Multisite Field Trial for LTE and Advanced Concepts

Ralf Irmer, Vodafone

Hans-Peter Mayer, Andreas Weber, Volker Braun, Michael Schmidt, Michael Ohm, and Norbert Ahr, Alcatel-Lucent Bell Labs

André Zoch, Signalion GmbH

Carsten Jandura, Patrick Marsch, and Gerhard Fettweis, Technische Universität Dresden

ABSTRACT

The 3GPP LTE standard is stable now in its first release (Release 8), and the question is how good its performance is in real-world scenarios. LTE is also a good base for further innovations, but it must be proven that they offer performance advantages for the price of their complexity. This article evaluates the performance of LTE Release 8 as a baseline and advanced concepts currently in discussion such as cooperative MIMO based on system-level simulations, and measurements in the laboratory and a multisite field testbed within the EASY-C project.

INTRODUCTION

The mobile Internet has finally arrived with the worldwide deployment of high-speed packet access (HSPA) networks and broad availability of third-generation (3G) terminals, mobile broadband USB sticks, and, increasingly, notebooks with integrated HSPA modules. With flatrate data tariffs, the usage of mobile Internet has skyrocketed in 2008. Third-generation technology was developed more than a decade ago, and the uptake after launch was below expectations in many cases. There are various reasons for that, including initial lack of handset availability and initial technology performance below predictions.

The Next Generation Mobile Networks (NGMN) Alliance has set out requirements for future mobile networks [1], and the Third Generation Partnership Program (3GPP) is addressing them with the development of long-term evolution (LTE). Among the requirements for LTE are increased average and peak data rates, reduced latency, spectrum flexibility addressing bandwidths of up to 20 MHz, and, last but not least, reduced cost of ownership. The targets in NGMN and LTE are set challenges to ensure a significant performance step from HSPA to a new technology generation.

The performance of LTE meets the essential NGMN requirements, but not the preferred requirements in important key performance indicators (KPIs) like spectral efficiency and cell-edge throughput. Therefore, development of LTE technology is continuing beyond Release 8 to address operator requirements as well as those of the International Telecommunications Union (ITU) for future technologies in the newly identified spectrum. 3GPP has initiated the "LTE-Advanced" study item and defined requirements in [2].

The research project Enablers for Ambient Services and Systems — Part C Wide Area Coverage (EASY-C) is developing technologies for future wireless systems such as LTE-Advanced. The special feature of EASY-C is that research ideas are tested in research field testbeds at the system level. In EASY-C, 16 partners work together across the value chain, including academic institutions, mobile operators, network infrastructure, antenna, and test equipment providers, terminal chipset vendors and semiconductor companies, and network planning specialists.

OVERVIEW OF LTE RELEASE 8

The radio interface of 3GPP LTE/SAE Release 8 uses orthogonal frequency-division multiple access (OFDMA) with cyclic prefix in the downlink and single-carrier frequency-division multiple access (SC-FDMA) with cyclic prefix in the uplink. The physical layer of LTE is defined in a bandwidth agnostic way and supports various system bandwidths up to 20 MHz. Radio resources are subdivided into physical resource blocks (PRBs) consisting of 12 subcarriers with 15 kHz spacing and a time duration of 1 ms. PRBs are dynamically allocated to users in order to realize multi-user diversity gain in both time and frequency domains, leveraging adaptive modulation and coding (AMC) with hybrid automatic repeat request (HARQ).

To meet the performance requirements [3], LTE Release 8 relies on multi-antenna-based multiple-input multiple-output (MIMO) transmission and reception techniques, with 2 × 2 MIMO as the baseline for downlink and 1 × 2

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MIMO for uplink. However, higher order antenna configurations are supported. In the downlink closed-loop MIMO with code-book-based linear precoding can be applied, which allows for spatial multiplexing with dual code-word transmission on up to four transmission layers with fast rank adaptation. Additionally, an Alamouti-type transmit-diversity technique called space-frequency block coding (SFBC) is supported. In the uplink multi-user ("virtual") MIMO is used for capacity enhancement, in which pairs of spatially near-orthogonal users may transmit concurrently on the same physical resource blocks.

EVALUATION OF NEXT-GENERATION NETWORKS

As mentioned previously, the performance of 3G network equipment and terminals was not verified to the full extent when 3G was launched in early deployments. This is one lesson learned; therefore, NGMN [1] requested performance evaluation and field trials in parallel to standards development. NGMN and 3GPP have initiated the LTE/SAE Trial Initiative (LSTI), which conducts trial activities and facilitates interoperability tests of LTE equipment.

Provided the metrics are meaningful and the methodology reflects realistic networks, simulations are a good way to compare different concepts and predict absolute values of network performance. The NGMN performance evaluation methodology [4] is well established and allows comparison of different standards. However, there are still a lot of effects that are hard to foresee or model realistically in simulations; therefore, field trials are essential to assess the performance. Also, field trials are a good proof of concept for innovative system-level concepts with lots of interdependencies such as advanced concepts addressing interference. Field trials also allow the calibration of simulations and allow research and development to be focused on tackling the right issues.

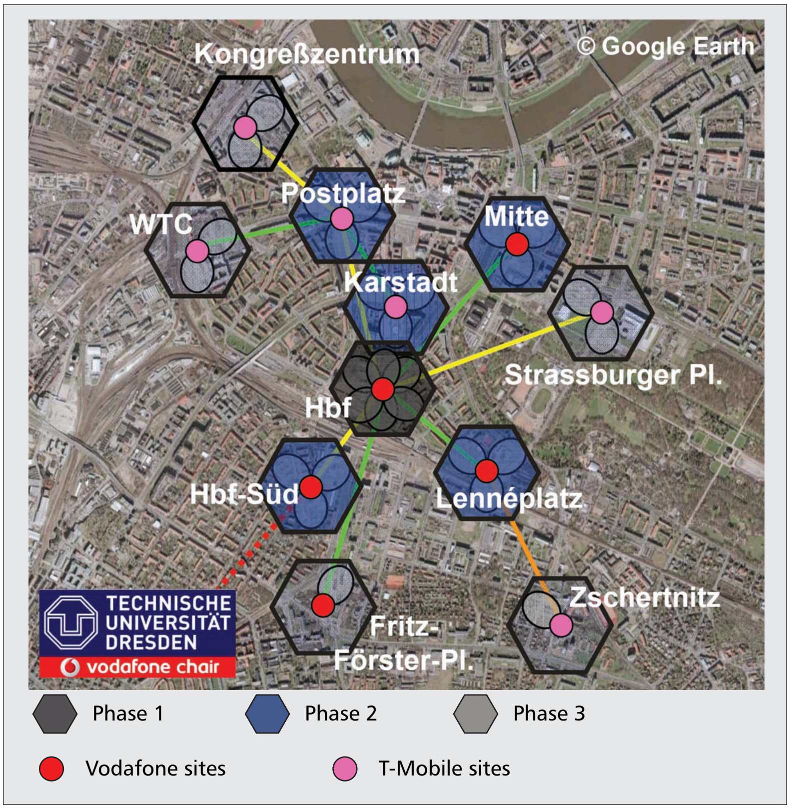
Cellular networks cannot be characterized well by single links. Interference, resource allocation, and propagation environment all impact system performance. To capture all effects, a sufficiently high number of interferers must be present, and multiple sectors and sites have to be involved.

Simulations and field trials focus mainly on technical KPIs such as throughput and latency. However, it has to be kept in mind that the ultimate criterion for the mobile Internet is *user experience*. This is hard to define, depends on particular applications, and changes over time — and is beyond the scope of this article.

EASY-C: A FIELD TESTBED IN DRESDEN

FIELD TESTBED AREA AND MEASUREMENT SCENARIO

Two testbeds have been built and operated within the above mentioned research project EASY-C. In this article we concentrate on a physical layer focused testbed in downtown Dresden, Germany, using existing 2G/3G network sites of operators Vodafone and T-Mobile. Both operators are also involved in the trials. An additional testbed focused on applications enabled through LTE and advanced concepts is being set up in Berlin.



■ Figure 1. *Field test area in Dresden.*

The chosen testbed location in downtown Dresden covers various propagation conditions, which are of special interest for evaluation of fourth-generation (4G) systems with MIMO links and interference conditions typical in *frequency reuse one* networks like LTE, and for the development of advanced algorithms such as cooperative MIMO:

- A representative area of a medium-sized European city
- Hills in the south causing signal reflections
- A river through the city causing superrefractions and tropospheric refraction
- Urban areas with multistory buildings, leading to shadowing effects
- An average intersite distance of 500 m

The testbed is being built in three phases. In the first phase, one site with three cells started operating in April 2008. This central site is located near Dresden's main railway station, as shown in Fig. 1. The antenna height is 55 m. The second phase will cover a tier of sites around this central site and consist of six sites with a total of 18 cells. In the final stage the testbed will comprise 10 sites with a total of 25 cells. Additional interferers will surround outer cells in order to emulate the interference intensity and distribution of a network with three tiers of sites. Such a rather extensive setup is necessary to capture all effects of a real-world deployment.

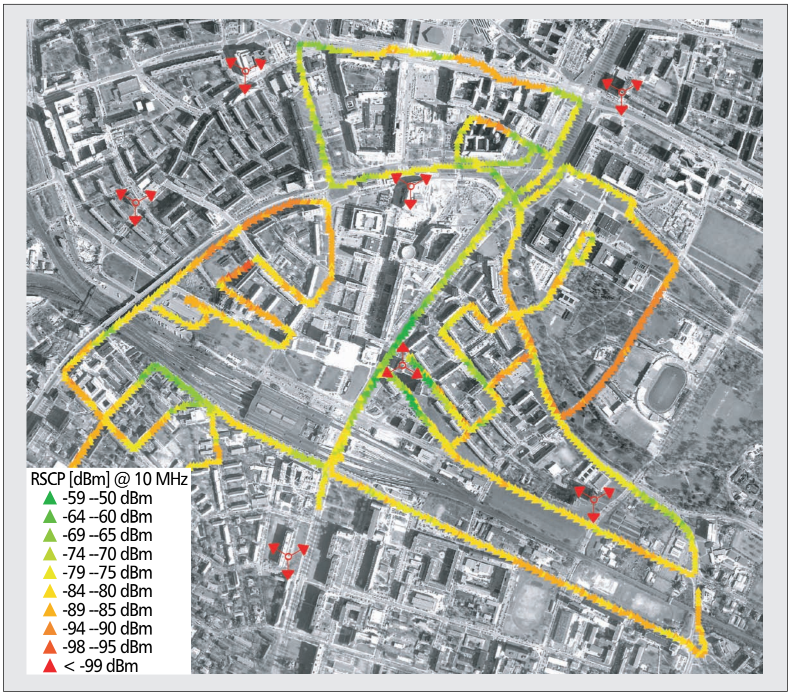
At these locations new base station antennas, feeders, and microwave link equipment are installed.

With this three-tier network, realistic scenarios can be set up to investigate LTE and advanced algorithms beyond LTE Release 8.

Furthermore, the baseline trial setup consists of a testbed platform of base stations and mobile equipment provided by the project partner Signalion. Other project partner's equipment (i.e., base stations, mobile, and chip prototypes) will be inserted into the testbed for various test cases.

This infrastructure enables well defined and reproducible interference scenarios in both uplink and downlink.

■ Figure 2. *Test base station with antennas and microwave link at central site.*



■ Figure 3. *Signal coverage of the trial area based on drive tests.*

FIELD TESTBED EQUIPMENT

Figure 2 shows a test base station with a baseband unit, radio frequency (RF) hardware (including duplex filters and power amplifiers), antenna columns, and microwave backhaul units. LTE does not require GPS controlled reference clocks for synchronization, but they are included in this trial to investigate advanced multicell algorithms. The sensitivity of these algorithms to synchronization errors is one major research topic. The backhaul between the sites is accomplished by low-latency microwave links. These links operate in the 5 GHz frequency band and have a maximum throughput of 300 Mb/s.

FIELD TESTBED MEASUREMENTS

Within the testbed a number of tests are planned. For characterization of the radio environment, channel-sounding campaigns and coverage measurements are conducted. The objective of these measurements is, on one hand, the calibration of raytracing tools and the development of prediction algorithms for multicell MIMO operation in LTE-Advanced. On the other hand, cell edges can be identified: geographical locations where signals from several cells impinge with similar signal strengths.

Figure 3 shows the coverage map of the trial area based on drive tests.

LAB RESULTS

Laboratory tests with pre-standard equipment and fading emulators have been carried out to assess the data rates and latencies that can be expected with LTE Release 8. The results were partly used by Alcatel-Lucent and Signalion to leverage the proof-of-concept work of LSTI.

Examples of the earlier laboratory test results are presented here to highlight inherent LTE capabilities such as AMC or frequency-selective scheduling. Further laboratory tests will be performed to prepare and complement the planned field trial activities, with particular emphasis on MIMO features.

Figure 4 depicts the physical layer cell throughput measured from downlink single-input single-output (SISO) as a function of average signal-to-noise ratio (SNR) with the following configurations:

- 10 MHz system bandwidth
- AMC, hybrid ARQ, and multi-user scheduling in downlink (DL) under control of the eNodeB
- Acknowledgment (ACK)/negative ACK (NACK) and channel quality reporting in the uplink (UL)
- Single cell with a single user (blue curve) or two users (red curve) in the cell
- Full queue in the eNodeB for each user
- Pedestrian A 3 km/h fading channels in downlink and static channels in uplink

Figure 4 illustrates the capability of the AMC to finely adjust the user data rate to the channel quality. This is achieved in the downlink by reporting channel quality indicators (CQIs) back to the eNodeB from the user equipment (UE). In this example the update rate is 1 kHz/subband. The peak data rate observed in Fig. 4 can be scaled to the often quoted 88.7 Mb/s by assuming 20 MHz system bandwidth, code rate 1.0, and pilot/signaling overheads < 15 percent as achievable with LTE Release 8.

Figure 4 further illustrates the gain in cell throughput obtained by applying a time- and frequency-selective multi-user scheduling algorithm. This gain can be quantified by relating the multi-user cell throughput to the throughput of a single user. For slowly moving user terminals, this gain can be substantial, particularly in the low and moderate SNR regions. It is enabled by the particular definition of the CQI, which allows the full system bandwidth to be divided into subbands and apply the CQI reporting at the subband level.

In another type of measurement, the two-way air interface latency between UE and eNodeB was demonstrated to meet the 3GPP requirement of below 10 ms in an unloaded cell with a prescheduled UL channel [3]. Measured latencies are summarized in Table 1 for different scenarios, each using a PING application with 64 bytes payload size triggered from a PC connected to the UE.

While laboratory tests are a valuable means of system characterization, they have limitations due to complexity and cost of laboratory equipment, particularly when multiple sites or antennas are involved, and often also are not representative of real-world conditions. There remains, therefore, a strong motivation to carry out field trials, in particular to gain insight into the performance of a multicellular network.

SYSTEM-LEVEL SIMULATION RESULTS

The scope of EASY-C is to prepare and support the standardization of LTE-Advanced and prove the enhanced concepts by field trials. The field trials are accompanied by system simulations in order to evaluate and optimize candidate algorithms for, say, collaborative or network MIMO before they are implemented in the trial system. On the other hand, the accuracy of simulation results will be investigated by comparing these results with measurements from the field trial system.

The system simulators are compliant wtih 3GPP and NGMN performance verification frameworks [4, 5]. The interference is modeled and simulated in detail. In order to avoid boundary effects and, hence, an overestimation of system performance, wrap around is applied. Both interfering and data channels are modeled by a spatial channel model. Furthermore, the simulations shall be realistic in terms of channel estimation loss and delays. In order to obtain the full capacity of the simulated radio access network, full buffer services are assumed. The simulators are able to simulate different receive and transmit antenna configurations with different antenna spacings. For quick randomization of measurements, the event-driven simulation is subdivided into drops in which new mobile positions are randomly chosen. CQI feedback and precoding matrix identifier (PMI) feedback are modeled with realistic granularity and with all relevant delays based on measured pilot SINR. The receivers are explicitly modeled and, for block error rate (BLER) calculation, the so-called mutual information effective SINR mapping (MIESM) link to the system interface is applied.

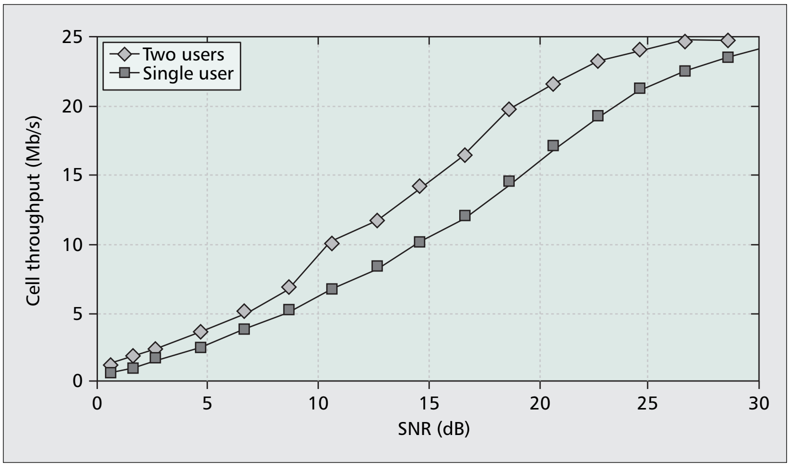


Figure 4. *Downlink cell throughput vs. SNR with one or two SISO users in 10 MHz system bandwidth.*

Scenario	Latency
Single user Unloaded cell UL channel prescheduled No channel impairments	9.9 ms
Single user Unloaded cell UL channel set-up after scheduling request No channel impairments	19.4 ms
Single user Unloaded cell UL channel prescheduled Channel impairments in DL	17.9 ms
Two users Cell fully loaded in DL by second user UL channel prescheduled No channel impairments	9.8 ms

Table 1. *Measured average air interface latencies.*

BASELINE: LTE RELEASE 8

Table 2 shows exemplary results for the DL performance of the 2 ×2 closed-loop baseline system for two different intersite distances of 500 and 1732 m, respectively. The performance is presented as sector spectral efficiency and cell border throughput, which is defined as the 5th percentile of the UE throughput. The bandwidth applied is 10 MHz. The operation point has been set to 30 percent BLER for the first transmission. HARQ is adaptive and asynchronous; that is, retransmissions are adapted to the instantaneous channel quality and can be postponed if, for example, the subframe foreseen for the retransmission is already occupied by other retransmissions. The scheduler is proportionally fair and frequency selective. Twenty-seven different modulation and coding schemes (MCSs) have been used for link adaptation and cover

Antenna configuration	Intersite distance (m)	Spectral efficiency (b/s/Hz)	Cell border throughput (kb/s)
2×2	500	1.46	345
2×2	1732	1.37	255

Table 2. *LTE Release 8 downlink baseline performance.*

Antenna configuration	Intersite distance (m)	Spectral efficiency (b/s/Hz)	Cell border throughput (kb/s)
1×2	500	0.97	295
1×2	1732	0.85	57

Table 3. *LTE Release 8 uplink baseline performance.*

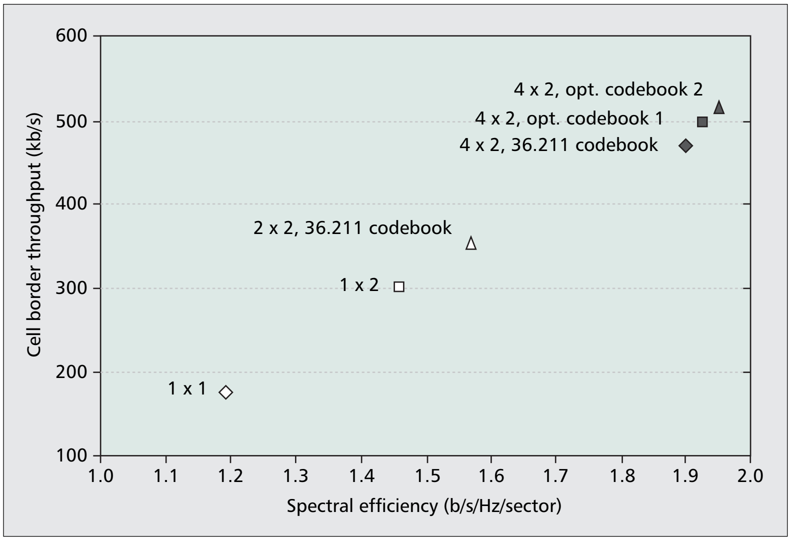


Figure 5. *Cell border throughput vs. system spectral efficiency for LTE DL with different antenna systems and precoding matrices.*

channel qualities from –6 up to 20 dB SINR. Please note that a rather pessimistic channel estimation loss model has been assumed, which causes the decrease of cell border throughput in case of larger intersite distances.

Table 3 shows exemplary results for the corresponding uplink performance for single antenna transmission and receive diversity. Path loss compensation has been applied in order to keep the per mobile average received signal power spectral density at the eNodeB constant. The maximum UE transmit power is 24 dBm. The frequency-selective proportionally fair scheduler considers this maximal transmission power so that the transmission reaches the required power spectral density. An exception to this rule is allowed if the required power for only one assigned resource block exceeds the maximal transmission power. Due to the applied SC-FDMA, the scheduler assigns only adjacent resource blocks. Obviously, due to the limited transmit power of the mobiles, the cell border throughput decreases significantly for the 1732 m ISD case. Different techniques such as interference coordination, or cooperative or network MIMO may enhance cell border throughput and spectral efficiency, and will be investigated in the EASY-C project.

Optimized Codebooks for 4 ×2 SU-MIMO in the Downlink

In this section we show exemplary results of a study on enhancements of LTE beyond Release 8.

Figure 5 shows LTE downlink results for different antenna configurations. The results for 2 ×2 and 4 ×2 are shown for precoding matrices conformant with 3GPP standard TS 36.211 [6]. Additionally, in the same diagram results for optimized codebooks are shown. These codebooks are optimized for linear arrays of X-polarized antennas with an antenna spacing of half of the wavelength of the carrier frequency. This approach saves up to 50 percent of feedback signaling load in the uplink, and at the same time improves cell border throughput and spectral efficiency in the downlink.

Evolution of LTE Beyond the Initial Release 8: LTE-Advanced

With the standardization of LTE Release 8 nearing completion, 3GPP has already created a new study item in order to explore candidate technologies for further technology evolution called LTE-Advanced, which are targeted to meet operator requirements and ITU-R's *IMT-Advanced* requirements. While maintaining backward compatibility with LTE Release 8, these ambitious performance targets include, among others [2]:

- Average spectrum efficiencies of up to 3.7 b/s/Hz/cell in the DL (4 × 4) and 2.0 b/s/Hz/cell in the UL (2 ×4)
- Cell edge spectrum efficiencies of 0.12 b/s/Hz in the DL (4 ×4) and 0.07 b/s/Hz in the UL (2 ×4)
- Peak data rates of up to 1 Gb/s in the DL and 500 Mb/s in the UL
- Peak spectrum efficiencies of 30 bit/s/Hz in the DL and 15 bit/s/Hz in the UL using antenna con-figurations of up to 8×8 in the DL and 4×4 in the UL
- Low cost of infrastructure deployments and terminals and power efficiency in the network and terminals

Within the EASY-C project, the following concepts are investigated among others that appear to be promising to address the above-mentioned targets:

- Advanced single-site MIMO
- Multisector coordination/cooperation
- Multisite coordination/cooperation

The schemes are illustrated in Fig. 6.

Using a high number of transmit and receive antennas in both the DL and UL addresses the demanding requirements for peak and average performances. Single-user MIMO with a large number of transmit and receive antennas is the enabler of high peak data rates. DL multi-user MIMO with optimized fixed beams or user-specific beams is the key to high spectrum efficiencies.

User-specific beams are especially suited for low mobility where accurate channel information at the transmitter must be available in order to create beams with high interference suppression. Fixed beams are suitable for moderate to high mobility, because a user's preferred beam is directly related to its position in the cell and only changes on a rather slow timescale. For compact X-polarized antenna configurations, fixed beamforming can further be elegantly combined with diversity for link enhancement and/or spatial multiplexing.

Multisector and multisite cooperation additionally boosts spectral efficiency and especially cell edge performance. For instance, interference coordination can be used to mitigate the impact of multisector interference, and joint signal processing concepts — often referred to as network MIMO or coordinated multipoint transmission/reception — actually allow interference to be exploited, and yield additional array and diversity gain. From a theoretical point of view, vast performance gains have been predicted for these schemes for both UL [7] and DL [8]. However, major research is still required for various practical aspects connected to network MIMO, such as:

- Synchronization of jointly processed terminals in time and frequency, and detection under remaining synchronization offsets
- Multisector channel estimation, feedback of channel information to the base stations, the impact of imperfect channel estimation on network MIMO, and robust signal processing algorithms
- Performance of network MIMO and concrete signal processing algorithms under a limited backhaul infrastructure between cooperating base stations [9]
- Cooperative scheduling for network MIMO

In EASY-C all the above mentioned aspects are researched, and the first laboratory and field test results for LTE-Advanced technologies are expected in 2009.

In order to optimally exploit all the various features, generalized multisite multi-user schedulers taking advantage of single-user, multi-user, and multisite technologies must be designed.

CONCLUSIONS AND OUTLOOK

This article shows performance results of the LTE standard based on system-level simulations and laboratory tests for user throughput, spectral efficiency, and latency. However, it is essential for realistic assessment of LTE and the development of further improvements to the standard to conduct trials with multiple sectors that reflect real-world interference conditions. Such a trial environment has been established within the EASY-C project. Advanced algorithms such as advanced single-site MIMO, and multisector and multisite cooperation are promising from a theoretical point of view, and the established testbed will be used to develop such concepts in detail and evaluate their real-word performance.

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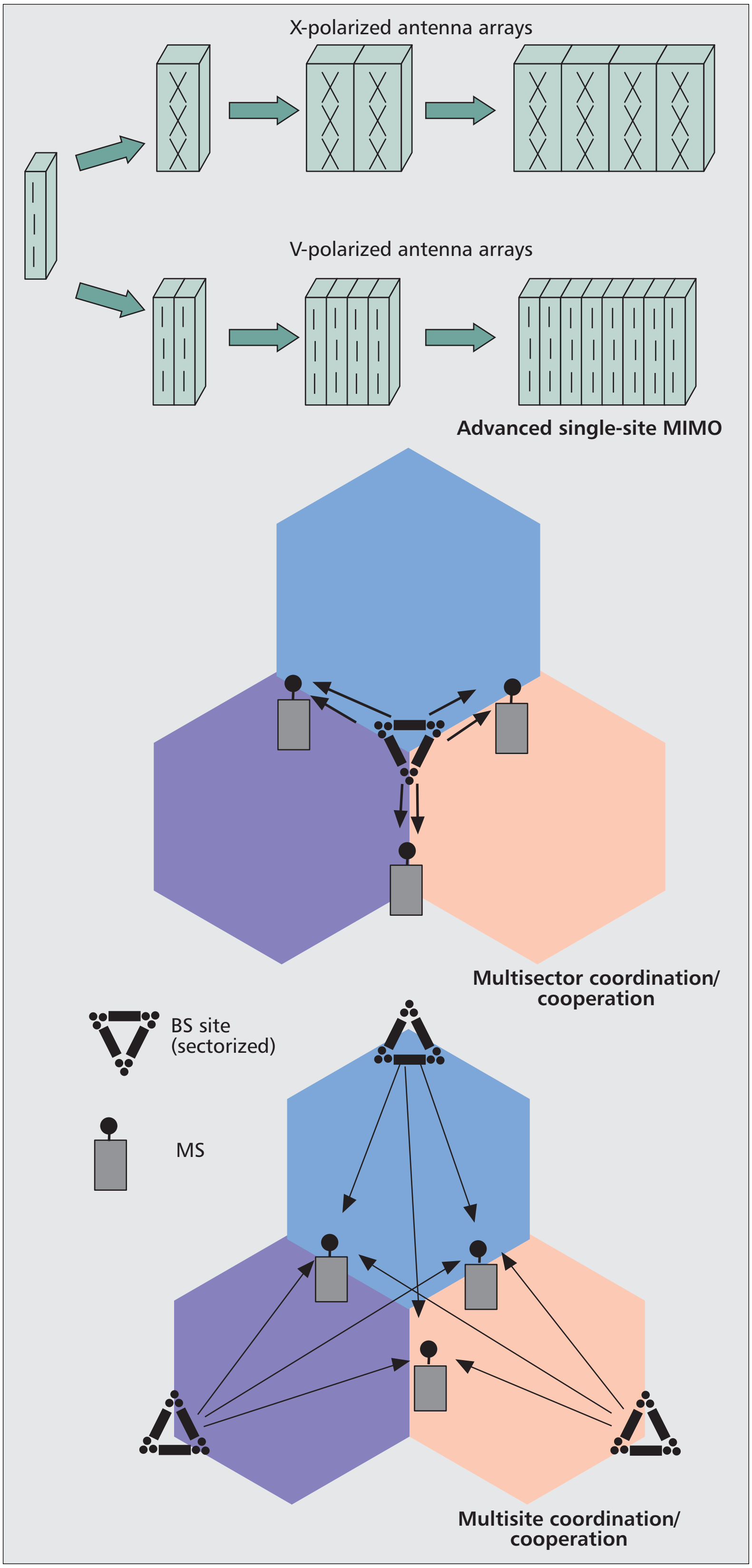

■ Figure 6. *Candidate technologies for LTE advanced.*

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BIOGRAPHIES

RALF IRMER (ralf.irmer@vodafone.com) received his Dipl-Ing. and Dr.-Ing. degrees from Technische Universität Dresden in 2000 and 2005, respectively. He joined Vodafone Group R&D in 2005, where he is working in the Beyond 3G group, which is responsible for Vodafone's strategy on LTE, WiMAX, and other technologies such as wireless mesh networks and WLAN. Previously he worked for five years as a research associate at TU Dresden. He holds several patents, and has published more than 30 conference and journal publications. He had a leading role in several research projects, including WIGWAM, WINNER, and EASY-C.

HANS-PETER MAYER (Hans-Peter.Mayer@alcatel-lucent.de) received his Ph.D. degree in physics from the University of Tübingen in 1987. He joined Alcatel-Lucent and initially worked on high-speed optoelectronic components. From 1992 to 1995 he led the R&D activity on 1.55 µm DFB laser products for WDM. From 1996 to 1999 he was responsible for servers and databases for 3G mobile networks and early UMTS system studies, followed by realization of the first UMTS and HSPA trial systems. Within Bell Labs he is currently responsible for the Advanced MAC department and LTE-Advanced projects.

ANDREAS WEBER (Andreas.Weber@alcatel-lucent.de) received Dipl.-Ing. and Dr.-Ing. degrees in electrical engineering from the University of Stuttgart, Germany, in 1988 and 1998, respectively. From 1989 to 1995 he worked in the field of satellite communications as a member of scientific staff at the Institute of Communications Switching and Data Technics, University of Stuttgart. In 1996 he joined Alcatel Research & Innovation (now Alcatel-Lucent Bell Labs). Currently, he is the team leader of the mobile system performance evaluation group in Alcatel-Lucent Bell Labs Stuttgart.

MICHAEL SCHMIDT (Mi.Schmidt@alcatel-lucent.de) received his diploma degree in physics in 1999 and joined Alcatel Research & Innovation (now Alcatel-Lucent Bell Labs) in 2000. He worked on several research projects in diverse fields such as optical signal processing and ultra-high-bitrate optical transmission systems, as well as dynamic radio resource management and packet scheduling for 3G wireless communications. He has authored or co-authored 24 papers in refereed journals/conferences. His current research interests at Alcatel-Lucent Bell Labs include advanced MAC and cooperative control algorithms for LTE/LTE-Advanced.

VOLKER BRAUN (Volker.Braun@alcatel-lucent.de) received his doctoral degree in 1997 and joined Alcatel in 1998. He is currently a project leader in the radio access domain at Alcatel-Lucent Bell Labs, where he has lately contributed to 3G base station prototyping for the HSPA and LTE standards.

MICHAEL OHM (Michael.Ohm@alcatel-lucent.de) received Dipl.-Ing. and Dr.-Ing. degrees in electrical engineering from the University of Stuttgart, Germany, in 2001 and 2006, respectively. From 2001 to 2006 he worked at the Institute of Telecommunications, University of Stuttgart, in the field of telecommunications with a focus on optical communications. He joined Alcatel Research & Innovation (now Alcatel-Lucent Bell Labs) in 2006, where he has been engaged in research and standardization for the LTE system. He is a member of VDE and ITG.

NORBERT AHR (Norbert.Ahr@alcatel-lucent.de) joined Alcatel in 1998, and Alcatel Research & Innovation (now Alcatel-Lucent Bell Labs) in 2004. He is currently working on implementation and integration of software on 3G prototype base stations for LTE.

CARSTEN JANDURA (Carsten.Jandura@ifn.et.tu-dresden.de/ Carsten.Jandura @vodafone.com) received a Dipl.-Ing. degree in electrical engineering from the Technical University of Dresden in 1994. Since 1995 he has been with Mannesmann Mobilfunk GmbH and later Vodafone D2 GmbH. His special topic is network optimization for GSM and UMTS networks with a focus on field measurement and performance measurement evaluation. Since 2005 he is with the Vodafone Chair Mobile Communication Systems.

PATRICK MARSCH (marsch@ifn.et.tu-dresden.de) received his Dipl.-Ing. degree from Technische Universität Dresden in 2004, after completing an apprenticeship at Siemens AG and studying at TU Dresden and McGill University, Montréal, Canada. After an internship with Philips Research East Asia in Shanghai, P.R. China, he joined the Vodafone Chair in 2005, where he is focusing on multicell cooperative signal processing schemes under a constrained backhaul. Since April 2007 he has been the technical project coordinator of EASY-C.

GERHARD FETTWEIS (fettweis@ifn.et.tu-dresden.de) earned his Dipl.-Ing. (1986) and Ph.D. (1990) degrees from Aachen University of Technology (RWTH), Germany. From 1990 to 1991 he was a visiting scientist at the IBM Almaden Research Center, San Jose, California, working on signal processing for disk drives. From 1991 to 1994 he was with TCSI Inc., Berkeley, California, responsible for signal processor development. Since 1994 he holds the Vodafone Chair at TU Dresden. He is coordinating the EASY-C research project.

ANDRÉ ZOCH (andre.zoch@signalion.com) received his Dipl.-Ing. and Dr.-Ing. degrees in electrical engineering from the Technical University of Dresden, Germany, in 1998 and 2004, respectively. From 1998 to 2004 he worked with the Vodafone Chair Mobile Communications Systems at the Technical University of Dresden with a focus on UMTS receiver design and implementation. He is co-founder of Signalion GmbH and has with Signalion since 2004 in the field of prototyping wireless communication systems.