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Poster Paper

WINNER II System Concept: Advanced Radio Technologies for Future Wireless Systems

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Abstract: WINNER has been an ambitious research project aiming at identification and assessment of key technologies for Beyond 3G mobile systems. The WINNER mobile radio access network provides a system that is highly flexible and efficient and can provide a wide range of services to a multitude of users in many different environments. This paper provides a concise overview of the WINNER system concept and presents the main technical innovation areas addressed by the project.

Keywords: IMT-Advanced, OFDMA, System Concept, Relaying, Dynamic Spectrum Use, Advanced Antenna Concepts.

1. Introduction

WINNER Phase I (2004-2005) and Phase II (2006-2007) were ambitious research projects aiming at identification and assessment of key technologies for Beyond 3G mobile systems. The main outcomes of the projects were the definition of the WINNER system concept, and the related system design backed up by proof-of-concept in the form of performance assessment in realistic system deployments. The goal of the WINNER mobile access network is a system that is highly flexible and efficient and can provide a wide range of services to a multitude of users in many different environments.

This paper provides an overview to the WINNER system concept and several of its key innovative components. Section 2 provides an overall description to the logical node architecture that uses as few logical nodes as possible to keep the number of interfaces small. Further it presents the flexible protocol architecture. Section 3 describes the developed solutions for multiple access and medium access control especially designed for short radio interface delays. Section 4 focuses on pilot design supporting various types of spatial processing. Section 5 provides an overview of the relaying concept which is an integrated part of the system concept. Section 6 describes the dynamic spectrum use solutions, enabling operation in shared spectrum and allowing for inter-system coordination. Section 7 describes the utilized e2e performance assessment framework, and provides detailed results on advanced multi-antenna concepts. Section 8 concludes the paper.

2. WINNER System Concept

2.1 Logical Node Architecture

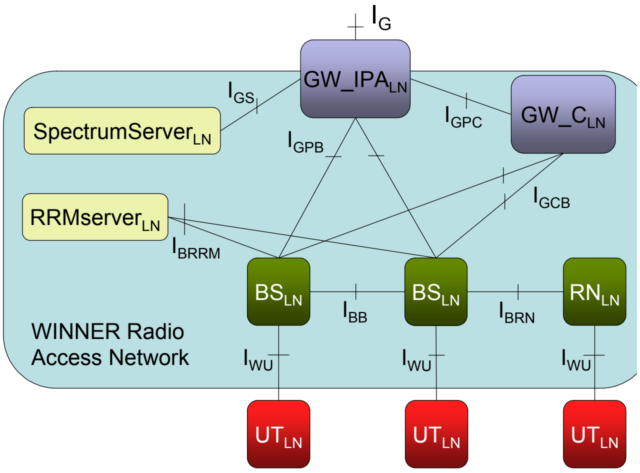

Figure 1: WINNER Logical Node Architecture.

It is the purpose of the logical node architecture to show a high level function grouping and the basic flow of user data, control data, and functional interactions. As the WINNER system is designed to work well over a wide range of operating scenarios, the function grouping is defined such that it enables a flat architecture (e.g. there are only two nodes in the user plane which reduces the number of involved nodes in the connections) and flexible, scalable and cost efficient implementations (e.g. by defining logical nodes as pooled resources). Figure 1 illustrates the WINNER logical node architecture. The Base Station logical node BS_{LN} performs all radio related functions, including user mobility, for both active and idle terminals and is responsible for governing radio transmission to and reception from User Terminal logical nodes UT_{LN} and Relay Node logical nodes RN_{LN}. The BS_{LN} controls the relays (if used), e.g. determines routes (i.e. handovers), and forwards packets to the respective relay. The RN_{LN} operates as a decode-and-forward layer 2(L2)-relay, hence allowing advanced forwarding that can take advantage of adaptive transmission with different modulation and coding schemes. The BS_{LN} and the RN_{LN} form a tree topology to avoid complex routing schemes. Moreover, the RN_{LN} is transparent to the UT_{LN}, i.e. there is no necessity for the UT_{LN} to distinguish between RN_{LN} and BS_{LN}.

The $SpectrumServer_{LN}$ enables sharing and co-existence with other radio access technologies and spectrum assignment between WINNER networks. If present, the $RRMserver_{LN}$ performs e.g. load sharing and user mobility control. The Gateway IP Anchor logical node GW_IPA_{LN} is a user plane node (governing e.g. header compression and ciphering), whereas the Gateway Control logical node GW_C_{LN} is a control plane node (governing e.g. idle mode mobility). It is possible to pool a number of GW_C_{LN} or GW_IPA_{LN} together in order to eliminate the risk of single point of failure. Hence, no change of GW_C_{LN} or GW_IPA_{LN} is normally required when the UT_{LN} moves around in the network. For further details on the logical node architecture, see [1].

2.2 Protocol and Service Architecture

The WINNER protocol architecture encompasses the three lowest layers of the OSI stack, supporting both single hop and multi-hop communication. The two lowest layers, represented by the physical (PHY), Medium Access Control (MAC) and Radio Link Control (RLC) sub-layers are assumed present in all BS, UT and RN logical nodes. This enables an efficient co-design of these layers (e.g. HARQ at MAC and RLC-ARQ minimizing overhead whilst providing high robustness). In the user plane the IP Convergence Layer (IPCL) terminated in the GW_IPA is located above RLC, whereas in the control plane the Radio Resource Control (RRC) layer terminated in the BS is located above RLC.

Figure 2 gives an overview of functions mapped to the (user plane) protocol layers. The scheduler (located at MAC in Figure 2) is a cross-layer function, controlling actions at the RLC, MAC and PHY layers. The RRC layer (not shown in Figure 2) controls the radio resources and configures the UT accordingly. The RRC includes measurement, exchange and control of radio resource related indicators and commands between the network and the UTs, as well as user mobility.

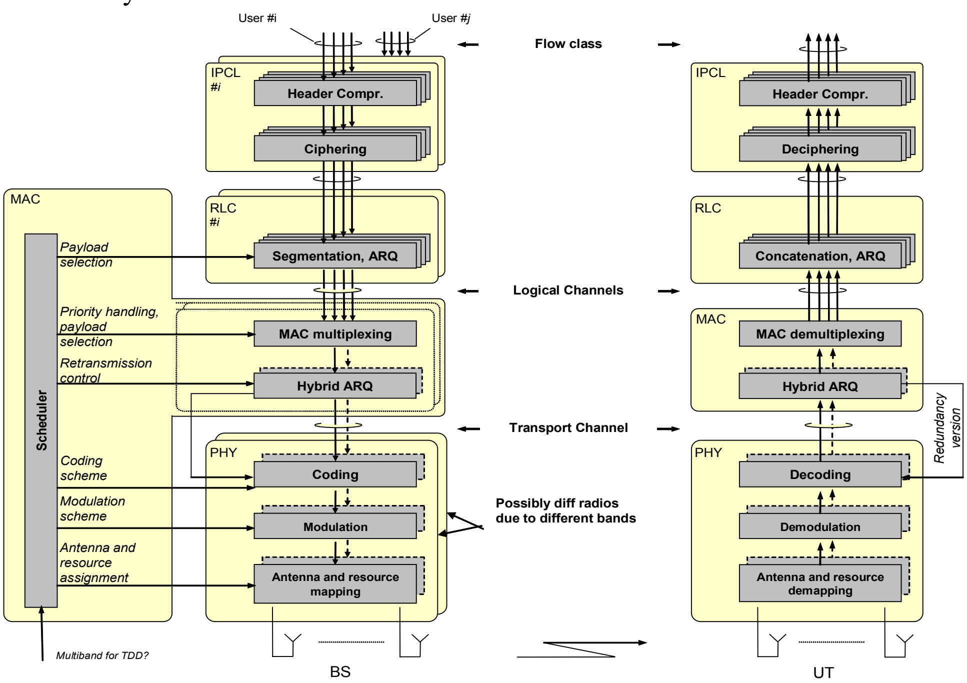

Figure 2: WINNER User Plane Protocol Architecture

3. Multiple Access and Medium Access Control

The WINNER Medium Access Control (MAC) layer is designed for *short delays* over the radio interface. A low latency is important for several reasons. It enables adaptivity with respect to fast channel variations, so link adaptation and multi-user scheduling gains can boost the spectral efficiency. It also enables fast link retransmissions with Hybrid Automatic Repeat Request (HARQ), which facilitates high-throughput TCP/IP traffic and provides reliable links even for real-time services. Minimal delays over the air interface of 1 ms in downlink and 2 ms in uplink are attained over single hop transmission, by a combination of short frame durations and tight feedback control loops, see [1] for further details. The packet processing procedure, as well as the physical layer processing, is controlled by the scheduler within the MAC layer, see Figure 2.

The OFDM based resource allocation scheme 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 quality information can be obtained. In these cases, the resource allocation is based on frequency-adaptive transmission. We then use fast multi-user scheduling and individual link adaptation of time-frequency-spatial resource blocks (denoted chunk layers"), with a TDMA/OFDMA multiple access scheme. With a suitable multi-user, multi-flow scheduler, a very high spectral efficiency is obtained. The downlink signaling overhead is reduced by an adaptive hierarchical design of the allocation tables. 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 layer while the same code rate is applied to all chunks of the same user. The associated novel bit-loading algorithm [2, 3] is based on the mutual information per coded bit and allows the combination of fine-grained adaptation with strong channel coding for arbitrary codeword lengths. Additionally, it has been shown [3] that this adaptation scheme yields a performance close to optimum at a very low computational complexity.

A robust, diversity-based transmission scheme is also needed, e.g. at high velocities. In the WINNER project a highly adaptable ***non-frequency-adaptive*** transmission mode has been developed. The scheme obtains its robustness by dispersed allocation of resources to obtain sufficient diversity from the frequency and spatial domains. The resource allocation structure in frequency and time enables tunable degree of frequency diversity, with support for high power amplifier efficiency by the use of a DFT precoding step (in uplinks). In addition, micro-sleep is supported by a time-localized allocation, which enables improved battery life in user terminals. The schemes are denoted Block Interleaved Frequency Division Multiple Access (B-IFDMA) in the uplink and Block Equidistant Frequency Division Multiple Access (B-EFDMA) in the downlink [4], see Figure 3. This transmission mode is also efficient for low data rate transmission and transmission of small packets, see [1] for further details.

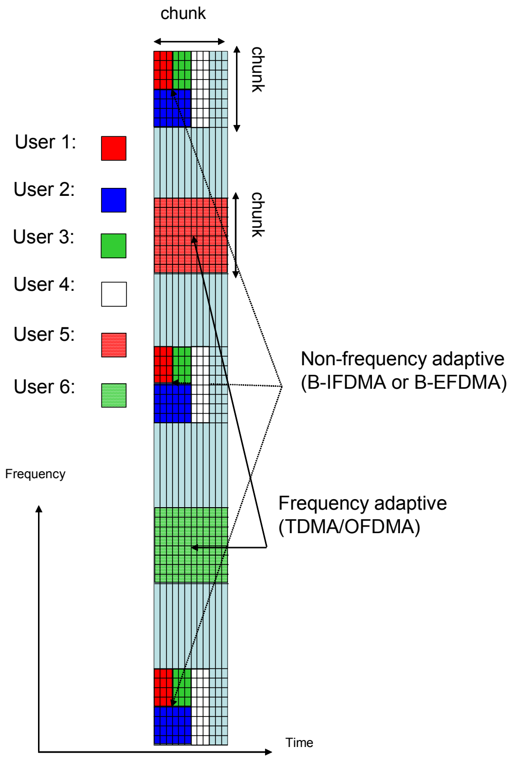

Figure 3: Illustration of the Multiple Access Resources Allocation: Chunck-Wise Adaptive TDMA/OFDMA, B-IFDMA and B-EFDMA

The MAC layer may multiplex packets belonging to different flow classes. The resulting packets are encoded and controlled by a HARQ function that works over each hop in a similar way, independent on the resource allocation mode. WINNER uses advanced Type-II incremental redundancy HARQ. The single low code rate mother code is punctured to obtain multiple higher coding rates (rate compatible punctured code or RCPC). The full parity-check matrices of the base model matrices for the applied *Quasi-Cyclic Block Low-Density Parity Check Codes* can be found in Annex of [5]. The modulation and coding requirements for control channel signalling are different than the ones for user data transmission, due to very short packet sizes being considered (in the order of 25 information bits). Therefore low rate tail-biting convolutional codes have been introduced and lead to good performances [5].

4. Pilot Design for Advanced Antenna Systems

Reference symbols known to the transmitter, referred to as pilots, are required to facilitate coherent detection at the receiver, as well as to transfer channel state information (CSI) for adaptive transmission to the transmitter. As pilots add overhead that grows proportionally with the number of transmit antennas, a sophisticated pilot design needs to flexibly support different variants of the WINNER advanced antenna concept while keeping the overhead at an acceptable level.

The WINNER pilot design is a modular concept consisting of basic building blocks defined on the chunk level. These building blocks are described in the following [1].

The **pilot pattern** specifies the position of pilots within the chunk. The pilot positions are chosen such that a globally regular pilot pattern is obtained, i.e. a two dimensional grid with equidistantly spaced pilots in time and frequency, which enable channel estimation by interpolation [7].

The **pilot type** indicates whether pilots include user specific precoding or not. The type of pilot is determined entirely by the spatial transmit processing scheme that is used in a particular chunk (e.g. grid of beams (GoB), MU MIMO precoding, or linear dispersion codes (LDC)).

The **orthogonal pilot set** determines whether pilots associated to different spatial streams are orthogonally separated in time and/or frequency, or pilots are spatially reused, i.e. pilots of two spatial streams are placed on the same subcarriers. Pilots from different spatial streams are reused if the associated beams are well spatially separated. In case of overlapping beams or unweighted transmit signals, pilots are to be orthogonally multiplexed in time and frequency.

This modular concept avoids that several pilot grids corresponding to different pilot types are inserted within a frame. Instead only one pilot grid is inserted in the frame and the pilot type is determined by the chunk specific spatial transmit processing. Thus, a highly flexible and adaptive system concept can be supported with a modest pilot overhead not exceeding 16% [1]. One implication of the WINNER pilot design is that basic pilot-based channel estimation needs to be enhanced by iterative channel estimation (ICE), so to meet the required channel estimation accuracy [8]. Figure 4 illustrates how the reference pilot design facilitates the coexistence of various flavours of spatial processing schemes.

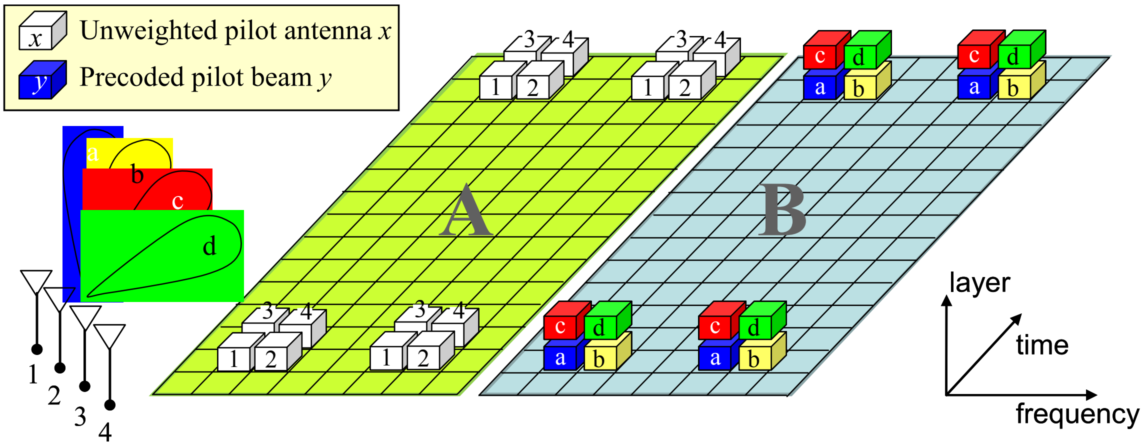

Figure 4: Pilot Design to Enable Spatial Processing in Metropolitan Area

5. Relaying Concept

The main purpose of relay based deployments is to reduce the deployment cost of a system. The cost reduction due to relays is based on the cheaper cost of the Relay Node (RN) in terms of capital expenditure and operational expenditure compared to a Base Station (BS), while still maintaining the required traffic performance. Cost comparison studies in WINNER [9] identified a cost ratio micro BS/RN of 1.5 (unequal traffic density) and 3 (equal traffic density) for relay deployments to be cost efficient. During the WINNER project a relaying concept has been developed as integral part of the WINNER system concept that can fulfil this promise. The WINNER relay is a half-duplex “decode and forward” (L2) relay with fixed location, which can take advantage of adaptive transmissions with different modulation and coding schemes when receiving and forwarding data. This is especially beneficial for "intelligent" deployments with a good link quality between BS and RN.

The WINNER relaying concept does not cause overhead to cells that do not use relays and it is optimized for two hop connections. The BS and the RN form a tree topology to avoid complex routing schemes. RNs provide an identical interface towards User terminals (UT), i.e. there is no necessity for the UT to distinguish between RN and BS. The defined protocol functions include for example packet forwarding in both FDD and TDD mode, end-to-end ARQ, flow control as well as concatenation, segmentation and reassembly [1]. Figure 5 shows how the RN is integrated in the WINNER architecture.

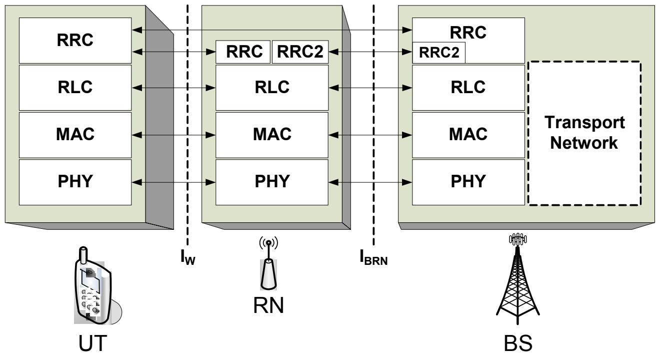

Figure 5: RNs within the WINNER architecture, the control plane.

Radio resource management (RRM) within a relay enhanced cell is of crucial importance to exploit the potential benefits of a relay based deployment. The relaying concept proposes a “distributed" MAC, i.e. the BS dynamically assigns the resources to itself and the RNs in the REC. The RNs can then independently allocate these resources and thus frequency adaptive transmissions and multi-antenna schemes for UTs served by RNs can be supported without forwarding all the required control signalling to the BS. The actual resources that are assigned depend on the utilized interference coordination schemes. Cooperative relaying can further boost the capacity and has been integrated as an add-on to the concept. Multiple radio access points form a virtual antenna array. Any MIMO transmission scheme can then for example be applied to the BS antennas augmented by the antennas of a RN.

An end-to-end performance assessment of the relaying concept for the Base coverage urban (BCU) and metropolitan area (MA) deployment scenarios has been made using system simulations. For the BCU case the spectral efficiency increased by 25% and for the MA the spectral efficiency increase by 28%. The results also indicate the potential of cooperative relaying based on distributed multi-user precoding with an increase in spectral efficiency of 94% in the MA excluding overhead [10]. In the wide area scenario the BS utilizes dynamic resource sharing and coordinates the resources assigned to the RN with the interference coordination at the BS and in the metropolitan area soft frequency reuse is used.

6. Dynamic Spectrum Use

The WINNER system aims at fulfilling the requirements set to beyond 3rd generation wireless communication systems; these requirements include the need to deliver high data rates. In combination with rising numbers of users this leads to an increased spectrum demand. The spectrum demand has been calculated to be in the order of magnitude of 1200 MHz in 2015 [11]. Given the number of wireless systems already deployed today and the increased use of these, identification of exclusive spectrum for new radio systems is becoming increasingly difficult. Flexible spectrum use and spectrum sharing can therefore be seen as key enabling technologies for future radio networks.

The Dynamic Spectrum concept in WINNER is classified in two categories of functionalities:

Spectrum Sharing considers sharing the spectrum on a flexible basis between WINNER and Non-WINNER systems. Two classes of mechanisms are distinguished: horizontal and vertical ones. The *horizontal sharing* is designed for RATs (Radio Access Technologies) with equal access rights to the medium (e.g. co-primary use of a band), *vertical sharing* assumes a hierarchy, i.e. one RAT is primary, the other RAT is secondary.

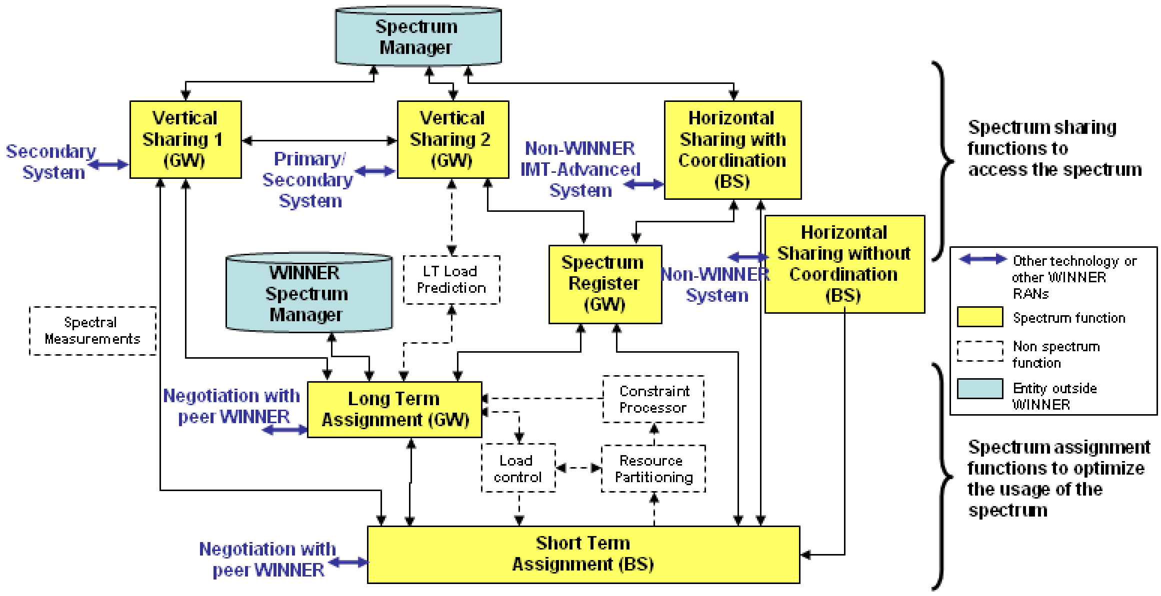

Figure 6: Illustration of the Interactivity of the Spectrum Sharing and Spectrum Assignment Functions in the WINNER Concept

Spectrum Assignment controls the flexible spectrum usage between WINNER RANs (Radio Access Network) and for WINNER RAT (Radio Access Technology) only. *Long term* spectrum assignment mechanisms are applied to exploit long-term averaging effects over daily, weekly traffic patterns for a larger geographical area. Short-term variations on these long-term effects are addressed using the *short-term* mechanism which exploits more locally the fast variations between networks and cells.

The most salient spectrum control functions and interfaces are presented in Figure 6. The figure shows the main interactions between the spectrum control functions and related RRM functions in WINNER, see also [12]. Spectrum is first allocated via the sharing mechanisms; subsequently the spectrum assignment functions within the system further optimize the allocations. The spectrum manager functionality coordinates the negotiations between radio technologies, and additional inputs are included from functions such as resource partitioning, and load prediction.

In light of the outcome of the World Radiocommunications Conference 2007 flexible spectrum technologies are important for IMT systems from two points of view. First, the possibility to share spectrum with other technologies will enable deployments in mobile bands that are not exclusively allocated to IMT. Secondly the flexible spectrum use between different operators will allow for the sharing of resources within the allocated band, enabling operators to offer services to users using higher bandwidths (and thus data rates) than without dynamic spectrum use. One possible implementation is to assign a guaranteed narrow band to each operator and to share the remaining part of the band. This multiband operation is enabled by the Multiband Scheduling concept developed in WINNER [13].

7. End-to-End Performance

7.1 System-Level Evaluation Methodology

As a consequence of the user-centric approach in WINNER, a framework to evaluate system-level spectral efficiency under Quality-of-Service (QoS) constraints was developed. The complex matter of QoS is modelled in a way suitable for MAC and PHY-oriented system-level simulations by a so-called satisfied user criterion (SUC). The SUC requires 95% of the users to achieve a certain minimum average user throughput. In case traffic models are used, an additional requirement on the 95%-ile of the users' average packet delay is applied. The actual throughput and delay requirement values are service-dependent, for the full buffer results shown in this paper 95% of the users are required to have an average user throughput of at least 2 Mbps. In simulations the number of users per sector is increased up to a load, where this SUC is still met. At this maximum number of supported user, the cell spectral efficiency is determined, as illustrated in Figure 7. In this example technique 2 would provide a higher spectral efficiency in the measurement point of this particular SUC threshold than technique 1. The maximum number of supported user (32 in this example) is a key performance indicator, which is important for the business case of a network operator deploying the network.

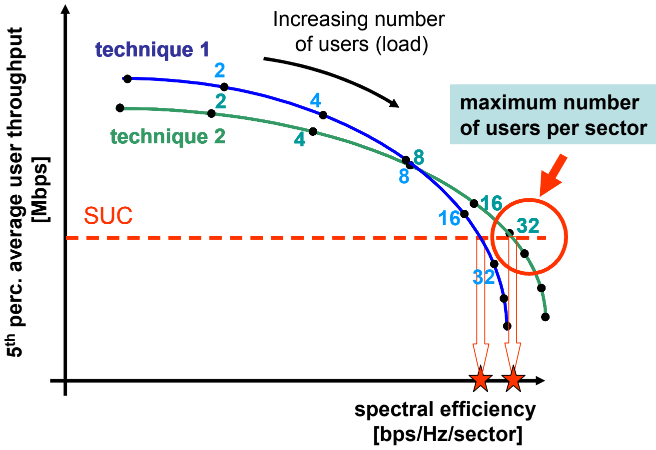

Figure 7: Evaluation methodology for spectral efficiency under QoS constraints modelled by a satisfied user criterion.

7.2 Performance of Advanced Antenna Schemes

Figure 8 shows a comparison of spectral efficiency under SUC constraints and supported number of users for different spatial processing and link adaptation schemes in the downlink of the base coverage urban test scenario [14] using proportional fair scheduling. Basic link adaptation (BLA) is a scheme where adaptation is based on the average SINR, Mutual Information based Adaptive Coding and Modulation (MI-ACM) refers to the bit loading algorithm as described in Section 3. It can be seen that the 4x2 Grid-of-Beams-based schemes (denoted "GoB", "GoB+SDMA") in particular boost the maximum number

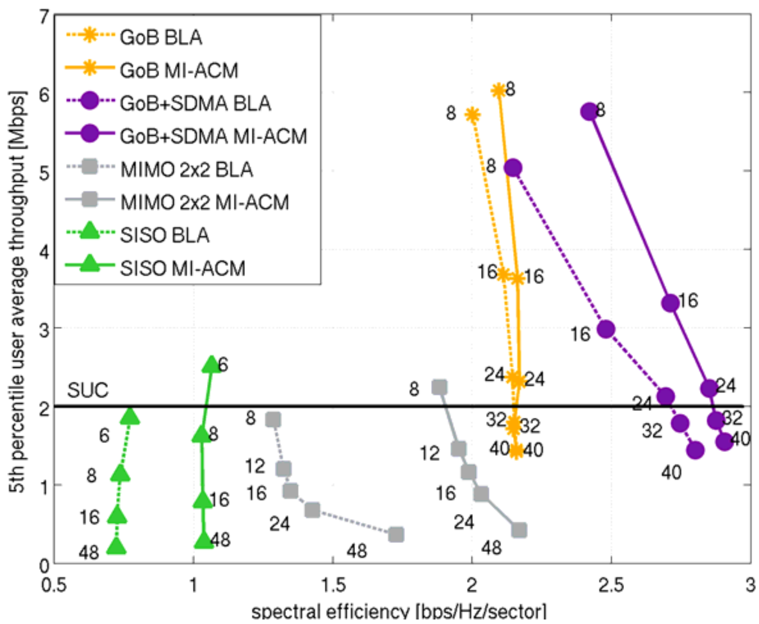

Figure 8: Performance of Spatial Processing and Link Adaptation

of satisfied users: from 7 users per sector for SISO, to 9 users for 2x2 adaptive MIMO, to 28 users for GoB, and to 30 users for GoB+SDMA. The spectral efficiency achieved for this maximum supported load is 1.0, 1.9, 2.2, and 2.9 bps/Hz/sector for SISO, 2x2 MIMO, 4x2 GoB, and 4x2 GoB+SDMA, respectively. Apart from the GoB case, where the limitation of the highest MCS impacted proper link adaptation, significant system-level gain is observed by the MI-ACM scheme.

8. Conclusions

This paper provides a concise overview of the essential, key features of the WINNER system concept, the highlights of the resulting system design, and performance assessment methodology to obtain e2e performance results. These results show the WINNER system concept to be a promising system proposal for the IMT-Advanced process of the ITU which is currently ongoing and planned to be completed early 2011. More details on the WINNER system concept can be obtained from [1]. A follow up project named WINNER+ has been initiated under the Celtic label building on the innovations from WINNER, and the actual status in ITU-R and 3GPP LTE.

Acknowledgements

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