Technology Radar Edition III/2010

Feature Paper

Next Generation Mobile Networks

(R)evolution in Mobile Communications

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Introduction

by Dr. Gerhard Kadel, Deutsche Telekom Laboratories (Editor of Feature Paper)

Mobile data services are one of the fastest growing segments in telecommunications. Drivers are the rising customer demand for mobility and flexibility, the boost of data-centric mobile and portable devices such as smart phones, notebooks, netbooks & tablet PCs, and the tremendous growth of customized mobile applications, in particular for smart phone devices. These trends result in an exponential growth of traffic volumes in mobile networks, whereas the revenues are growing slowly or stagnating. In consequence, mobile operators are faced with the challenge to increase data capacity in their networks quickly while significantly reducing the costs per transported bit.

The "Next Generation Mobile Networks (NGMN)", also named as "Fourth Generation (4G)" mobile systems, will help to overcome these challenges and will continue the success story of mobile communications. 4G networks will incorporate LTE (Long Term Evolution) as a new broadband air interface enabling higher peak data rates, higher capacity and lower latency compared to previous mobile technologies. Another important feature of NGMN is a flat, all IP-based network architecture, in line with the clear trend in the fixed network domain towards IP-based "Next Generation Networks (NGN)". According to present status LTE technology as globally standardized by 3GPP (Third Generation Partnership Project) will be the mainstream for future mobile networks, and major operators around the world are preparing for LTE deployments.

The present feature paper will provide a comprehensive overview on NGMN, mainly from a technology and infrastructure perspective. Experts from the mobile industry, regulatory bodies and universities describe their experience and their views on various topics relevant for NGMN. Intentionally, the paper shall complement the Deutsche Telekom internal expertise by external views and it may highlight some aspects from another perception or even may provide some challenging positions.

As an introduction, the chapter on "Evolution of Mobile Technologies and Networks" by Armin Dekorsy provides an overview on the global developments of mobile technologies and networks. The roles of 3GPP, ITU and the NGMN Alliance are explained. The overview on "Spectrum for NGMN" by Reiner Liebler addresses the question of spectrum availability, one of the most important preconditions for deployment of mobile networks. Specific focus is on the results of the NGMN spectrum auction in Germany, and on future spectrum perspectives.

The chapter on "Design and Deployment of LTE Radio networks" by Peter Merz and Ulrich Rehfueß presents LTE-specific deployment considerations, in particular related to the variability of LTE in view of frequency bands and channel bandwidths. In addition, some initial technical performance results from LTE deployments are described. The article "Self-Organization in LTE Networks" by Ulrich Barth and Edgar Kühn deals with the need of a paradigm change for mobile network management to cope with increasing complexity, to optimize network performance and to limit operational effort. As an example, results from investigations on self-optimization of antenna tilt are presented. "Challenges and Solutions for LTE/HSPA Chipsets and Devices" are discussed by Vieri Vanghi. The paper shows that besides the higher throughput of LTE the need to support a high number of frequency bands and to allow for multi-mode LTE/HSPA operation are key issues for the implementation of NGMN-enabled chipsets and devices.

The chapter on "Key Technologies for LTE-Advanced" by Joachim Speidel, Philipp Frank and Heinz Droste gives on overview on the different methods currently under investigation in research and standardization for further improvements of the LTE technology. Examples from performance simulations and from techno-economic assessments are provided. Finally, the contribution "Future Research Challenges for Mobile Networks" by Holger Boche discusses various research concepts for future improvements of mobile technologies and networks. Basic approaches from an information theoretic point of view and their potentials are described.

The editor wishes to thank all the contributing authors for their effort. Their valuable inputs and their excellent cooperation during the preparation of this document are gratefully acknowledged.

Mobile Broadband Technology Evolution – From HSPA to LTE and LTE-Advanced

by Prof. Dr. Armin Dekorsy
(University of Bremen)

Mobile data services have taken off and due to the innovations introduced in the last few years mobile broadband connectivity is on the verge of becoming ubiquitous. Through constant evolution of mobile networks the always-on and everyplace-network connectivity has come in place and especially Third-Generation (3G) technology has ignited a massive wave of industry innovation in this field that spans devices, network infrastructure, and new services and applications. Building on the phenomenal success of the Global System for Mobile communication (GSM) the constant evolution towards GSM-EDGE and especially towards 3G mobile communications systems with Universal Mobile Telecommunications System/Wideband Code Division Multiple Access (UMTS/WCDMA) succeeded by the even more data-oriented-designed High-Speed-Packet-Access (HSPA) technology has led to an explosive increase of high-speed mobile data traffic. The enhanced speeds and performances are, however, not the sole cause of this dramatic growth in mobile broadband traffic. An innovative approach to tariffing by offering flat-rate tariffs combined with the expectations of users to use mobile internet applications everywhere have coincided with the technology availability to drive the growth in data traffic.

The Third-Generation Partnership Project [3GPP] standards body has developed a series of new radio technologies to evolve mobile networks. A major and important characteristic of 3GPP standards is backward compatibility allowing phased upgrades and a choice of smooth evolution paths for operators.

The first 3G specification of 3GPP was UMTS/WCDMA released in January 1998 as UMTS-Rel99 [Holma & Toskala 2007]. UMTS/WCDMA was a consolidation of the underlying GSM specifications and the development of the new UMTS Terrestrial Radio Access Network (UTRAN) that uses CDMA instead of Time Division Multiple Access (TDMA) as basic radio access technology. By still using CDMA as basic radio access technology, the next evolution with HSPA and HSPA+ has provided spectrally highly efficient wireless solutions through the introduction of features like Continuous Packet Connectivity which enables packet-switched data transmission in core and access networks, Multiple Input Multiple Output (MIMO) antennas, and Higher-Order Modulations [Holma & Toskala 2007]. This in turn allows for providing an improved support and performance for real-time conversational and interactive services such as Push-to-Talk over Cellular, picture and video sharing, and Voice and Video over Internet Protocol (IP). 3GPP completed the HSPA Rel8 specification in March of 2009.

The 3GPP Rel8 specification can also be seen as the starting point for the definition of Next-Generation Mobile Networks (NGMN). In addition to UMTS/HSPA enhancements, Rel8 also defines the new air-interface technologies Orthogonal Frequency Division Multiple Access/Single-Carrier Frequency Division Multiple Access (OFDMA/SC-FDMA) through the Long-Term Evolution (LTE) work item [Holma & Toskala 2009]. This new air interface is also often referred to as the Evolved UMTS Terrestrial Radio Access (E-UTRA). A key attraction of LTE is its inherent spectral flexibility through scalable carrier bandwidths ranging from 1.4 MHz up to 20 MHz. This feature enables mobile operators to deploy LTE in many different frequency bands with minimal changes to the radio interface and is therefore key to addressing the fragmented availability of frequency bands in the world.

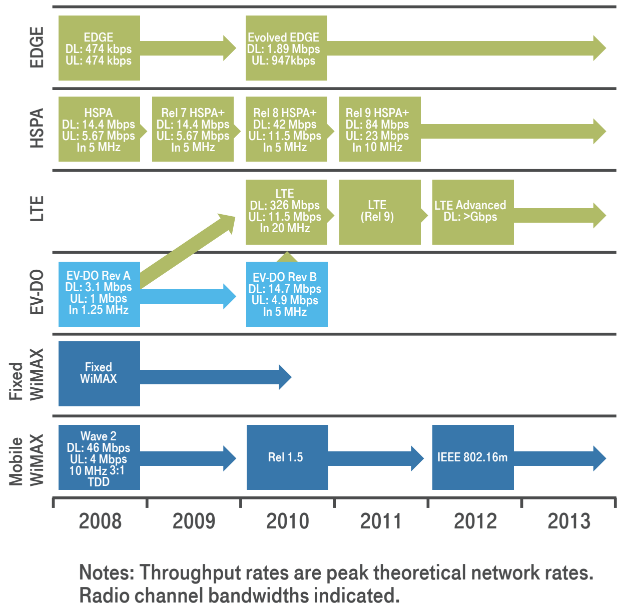

Fig. 1: Evolution of TDMA, CDMA and OFDMA by Peak Data Rates (Source: Rysavy Reserach).

Figure 1 illustrates the evolution of the 3GPP standards EDGE, HSPA and LTE through a set of phased releases to existing systems or the deployment of new technologies. The various options are assessed by comparing peak data rates. Dates refer to expected initial commercial network deployments, except 2008 and 2009, which shows available technologies that year. In addition to the backward compatibility of LTE with 3GPP networks, LTE is also backward compatible with non-3GPP networks such as 3GPP2 EV-DO [3GPP2]. This raises the possibility of migration as illustrated in Figure 1.

The evolution of mobile networks also comprises evolved Worldwide Interoperability for Microwave Access (WiMAX) networks formed by the IEEE 802.16 standardization [IEEECOMM 2008]. As for 3GPP networks the evolution track of WiMAX on radio technologies is TDMA and OFDMA and IEEE 802.16m is seen as competitive to LTE.

Beside the technology evolution of the radio access resulting in higher peak data rates the uptake of mobile broadband is also due to offering end-users low pricing models with flat-rate data tariffs. This combination has led to a decoupling of revenues and traffic wherein operators are experiencing a 10-fold increase in data traffic but with only a 10% increase in data revenue [UMTS Forum 2009]. This data traffic and revenue challenge has demanded a paradigm shift in network design from voice-dominated GSM networks to data-dominated HSPA/LTE networks.

The entirely new approach of designing NGMN has not been restricted to the new air interface only, instead, the design includes the entire radio access network and the backhaul infrastructure. NGMN needs to be designed to offer greater capacity, but with lower cost per bit. As a consequence, with HSPA+ 3GPP has introduced for the first time an optional all-IP flat radio access network architecture with reduced latency and an infrastructure backhaul based on Multi-Protocol Label Switching (IP/MPLS) transport. Flat architecture means that the base station acts as an IP router connected via standard Gigabit Ethernet to the backhaul network. Furthermore, functionality was moved from the back of the network to the base station. This shift improves response times for channel adaptive transmission schemes such as scheduling and adaptive modulation and coding ensuring the highest possible data rate.

However, the big step of 3GPP to NGMN has been the definition of the Evolved Packet Core (EPC), formerly called System Architecture Evolution (SAE). In line with the 3GPP phase approach, EPC additionally defines a flat core architecture that provides seamless integration with IP-based communication networks while also vastly reducing cost per bit. With this seamless integration of Internet applications EPC drives the convergence of fixed and mobile systems and facilitates new types of services such as emergency services, location services, and broadcast services. Enhancements to support home base stations, i.e. femto-cells, and the evolution of the IP Multimedia System (IMS) architecture is a focus of Release 9. Furthermore, plug-and-play and self-configuration and the automation of network processes through the adoption of self-organizing network (SON) principles are also key features of LTE/EPC, especially demanded by operators for the low-cost deployment and maintenance of home base stations.

To be successful globally, technologies not only have to deliver competitive performance, but also have to become the kernel of a vibrant and widespread ecosystem worldwide. The 3GPP wireless ecosystem is vibrant and expansive; the evolutionary roadmap is clearly marked with a variety of flexible options for operators depending upon their business strategies, spectrum assets, legacy networks, the competitive market and their customer bases.

Figure 2 illustrates an up-to-date volume prediction of wireless subscribers across networks.

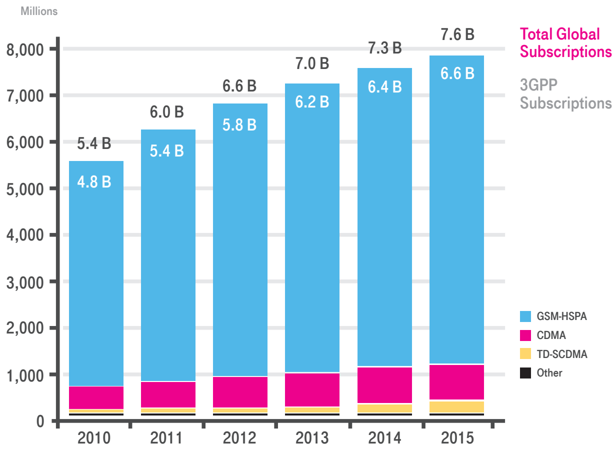

Fig. 2: Volume Prediction of Wireless Subscribers Accross Networks (Source: Informa Telecoms & Media Forcasts, WCIS+, June 2010)

Subscriptions to 3GPP-based networks (GSM, UMTS/WCDMA, HSPA) are growing rapidly. There were an estimated 4.8 billion 3GPP subscriptions from a total of 5.4 billion subscriptions globally, ~90% 3GPP subscriptions, at the end of 2010 and this is expected to reach 6.6 billion from a total of 7.6 billion by 2015, ~90% 3GPP subscriptions. A global 3G forecast, i.e. without GSM, but including LTE, is illustrated in Figure 3.

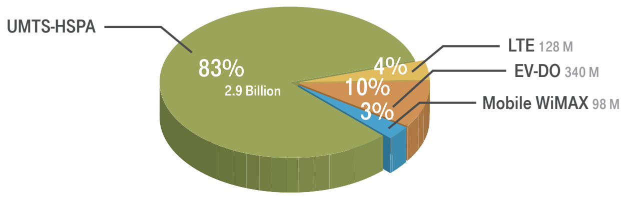

Fig. 3: 2014 Global 3G Forecast (Source: Informa Telecoms & Media, WCIS+, March 2010)

The healthy industry ecosystem that surrounds 3GPP networks displays very strong operator commitment to 3GPP networks, not only from key members of the 3GPP community, but also from prominent players currently deploying 3GPP2-based technologies. This is partly reflected in Table 1 that already indicates the gathering momentum behind the evolutionary roadmap that positions LTE/EPC to be the Next-Generation Mobile Network.

UMTS	HSPA	HSPA+	LTE
372	356	67	2
151	142	35	2
83	76	N/A	126 Commitments & 85 Potential Networks

Tab. 1: Global Network Deplyoment (Numbers reflect the numbers of deployed networks; Source: 3G americas)

The development of a global LTE ecosystem is evidenced by the LTE/SAE Trail Initiative (LSTI) which has provided support to ensure timely development of the LTE ecosystem [LSTI]. Leading vendors and operators for LTE are actively participating in LSTI by performing interoperability testing to ensure the availability of wide-range LTE devices that will function consistently on all LTE networks worldwide. By the third quarter of 2008, the Next-Generation Mobile Networks Alliance – a group of major mobile operators and leading manufacturers – selected LTE as sole technology that broadly meets NGMN recommendations. The NGMN Alliance established performance targets, recommendations, and deployment scenarios for NGMN [NGMN WP 2006]. Other technologies, e.g., WiMAX were not selected at that time.

The International Telecommunication Union [ITU] is the internationally recognized entity chartered to produce an official definition of the next generation of wireless technologies. Today, the first family of standards derived from the IMT concept – IMT-2000 – is often known as 3G. With IMT-Advanced the ITU has formulated a technology vision targeted at satisfying far-future needs. The IMT-Advanced technologies are the next generation of technologies, and often termed 'true' 4G. IMT-Advanced demands higher data rate and lower latency requirements to support advanced services and applications. It further requires a high degree of commonality of functionality worldwide, and especially, the capability of interworking with other radio access systems (References IMT-Advanced requirements) aiming for a global harmonization and standardization. At the end of October 2009 six candidates were submitted but some of the proposals were technically identical leaving just two candidates: The 3GPP technology LTE-Advanced and the IEEE technology 802.16m. The evaluation process by a dozen evaluation groups is ongoing and is scheduled to reach a final decision in October 2010.

3GPP LTE-Advanced is an evolution of LTE which will be covered by Release 10 specifications to be published in the first half of 2011. Vendors are already strongly progressing LTE-Advanced demonstrating that the evolution of LTE is secure and proof. Key technologies for LTE-Advanced are (1) Coordinated Multipoint Technologies (CoMP) (2) relaying technologies, and (3) bandwidth aggregation. All of these technologies are expected to improve the user-experience by increasing the average sector throughput and/or the peak data rates. LTE-Advanced supports peak data rates up to 100 Mbit/s for high and up to 1 Gbit/s for low mobility scenarios. In addition to the 3GPP LTE-Advanced standardization work, LTE-Advanced and already its evolution is a major topic being addressed in funded European research projects [EASY-C], [ARTIST4G], [BeFemto].

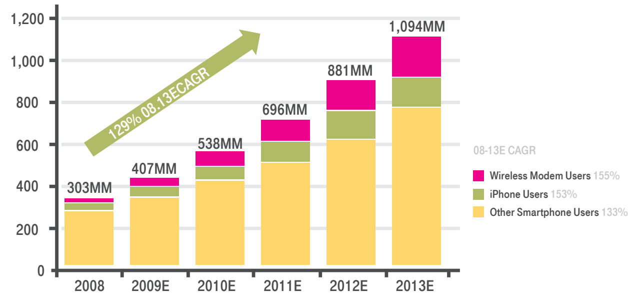

Fig. 4: Growth in Heavy Mobile Data Users (Source: Morgan Stanley).

From an economic perspective, a still-rapid adaption rate of mobile internet is evidenced by the surging use of smartphones, dongles, and laptops leading to a tremendous growth of mobile internet traffic as illustrated in Figure 4 and referenced in [UMTS Forum 2010] – some operators are already finding their network capacities stretched.

But this is just the start. Massive waves of video traffic (e.g., YouTube) will require further evolutions of networks to upgrade network performance. Those evolving technologies will have to deliver mobile data capability at reduced costs to enable new business models and to become a vibrant and widespread ecosystem worldwide.

Spectrum for NGMN

by Reiner Liebler (Bundesnetzagentur)

Today the four big German mobile network operators provide their services to their customers with spectrum resources of roughly 300 MHz. These resources are located in the 900 MHz, 1.8 GHz and 2 GHz range.

However, according to studies carried out by the International Telecommunication Union, the United Nations agency for information and communication technology issues (ITU), spectrum requirements for NGMN will be in the order of 1280 – 1720 MHz by the year 2020. Although spectrum requirements put together in ITU by protagonists of mobile services might be exaggerated to some degree, the ITU estimations nevertheless clearly demonstrate that radio spectrum is and will be a limited, scarce natural resource which is to be used in an efficient manner [ITU-R 2007].

With regard to spectrum availability for NGMN a landmark was set in Germany on 20 May 2010. After 27 days and 224 auction rounds carried out on the premises of the Federal Network Agency in Mainz, spectrum resources available in Germany for NGMN were more than doubled.

Altogether 360 MHz were auctioned. 60 MHz at 0.8 GHz, 50 MHz at 1.8 GHz, 60 MHz at 2.0 GHz and 190 MHz at 2.6 GHz. The auction provided the German Ministry of Finance with an additional 4.4 billion € for the government budget. At first glance this looks like a tremendous amount of money – but compared to the auction result for the so-called UMTS frequencies (the auction took place in the year 2000 at the same location) the result is low from the finance minister's perspective. In 2000, spectrum in the order of 150 MHz was auctioned for 50 billion €. But perhaps the now lower financial result achieved in 2010 allows the successful bidders to make the necessary financial investment in a short timeframe and provide the market with high data rate services at reasonable prices.

Auktionsrundenergebnis

Ende der Auktion

Frequenzbereich	Block	Ausstattung	Höchst-bieter	Höchstgebot (€ in Tsd)
0,8 GHz (gepaart)	0,8 GHz A	2x5 MHz konkret	To2 GER	616.595
	0,8 GHz B	2x5 MHz abstrakt	To2 GER	595.760
	0,8 GHz C	2x5 MHz abstrakt	Telekom D	570.849
	0,8 GHz D	2x5 MHz abstrakt	Telekom D	582.949
	0,8 GHz E	2x5 MHz abstrakt	Vodafone	583.005
	0,8 GHz F	2x5 MHz abstrakt	Vodafone	627.317
1,8 GHz (gepaart)	1,8 GHz A	2x5 MHz abstrakt	Telekom D	20.700
	1,8 GHz B	2x5 MHz abstrakt	Telekom D	20.700
	1,8 GHz C	2x5 MHz abstrakt	Telekom D	19.869
	1,8 GHz D	2x5 MHz konkret	E-Plus Grp	21.550
	1,8 GHz E	2x5 MHz konkret	E-Plus Grp	21.536
2,0 GHz (gepaart)	2,0 GHz A	2x4,95 MHz konkret	Vodafone	93.757
	2,0 GHz B	2x4,95 MHz konkret	E-Plus Grp	103.323
	2,0 GHz C	2x4,95 MHz konkret	E-Plus Grp	84.064
	2,0 GHz D	2x4,95 MHz konkret	To2 GER	66.931
2,0 GHz (ungepaart)	2,0 GHz E	1x5 MHz konkret	To2 GER	5.731
	2,0 GHz F	1x14,2 MHz konkret	To2 GER	5.715

Ausgeschiedene Bieter:

Frequenzbereich	Block	Ausstattung	Höchst-bieter	Höchstgebot (€ in Tsd)
2,6 GHz (gepaart)	2,6 GHz A	2x5 MHz abstrakt	Telekom D	19.096
	2,6 GHz B	2x5 MHz abstrakt	Telekom D	19.025
	2,6 GHz C	2x5 MHz abstrakt	To2 GER	17.364
	2,6 GHz D	2x5 MHz abstrakt	To2 GER	17.364
	2,6 GHz E	2x5 MHz abstrakt	Vodafone	18.948
	2,6 GHz F	2x5 MHz abstrakt	Vodafone	19.025
	2,6 GHz G	2x5 MHz abstrakt	Telekom D	19.069
	2,6 GHz H	2x5 MHz abstrakt	Telekom D	19.038
	2,6 GHz I	2x5 MHz abstrakt	To2 GER	18.948
	2,6 GHz J	2x5 MHz abstrakt	E-Plus Grp	18.931
	2,6 GHz K	2x5 MHz abstrakt	E-Plus Grp	17.739
	2,6 GHz L	2x5 MHz abstrakt	To2 GER	17.739
	2,6 GHz M	2x5 MHz abstrakt	Vodafone	17.739
	2,6 GHz N	2x5 MHz abstrakt	Vodafone	17.752
2,6 GHz (ungepaart)	2,6 GHz O	1x5 MHz abstrakt	Vodafone	9.130
	2,6 GHz P	1x5 MHz abstrakt	Vodafone	9.130
	2,6 GHz Q	1x5 MHz abstrakt	Telekom D	8.598
	2,6 GHz R	1x5 MHz abstrakt	Vodafone	8.598
	2,6 GHz S	1x5 MHz abstrakt	Vodafone	9.051
	2,6 GHz T	1x5 MHz abstrakt	Vodafone	9.051
	2,6 GHz U	1x5 MHz abstrakt	E-Plus Grp	8.273
	2,6 GHz V	1x5 MHz abstrakt	To2 GER	8.229
	2,6 GHz W	1x5 MHz abstrakt	To2 GER	8.229
	2,6 GHz X	1x5 MHz abstrakt	E-Plus Grp	8.229

Summe aller gehaltener Höchstgebote (€ in Tsd)	4.384.646
Zahlungsverpflichtung aufgrund zurückgenommener Höchstgebote (€ in Tsd)	0
Summe	4.384.646

Fig. 5: Detailed Result of NGMN Frequency Auction in Germany in May 2010 (Source: Bundesnetzagentur).

The auction has given the German market a clear perspective of spectrum availability for NGMN. Focus of interest was the lower UHF part, a spectrum of 60 MHz at around 800 MHz, which itself raised more than 3.5 billion €, about 80 % of the entire auction revenue. The reason for this was that mobile network operators consider these 60 MHz much more valuable than the other parts of the auctioned spectrum. This is due to excellent coverage and very good indoor-penetration at 800 MHz.

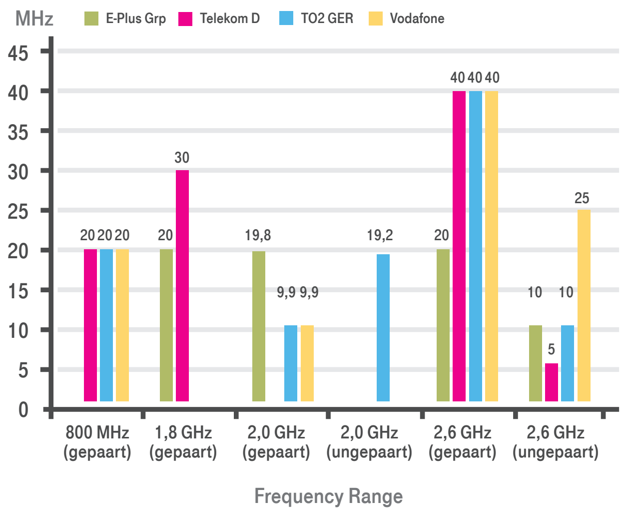

Fig. 6: Distribution of NGMN Spectrum in Germany with regard to Frequency Ranges and Operators after Frequency Auction in May 2010. (Source: Bundesnetzagentur).

The ITU World Radio Conference (WRC), held in Geneva in November 2007, set the necessary international regulatory framework to allow usage of 800-MHz frequencies by commercial mobile networks. It is to be noted that Germany, in line with the WRC decision, is the first country in Europe actually providing spectrum at 800 MHz to the mobile market. There will be a leading role for the German operators in the rollout of 800-MHz networks in Europe. The advantages of using 800-MHz spectrum for NGMN can be demonstrated now – and depending on the success – other countries in Europe will follow the German example.

However, the usage of the 800-MHz range by mobile networks embeds also another challenge. It might cause some radio interference cases in the customer's home. In particular the adjacent broadcasting service DVB-T (Terrestrial Digital Video Broadcasting) below 790 MHz will require the application of special mitigation techniques. With regard to compatibility with DVB-T the most important measure is the application of an appropriate mobile band plan decoupling the frequency of the mobile equipment from the broadcasting receiving frequency by more than 40 MHz in the consumer's home. As in many other cases in the past, further interference mitigation techniques are to be applied, depending on the actual scenario.

How is the NGMN spectrum from a regulatory point of view to be used? Here, the European Wireless Access Policy for Electronic Communication Services (WAPECS) sets the framework for the national regulation. According to this policy neither the detailed service to be provided nor the technology to be used is to be determined by the regulator. It is left to the market and thereby up to the operator to decide what he thinks provides the best value to his customers – and what the customers are prepared to pay for. In line with this principle the spectrum utilization conditions only cover minimum requirements for interference-free and compatible operation. In particular the concept of defining Block Edge Masks (BEM), which just provides the spectral envelope of the transmission, is the tool to achieving compatibility without unnecessarily restricting technology and services.

In Germany, however, the 60 MHz in the 800-MHz range have been made available with the some additional obligations to the successful bidders. They are obliged to cover rural areas with priority in order to fill the digital gaps in the countryside, where alternative wired solutions have not been made available yet to provide broadband internet access. This obligation stems from the German broadband policy and was the driving argument to make the spectrum available on a short-term basis in Germany. So Germany will be a locomotive in opening the market and many other European regulators will have their eyes on the way it is handled in Germany.

It is to be said that for the coming years no major additional resources going beyond the 360 MHz auctioned will become available. So it is in the strong interest of the mobile operators to use their available frequencies in the most efficient way.

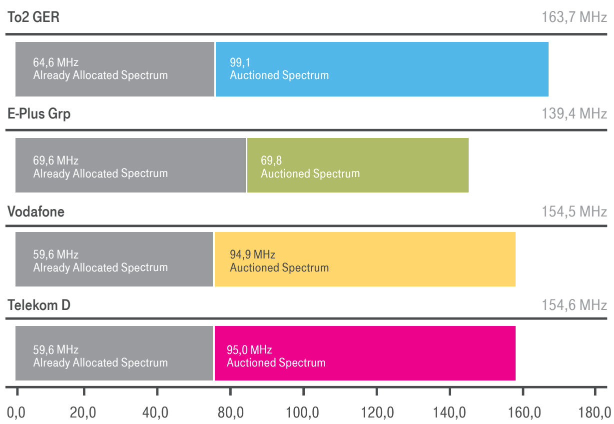

Fig. 7: Total available Frequency Spectrum of the four Mobile Operators in Germany after theFrequency Auction in May 2010 (Source: Bundesnetzagentur).

Mobile operators are of course looking for additional attractive spectrum in the range just below 790 MHz. From today's perspective the chances are quite low of making additional spectrum for NGMN available below 790 MHz. In Germany, as in many other countries in Europe, for the foreseeable future the spectrum between 470 and 790 MHz will continue to be used by DVB-T. But one may of course ask whether in the medium- and long-term broadcasting and mobile may converge from the network and technology point of view anyway. The consumer does not care about the technology and the network – he wants to get the service and the content instantly and according to his needs, by whatever way and network. And this may lead to co-operations between broadcasting and mobile we cannot imagine of today.

The other long-term option is to provide spectrum between 3.4 and 3.8 GHz for NGMN. This part of the spectrum can provide sufficient capacity for bit-consuming NGMN services in the long term. The worldwide regulatory conditions lack some clarity. Perhaps, as was the case at 800 MHz, a future World Radio Conference should set the appropriate political and regulatory frame in order to make these promising, broad frequency ranges actually available for the NGMN markets.

Design and Deployment of LTE Radio Networks

by Peter Merz and Ulrich Rehfueß
(Nokia Siemens Networks)

Introduction - LTE Business Perspective

Some position LTE as the solution that can solve all of the operator's problems while customers will never complain again about their mobile broadband experience. Actually, in a side-by-side comparison LTE outperforms all legacy mobile technologies, even when normalized to channel bandwidth. While opening new business opportunities and providing substantial cost savings, the business case for LTE remains an important topic and issues like spectrum availability, spectrum fragmentation and device complexity/costs are of primary concern.

Some analyst sources predict that today's legacy 3G technologies are still several years away from reaching their peak and LTE is probably yet another decade away from its peak, as determined by the terminal sale and penetration of LTE-capable handsets. On the other hand, the rise of multimode base stations as well as multimode support in UE chipsets suggest that migration from 2G/3G to LTE can happen much faster than the one from 2G to 3G. In any case, LTE deployment will have to take into consideration the legacy technologies operators have deployed today.

In a global digital world, a modern broadband communication infrastructure pays out as a competitive advantage due to its inherent innovation potential. While broadband access is available in cities via DSL, cable or the 3G/HSPA wireless networks, there are obvious shortcomings of broadband coverage in rural areas. Part of the population is still excluded from the modern information society, small and medium-sized companies without broadband connectivity do not have adequate competitive chances. People and enterprises in the countryside should get as fast and as reliable internet access as those in densely populated areas. In addition, mobile broadband technology enables new fields of application, e.g., cars can get fast internet access. This greatly enhances the situation for many industry branches such as logistics, telematics and emergency aid, to name a few examples.

A prerequisite for an operator's LTE business is basic coverage. The business case for LTE is most attractive when it is deployed in the highest available channel bandwidths i.e. 2x10 MHz or 2x20 MHz and – as for all radio – when it is deployed in lower-frequency bands. Unfortunately, the two do not go hand-in-hand. Wider channel bandwidths are typically available at 1800 MHz or above 2 GHz, which increases the cost of basic network coverage deployment.

LTE Deployment Considerations - Divide & Conquer

Suitable spectrum resources are essential assets of all operators. If an operator only had 800-MHz spectrum, that enables fast and cost-efficient basic coverage including rural areas, he may soon run into capacity limitations in urban areas and may not be able to offer competitive peak data rates. Conversely, if he only had 2600-MHz spectrum, ubiquitous coverage in less populated areas and to penetrate deep indoors obviously provides technical and economic challenges (Figure 8).

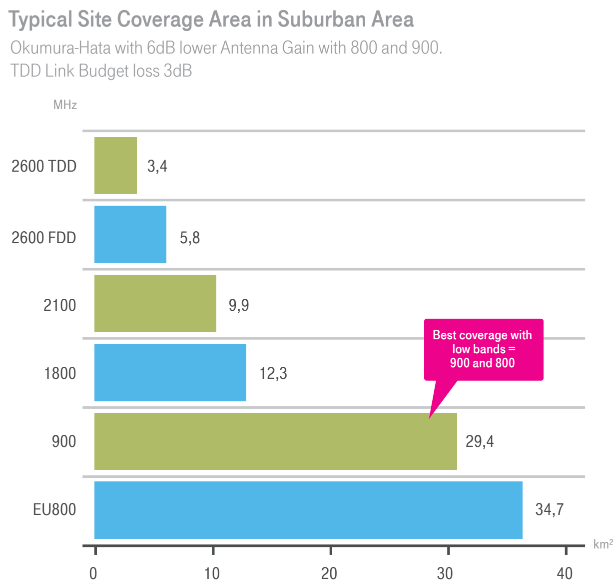

Fig. 8: Site Coverage versus Frequency Band.

Unlike 3G, the availability of lower-frequency bands such as 700 MHz in North America and the 800-MHz digital dividend spectrum in Europe provide excellent opportunities for fast rollout of a ubiquitous nationwide LTE coverage without touching the revenue-generating legacy systems in their respective bands. The availability of 800 MHz in Europe and 700 MHz in North America also allows for maximizing the value of support of HSPA in the installed terminal base in 900 and 850 MHz, respectively, by reserving those bands for an HSPA+ evolution path in the near future.

The 1800-MHz band presents an attractive option providing both coverage and capacity. Many European and Asia-Pacific operators already own 2x20 MHz and more, in many cases sparsely used as GSM capacity-enhancement layer in small high-traffic areas. This gives the ability to support an LTE capacity layer up to 2x20 MHz in the near future, especially after migrating GSM traffic to either GSM at 900 MHz or to 3G. At the same time, 1800 MHz provides excellent coverage on the existing 3G 2100 MHz site grid built out in densely populated areas where the majority of revenues are generated.

2600 MHz adds a new band for additional LTE capacity layers. Initial auction results in Europe indicate that even more than 2x20 MHz of FDD spectrum or combinations of 2x20 MHz FDD spectrum with, e.g., 20 MHz of TDD spectrum can be utilized to deploy capacity exactly to the geographical areas where offered traffic is high. Consequently, the 2100-MHz spectrum can be fully exploited for HSPA and its evolution not being burdened by LTE capacity needs for the next years.

Similar thoughts apply in North America where AWS (Advanced Wireless Services) spectrum for many operators provides the opportunity of a balanced LTE coverage/capacity layer on top of the initial 700-MHz coverage. Additional opportunities exist in the 1600-MHz L-Band and in the very wide 2500-MHz band while the cellular 850-MHz and the PCS 1900-MHz bands can be expected to be utilized by their respective legacy systems for quite some time.

Big countries in Asia like China and India typically have similar spectrum assigned in 900, 1800 and 2100 MHz. While 2600 MHz bands are not yet assigned, the 2300- MHz unpaired band creates huge momentum for TD-LTE which in LTE – unlike 3G – provides a true complement to FDD as both are parts of a single standard and allow for maximum re-use in UE chipset and eNB baseband processing allowing for multimode support both on terminal and infrastructure side.

With penetration levels in developed economies well above 100%, the number of subscribers cannot be expected to grow much further. Machine-to-machine application and multiple devices per subscriber may still drive the number of subscriptions significantly. Most of all, the amount of traffic will grow dramatically, e.g., Nokia Siemens Networks envisions a traffic growth by a factor of 100 over the next 5 years.

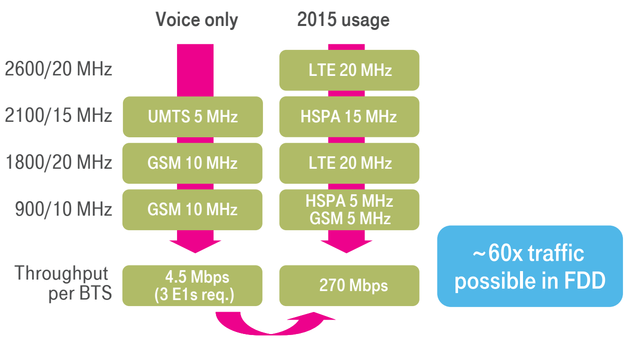

Fig. 9: Site Throughput Evolution.

One can estimate that part of the additional capacity can be deployed in existing sites by adding the above-discussed new bands and re-farming existing bands to state-of-the-art air-interface technology fully exploiting the advances in spectrum efficiency (Figure 9). Still, other measures have to be taken to cover the rest of the expected traffic growth. Additional methods include higher sectorization (i.e. transforming existing 3 sector sites to 6 sector sites), higher- order MIMO and/or beamforming, adding additional spectrum such as 2.6 GHz TDD, 3.5 GHz TDD or FDD, and adding sites. As much of the additional traffic needs to be expected indoors and in public hotspots, small cell solutions and means to operate them efficiently together with the macro network will become very important.

Heterogeneous Networks – LTE as part of Multi-Radio and Multi-Layer Networks

A heterogeneous network is comprised of multiple RAN technologies (GSM, HSPA, LTE and WiFi) and different network layers (macro, micro, pico and femto). The use of multiple network layers is especially interesting since it hinges on the notion that the best way to improve user data rates and overall network/spectral efficiency is to bring the user closer to the eNodeB, or vice versa (Figure 10).

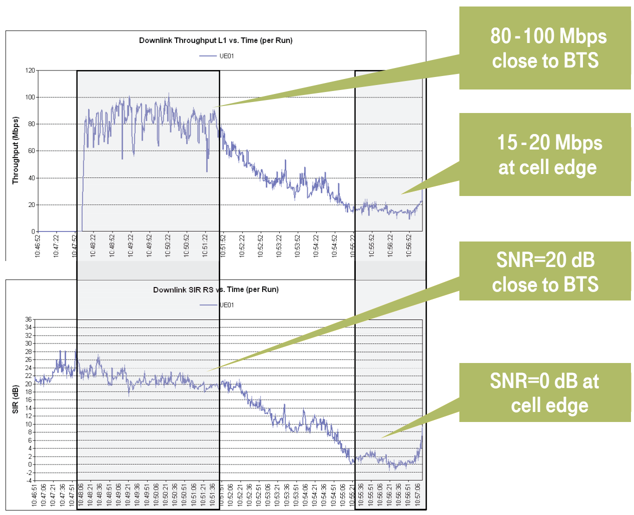

Fig. 10: LTE Downlink Throughput Measurements (Source: Nokia Siemens Networks).

In the near term, LTE will be most likely a mobile data and 3G capacity offload game. Soon however, as operators start to offer unique/branded services and voice over LTE, there will be the opportunity for operators to additionally differentiate themselves and their LTE networks.

The LTE standard covers a very large number of frequency options. With >20 potential FDD bands and 8 potential TDD bands the possibilities seem endless, which offers opportunities but also challenges for the technology. A typical LTE device may support a certain number of frequency bands but there will also be cost-optimized solutions for a subset of those bands. Further, one must also take into consideration an operator's legacy technologies and the frequency bands in which those technologies operate as well as bands used for roaming and the non-3GPP technologies such as WiFi, Bluetooth, A-GPS, and FM Radio which add another RF design challenge.

Some of the early LTE devices have been single-mode single-band, with legacy support introduced in later versions. There is also development towards multi-band multi-mode devices, like the Nokia Internet Modem RD-3, which is the Nokia development platform supporting GSM/EDGE, WCDMA/HSPA and LTE Cat 3 on number of different bands (Figure 11).

Fig. 11: Nokia Internet Modem RD-3 (Source: Nokia).

LTE Initial Deployment Results

LTE measurement results that were obtained in multiple trials and early commercial deployments show that the peak rates of 150 Mbps DL and 50 Mbps UL as well as latencies down to 10 ms are achieved (round-trip time to an application server with a 32-Byte packet) (Figure 12-1 & 12-2). Moreover, average downlink spectral efficiency above 2 bits/s/Hz both for FDD and TDD implementations under typical network load conditions exceeded 3GPP and NGMN simulation results. Finally, the transition time from idle to active was found to be as low as 100-125 ms.

First commercial grade UEs are typically of category 3 with MIMO support and 100 Mbps DL paired with 50 Mbps UL capabilities. Consequently, LTE networks can offer unrivalled user experience from day one without a tedious process over years of terminal technology getting ready for large-scale deployment.

Summary and Outlook

LTE with its variety of addressable bands for deployment provides excellent means for a profitable provisioning of large area coverage and scalable capacity. It is well prepared for coping with the enormous growth in traffic to be expected by means of improved spectrum efficiency, tight interworking with the 2G and 3G legacy systems and their evolutions, new RF bands and support of heterogeneous networks. History revealed that it took GSM roughly 20 years to reach its peak, as determined by the number of worldwide handset sales. UMTS started in 2001 and may not take as long to reach its peak as it took for 2G, but the peak is at least several years away due to the only recent 3G markets opening in China and India, which represent two of the largest cellular markets in the world. LTE can be assumed to grow into the 2020s before reaching culmination. With LTE-Advanced, 3GPP provides a sound evolution path over these years into IMT-Advanced.

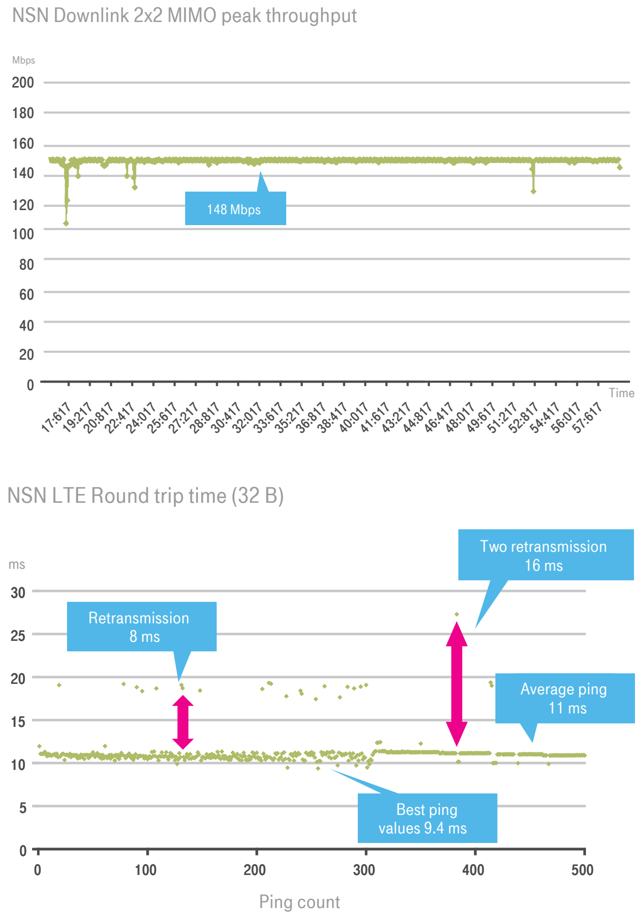

Fig. 12: LTE DL Peak Rate Measurement (12-1) and Latency (RRT) Measurement (12-2) (Source: Nokia Siemens Networks).

LTE has proven in trials and first commercial deployments to live up to its promises and to deliver the very compelling user experience required by the NGMN Alliance opening the mobile domain to the huge potential of the applications seen over fixed broadband today.

Self-Organization in LTE Networks

by Ulrich Barth and Dr. Edgar Kühn,
(Alcatel-Lucent, Bell Labs Germany)

Introduction

Mobile-access technology evolution is required to deliver high data rates with high quality of service (QoS) for a variety of applications without the need for extensive operational effort. The scale and complexity of modern mobile communication systems and the progressively decentralized nature of their ownership are strong reasons to look at self-organization and self-optimization (referring to in the following as SON, Self-Organizing Networks for short), as possible models for management and control of these highly complex systems. Complexity here is not merely a computational and transport challenge that could be overcome through acquisition of vast amount of computational, switching and transmission resources, it is the diversity of applications, volume of connections, geographic spread of users, localized ownership of the network and "connectivity, anytime, anywhere" with ever-increasing bandwidth that make the underlying systems challenging to manage in traditional ways.

The amount of wireless data being consumed by users, as well as the associated growth rate, has dramatically increased with significant implications for the mobile operators. The growth rate of the total data throughput far exceeds the growth rate of the revenues; consequently modern networks must deliver ever-increasing data rates at an ever-decreasing cost per bit. This also implies that the spectral efficiency has to further improve and therefore the spatial reuse of the spectrum will increase through large numbers of pico- and femto-cells. A combination of such small cells and macro cells is often referred to as layered or heterogeneous network. Together with the presence of multiple technologies, they imply growing radio access network complexity [3G America 2009]. The performance of such networks still needs to be optimized which leads to the simultaneous optimization of a large number of parameters. Often changes in these network parameters will need to be coordinated across technologies and layers, and varied over a wide range of loads, applications, and time scales.

Therefore, we believe that the consequences of the wireless data growth rate will change the paradigm of network management. Future networks have to organize and optimize their parameters by themselves and have to reduce the human interaction to a minimum. Only a few high-level performance indicators and a small number of policies shall be necessary to monitor and control the networks. However, it will take some time until this level of self-organization is achieved because the SON algorithms have to prove their performance and stability in an environment where any failure has a huge commercial impact. Extensive field verification and step-by-step introduction of SON features is required to develop the confidence of the mobile operators in the SON algorithms.

Standardization activities

With introduction of the new mobile communication standard LTE (Long-Term Evolution), the 3rd-Generation Partnership Project [3GPP] has started standardization of first self-configuration and self-optimization features already in the first release of LTE standards [3GPP Technical Report]. These features focus first on self-configuration of neighborhood relations and on self-optimization of handover performance. It has to be noticed that 3GPP restricts to the definition of procedures especially regarding measurements and signaling that are required to enable self-organization and to guarantee interoperability between user equipment, network infrastructure nodes and network management. Algorithms and procedures for optimization remain under responsibility and competition of vendors. 3GPP successively extends standardization of new use cases for self-organization in following releases.

One strong driver in mobile network self-organization is the Next-Generation Mobile Networks alliance NGMN. One of the NGMN projects targets is to evaluate and define SON solutions in preparation of 3GPP standardization. NGMN has figured out an exhaustive set of SON use cases, such as mobility robustness or automatic neighbor relations, and worked out detailed descriptions for them together with requirements and recommendations for corresponding SON solutions [Use Cases related to Self Organising, 2007], [NGMN Recommendation on SON and O&M Requirements, 2008]. One further important aspect, also covered in NGMN, is the so-called multi-vendor interoperability which shall guarantee seamless operation of network infrastructure equipment from different vendors.

Self-optimization of antenna tilt

Many self-optimization tasks in radio access networks can be understood as maximization of dedicated target functions by an automated tuning of network control parameters. An important optimization task is, e.g., related to the antenna tilt. This configuration parameter is conventionally associated with a high optimization effort and strongly impacts cell coverage as well as cell capacity. Cell coverage becomes critical at cell border where the signal to interference ratio (SINR) drops down to levels below 0 dB because of neighbor cell interference in a reuse one system. So the optimization target is first to provide continuous coverage in which connections can be established with acceptable service quality. This holds strictly for outdoor coverage whereas indoor coverage should of course be also considered as far as possible. Cell capacity is the second optimization target because SINR distribution over the cell area depends again on antenna tilt.

In order to cope with this optimization targets we have used for our antenna-tilt simulation studies two metrics, the cell throughput under full buffer assumption and the 5-percentil of the throughput cumulative distribution function (CDF), the latter reflecting cell-edge coverage. The throughput was calculated from simulated user equipment (UE) SINR values using the hull curve of the throughput values of all MCSs (Modulation and Coding Schemes).

The optimization process was simulated for 19 tri-sectorized base stations which have been located on basis of a hexagonal cell layout with 500m inter-site distance but applying to each base station a random displacement which was equally distributed among the 19 base stations in the range between 0m and 200m. The antenna height was 32m. Fast- fading and position-depending shadowing was considered. The spatial distribution of SINR values has been collected from a UE performing a random walk through the simulation area. Good optimization results have been obtained for a utility function consisting of a weighted sum of the cell border performance and the cell throughput in the optimization algorithm.

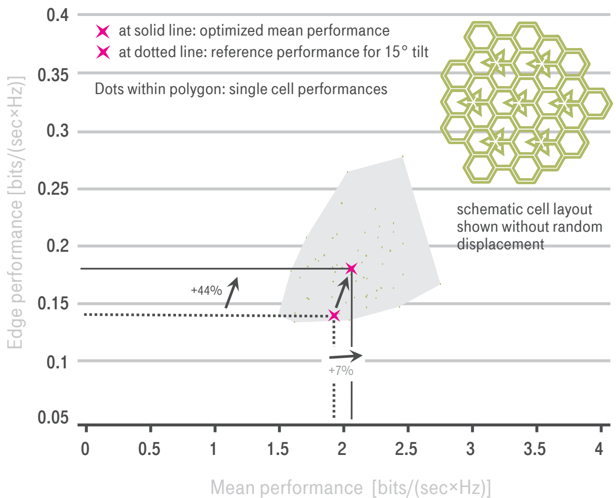

Fig. 13: Mean Cell and Mean Cell-Edge Performance before (dotted line) and after Tilt Optimization (solid line). The Respectve Cell Performances are indicated as Single dots within the Polygon area.

Figure 13 shows the performance gain of the optimization process starting from a uniform 15-degree tilting in each sector. The two crosses indicate both metrics mentioned above, the mean cell throughput (x-axis) and the cell-edge performance (y-axis) for the initial 15- degree configuration (dotted lines) and the tilt optimized configuration (solid lines). The individual performance figures of the 57 sectors after the optimization process are indicated by the dots within the polygon area. Their varying performance is due to the area correlated shadowing and the individual base station displacement. Effectively, the optimization process yields a significant mean improvement of 44% for the cell-edge performance (5-percentile metric) and of 7% for the mean cell throughput.

The optimization was done by successive optimization steps with decentralized optimization functions in the base stations. Figure 14 shows a fast and stable convergence of the performance after about 60 optimization steps. This represents a rather good convergence behavior.

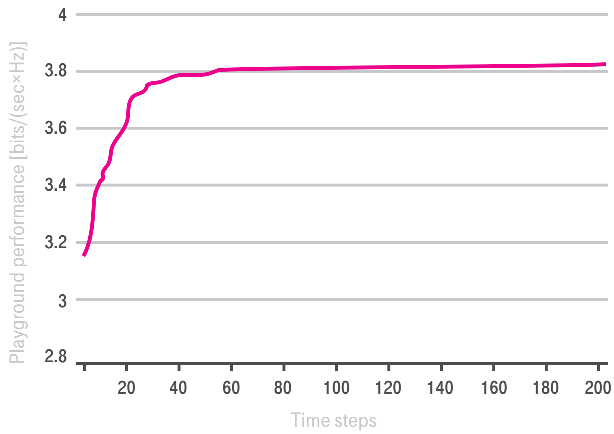

Fig. 14: Convergence of the Tilt Optimization Process.

The potential of tilt optimization for the extreme case where one sector fails or is switched off temporarily for power-saving reasons and where coverage in the affected area has to be taken over by neighbor cells is shown in Figure 15. Here a regular hexagonal base station deployment was used without displacement. As shown in Figure 15, the 5-percentile of the Geometry (long-term SINR) drops down to -4.7dB which leads to large badly or even uncovered areas. Also the cell capacity characterized by the mean Geometry worsens by 7dB. After outage compensation by neighbor cell- tilt adaptation the coverage could be re-established to a large extent as shown by the increase in the 5-percentile of the Geometry. Of course, this is at the expense of a reduced cell capacity. But nevertheless, a mean Geometry of 4.2dB could be achieved within the affected area and shows also a significant potential for self-healing.

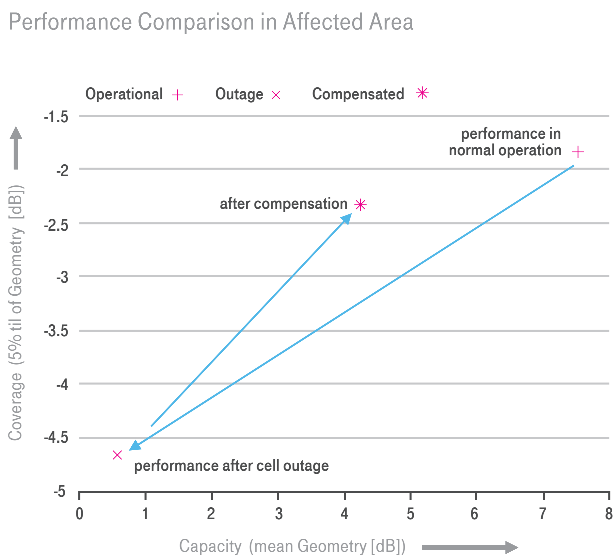

Fig. 15: Simulated Cell Outage Compensation: Coverage and Capacity in Terms of Geometry (long-term SINR) for Operational Cell, after Outage and after Compensation.

Vision and Conclusion

As we pointed out, there are ambitious efforts for introducing self-organization functionality into future mobile networks. Driving forces are network operators, infrastructure vendors and standardization organizations. Besides an increasing number of solutions that are already developed today for different use cases, there is a clear trend to put the intelligence for network management and optimization down into the network nodes.

In future, this will cause a paradigm change in network operations. While today it is a matter of course to have full control over an tremendous set of network configuration and operation parameters, network management will focus in future on performance management by defining rules and policies for the SON algorithms. So, future network management tasks will no longer be parameter setting and tuning but will concentrate on network planning, alarm and performance monitoring and high-level performance steering.

The SON functions will be implemented as distributed functionality in the network nodes allowing permanent network optimization and including real plug-and-play functionality. These SON functions will rely on context information from the user terminal like, e.g., radio measurements, mobility situation or location information as well as on performance indicators from the network side like measurements, counters and alarms. They will allow to a large extent an autonomous network operation which is tuned by policies and constraints according to operators' needs directly from network management as shown in Figure 16.

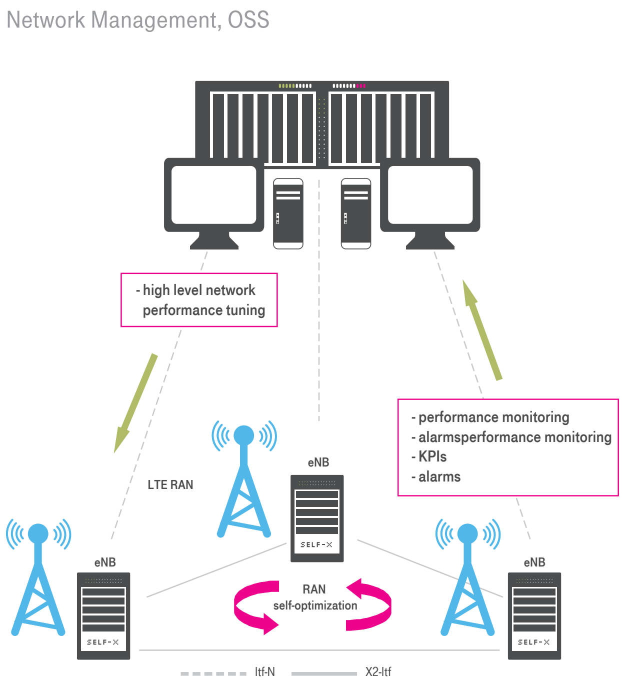

Fig. 16: Vision of Future Management Architecture for SON-enhanced Radio Access Networks.

This network management evolution will lead on one side to a more flat and cost-efficient network management architecture and on the other side, it will pave the way for massive introduction of smaller cells and relays. This will finally enable a better spatial tailoring of the cell topology w.r.t. required capacity and allow support of higher data rates per user. Also, this will enable more flexible methods for power saving by dynamical control of used hardware resources, e.g., by switching off unneeded cells during low-traffic periods.

Still challenging is the need for managing and controlling the interworking of different SON functions. Because many SON use cases are mutually dependent on each other, e.g., because they impact the same network control parameters, new mechanisms for control of that interworking are required. Even if the first encouraging concepts are available [FP7 EU project], convergence as well as stability in space and time of interworking SON algorithms will be an important area for further research work.

In summary, we conclude that self-organization in mobile networks not only has the scope of cost saving. It has rather a large potential for achieving real plug-and-play behavior and permanent network optimization. Moreover, it opens the way for a more flexible and adapted cell topology as well as for new energy-saving methods.

Challenges and Solutions for LTE/HSPA Chipsets and Devices

by Dr. Vieri Vanghi (Qualcomm)

Several challenges exist to bringing to market LTE chipset solutions and devices. For example, challenges are inherent in the higher peak data rates afforded by LTE. LTE devices also need to support a higher number of RF bands. Finally, since LTE networks are at least at the beginning being deployed (typically) as hot spots that rely on ubiquitous HSPA coverage for service and user-experience continuity, multi-mode devices are needed that require highly integrated LTE and HSPA modem solutions.

What are the challenges?

High peak rates

Firstly, it is all about the high peak data rates. First-generation LTE modems typically support data rates up to 100Mbps, which is a two-fold increase relative to the data rates of HSPA modems (DC-HSDPA at 42Mbps) of the same generation. Peak data rates have a profound impact on modem architecture as they determine: the required modem processor(s) horsepower; the demand for bandwidth of internal buses and external memories; the amount of current consumed and heat that needs to be dissipated; and ultimately the size of the silicon die and therefore the cost structure of the chipset and of the device.

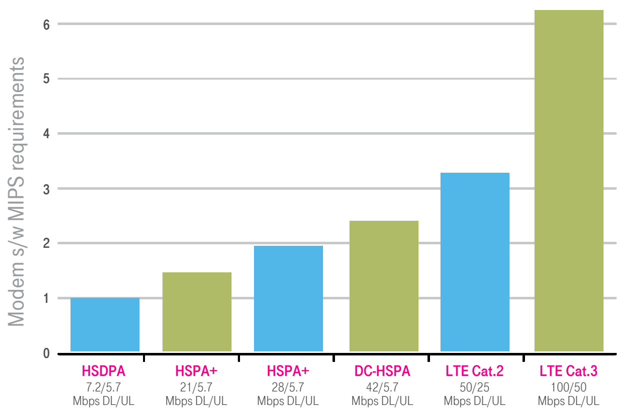

Fig. 17: Data Rates LTE and HSPA.

One of the indicators of modem processor 'horsepower' is its capability expressed in MIPS. The chart above, while derived from profiling of a specific implementation, is representative of the MIPS required of a typical modem processor to support concurrent downlink and uplink data transfer at various data rates and for both LTE and HSPA.

An HSPA modem capable of 7.2/5.7 Mbps downlink/uplink is used as reference. It can be noted that the required MIPS increase by ~ 50% with the doubling of the combined downlink and uplink peak data rates, and that such increase applies equally to Rel-8 LTE, Rel-8 DC-HSPA and legacy HSDPA technologies alike. In absolute terms, an LTE Cat.3 modem processor is expected to handle a work load in order of hundreds of MIPS.

Higher data rates also imply higher bandwidth required of the internal bus for moving data across the stack, and to access external memories. The bandwidth that the internal bus needs to offer is basically doubled with doubling of peak data rates. If external memory performance is inadequate, then internal memory can be used to ease external memory bandwidth, but that comes at the cost of additional silicon.

Finally, higher data rates impact negatively current consumption because processors and buses need to be clocked at higher rate. Current consumption increase not only impacts user experience because the battery is drained at a faster pace, but also more heat is generated that needs to be dissipated through the device case. That, in turns, means the size of the device needs to increase to avoid excessive overheating. In the case of mono-block type of devices, such as the USB modems that attach to a portable computer, the average temperature rise over the ambient temperature measured on the surface of the device can be easily estimated based on the power dissipation density, that is, based on current consumption and surface of the device as depicted in the graph below.

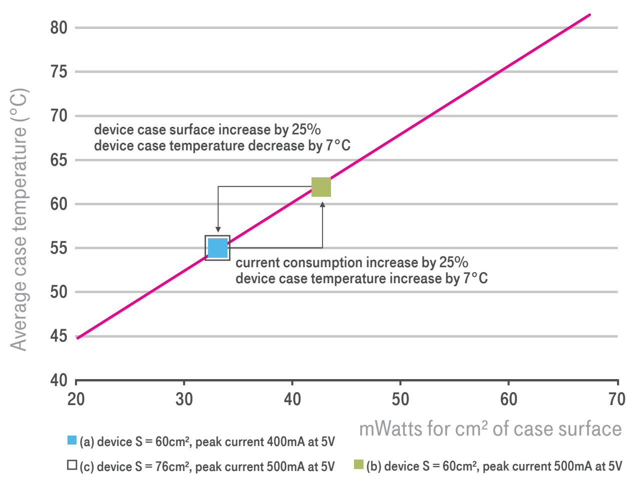

Fig. 18: Average Temperature of the Device.

Take, for example, a device – case (a) – designed to achieve average temperature of 55°C in an ambient temperature of 25°C while dissipating 33 mW of power per cm^2. If the current consumption increases by 25% reaching 42 mW/cm^2, then the average temperature of the device – case (b) –will rise to 62°C. While such temperature increase may seem limited, one needs to consider that these values represent averages. In practice, power dissipation density on the device case is not uniform because of constraints in placement of the electrical components inside it, which create hot spots. Hence, a 7°C increase as in the example above may violate thermal constraints. In such case, then the device surface needs to increase by 25% as in case (c) to keep the power density unchanged and achieve the 55°C design target despite the increase in current consumption.

High number of RF bands

Challenges discussed above are direct consequence of the LTE physical layer design. But LTE also brings, indirectly, other challenges such as the need for devices to support a higher number of RF bands. With the availability of new and refarmed spectrum used for LTE, the number of RF bands and band combinations supported in one same device is growing fast. In the not-so-distant future, multi-mode devices may be required to support up to 10 RF bands. Two problems arise: Firstly, additional RF bands require additional discrete front-end components (e.g., duplexers, power amplifiers), which increase routing complexity and size of the circuit board, and also increase device cost. Secondly, more RF bands also mean more RF band combinations required by a particular market or operator. That it turns means a higher number of device variants that need to be developed using the same platform, thus increasing device fragmentation and non-recurrent expenses.

LTE/HSPA modem solutions for multi-mode devices

Modem integration

Different multi-mode LTE/HSPA chipset solutions are becoming available. There are those based on a 'velcro' approach in which two discrete modems, one for LTE and one for HSPA, are paired together. The velcro approach is very inefficient as it results in higher chipset cost and footprint. Not only is there no re-use between the two separate modems, but also each modem may need its own memory subsystem and its own power-management subsystem. Power consumption will also be inevitably higher in such solutions.

Another solution is one in which two discrete modems are implemented in separate silicon dies packaged together in a so-called SiP (System-in-Package) solution. With SiP, memory and peripherals can be more easily reused, but yet there is no re-use of the silicon used by each of the modems, and also the package size increases, all of which leads to a sub-optimum implementation.

The optimal solution is represented by a truly SoC (System-on-Chip) solution in which both LTE and HSPA modem cores are implemented in the same silicon die and with high level of re-use of fundamental H/W blocks. In such a SoC, both LTE and HSPA S/W stacks run on the same modem processor, which is sized according to the most demanding of the two radio technologies. Internal memories, if present, can be re-used. Also many of the H/W blocks required for low-level PHY processing can be re-used despite differences in radio technology. The analog core, which includes the Rx ADC, the Tx DAC, PLLs, temperature sensors etc. can also be entirely re-used. Considering that in a typical design, the analog core, bus, memories, peripheral subsystem, account for ~25% of the total silicon, while modem processors and dedicated H/W blocks make for the remaining 75%, a highly integrated dual-mode LTE/HSPA SoC solution can therefore achieve a high degree of efficiency in silicon re-use.

Techniques for low power

We have seen earlier how form factor and thermal performance of an LTE device may be affected by the higher current consumption induced by higher clock rates and in general larger silicon die. Several techniques exist to minimize current consumption.

Modems support low-power modes controlled by means of Dynamic Voltage and Clock Scaling (DVCS). DVCS allows reducing voltage and clocking when chip is in an operational mode for which full performance is not required. In extreme scenario, power collapse over multiple and independent power domains allows to completely turn off certain H/W resources.

For those operational modes that require full performance and thus determine peak power consumption, DVCS is not applicable. Hence, low-power strategy calls for certain MIPS-intensive functions to be implemented in H/W, as H/W tends to be more power-efficient than any conceivable S/W implementation.

RF front-end improvements

Alongside with improvements in miniaturization of RF discrete components, new technologies that increase the level of integration of the RF front-end can be leveraged to compensate for the increase of RF bands supported by a multi-mode LTE/HSPA device. Modules will soon be available to combine switchplexers, duplexers, and filters. Tx filters and inter-stage Rx filters are made redundant by improvements in RF IC transceiver technology. And even when needed, some Rx filters can be eliminated by co-banding across different radio technologies. Also, multi-mode multi-band power-amplifier modules are emerging that will replace the discrete components available today.

Another short-term opportunity for simplifying front-end design is the adoption of MIPI RFFE, a 2-wire multidrop serial interface being standardized by Mobile Industry Processor Interface (MIPI) for RF front-end control. MIPI RFFE can replace the existing parallel interface for RF front-end control, allowing for chipset cost reduction (pin reduction and bump spacing increase alleviate packaging constraints and cost). Also, fewer pins/signals enable simpler layout and routing on PCB (Printed Circuit Board), and therefore a simpler (and less costly) PCB stack-up.

But the ultimate design goal in RF front-end optimization will be achieved with tuneable front-ends, which leverage MEMS capacitors to improve Q-factor, tuning range and linearity. Such technology will enable devices that can efficiently support in excess of 10 RF bands, but it will not be available for the next few years. Till then, devices supporting up to 10 RF bands are possible but at the expense of cost and size.

Conclusions

LTE peak data rates primarily drive modem performance requirements and device thermal design. H/W implementation of MIPS intensive functions need to complement efficient DSP architecture to minimize power consumption. As HSPA capability is needed a long side LTE, a high level of tight integration of both modems in a true System-on-Chip solution allows size and cost of the solution to be minimized and optimizing of its performance. LTE leverages new and refarmed spectrum, hence a multi-mode LTE/HSPA device needs to support a higher number of RF bands. In the short term, availability of highly integrated RF front-end modules is needed to alleviate the complexities that come with such higher number of RF bands, and avoid impact on device size and form factor.

LTE-Advanced

by Prof. Joachim Speidel (University of Stuttgart), Heinz Droste and Philipp Frank (Deutsche Telekom Laboratories)

Key Technologies for LTE-Advanced

Requirements for LTE-Advanced

Mobile systems according to the LTE Release 8 specification can provide peak data rates of more than 300 Mbit/s on the downlink (DL), and 75 Mbit/s on the uplink (UL) using a frequency band of up to 20 MHz. Currently, major performance enhancements are studied in 3GPP under the item LTE-Advanced (LTE-A, also called LTE Release 10), which will even exceed the International Mobile Telecommunications-Advanced (IMT-A) requirements [3GPP TR 36.913 2009]. Peak data rates of more than 1 Gbit/s in the downlink, and 500 Mbit/s in the uplink are the targets. Consequently, the peak spectral efficiency has to be increased up to 30 bit/s/Hz (DL), and 15 bit/s/Hz (UL) at 40 MHz bandwidth. The available bandwidth shall be expanded up to 100 MHz. Furthermore, the cost per bit has to be further lowered and the flexibility of the network enhanced. LTE-A has to be considered as an evolution of LTE with the strong requirement of backwards compatibility to Release 8 user equipment (UE).

Overview of Key Technologies for LTE-A

In the following, the major technologies are introduced that are currently considered in 3GPP for achieving the previously outlined performance targets.

Bandwidth Aggregation

In general, the data rate is proportional to the bandwidth covered by the transmit signal. In 2007 the World Radio Conference (WRC) identified additional spectrum for IMT-2000 and IMT-A. These frequency bands are fragmented and located in the regions of 800 MHz, 1.8 GHz, 2 GHz, 2.6 GHz and 3.5 GHz. Spectra used for transmission, called component carriers (CC), can be aggregated to an enlarged transmission spectrum [3GPP RP-091440 2009, 3GPP R1-102601 2010]. Each CC will handle separate data streams, which are aggregated at the Medium Access Control (MAC) layer. If two or more CCs lie contiguously in the same frequency band, a single transmission chain with only one inverse discrete Fourier transform (IDFT) can be used in the base station (eNodeB or eNB in 3GPP terminology) for downlink OFDM transmission. Figure 19 shows an example. The zeros at the input of the IFFT indicate that these OFDM subcarriers are not used. The spacing between center frequencies of contiguously aggregated CCs has to be a multiple of 300 kHz to ensure compatibility with the 100-kHz raster of Release 8/9, and to preserve orthogonality of the OFDM subcarriers with 15-kHz spacing. CCs in different frequency bands are non-contiguous. This also holds for CCs in the same band, if they are separated by carriers of other use. In both cases carrier aggregation requires separate chains in the eNB as well as the UE [3GPP R1-103348 2010]. Note, that carrier aggregation in general does not increase spectral efficiency.

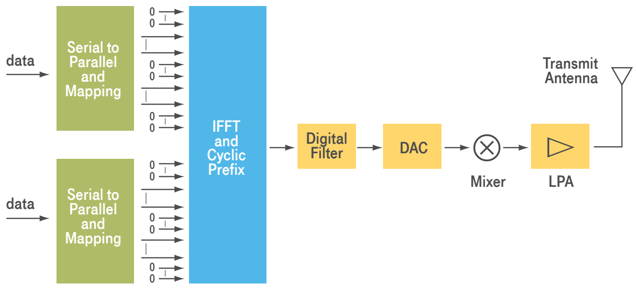

Fig. 19: Carrier Aggregation in eNB to enlarge Bandwidth for Downlink Transmission with increased Date Rate.

Higher-Order MIMO and Beamforming

The spectral efficiency can be increased by using multiple-input multiple-output (MIMO) antenna arrays at both the transmitter and the receiver. LTE Rel. 8 already supports single-user (SU) and multi-user (MU) MIMO transmission. With SU-MIMO method, one UE is served at a time on a certain frequency resource whereas with MU-MIMO multiple UEs may be served simultaneously. In this regard, the separation of the different UE signals can be achieved by appropriate spatial pre-coding at the transmitter side.

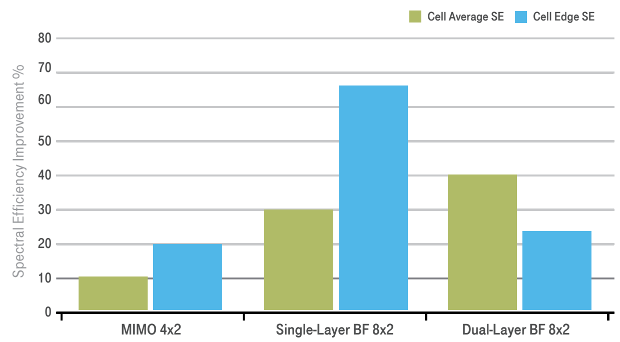

Fig. 20: Average and Cell-edge Spectral Efficiency Improvement in Comparison with Conventional MIMO 2x2 for the 3GPP Urban Macro Case 1 (SE Spectral Efficiency, BF Beamforming).

LTE-A supports larger antenna arrays than LTE Rel. 8, namely 8x8 MIMO for the DL, thus enabling spatial multiplexing with a maximum of 8 different layers while in the uplink at most 4-layer spatial multiplexing is foreseen. In general, both single-layer (one data stream) and multilayer (more data streams) transmission is supported. Higher-order MIMO with spatial multiplexing can particularly increase peak and average data rates whereas beamforming, which is also possible with antenna arrays, can be effective for reducing interference for users at the cell edge. Figure 20 shows the results of computer simulations taken from "LTE-Advanced - A Further Evolutionary Step for Next-Generation Mobile Networks" outlining the significant increase of spectral efficiency compared to conventional 2x2 MIMO of LTE Rel. 8.

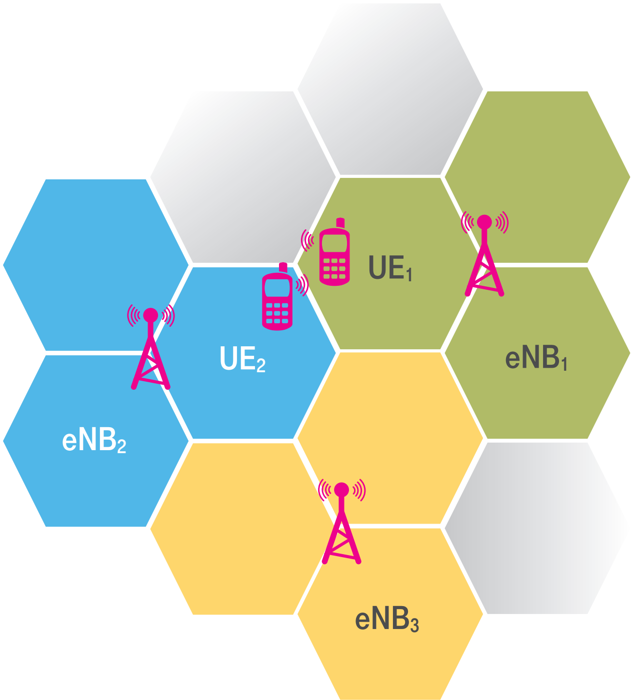

Fig. 21: Cellular Network.

Coordinated Multipoint (CoMP) Transmission and Reception

Interference is the main obstacle for a further increase of data rate and throughput at a given spectral efficiency. For example, in the scenario depicted in Figure 21, UE1 suffers from intra-cell interference inside a hexagon, from inter-site interference coming from the three cells (sectors) surrounding the anchor eNB1, and from inter-cell interference generated by the adjacent cells belonging to eNB2 and eNB3. With OFDMA in the downlink, and single carrier (SC) – OFDMA in the uplink specified in LTE Rel. 8, intra-cell interference is rather low. Thus inter-cell interference normally dominates, in particular if UE1 moves closer to the cell edges in Figure 21. Various advanced interference reduction techniques have been studied, and two powerful technologies were discussed for LTE Rel. 10, namely base-station-coordinated scheduling and/or beamforming as well as joint downlink transmission, which are outlined in the following. These methods are based on the cooperation of several eNBs to serve one UE, and are named as Coordinated Multipoint (CoMP) Transmission and Reception techniques. Figure 21 shows the principle with two eNBs. A backhaul network is linking the cooperating eNBs for fast information exchange about the parameters of the radio channels between the UEs and the eNBs.

Joint Downlink Transmission

UE1 signals multi-cell channel information to eNB1, i.e. information about the physical channels between UE1 and eNB1 as well as between UE1 and eNB2. This information is distributed by eNB1 via the backhaul network to all collaborating eNBs. Consequently, UE1 can be served jointly by all cooperating eNBs. The advantage is twofold, because the signal for UE1 and the interference for other UEs (UE2 in Figure 22) can be optimized at the same time. In order to avoid a loss of spectral efficiency, joint transmission usually should be combined with multi-user MIMO techniques applied across the various cooperating cells so that always the number of served UEs corresponds to the number of cooperating eNBs.

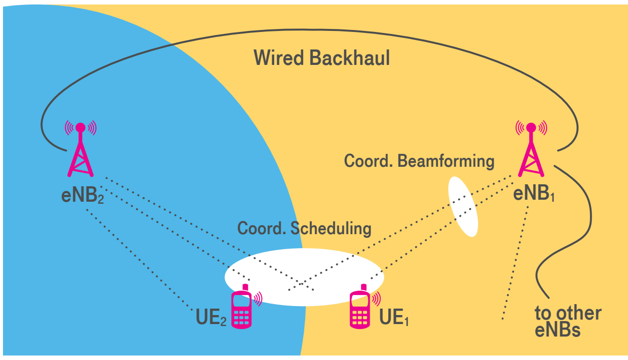

Fig. 22: Cooperating eNBs as an example for CoMP Transmission.

Exchanging multi-cell channel information among the cooperating eNBs can also improve the detection of the uplink signal in the eNB (in Figure 22 eNB1) significantly, because the cooperating eNBs virtually increase the number of receive antennas in the uplink (Distributed/Network MIMO) and thus spatial diversity is exploited. If multi-cell channel information is available at the eNB1 from all cooperating eNBs, interferences from the UEs at eNB1 turn into useful signals, enabling reduced bit-error rates by joint detection methods.

Coordinated Scheduling and/or Beamforming

With this technique only one of the cooperating eNBs, namely the anchor eNB transmits data to the UE and no multipoint downlink transmission takes place. Scheduling is coordinated with the other eNBs and executed in the anchor eNB for the associated UEs. This method can also be very effective for interference reduction. The principle is depicted in Figure 22. UE1 and UE2 shall be located at their cell edges, thus experiencing heavy interference if the eNBs transmit at the same time and on the same frequency resources. If eNB1 and eNB2 were not to cooperate they could even schedule beamforming to their respective UEs which would be completely wrong, because it would result in even stronger interference. On the other hand, as an example, if eNB1 knows due to cooperation that UE2 is not active, then beamforming to UE1 would be the right method, because it lowers the interference for all other UEs due to a concentration of the radio beam in one direction. Thus, by coordinating the resource allocation and the selection of appropriate MIMO precoders across various cells, coordinated scheduling and/or beamforming techniques can significantly increase data rate and throughput.

With the joint downlink transmission technique discussed before, the feedback signaling channels from the UEs to their anchor ends generally may have to carry a significant higher load compared to non-cooperative systems, because multi-cell channel information has to be transmitted. A way out is to refrain from the feedback of multi-cell channel information and to focus on coordinated scheduling in the ends.

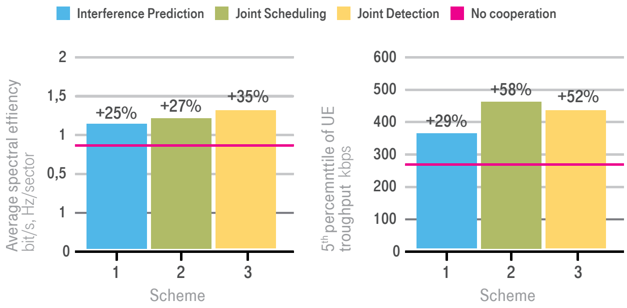

Fig. 23: Average Spectral Efficiency and Cell-edge Throughput for the LTE Uplink with Interference Prediction, Joint Scheduling and Joint Detection for the 3GPP Urban Macro Case 1, assuming 6 Cooperating Sectors per Base Station. The given Percentages denote the relative Performance Gains compared to the Reference Release 8 Setup without any Cooperation.

In order to get an idea what gains can be achieved with CoMP techniques intensive simulations have been done by T-Labs in the BMBF research project EASY-C [Stencel et.al. 2010, Müller et.al. 2010, Frank et.al. 2010]. Some results are depicted in Figure 23.

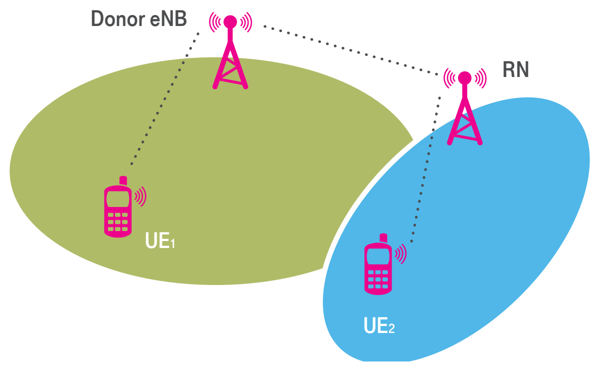

Fig. 24: Relay Node (RN) in a Mobile Network.

Relay Nodes

In LTE-A Rel. 10 relays are introduced to extend coverage in certain areas of the network, where an increase of transmit signal power by the eNB would deteriorate reception condition of other UEs by enhanced interference. This situation may, for example, occur for high data rate users located in buildings and thus suffering from low signal level. The principal deployment of a relay node (RN) is depicted in Figure 24. The donor eNB forwards the data traffic to the region of the RN. Simple relays would just amplify their received signal ("amplify and forward relay"). More sophisticated RNs, which fully decode the received signal ("decode and forward relay") are recommended in 3GPP for LTE-A. Therefore, the RN can be considered as a simple eNB, that is connected to the donor eNB by a wireless backhaul link either in-band or out-of-band. From the UE2 point of view in Figure 24 such a RN should function similarly to an eNB including layer-2 and -3 processing. RN and their associated UEs can operate with higher spectral efficiency and thus with higher data rates which is a further advantage of this technique.

Economic Assessment of LTE-Advanced Key Technologies

Implementation Challenges

Carrier Aggregation

As outlined before, carrier aggregation is an important feature of LTE-A to increase data rates. At the same time, however, it comes along with an increased implementation complexity of both, eNBs and terminals, especially if the carriers are non-contiguous. The wider frequency bands put strong requirements on the linearity of the power amplifier (LPA in Figure 19) of the eNB as well as in the UE. Moreover, implementation of channel estimation will become a challenging task, because RF propagation is different in the associated frequency bands, and reciprocity of the uplink and downlink channels is not always fulfilled. An important feature of carrier aggregation with LTE-A is backwards compatibility to UEs which only support LTE Rel. 8. Allocation of different numbers of carriers in the uplink and the downlink can increase network flexibility to take care of asymmetric data traffic.

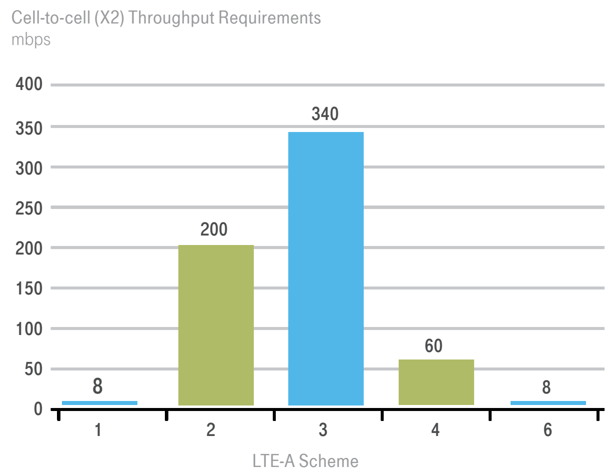

Fig. 25: Backhaul Throughput Requirements for different LTE-A Schemes; 1 = Uplink Interference Prediction, 2 = Uplink Joint Scheduling, 3 = Uplink Intersite Joint Detection, 4 = Uplink Distributed Successive Interference Cancellation, 6 = Combination of Intrasite Joint Detection and Intersite Interference Prediction.

Coordinated Multipoint Transmission and Reception

Cooperation of eNBs provides powerful mechanisms to reduce interference, specifically for UEs at the cell edge. Theoretical considerations and simulations are very promising, and are showing impressive results. However, it has to be expected that the gain of real implementations is well below, yet significantly large. There are various reasons, such as multi-cell channel estimation and synchronization errors. Moreover, cooperating eNBs should lie in close geographical vicinity, which will not be given in all practical cases. Multi-cell channel estimation will be an implementation challenge especially in the UE, where cost and battery power are important issues.

Backhaul Requirements for different CoMP Types

As outlined previously a major prerequisite of CoMP is the distribution of multi-cell channel information and other parameters of the UEs between the cooperating eNBs. This has to be done through the backhaul network, which links all associated eNBs. The required bit rate strongly depends on the dedicated CoMP method used, the number of cooperating eNBs, and the number of active UEs. With coordinated multipoint transmission and joint detection in the uplink, the bit rates may reach several Gbit/s per eNB, as shown for some scenarios in "Inter-site joint detection with reduced backhaul capacity requirements for the 3GPP LTE uplink" [Frank et.al. 2010]. Much lower bit rates are required, if the eNBs refrain from transmitting complete multi-cell channel information and focus on the coordination of the resource allocation and the selection of dedicated MIMO pre-coders across the various cells, while the actual data is still transmitted by a single eNB only. An example of cell-to-cell throughput demand calculated for different LTE-A schemes under clearly defined conditions is depicted in Figure 25.

Besides the high throughput demand most CoMP schemes require low end-to-end latency of the backhaul connection. In real networks these requirements could be solved by traffic prioritization, primarily if the throughput demand at the same time is sufficiently low.

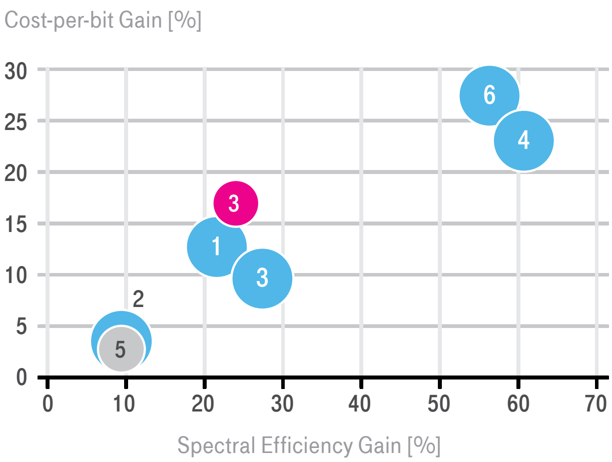

Fig. 26: Estimation of relative Deployment Cost divided by Relative Performance Gain (Cost-per-bit Gain) for different LTE-A Schemes ; 1 = Uplink Interference Prediction, 2 = Uplink Joint Scheduling, 3 = Uplink Intersite Joint Detection, 3 (red) = Uplink Intra-site Joint Detection, 4 = Uplink Distributed Successive Interference Cancellation, 5 = Downlink MU MIMO (with Low Air Interface Feedback), 6 = Combination of Intrasite Joint Detection and Intersite Interference Prediction.

A cost-efficient solution for CoMP is the cooperation between the different sectors of only the same site, because backhaul cabling is minimal. However, only intra-site interference can be mitigated in this case.

Impacts on Implementation Cost

In general a detailed estimation of implementation cost for future technologies is not easy. However, there are quite some hints at challenges which have to be solved. Figure 26 shows an estimation of the cost-per-bit reductions to be gained by different LTE-A technologies. These gains are calculated by relating scheme-specific deployment cost increase (compared to baseline LTE Rel.8) to scheme-specific average spectral efficiency gain.

As can be seen scheme 6 which is a combination of intra- and inter-site cooperation is most promising, also because it requires only low backhaul throughput, as indicated in Figure 25.

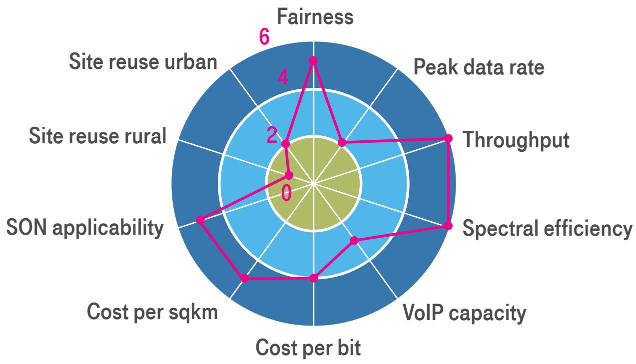

Fig. 27: Assessment of Distributed Multiple Antennas (Distributed/Network MIMO; SON = Self-Organizing Networks).

In „Analyse und Bewertung künftiger Mobilfunksysteme" [VDE-Kongress 2008, München], an interesting metric to compare the relative benefits of the various proposals for LTE-A was introduced and successfully applied during the EASY-C research project [Müller et. al. 2010]. As outlined in the previous section, an important feature of CoMP technology is the generation of virtual distributed antennas in the uplink without installing new antennas at the anchor eNBs. The qualitative assessment of this technology is given in principle in Figure 27 with respect to various parameters: 6 is the highest, 0 the lowest ranking. Due to the achievable high throughput data rate, the cost per bit is promising for an economic operation.

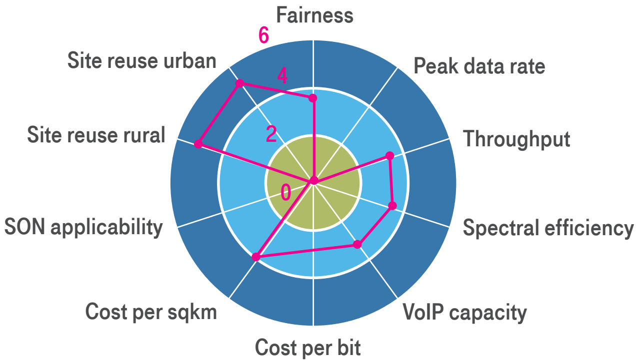

Fig. 28: Assessment of relaying.

As a further example Figure 28 shows the principal assessment of cooperating relays [Droste 2008]. As expected, the largest benefit of this technique is given by the site reuse capability in urban as well as rural areas whereas operational cost savings – indicated by SON applicability – are not to be expected.

In the future the network carriers will be faced with a rapidly increasing demand for data rates, which cannot be satisfied by improved transmission technologies exclusively. As a solution the deployment strategy may shift towards new network structures, namely the introduction of heterogeneous networks including macro-, pico- and femto-cells.

In conclusion LTE-A provides significant gains in performance and flexibility. Complexity is moderately increased. It can be expected that reasonable cost savings will be achieved with this new technology, but many implementation and deployment details have currently not been solved.

Future Research Challenges for Mobile Networks

by Prof. Holger Boche (Fraunhofer Institute for Telecommunications (HHI))

Studies of future communication systems predict that data traffic will increase by up to a factor of 1000 in the next 10 years, which roughly corresponds to a doubling of traffic every year. Especially for future wireless systems this comes along with enormous challenges, and obviously, current frequency bands will not suffice so that new frequency bands are needed. Beside the demand of new frequencies, it is clear that there will not be a single key technology that enables such an increase in performance. Rather, there is the need for several of them. Furthermore, it is clear that with increasing mobility or decreasing channel quality it becomes harder to successfully establish a transmission supporting high data rates. Therefore, an intelligent access management will be indispensible that connects users to different wireless networks based on their channel quality and mobility. Another important point is the need for an increase in spectral efficiency of wireless systems by improving existing techniques as well as by using new concepts. Some key concepts of future wireless systems are:

- MIMO (multiple-input multiple-output): The use of multiple antennas at the transmitter and the receiver leads to significantly improvements in the overall performance [Biglieri et.al. 2007]. This is mainly based on the fact that the spatial domain becomes useable to increase diversity.
- Relaying: Coverage and throughput are a challenging task for cellular systems especially at the cell edges where the direct link is of bad quality. Relays are a promising approach to increase the performance in these scenarios.
- Cooperative transmission: Significant gains in the performance will be obtained in future cellular systems if coordinated transmission schemes are applied [Jungnickel et.al. 2009]. Here, the base stations use backhaul connections between themselves to coordinate their transmissions to the mobile devices.
- Modulation schemes: New techniques are needed that do not have such strict requirements on the orthogonality as OFDM. In particular, this becomes important for cooperative transmission scenarios where full synchronization and orthogonality is hard to achieve.
- Adaptive resource allocation: An intelligent resource allocation will enable gains in throughput by allocating the resources according to the channel qualities. What kind of gains are achievable can already be guessed by current HSPA technologies.
- Physical layer security and privacy: Due to the broadcast nature of the wireless medium a transmitted signal is received by the intended mobile device but can also be overheard by possible eavesdroppers that are not legitimated to receive certain private or confidential information. Current security mechanisms rely on the fact that available computation power does not suffice to compute the used secret keys that are used to hide the information from possible eavesdroppers. Physical layer security refers to a strategy that establishes a secure communication on the physical layer [Wyner 1975], [Csisz´ar & Körner 1978].
- Physical layer multicast: Currently, cellular system operators offer multicast services additionally to traditional (voice) services which are nowadays realized by a policy that allocates different services on different logical channels. There is a trend to merge multiple services efficiently from an information theoretic point of view to work on the same wireless resources. This enables a joint resource allocation resulting in a significantly reduced complexity and improved energy efficiency.
- Network coding: Traditional coding schemes regard information flows as "fluids" [Ahlswede et.al. 2000]. The concept of network coding breaks with the common model and constitutes a paradigm shift by allowing the encoders to combine different information flows.

It is obvious that none of the above mentioned concepts will lead to the needed improvements in the performance if they are applied for its own. Rather, the interaction of different concepts and ideas will yield appropriate results. In the following we discuss and present some of these concepts in more detail.

If one uses relays for coverage extension in wireless networks, one is confronted with the fact that relays cannot transmit and receive at the same time and frequency, and, consequently, need orthogonal resources for transmission and reception. This inherent loss in spectral efficiency can be reduced if bidirectional communication is considered [Rankov & Wittneben 2007], [Larsson et.al. 2005].

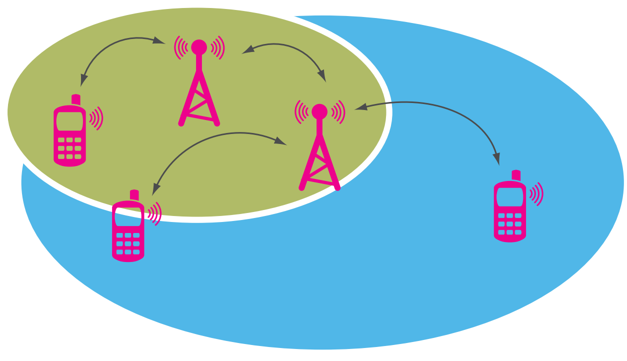

Fig. 29: Bidirectional relaying in a Cellular System.

Therefore, let us consider bidirectional relaying three-node network where a half-duplex relay node establishes a bidirectional communication between two other nodes using a two-phase decode-and-forward protocol. This scenario is of practical interest, since it occurs, for example, in a cellular system, where two mobile users want to communicate with each other as shown in Figure 29.

In the first phase both nodes transmit their messages to the relay node. Since we assume the relay to decode both messages, we end up with the classical multiple access channel. In the succeeding phase it remains for the relay to broadcast a re-encoded message such that both nodes are able to decode their intended message using their own message from the previous phase as side information.

It shows that the performance in the broadcast phase can be significantly improved if the relay encodes both messages that it received in the initial multiple access phase using principles from network coding [Oechtering et.al. 2008]. It combines both decoded messages and broadcasts an optimal re-encoded message. Interestingly, it shows that it is optimal to broadcast a single data stream that is used by the receiving nodes to decode their intended message with the help of their own message. In contrast to the broadcast of a common message both nodes can achieve different rates. These ideas also extend to robust strategies for the case of imperfect channel knowledge [Wyrembelski et.al. 2010].

Figure 30 shows the capacity region of the broadcast phase and illustrates the gain in performance if the optimal coding strategy based on the network coding idea is used instead a suboptimal superposition technique that simply encodes both messages separately and broadcasts a superposition of them.

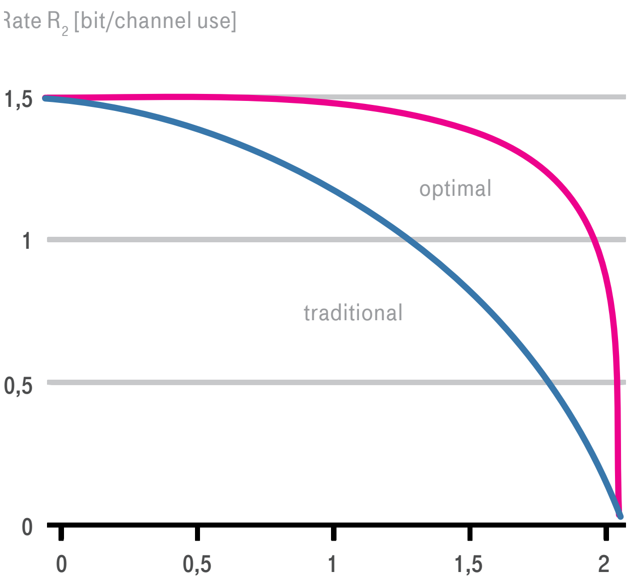

Fig. 30: Capacity Region of bidirectional Broadcast Phase.

Another important issue is the convergence of different services on the physical layer. The coding strategy mentioned above can be easily modified to enable an additional multicast communication. Besides this, there are services that are subject to certain security constraints. Based on coding ideas from (Wyner 1975), (Csisz´ar & Körner 1978) one can design coding strategies that enable an additional private or secure communication within such wireless networks where non-legitimated receivers can be kept completely ignorant of the private/secure information. For bidirectional broadcasting with an additional private communication the coding strategy is based on a codebook design that consists of two layers. The first layer corresponds to usual codebook suitable for bidirectional relaying (with additional multicast communication). But the important idea is to create a sub-codebook as follows. For each codeword from the usual codebook, a confidential codebook with a product structure is created. Here, the legitimate receiver for the private information can decode each codeword regardless in which column or row it is. But the main idea behind such a codebook design is that the non-legitimated receiver decodes one index, e.g., the one of the column, of the transmitted codeword with the maximum rate its channel provides, and therefore is not able to decode the remaining index. This coding strategy guarantees security on the physical layer.

So far classical coding strategies are based on convolutional codes or algebraic codes. Such codes are well understood for simple communication scenarios such as point-to-point AWGN (additive white Gaussian noise) channels. For more complicated multi-user scenarios where possibly additional unknown interference from other transmitters is present, new concepts are needed that include ideas and techniques from information-theoretic results as mentioned above. Moreover, a new channel estimation or pilot symbol design is needed that applies to more involved multi-user settings as well.

Another important research area is the concept of cooperative transmission. In current cellular systems, one mobile is assigned exactly to one base station. For future cellular systems one expects significant gains by allowing base stations of different cells to cooperate with each other. There, the base stations use the backhaul to exchange information about the information to be transmitted as well as knowledge about the actual channel state. The theory of conferencing encoders [Willems 1983] allows one to analyze the expected gains in detail and it shows that these fixed glass-fiber connections between the base stations lead to gains in the air. More precisely, with increasing cooperation capability the interference can be reduced and the maximal achievable rates for the wireless transmission are increased.

Since this model includes the cases of limited cooperation due to finite backhauls capacities as well as the case of full cooperation, it is possible to analyze how much backhaul capacities are needed to achieve the full cooperation performance. Recently, for the simplest cooperative scenario with two base stations serving one mobile user the performances are characterized in [Wiese et.al. 2010].

The next important challenge of future communication systems is known under the topic ‘Green IT’. Recent studies show that 2% of global CO_2 emissions are generated by communication systems. Within wireless systems a significant portion of the energy consumption occurs at the amplifiers. Therefore, one is interested in decreasing the energy consumption of current communication systems and especially the amplifiers to reduce CO_2 emissions. Clearly, from the operator point of view the use of energy-efficient systems is desirable since this will reduce the OPEX. Moreover, the hardware for such efficient systems will be not so expensive so that the CAPEX will be reduced as well.

The problem is that higher transmission rates lead to more involved transmit signals that consist of several individual signals within the same frequency band. This leads to higher peak-to-average power ratios (PAPR) which is contra-productive for energy-efficient amplifiers. Therefore, one is interested in a system design, where the PAPR of the transmitted signal is small which would result in more energy-efficient amplifiers. Recent wireless systems, e.g., based on OFDM or CDMA techniques, suffer from this PAPR problem. This initiates the need of new transmission techniques or wave forms for the modulation. Unfortunately, it shows that all meaningful wave forms display this problem [Boche & Pohl 2007].

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Bundesnetzagentur

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Ulrich Rehfueß

Nokia Siemens Networks

Ulrich holds a Diploma degree in Electrical Engineering from the Technical University of Munich, Germany and a Diploma degree in Business and Engineering of Fernuniversität Hagen, Germany. After working for 5 years in Siemens Corporate Research, he joined Siemens Mobile Networks division in 1996. Since then, he has been working on GSM, EDGE, WCDMA and HSPA network capacity and product strategy before moving to FLASH-OFDM and WiMAX in 2004. From 2007 to date, Ulrich has been managing the E2E performance aspects of the LTE system in Nokia Siemens Networks.

Prof. Dr.-Ing. Joachim Speidel

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Joachim Speidel received the Dipl.-Ing. and Dr.-Ing. degrees (both summa cum laude) in Electrical Engineering from Stuttgart University, Germany, in 1975 and 1980, respectively. Since 1992 he has been a Professor with the Faculty of Electrical Engineering and Computer Science, Stuttgart University, where he heads the Institute of Telecommunications Transmission. His research group works in the broad field of wireless and wireline transmission with emphasis on coding, modulation and detection. Application areas are digital radio, mobile communications, MIMO as well as fiber optic transmission (www.inue.uni-stuttgart.de). From 1980 to 1992 he was with Philips Communications. There he and his team have developed the first 2 Mbit/s video codec in 1985 and have contributed to the international standardization of new coding algorithms. His R&D work has spanned several disciplines like subscriber access systems, and fiber optic transmission. He has held various positions, as a member of technical staff, head of laboratories and as Philips product division managing director. With a large number of patents he has contributed to the success of products and international standards. Professor Speidel is a member of various national/international organizations and advisory boards, such as member of the board of ITG/VDE.

Dr. Vieri Vanghi

Qualcomm

Vieri Vanghi received the Laurea in Electrical Engineering from the University of Florence in 1991. He continued his studies in the U.S., obtaining the Doct. of Science degree from The George Washington University, and the Master in Business Administration from the San Diego University in 1995 and 2001, respectively. Vieri is currently Sr. Director of technology with the Qualcomm CDMA Technology division (QCT), involved in the definition of 3GPP WWAN product technology and industry strategy for QCT. He first joined Qualcomm in 1995 as a systems engineer, working on the design of the first Qualcomm IS-95 CDMA base stations. He was then involved in the design of Qualcomm UMTS chipset solutions, and more recently he was responsible for modem-related product marketing activities in Europe. From 1999 to 2001, Vieri was with Ericsson, U.S., managing the Radio Systems department and project engineer for the Ericsson first cdma2000 base station products. Prior to that he was a researcher with the European Space Agency, Holland.

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