# WINNER MAC for Cellular Transmission

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***Abstract*— This paper summarizes recent work towards an advanced cellular packet data system using a multicarrier-based beyond 3G air interface, developed within the European IST research project WINNER I. The resulting air interface concept has a medium access control (MAC) system layer that performs resource allocation and packet scheduling within relay-enhanced cells. It also performs flexible allocation of antenna resources on a per-flow basis and provides support for flexible spectrum use. The present paper focuses on the resource allocation problems and outlines the time-frequency-spatial resource units and control function blocks designed to solve them.**

***Index Terms*—WINNER, Medium Access Control, mobile wireless systems, radio resource control, OFDM.**

## I. Introduction

The European research project WINNER is a cooperation of 39 partners from industry, operators, and academia, which is partly funded by the European Union. It has the overall goal to develop a single radio interface covering the full range from isolated hot spots to wide area cellular scenarios by using different modes of a common technology [1]. It targets increased data rates, low latency, and high system capacity based on adaptive transmission schemes, flexible spectrum usage, relaying, and advanced multi-antenna processing. The WINNER I project (2004-2005) evaluated technologies and combined them into a system concept. It forms the basis for the WINNER II project (2006-2007), which aims at the design and detailed assessment of a beyond 3G system proposal.

The WINNER radio interface design is aimed at attaining *both* high flexibility in terms of spectrum use and fulfillment of user requirements *and* a high spectral efficiency in different deployment and usage scenarios; two goals that are often contradictory and difficult to combine.

The medium access control (MAC) system layer plays an important role for fulfilling these goals. It performs tasks that in existing systems are associated with Logical Link Control, Medium Access Control and Radio Resource Control protocol (sub)layers. The present paper focuses on the resource allocation problems that are to be solved and outlines the time-frequency-spatial resource units and control function blocks designed to solve them. Detailed protocol aspects of the MAC system layer are not discussed here, and are at present being developed within WINNER II.

The conceptual design of the MAC system layer has focused on enabling the following novel features:

- Operation in spectrum shared with other operators who all use the WINNER radio interface [6] is an integral feature of the design. Spectrum sharing with e.g. fixed microwave links or satellite systems is supported to enable coexistence within frequency bands allocated for these uses.

- The resource partitioning is designed to work efficiently in conjunction with inter-cell interference-avoidance schemes. It is designed for relay-enhanced cells (RECs), so that base stations (BSs) and a set of OSI layer two relay nodes (RNs) can share the spectral resources efficiently.

- A super-frame is designed with pilots that support self-organised synchronisation of all involved base stations, relay nodes and user-terminals. Ensuring a synchronised network enables an improved spectral efficiency in two ways: it makes large guard-bands unnecessary and it simplifies interference-avoidance scheduling between cells and relay nodes.

- Low transmission latency and very low retransmission delays over the radio interface (around 2 ms) are supported [4]. These properties are keys to attaining high spectral efficiency via adaptive schemes, reliable communication through efficient re-transmission and high data rates for TCP/IP traffic.

- Adaptive transmission is integrated into the design, on all time scales. Up to moderate vehicular velocities, link adaptation and scheduling is performed with fine granularity in the frequency domain (TDMA/OFDMA) [3,10]. This provides multi-user scheduling gains for mobile as well as stationary terminals. For higher velocities, the transmission only adapts to the path loss and shadow fading. On slower time scales, the resource partitioning adapts to the traffic demand.

- Multi-antenna transmission can be adjusted in a very flexible way per user data flow, to obtain an appropriate balance between different objectives: Obtaining multiplexing gains to boost throughput, achieving robustness via diversity transmission, and obtaining SDMA gains by transmitting flows to different user terminals over different spatial channels [8,9].

Section II below summarizes the WINNER I system concept and Section III outlines some aspects of the physical layer. Section IV then introduces the MAC system layer as described by WINNER deliverables D2.10 [4] and D7.6 [7].

## II. SYSTEM LAYERS, MODES AND PARAMETERIZATIONS

There are four system layers in the WINNER I concept [7]. These layers are further divided into *user plane* and *control plane*. Services that need to operate directly on individual packets are located in the user plane.

### A. The system layers

**IP convergence (IPC)**

The WINNER RAN is designed for packet data traffic. The user plane 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 control plane is responsible for RAN association as well as IP level mobility.

**Radio link control (RLC)**

The user plane of the RLC system layer provides reliable packet transfer over the radio interface. It also performs confidentiality protection and packet prioritisation in order to meet the quality-of-service (QoS) goals. The control plane takes care of flow establishment and release, location services, load, spectrum, and micro-mobility control.

**Medium access control (MAC)**

There is a tight inter-layer interaction between MAC and physical layers and this is crucial for the performance of the WINNER system. Some functions, such as encoding and decoding, that are traditionally placed in the physical layer are in the WINNER system concept placed in the MAC layer. The MAC system layer will be described in Section IV below.

**Physical (PHY)**

The PHY system layer handles the physical transmission of flows and of measurements and control signalling directly related to the radio interface. The PHY system layer is not separated into user plane and control plane since it is assumed that all control functionality for the PHY layer resides within the MAC system layer.

### B. Modes and flexible parameterizations

A basic goal is that the WINNER radio interface should present a unified set of services to higher layers, yet include some specific parts that provide the required flexibility. To provide flexibility and convergence in a structured way, the definition of *modes* is helpful. A *system mode* represents a specific combination of *physical layer modes (PLM)* and *MAC modes*, described below. All IPC and RLC functions are designed to be mode-independent (generic) and form the unified interface of the WINNER system.

A physical layer mode can be defined where there is a significant impact (discontinuity in adaptation) of PHY functionality. Two PLMs have been defined:

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

. There are three MAC modes within the WINNER I concept:

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

The two MACs for cellular transmission are largely similar and are introduced in this paper. The peer-to-peer MAC is described in the companion paper [11] and in [4].

The combinations of PHY and MAC modes thus define three system modes: *FDD cellular*, *TDD cellular* and *Peer-to-peer*.

Parameterisations within modes provide further flexibility and adaptability. Both PLMs use generalised multi-carrier (GMC) transmission, which includes cyclic prefix-OFDM and serial modulation as special cases [2], [4]. Multiple access is realised in frequency, time, space, and in particular cases also in the code domain [4].

The basic time-frequency unit for resource partitioning is denoted a *chunk*. It consists of a rectangular time-frequency area, see Fig.1a), that contains payload symbols and pilot symbols. The channel variations should be rather small within chunks so that the same link adaptation parameters can be used. Use of multiple antennas is an integral part of the WINNER RI design. The time-frequency resource defined by the chunk may be reused by spatial multiplexing. A *chunk layer* represents the spatial dimension (Fig. 1b).

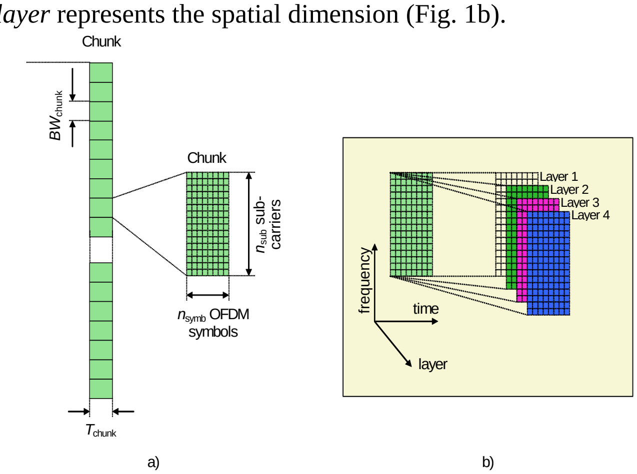


Fig. 1. : a) Physical channel structure and chunks in multicarrier channel. b) Chunk layers obtained by spatial reuse.

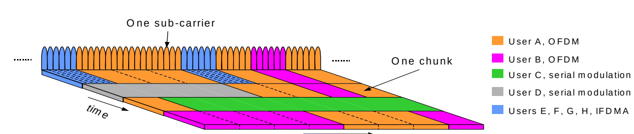


Fig. 2. : Use of different GMC variants by different uplink users.

The chunks and chunk layers are pre-assigned to different classes of data flows, on a super-frame time scale (Section IV below). They are then used in a flexible way to optimise the transmission performance. For example, the available antenna resources can be used differently for different flows to/from user terminals.

## III. THE PHYSICAL LAYER

The WINNER physical layer is based on multicarrier transmission. This simplifies a flexible use of spectral resources. After considering different alternatives, standard cyclic prefix OFDM (CP-OFDM) has been selected whenever terminal power consumption is not a critical constraint. For power-constrained uplinks, the baseline scheme is to use a serial modulation waveform, with low peak-to-average power ratio, in the allocated chunks, as illustrated by Fig. 2. This scheme (DFT-precoded CP-OFDM) is obtained by applying an extra DFT at the transmitter and at the receiver [2].

During the later part of WINNER I, two particular example designs, a 2x20 MHz FDD scheme and TDD transmission over a 100 MHz unpaired band, were used for assessment by simulation [4]. Table 1 below illustrates the corresponding radio parameters. The WINNER system will also be required to support several other configurations (parameter sets).

**Table 1: Basic transmission parameters for simulation**

| Parameter | FDD mode | TDD mode |
|---|---|---|
| Centre frequency (GHz) | 5.0 DL/4.2 UL | 5.0 |
| Duplexing method | FDD (paired) | TDD |
| FFT bandwidth (MHz) | 20.0 | 100.0 |
| Number of subcarriers in GMC | 512 | 2048 |
| Subcarrier spacing (Hz) | 39062 | 48828 |
| Symbol duration (excl. cycl prefix) (µs) | 25.60 | 20.48 |
| Cyclic prefix (µs) | 3.20 | 1.28 |
| Number of subcarriers in use | 416 | 1664 |
| Signal bandwidth (MHz) | 16.25 | 81.25 |
| Chunk size (subcarriers x symbols) | 8 x 12 = 96 | 16 x 5 = 80 |

## IV. THE MAC SYSTEM LAYER

### A. *The MAC services and tasks*

The MAC system layer for FDD or TDD cellular transmission has a set of MAC protocols implemented in its user plane. It also contains resource allocation and planning functions in its control plane. It provides the following services to the RLC system layer:

- ***Radio packet transfer***, i.e. transmission and reception over the radio interface of packets belonging to the transport channels defined below,
- ***MAC radio-resource control***,
- ***MAC control feedback***.

The WINNER *transport channels* define the basic types of radio-packet transfer that are provided:

- 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**), used for initial access to a base station (BS) or relay node (RN), and also for BS-to-BS control signaling in the TDD mode,
- 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,
- Targeted control channel (**TCC**) for control-plane generated control messages.

### B. *Control of relay-enhanced cells*

The MAC system layer is designed to work in *relay-enhanced cells* (REC), where a set of nodes (RNs or BS) are linked to each other over the air [12]. The BSs, but not the RNs, have a fixed backbone connection. The RNs may be used for improving the coverage within the cell or for extending the range of the cell [5]. Each RN is connected to one but not more BSs. The RNs essentially control separate sub-cells. The MAC system layer is implemented at each BS and each RN and it controls flows over a single hop. Flow QoS control over links spanning multiple hops is handled by the RLC layer.

The cellular MAC design has so far mainly focused on the case of homogenous relaying, where RNs and BS use the same PLM and thus have to share the spectral resources. The total time-frequency resources are then partitioned into parts used by the BS, shared parts, and parts used by RNs. This partitioning is computed at a central location in cooperation with the MAC that is implemented at the BS. It is then signalled to all RNs and user terminals [4,5,13].

### C. *The chunk, slot, frame and super-frame structure*

As outlined in Section II B, the basic time-frequency unit for resource allocation is the chunk. In the FDD physical layer mode described in Table 1, chunks comprise 8 subcarriers by 12 OFDM symbols or 312.5 kHz × 345.6 µs. In the TDD physical layer mode, mainly evaluated in short-range scenarios, the chunk dimension is 16 subcarriers by 5 OFDM symbols, or 781.25 kHz × 108.0 µs.

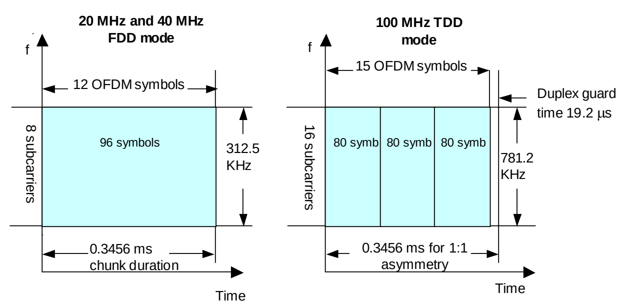


Fig. 3. : Summary of assumed chunk sizes in the two physical layer modes. A slot (half of the frame) is shown in each case, assuming 1:1 TDD asymmetry.

The chunks are organised into *frames*. In the TDD mode, each frame consists of a downlink transmission interval followed by an uplink transmission interval, denoted *slots*, or *time-slots*. In FDD, the frame is also split into two slots. Half-duplex terminals may be separated into two groups, where one group has downlink transmission in the first slot and transmits in uplinks in the other, while the other group uses the opposite scheme. FDD base stations use full duplex and full duplex terminals are also supported

The frame duration has been set equal in the two PLMs, to facilitate inter-mode cooperation. With a frame duration of

691.2 μs, an FDD frame consists of two chunk durations, with one chunk per slot. A TDD frame consists of in total 6 chunks and two duplex guard intervals, organised into a downlink slot and an uplink slot. With downlink-uplink asymmetry 1:1, the TDD slot thus consists of three downlink chunks followed by three uplink chunks, see Fig. 3.

The *super-frame* (SF) is a time-frequency unit that contains pre-specified resources for all transport channels. Fig. 4 illustrates its preliminary design, comprising of a *preamble* followed by $n_f$ frames. In the example, $n_f$ = 8, resulting in super-frames of duration 5.6 ms.

The super-frame is synchronous in all BS and RN. In the FDD mode, a separate super-frame is required in each of the paired bands. It is assumed that there exist some frequency bands allocated to WINNER that are available everywhere. The super-frame preamble is transmitted in such a commonly available frequency band. It has the following structure:

- It contains two synchronisation slots. Self-organising synchronisation of terminals and network nodes, as described in [2] can be used on a super-frame basis by this design.
- In-between the synchronisation slots, a short timeslot over the whole band is reserved for the contention-based random access channel (RAC), plus a guard time.
- Subsequently, a set of OFDM symbols contains the broadcast control channel (BCH) messages from the RLC layer. It also contains a control message that specifies the overall resource allocation used within this super-frame.

The remaining $n_f$ frames may use the commonly available frequency band and may also use other bands that are available at some locations, or to some operators, but not to others. All bands are spanned by one FFT at the receiver and are at present assumed to span at most 100 MHz. This part of the super-frame is shared by the contention-based direct access channel (DAC), the scheduled data channels CDC and TDC, and their related control signaling. The DAC resource is used both for the DAC channel and for peer-to-peer transmission [11]. It is organised as a constant set of frequencies over the whole super-frame, to enable the use of carrier-sense multiple access contention based transmission.

MAC flow control and resource allocation is performed on two time scales: That of the slot and that of the super-frame:

- Time-frequency *resource partitioning* and *spatial scheme control* is planned on a time scale of the super-frame (5–10 ms): The allocation to different transport channels is adjusted on this time scale, based on the aggregated demand within each transport channel. Specification of unused chunks enables flexible spectrum use between WINNER operators/users [6] and adaptive interference avoidance between cells and parts of cells.
- *Resource scheduling* (RS) is performed on the time scale of the slot (0.34 ms): Scheduled flows are allocated to time-frequency-spatial resources in one of two ways: *Adaptive* RS adapts to the frequency-selective fading. This requires fast processing of PHY layer feedback. *Non-frequency adaptive* RS uses diversity-based transmission within the frame.

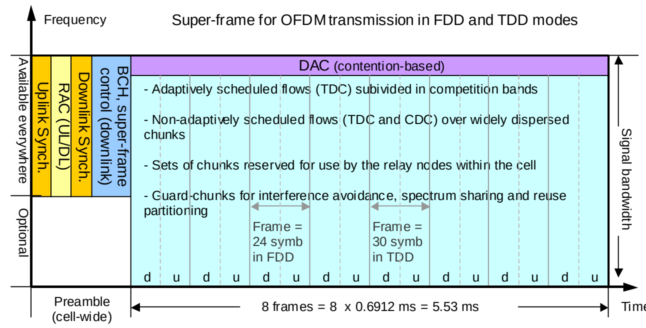


Fig. 4. : Preliminary super-frame structure for both FDD and TDD physical layer modes. u = uplink transmission in TDD and d = downlink in TDD.

### *D. Overview of main functions*

The MAC control function blocks are illustrated in Fig. 5. Control functions that directly control packet transmission on a *slot* time scale reside in the user plane. Slower functions reside in the control plane. For further details, please see [4,7].

- ***Resource partitioning***. Partitions the super-frame into sets used for adaptive, non-frequency adaptive and DAC transmission, as well as into chunks reserved for use by RNs, relay links and as guards for interference avoidance with respect to other cells and operators.
- ***Spatial scheme control***. The appropriate spatial transmit scheme is determined for each flow, and it is held fixed within a super-frame. It is influenced by many parameters, including PLM, deployment, transport channel type, cell load, traffic type, BS antenna configuration, terminal capabilities, propagation channel, and interference conditions [9].
- ***Flow setup and termination*** performs flow context establishment and release over one hop.
- ***Constraint processor***. Combines constraints on the use of chunks and chunk layers. These arise from interference between user terminals, interference avoidance scheduling with neighboring cells and spectrum sharing between operators. The output is in the form of chunk masks that define restricted use of a super-frame's chunks. It also processes measurements that support the RRM spectrum assignment/negotiation at the RLC system layer [6].
- ***Flow state controller.*** Controls the segmentation and FEC coding/decoding of packets.
- ***Resource scheduler.*** Controls the mapping onto transmission resources of TDC and CDC packets and controls the spatial link adaptation. Power control in both uplinks and downlinks is performed under the control of the resource scheduler and is integrated into the optimisation of the transmission parameters.

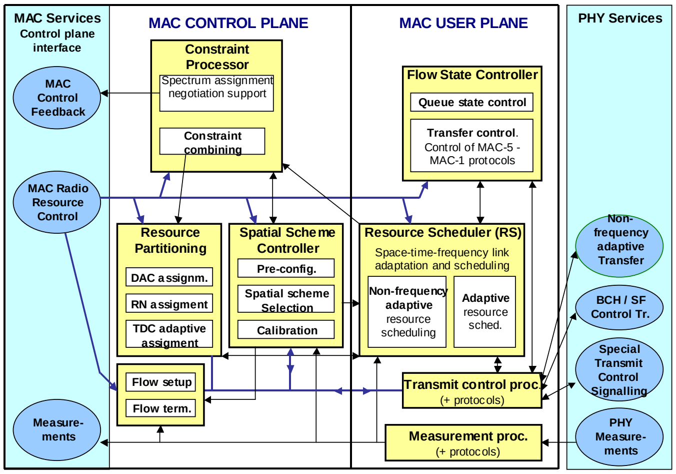


Fig. 5. : Control functions: Services and main function blocks.

The resource scheduler optimizes the allocation of physical channel resources under certain constraints such as interference avoidance. It determines the resource mapping for TDC and CDC flows on a slot time-scale, using one of two scheduling algorithms for each flow:

- The *Adaptive resource scheduler*, used for high-performance TDC transmission. Adaptive transmission is feasible up to a limiting velocity (around 70 km/h) or down to a certain average user SINR [10]. The resource scheduler performs adaptive scheduling when feasible.

- The *Non-frequency adaptive resource scheduler*, used for all CDC flows and as a fallback for TDC flows, when channel adaptation is infeasible. It is also foreseen to be used for control signaling.

The scheduled bits are mapped onto the physical channel resource units, i.e. chunks (in general chunk layers when more than one spatial dimension is utilized [8]). Link adaptation is performed individually within each chunk layer.

Non-frequency-adaptive transmission uses averaging w.r.t. frequency-selective channel variations by mapping the scheduled packets onto sub-carriers in well-dispersed chunks.

The data flows in the user plane are outlined in Fig. 6. Note here that segmentation into retransmission blocks (RTUs) and encoding is performed *before* the mapping onto chunks. The proposed design thus decouples the segment size used for retransmission from the chunk size. It also decouples the code block size from the chunk size. This enables the evaluation of various schemes that combine outer coding, link adaptation that may involve inner coding, and hybrid-ARQ mechanisms.

## V. CONCLUSIONS

The MAC system layer design outlined above aims to support a radio interface to be both efficient and flexible in terms of user requirements, spectrum use, deployment aspects and terminal capabilities. Within the WINNER II project the basic concept is now developed further into a complete MAC layer by design and comparison of specific protocol features.

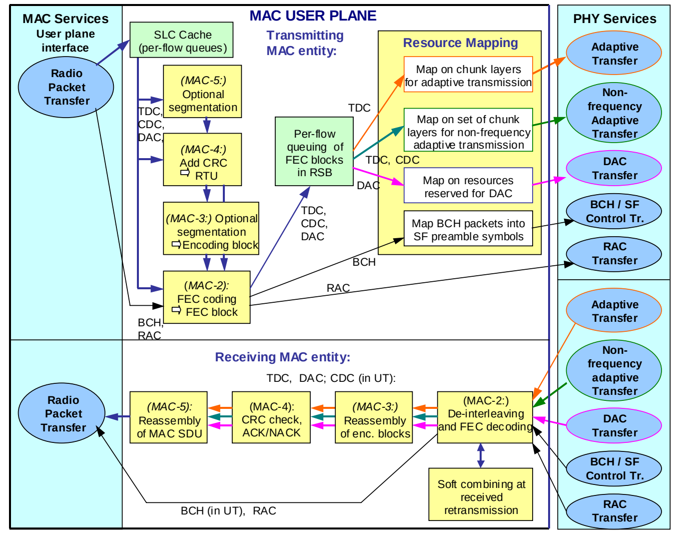


Fig. 6. : User-plane services and some aspects of the packet processing.

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