarios

antenna element gain of the RN is smaller than that of the BS, resulting in a smaller total antenna gain on the RN - UT links and therefore smaller range than on the BS – UT links.

Parameter	value
channel model	hop 1: LOS hop 2: NLOS
BS Tx power [dBm]	scenario dependent
RN Tx power [dBm]	scenario dependent
BS antenna element gain [dBi]	12
BS beamforming gain [dB]	6
RN antenna element gain [dBi]	8
RN Rx beamforming gain [dB]	0
RN Tx beamforming gain [dB]	6
RN receiver noise figure [dB]	5
UT antenna element gain[dBi]	0
UT beamforming gain [dB]	-3
UT receiver noise figure [dB]	9
interference margin [dB]	scenario dependent
shadowing margin [dB]	$\sigma \cdot 1.64$

Table 7-4: Multi-hop parameters

7.5 A1 – "In and Around Building"

7.5.1 Considered Carrier Frequencies and Bandwidths

We assume the operation of both FDD and TDD physical layer modes in this scenario. Furthermore, carrier frequencies and channel bandwidths as given below are considered for both, single- and two-hop cases:

- 3.5 GHz, 10, 50 and 100 MHz BW
- 5 GHz, 10, 50, and 100 MHz BW

7.5.2 Single-Hop Downlink

7.5.2.1 Description

Measurements for this pathloss model were carried out in typical office buildings with corridors of widths of 1.8 to 3.5 m and approximate room sizes of 10 x 10 m. Since only indoor-to-indoor cases were investigated all range calculations throughout the following are carried out without consideration of any penetration losses due to outwalls of buildings. Penetration losses due to inside walls are inherently covered by the model (see summary of considered cases below).

For the measurements following cases were distinguished:

- corridor-to-corridor LOS: both BS and MS were placed at the corridors
- room-to-corridor and corridor-to-room NLOS: BS in a room, UT in an adjacent corridor and vice versa
- room-to-room LOS/OLOS: both BS and UT in the rooms
- corridor-to-corridor NLOS

The pathloss model used is the A1"In and Around Building" model [WIND54]. Table 7-5 summarises the system parameters used to analyse the single-hop downlink for the "In and Around Building" propagation environment[9]. In order to reflect the worst case conditions with respect to the achievable range, we assume the NLOS case only.

parameter	value
channel model	A1 NLOS [WIND54]
BS Tx power [dBm]	20
channel estimation degradation [dB]	1
BS antenna element gain [dBi]	12
BS beamforming gain [dB]	6
UT antenna element gain[dBi]	0
UT beamforming gain[dB]	-3
UT receiver noise figure [dB]	9
interference margin [dB]	0
shadowing margin [dB]	5.7

Table 7-5: System parameters assumed for "In and Around Building" scenario (single-hop)

7.5.2.2 Link budget

Applying the NLOS pathloss model for the "In and Around Building" environment as given in Table 7-1 ranges for different combinations of available bandwidth, carrier frequency, and link data rates as summarised in Table 7-6 below can be achieved.

link data rate [Mbps]	totally available spectrum for deployment					
	10 MHz @ 3.5 GHz	50 MHz @ 3.5 GHz	100 MHz @ 3.5 GHz	10 MHz @ 5.0 GHz	50 MHz @ 5.0 GHz	100 MHz @ 5.0 GHz
5	266 (2.8 dB)[10]	344 (-8.3 dB)	357 (-11.9 dB)	219 (2.8 dB)	283 (-8.3 dB)	294 (-11.9 dB)
10	146 (12.4 dB)	263 (-4.0 dB)	285 (-8.3 dB)	120 (12.4 dB)	217 (-4.0 dB)	235 (-8.3 dB)
20	-	201 (0.3 dB)	218 (-4.0 dB)	-	165 (0.3 dB)	179 (-4.0 dB)
50	-	94 (12.4 dB)	142 (2.8 dB)	-	78 (12.4 dB)	117 (2.8 dB)

Table 7-6: Achievable DL range in [m] for "In and Around Building" scenario as function of link data rate, bandwidth and carrier frequency (single-hop)

7.5.3 Two-Hop Downlink

7.5.3.1 Description

The same pathloss model is used as in case of single-hop deployment. To reflect the benefits of having the opportunity of relaying, we assume that transmission over the first hop takes place under LOS conditions. For the second hop NLOS propagation is assumed (as for single-hop). Table 7-7 below summarises the underlying system parameters for the two-hop range calculations.

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9 For convenience reasons we use the term "environment" instead of "propagation environment" throughout the following.

10 Figures in brackets indicate the minimum required SNR to achieve target link data rate within specified channel bandwidth for the respective link. This nominclature is used in other tables of this type following below as well.

parameter	value
channel model	hop 1: A1 LOS [WIND54] hop 2: A1 NLOS [WIND54]
BS Tx power [dBm]	20
RN Tx power [dBm]	20
BS antenna element gain [dBi]	12
BS beamforming gain [dB]	6
RN antenna element gain [dBi]	8
RN Rx beamforming gain [dB]	0
RN Tx beamforming gain [dB]	6
RN receiver noise figure [dB]	5
UT antenna element gain[dBi]	0
UT beamforming gain [dB]	-3
UT receiver noise figure [dB]	9
interference margin [dB] [11]	0 / 0
shadowing margin [dB]	5.1 / 5.7

Table 7-7: System parameters assumed for "In and Around Building" scenario (two-hop)

7.5.3.2 Link Budget

Applying the LOS and NLOS pathloss model for for the 1st and 2nd hop in "In and Around Building" environment ranges for different combinations of available bandwidth, carrier frequency, and link data rates as summarised in Table 7-8 and Table 7-9 below can be achieved.

		totally available spectrum for deployment					
		10 MHz @ 3.5 GHz		50 MHz @ 3.5 GHz		100 MHz @ 3.5 GHz	
link	**link data rate [Mbps]**	**channel BW [MHz]**	**range [m]**	**channel BW [MHz]**	**range [m]**	**channel BW [MHz]**	**range [m]**
BS-RN	5	-	-	3.125 (20.0 dB)	33,770	3.125 (20.0 dB)	33,770
BS -UT	5	-	-	11.719 (1.0 dB)	285	24.219 (-4.0 dB)	320
RN-UT	5	-	-	11.719 (1.0 dB)	222	24.219 (-4.0 dB)	249
BS-RN	10	-	-	6.25 (20.0 dB)	23,311	6.25 (20.0 dB)	23,311
BS-UT	10	-	-	10.938 (11.0 dB)	155	23.438 (1.0 dB)	236
RN-UT	10	-	-	10.938 (11.0 dB)	121	23.438 (1.0 dB)	184
BS-RN	20	-	-	-	-	12,5 (20.0 dB)	16,091
BS-UT	20	-	-	-	-	21.875 (11.0 dB)	129
RN-UT	20	-	-	-	-	21.875 (11.0 dB)	100

[11] First value corresponds to first and second value to second hop, respectively.

		totally available spectrum for deployment					
		10 MHz @ 3.5 GHz		50 MHz @ 3.5 GHz		100 MHz @ 3.5 GHz	
link	**link data rate [Mbps]**	**channel BW [MHz]**	**range [m]**	**channel BW [MHz]**	**range [m]**	**channel BW [MHz]**	**range [m]**
BS-RN	50	-	-	-	-	-	-
BS-UT	50	-	-	-	-	-	-
RN-UT	50	-	-	-	-	-	-

Table 7-8: Achievable DL range in [m] for "In and Around Building" scenario as function of link data rate, bandwidth and carrier frequency = 3.5 GHz (two-hop)[12]

		totally available spectrum for deployment					
		10 MHz @ 5.0 GHz		50 MHz @ 5.0 GHz		100 MHz @ 5.0 GHz	
link	**link data rate [Mbps]**	**channel BW [MHz]**	**range [m]**	**channel BW [MHz]**	**range [m]**	**channel BW [MHz]**	**range [m]**
BS-RN	5	-	-	3.125 (20.0 dB)	23,060	3.125 (20.0 dB)	23,060
BS -UT	5	-	-	11.719 (1.0 dB)	235	24.219 (-4.0 dB)	264
RN-UT	5	-	-	11.719 (1.0 dB)	183	24.219 (-4.0 dB)	205
BS-RN	10	-	-	6.25 (20.0 dB)	15,918	6.25 (20.0 dB)	15,918
BS-UT	10	-	-	10.938 (11.0 dB)	128	23.438 (1.0 dB)	195
RN-UT	10	-	-	10.938 (11.0 dB)	100	23.438 (1.0 dB)	152
BS-RN	20	-	-	-	-	12.5 (20.0 dB)	10,988
BS-UT	20	-	-	-	-	21.875 (11.0 dB)	106
RN-UT	20	-	-	-	-	21.875 (11.0 dB)	83
BS-RN	50	-	-	-	-	-	-
BS-UT	50	-	-	-	-	-	-
RN-UT	50	-	-	-	-	-	-

Table 7-9: Achievable DL range in [m] for "In and Around Building" scenario as function of link data rate, bandwidth and carrier frequency = 5.0 GHz (two-hop)

7.5.4 Comparison of Single-Hop and Two-Hop Downlink Maximum Ranges

Table 7-10 and Figure 7-4 compare the effective covered area per cell (in case of single-hop) or REC (in case of two-hop). The effective covered area of a REC is calculated as the sum of the areas covered by the BS and the 3 RNs. This assumes that RECs can be tessellated for contiguous coverage without any

[12] Figures in brackets indicate the minimum required SNR to achieve target link data rate within specified channel bandwidth for the respective link. This nominclature is used in other tables of this type following below as well.

overlap, which can be assumed without big errors as long as the ranges the BS – RN and RN – UT are not too different. The effective range as the radius of a circle of the same area is provided for easy comparison. For a hint on the economical viability, the RAP density (RAP/area) is given as well for both deployments (cf. Figure 7-5).

				single-hop			**two-hop**		
case	**link data rate [Mbps]**	**carrier frequency [GHz]**	**total BW [MHz]**	**covered area [km^2]**	**effective range [m]**	**RAP/ area [1/km^2]**	**covered area [km^2]**	**effective range [m]**	**RAP/ area [1/km^2]**
I	5	3.5	10	0.222	266	4.5	-	-	-
II	10	3.5	10	0.067	146	15.0	-	-	-
III	20	3.5	10	-	-	-	-	-	-
IV	50	3.5	10	-	-	-	-	-	-
V	5	3.5	50	0.371	344	2.7	0.720	479	5.6
VI	10	3.5	50	0.217	263	4.6	0.214	261	18.7
VII	20	3.5	50	0.127	201	7.9	-	-	-
VIII	50	3.5	50	0.028	94	35.9	-	-	-
IX	5	3.5	100	0.400	357	2.5	0.907	537	4.4
X	10	3.5	100	0.255	285	3.9	0.494	397	8.0
XI	20	3.5	100	0.149	218	6.7	0.147	216	27.3
XII	50	3.5	100	0.064	142	15.7	-	-	-
XIII	5	5.0	10	0.151	219	6.6	-	-	-
XIV	10	5.0	10	0.045	120	22.0	-	-	-
XV	20	5.0	10	-	-	-	-	-	-
XVI	50	5.0	10	-	-	-	-	-	-
XVII	5	5.0	50	0.252	283	4.0	0.488	394	8.2
XVIII	10	5.0	50	0.147	217	6.8	0.145	215	27.6
XIX	20	5.0	50	0.086	165	11.6	-	-	-
XX	50	5.0	50	0.019	78	52.9	-	-	-
XXI	5	5.0	100	0.272	294	3.7	0.615	443	6.5
XXII	10	5.0	100	0.173	235	5.8	0.335	327	11.9
XXIII	20	5.0	100	0.101	179	9.9	0.100	178	40.2
XXIV	50	5.0	100	0.043	117	23.2	-	-	-

Table 7-10: Comparison of DL ranges of single-hop and two-hop case within "In and Around Building" scenario

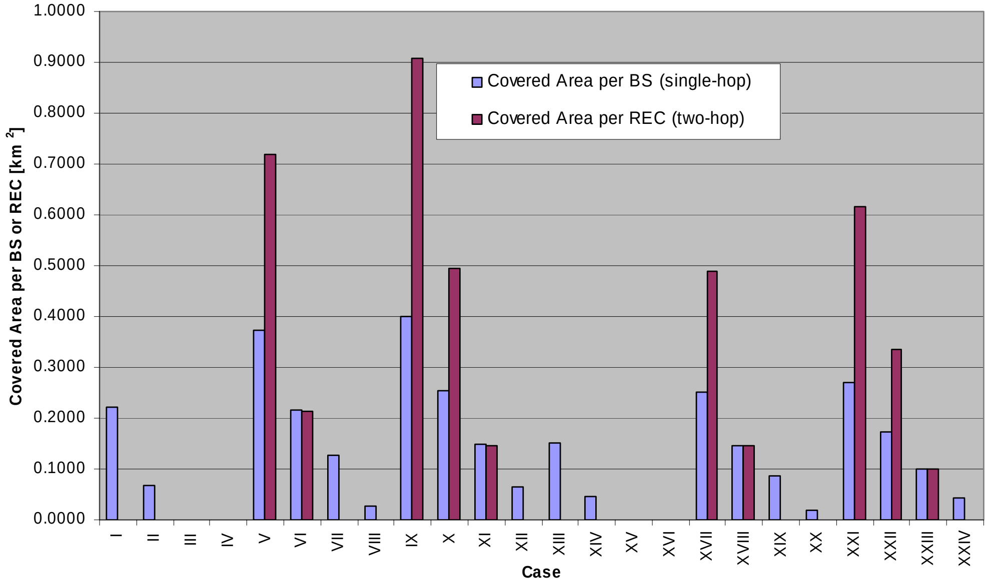

Figure 7-4: Single-hop and two-hop coverage for "In and Around Building" scenario

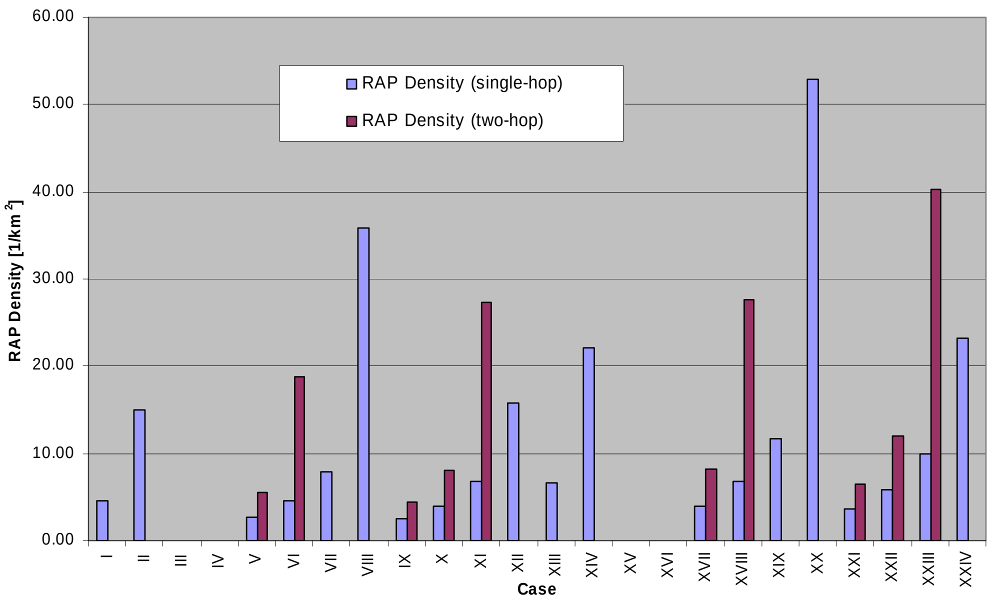

Figure 7-5: Single-hop and two-hop RAP density "In and Around Building" scenario

7.5.4.1 Conclusions

- Single-hop deployments obtain the "high end" target data rate of 50Mbps required according to R3.2, [WIND71] at a maximum range of 117m with 100MHz @5GHz and 142m with 100MHz @ 3.5GHz under the given assumptions in the "in and around building – scenario".
- Multi-hop was only possible to be calculated for high bandwidths because no link level results with the needed higher modulation order were available in order to transmit the target link data rate to the relay node.

- Multi-hop deployments according to section 7.4.2 give significant coverage gains in cases V, IX, X, XVII, XXI, XXII (set 1), whereas cases VI, XI, and XXIII (set 2) show no coverage gains in the “in and around building - scenario. The gains come with the price of a higher number of RAPs in all cases. It should be noted although this investigation is based on single – user link budgets and capacity is not in the focus, the multi-hop deployment support four times the number of users with the target data rate.
- With the present assumptions, the range of the multi-hop deployments is determined by the UT – links. The BS-RN hop has a very large link budget margin that in a further developed WINNER concept can be utilised to reduce the BS-RN system bandwidth by employing larger modulation alphabets. This in turn increases the remaining bandwidth for communication with the UTs, and thus reduces the bottleneck effect of the hop to the UT. However, even 256-order modulation would not result in considerable change of the UT link range. This means for effective usage of the relay – link, very high order modulation schemes have to be implemented. Other options, e.g. spatial multiplexing, should be investigated.
- Alternatively, the link budget margin can be exploited by moving the BS-RN communication to a higher carrier frequency.
- Analysing the differences between the set 1 cases showing coverage gains for multi-hop and set 2 cases showing no gains, set 2 cases are the ones designed for higher link data rates. These require bandwidth efficiencies on the critical BS and RN to UT – links is in the order of 1bit/s/Hz or more, whereas in the set 1 multi-hop cases the required bandwidth efficiency is below 0.5 bit/s/Hz. The increased bandwidth efficiency requires a disproportionately higher SNR that reduces the effective common range of the two links below the respective single – hop range. This means in the given scenario with simple bandwidth allocation scheme, multi-hop coverage gains are restricted to cases with low required bandwidth efficiency or relatively low link data rate per available bandwidth. Therefore, WINNER studies on advanced bandwidth allocation schemes that improve the frequency re-use in the relay – enhanced cell and relax the required bandwidth efficiency should be continued.

7.6 B1 – “Hot Spot / Hot Area”

7.6.1 Considered Carrier Frequencies and Bandwidths

We assume the operation of both FDD and TDD physical layer modes in this scenario. Furthermore, carrier frequencies and channel bandwidths as given below are considered for both, single- and two-hop cases:

- 2.6 GHz, 20 MHz BW
- 5 GHz, 20, 50 and 100 MHz BW

7.6.2 Single-Hop Downlink

7.6.2.1 Description

The underlying assumption for the “Hot Spot / Hot Area Scenario” is a Manhattan like propagation environment according to [WIND54] with a block size of 200m x 200 m (cf. UMTS 30.03 [UMTS]), as depicted in Figure 7-6. BS antennas are assumed to be installed in approximate heights of 10m. In the majority of cases, this is below the average roof-top level of 12-15m, i.e. 4-5 story buildings [WIND54]. The UT antenna height is 1.6m. We consider the shadowed (worst) case, i.e. UTs do not have a line-of-sight path to the BS due to obstructive buildings in the propagation path as depicted in Figure 7-6 (UT located in perpendicular street). Consequently we use the B1 LOS model [WIND54]. BS antenna element gain is assumed to be 12dBi. For the UT we assume 0dBi antenna element gain. Since WINNER systems will have to compete with other systems addressing the hotspot scenario (i.e. IEEE 802.11n and 802.16), which already employ multiple antennas in the UT, we expect that a number of up to two antennas (M=2) in the UT is a reasonable assumption. For the BS we assume 4 antennas. We consider this by a BS beamforming and UT combining gain, respectively, of 10*log10(M). Tx power has been set to a maximum level of 30dBm which seems reasonable because of the relatively low antenna installation heights (low minimum coupling loss). Furthermore, we consider the noise-limited case, i.e. a single isolated cell. As a consequence, we set the interference margin to 0dB. The shadowing margin for this case is set to 5.1dB. The pathloss model used is the B1“Urban micro-cell” model [WIND54]. Power and gain settings as well as margins are summarized in Table 7-11.

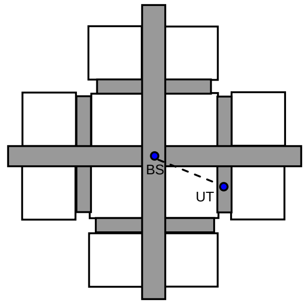

Figure 7-6: Area covered by the BS in Manhattan grid (single-hop)

Parameter	value
channel model	B1 NLOS [WIND54]
BS Tx power [dBm]	30
channel estimation degradation [dB]	1
BS antenna element gain [dBi]	12[13]
BS beamforming gain [dB]	6
UT antenna element gain[dBi]	0
UT beamforming gain [dB] [14]	-3
UT receiver noise figure [dB]	9
interference margin [dB]	0
shadowing margin [dB][15]	5.1

Table 7-11: System parameters for "Hot Spot / Hot Area" scenario (single-hop)

7.6.2.2 Link Budget

The ranges resulting from the assumptions described in section 7.6.2.1 are summarised in Table 7-12 below. The achievable ranges lie between 32 and 367 m.

link data rate [Mbps]	totally available spectrum for deployment			
	20 MHz @ 2.6 GHz	20 MHz @ 5.0 GHz	50 MHz @ 5.0 GHz	100 MHz @ 5.0 GHz
5	367 (-2.6 dB)	209 (-2.6 dB)	247 (-8.3 dB)	262 (-11.9 dB)
10	214 (2.8 dB)	122 (2.8 dB)	162 (-4.0 dB)	184 (-8.3 dB)
20	83 (12.4 dB)	47 (12.4 dB)	105 (0.3 dB)	120 (-4.0 dB)
50	-	-	32	61

[13] Typical BS antennas with ~60° 3dB beamwidth provide gains of ~18dBi. For the omnidirectional cell we assume a gain of 12dBi.

[14] For the sake of simplicity we take gains achievable due to the application of multiple antennas into account by assuming an additional 3dB SNR gain for each doubling of the number of antennas, i.e. we assume correlated signals and uncorrelated noise at the antennas. In fading channels achievable gains may be considerably larger.

[15] Shadow fading margin for 95 percentile coverage is derived by multiplying shadow fading standard deviation σ with 1.64.

link data rate [Mbps]	totally available spectrum for deployment			
	20 MHz @ 2.6 GHz	20 MHz @ 5.0 GHz	50 MHz @ 5.0 GHz	100 MHz @ 5.0 GHz
			(12.4 dB)	(2.8 dB)
100	-	-	-	24 (12.4 dB)

Table 7-12: Achievable DL range in [m] for "Hot Spot / Hot Area" scenario as function of link data rate, bandwidth and carrier frequency (single-hop)

7.6.3 Two-Hop Downlink

7.6.3.1 Description

Like in the single-hop case we assumed according to [WIND54] a Manhattan grid deployment with a block size of 200m x 200 m (cf. UMTS 30.03 [UMTS]) for the two-hop case as well (cf. Figure 7-6). For the basic relaying scenario we consider line-of-sight conditions for the first hop and non-line-of-sight conditions for the second hop. For these two cases we use the B1 LOS and NLOS models respectively [WIND54]. In order to be able to fairly compare the single and two-hop cases further assumptions on bandwidth and data rates are necessary. For this purpose a multi-hop scenario has been defined which is described in detail in section 7.4.2 above. Furthermore, we assume that the link data rate on the BS-UT link in case of single-hop must be the same as the link data rate on the RN-UT link in case of two-hop deployment, for a fair comparison of both scenarios. By this method we assume the same total bandwidth available within the cell or relay enhanced cell (REC), respectively.

parameter	value
channel model	hop 1: B1 LOS [WIND54] hop 2: B1 NLOS [WIND54]
BS Tx power [dBm]	30
RN Tx power [dBm]	30
BS antenna element gain [dBi]	12
BS beamforming gain [dB]	6
RN antenna element gain [dBi]	8
RN Rx beamforming gain [dB]	0
RN Tx beamforming gain [dB]	6
RN receiver noise figure [dB]	5
UT antenna element gain[dBi]	0
UT beamforming gain [dB]	-3
UT receiver noise figure [dB]	9
interference margin [dB] [16]	4 / 0
shadowing margin [dB]	3.8 / 5.1

Table 7-13: System parameters for "Hot Spot / Hot Area" scenario (two-hop)

7.6.3.2 Link Budget

The ranges resulting from the assumptions described in section 7.6.3.1 are summarised in Table 7-14 below. The achievable cell ranges for the BS-UT link lie between 70 and 221 m. For the RN-UT link, ranges lie between 47 and 148 m.

[16] First value corresponds to first and second value to second hop, respectively.

		totally available spectrum for deployment							
		20 MHz @ 2.6 GHz		20 MHz @ 5.0 GHz		50 MHz @ 5.0 GHz		100 MHz @ 5.0 GHz	
link	Link data rate [Mbps]	channel BW [MHz]	range [m]	channel BW [MHz]	range [m]	channel BW [MHz]	range [m]	channel BW [MHz]	range [m]
BS-RN	5	3.125 (20.0 dB)	26,608	3.125 (20.0 dB)	14,955	3.125 (20.0 dB)	14,955	3.125 (20.0 dB)	14,955
BS-UT	5	4.219 (13.5dB)	145	4.219 (13.5 dB)	83	11.719 (1.0 dB)	184	24.219 (-4.0 dB)	221
RN-UT	5	4.219 (13.5dB)	98	4.219 (13.5 dB)	56	11.719 (1.0 dB)	124	24.219 (-4.0 dB)	148
BS-RN	10	-	-	-	-	6.25 (20.0dB)	11,020	6.25 (20.0 dB)	11,020
BS-UT	10	-	-	-	-	10.938 (11.0 dB)	70	23.438 (1.0 dB)	136
RN-UT	10	-	-	-	-	10.938 (11.0 dB)	47	23.438 (1.0 dB)	92
BS-RN	20	-	-	-	-	-	-	-	-
BS-UT	20	-	-	-	-	-	-	-	-
RN-UT	20	-	-	-	-	-	-	-	-
BS-RN	50	-	-	-	-	-	-	-	-
BS-UT	50	-	-	-	-	-	-	-	-
RN-UT	50	-	-	-	-	-	-	-	-
BS-RN	100	-	-	-	-	-	-	-	-
BS-UT	100	-	-	-	-	-	-	-	-
RN-UT	100	-	-	-	-	-	-	-	-

Table 7-14: Achievable DL range in [m] for "Hot Spot / Hot Area" scenario as function of link data rate, bandwidth and carrier frequency (two-hop)

7.6.4 Comparison of Single-Hop and Two-Hop Downlink Maximum Ranges

Table 7-15 and Figure 7-7 compare the effective covered area per cell (in case of single-hop) or REC (in case of two-hop). The effective covered area of a REC is calculated as the sum of the areas covered by the BS and the 3 RNs. This assumes that RECs can be tessellated for contiguous coverage without any overlap, which can be assumed without big errors as long as the ranges the BS – RN and RN – UT are not too different. The effective range as the radius of a circle of the same area is provided for easy comparison. For a hint on the economical viability, the RAP density (RAP/area) is given as well for both deployments (cf. Figure 7-8).

				single-hop			two-hop		
case	link data rate [Mbps]	carrier frequency [GHz]	total BW [MHz]	covered area [km^2]	effective range [m]	RAP/ area [1/km^2]	covered area [km^2]	effective range [m]	RAP/ area [1/km^2]
I	5	2.6	20	0.422	367	2.4	0.156	223	25.7
II	10	2.6	20	0.145	214	6.9	-	-	-
III	20	2.6	20	0.022	83	46.5	-	-	-
IV	50	2.6	20	-	-	-	-	-	-
V	100	2.6	20	-	-	-	-	-	-
VI	5	5.0	20	0.137	209	7.3	0.050	127	79.4

				single-hop			two-hop		
case	link data rate [Mbps]	carrier frequency [GHz]	total BW [MHz]	covered area [km^2]	effective range [m]	RAP/ area [$1/km^2$]	covered area [km^2]	effective range [m]	RAP/ area [$1/km^2$]
VII	10	5.0	20	0.047	122	21.4	-	-	-
VIII	20	5.0	20	0.007	47	143.7	-	-	-
IX	50	5.0	20	-	-	-	-	-	-
X	100	5.0	20	-	-	-	-	-	-
XI	5	5.0	50	0.192	247	5.2	0.250	282	16.0
XII	10	5.0	50	0.082	162	12.2	0.036	108	109.8
XIII	20	5.0	50	0.035	105	28.7	-	-	-
XIV	50	5.0	50	0.003	32	316.6	-	-	-
XV	100	5.0	50	-	-	-	-	-	-
XVI	5	5.0	100	0.216	262	4.6	0.360	339	11.1
XVII	10	5.0	100	0.106	184	9.5	0.137	209	29.1
XVIII	20	5.0	100	0.045	120	22.2	-	-	-
XIX	50	5.0	100	0.012	61	85.6	-	-	-
XX	100	5.0	100	0.002	24	575.5	-	-	-

Table 7-15: Comparison of DL ranges of single-hop and two-hop case in "Hot Spot / Hot Area" scenario

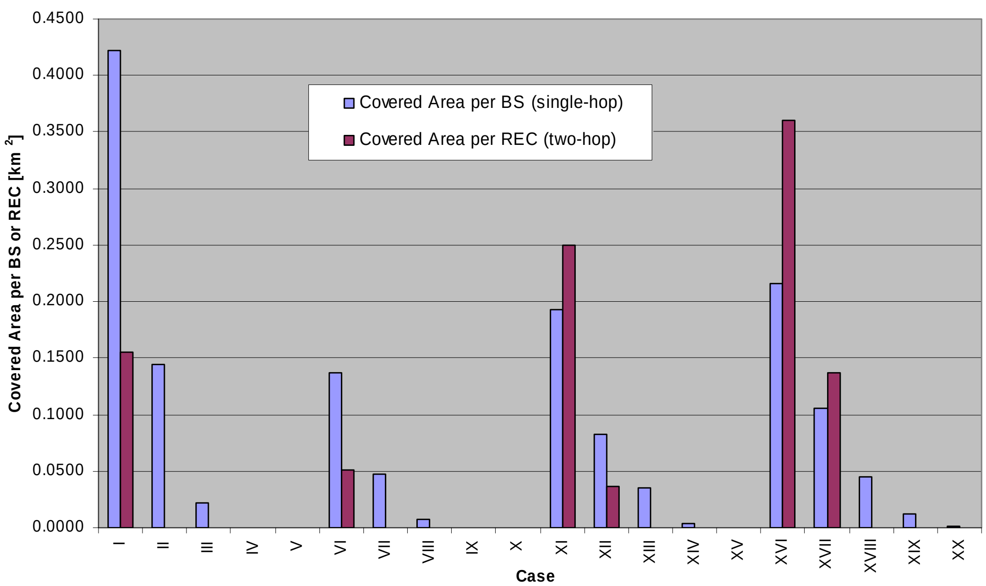

Figure 7-7: Single-hop and two-hop coverage for "Hot Spot / Hot Area" scenario

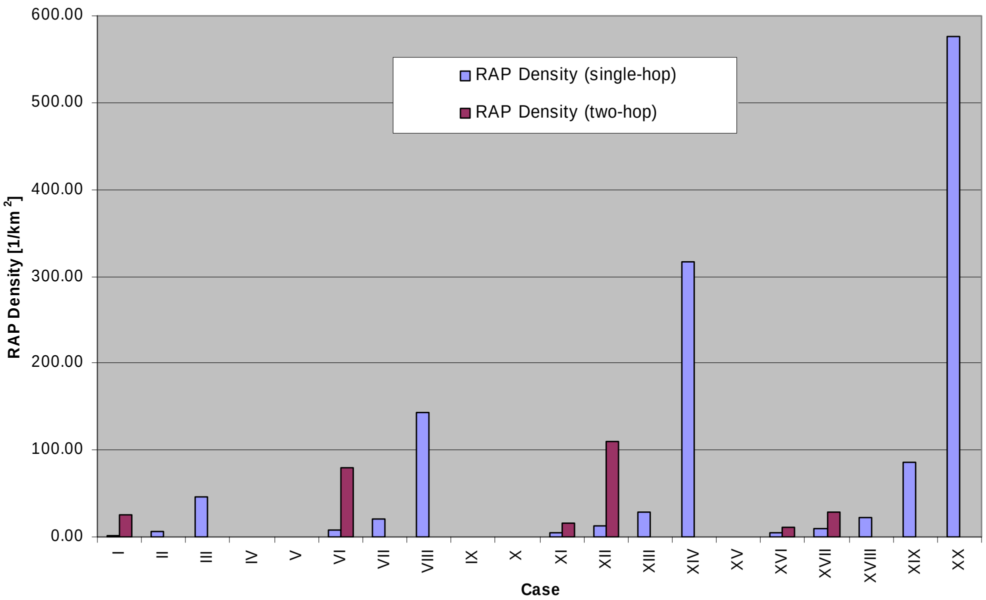

Figure 7-8: Single-hop and two-hop RAP density "Hot Spot / Hot Area" scenario

7.6.4.1 Conclusions

- Single-hop deployment with non-light-of-sight links targeting at the "high end" data rate of 50Mbps according to R3.2, [WIND71] at a high carrier frequency of 5GHz results in small ranges lower than 100m under the given assumptions in this scenario.
- Two-hop deployments according to section 7.4.2 give low coverage gains in cases XI, XVI and XVII (set 1), whereas cases I, VI and XII (set 2) show negative coverage gains in this scenario. The gains come with the price of a higher number of RAPs in all cases. It should be noted although this investigation is based on single – user link budgets and capacity is not in the focus, the multi-hop deployment support four times the number of users with the target data rate.
- With the present assumptions, the range of the multi-hop deployments is determined by the UT – links. The BS-RN hop has a very large link budget margin that in a further developed WINNER concept can be utilised to reduce the BS-RN system bandwidth by employing larger modulation alphabets. This in turn increases the remaining bandwidth for communication with the UTs, and thus reduces the bottleneck effect of the hop to the UT. However, even 256-order modulation would not result in considerable change of the UT link range. This means for effective usage of the relay – link, very high order modulation schemes have to be implemented. Other options, e.g. spatial multiplexing, should be investigated.
- Analysing the differences between the set 1 cases showing coverage gains for multi-hop and set 2 cases showing no gains, set 2 cases are the ones designed for higher link data rates. These require bandwidth efficiencies on the critical BS and RN to UT – links is in the order of 1bit/s/Hz or more, whereas in the set 1 multi-hop cases the required bandwidth efficiency is below 0.5 bit/s/Hz. The increase of the bandwidth efficiency requires a disproportionately higher SNR that reduces the effective common range of the two links below the respective single – hop range. This means in the given scenario with simple bandwidth allocation scheme, multi-hop coverage gains are restricted to cases with low required bandwidth efficiency or relatively low link data rate per available bandwidth. Therefore, WINNER studies on advanced bandwidth allocation schemes that improve the frequency re-use in the relay – enhanced cell and relax the required bandwidth efficiency should be continued.

7.7 C1/C2 – "Metropolitan (sub-urban / urban)"

7.7.1 Considered Carrier Frequencies and Bandwidths

- 900 MHz, 5 MHz BW
- 2.1 GHz, 5 and 10 MHz BW
- 2.6 GHz, 20 MHz BW
- 5 GHz, 20 and 50 MHz BW

7.7.2 Single-Hop Downlink

7.7.2.1 Description

The "Metropolitan" scenario considers contiguous coverage over cities and large towns. BS antennas are considered to be placed above or at rooftop height, e.g. ~20 m. The UT is assumed at 1.6m height. This scenario corresponds to today's dense macro-cellular deployments. BS transmit power levels are assumed accordingly (i.e. 43 dBm). Since BS antennas are located above roof-top level and it is likely that obstacles such as buildings are in the propagation path, NLOS conditions are assumed between BSs and UTs. Outdoor and outdoor-to-indoor cases are distinguished. For the outdoor-to-indoor case an additional wall penetration loss of 20 dB is assumed. As for all other scenarios BSs have 4 antennas. UTs have 2 antennas. The pathloss model used is the C2 "Urban macro-cell" model [WIND54]. Table 7-16 summarises the system parameters used for single-hop deployment.

Parameter	**value**
channel model	C2 NLOS [WIND54]
BS Tx power [dBm]	43
channel estimation degradation [dB]	1
BS antenna element gain [dBi]	12
BS beamforming gain [dB]	6
UT antenna element gain[dBi]	0
UT beamforming gain[dB]	-3
UT receiver noise figure	9
interference margin [dB]	4
shadowing margin [dB]	13.1

Table 7-16: System parameters for "Metropolitan" scenario (single-hop)

7.7.2.2 Link Budget

The ranges resulting from the assumptions described in section 7.7.2.1 are summarised in Table 7-17 below. For pure outdoor propagation the achievable cell ranges lie between 115 and 590 m. In case of outdoor-to-indoor propagation, ranges between 31 and 158 m can be achieved.

link data rate [Mbps]	**totally available spectrum for deployment**					
	5 MHz @ 0.9 GHz	**5 MHz @ 2.1 GHz**	**10 MHz @ 2.1 GHz**	**20 MHz @ 2.6 GHz**	**20 MHz @ 5.0 GHz**	**50 MHz @ 5.0 GHz**
5	590/158 (12.4 dB)	364/98 (12.4 dB)	561/150 (2.8 dB)	573/154 (-2.4 dB)	395/106 (-2.4 dB)	448/120 (-8.3 dB)
10	-	-	298/80 (12.4 dB)	407/109 (2.8 dB)	280/75 (2.8 dB)	337/91 (-4.0 dB)
20	-	-	-	217/58 (12.4 dB)	149/40 (12.4 dB)	254/68 (0.3 dB)

link data rate [Mbps]	totally available spectrum for deployment					
	5 MHz @ 0.9 GHz	5 MHz @ 2.1 GHz	10 MHz @ 2.1 GHz	20 MHz @ 2.6 GHz	20 MHz @ 5.0 GHz	50 MHz @ 5.0 GHz
50	-	-	-	-	-	115/31 (12.4 dB)

Table 7-17: Achievable DL range in [m] for "Metropolitan scenario" as function of link data rate, bandwidth and carrier frequency (single-hop; outdoor / outdoor-to-indoor)

7.7.3 Two-Hop Downlink

7.7.3.1 Description

In case of two-hop deployments within "Metropolitan" propagation environment, we assume the same antenna installation height for BS and RN (i.e. ~20 m). The RN transmit power is assumed to be 30 dBm. As both BS and RN are located at rooftop, LOS propagation is assumed between BS and RN and NLOS between BS / RN and UT. BSs and RNs have 4 antennas. UTs have 2 antennas. All other deployment parameters are as in the single-hop case. Table 7-18 summarises the system parameters used for two-hop deployment.

parameter	value
channel model	hop 1: C1 LOS [WIND54] hop 2: C2 NLOS [WIND54]
BS Tx power [dBm]	43
RN Tx power [dBm]	30
BS antenna element gain [dBi]	12
BS beamforming gain [dB]	6
RN antenna element gain [dBi]	8
RN Rx beamforming gain [dB]	0
RN Tx beamforming gain [dB]	6
RN receiver noise figure [dB]	5
UT antenna element gain[dBi]	0
UT beamforming gain [dB]	-3
UT receiver noise figure	9
interference margin [dB]	4 / 4
shadowing margin [dB][17]	6.6; 9.8 / 13.1

Table 7-18: System parameters for "Metropolitan" scenario (two-hop)

7.7.3.2 Link Budget

The ranges resulting from the assumptions described in section 7.7.3.1 are summarised in Table 7-19 below. For pure outdoor propagation the achievable cell ranges for the BS-UT link lie between 194 and 368 m. In case of outdoor-to-indoor propagation, ranges between 52 and 99 m can be achieved. For the RN-UT link, ranges lie between 63 and 120 m in case of outdoor and 17 to 32 m in case of outdoor-to-indoor propagation.

[17] Values before "/" correspond to 1st, values after "/" correspond to 2nd hop, respectively.

		totally available spectrum for deployment					
		20 MHz @ 2.6 GHz		20 MHz @ 5.0 GHz		50 MHz @ 5.0 GHz	
link	data rate [Mbps]	channel BW [MHz]	range [m]	channel BW [MHz]	range [m]	channel BW [MHz]	range [m]
BS-RN	5	3.125 (20dB)	12,886	3.125 (20dB)	12,110	3.125 (20dB)	12,110
BS-UT	5	4.219 (13.5dB)	314 / 84	4.219 (13.5dB)	216 / 58	11.719 (1dB)	368 / 99
RN-UT	5	4.219 (13.5dB)	103 / 28	4.219 (13.5dB)	71 / 19	11.719 (1dB)	120 / 32
BS-RN	10	-	-	-	-	6.25 (20dB)	10,183
BS-UT	10	-	-	-	-	10.938 (11dB)	194 / 52
RN-UT	10	-	-	-	-	10.938 (11dB)	63 / 17
BS-RN	20	-	-	-	-	-	-
BS-UT	20	-	-	-	-	-	-
RN-UT	20	-	-	-	-	-	-
BS-RN	50	-	-	-	-	-	-
BS-UT	50	-	-	-	-	-	-
RN-UT	50	-	-	-	-	-	-

Table 7-19: Achievable DL range in [m] for "Metropolitan" scenario as function of link data rate, bandwidth and carrier frequency (two-hop; outdoor / outdoor-to-indoor)

7.7.4 Comparison of Single-Hop and Two-Hop Downlink Maximum Ranges

Table 7-20 and Table 7-21 as well as Figure 7-9 and Figure 7-11 compare the effective covered area per cell (in case of single-hop) or REC (in case of two-hop) for indoor and outdoor-to-indoor propagation, respectively. The effective covered area of a REC is calculated as the sum of the areas covered by the BS and the 3 RNs. This assumes that RECs can be tessellated for contiguous coverage without any overlap, which can be assumed without big errors as long as the ranges the BS – RN and RN – UT are not too different. The effective range as the radius of a circle of the same area is provided for easy comparison. For a hint on the economical viability, the RAP density (RAP/area) is given as well for both deployments (cf. Figure 7-10 and Figure 7-12).

				single-hop			two-hop		
Case	Link data rate [Mbps]	carrier frequency [GHz]	total BW [MHz]	covered area [km^2]	Effective range [m]	RAP/ area [$1/km^2$]	covered area [km^2]	effective range [m]	RAP/ area [$1/km^2$]
I	5	0.9	5	1.093	590	0.9	-	-	-
II	10	0.9	5	-	-	-	-	-	-
III	20	0.9	5	-	-	-	-	-	-
IV	50	0.9	5	-	-	-	-	-	-
V	5	2.1	5	0.415	364	2.4	-	-	-
VI	10	2.1	5	-	-	-	-	-	-
VII	20	2.1	5	-	-	-	-	-	-
VIII	50	2.1	5	-	-	-	-	-	-

				single-hop			two-hop		
Case	**Link data rate [Mbps]**	**carrier frequency [GHz]**	**total BW [MHz]**	**covered area [km^2]**	**Effective range [m]**	**RAP/ area [1/km^2]**	**covered area [km^2]**	**effective range [m]**	**RAP/ area [1/km^2]**
IX	5	2.1	10	0.988	561	1.0	-	-	-
X	10	2.1	10	0.279	298	3.6	-	-	-
XI	20	2.1	10	-	-	-	-	-	-
XII	50	2.1	10	-	-	-	-	-	-
XIII	5	2.6	20	1.033	573	1.0	0.410	361	9.8
XIV	10	2.6	20	0.521	407	1.9	-	-	-
XV	20	2.6	20	0.147	217	6.8	-	-	-
XVI	50	2.6	20	-	-	-	-	-	-
XVII	5	5.0	20	0.489	395	2.0	0.194	249	20.6
XVIII	10	5.0	20	0.247	280	4.1	-	-	-
XIX	20	5.0	20	0.070	149	14.3	-	-	-
XX	50	5.0	20	-	-	-	-	-	-
XXI	5	5.0	50	0.630	448	1.6	0.560	422	7.1
XXII	10	5.0	50	0.358	337	2.8	0.156	223	25.6
XXIII	20	5.0	50	0.203	254	4.9	-	-	-
XXIV	50	5.0	50	0.041	115	24.2	-	-	-

Table 7-20: Comparison of DL ranges of single-hop and two-hop case in “Metropolitan” scenario (outdoor)

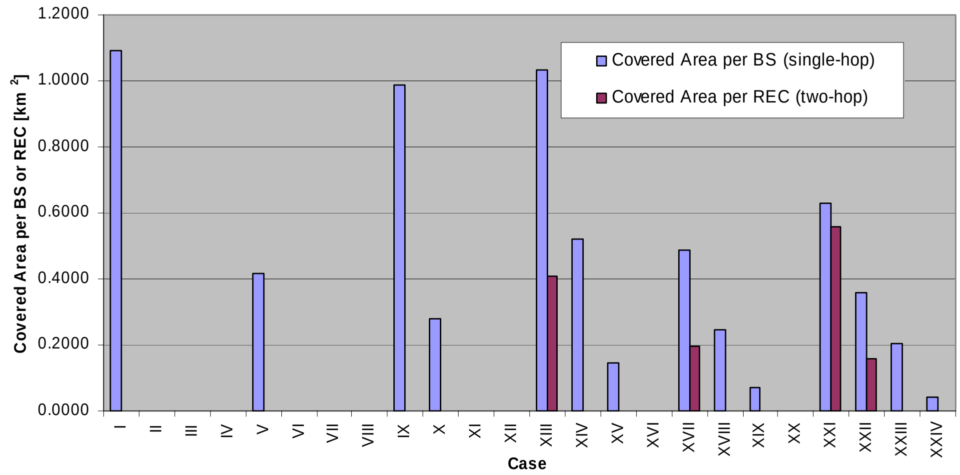

Figure 7-9: Single-hop and two-hop coverage for "Metropolitan" scenario (outdoor)

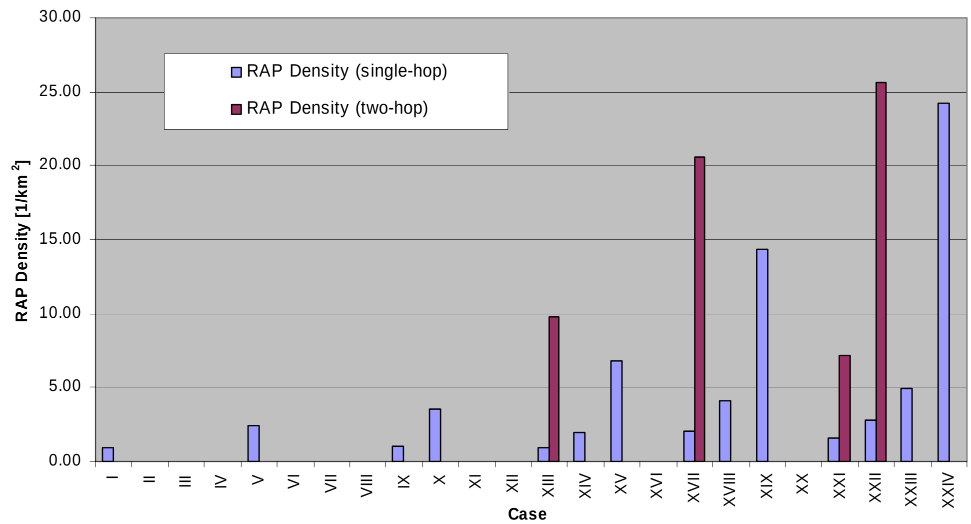

Figure 7-10: Single-hop and two-hop RAP density for "Metropolitan" scenario (outdoor)

				single-hop			two-hop		
Case	**Link data rate [Mbps]**	**carrier frequency [GHz]**	**total BW [MHz]**	**Covered area [km^2]**	**Effective range [m]**	**RAP/ area [1/km^2]**	**covered area [km^2]**	**effective range [m]**	**RAP/ area [1/km^2]**
I	5	0.9	5	0.079	158	12.7	-	-	-
II	10	0.9	5	-	-	-	-	-	-
III	20	0.9	5	-	-	-	-	-	-
IV	50	0.9	5	-	-	-	-	-	-
V	5	2.1	5	0.030	98	33.5	-	-	-
VI	10	2.1	5	-	-	-	-	-	-
VII	20	2.1	5	-	-	-	-	-	-
VIII	50	2.1	5	-	-	-	-	-	-

				single-hop			two-hop		
Case	**Link data rate [Mbps]**	**carrier frequency [GHz]**	**total BW [MHz]**	**Covered area [km^2]**	**Effective range [m]**	**RAP/ area [1/km^2]**	**covered area [km^2]**	**effective range [m]**	**RAP/ area [1/km^2]**
IX	5	2.1	10	0.071	150	14.1	-	-	-
X	10	2.1	10	0.020	80	49.7	-	-	-
XI	20	2.1	10	-	-	-	-	-	-
XII	50	2.1	10	-	-	-	-	-	-
XIII	5	2.6	20	0.074	154	13.5	0.030	97	135.7
XIV	10	2.6	20	0.038	109	26.7	-	-	-
XV	20	2.6	20	0.011	58	94.3	-	-	-
XVI	50	2.6	20	-	-	-	-	-	-
XVII	5	5.0	20	0.035	106	28.4	0.014	67	286.6
XVIII	10	5.0	20	0.018	75	56.3	-	-	-
XIX	20	5.0	20	0.005	40	199.2	-	-	-
XX	50	5.0	20	-	-	-	-	-	-
XXI	5	5.0	50	0.045	120	22.1	0.040	113	99.2
XXII	10	5.0	50	0.026	91	38.9	0.011	60	355.5
XXIII	20	5.0	50	0.015	68	68.4	-	-	-
XXIV	50	5.0	50	0.003	31	336.2	-	-	-

Table 7-21: Comparison of DL ranges of single-hop and two-hop case in “Metropolitan” scenario (outdoor-to-indoor)

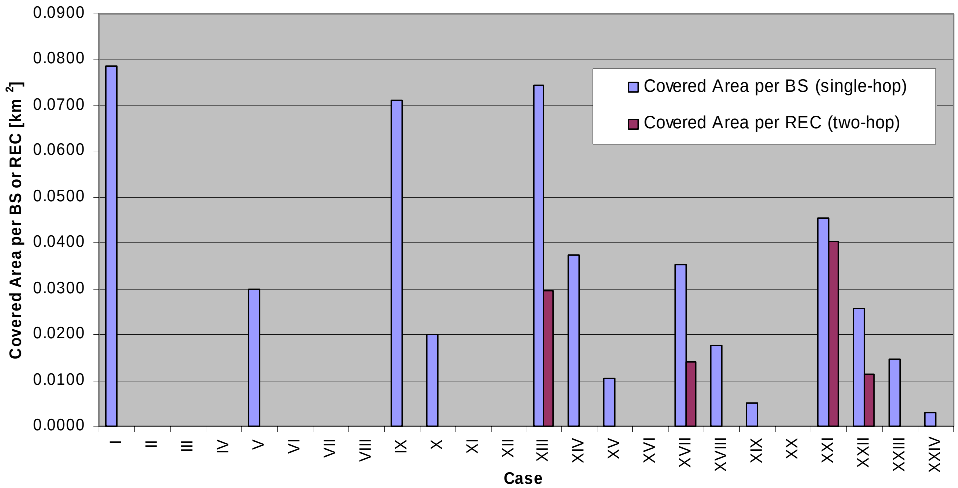

Figure 7-11: Single-hop and two-hop coverage for "Metropolitan" scenario (outdoor-to-indoor)

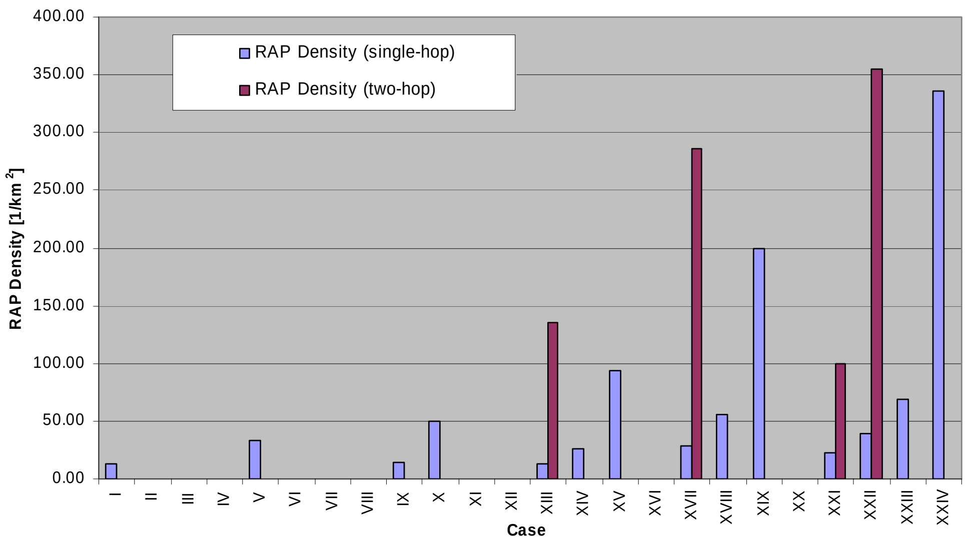

Figure 7-12: Single-hop and two-hop RAP density for "Metropolitan" scenario (outdoor-to-indoor)

7.7.4.1 Conclusions

- Single-hop deployment with non-light-of-sight links targeting at the "high end" data rate of 50Mbps according to R3.2, [WIND71] at a high carrier frequency of 5GHz results in small ranges in the order of 100m without outdoor – to – indoor coverage.
- Single-hop deployment with non-light-of-sight links targeting at the ubiquitous data rate of 5Mbps according to R3.2, [WIND71] at a carrier frequency of 2.6GHz and 20MHz bandwidth results in a range of more than 500m without outdoor – to – indoor coverage. Going to higher carrier frequencies reduces this range considerably (400m at 5GHz). Even increase of the bandwidth to 50MHz does not compensate this reduction.
- With the present assumptions, the range of the multi-hop deployments is determined by the UT – links. The BS-RN hop has a very large link budget margin that in a further developed WINNER concept can be utilised to reduce the BS-RN system bandwidth by employing larger modulation alphabets. This in turn increases the remaining bandwidth for communication with the UTs, and thus reduces the bottleneck effect of the hop to the UT. However, even 256-order modulation would not

result in considerable change of the UT link range. This means for effective usage of the relay – link, very high order modulation schemes have to be implemented. Other options, e.g. spatial multiplexing, should be investigated.

- None of the cases where a comparison was possible showed multi-hop coverage gains. The required bandwidth efficiencies on the critical BS and RN to UT – links limited the effective common range of these two links below the respective single – hop range. With the propagation model used for this scenario, already at a bandwidth efficiency of 0.43 bps/Hz on the UT-links, no coverage has been achieved anymore. Especially for this scenario, advanced frequency re-use schemes are recommended for further study in WINNER in order to extend the range for metropolitan deployments.

7.8 D1 – "Rural"

7.8.1 Considered Carrier Frequencies and Bandwidths

- 450 MHz, 2.5 MHz BW
- 900 MHz, 5 MHz BW
- 2.1 MHz, 5 MHz BW
- 2.1 MHz, 10 MHz BW
- 2.6 GHz, 20 MHz BW

7.8.2 Single-Hop Downlink

7.8.2.1 Description

For single-hop deployment in rural propagation environment, it is assumed that the BS antenna height is ~18 m. The UT is assumed at 1.7m high. NLOS conditions between BS and UT dominate propagation. This scenario corresponds to today's macro-cellular deployments. BS transmit power levels are assumed accordingly (i.e. 43 dBm). Outdoor and outdoor-to-indoor cases are distinguished. For the outdoor-to-indoor case an additional wall penetration loss of 20 dB is assumed. As for all other scenarios discussed in this document BSs have 4 antennas. UTs have 2 antennas. The pathloss model used is the D1 Rural Macro-cell model [WIND54]. Table 7-16 summarises the system parameters used for single-hop deployment.

Parameter	Value
channel model	D1 NLOS [WIND54]
BS Tx power [dBm]	43
channel estimation degradation [dB]	1
BS antenna element gain [dBi]	12
BS beamforming gain [dB]	6
UT antenna element gain [dBi]	0
UT beamforming gain [dB]	-3
UT receiver noise figure	9
interference margin [dB]	4
shadowing margin [dB]	13.1

Table 7-22 System parameters for "Rural" Scenario (single-hop)

7.8.2.2 Link Budget

The ranges resulting from the assumptions described in section 7.8.2.1 are summarised in Table 7-23 below. For pure outdoor propagation the achievable cell ranges lie between 872 and 3527 m. In case of outdoor-to-indoor propagation, ranges between 139 and 563 m can be achieved.

Link data rate [Mbps]	totally available spectrum for deployment				
	2.5 MHz @ 0.45 GHz	5 MHz @ 0.9 GHz	5 MHz @ 2.1 GHz	10 MHz @ 2.1 GHz	20 MHz @ 2.6 GHz
5	-	3527 / 563 (12.4 dB)	1795 / 287 (12.4 dB)	3286 / 525 (2.8 dB)	3389 / 541 (-2.4 dB)
10	-	-	-	1362 / 218 (12.4 dB)	2103 / 336 (2.8 dB)
20	-	-	-	-	872 / 139 (12.4 dB)
50	-	-	-	-	-

Table 7-23: Achievable DL range in [m] for "Rural" scenario as function of link data rate, bandwidth and carrier frequency (single-hop; outdoor / outdoor-to-indoor)

7.8.3 Two-Hop Downlink

7.8.3.1 Description

For the rural case we assume the same antenna installation height for BS and RN (i.e. ~18 m). Consequently, there is LOS propagation between BS and RN, whilst NLOS is assumed between BS and UT, and between RN and UT. The RN transmit power is assumed to be 30 dBm. The pathloss model used is the D1 Rural Macro-cell model [WIND54]. It is assumed that BS and RN have 4 antennas, and UT have 2 antennas. All other deployment parameters are as in the single-hop case. Table 7-24 summarises the system parameters used for two-hop deployment.

parameter	value
channel model	hop 1: D1 LOS [WIND54] hop 2: D1 NLOS [WIND54]
BS Tx power [dBm]	43
RN Tx power [dBm]	30
BS antenna element gain [dBi]	12
BS beamforming gain [dB]	6
RN antenna element gain [dBi]	8
RN Rx beamforming gain [dB]	0
RN Tx beamforming gain [dB]	6
UT antenna element gain[dBi]	0
UT beamforming gain [dB]	-3
interference margin [dB]	4/ 4
shadowing margin [dB][18]	6.6; 9.8 / 13.1

Table 7-24: System parameters for "Rural" scenario (two-hop)

7.8.3.2 Link Budget

The ranges resulting from the assumptions described in section 7.8.3.1 are summarised in Table 7-25 below. For pure outdoor propagation the achievable cell range for the BS-UT link is 870 m. In case of outdoor-to-indoor propagation a maximum range of 139 m can be achieved. For the RN-UT link the ranges 183 m in case of outdoor and 29 m in case of outdoor-to-indoor propagation.

[18] Values before "/" correspond to 1st, values after "/" correspond to 2nd hop, respectively.

		totally available spectrum for deployment									
		2.5 MHz @ 0.45 GHz		5 MHz @ 0.9 GHz		5 MHz @ 2.1 GHz		10 MHz @ 2.1 GHz		20 MHz @ 2.6 GHz	
link	**link data rate [Mbps]**	**channel BW [MHz]**	**range [m]**	**channel BW [MHz]**	**range [m]**	**channel BW [MHz]**	**range [m]**	**channel BW [MHz]**	**range [m]**	**channel BW [MHz]**	**range [m]**
BS-RN	5	-	-	-	-	-	-	-	-	3.125 (20 dB)	29,341
BS-UT	5	-	-	-	-	-	-	-	-	4.21875 (13.5 dB)	1465 / 234
RN-UT	5	-	-	-	-	-	-	-	-	4.21875 (13.5 dB)	308 / 49
BS-RN	10	-	-	-	-	-	-	-	-	-	-
BS-UT	10	-	-	-	-	-	-	-	-	-	-
RN-UT	10	-	-	-	-	-	-	-	-	-	-
BS-RN	20	-	-	-	-	-	-	-	-	-	-
BS-UT	20	-	-	-	-	-	-	-	-	-	-
RN-UT	20	-	-	-	-	-	-	-	-	-	-
BS-RN	50	-	-	-	-	-	-	-	-	-	-
BS-UT	50	-	-	-	-	-	-	-	-	-	-
RN-UT	50	-	-	-	-	-	-	-	-	-	-

Table 7-25: Achievable DL range in [m] for "Rural" scenario as function of link data rate, bandwidth and carrier frequency (two-hop; outdoor / outdoor-to-indoor)

7.8.4 Comparison of Single-Hop and Two-Hop Downlink Maximum Ranges

Table 7-26 and Table 7-27 as well as Figure 7-13 and Figure 7-15 compare the effective covered area per cell (in case of single-hop) or REC (in case of two-hop) for indoor and indoor-to-outdoor propagation, respectively. The effective covered area of a REC is calculated as the sum of the areas covered by the BS and the 3 RNs. This assumes that RECs can be tessellated for contiguous coverage without any overlap, which can be assumed without big errors as long as the ranges the BS – RN and RN – UT are not too different. The effective range as the radius of a circle of the same area is provided for easy comparison. For a hint on the economical viability, the RAP density (RAP/area) is given as well for both deployments (cf. Figure 7-14 and Figure 7-16).

				single-hop			two-hop		
case	**link data rate [Mbps]**	**Carrier frequency [GHz]**	**total bandwidth [MHz]**	**covered area [km^2]**	**effective range [m]**	**RAP/ area [1/km^2]**	**covered area [km^2]**	**effective range [m]**	**RAP/ area [1/km^2]**
I	5	0.45	2.5	-	-	-	-	-	-
II	10	0.45	2.5	-	-	-	-	-	-
III	20	0.45	2.5	-	-	-	-	-	-
IV	50	0.45	2.5	-	-	-	-	-	-
V	5	0.9	5	39.074	3527	0.03	-	-	-
VI	10	0.9	5	-	-	-	-	-	-
VII	20	0.9	5	-	-	-	-	-	-
VIII	50	0.9	5	-	-	-	-	-	-

				single-hop			two-hop		
case	link data rate [Mbps]	Carrier frequency [GHz]	total bandwidth [MHz]	covered area [km^2]	effective range [m]	RAP/ area [1/km^2]	covered area [km^2]	effective range [m]	RAP/ area [1/km^2]
IX	5	2.1	5	10.127	1795	0.10	-	-	-
X	10	2.1	5	-	-	-	-	-	-
XI	20	2.1	5	-	-	-	-	-	-
XII	50	2.1	5	-	-	-	-	-	-
XIII	5	2.1	10	33.927	3286	0.03	-	-	-
XIV	10	2.1	10	5.829	1362	0.17	-	-	-
XV	20	2.1	10	-	-	-	-	-	-
XVI	50	2.1	10	-	-	-	-	-	-
XVII	5	2.6	20	36.075	3389	0.03	7.638	1559	0.52
XVIII	10	2.6	20	13.895	2103	0.07	-	-	-
XIX	20	2.6	20	2.387	872	0.42	-	-	-
XX	50	2.6	20	-	-	-	-	-	-

Table 7-26: Comparison of DL ranges of single-hop and two-hop case in "Rural" scenario (outdoor)

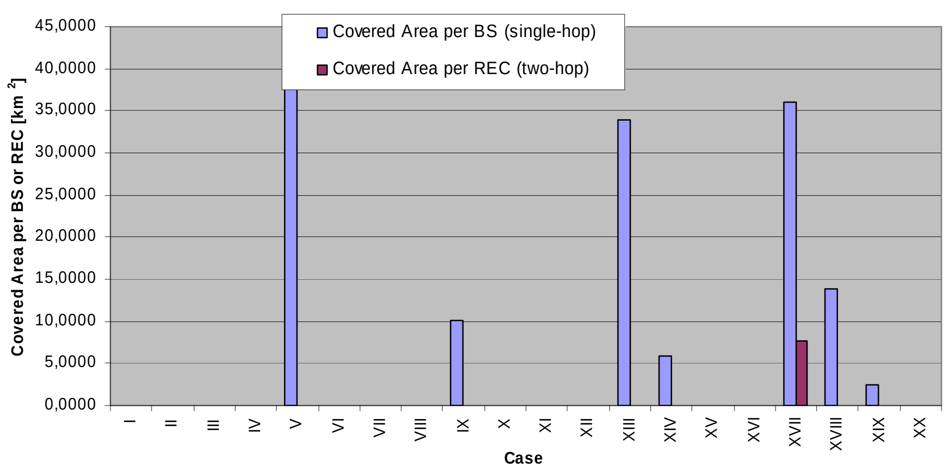

Figure 7-13: Single-hop and two-hop coverage for "Rural" scenario (outdoor)

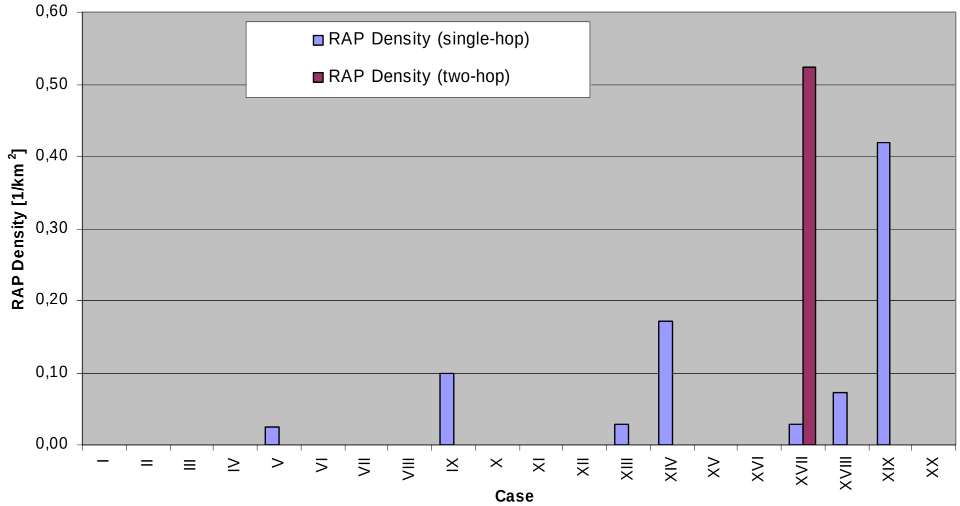

Figure 7-14: Single-hop and two-hop RAP density for "Rural" scenario (outdoor)

				single-hop			two-hop		
case	**link data rate [Mbps]**	**Carrier frequency [GHz]**	**total bandwidth [MHz]**	**covered area [km^2]**	**effective range [m]**	**RAP/ area [1/km^2]**	**covered area [km^2]**	**effective range [m]**	**RAP/ area [1/km^2]**
I	5	0.45	2.5	-	-	-	-	-	-
II	10	0.45	2.5	-	-	-	-	-	-
III	20	0.45	2.5	-	-	-	-	-	-
IV	50	0.45	2.5	-	-	-	-	-	-
V	5	0.9	5	0.996	563	1.0	-	-	-
VI	10	0.9	5	-	-	-	-	-	-
VII	20	0.9	5	-	-	-	-	-	-
VIII	50	0.9	5	-	-	-	-	-	-
IX	5	2.1	5	0.258	287	3.9	-	-	-
X	10	2.1	5	-	-	-	-	-	-
XI	20	2.1	5	-	-	-	-	-	-
XII	50	2.1	5	-	-	-	-	-	-
XIII	5	2.1	10	0.865	525	1.2	-	-	-
XIV	10	2.1	10	0.149	218	6.7	-	-	-
XV	20	2.1	10	-	-	-	-	-	-
XVI	50	2.1	10	-	-	-	-	-	-
XVII	5	2.6	20	0.920	541	1.1	0,195	249	20,55
XVIII	10	2.6	20	0.354	336	2.8	-	-	-
XIX	20	2.6	20	0.061	139	16.4	-	-	-

				single-hop			two-hop		
case	**link data rate [Mbps]**	**Carrier frequency [GHz]**	**total bandwidth [MHz]**	**covered area [km^2]**	**effective range [m]**	**RAP/ area [1/km^2]**	**covered area [km^2]**	**effective range [m]**	**RAP/ area [1/km^2]**
XX	50	2.6	20	-	-	-	-	-	-

Table 7-27: Comparison of DL ranges of single-hop and two-hop case in "Rural" scenario (outdoor-to-indoor)

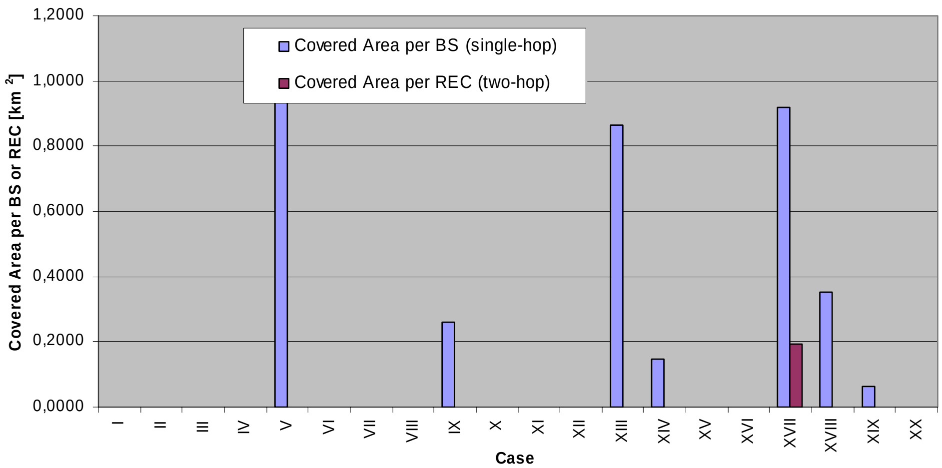

Figure 7-15: Single-hop and two-hop coverage for "Rural" scenario (outdoor-to-indoor)

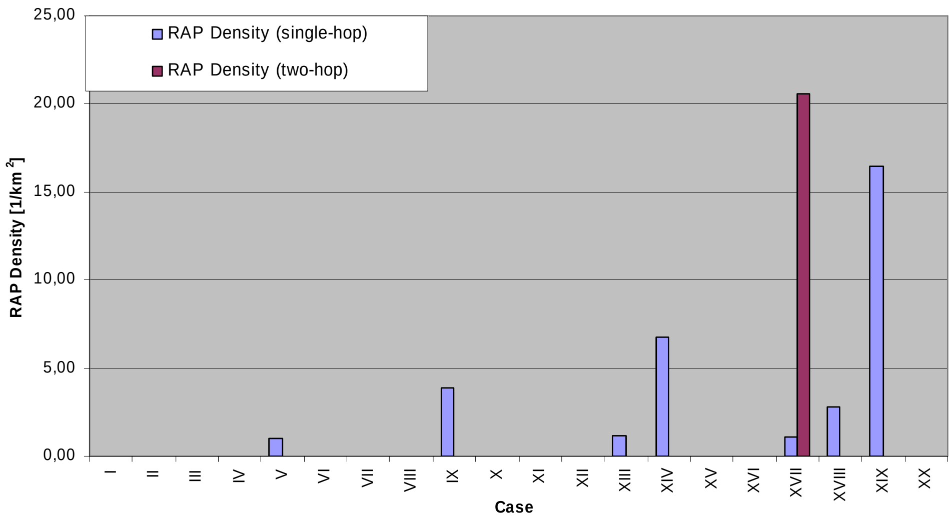

Figure 7-16: Single-hop and two-hop RAP density for "Rural" scenario (outdoor-to-indoor)

7.8.4.1 Conclusions

- Single-hop deployment with non-light-of-sight links targeting at the ubiquitous data rate of 5Mbps according to R3.2, [WIND71] at a carrier frequency of 2.6GHz and 20MHz bandwidth results in a range of more than 3000m without outdoor – to – indoor coverage. For outdoor – to – indoor coverage, the range decreases to less than 600m.
- A multi-hop comparison was only possible for one case because no link level results with the needed modulation order higher than 64QAM were available, but required to transmit the target link data rate to the relay node. However, a relative large band compared to the total BW is required for the first hop and the rest has to be shared by the four BS/RN – UT links, resulting in required bandwidth efficiency on these links of 1.19 bps/Hz, which reduced the effective below the single – hop range.
- The BS-RN hop has a very large link budget margin which could not be reduced by higher spectral efficiency in favour of the UT links. Further studies are recommended that improve the spectral efficiency of the BS-RN – link and the spatial re-use of the bandwidth between the RNs.

7.9 Conclusions

In this section, range calculations based on downlink link budgets have been presented for 4 prioritised WINNER scenarios, using the pathloss models developed by WP5 [WIND54]. The calculations give a first exemplary estimation of achievable cell ranges for high-data rate transmissions at high carrier frequencies using basic technology. They do not represent range figures for WINNER systems, but provide a basis for further evaluations by system level simulations that include advanced technologies. Additionally to conventional single – hop deployments, multi-hop deployments based on a simple radio resource allocation scheme in the relay-enhanced cells have been calculated. It should be noted that the capacity limits of the system of course cannot be accounted for in the link budget approach. One user per cell in the single-hop case and 4 users in the multi-hop case are considered.

Single-hop deployment with non-light-of-sight links targeting at the "high end" data rate of 50Mbps at high carrier frequencies of 5GHz results in small maximum ranges in the order of 100m in any scenario under the given assumptions, not taking outdoor – to – indoor coverage into account. This range can be satisfying for indoor or hot-spot scenarios. For metropolitan coverage, the range seems to be too low for economic deployments. Therefore, range – extending technologies not taken into account in this calculation and/or innovative deployment concepts will be needed for future systems. Lower carrier frequencies would relax the range problem.

Single-hop deployment with non-light-of-sight links targeting at the ubiquitous data rate of 5Mbps according to R3.2, [WIND71] at a carrier frequency of 2.6GHz and 20MHz bandwidth results in a range of about 600m in metropolitan and more than 3000m in rural scenarios without outdoor – to – indoor coverage. For outdoor – to – indoor coverage, the range decreases considerably.

Multi-hop comparison under the given assumptions requires a relative large band compared to the total bandwidth for the first hop due to the limited modulation order of 64QAM. The rest of the bandwidth is shared by the four BS/RN – UT - links. Therefore, the range of the multi-hop deployments is determined by the UT – links. The BS-RN hop has a very large link budget margin that in a further developed WINNER concept can be utilised to reduce the BS-RN system bandwidth by employing larger modulation alphabets. This in turn increases the remaining bandwidth for communication with the UTs, and thus reduces the bottleneck effect of the hop to the UT. However, even 256-order modulation would not result in considerable change of the UT link range. This means for effective usage of the relay – link, very high order modulation schemes have to be implemented. Other options, e.g. spatial multiplexing, should be investigated.

Coverage gains by multi-hop are achieved in cases with relatively high system bandwidth in relation to target link data rate. The bandwidth efficiency on the critical BS/RN to UT – links remains below 0.5bps/Hz in these cases. Higher bandwidth efficiencies require disproportionately higher SNRs that reduce the effective common range of the two links below the respective single – hop range. This means in the given scenario with simple bandwidth allocation scheme, multi-hop coverage gains are restricted to cases with low required bandwidth efficiency or relatively low link data rate per available bandwidth. Therefore, WINNER studies on advanced bandwidth allocation schemes that improve the frequency re-use in the relay – enhanced cell and relax the required bandwidth efficiency should be continued.

These results re-emphasise the need for advanced antenna solutions and interference mitigation techniques within the WINNER system concept.

8. Mode Definition

Modes are used in the project as a synonym for adaptivity of the system to different application scenarios, radio environments, spectrum bands, etc. In [WIND71] the concept of a mode was introduced and defined in the following way (bold added):

“A goal of the WINNER project is to develop one RAT which can be adapted to a wide range of situations and environments, e.g. ranges, mobility, user densities. The adaptation of the RAT might require different parameterisations or use of different algorithms. **Certain combinations of parameter or algorithm assignations or ranges of parameter or algorithm assignations may be referred to as “Modes”**.

However a more detailed understanding and further definition has been required and this chapter describes this developed concept of modes within WINNER. Firstly “external” drivers to modes are reviewed and then “technology” or “internal” drivers. Finally principles on modes which should be followed throughput the project are defined.

8.1 “External” drivers to modes

One of the reasons why modes have been considered early in the WINNER process is recognition that the scope of WINNER is greater than that of any single communication system developed in the past. The amount of flexibility and adaptivity required is considered to be too large to accommodate without some significant change in system parameters.

It is therefore valuable to consider what are the external drivers or constraints which require such adaptivity, and do they create a need for different modes, or can they accommodated purely with flexibility within a mode?

The key question to be applied to each of these possibilities is: does the flexibility/adaptivity required by the driver lead to a fundamental different in the technical solution, whether that is the physical, MAC or RLC layer?

8.1.1 Physical environment / radio environment

It is not clear that physical environment / radio environment alone create a requirement for different modes. Different characteristics that arise (e.g. delay, range of pathloss) need to be considered within the physical layer design but none necessarily require a fundamentally different approach, but instead can be integrated into the physical layer adaptation. The only exception is the duplex scheme, which is further considered in chapter 8.2.1.

8.1.2 Service classes/application requirements

This could be considered as aggregate traffic requirements, or individual service requirements which are treated individually by the flow concept. This might not consider only specific requirements, but also types of applications, which relates closely to (end user) device capabilities/classes.

Two areas need to be considered:

- Impact onto aggregated traffic in combination with desired coverage area then leads into required spectrum. Whether the amount of spectrum drives different modes is a “technology” issue.
- Service requirements will lead to constraints on the scheduler and resource management that are considered in the MAC and RLC development.

8.1.3 (End user) Device capabilities/classes

The types of applications supported by a device, and/or the service/application capabilities of a device, might be a driver for different modes. Other aspects of the device capabilities (e.g. required battery life, form factor) might also be drivers.

Definitely for a system with the scope of WINNER there will be different device classes, with different service and radio capabilities, so it may make sense to have a relationship between modes and device classes (which should be driven from the device classes and service requirements, not from the modes).

However, modes do not necessarily have a one-to-one relationship to device capability classes. It could, for example, be the case that a certain parameter variation leads to different device capability classes but does not result in different modes. For example, the number of transmit and receive antennas in a MIMO transmission scheme could be a criterion for the definition of different device capability classes but a variation of these parameters does not justify an additional mode as long as spatial processing is able to adapt to the number of antennas.

Device capability classes should be defined independently from the modes. However, certain capabilities may be reflected in modes later on, e.g. the supported duplex scheme.

8.1.4 Spectrum issues

8.1.4.1 Paired vs. unpaired spectrum

This links with the choice of duplex discussion from the "technology" differences. Paired spectrum does not obviously place any constraints (we can use FDD or TDD or a combination). Unpaired spectrum would disallow FDD, unless the band was sufficiently wide to allow the use of paired sub-bands from within the band, but this is not typically a preferred use of spectrum.

This need not be a driver necessitating the use of different modes. However, it will influence choice of duplex, which may be considered an internal driver of modes.

8.1.4.2 Licensed vs. license exempt spectrum

See discussion below..

8.1.4.3 Dedicated vs. single system shared vs. "open" shared spectrum

In the WINNER concept, different options for spectrum usage are integrated:

1) Dedicated - spectrum is available for a single deployment of the WINNER based RAN (e.g. similar to current GSM bands)
2) **Single system shared** - spectrum is available for WINNER only, but multiple independent deployments are possible in the same bands (e.g. similar to current DECT bands). The related service in the WINNER systems is referred as “spectrum assignment”.
3) **Horizontal sharing**: The involved systems in the shared frequency band have equal regulatory status, i.e. no system has priority over the other(s) in accessing the spectrum.
    - *Horizontal sharing without coordination*: No signalling is possible between the involved systems, as e.g. nowadays in the 2.4 GHz band for WLAN and Bluetooth. Since QoS cannot be guaranteed for any system, this possibility is not considered in further detail.
    - *Horizontal sharing with coordination*: The involved systems coordinate their spectrum access based on a set of predefined rules (spectrum etiquette) that all systems adhere to. This requires capabilities for signalling or at least detection of the other systems.
4) **Vertical sharing:** In this modality, sharing is performed with clearly established priorities. The primary system has preference in accessing the spectrum and the secondary system(s) may only use the spectrum as long as they do not cause harmful interference towards the primary.
    - *(1)* WINNER is the primary system: WINNER can (but is not obliged to) assist the secondary systems by signalling the free spectrum resources via its broadcast channel. Depending on the expected incentives for the WINNER operators, free spectrum could be actively created.
    - *(2)* WINNER is the secondary system: WINNER has to control its emissions (from the BS and all terminals) in order to avoid interference towards the primary system. This requires considerable knowledge about the deployed primary (legacy) system.

Items 2 – 4 could drive modes, but are seen as integral part of the concept that are not subdivided into different modes.

8.1.5 Business models/ industry structures.

Different types of business models or industry structures could include:

- operator controlled infrastructure
- non-commercial infrastructure/LANs
- ad-hoc deployments
- peer to peer connections

It is not clear at this stage what would or would not be involved here; perhaps it can be simplified into:

- externally managed deployments (e.g. planned deployments by operators)
- self managing deployments (e.g. semi-permanent deployments which are able to self coordinate resources between/across BSs)
- instantaneous/opportunistic/ad-hoc "deployments".

No immediate impact is foreseen but this aspect must be considered with the system concept.

8.2 “Technology” differences between modes

This chapter briefly reviews “technology” differences that may lead to different modes. However it is important that where two (or more) divergent technical solutions are chosen that this is in response to an external constraint or requirement.

8.2.1 Duplex

Current options: half-duplex FDD and TDD.

Definitely requires a different physical layer. The impact on the MAC is seens as low that no separate MACs are required.

Fundamentally only one duplex scheme could be chosen however half-duplex FDD and TDD display desirable characteristics that can be exploited within the WINNER system (full discussion can be found in [WIND25]).

8.2.2 Underlying Modulation

Current options: OFDM, Generalised Multi-Carrier (GMC)

Since GMC is a generalisation of OFDM and it requires only a different parameterisation of PHY and MAC to switch between these two options, separate modes are not required.

8.2.3 Carrier Frequency

Current options: WINNER requirements state that it will operate in new spectrum between 2.7 and 5GHz as well as in existing mobile bands such as 900MHz, 2.1GHz, etc.

Changing the carrier frequency may impact on the PHY since the propagation and Doppler properties of the radio environment will change. That is the channel impulse response length and variability will change which means that different guard interval lengths, pilot patterns, and estimation methods may be needed. However these differences may still be seen as variations that can be handled within a given PHY as part of the PHY adaptivity.

8.2.4 Bandwidth

Range: 2.5MHz to 100MHz

In general terms bandwidth should not effect the mode definition as it can be seen as a constraint to the scheduler by scaling the resource available. However the linear increase in signalling overhead that may be needed in such an approach may motivate the definition of multiple physical layer modes.

8.2.5 Multiple Access

Current dimensions: frequency, time, code and space are all considered.

At present multiple access is treated in a generic manner, where the “chunk-based” scheme allows all dimensions to be treated in the same way by defining scheduling constraints.

8.2.6 Spectrum type

Options: dedicated, shared (single system or “open”)

Different interference suppression techniques may be needed on the physical layer but that can be seen as part of the physical layer adaptivity. Spectrum sharing requires new functions on the MAC and RLC and hence a different “mode” could be defined..

8.2.7 Modulation alphabet range

Range: Q-PSK, 16-QAM, 64-QAM,…

The modulation alphabet range is purely a physical layer parameter.

8.2.8 Multi-antenna technology

Choice of the multi-antenna technology may be seen as part of the link adaptation process.

8.2.9 Relaying

Relaying is seen as an integral part of the WINNER system concept therefore there should be an integrated approach allowing multi-hop and single-hop deployments to be seen as cases of the overall concept.

8.2.10 Functionalities in the MAC and RLC

Thus far the previous chapters have mainly considered physical layer technology choices and any impacts onto the higher layers. No functionalities that reside in, or configurations of, the MAC and RLC have been identified yet that lead to the need for an additional “mode”.

8.3 Conclusions

- A minimum set of modes should be defined in order to meet the WINNER requirements
- The multi-mode protocol reference architecture provides the framework
- A **System Mode** is the combination of a PLM and a MAC.
- A **Physical Layer Mode (PLM)** can be defined where there is a significant impact (discontinuity in adaptation) of PHY functionality on the air interface concept.
    - At the present time only one such functionality leads to different PLMs – duplex. Therefore only 2 PLMs are considered.
    - All other PHY parameters are assumed to be adaptable within the ranges considered in the project (e.g. carrier frequency, bandwidth, multiple access, coding, underlying modulation, modulation alphabet).
- MAC
    - Current thinking is that different MACs are needed for:
        - FDD/TDD "cellular"
        - P2P
    - The RLC and MAC design takes into account horizontal sharing with coordination and vertical sharing.
- Node/device (i.e. BS, RN, UT) capability will take into account both modes (system and PLM) and other adaptive parameters.
- There should be no reference or definition of "wide area" or "short range" modes. If the terms "wide area" and "short range" are used it should be cleared stated as simulation assumptions or system configuration. Similarly there will not be device "classes" of "wide area" or "short range"

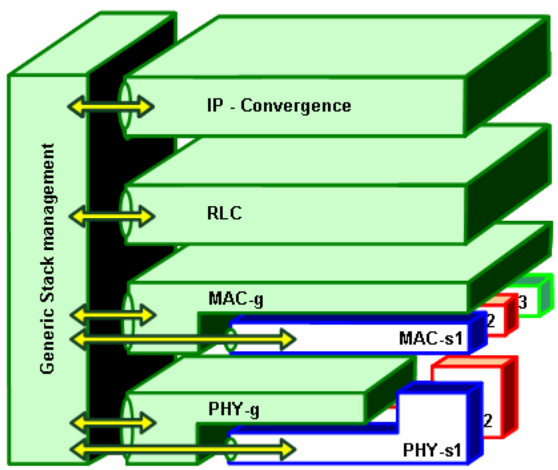

Figure 8-1: Multi-mode-reference model

9. Conclusions

9.1 Integrating WINNER technical results into a system concept

The integration of the various concepts and technologies investigated in the WINNER work packages into one coherent concept is a challenging task that requires a clearly structured approach. The result of the chosen system engineering approach is presented in this document. It is based on a UML2.0 – like notation that structures the concept into services which are grouped in system layers IP – convergence, Radio Link Control, Medium Access Control and Physical Layer. These are subdivided further into user and Control Plane separating clearly control from packet transmission functions in order to allow a scalable implementation. Services are broken down into service components. Their internal behaviour is clearly described by state – machines and linked to external interfaces with service primitives.

The selected novel approach combines a systematic top – down way of analysing and defining a system concept with a clear and unambiguous description constituting a major improvement from conventional, text – only based descriptions. It clearly identifies the role of each functionality in the concept and allows integration of results from the technical work packages in a coherent concept. By that, technical concepts from all WINNER technical work packages, namely WP2, WP3, WP4 and WP6, have been assimilated and are explained in the context of the overall concept.

A basic enabler for clear mutual understanding is an agreed terminology that is consistently used in the whole project. The developed terminology is mandatory for the WINNER project and applied successfully. The main problems solved by each system layers, which motivates the way they are constructed, are summarized below.

9.2 IP Convergence layer

The WINNER RAN has been developed to be a packet based system right from the beginning. For example, there are no radio bearers or long term radio channel allocations, like in traditional cellular systems which have been designed, first and foremost, for circuit-switched voice traffic. In the WINNER concept, radio resources are allocated dynamically whenever there are packets to be transmitted. Instead of a radio bearer, WINNER utilizes the concept of a flow that is internal to the RAN (i.e. it is not assumed that the flow would be established above the WINNER RAN). The User Plane of the top system layer (IP Convergence Layer) receives IP packets from the user of the WINNER RAN, maps them into flows and performs header compression and decompression. Flows of one user are treated independently, allowing individual transmission according to their specific quality-of-service requirements. This capability ensures that all packets travelling through the WINNER RAN are treated effectively and consistently regardless of where or how they originate. The IPC Control Plane is responsible for RAN association functions as well as for macro-mobility (IP level mobility).

9.3 Radio Link Control layer

Even though packet transfer is an efficient method for sharing communication resources among multiple users, there are consequences that need to be taken into account in the system concept. Scheduling functions, re-transmission protocols and (dynamic) routing schemes are examples of functionalities that change the packet transmission and reception order. Similarly, re-transmission ambiguities, signalling errors, and unreliable feedback channels results in spurious re-transmissions and residual errors. Out-of-order delivery, duplicates, and lost packets are therefore typical error events that occur in this type of communication systems. The solution to that is the RLC User Plane service *Reliable Packet Transfer* that provides reliable packet transfer over the air-interface. It also performs confidentiality protection and packet prioritisation in order to meet the QoS goals. Unlike the existing technologies, the RLC User Plane provides only one single packet transfer service towards the upper layer. In that way, the details of the layer are not visible to the upper layer.

The RLC User Plane is also responsible for maintaining the QoS of the different flows in the RAN. It monitors, conditions and schedules the flows by the service level controller. The traffic of each flow is conditioned to ensure that it complies with the corresponding profile definition; in particular the defined maximum traffic rate. This can be achieved through delaying (shaping) or dropping (policing) packets.

The basic hypothesis for the scheduling architecture is that scheduling is partitioned into two levels, namely flow scheduling (residing at the RLC layer) and resource scheduling (residing in at the MAC layer). Flow scheduling may be considered as management between flows and determines the order in which PDUs will be forwarded to the MAC layer and works on a time scale characterised by the packet arrival rates. The scheduler takes inter-flow fairness, service class profiles as well as moving average statistics about the SLC cache contents.

The RLC Control Plane takes care of flow establishment and release, location services, load, spectrum and micro-mobility control. One of the WINNER RLC Control Plane advantages is that it handles the handover process per flow rather than per UT. Therefore, a UT might send/receive traffic over different cells and routes that match best the requirements of the specific flow. Additionally, it includes functionalities for coordinated spectrum sharing with other radio access networks using the same radio access technology as well as for spectrum sharing with other radio access technologies. Finally, unlike in existing systems, admission control is not responsible for only admitting a new, or handover flow to a new cell but selecting the best cell among a group of candidate cells that are nominated by the micro mobility functionality.

With respect to inter-system aspects, the importance of providing a Cooperative RRM (CRRM) functionality has been highlighted. It is very likely that a WINNER system will not just co-exist with legacy Radio Access Networks (RANs) but will rather inter-work with them. Therefore, a specific RRM entity is included within the WINNER concept that provides the cooperation interface with the CRRM entity outside of WINNER, but developed by WP4. Medium access control

9.4 Medium Access Control layer

The MAC User Plane provides the service *Radio Packet Transfer,* i.e. transmission and reception over the radio interface of packets. An important part of this service is the scheduling of packets over the radio interface. The Control Plane provides the *MAC Radio Resource Control* service, i.e. acceptance and execution of control messages from higher layers that specify required transmission parameters and boundary conditions. Furthermore, it implements *MAC Control Feedback*, i.e. messaging that supports the flow control, the QoS control and the spectrum assignment and other functions at the RLC layer.

The MAC is designed to work in Relay-Enhanced Cells. A set of relay nodes may be directly connected to the base station and share the spectral resources with it. Each relay node is connected to one but not more base stations. Some or all user terminals may communicate directly with the base station. If relay nodes are present, some user terminals may transmit to/receive from these relays. The MAC implemented in each relay node controls those transmissions. Thus, the RNs essentially control separate sub-cells. A complete MAC layer is assumed to be implemented at each base station and also at each relay node.

The MAC layer enables the effective usage of the radio spectrum by adapting the transmission as best as possible to the actual radio propagation conditions and user requirements. Adaptive transmission is integrated into the design, on all time-scales. Up to moderate vehicular velocities, link adaptation and scheduling can be performed with fine granularity in the frequency domain (OFDMA/TDMA). This enables multi-user scheduling gains to be obtained. For higher velocities, the transmission adapts to the shadow fading. On a superframe time-scale, the resource partitioning can adapt to the traffic demand over different transport channels. The MAC enables fast transmission and very low re-transmission delays over the radio interface. These properties are the key to attaining high spectral efficiency via adaptive schemes and reliable communication through efficient re-transmission.

The MAC layer is designed for efficient support of multi-antenna transmission from the beginning. The multi-antenna processing can be adjusted in a very flexible way per flow, to obtain an appropriate balance between obtaining multiplexing gains to boost throughput, achieving robustness via diversity transmission, and obtaining SDMA gains by transmitting different flows over different spatial channels.

Additional features supported by the MAC include self-organized synchronisation of all involved base stations, relay nodes and user-terminals, and operation in spectrum shared with other operators who use the same physical layer WINNER mode. Operation in dedicated bands is seen as a special case of this situation.

9.5 Physical layer

The PHY layer handles the physical transmission of chunks and measurements and control signalling directly related to the radio interface. The PHY layer is not separated into User Plane and Control Plane since it is assumed that all control functionality for the PHY layer resided within the Control Plane of the MAC layer. It offers different transfer services for adaptive and non-frequency–adaptive transmission, direct transmission between user terminals, random access and control transmission. Towards higher layers, it reports measurements from user terminals required by the MAC and the RLC layers.

The PHY layer transmission chain implements OFDM transmission in the downlink and GMC in the uplink which includes OFDM transmission and frequency-domain generated serial modulation as special cases. The basic time-frequency resource unit of the PHY is denoted a chunk. It consists of a rectangular time-frequency area that comprises a number of subsequent OFDM symbols and a number of adjacent subcarriers. The chunk durations and frame durations are short, which is a basic requirement for a low transmission delay over the air interface. Channel prediction is used to expand the possibility for using adaptive transmission to include vehicular users. Efficient means have been developed for compressing the channel quality information feedback required for adaptive transmission and the channel state information required for some multi-antenna schemes. These methods reduce the required feedback overhead to reasonable levels. The non-frequency adaptive transfer maps flows onto sets of chunk layers that should provide large channel diversity. These chunks should also be well dispersed over the available spectrum to maximize the available diversity. To jointly provide the maximum diversity, chunk allocations for adaptive and non-frequency adaptive transfer should be mixed in the frequency domain, rather than being given separate contiguous sub-bands.

The WINNER multi-antenna concept is a generic architecture that aims at performing multi-user spatial domain link adaptation, based on the following basic components: (linear) dispersion codes, directive transmission (beamforming), per stream rate control, and multi-user precoding. This architecture allows fostering the spatial processing gains introduced above in flexible combinations as required by different scenarios, i.e. different combinations of physical layer mode, link direction, transport channel type, deployment, propagation conditions, cell load, traffic type, BS antenna configuration, and terminal capabilities. It therefore embeds different spatial processing algorithms into a common framework.

9.6 Logical Node Architecture, Modes and Reference Protocol Architecture

The architectural view of the system concept is presented in the logical node architecture. The services are grouped to logical nodes between which there may be a need for defining open interfaces. In particular, the logical node architecture needs to support all envisioned deployment scenarios for WINNER (as well as not yet foreseen deployment scenarios) without introducing too many logical nodes and/or interfaces.

The WINNER radio interface is assumed to operate in different modes to serve different environments, e.g. rural or urban scenario, or usage scenarios in an optimal way, which means that the scope of WINNER is greater than that of any single communication system developed in the past. The amount of flexibility and adaptivity required is considered to be too large to be accommodated without some significant change in system parameters; otherwise the system performance may be compromised in some area. Therefore, the "modes concept" has been developed, defining a set of physical layer and system modes. To support the modes, a "Reference Protocol Architecture" has been developed to provide means to generalize the radio interface to the higher layers and to allow a smooth interworking between the different modes.

9.7 Reference Physical Deployment Characteristics

Range calculations based on downlink link budgets and pathloss models developed by WP5 are presented for 4 prioritised WINNER scenarios that give a first exemplary estimation of achievable cell ranges for high-data rate transmissions at high carrier frequencies using basic technology. They do not represent range figures for WINNER systems, but provide a basis for further evaluations by system level simulations that include advanced technologies. Additionally to conventional single – hop deployments, multi-hop deployments based on a simple radio resource allocation scheme in the relay-enhanced cells have been calculated.

Single-hop deployment with non-light-of-sight links targeting at the "high end" data rate of 50Mbps at high carrier frequencies of 5GHz results in small maximum ranges in the order of 100m under the given assumptions. These results re-emphasise the need for advanced antenna solutions and interference mitigation techniques within the WINNER system concept. Lower carrier frequencies would relax the range problem. The calculated ranges for a targeted ubiquitous data rate of 5Mbps according to R3.2, [WIND71] are from about 600m in metropolitan and more than 3000m in rural scenarios without outdoor – to – indoor coverage. For outdoor – to – indoor coverage, the range decreases considerably.

Multi-hop comparison under the given assumptions requires a relative large band compared to the total bandwidth for the first hop due to the limited modulation order of 64QAM. The rest of the bandwidth is shared by the four BS/RN – UT - links. Therefore, the range of the multi-hop deployments is determined by the UT – links. The BS-RN hop has a very large link budget margin that in a further developed WINNER concept can be utilised to reduce the BS-RN system bandwidth by employing larger modulation alphabets. This in turn increases the remaining bandwidth for communication with the UTs, and thus reduces the bottleneck effect of the hop to the UT. However, even 256-order modulation would not result in considerable change of the UT link range. This means for effective usage of the relay – link, very high order modulation schemes have to be implemented. Other options, e.g. spatial multiplexing, should be investigated.

Coverage gains by multi-hop are achieved in cases with relatively high system bandwidth in relation to target link data rate. Higher bandwidth efficiencies require disproportionately higher SNRs that reduce the effective common range below the respective single – hop range. This means in the given scenario with simple bandwidth allocation scheme, multi-hop coverage gains are restricted to cases with low required bandwidth efficiency or relatively low link data rate per available bandwidth. Therefore, WINNER studies on advanced bandwidth allocation schemes that improve the frequency re-use in the relay – enhanced cell and relax the required bandwidth efficiency should be continued.

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