KEY TECHNOLOGIES FOR IMT-ADVANCED MOBILE COMMUNICATION SYSTEMS

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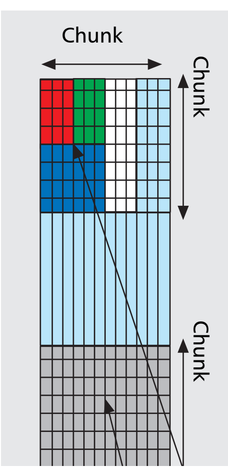

WINNER is an ambitious research project aiming at identification, development and assessment of key technologies for IMT-Advanced mobile communication systems.

ABSTRACT

WINNER is an ambitious research project aiming at identification, development, and assessment of key technologies for IMT-Advanced mobile communication systems. WINNER has devised an OFDMA-based system concept with excellent system-level performance for flexible deployments in a wide variety of operating conditions. The WINNER system provides a significant step forward from current 3G systems. Key innovations integrated into the system concept include flexible spectrum usage and relaying, adaptive advanced antenna schemes and pilot design, close to optimal link adaptation, hierarchical control signaling, and a highly flexible multiple access scheme. The end-to-end performance assessment results demonstrate that the WINNER concept meets the IMT-Advanced requirements.

INTRODUCTION

International Mobile Telecommunications — Advanced (IMT-Advanced) systems are mobile broadband communication systems that include new capabilities that go significantly beyond those of the IMT-2000 family of systems such as wideband code-division multiple access (WCDMA) or WiMAX. One of the key features of IMT-Advanced are the enhanced peak data rates to support advanced services and applications. A peak spectral efficiency of 15 b/s/Hz is required for the downlink (DL), and 6.75 b/s/Hz for the uplink (UL) [1]. As an example, in 40 MHz bandwidth the DL peak rate is 600 Mbytes/s; in a 100 MHz the DL peak rate is 1.5 Gbytes/s . A request for IMT-Advanced technology proposals has been issued by the International Telecommunication Union (ITU) [2], according to which candidate radio interface technologies can be submitted during 2008 and 2009 (October 2009 is currently proposed as the deadline to submit proposals). The evaluation phase is scheduled to be finalized in June 2010. In parallel with the evaluation activities, an assessment of the evaluations and consensus building between the proposals will take place. This process will continue until October 2010. An ITU — Radiocommunication Standardization Sector (ITU-R) Recommendation containing the IMT-Advanced radio interface specification is scheduled for February 2011 [2].

Wireless World Initiative New Radio (WINNER) was an ambitious research project funded during 2004–2007 by the Sixth Framework Program of the European Commission, aiming at identification and assessment of key technologies for IMT-Advanced mobile communication systems. The project partners consisted of the major industrial and academic players in mobile communications. The main outcome of the project is the definition of the WINNER system concept and the related system design, backed up by a proof of concept in the form of extensive system-level simulations under realistic system deployments [3, 4].

While the WINNER radio access network (RAN) is designed to fulfill the IMT-Advanced requirements, additional and in certain cases stricter requirements are derived from services the WINNER RAN has to support. For exam-

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ple, a minimum transmission delay of 1 ms in DL and 2 ms in UL over the radio interface has been required to support highly interactive services, whereas IMT-Advanced requires a user plane delay of less than 10 ms over the air interface [1]. The WINNER system concept is based on orthogonal frequency-division multiple access (OFDMA); thus, the key technology components and assessment results provide relevant input for the future evolution toward IMT-Advanced of other OFDMA-based systems such as WiMAX [5] and Third Generation Partnership Project (3GPP) Long Term Evolution [6].

This article provides an overview of the WINNER system concept and several of its key innovative technology components. The next section provides a description of the system capabilities and the logical node architecture. We then describe the developed solutions for multiple access and medium access control (MAC). We then focus on the advanced antenna concept with end-to-end performance results. We provide an overview of the relaying concept and describe the dynamic spectrum use solutions. The final section concludes the article.

WINNER System Concept

WINNER System Capabilities

The WINNER system has been designed to meet the IMT-Advanced requirements in diverse deployment scenarios: wide, metropolitan, and local areas. Wide area deployment provides ubiquitous coverage in a manner similar to cellular systems known today; the metropolitan area targets dense urban scenarios, typically built according to a tight city plan; and the local area concentrates on the provision of high data rates to indoor users. The air interface is based on OFDMA, allowing flexible and fine-grained multi-user resource allocation. Parameterizations of the air interface provide flexibility and maximum efficiency depending on such factors as the particular radio environment, usage scenario, and economic model. The system provides a user-centric and flexible protocol architecture, integrating relaying, advanced spatial processing schemes, and dynamic spectrum use.

The main WINNER system parameters are provided in Table 1. The system design has been iterated and refined based on extensive system simulations to find an optimum trade-off between system performance, complexity, and deployment cost. Compared to current 3G systems, these provide a significant step forward, providing in particular a large scalable bandwidth of up to 100 MHz, and support for significantly higher data rates than in use today and extremely low latencies of the air interface. The flexible multiple access scheme simultaneously enables frequency adaptive transmission with high spectral efficiency for high-data-rate users and low mobility, and diversity transmission for low-data-rate and high-mobility users. Capabilities for spectrum sharing enable new modes of operation and provide access to spectrum bands that would otherwise be unavailable. Two categories of mechanisms have been developed. One category enables operation in shared spectrum between IMT-Advanced and other technologies, and another category provides mechanisms for intersystem coordination between different networks all deploying IMT-Advanced technology. The envisioned high-data-rate services will only be adopted by users if the cost per transmitted bit is sufficiently low. Relay-based deployments have been identified as a key technology component to provide cost-efficient high-bit-rate coverage exploiting the cost advantage of relays due to their flexible deployment. Finally, advanced multi-user multiple-input multiple-output (MU-MIMO) schemes are crucial in achieving high spectral efficiency. Their adaptable design together with appropriately designed pilot symbol patterns and the use of hierarchical control signaling enables the usage of multi-antenna techniques tailored to a wide range of scenarios without excessive control and pilot signaling overhead. The required spectral efficiency of 15 b/s/Hz for IMT-Advanced systems, for example, can be achieved with eight antennas and four parallel streams to four users each having 64-quadrature amplitude modulation (QAM) and code rate 2/3. However, more important than the peak data rates are the data rates that are achieved in a realistic deployment with a guaranteed throughput to the users. In such a scenario the WINNER system achieves a spectral efficiency of about 10 b/s/Hz in a wide area deployment.

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System Architecture

The WINNER system architecture defines logical nodes and the corresponding interfaces. The objective is to define as few logical nodes as possible to keep the number of interfaces small. Sophisticated function grouping enables a flat architecture as in the system architecture evolution of 3GPP Long Term Evolution [6]. For example, there are only two nodes in the user plane, which reduces the number of involved nodes in the connections, as well as flexible, scalable, and cost-efficient implementations (e.g., by defining logical nodes as pooled resources to recover from node failures). The system architecture addresses the lowest three layers of the open systems interconnection (OSI) stack, supporting both single-hop and multihop communication. The two lowest layers, represented by the physical (PHY), MAC, and radio link control (RLC) sublayers, are present in all base station (BS), user terminal (UT), and relay node (RN) logical nodes, denoted BS_{LN}, UT_{LN}, and RN_{LN}, respectively. This enables efficient cross-layer design of these layers. For example, fast hybrid automatic repeat request (HARQ) with low additional control overhead (low code protection of the feedback signaling) takes place at the MAC layer, whereas the more robust RLC-ARQ facilitates recovery from occasional HARQ negative acknowledgments (NACKs) interpreted as acknowledgments (ACKs).

Figure 1 illustrates the WINNER logical node architecture [3], providing a logical mapping of the interactions between different func-

Capability	Value
Spectrum	
Carrier frequencies	Generally between 450–5000 MHz, including the newly identified bands for IMT: 450–470 MHz, 698–892 MHz, 2.3–2.4 GHz, 3.4–3.6 GHz
System bandwidth	1.25–100 MHz
Duplexing	FDD (wide area) and TDD (metropolitan area, local area)
Flexible spectrum sharing with other RANs	Supported by flexible spectrum use
Flexible spectrum sharing with other primary or secondary systems	Supported by sharing and coexistence schemes
Link adaptation	
Modulation	BPSK, QPSK, 16-QAM, 64-QAM, 256-QAM
Channel coding	Convolutional coding and LDPC codes optimized for short and long block lengths, respectively
Spatio-temporal processing	MU-MIMO with 2 terminal antennas and up to 32 base station antennas (metropolitan area and local area), grid of beams with SDMA (wide area).
Hybrid ARQ	LDPC-based incremental redundancy, mother code rate = 1/3
Multiple access methods	
Multiple access	Chunk-wise adaptive TDMA/OFDMA, B-IFDMA (UL), B-EFDMA (DL) combined with SDMA when appropriate
Subcarrier spacing	FDD: approx .39 kHz TDD: approx .49 kHz
Superframe/frame duration	5.69 ms/0.6912 ms
Scenarios/Deployments	
Cyclic prefix (CP)	3.2 μs (FDD mode), 1.2 μs (TDD mode)
Mobility	≤ 10 km/h (local srea), ≤ 50 km/h (metropolitan area), ≤ 350 km/h (wide area)
Relaying	Decode-and-forward relaying with cooperative relaying as an optional add-on
Peak Spectral Efficiency	Exceed the IMT-Advanced requirements of 15 b/s/Hz
Minimum delay	Downlink: 1 ms Uplink: 2 ms

■ **Table 1.** *Main WINNER system capabilities with parameterization for different scenarios.*

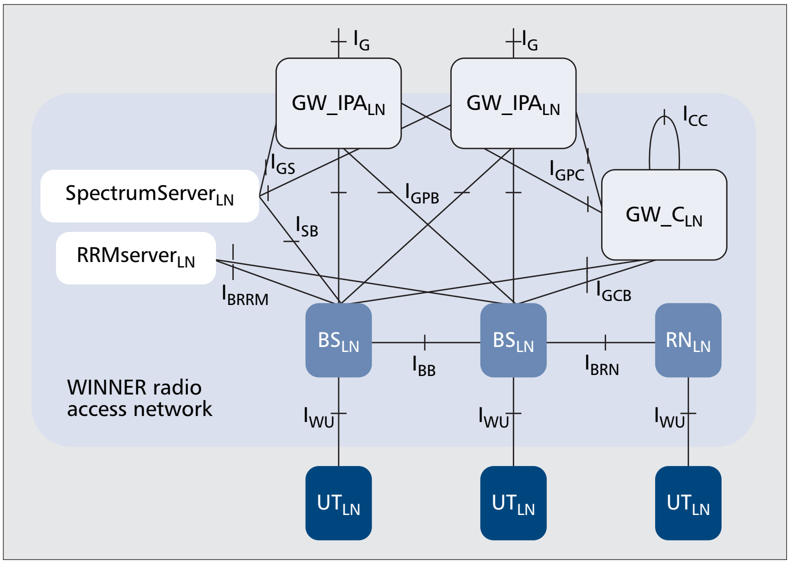
tional entities, whereas some of them might be combined into single physical nodes.

The BS logical node BS_{LN} performs all radio related functions, including user mobility, for active terminals, and is responsible for governing radio transmission to and reception from UT logical nodes UT_{LN} and RN logical nodes RN_{LN}. The BS_{LN} controls the relays, determines routes (i.e., handovers), and forwards packets to the respective relay. 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}, so there is no necessity for the UT_{LN} to distinguish between RN_{LN} and BS_{LN}. The $SpectrumServer_{LN}$ enables sharing and coexistence with other radio access technologies, as well as spectrum assignment between WINNER networks. An optional $RRMserver_{LN}$ could be used, for example, for load sharing and user mobility control. The GW_IPA_{LN} is a user plane node that provides access to external data networks and operator services, terminates flows on the network side, and serves as the anchor point for external routing. It is accompanied by the GW_C_{LN}, which provides control functions for UT_{LN}s that are not active (i.e., terminals not sending data) and functions that control and configure the GW_IPA_{LN}.

MULTIPLE ACCESS AND MAC

The WINNER MAC layer is designed for minimum air interface delays of 1 ms in DL and 2 ms in UL, which are attained for single-hop transmission by short frame durations of 0.7 ms. The low latency enables adaptability with respect to fast channel variations, so link adaptation and multi-user scheduling gains can boost the spectral efficiency. A tight feedback control loop enables fast HARQ retransmissions with a retransmission delay below 1.4 ms, which facilitates high-throughput TCP/IP traffic and provides reliable links even for real-time services.

The packet processing procedure, as well as the physical layer processing, is controlled by the scheduler within the MAC layer. The scheduler adaptively distributes the available resources to multiple users in time, frequency, and space, conditioned on the available channel state information (CSI), and can be deployed in a wide variety of system bandwidths and propagation scenarios. Depending on the channel conditions and/or user velocities, the scheduler distinguishes between *frequency-adaptive* and *non-frequency-adaptive* transmission. When the user velocities are sufficiently low, the BS can utilize short-term CSI at the transmitter, giving rise to frequency-adaptive transmission. Frequency-adaptive transmission combines multi-user scheduling and individual link adaptation of time-frequency-space resource blocks (denoted *chunk layers*), with a chunk-wise adaptive time-division multiple access (TDMA)/OFDMA scheme. With a sophisticated multi-user multiflow scheduler, very high spectral efficiency is obtained, while also taking user fairness restrictions into account. The DL signaling overhead is reduced by an adaptive hierarchical design of the allocation tables containing the resource allocation to the users within the frame [7]. A small table with robust channel coding is broadcast to all users and describes for every user how to decode a second table. The second table contains the relevant resource allocation information encoded with different levels of coding depending on the user's link quality. The short frame duration in combination with channel prediction enables frequency-adaptive transmission even at vehicular speeds [8]. 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. This method has several advantages over adapting both modulation and code rate per chunk. First, the system complexity is kept low since only one encoder/decoder pair is required. It also facilitates the implementation of rate-compatible puncturing, which is required for seamless integration of HARQ strategies. The common encoding over all chunks allows the full potential of the channel code to be exploited and is thus particularly powerful for the applied *quasi-cyclic block low-density parity check code* [3]. Last but not least, since this transmission scheme is a multicarrier version of bit-interleaved coded modulation, iterative decoding techniques are directly applicable. The associated novel bit-loading algorithm, called Mutual Information Based Adaptive Coding and Modulation (MI-ACM) [9], is based on the mutual information per coded bit. This allows the combination of fine-grained adaptation of the resources within a code block with strong channel coding for arbitrary codeword lengths. Apart from its high accuracy in meeting the targeted error rate, this algorithm stands out for its very low complexity: the modulation scheme per chunk is assigned by a simple table lookup, and it contains no iterations. Additionally, it has been found that this adaptation scheme, even without employing power loading, yields performance very close to the theoretical optimum.



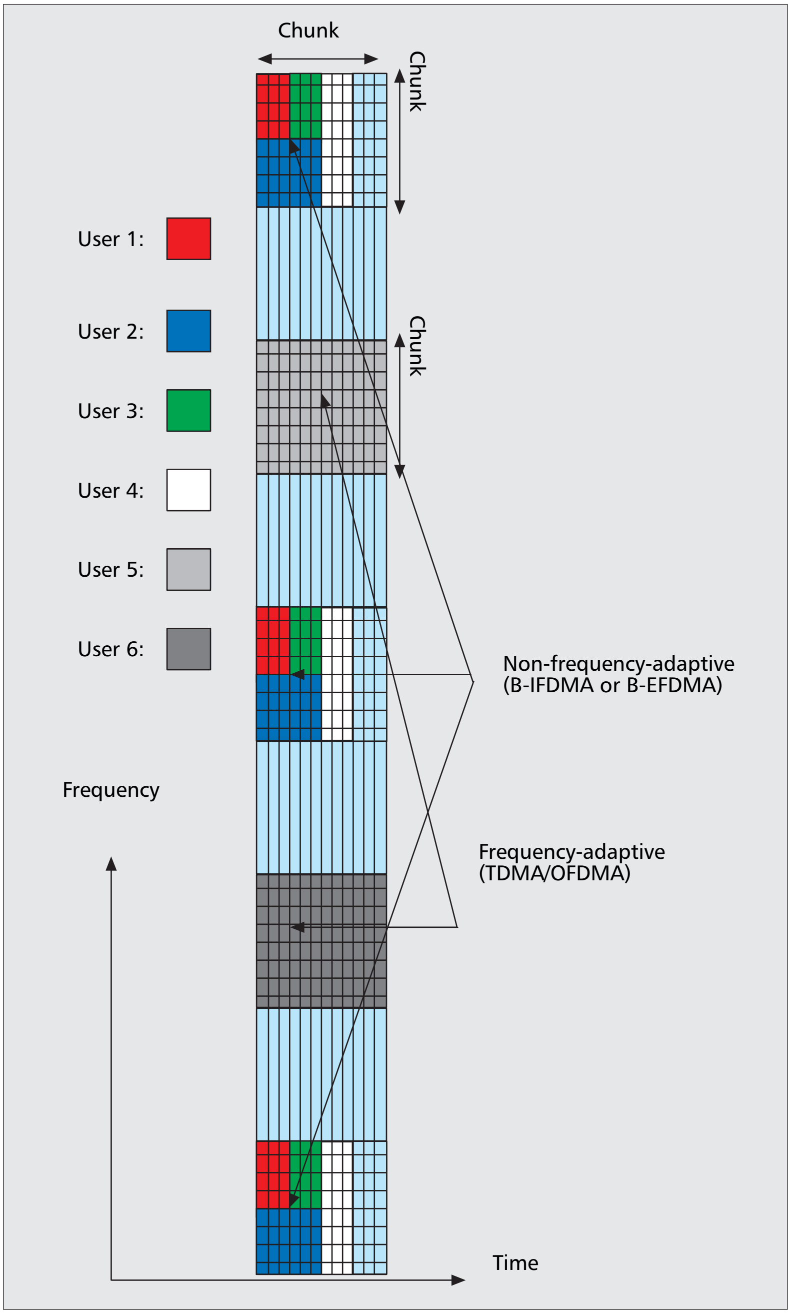
■ **Figure 1.** *WINNER logical node architecture providing as few logical nodes as possible, and keeping the number of interfaces small. The architecture includes base stations (BSs), relay nodes (RNs), gateways (GWs), user terminals (UTs), a spectrum server, and an optional radio resource management server.*

For users with high speed and for short control packets, a robust diversity-based transmission scheme is also needed. The WINNER system then resorts to the non-frequency-adaptive transmission mode that obtains its robustness by dispersed allocation of resources, providing diversity from the frequency and spatial domains. The resource allocation structure in frequency and time provides a tunable degree of frequency diversity. In order to support for high power amplifier efficiency, envelope variations are reduced by a discrete Fourier transform (DFT) precoding step in the UL. In addition, an adjustable time-localized allocation allows the receiver to be switched off for short periods within an OFDMA chunk, which enables improved battery life in UTs. These time-localized and regularly frequency dispersed allocations form block allocations in the time-frequency domain, as illustrated in Fig. 2. The allocated blocks are separated equidistantly in frequency to facilitate the use of DFT precoding in ULs. The corresponding medium access schemes are denoted block interleaved frequency-division multiple access

(B-IFDMA) in the UL and block equidistant frequency-division multiple access (B-EFDMA) in the DL [3].

An important enabler for efficient coexistence and switching of the two transmission modes is the cross-layer design of the MAC layer, as illustrated in Fig. 3. Efficient switching between frequency-adaptive and non-frequency-adaptive transmission is supported by a common approach to channel coding and retransmissions.

The modulation and coding requirements for control channel signaling are different than the ones for user data transmissions, due to very short packet sizes being considered (on the order of 25 information bits). Therefore, low-rate tail-biting convolutional codes have been introduced and lead to good performance [3].



■ **Figure 2.** *Illustration of multiple access resources allocation: chunk-wise adaptive TDMA/OFMDA, B-IFDMA, and B-EFDMA.*

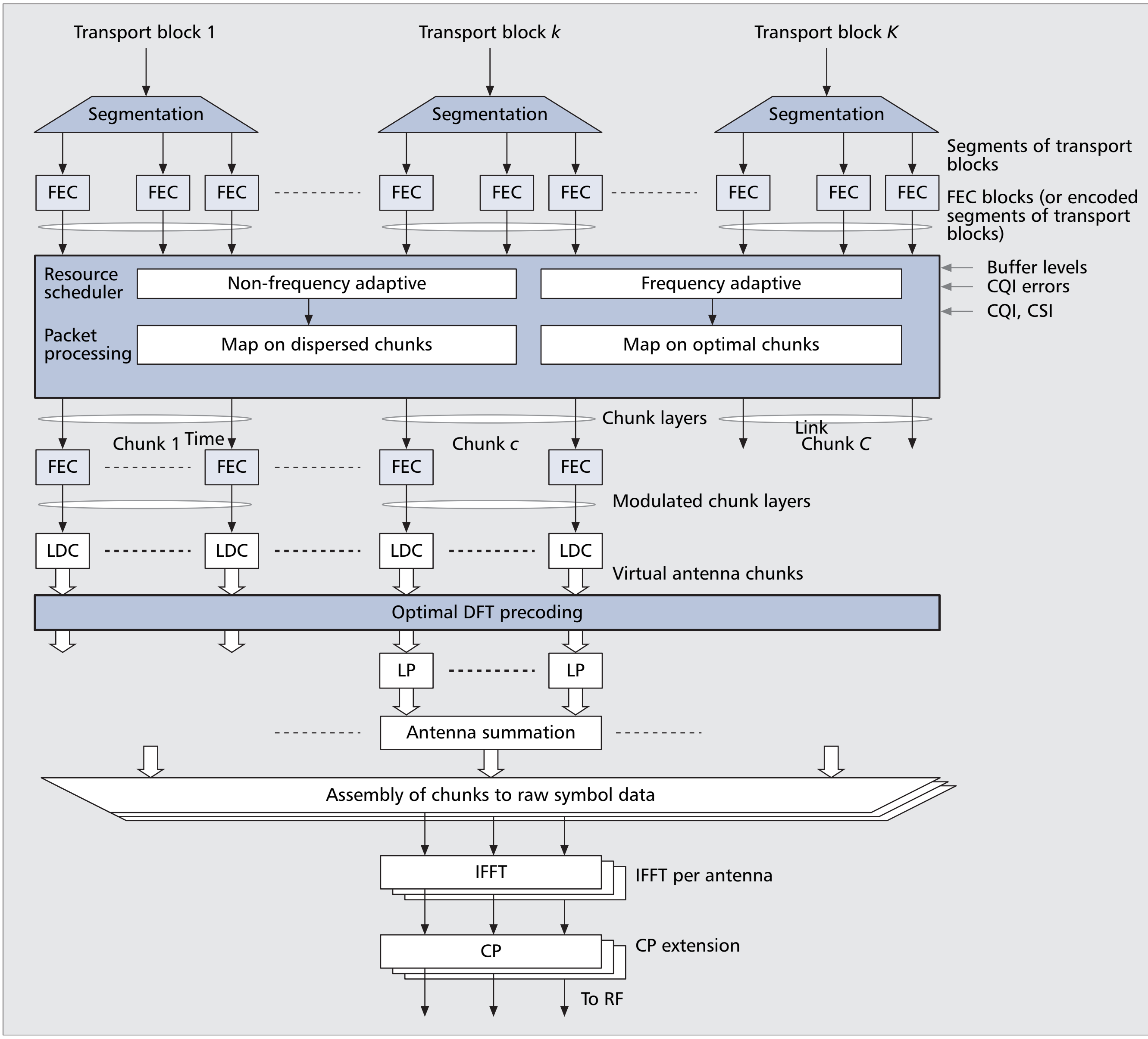
Advanced Antenna Concept and Performance Assessment

The flexible WINNER advanced antennas concept [10] works with varying degrees of available channel knowledge at the transmitter. It supports flexible combinations of spatial multiplexing, space-division multiple access (SDMA), spatial diversity, beamforming, and a means of enhanced interference management. The WINNER transmitter concept is illustrated in Fig. 3. The transport blocks of the scheduled flows are segmented, channel encoded (forward error correction [FEC]), and multiplexed onto the available chunks. After modulation, the selected spatial temporal processing techniques are applied: linear dispersion ccode (LDC), DFT precoding, and linear precoding (LP). Not all of these function blocks will be operational all 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). Thereafter the chunks are summed and passed to OFDM modulation per antenna. The transmit schemes can be selected and optimized per flow instead of per user. Thus, the concept enables the use of different multi-antenna schemes for multiple flows to a single user that have different quality of service (QoS) requirements.

The multi-antenna function blocks can operate based on long-term or short-term CSI. Long-term CSI operation is most useful in wide area deployments, supporting medium to large cells and user velocities up to 350 km/h. In wide area deployments the BS antennas are typically mounted above the rooftop. The narrow angular spread of electromagnetic waves results in high spatial correlation between BS antenna elements. We have identified linear beamforming as providing the best performance vs. complexity trade-off for these cases [10]. A four-element uniform linear array is used to form eight fixed beams (so-called grid of beams [GoB]). This solution allows transmissions to multiple users on the same chunk in different beams. In combination with advanced receive combining techniques, a spectral efficiency of more than 8 b/s/Hz/site can be reached [10].

Short-term-CSI-based operation is most useful in metropolitan and local area deployments, supporting small urban and indoor cells with limited user mobility. In these scenarios it is assumed that accurate CSI is available at the transmitter, which is required for advanced MU-MIMO precoding schemes. These techniques spatially multiplex streams of several users with low or no interference between the streams in order to provide very high system throughput. The gain is especially pronounced in a rich scattering radio environment (i.e., local area) where distributed antennas can achieve spectral efficiency of more than 13 b/s/Hz for a BS equipped with 8 antennas [10]. In urban scenarios a spectral efficiency of more than 9 b/s/Hz was reached with 8 BS antennas.

In system-level performance assessments of

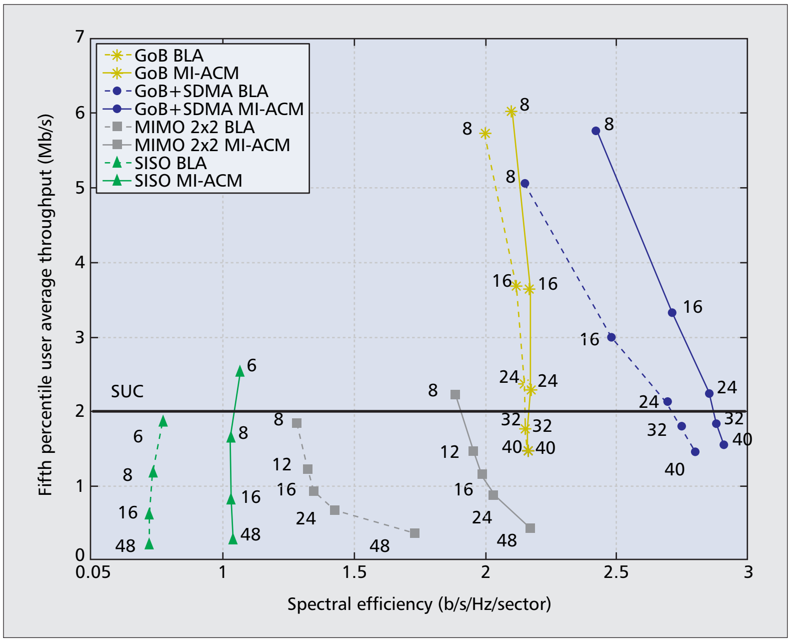


■ **Figure 3.** *The WINNER transmitter structure integrates the multiple access schemes for the frequency-adaptive and non-frequency-adaptive transmission modes in the MAC layer.*

the advanced antenna concept, a user-centric approach based on the satisfied user criterion (SUC) was adopted. The SUC requires 95 percent of users to have an average user throughput of 2 Mb/s or higher in the DL [4] (i.e., the system provides a good level of service at the cell edge). Figure 4 shows an example comparison of spectral efficiency under the SUC and the supported number of users for a wide area deployment using the frequency-division duplex (FDD) mode at a carrier frequency of 3.95 GHz and 2 × 50 MHz system bandwidth. The BS sites are deployed on a 19-cell hexagonal grid layout with 1 km distance, each having three sectors with a uniform linear array of four antenna elements ($\lambda/2$ element spacing), and a wraparound technique is used to avoid edge effects. The users are uniformly distributed with a speed of 3 km/h, and full buffer traffic is assumed.

Different spatial processing and link adaptation schemes are compared in the DL using proportional fair scheduling. Basic link adaptation (BLA) is a scheme where adaptation is based on the average signal-to-interference-plus-noise ratio (SINR), and MI-ACM refers to the bit loading algorithm described in the previous section. It can be seen that the 4 × 2 GoB-based schemes (denoted GoB, GoB+SDMA) in particular boost the maximum number of satisfied users: from 7 users/sector for single antennas at BS and UT (single-input single output [SISO]) to 9 users for 2 × 2 adaptive MIMO, 28 users for GoB, and 30 users for GoB+SDMA. The spectral efficiency achieved for this maximum supported load is 3.0, 5.7, 6.6, and 9.7 b/s/Hz/site for SISO, 2 × 2 MIMO, 4 × 2 GoB, and 4 × 2 GoB+SDMA, respectively. Apart from the GoB case, where the highest modulation and coding scheme limited the observed throughput, a significant system-level gain is observed by the proposed MI-ACM scheme.

Reference symbols known to the receiver



■ **Figure 4.** *Performance of spatial processing and link adaptation.*

(pilots) are commonly used to support coherent detection at the receiver. *Dedicated pilots per beam* that include user-specific spatial processing are required to estimate the effective channel at the receiver. Furthermore, common pilots probe the channel over the entire frequency band to facilitate frequency-adaptive transmission. Unfortunately, straightforward combination of common and dedicated pilots may lead to prohibitive pilot overheads, especially when the number of transmit antennas is large. The WINNER pilot design exploits spatial correlation at the transmitter to retain a modest pilot overhead that does not exceed 16 percent [4]. In this design dedicated pilots associated with well spatially separated beams may be multiplexed in space (i.e., pilots of different spatial streams are placed on the same subcarriers). Moreover, common pilots may only be selectively inserted with reduced rate on a subset of transmit antennas [11]. One implication of the bandwidth-efficient pilot design is that iterative channel estimation is needed to meet the required channel estimation accuracy [12].

Relaying Concept

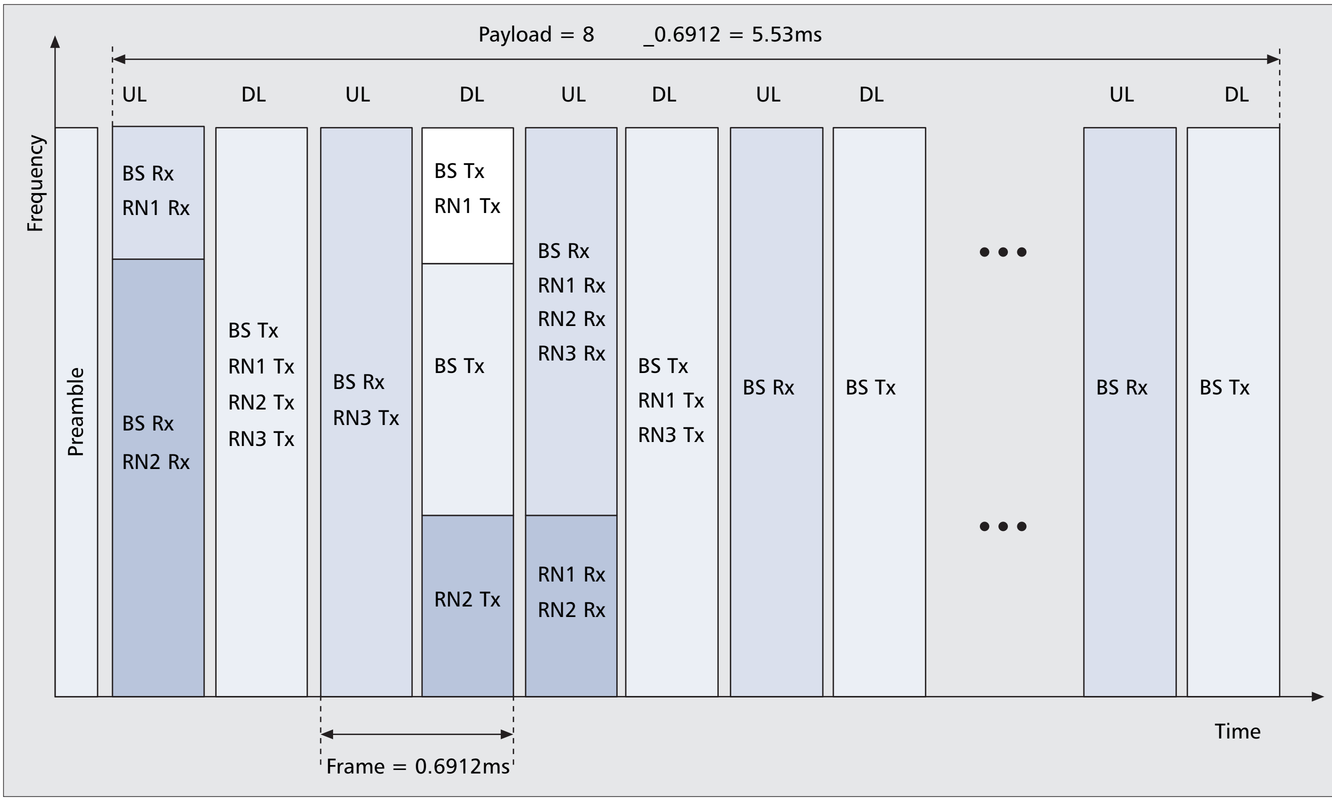
Next to performance targets, IMT-Advanced mobile communication systems need to significantly reduce the cost per transmitted bit in order to be commercially successful. Relay-based deployments are an integral part of the WINNER system architecture, and are effective to reduce the deployment costs of the system.

Relay-based deployments were found to be cost efficient in wide area deployments, with cost ratios between micro BS and RN of at least 1.15, given a nonuniform traffic density [13]. In [14] two cellular metropolitan area networks with an equal target area capacity and uniform traffic density were compared; a micro BS scenario consisting of smaller cells (and thus a high number of BSs) and a relay-based scenario consisting of larger cells but with relays in each cell. In this comparison the cost efficiency of the relay-based deployment exceeds the micro-BS-based deployment for a cost ratio of 3. The cost advantage of relays is mainly achieved by lower deployment and site rental costs relative to deploying BSs, which affects both capital and operational expenditures. The deployment costs of relays are decreased through smaller physical size, due to lower output power and lower complexity than a micro BS. Moreover, relays benefit from superior deployment flexibility, since relays do not require a wired backhaul connection. Furthermore, they operate on the same band as the BS, and no additional spectrum is required.

The WINNER relay is a half-duplex decode and forward relay at a fixed location, which can take advantage of adaptive transmissions with different modulation and coding schemes. This is especially beneficial for intelligent deployments with good link quality between BS and RN, which is observed, for example, by deploying RNs in the same street as the BS. The relay concept is designed and optimized for two-hop connections, but the topology may be extended to more than two hops. An RN can (re)segment received packets when forwarding them to another RN or UT, an end-to-end RLC-ARQ process ensures reliable packet transmission in the case of handovers, and flow control avoids buffer overflows at the RN [3].

Radio resource management within a relay enhanced cell (REC) is of crucial importance to exploit the potential benefits of a relay-based deployment. A *distributed* MAC scheme is applied. The BS dynamically assigns the resources to itself and the RNs in the REC. The RNs can then independently allocate these resources; thus, frequency adaptive transmissions and multiantenna schemes for UTs served by RNs can be supported without forwarding all the required control signaling to the BS. Figure 5 illustrates the flexible assignment of resources for an example scenario with three relays in the REC. Different allocations between BSs and relays, here referred to as radio access points (RAPs), are possible: a frame can be shared between all RAPs, or part of a frame can be allocated to a limited number of RAPs or a unique RAP. The actual resources assigned depend, for instance, on delay requirements, traffic load, or the interference coordination scheme utilized. As an example, in a wide area deployment the BS can utilize a grid of beams; beams overlapping with the relays are not used when the RN is serving UTs. In the metropolitan area, interference coordination by assigning power masks (soft frequency reuse) to BS and RNs has been shown to be effective [14]. If an RN is not serving UTs, it transmits or receives traffic from the BS.

Cooperative relaying can further boost the capacity and has been integrated in the concept as an add-on to single-path relaying. Multiple RAPs form a virtual antenna array, and the MIMO transmission schemes of the previous section can be applied to the BS antennas augmented by the antennas of a RN. Cooperative relaying is only applied to UTs having similar received signal strength from multiple RAPs in the same tree topology.



■ **Figure 5.** *Example allocation of a superframe using the flexible resource partitioning scheme in a relay enhanced cell with three relays (RNs). The superframe consists of a preamble and an eight-frame payload. The BS allocates (a part of) the resources to the RNs; the RNs independently schedule their associated users within their allocations.*

End-to-end performance assessment results of the relaying concept [4, 15] show that adding one RN per BS sector increases the spectral efficiency by 25 percent for the wide area scenario and 28 percent for the metropolitan area scenario. Cooperative relaying based on distributed multi-user precoding can boost the spectral efficiency by 94 percent in the metropolitan area, excluding signaling overhead and imperfections.

Dynamic Spectrum Use

In light of the outcome of the World Radiocommunications Conference 2007, flexible spectrum technologies are important for IMT systems for two reasons. First, the possibility of sharing spectrum with other technologies will enable deployments in mobile bands that are not exclusively allocated to IMT. Second, flexible spectrum use between different operators will allow sharing of resources within the allocated band, enabling operators to offer services to users using higher bandwidths and thus data rates.

Therefore, the spectrum usage concept in WINNER is classified in two categories, as illustrated in Fig. 6: spectrum sharing (frequency sharing between the WINNER system and other radio technologies) and flexible spectrum use (FSU, frequency sharing between WINNER systems). The goal of spectrum sharing is to obtain access to spectrum bands that would otherwise be used exclusively by a single technology. On the other hand, flexible spectrum use provides a means of sharing the spectrum between networks of the same technology, increasing both overall system efficiency as well as the flexibility and scalability of the system. An example of a spectrum sharing scenario is sharing the spectrum between WINNER and fixed satellite services (FSS) in the C-band DL (3.7–4.2 GHz).

Under the spectrum sharing umbrella, two different types of schemes have been developed [3]. They are based on system-specific spectrum access rights. If one of the systems has higher access rights to the spectrum, *vertical* sharing schemes are used. When WINNER is the primary system, it can assist the secondary system by enabling resource negotiations and broadcasting resource information. If WINNER is the secondary system, the emissions of its BS and UTs are controlled not to interfere with the primary system. The activity of the primary system and information about exclusion zones where WINNER UTs are not allowed to operate may be obtained, for example, from a beacon signal transmitted by the primary system. Using these mechanisms, WINNER can share the spectrum with primary systems, such as the earth stations of FSS. Given the uncertain availability of shared bands with other systems, the WINNER concept provides efficient multiband operation with fast band switching. A dedicated band allows guaranteed access, while the shared band is used only when available [16].

If the WINNER system shares spectrum with other systems on the basis of equal access rights, *horizontal* sharing schemes are applicable. The systems contending for the spectrum coordinate spectrum use by means of negotiations. When the systems cannot negotiate, coexistence

The WINNER system concept and design is user centric and flexible, enabling operation in multiple bands with scalable bandwidths. The system can be utilized in a wide range of deployment scenarios.

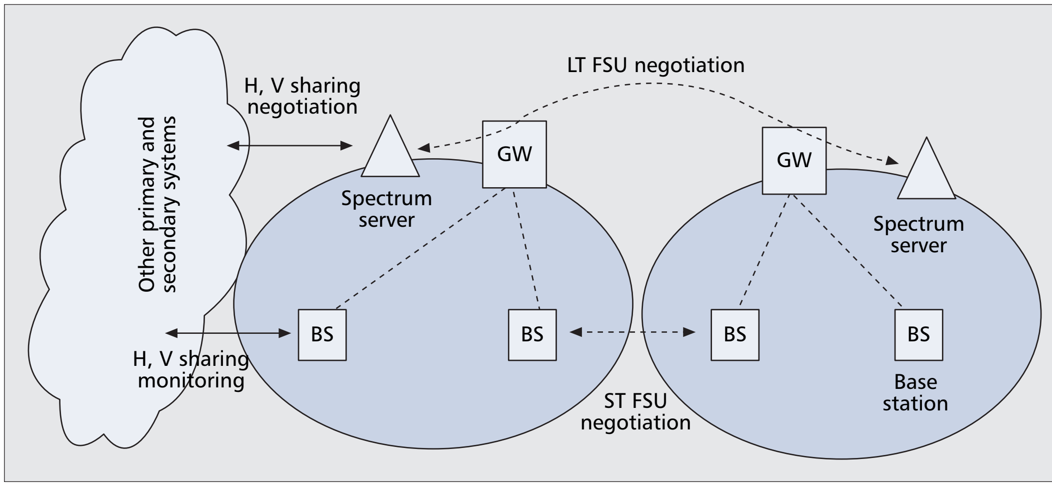


Figure 6. *Different spectrum sharing mechanisms horizontal and vertical sharing with other systems and long-term and short-term FSU between systems of the same technology.*

between competing systems is maintained by observing the spectrum use and following certain etiquette rules. The monitoring of spectrum use by other technologies is done at the BS.

The WINNER system supports two different FSU strategies to share the spectrum with other WINNER systems: long-term (LT) and short-term (ST) FSU, taking 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, and the spectrum is negotiated over a longer timescale (i.e., on the order of minutes). The ST assignment acquires the fine tuning of the spectrum assignment at the cell level. This is performed at shorter timescales than in LT assignment: the ST assignment negotiation of spectrum is performed over time periods of several hundred milliseconds in duration.

Conclusions

WINNER was an ambitious research project aiming at identification, development, and assessment of key technologies for IMT-Advanced mobile communication systems. The WINNER system concept and design is user-centric and flexible, enabling operation in multiple bands with scalable bandwidths. The system can be utilized in a wide range of deployment scenarios, ranging from rural environments to dense metropolitan scenarios. The WINNER system provides a significant improvement over cellular 3G networks deployed today. Key innovations in the concept include a flexible advanced antenna and pilot design, close to optimal link adaptation, hierarchical control signaling, a flexible multiple access scheme, relaying, and flexible spectrum use. The end-to-end performance of the final system concept and its components has been assessed showing high spectral efficiency and providing high data rates to users at the cell edge.

The IMT-Advanced process is currently ongoing in the ITU and scheduled to be completed early 2011. We show that the WINNER system concept is a promising IMT-Advanced-compliant system concept, achieving the required high data rates and peak spectral efficiencies. The key technology components and assessment results provide relevant input to future evolutions toward IMT-Advanced of other OFDMA-based systems such as WiMAX and 3GPP Long Term Evolution.

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