A high-performance optical access network is the basis

5G Mobile Communications – the Next Generation

An overview of history, technology and areas of application by Dr.-Ing. Alexander C. Adams

Most of us "cable guys" know one or the other person within our circle of friends whom in light of our long-standing involvement in the cable industry is inclined to comment that in a few years cable guys like us will be out of a job. In a few years they say, digital communications will not need wires anymore, it will be all wireless. To underscore this reasoning, the mobile communications standard 5G frequently serves as an argument. However, this can be considered a fallacy. More so, 5G means more cables and not less of them. For a closer consideration of this idea a short excursion into botanic realms proves informative. A mobile communications network is not unsimilar to the common mushroom inhabiting our often damp and foggy Central European forests in outright packs. Mushrooms pose one of the largest organisms on the planet, they can stretch over hundreds of square meters underneath the forest soil, living in symbiosis with several trees and plants for the exchange of nutrients. Mushrooms form an interconnected network that plants use for communication amongst each other, as illustrated in Figures 1 and 2. There indeed is a botanical internet right underneath our feet, invisible to our very eye. We really only notice a mushroom when we spot the spore-transmitters for the transferal of its genetic information across an aerial interface amidst the silvan shrubbery. Consequently, what we commonly consider a mushroom is actually just the sometimes tasty, sometimes hallucinogenic part of a much larger organism.

Most of the distance covered over fixed-wire infrastructure

A mobile network exposes a similar structure. The transmission of information between mobile devices in the United States and in Europe will only travel a tiny fraction of the distance to be covered over the radio-access-network (RAN). The information is sent over the aerial interface from the transmitting mobile device to the next mobile base-station in the vicinity. At the base-station the signal is received and fed into a fixed-wire core-network, optimally a fiber-optic core-network. The signal is routed along optical networks all the way across the big pond and is ultimately being sent to the mobile base-station closest to the recipient of the message. Upon reception on the fiber, this mobile base-station transmits the signal to the recipient's mobile device, once again across the radio-access network. In analogy to the tasty parts of mushrooms we only see the mobile base-stations as part of our cityscapes. We do not notice the fixed-wire infrastructure interconnecting these base-stations, just as we fail to notice the extensive network-like structures mushrooms create underneath our feet.

Mobile networks emerged in 1918

Mobile networks are great, especially for those of us who were once introduced to the miracle of telephony by the

Figure 1: Fly agaric (Amanita muscaria)

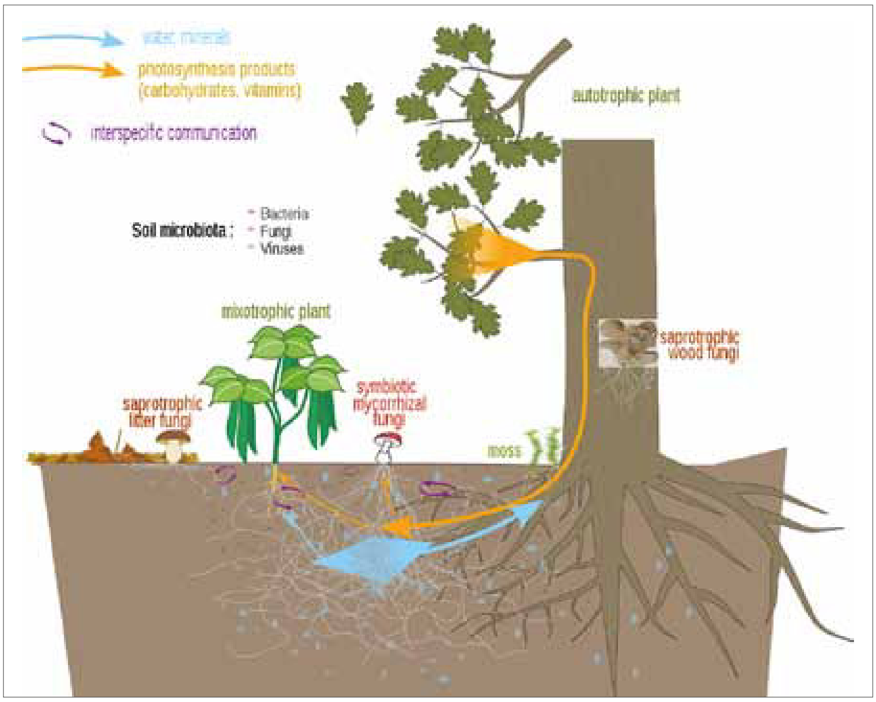


Figure 2: Schematic of mushroom structure

adventure of using a fixed-wire box with a dial and little round holes while speaking and listening to a bone. In case you had a sister who had perfected the use of that box in the time-domain, you definitely appreciate today's mobile capabilities. However, the idea is not as fresh as one is led to believe in light of the recent advances in technology. The "Deutsche Reichsbahn" (Imperial German Railway Services) had already tested mobile telephony approaches as early as 1918. In 1926, mobile communication was offered as a service for first class passengers on the railway connection between Hamburg and Berlin. The so-called "A-Netz" in 1958 and the "B-Netz" in 1972 provided a national analog mobile network in the Federal Republic of Germany. ("Netz" is German for network.) These services did not find many users, since the technology was fairly expensive and not affordable to the broad market. It was mainly used for telephony capabilities in automobiles, nicknamed "car-phones". Since the early Eighties every child in Germany knows "car-phones" from the audio-tape series "Drei ???" ("The Three Question-Marks"), the adventures of three Californian junior detectives from Rocky Beach, CA. In 1985 the "C-Netz" provided the first cellular network in Germany. However, it was still based on analog technology. The introduction of the "C-Netz" posed the decisive step to real cellular devices. These were still mainly "car-phones", but they had a portable unit that could be used as a mobile-phone, neglecting the fact that the added mobility came with hauling along a medium-size suitcase on a broad shoulder strap, making every phone call resemble a military expedition. "A-Netz", "B-Netz" and "C-Netz" are combined into the 1st Mobile Communications Generation (1G) in Germany.

From 2G to 4G

The introduction of the Global System for Mobile Communications (GSM) in 1992 marks the advent of the age of digital mobile communications in Germany. Based upon this technology, "D-Netz" (1992) and "E-Netz" (1994) mobile architectures were established. The transition to digital data communications marked the start of the 2nd Mobile Communications Generation (2G). The "D-Netz" provided

Figure 3: Five generations of mobile networks

Source: SCTE • ISBE

unprecedented mobile access to large parts of the population. The demand for mobile devices increased dramatically and the costs for those devices reduced to affordable ranges. Also, the "D-Netz" offered roaming capabilities for the first time and the German language was enriched by the remarkable anglicism "Handy" for a cellphone … a word that the English language preferably used as an adjective and not in regular conjunction with mobile communications.

Next to the transmission of classic voice signals in good quality, GSM enabled data services such as Fax or SMS from 1995 onward. GSM was expanded to General-Packet-Radio-Service (GPRS) around the turn of the millennium, enabling the mobile use of the Internet, albeit with low data rates of 55.6 kbps. These were increased in the GSM-enhancement EDGE, standing for Enhanced-Data-Rates-for-GSM-Evolution. EDGE provided data rates of 59.6 kbps per time slot, using up to eight time slots in parallel (Figure 3 assumes two time slots).

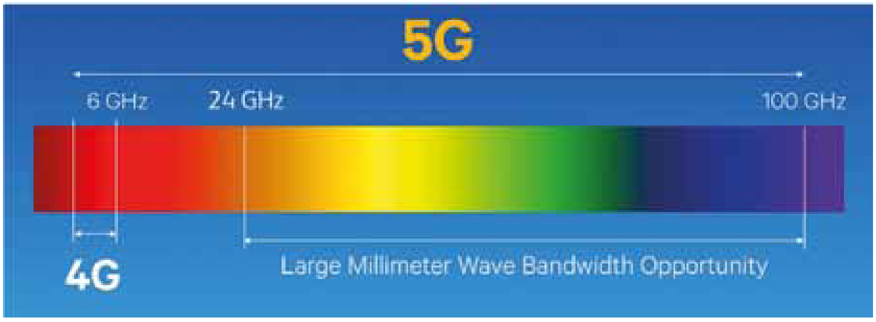
The 3rd Generation of Mobile Communications (3G) introduced the Universal-Mobile-Telecommunications-System-Standard (UMTS). UMTS introduced a completely new technology into the mobile networks, requiring planning, design and construction of independent UMTS-networks as well as the conceptualization of mobile devices supporting UMTS and GSM in parallel. In general, UMTS and GSM are not unsimilar in concept, but UMTS transmits voice signals in data-format and allocates more spectrum to the transmission of data. So, UMTS enabled the simultaneous transmission and reception of voice as well as data signals. The introduction of broadband technology had a tremendous impact on the mobile industry. Data-rates of up to 384 kbps turned a cellphone into a digital medium for the use of mobile data and ever since telephony is only one of many functions of the palm-computers we call smartphones. Nonetheless, in Germany we still call them "Handy", regardless of their degree of smartness. Nowadays, UMTS-networks provide data-rates up to 42 Mbps, utilizing UMTS-enhancements such as High-Speed-Packet-Access (HSPA, HSPA+).

LTE is short for Long-Term-Evolution and stands for the 4th Generation of Mobile Communications (4G). In Germany, LTE was introduced in 2010, tending to the ever-growing thirst for bandwidth and enhancing the performance of mobile networks by providing even higher data-rates. Downlink-rates of 300 Mbps as well as uplink-rates of 50 Mbps are possible with LTE. Within the frequency spectrum, LTE in Germany is allocated at around 700 MHz, 800 MHz, as well as 1.8 GHz and 2.8 GHz.

5G: highly increased data rates

In the fixed-wire cable industry we have observed an accelerated process in the development and deployment of communications technology in the recent years. The mobile industry is no different in this respect. While 4G networks are being operated and constantly fine-tuned, the henceforth next, in sequence the 5th Generation of Mobile Communications (5G) is ready for stage-time. The 5G-standard was published in 2017. It pertains a lot less to voice communications than its older siblings, instead it primarily focusses on the orchestration of large data-throughput. 5G-technology achieves symmetric data-rates of 10 Gbps, utilizing higher parts of the spectrum not allocated to mobile communications before. So, 5G exhibits highly increased data rates in up- and downlink. The standard uses very similar modulation and multiplexing schemes to those used in 4G LTE. The primary modulation technique is Orthogonal-Frequency-Division-Multiplexing (OFDM), albeit the approach finding application in 5G is named CP-OFDM (Cyclic-Prefix OFDM) posing an enhancement compared to 4G. The Quadrature-Amplitude-Modulation (QAM) orders used in conjunction with the mobile OFDM-carriers are QPSK, 16-QAM, 64-QAM and 256-QAM, all of them being robust modulation orders compared to HFC-DOCSIS 3.1 networks, all exhibiting square constellation diagrams. Additionally, 5G is built upon the massive utilization of carrier-aggregation techniques. Carrier-aggregation bundles up to 16 OFDM-carriers to increase their data throughput, an approach we are familiar with from DOCSIS as channel-bonding, applied here as a form of mobile channel-bonding.

5G tackles the latency problem very efficiently. 5th-generation latency ranges from a few milliseconds to about a single millisecond, which is considered close to real time. With respect to latency, it needs to be taken into account that information is not only passed across the radio access network. The network behind the mobile base stations always needs to be taken into consideration when designing 5G networks.



Source: SCTE • ISBE

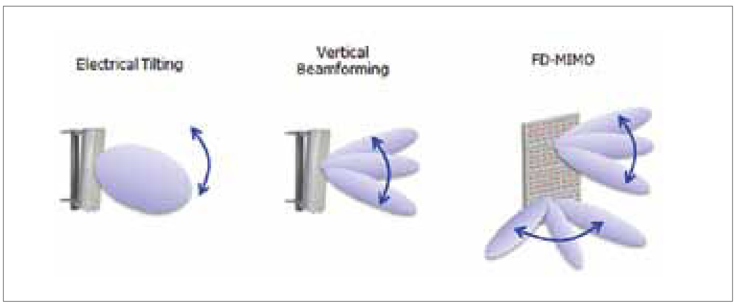
Figure 4: Overview of 5G-spectrum

Two frequency ranges

The frequency spectrum utilized for 5G-transmission is divided into two parts, denominated FR1 and FR2. Frequency Range 1 (FR1) stands for the spectrum between 600 MHz and 6 GHz. Time- and frequency division duplex methods are applied in this spectral region. In Germany, the spectral regions around 700 MHz, 2 GHz, 2.4 GHz and 3.7 GHz are designated to 5G within FR1. Signals of lower frequency exhibit a longer wavelength than signals of higher frequency and they have a longer range. They have good propagation properties and are well-suited for covering designated geographical areas. Frequency Range 2 (FR2) starts above 24 GHz and therefore operates close to the millimeter-wave-spectrum. (Physically the millimeter-wave-spectrum is located between 30 GHz and 300 GHz.) At this point in time, spectrum up to 40 GHz has been released for 5G signaling in Germany, an extension of this spectrum to 60 GHz or 80 GHz is planned. Figure 4 gives a broad overview of FR1 and FR2. A disadvantage of electromagnetic radiation is the fact that its effective range decreases with increasing frequency. Electromagnetic radiation of, for example, 28 GHz frequency cannot realistically penetrate obstacles such as walls or even vegetation, but the radiation can be re- and deflected from the surfaces of obstacles and then reach its destination via a detour. The different time-shifts experienced upon reception of the different reflected signals are irrelevant due to the benefits of OFDM-technology.

Phased array antennas und beamforming

5G is based upon the use of "phased array" antennas, bundling and forming electromagnetic radiation and directing it toward its destination. This bundling of electromagnetic radiation is called "beamforming", and it results in a precise and tracked beam directed toward a potentially moving destination. Please refer to Figure 5 for a representation of this idea. The main direction of transmission is directed in a way that several mobile devices may be addressed with it. This may be accomplished by direct reception of signals and/or the reception of reflected signals. This results in the advantage that compared to 4G notably less transmission power is needed for the operation of 5G transmitters. Further, the transmission power may be adjusted to the needs of the application at hand. Additionally, beamforming improves the signal-to-noise ratio and supports the simultaneous transmission of data to different devices within the same



Source: Adams Group, Master Thesis Boubakar Barry

Figure 5: Multiple-antenna-systems and beamforming

frequency spectrum by forming different simultaneous beams (space-division multiplexing). A lower degree of transmission power-scattering increases the overall efficiency of the system.
The 5G specifications allow phased-arrays with a multitude of antennas – hundreds or even thousands of them – which are being interconnected into a massive Multiple-Input-Multiple-Output" (mMIMO) antenna system. Individual groups of antennas form individual beams to facilitate mobile communication to different devices, independently of each other. Space-time coding takes advantage of temporal and spacial dimensions to improve signal quality and data-rates of the transmission. The performance of mobile networks can be greatly enhanced by the appropriation of multiple-antenna-systems and a large number of users can be on the system simultaneously.

Increased power consumption expected

Ideally, the theoretical power consumption per bit of a 5G system is about one percent of what a 4G system requires. In addition, the commitment of 5G technology is beneficial to provide a powerful infrastructure for the billions of internet-capable devices expected to demand bandwidth of our networks in the coming years. Although a single bit is definitely a lot cheaper in average power consumption on a 5G network than on its 4G cousin, the ongoing increase in data consumtion will let overall power requirement rise in the future. Also, the utilization of higher parts of the spectrum increases the temperature of the deployed equipment, which generally raises power consumption. Additionally, the utilization of the millimeter-wave spectrum reduces the range of mobile base-stations. This requires the deployment of new 5G base-station to be operated together with the 4G system. New base-stations need to be connected with fixed-wire fiber-optic networks, and that is why 5G does not mean less cable but more cable.

5G architecture depends on individual needs

A significant difference between 5G and its predecessors lies within the fact that the number of 5Gstations deployed in a geographical area is not directly dependent on the population density in this area. The architecture of a 5G network strongly and decisively depends on the individual needs of the users within a geographical area. This underscores the flexibility of 5G systems. A 5G application within a production workshop with a large number of people and machines working simultaneously has different requirements of a network than a 5G application along an Autobahn, focusing on ultra-reliable low-latency signaling that enables autonomous driving. In the current phase of 5G deployment, so-called 5G small-cells are being implemented, set upon the existing 4G-architecture and cooperating with it. 5G technology generally is backward-compatible to 4G technology. 5G and 4G networks are operated in parallel and in conjunction, facilitating a flexible tiered approach to deployment.

Multitude of virtual networks

Mobile infrastructure up to and including 4G is based upon cell towers and classic roof collocations. These make up for the geographical coverage of a certain area. The deployment of 5G technology results in a more pronounced geographical diversity of collocation density. Further, the locations also differ optically and with respect to efficiency from their 4G counterparts. Next to the further needed roof-collocations, the architecture of small cells is being deployed. A unified architecture for all users will not be established in 5G the way it articulated itself in all other generations of mobile communications before. The plethora of different 5G applications results in a multitude of different virtual networks, optimized to the special boundary conditions of their applications and operated on the basis of a common infrastructure.

Pack a big punch in a small space

Small cells are committed at locations with a high user-density, such as pedestrians' areas, populated squares or football stadiums. Small cells can bridge gaps in the overall coverage provided by large cells. Small cells are no replacement for roof-collocations or cell towers, but they augment and densify the network at points of high network demand. Several small cells within a relatively small area increase the number of simultaneously serviceable users significantly. Hence, small cells are ideal to pack a big punch in a small space. Users on a small cell also profit from power-regulation mechanisms between transmitter and receiver, since their application results in lower power consumption at the users' mobile devices, which in conclusion makes the batteries last longer.
A small cell is a mobile communications cell with low power capabilities, resulting in a maximum service range of merely 150 meters. This can be compared to a WLAN hotspot with connection to the mobile network. The location of these cells is chosen rather close to the user hence a number of cells need to be activated to ensure uninterrupted service to the above-mentioned pedestrians' area. Small cells are operated with less than 10 Watts of power. The antennas for millimeter-wave utilization in 5G systems are noticeably smaller than in the mobile equipment we have been used to so far, and can be installed on walls, streetlights, advertising columns, or other commonplace locations within our daily vicinity. The dimension of antennas used for transmission and reception of electromagnetic radiation within the millimeter-wave spectrum is also just a few millimeters, therefore a lot of antennas can be accommodated within an array.

Three fields of application

Engineers and technicians generally differentiate between three fields of application for 5G-networks: High-speed mobile internet (enhanced mobile broadband), the communication of machines and applications amongst each other (massive machine-type communications, M2M), as well as highly reliable networks exhibiting extremely low latency (ultra-reliable low-latency communications). They are summarized in an overview in Figure 6. Each of these fields of application has different boundary conditions. Therefore, a

5G network needs to be flexible to be able to give consideration to the above-mentioned fields of application and their individual needs. 5G promises high data-rates at low operational cost. However, 5G can only unfold its potential if the connection of the mobile stations to the fiber-optic backbone of the core-network is expedited.

The last few years saw a significant increase in the use of fast mobile internet. Mobile data consumption increases by about 50 percent annually. This is congruent with "Nielsen's law" and there is no downward tendency to be detected for the next years. Customers as well as network operators will need high-capacity networks to be able to cope with the expected amount of data that applications such as 4K- and 8K-video will generate on the networks. 5G provides a solid technical foundation to tend to such needs, enabling symmetric data-rates of 10 Gbps. Further, 5G networks are capable of providing to applications such as augmented and virtual reality. These types of application need high data-rates and low-latency capabilities. 5G fields of operation are plentiful, they can range from digital pizza service to digital remote surgery.

The interconnection of industries, of branches and markets, as well as of society as a whole will continue. It will advance in an accelerated fashion and even the process itself will change over time. While in the past the interconnection of people was a primary focus in the consumption and utilization of data, the focus has now shifted to the interconnection of machines, things and processes. Eventually, this development will form an internet-of-everything. Concepts such as Industry 4.0, machine-to-machine communications (M2M) and the internet-of-things (IoT) describe the interconnection of machines and applications. This applies to production and industry applications as well as to the interconnection of everyday appliances such as vacuum cleaners, washers, sport shoes and that cool refrigerator ordering its own beer. All these applications have in common, that for themselves they only produce small amounts of data. For example, a beer-order of a digital fridge will not consume much bandwidth. However, as mentioned above, billions of internet-capable devices are expected to join the internet community worldwide in the next few years. Small amounts of data in large geographic footprints require flexible and large-scale networks capable of handling signals from a very large amount of simultaneously communicating devices. The focus with these types of devices is not primarily on latency or high data-rates, but rather on low energy consumption.

Some applications on 5G networks leave little room for error and require low latency performance as well as very short reaction times. Ultra-reliable low-latency 5G networks guarantee these characteristics. A prime example for this type of application is autonomous driving, placing some very special requirements on the network. The transmission of information as close to real time as possible is imperative for this type of application. In 3G networks latency was at about a hundred milli-

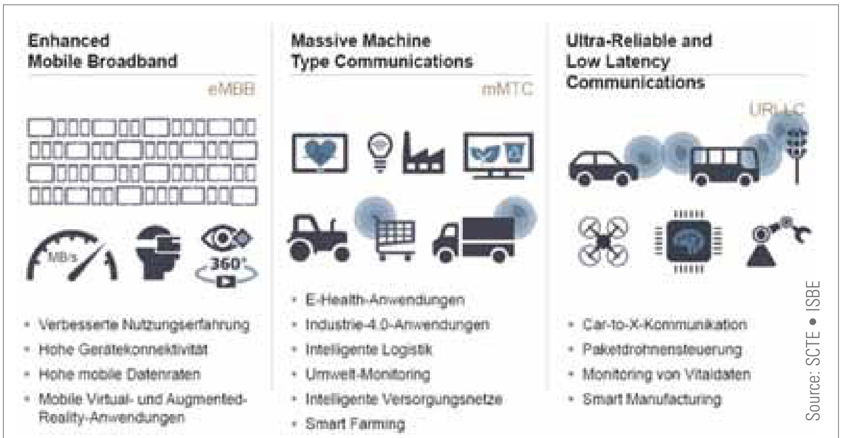
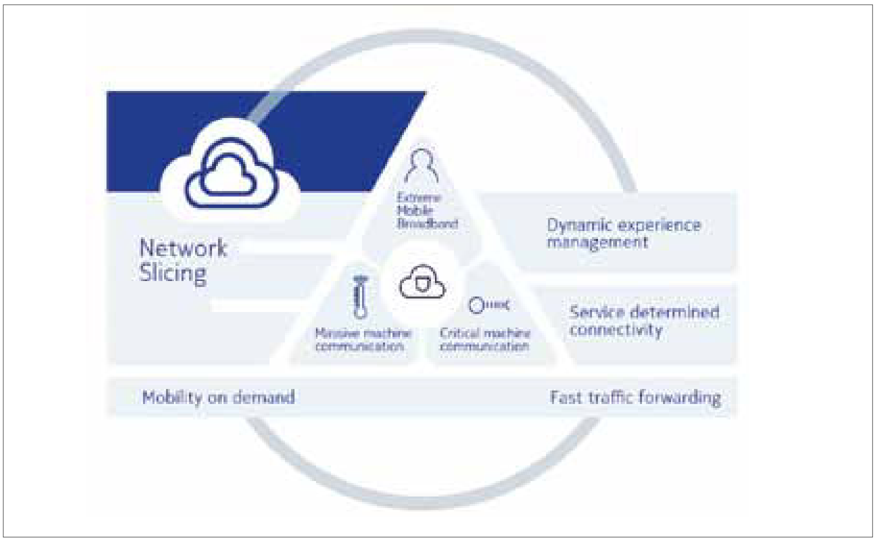


Figure 6: Fields of application for 5G-technology

seconds, in 4G networks at about ten milliseconds and in 5G networks latency is reduced to one millisecond. One millisecond is considered real-time and fast enough to make autonomous driving more than a vision in not too distant a future. Applications like "driving-while-reading-the-paper" require the highest reliability of the transmission networks involved. Also, processes developing very fast require highly reliable network connections, such as medical or industrial imaging methods.

Flexibility is essential

A flexible network design is prudent, since different users and applications have different individual needs of the network. A method called "network-slicing" enables the virtual sectioning of the network for these different needs. This puts the network operator into a position to provide defined quality assurance for certain applications or groups of customers, such as a certain data-rate or a certain minimum latency. In this fashion a number of different networks can be realized and administrated virtually over a common physical infrastructure. Figuratively speaking, the network operator slices parts out of the network like slicing a cake, fitting the boundary conditions of the application to run on it. Figure 7 illustrates this "network-as-service" approach. Another advantage of 5G and its network architecture lies within the concept of relocating large portions of the computing power needed for proper network operation close to the mobile base-stations. The concept is referred to as Mobile Edge Computing (MEC), placing flexible computing resources in direct vicinity to mobile users, henceforth enabling reliable network speeds.



Source: SCTE • ISBE

Figure 7: Network slicing and virtualization

Urgent need for 5G

Network operators are expediting their 5G roll-out efforts, things are moving forward especially in areas exhibiting a high population density. Apparently, they are in more of a hurry than they were during 4G deployment, which in Germany kicked off in 2010 and still hasn't been entirely concluded to this very day. The haste is not without concept, for the industry urgently needs 5G. The industry needs stable, fast and flexible data networks, because herein lies the key to the future of Germany as a humming industrial and technological hub. However, a simple network upgrade is not going to pack the punch needed for this transition. The "Fatherland" needs new antennas and new base stations working with mobile edge computing, it needs more fiber-optic connections. Only the bandwidth provided by fiber poses a long-term solution to ensure base stations can provide high-throughput connections into the core network. Everything else will slow 5G down.

The 5th generation of mobile communications opens the door to a multitude of opportunities. Not only will my daughters be able to drive their online-time beyond the (imaginary) digital "Richter-scale", more so, 5G will become a decisive economic factor. People and machines will interconnect in unprecedented ways and manners, creating new economic and social possibilities. The future will tell the journey's destination. ■

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Curriculum Vitae

Dr.-Ing. Alexander C. Adams is managing director of Adams Network Engineering, a company of the Adams Group. Alex looks back upon 20 years of experience in the German, European and international cable industry. He is the European representative of SCTE – Society of Cable Telecommunications Engineers (US), as such part of the CableLabs Proactive Network Maintenance Research Group, and Instructor at the Jade University of Applied Science in Wilhelmshaven/Oldenburg, Germany. Further, he is auditor with dibkom – German Institute for Broadband Communications. Alex holds a Bachelor- as well as a Master-of-Science degree in Electrical Engineering from the University of Hawai'i, USA, and a Doctorate degree (Dr.-Ing) from the Technical University of Darmstadt, Germany.