The Road to IMT-Advanced Communication Systems: State-of-the-Art and Innovation Areas Addressed by the WINNER+ Project

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ABSTRACT

Phases I and II of the WINNER project contributed to the development, integration, and assessment of new mobile network techniques from 2004 to 2007. Some of these techniques are now in the 3GPP LTE and IEEE 802.16 (WiMAX) standards, while others are under consideration for LTE-Advanced and 802.16m. The WINNER+ project continues this forward-looking work for IMT-advanced technologies and their evolution, with a particular focus on 3GPP LTE-Advanced. This article provides an overview of the WINNER system concept and several of its key innovative components.

INTRODUCTION

The race toward international mobile telecommunications–advanced (IMT-A) radio-access technologies was officially started in March 2008 when the International Telecommunications Union (ITU) Circular Letter was sent to invite submissions for technology proposals [1]. For IEEE 802 standards, the work on IMT-A already had started in 2007, and the requirements for the targeted interface — the IEEE 802.16m — were completed at the end of 2007. The long-term evolution-advanced (LTE-A) study item was launched by the 3rd Generation Partnership Project (3GPP) in May 2008.

The Wireless World Initiative New Radio (WINNER) project: Phase I and Phase II [2] was a major European Union-funded initiative joining the effort of major industrial and academic players in mobile communications. Its main outcomes were the definition of an innovative high-performance-system concept and the related system design, backed by a proof-of-concept in the form of performance assessments in realistic system deployments [3–5]. The Cooperation for a sustained European Leadership in Telecommunications (CELTIC) WINNER+ project continues this forward-looking work in order to contribute to the definition of the IMT-A technology proposals and their evolution, in particular, the 3GPP LTE-A [6]. The core activity of the project is the development of innovative techniques integrated with the overall system functionalities, whose benefits are demonstrated by meaningful end-to-end performance assessments.

The basis of the WINNER+ concept is the current LTE Release 8 (R8) standard, enhanced by selected features from WINNER-II. Therefore, its basic characteristics can be outlined from the commonalities between WINNER-II and LTE R8 systems. Indeed, a close link exists

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between the WINNER-II concept and the 3GPP LTE technology. Both were developed simultaneously, and many major contributors to 3GPP were also members of the WINNER-II consortium. Therefore, it was natural to observe a certain convergence between the technological choices of both concepts, particularly for the physical layer, while the consensus on the performance of the different techniques was being established. The WINNER project time plan compared to 3GPP and ITU activities is shown in Fig. 1.

In LTE R8, the radio-access network (RAN) is composed only of base stations (BSs, also called eNodeBs) providing the user plane and control plane protocol terminations toward the user equipment (UE) [7]. The BSs are interconnected and directly linked to a gateway providing connection to other IP-based networks. This so-called flat architecture simplifies the user data flow and enables flexible and cost-effective capacity scaling.

The multiple-access scheme in the downlink is based on orthogonal frequency division multiplexing (OFDM) with cyclic prefix. The uplink scheme is based on single-carrier frequency division multiple access (SC-FDMA), having a low peak-to-average power ratio that facilitates UE design.

The LTE radio bandwidth is scalable, ranging from 1.4 MHz to 20 MHz. Frequency-division duplex (FDD) and time-division duplex (TDD) modes are supported. The FDD mode enables half and full duplex from the point of view of the UE.

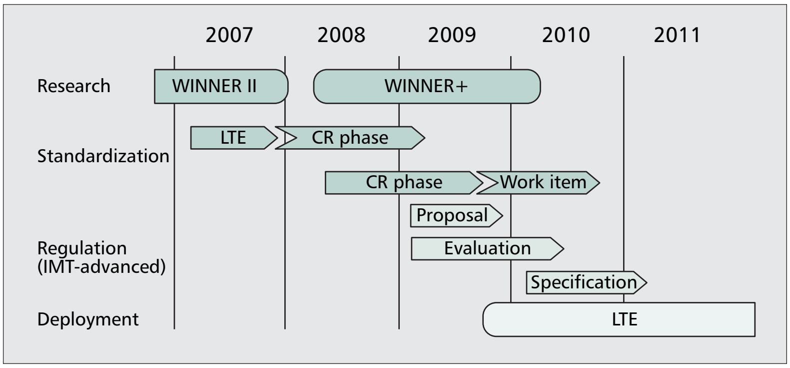
Cross-layer mechanisms, such as link adaptation and hybrid automatic-repeat request (HARQ) with soft combining, ensure efficient use of the time-frequency resources. The transmit time interval is short (1 ms) for low latency and also to enable the system to take advantage of multi-user diversity through time- and frequency-adaptive scheduling.

Multi-antenna support is a key feature for link robustness and high average user throughputs: two to four transmit antennas can be used for transmit diversity and codebook-based linear precoding. The designed system allows up to four spatial layers for single-user multiple-input-multiple-output (MIMO) transmission. Multi-user MIMO (MU-MIMO) in both uplink and downlink are also available mechanisms for improving the cell capacity. More detailed information about LTE can be found in [8].

This article provides an overview of the WINNER+ system concept and several of its key innovative components. The key innovative components from WINNER-II are summarized in the next section. We then present the innovation areas targeted by WINNER+. The final section concludes the article.

KEY FEATURES OF THE WINNER-II SYSTEM CONCEPT

The WINNER-II system concept [3, 5] was designed as a user-centric system with a goal of meeting the IMT-A requirements. Beyond the common basis with LTE R8 and the support of wider bandwidths (up to 100 MHz in total, shared between uplink and downlink), new ideas and techniques were proposed, in particular in the areas of multiple access, medium access control (MAC) layer and advanced antennas, relaying, and spectrum functionalities. These ideas are discussed below. Some of them can be integrated directly into the current LTE standard, whereas others might require changes in the specifications. The key features of WINNER-II, along with LTE R8 and LTE-A, are summarized in Table 1.



■ **Figure 1.** *WINNER+ timeline compared to 3GPP and ITU activities.*

MULTIPLE ACCESS, MAC, AND ADVANCED ANTENNAS

The WINNER MAC layer is designed for minimum delays[1] of 1 ms in the downlink and 2 ms in the uplink, which is attained for single-hop transmission by a combination of short frame durations and tight feedback-control loops. This low latency enables adaptability with respect to fast-channel variations so that link adaptation and multi-user scheduling gains can boost spectral efficiency. It also enables fast-link retransmissions with HARQ, which facilitates high-throughput Transmission Control Protocol/Internet Protocol (TCP/IP) traffic and provides reliable links even for real-time services.

The OFDM access (OFDMA)-based multiple-access concept is highly flexible and can be deployed in a wide variety of system bandwidths and propagation scenarios. For good channel conditions and/or low user velocities, accurate channel-state information (CSI) can be obtained. In these cases, the resource allocation is based on *frequency-adaptive* transmission with adaptive TDMA/OFDMA, which enables increased spectrally efficient transmission through multi-user scheduling and individual link adaptation of time-frequency-space resources. The downlink signaling overhead is reduced by an adaptive hierarchical design of the allocation tables containing the resource assignment description. The short frame duration, in combination with channel prediction, enables frequency-adaptive transmission even at vehicular speeds. The frequency-adaptive transmission scheme adapts the modulation individually for each chunk (set of contiguous OFDM subcarriers), while the same code rate is applied to all the chunks of a given user. The associated bit-loading algorithm [9] is based on the mutual information per coded

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[1] *Delay from the MAC layer of the source to the MAC layer of the destination.*

	3GPP LTE	WINNER-II[1]	3GPP LTE-A
Max. peak data rate (Mb/s)	300	1000	1000
Channel bandwidth (MHz)	1.4 to 20	1.25 to 100	1.4 to 100
Spectrum band (GHz)	0.7 to 2.6	2 to 6	0.45 to 4.99
Access method	OFDMA SC-FDMA	Flexible	OFDMA SC-FDMA
Duplex mode	FDD, TDD	FDD, TDD	FDD, TDD
Relaying	Not integrated	Integrated	Under study
Domain	Wide area, metropolitan area, local area	Wide area, metropolitan area, local area	Wide area, metropolitan area, local area

[1] WINNER-II is shown for comparison purposes. In practice, WINNER+ will not be a competing technology with regard to IMT-A.

Table 1. *Key features of LTE, WINNER-II, and LTE-A.*

bit and allows for combining fine-grained adaptation with an efficient bit-interleaved coded-modulation (BICM) scheme, based on quasi-cyclic block low-density parity-check (QC-BLDPC) channel coding for arbitrary codeword lengths. Even without employing power loading, this scheme yields a performance that is very close to the theoretical optimum.

A robust diversity-based transmission scheme also is required for users with high speed or low data rate and for short control packets. The multiple-access scheme for these scenarios is based on a highly flexible *non-frequency-adaptive* transmission mode. The scheme obtains its robustness by means of a dispersed allocation of multiple blocks in frequency, each block consisting of a few consecutive subcarriers in a few consecutive OFDM symbols. This resource allocation structure enables a tunable degree of frequency diversity and low-allocation signaling overhead. Moreover, it provides support for high-power amplifier efficiency in the uplink by the use of a discrete Fourier transform (DFT) precoding step. Also, the possibility of a sub-slot allocation enables robust and efficient transmission for small packets and, at the same time, improved battery life in UE. The uplink scheme, denoted block-interleaved frequency division multiple access (B-IFDMA) [3, 5], is a generalization of the LTE SC-FDMA scheme.

An important enabler for efficient co-existence and switching of frequency-adaptive and non-frequency-adaptive transmission modes is the cross-layer design of the MAC layer. Efficient switching between the two modes is supported by a common approach for channel coding and retransmission with hop-by-hop HARQ. WINNER-II uses advanced type-II incremental redundancy HARQ. The single, low-rate mother code is punctured to obtain multiple higher coding rates (rate-compatible punctured code) [3, 5].

The flexible WINNER-II advanced antennas concept [10] works with varying degrees of CSI at the transmitter and can foster flexible combinations of spatial multiplexing, space-division multiple access (SDMA), spatial diversity and beamforming, and the means for enhanced interference management. The transmitter is illustrated in Fig. 2. Not all of the function blocks are operative all of the time. Their use depends on the scenario, system load, propagation conditions, number of receivers (unicast, multicast, or broadcast), and the corresponding desired multi-antenna processing gain (multiplexing, diversity, and directivity).

More advanced MU-MIMO precoding schemes, such as successive, minimum mean-square error, were proposed. These techniques multiplex streams to several users to provide very high performance gain. The gain is especially pronounced in a rich scattering radio environment (i.e., local area), where distributed antennas achieve a spectral efficiency of more than 13 bps/Hz [10].

RELAYING

Advanced relaying techniques are considered as an attractive solution to enhance coverage and/or capacity in specific locations [11, 12]. Important characteristics of these new network nodes are ease of deployment (due to in-band backhauling) and reduced deployment cost compared to a regular BS (due to lower site costs) [13].

The relay node (RN) was embedded in WINNER-II as an integral part of the system concept [4]. The same air interface is used for connecting the UE to the eNodeB (eNB) or RN and the RN to its serving eNB. Figure 3 shows the basic elements of a multihop connection. The UE is always connected to an eNB or RN by an access link. The relay link is between an eNB and an RN or two RNs, where a multihop link is comprised of at least one relay link and an access link. In a multihop scenario, the eNB, together with its served RNs, forms a relay enhanced cell (REC).

The introduction of relays in cellular communication systems entails a large number of deployment options to be investigated; in particular the layout of a REC depends on the num-

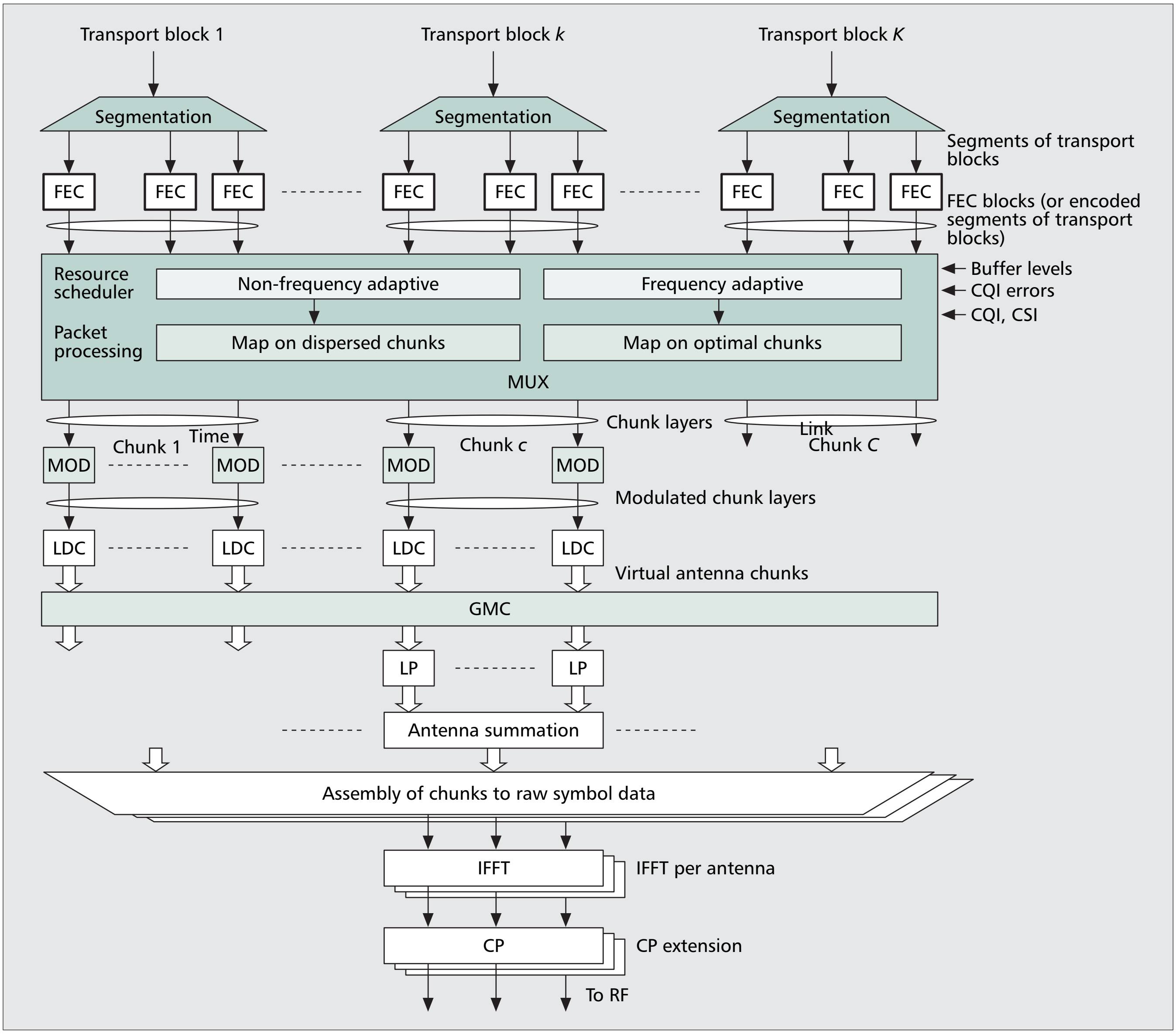


Figure 2. *The WINNER transmitter.*

ber of hops, the number of RNs served by one eNB, the positioning of the RN, the transmit power of an RN, the spatial temporal processing, and the radio environment (line-of-sight [LOS]/non-line-of-sight [NLOS] probabilities).

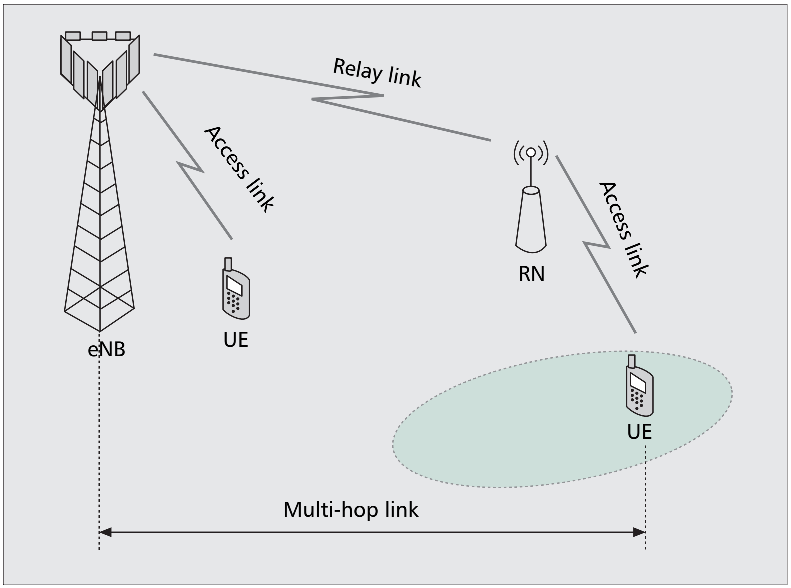
Therefore, a multitude of deployments can be envisioned, and different deployments are expected to be suitable for different scenarios.

The relaying concept was designed in WINNER-II under the following baseline assumptions:

- Layer 2 (decode and forward) relays
- Optimization of the system for two hops, but no restriction on the number of hops
- Tree-based topology (not mesh) to avoid complex routing schemes
- No additional overhead for cells that do not use relays
- Support of cooperative relaying as an additional feature to increase capacity

The performance of relays depends on the level of integration of the relaying concept into the protocol and system architecture. First, it is required to integrate the RN as part of the end-to-end multihop link between the UE and the RAN. This comprises user-plane and control-plane functions and protocols. In WINNER-II, one design goal was to provide the UE with a unique interface whether it is connected to an eNB or an RN. Second, the RN must be integrated into the RAN, which requires control-plane functions, mainly to enable relay-enhanced radio-resource management.

The integration of the RN to the control plane of the WINNER-II system is depicted in Fig. 4. The network-layer control-plane signaling is handled by the Radio Resource Control (RRC) protocol. The control and configuration of the RN is performed by the sub layer RRC2. The RRC at the eNB terminates the protocols initiated at both the RN and the UE. More details about the relaying concept designed by WINNER-II can be found in [3–5].



■ **Figure 3.** *Relay scenario investigated by WINNER-II.*

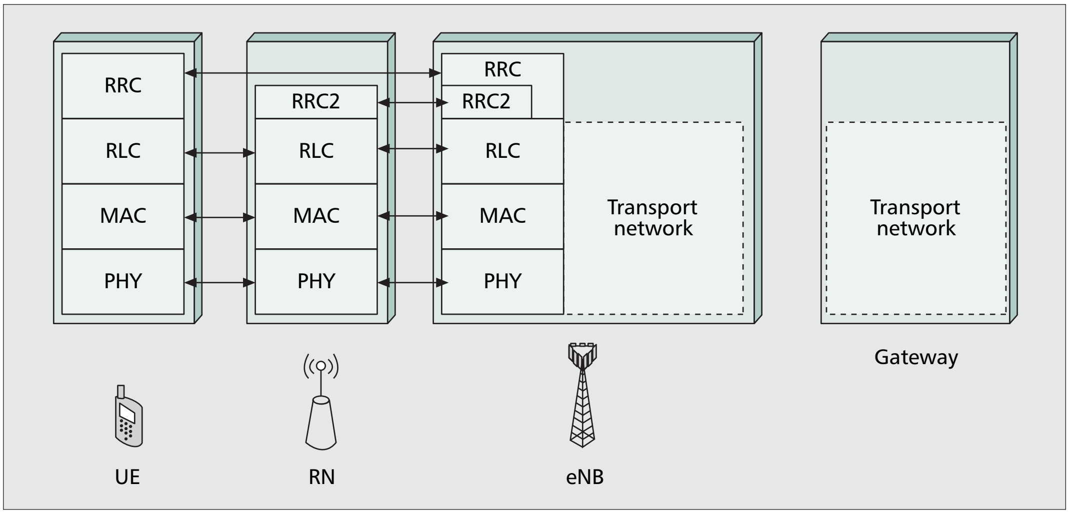
SPECTRUM FUNCTIONALITIES

A conceptual overview of the spectrum control functions was presented in the WINNER-II system concept description [3]. The most salient spectrum control functions are summarized in Table 2. Inter-radio-access technology (RAT), flexible spectrum use (FSU), and intra-WINNER FSU are distinguished. The WINNER-II system is understood to function under an IMT-A system (i.e., LTE-A system). The underlying FSU functions allocate spectrum resources to the IMT-A system or coordinate the spectrum access between the IMT-A system and other systems.

Under the spectrum-sharing (inter-RAT FSU) umbrella, four different schemes have been developed. They are based on the access rights of each system to the shared spectrum. If one system has priority access to the spectrum over another, then vertical sharing schemes are applied. In such a case, if the WINNER system is the primary system, then a scheme called vertical sharing 1 (VS1) is used. If the WINNER system is a secondary system and has higher priority access rights compared to another secondary system, then a scheme called vertical sharing 2 (VS2) is applied.

For instance, an IMT-A system can coexist with the fixed satellite system (FSS) where the latter functions as a primary system under the VS2 category. In this scenario, the IMT-A system can adopt a dynamic and opportunistic use of the unused part of the spectrum with useful knowledge about the deployed FSS system. A situation where WINNER and another system have the same access rights to the spectrum results in horizontal sharing, which involves two different sharing schemes. The first horizontal sharing scheme assumes that the systems contending for spectrum can coordinate with each other to enable efficient spectrum allocation. This is called horizontal sharing with coordination (HwC). The second scheme is considered when both systems do not coordinate with each other in the framework of spectrum-sharing functionalities. This scheme is called horizontal sharing without coordination (HwoC).

After the spectrum is allocated to the WINNER system, its allocation within the WINNER RANs (e.g., belonging to different operators) is determined by the spectrum-assignment scheme. WINNER considers long-term (LT) and short-term (ST) spectrum-assignment strategies to take advantage of the changing nature of the spectrum availability and the traffic demand in different parts of a multi-operator environment. The LT scheme assigns the spectrum at a higher level of geographical granularity between multiple RANs. During the LT-assignment functional procedure, the spectrum is negotiated over a long time scale, that is, in the order of tens of minutes, over the WINNER operational deployment. The ST assignment acquires the fine tuning of the spectrum assignment at the cell level. This is performed at shorter time scales than in LT assignment: the ST-assignment negotiation of spectrum is performed over time periods of several hundreds of milliseconds. Preferably, the ST functions are located at the lower layers and close to the radio front. On the other hand, the



■ **Figure 4.** *Control plane of the WINNER-II architecture enhanced by RN.*

LT functions are at the higher layers and close to the core network. For instance, the ST spectrum-assignment function can be allocated at the LTE-A eNB (if such an approach was considered for LTE-A). The LT-assignment function with more involvement of LTE-A eNBs can be allocated either in the control plane gateway (GW) or the operations and maintenance (O&M) server. However, due to large differences among different IMT-A deployment modes, namely, from local area to wide area, the functional allocation to the logical entities in IMT-A systems must be designed case by case.

Inter-RAT FSU	Intra-WINNER FSU
Spectrum sharing functions	Spectrum assignment functions
This group includes: • Vertical sharing 1 (VS1) • Vertical sharing 2 (VS2) • Horizontal sharing with coordination (HwC) • Horizontal sharing without coordination (HwoC)	This group includes: • Long-term assignment (LT) • Short -term assignment (ST)

Table 2. *Spectrum functionality classification.*

NEW AREAS OF INNOVATION IN WINNER+

The pioneer system integration of innovative techniques performed in WINNER-I and WINNER-II is being continued in WINNER+ to assist the development of highly competitive IMT-A air interfaces and especially, the LTE-A. Four key innovation areas are addressed:

- Advanced radio resource management (ARRM) deals in particular with radio resource allocation (scheduling), self-optimized networks (SON), and efficient multicast/broadcast services.
- Spectrum technologies aim at defining preferred spectrum-usage scenarios, based on the outcomes of the World Radiocommunication Conference (WRC) '07, and at investigating spectrum-sharing issues.
- Peer-to-peer (P2P) and network coding study the enhancement of cellular network performance through device-to-device communications and related cooperation schemes, together with network coding techniques.
- Advanced multiple-antenna systems involve two main tracks: the optimization of system aspects related to multiple-antenna schemes and the coordination of transmissions and/or reception from remote antennas to further enhance the system performance.

The remainder of this section outlines the main challenges of the innovations mentioned above.

ARRM

The concept of RRM has become a key element of current and future wireless and wired communication networks for providing the negotiated quality of service (QoS) to end users. The efficiency of RRM techniques has a direct impact on each user's individual performance and, furthermore, on the overall network performance and operational expenditures (OPEX). Consequently, these techniques must take advantage of the available resources for the benefit of users and operators.

According to the ITU — Radiocommunication Sector (ITU-R) requirements, IMT-A systems must enable ARRM techniques by gathering various statistics, including system and user parameters. Therefore, it is of paramount importance not only to devise new ARRM mechanisms but also to assess the signaling requirements of each proposal. These new ARRM mechanisms should address three important challenges:

- Maximize the system flexibility in resource allocation, both in uplink and downlink
- Support advanced and distributed interference mitigation schemes
- Take advantage of enhanced multicast broadcast services

Concerning the first challenge, the complexity of an OFDMA system, encompassing the time, frequency, and space dimensions requires the design of optimum dynamic resource allocation algorithms that enable extending the opportunistic scheduling concept to all dimensions. Within the WINNER+ project, several schedulers are proposed that include all of the dimensions and the fulfilling of user QoS requirements. At the same time, the allocated power must be controlled to reduce interference as much as possible.

Secondly, load and call admission control manages the access to the network and plays a major role in the avoidance of system congestion. The WINNER+ system adopted a combined centralized and distributed approach to the execution of load and admission control and in support of user mobility. This reduces the time for serving the users and provides the benefits of centralized control in situations of medium-to-high network loads.

Another key aspect for innovation in interference mitigation is the concept of self-organization. Self-organization enables the network to detect changes, make intelligent decisions based upon these inputs, and then implement the appropriate action. The system must be situation-aware and must take advantage of this information to dynamically configure itself in a distributed fashion. For example, when applied to RRM, SON enables the creation of a dynamic and automatic optimum coordination of the radio-resource utilization at the cell edge to reduce interference and avoid performance loss or service degradation.

Concerning the last challenge, two scenarios of broadcast networking are considered in WINNER+: the multi-frequency networking (MFN) and the single-frequency networking (SFN). The results indicate the clear advantage of SFN, which allows the signal transmitted from neighboring cells to be turned into a useful signal. Therefore, SFN retains limited receiver complexity and resource usage in terms of allocated

Spectrum scarcity and bandwidth fragmentation often lead the actual demand for transmission resources to exceed the available bandwidth. Dynamic spectrum sharing and FSU are promising technologies to overcome this problem.

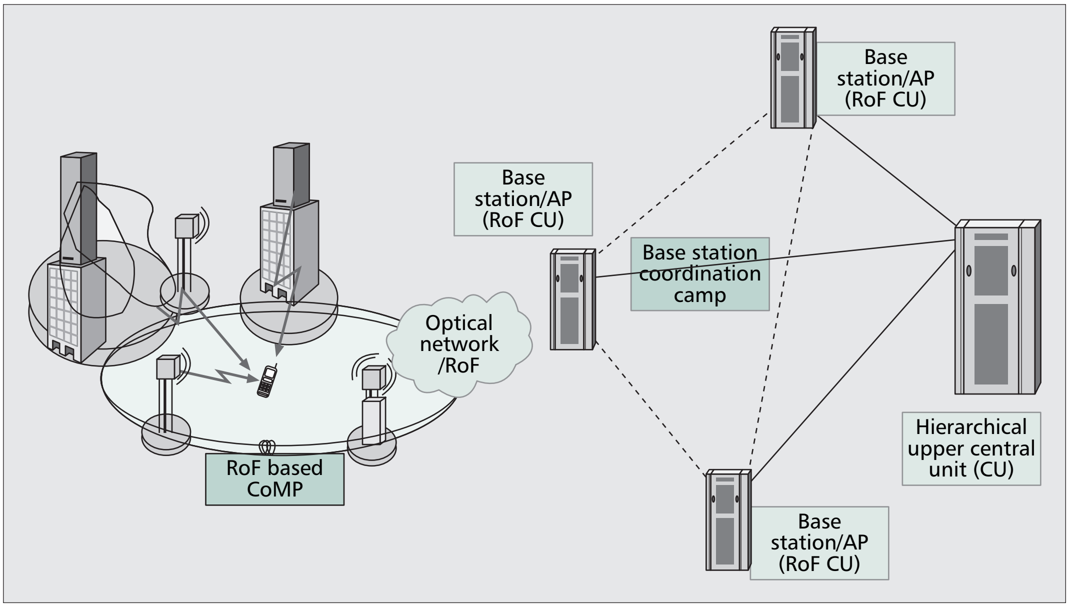


Figure 5. *CoMP architectures.*

subcarriers. In addition, optimum switching criteria between broadcast and unicast service are envisaged to increase the system efficiency.

FSU

To support the demand of future wireless systems for high data rates and large user capacities, efficient use of the available spectrum resources is of great importance. Spectrum scarcity and bandwidth fragmentation often lead the actual demand for transmission resources to exceed the available bandwidth. Dynamic spectrum sharing and FSU are promising technologies to overcome this problem.

At the WRC '07, the new spectrum bands for IMT systems were identified [14]. The new spectrum allocated for mobile communications does not correspond fully to what was required for IMT-A systems. Therefore, the mobile operators in some countries might be forced to aggregate spectrum of two or more separated sub-bands for down- and up-link bands. The bands of the separated regions can be situated in the same frequency band (e.g., in the 3.5-GHz band) or in separated bands (e.g., part in the 2-GHz band and part in the 3.5 GHz band). Some of the main open questions related to spectrum aggregation concern the maximum acceptable frequency distance and the maximum acceptable number of fragmented bands that are aggregated at the receiver. Also, the physical and hardware origins of these constraints must be established.

Technology-neutral spectrum allocation and spectrum liberalization provide an opportunity for spectrum holders to change the use of their spectrum, for example, by migrating spectrum used for 2nd generation (2G) and 3G systems toward IMT-A systems or to lease, or even to sell, spectrum on secondary spectrum markets. A related issue is the population of the spectrum made vacant by the switch of analog terrestrial-TV broadcasting in the frequency band of 470–862 MHz to digital TV. Since processing of digital data enables a more efficient use in terms of required bandwidth, a considerable amount of frequency spectrum can be released from broadcasting use, leading to the digital-dividend approach that enables launching IMT commercial systems in this band.

Self-organized networks in which coordination among wireless network entities is limited or even non-existent are one of the key components in future wireless systems. For example, femtocells are self-configurable miniature home BSs that are deployed in operator-owned spectrum and are based on the same cellular standards as macrocells. Due to the foreseen mass deployment, neither full coordination by a macrocell, nor control by a centralized maintainer is possible. Femtocells dynamically share the operator spectrum not only among themselves, but also with macrocells, resulting in an intra-operator FSU scenario. Femtocell BSs and femtocell UE cause interference on macrocell BSs and macrocell UE and vice versa. Thus, interference due to the femtocells deployment in the same band where macrocells already operate is a major concern, and dynamic spectrum sensing and resource negotiation among cells are envisioned for efficient spectrum use.

P2P AND NETWORK CODING

Future wireless systems will be characterized by a requirement for large user capacity and high reliability. Yet, the inherent fading and interference of wireless communications render these design objectives challenging. There are currently many diversity techniques proposed to combat fading, namely, MIMO for space diversity, channel coding for time diversity, OFDM, and so on. However, the applications of these techniques are limited by hardware complexity, size, delay, and bandwidth.

A promising alternative is to design the system from the point of view of an overall network capacity, that is, network information theory. In this context, device-to-device communications, in other words P2P radio communications, become a key feature to be supported by next-generation wireless designs. The advantages are manifold: offloading the cellular system, reducing battery consumption, increasing bit-rate, robustness to infrastructure failures, and so on. Thus, the design of an efficient device-to-device communication mode, with minimal interference to the cellular overlay network and maximum capacity, is definitely a key challenge to overcome.

In the emerging cellular-deployment concepts with multihop communications relayed by fixed or mobile entities (infrastructure-cooperative relaying, device-to-device communications, and cooperation), a new class of coding techniques, called network coding [15], is of high interest. Network coding was originally proposed to increase the information flow in computer networks (e.g., Internet backbone) by allowing information from different sources to mix in the finite field, at intermediate nodes of the route. Its application in cooperative wireless networks seems very attractive in terms of throughput increase through path diversity, energy efficiency, and simplicity of implementation [16]. However, network coding for wireless networks is at an early stage in terms of practical solutions design and performance impact evaluation.

ADVANCED ANTENNAS SYSTEMS

The work on advanced antenna systems is split according to two main tracks. Advanced multiple-antenna schemes focuses on optimizing system aspects of multiple-antenna systems, like CSI feedback and MU-MIMO optimized-resource allocation. Coordinated multipoint systems address coordinated antenna deployments where the cooperating points are geographically distant. The remainder of this section describes these two fields of investigation in more detail.

Advanced Multiple-Antenna Schemes — One of the principal radio techniques that must be considered when developing future radio systems is MIMO communication, based on multiple antennas, both at the transmitter and the receiver. The spectral efficiency of MIMO transmission can be dramatically increased if some level of CSI is available at the transmitter, allowing the system to effectively adapt to the radio channel and take full advantage of the available spectrum. The main challenge is to make the CSI available at the transmitter (CSIT). This can be achieved by conveying quantized instantaneous and/or statistical CSI as feedback information over the reverse link as in FDD systems. A TDD system uses the same carrier frequency alternately for transmission and reception, and thus the CSI can be tracked at the transmitter, provided that fading is sufficiently slow and the radio chains are well calibrated.

Another major challenge for wireless communication systems is how to allocate resources among users across the space, frequency, and time dimensions and jointly design all the transceivers (precoders, decoders) with different system optimization objectives, user QoS requirements, and practical constraints. Advanced MU-MIMO resource allocation and scheduling techniques can be used in both the uplink and downlink to allocate resources across different dimensions. Although non-linear precoding and decoding techniques, for example, dirty-paper coding in downlink, are known to achieve high capacity [17], linear precoding/beamforming is much simpler to implement to perform multi-user transmission and reception. Hence, it is an important solution in practical system design. The allocation problem still remains unresolved for a large variety of optimization criteria, especially when combined with practical modulation and coding schemes, as well as user-specific QoS constraints. The problem is a difficult non-convex combinatorial problem with integer constraints, and finding jointly optimal solutions is most likely intractable [18]. Therefore, efficient sub-optimal solutions are required in practice.

Coordinated Multipoint Systems — Providing high data rates for a large number of users, including cell-edge users, cannot be achieved by increasing signal power because multi-cell systems become interference limited because each BS processes in-cell users independently, and the other users are seen as inter-cell interference. One strategy to overcome such a limitation is to deploy coordinated multipoint systems (CoMPs). A CoMP refers to a system where several geographically distributed antenna modules coordinate to improve performance of the served users in the coordination area and are connected to each other through dedicated links.

Different architectures can be considered under the general term of CoMP. A possible CoMP implementation refers to radio-over-fiber (RoF) architectures, where the distributed modules are connected to a central station by means of fiber links, in simple (point-to-point) or more complex (bus, ring) scenarios. Another implementation is that of coordinated multi-cell transmission schemes, where the distributed modules are represented by the BSs with coordination criteria managing their overall operation. RoF-based CoMP and coordinated multi-cell CoMP are sketched schematically in Fig. 5.

The impact of each of these architectural innovations on the access network greatly depends on the selected scenarios. One of the main issues that was identified is the type and amount of data to be exchanged among coordinating nodes (the requirement of transmitting control information only or of also transmitting user data):

- RoF-like approaches have a small impact on the current network architecture because the interface between the BS control unit and the related remote heads is a proprietary one and no new central unit (CU) must be added to the network.
- Coordination among BSs requires a new hierarchical CU and an extensive revision of related interfaces.

A trade-off between the expected performance of a CoMP solution and the added system complexity is an important issue to be investigated. This trade-off strongly depends not only on the selected architecture that enables CoMP but also on the different CoMP approaches and the different levels of coordination and/or cooperation that can be envisioned.

Advanced multiple-antenna schemes focuses on optimizing system aspects of multiple-antenna systems, like CSI feedback and MU-MIMO optimized-resource allocation. Coordinated multipoint systems address coordinated antenna deployments where the cooperating points are geographically distant.

By joining the research forces of major players in the mobile communication industry and academia ahead of standardization, the WINNER project aims at fostering consensus building on new technologies at an early stage.

CONCLUSIONS

The WINNER+ project continues the forward-looking work of WINNER phases I and II by contributing to the development, integration, and assessment of new technologies for mobile networks. Phases I and II supported the community in understanding the practical benefits of techniques now in the 3GPP LTE and WiMAX standards (like OFDMA, MIMO, and frequency-adaptive scheduling). Furthermore, these previous phases were at the outpost for the design of spectrum functionalities and relays, the latter being currently studied within the LTE-Advanced Study Item and IEEE 802.16m. For the continuity of this work, WINNER+ focuses on the following innovation areas for IMT-A technologies and their evolution: ARRM, spectrum technologies, terminal-to-terminal (peer-to-peer) communications, network coding, advanced antenna schemes, and coordinated multipoint systems. The system integration of the innovations will be optimized to yield a WINNER+ system concept designed on the basis of LTE R8. An end-to-end performance assessment of this system concept will be performed by means of system-level simulations, as well as analytical calculations, using the system requirements and the evaluation criteria defined by ITU-R. By joining the research forces of major players in the mobile communication industry and academia ahead of standardization, the WINNER project aims at fostering consensus building on new technologies at an early stage, thereby easing the standardization process for the benefit of the whole community.

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