Networks of the future: Ideas and Concepts

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ABSTRACT

The ubiquitous access to information through mobile networks changed our lives. These mobile networks are in a state of permanent evolution. In this paper we identify the most probable drivers for future mobile networks. We provide an overview over the most successful commercial mobile networks and point out the technologies used in these mobile networks that will most likely be reused in future networks. We discuss the difficulties and requirements for future mobile networks that come with the deployment of billions of autonomous Machine-to-Machine devices. While some solutions have been proposed to deal with these Machine-to-Machine requirements many problems remain unsolved.

1. INTRODUCTION

Since the days of the ARPANET the permanent availability of information has become a vital part of our life. First through the Internet on a stationary computer and then over the mobile networks. These mobile networks are already in heavy use today, but are by far not full-grown. New trends emerge, such as Machine-to-Machine communication, that bring new requirements to mobile networks. At the same time the permanent need for faster Internet access has to be addressed. Multinational industrial associations and standardization bodies try to accommodate these needs by incrementally enhancing the cellular networks. While current mobile networks deal with the increasing data rates, attention is slowly shifting towards the specialized requirements aside Human-to-Human (H2H) oriented technologies. In this work we try to examine the drivers of future mobile networks by reviewing past cellular technology and discussing the requirements that Machine-to-Machine networks pose.

The content of this work is divided into two main parts, Section 2 and Section 3. In Section 2 we present the evolution of mobile networks to identify technologies that will most likely be reused in future networks. At first a brief overview of the 1G networks is given, which served the sole purpose to offer voice services. Then we review the second generation in which analog transmission was discarded in favor of digital transmission. After that we present the properties of 3G networks and outline the changes in the 3G network topology compared to 2G networks. In the following Subsection 2.4 we discuss the changes that are introduced by the latest cellular technologies. To conclude Section 2 we identify those core technologies of the different generations which can be reused in future networks in Subsection 2.5. In Section 3 at first we discuss Machine-to-Machine as major driver of future networks, especially in the context of mobile networks. After a short introduction into the Machine-to-Machine topic, we explain the requirements of such networks and the impacts of the ubiquitous mobile networks on Machine-to-Machine type communications. At last conclusions are provided in Section 4.

2. CELLULAR NETWORK EVOLUTION

The following subsections holds an overview over past mobile technologies. While new iterations of mobile networks often introduce massive changes in terms of technology and topology, some technologies can be kept and reused. By investigating the development of successful cellular networks, those core technologies can be identified that are also eligible for future networks.

2.1 1G (Analog)

The major problems in mobile networks are related to the nature of the wireless medium. Beside multipath propagation and attenuation the mobile network has to account for other participants, since the medium is shared. Not only between different network providers, but also between all participants within a single network. To ensure guaranteed bandwidth and therefore availability of the services at all times, the medium can be spatially divided into cells, as proposed by Engel and Frenkiel around 1970 [11] [15]. When serving a large area with one base, each portion of the bandwidth (radio channel) can only be used by one participant at the time. To serve a large group of participants within a wide area, a division into small zones or cells allows to reuse the radio channels. By assigning each such cell a set of radio channels, the adjacent cells are able to operate at complementary radio channels at the same time.

The first networks that made use of this technique became operational around 1980. Those heterogeneous cellular networks had in common that they were based on analog radio transmissions and were mostly restricted on voice transmission services. A few years later multiple networks were launched in Europe, each of them incorporating their own proprietary and incompatible system [32]. Most of these networks allowed for intercell, but not internetwork Roaming. Some networks that existed before, like the A-Netz in Germany, didn't even support handover between cells. In A-Netz a change of cell was impossible during a call, without breaking the current phone connection. Since two adjacent cells use different portions of the available spectrum

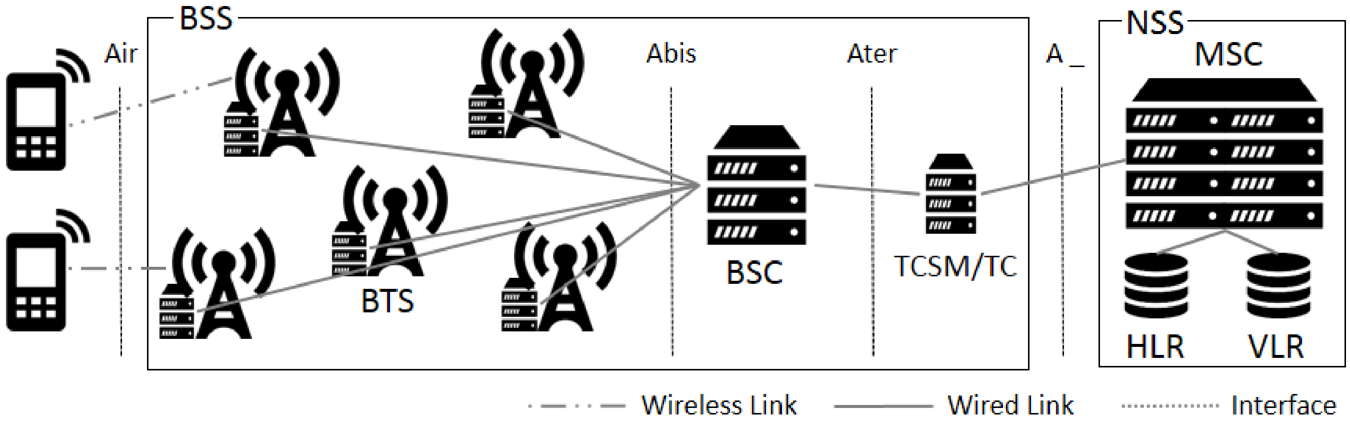

Figure 1: Simplified GSM Network Architecture.

a handover between cells is a complex task for the operator (which was a person in A-Netz). In spite of the fact that such a handover is complex most 2G networks already supported intranetwork roaming. To allow a participant to simultaneously receive and send voice data Frequency-division multiple access (FDMA) was used. Using FDMA to realize full-duplex allows to send and receive at the same time by assigning the Uplink and the downlink channel different frequency bands. While several aspects of those historical networks were discarded and exchanged, FDMA and especially the cell principle were carried over into future networks. The cell principle proved to be successful as it not only allows to serve a large area (even beyond the horizon) but also to artificially increase the number of possible Participants by adjusting the cell size (e.g. cell size: 100-500 m in cities and 35 km in rural areas).

2.2 2G (Digital)

To accommodate the needs for a more efficient, secure and reliable communication, analog transmission was discarded in favor of digital transmission in 2G systems. Digital systems offer a more stable and reliable communication, since digital transmission is more robust against background noise. Also transmission errors that would be hard to detect in analog signals can be traced and corrected (e.g. with the use of checksums). While 2G systems only make use of Forward Error Correction (FEC), later cellular technologies also featured sophisticated Backward Error Correction schemes like hybrid ARQ (HARQ). A higher system efficiency could be archived in 2G networks by compressing the digitized voice data through the use of codecs, which can be adapted to the current network load. Within the network of the provider the digitized voice data is transported without introducing further errors, resulting in an increased overall voice quality. While an analog signal attenuates over distance, a digital signal can be refreshed by regenerative repeaters to its original form arbitrarily often [14].

The first digital cellular networks were introduced to the market around the end of the 1980s. Those networks transmitted digital data using FDMA combined with Time division multiple access (TDMA) or Code division multiple access (CDMA) by circuit switching. By establishing a continuous circuit for the duration of the phone call a good voice quality could be ensured at the cost of efficiency. Packet Data services with low bit rates (14.4 kbit/s with reduced error-correction in GSM) were already offered, although they were transmitted in the circuit switching environment.

In the United States multiple 2G Networks were launched in parallel. The IS-54 (TDMA) in North America and the IS-95 (cdmaOne) network. Beside those networks a European 2G mobile system, the Global System for Mobile Communications (GSM), was adapted for the 1900 MHz Band. The GSM standardization body was founded in 1982 and presented the first GSM specification GSM900 in 1990. In GSM packet data was still transmitted in a circuit switched manner, like all other offered services. Beside the traditional voice services and the data service new services were added later on. Of this additional Value Added Services (VAS) the Short Message Service (SMS) proved to be one of the most commercial successful for providers. Also other services were introduced: the emergency number, conference calls or automated callbacks.

While 2G introduced many new technologies such as digital transmission, TDMA and CDMA certain technologies from the 1G networks were kept. TDMA and particularly the cellular network topology were reused and extended as concepts by the second generation networks. While 1G networks solely focused on the transmission of the voice data, the 2G networks also set a new focus on security to prevent eavesdropping of the transmissions.

The lack of seamless global roaming capabilities was one of the major drawbacks of the 1G Networks. By establishing a common standard throughout Europe GSM managed to provide such roaming at least within Europe. Parts of the intercell roaming logic in GSM was placed on the mobile units. A Mobile Station (MS) initiates the handover process between two base stations by signaling the most suitable adjacent base stations. To ensure continuous connections, especially during phone calls, it is crucial that the handover is initiated at the right moment, regarding the signal power of nearby base stations, the current velocity of the Mobile Station and other factors. By replacing the assigned frequency slot of each Participant after a certain time, effects of narrowband interferences could be minimized and a constant deep fade

Table 1: 1G to 4G. [5]

Generation	Requirements	Comments
`1G`	No official requirements. Analog technology.	Deployed in the 1980s.
`2G`	No official requirements. Digital technology.	First digital systems. Deployed in the 1990s. New services such as SMS and low-rate data. Primary technologies include CDMA2000 1xRTT & GSM.
`3G`	ITU's IMT-2000 required 144 kbps mobile, 384 kbps pedestrian, 2 Mbps indoors	Primary technologies include CDMA2000 EV-DO and UMTS-HSPA. WiMAX now an official 3G technology.
`4G (Initial Technical Designation)`	ITU's IMT-Advanced requirements include ability to operate in up to 40 MHz radio channels and with very high spectral. efficiency.	No commercially deployed technology meets requirements today. IEEE 802.16m and LTE-Advanced meet the requirements.
`4G (Current Marketing Designation)`	Systems that significantly exceed the performance of initial 3G networks. No quantitative requirements.	Today's HSPA+, LTE, and WiMAX networks meet this requirement.

could be avoided. This frequency hopping technique was realized by implementing a combination of TDMA and FDMA as multiple access scheme, assigning 200 KHz (400 KHz total for sending and receiving) for 577 µs to each participant. Beside the services and the Access Scheme GSM also specifies the structure of the network.

2.2.1 GSM Network Topology

While the structure of the GSM network is decentralized to some point, most of the processing takes place in high performance centralized components that are linked to local processing units (see Figure 1). Components in the GSM network are grouped into logical units. A Base Station Subsystem (BSS) consists of a number of Base Transceiver Stations and at least one Base Station Controller. The Mobile-services Switching Centre and the Visitor & Home Location Register Databases are part of the Network Switching Subsystem (NSS).

Base Transceiver Station (BTS)
The Base Transceiver Station provides the gateway for the mobile units and therefore contains all of the radio hardware (signal processing, antennas, amplifiers) needed to transmit within the assigned radio frequency range. The area a BTS covers can be contained within a single or even multiple radio cells, utilizing sectorized antennas which were introduced in 2G networks. Sectorized antennas can cover a wider area and serve more participants compared to omni-directional antennas [32]. Besides the pure routing of data, one of the responsibilities of the BTS is to coordinate the frequency hopping with the mobile units.

Base Station Controller (BSC)
Numerous Base transceiver stations are linked to a BSC over the Abis interface. The BSC handles amongst others the power control (intelligent choice of transmission power) and also the handover between BTSs. When the handover takes place between two BTSs that are linked to the same BSC the handover takes place locally, otherwise the superordinate Mobile-services Switching Centre is signalled.

Mobile-services Switching Centre (MSC)
The MSC is the central network node that links external networks over gateways to the GSM network and has the main responsibility of routing of data (e.g. voice calls, SMS) to the according BSC or MSC. The MSC is also responsible for the Call Management, Authentication and Location Management. The location information that is needed by the MSC to route incoming data to a mobile unit is stored within the Visitor Location Register and the Home Location Register.

Visitor & Home Location Register
The Visitor Location Register (VLR) and the Home Location Register (HLR) are databases that store network relevant data of subscribers. The HLR contains information about all subscribers that are authorized within the network. The VLR stores data that was collected from a HLR and directly from mobile units which roamed in the network. When a mobile units tries to register into the network, the serving MSC stores information about it within the corresponding VLR.

Gateway MSC (GMSC)
Gateway MSCs serve as the link to other networks, e.g. other mobile networks or the telephone network. Such a Gateway MSCs can have the sole purpose of routing, but is also able to handle a BSS on its own.

Later on additional specialized Components were introduced, like the Short Message Service Center (SMSC or SMS-SC [1]). The SMSC mainly takes care of the SMS processing, but the responsibilities of the SMSC are only roughly specified for modern networks.

A key difference between the structure of the GSM Network and a typical 1G network is the use of a hierarchical network topology in GSM. This linkage of the nodes in the GSM network allows to take load off the central processing nodes (the MSC in GSM). By defining strict interfaces between the nodes interoperability was ensured, allowing the providers to buy networks components from competing manufacturers.

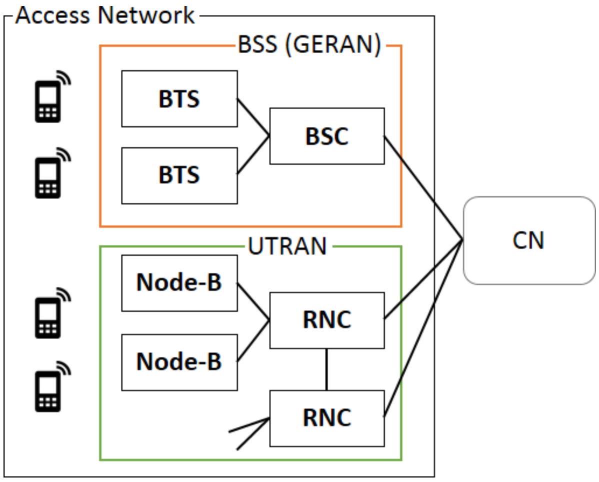

Figure 2: Shared Access Network in UTRAN.

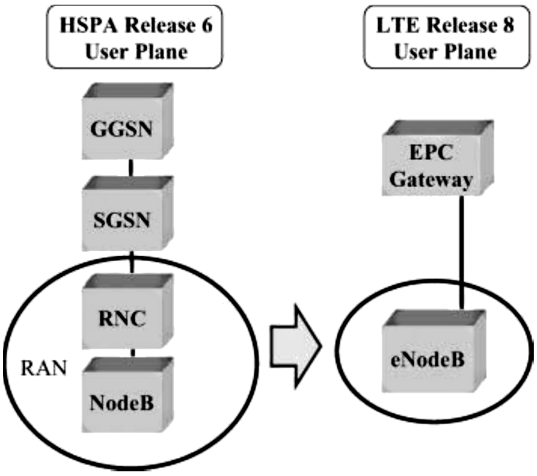

Figure 3: Evolution to the flat radio architecture with LTE. [17]

While data transmission in the initial GSM network was possible, the low data rates (4.8-14.4 kbit/s) didn't suffice for Internet Access or even multimedia applications.

Beside the low data rates also the payment plan for data transmission stood in the way of a widespread usage. This was due to the fact that the subscriber had to pay for the occupation time instead of the number of transmitted packages. To increase the throughput – and to change from the circuit switch oriented transmission to a packet-oriented transmission – new hardware was introduced into the GSM Network for the General Packet Radio Service (GPRS).

The GPRS Support Nodes (GSN) realize higher data rates by taking up all slots within a TDMA frame on demand for data transmission. To further improve the data rates GPRS was enhanced into Enhanced Data Rates for GSM Evolution (EDGE). Because the TDMA frame structure, the logic channels and the 200 kHz carriers were kept, no structural changes were required when upgrading from GPRS to EDGE. From the view of operators EDGE is attractive since the upgrade from GPRS to EDGE does not require any changes in the GSM core networks; only small upgrades in the BTS hardware and the BSS software are required.

2.3 3G (IMT-2000)

While in EDGE the accounting of data traffic was done packet-wise, the data was still transmitted like in a circuit switch call. To overcome the performance loss that comes with this circuit switch environment a new standard emerged. Because the fragmentation of worldwide standards like in 2G caused problems and incompatibilities, one of the requirements for the 3G standard was to be independent of the concrete underlying technological basis.

The International Telecommunication Union (ITU) defined the needs for a 3G Network (see Table 1) within the IMT-2000 specification. Mobile systems were then specified by different standardization bodies, which fulfilled those requirements. In Europe a mobile system was then launched as the Universal Mobile Telecommunications System (UMTS) by the European Telecommunications Standards Institute (ETSI). In the Unites States cdma2000 was introduced into the market, which evolved from the 2G standard cdmaOne (see Section 2.2). Later UMTS was taken over by a Worldwide Industrial Consortium of all global Players within the Mobile Market: the Third Generation Partnership Project (3GPP), which was founded in 1998. Those mobile networks were finally able to provide access to broadband data services and multimedia services like video-telephony. The underlying UMTS network that made this possible can be divided logically in two parts, the UMTS Radio Access Network (UTRAN) and the Core-Network (CN).

2.3.1 UMTS Network Topology

The Core-Network comprises parts of the existing network architecture of GSM (MSC, VLR, HLR etc.). UTRAN as well as the GSM EDGE Radio Access Network (GERAN), which is the radio part of GSM/EDGE, share an Access Network (see Figure 2).

Base Station (NodeB)

The NodeB can be compared to the BTS in GSM. It controls the antennas and handles the direct communication with the mobile units (”user equipment” in UMTS) over the air interface.

Radio Network Controller (RNC)

The RNC is the equivalent to the BSC in GSM with some key differences: The RNC has to manage the different Wideband CDMA (WCDMA) channels and multiple RNCs can be interconnected through the Iur interface. A subscriber can be connected to multiple cells at once, due to the properties of the code division access scheme. When the subscriber receives two streams of the same data stream simultaneously and one of the stream fades, the subscriber simply keeps listening to the other stream which allows for the so called ”soft handover”. In 2G networks the mobile unit has to decide when to ”hard switch” from one BTS to another. If the mobile unit would make a wrong decision (e.g. due to a fast velocity) the connection would break. The soft handover eliminates the need for such a decision since the mobile unit is already listening to the adjacent cells.

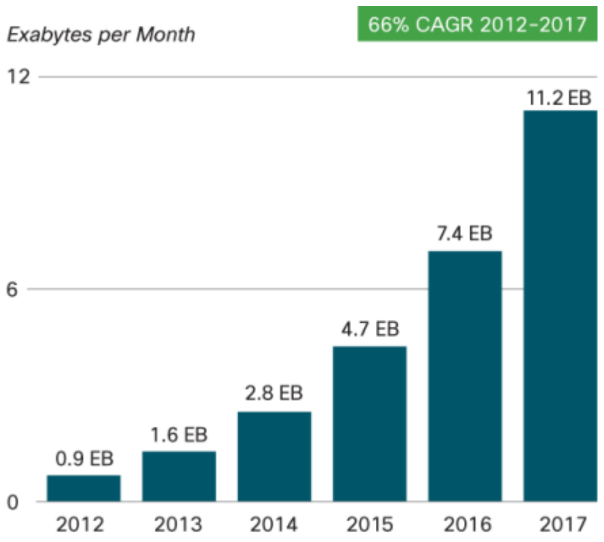

Figure 4: Estimated Global Mobile Data Traffic. [9]

The initial UMTS specification was extended by High Speed Packet Access (HSPA), which was first specified within Release 5 (HSDPA) and Release 6 (HSUPA). HSPA provides downlink speeds up to 42.2 Mbps Download and up to 11.4 Mbps in the Uplink. Within Release 11 the 3GPP specified HSPA+ as a further improvement to HSPA. HSPA+ theoretically offers data rates up to 672 Mbps in the Downlink, but a network serving such speed has not been deployed yet [34] [31]. Because high investments by the providers were required to launch the 3G Networks, the penetration of the market progressed slowly in the beginning. These costs originated from the auctioning of the frequencies and from new network equipment. The old equipment could not be reused or upgraded because UMTS operates in higher frequency bands. Despite these obstacles 3G network coverage is today present in many urban areas. While most countries settled for one 3G implementation, in some countries multiple implementations are used. For example in China WCDMA, cdma2000 and TD-SCDMA (TDD instead of FDD as as in WCDMA) were deployed simultaneously [28].

In UMTS most of the logic is located in the RNC, but in HSPA some logic was relocated onto the NodeB. This relocation allowed to reduce the response times by bringing decisions on radio channel allocation, adaptations to varying channel quality and the retransmission of erroneous packets (HARQ) closer to the radio interface. HSPA managed to reduce the number of delay spikes during transmission and therefore the perceived responsiveness. Also the Round Trip Time (RTT) could be reduced from 200 – 430 ms (during spikes) down to 80 ms compared to WCDMA [23] [16].

The 3G networks took a huge step forward to a broadband Internet access compared to 2G networks. By introducing packet switching as communications method for packet data higher efficiency could be archived. The flexibility of CDMA as access scheme allowed for flexible assigning of bandwidth and for more soft handovers between cells. Still the core network for telephony was kept from 2G which resulted in a coexistence of 2G and 3G networks.

2.4 4G (ALL-IP)

In March 2008 the ITU-R (ITU-Radio communications sector) announced the needs for a 4th Generation mobile network within the IMT-Advanced specification [21]. To satisfy the ever growing needs for higher data rates and lower latency IMT-Advanced demands 100 Mbit/s for high mobility and around 1 Gbit/s for low mobility.

The Candidates that were submitted to the ITU were all based on two technologies [19]. The first candidate 802.16m ("Mobile WiMAX") was specified by the IEEE, while LTE Advanced was specified by the 3GPP. The initial specification of LTE was published in Release 8 by the 3GPP, specifying a mobile system, which allowed for up to 299.6 Mbit/s in the Downlink and 75.4 Mbit/s in the Uplink [2]. These speeds could be archived by using Frequency Domain Equalization (FDE) techniques; in LTE OFDMA is applied in the Down- and SC-FDMA in the Uplink. Spread spectrum, which was used in 3G was discarded in favor of FDE technology. The usage of FDE allows to dynamically manage the bandwidth (e.g. to avoid narrowband interferences). Other techniques besides FDE such as MIMO, Turbo-Codes (used in FEC) or Adaptive Modulation were employed to increase the spectral efficiency.

While LTE did not meet the original IMT-Advanced Requirements, LTE was advertised as 4G, "near 4G" or "3.9G" technology, which caused some controversy. Finally the ITU stated that LTE and other "forerunners" may be referenced as 4G network [20]. Still the ITU differentiates systems that formally fulfill the IMT-Advanced requirements from the pre-4G systems by referencing LTE-Advanced and WiMAX-Advanced as "True 4G systems" [19] [22].

Besides the requirements regarding peak data rates another central requirement within IMT-Advanced is to realize all services – including voice call services – on IP-Packet based communication. One of the reasons to abandon the circuit-switch communication and to change to All-IP is to enhance data rates and to lower the costs. This was realized by integrating the logic of the RNC and the NodeB (see subsection 2.3.1). The logic was amalgamated into the newly introduced eNodeB network component and a set of servers and gateways [17] (see Figure 3).

Within Release 10 LTE was advanced into the backwards compatible LTE-Advanced. LTE-Advanced clearly focuses on reaching higher data rates and higher spectral efficiency. Through the use of Carrier Aggregation more bandwidth is provided for data transmission to a participant (up to 100 MHz with five component carriers). This theoretically allows for up to 3 Gbps in the Downlink and 1.5 Gbps in the Uplink. By introduction higher order MIMO (DL: 8x8; UL: 4x4) the spectral efficiency could be improved from 16bps/Hz in LTE Release 8 up to 30 bps/Hz [3].

The network topology of Release 8 was mostly kept. A new component are the Relay Nodes (RN), which are connected to a donor eNodeB (DeNB) through an air interface. Such a Relay Node extends the reach of the network without the need for a fixed fibre connection and allows for a heterogeneous "ad-hoc" network topology. The corresponding part for the Home Node B (HNB) is the Home evolved Node

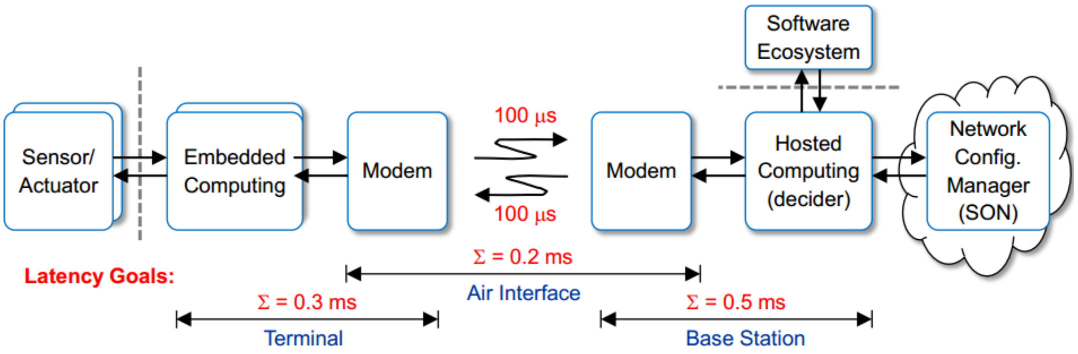

Figure 5: The impact of breaking down the 1 ms roundtrip delay. [13]

B (HeNB). The HeNB realizes a femtocell – which can be deployed at home or for small businesses – within the LTE-Advanced environment.

2.5 Insights

After investigating the evolution of cellular networks, core technologies can be identified that will most certainly be part of future networks. The 1G networks were the first to make commercial use of a cellular network topology for mobile communication. This network topology allowed to provide wide area coverage and to make efficiently use of radio resources. The analog transmission was discarded in favor of digital communication in 2G networks. Digital transmission proved to be superior to analog transmission in terms of robustness and flexibility. The inflexible centralized hierarchical structure was enhanced in the third Generation. HSPA managed to increase data rates and to reduce latencies by pushing parts of the CN logic closer to the radio interface. The 4G takes this principle even further by integrating multiple network components into the eNodeB on the edge of the network. Also a shift to an ALL-IP was made, by using IP-packet transmission for every communication (even for internal signaling). The expected growth of the mobile data traffic [9] (See Figure 4) will still be one the major drivers of upcoming mobile networks, but other parameters as latency and power efficiency gain more and more attention.

This shift in interest towards latency and devices with low data rates on a constant duty cycle takes place because so called Machine-to-Machine devices are expected to be the greatest driver of upcoming cellular networks.

3. MACHINE TO MACHINE (M2M)

Machine-to-Machine stands for the ubiquitous automated exchange of information between devices on the edge of networks such as mobile devices, computers, sensors, actuators or cars inside a common network. Both the term Machine-to-Machine and this common network, the so called ”Internet of Things”, are broad terms that cover a wide area of applications and concepts. It is widely recognized that M2M will be one of the drivers for the upcoming network generations. According to different estimations 30 – 50 Billion Machine Type Communication (MTC) devices will be interconnected in 2020, generating revenue up to $198 Million [7] [10] [6]. A major part of the application area of M2M communication are smart grids, which are intelligent electrical grids that use live information of all participants to dynamically react to changes. This dynamic adaption minimized costs (e.g. by detecting fraud) and also helps to optimize power generation on demand. To achieve these goals information and communication technologies (ICT) are adopted [30]. Other applications include the usage of M2M communication in cars. By automatically monitoring the traffic flow with sensors and cameras the need for traffic lights could be ultimately eliminated [18].

While most M2M Systems are unique and specific to their area of application some key concepts are common: In the first step data gets collected by some sort of MTC device (sensor, smart-meter, etc.). This data can be aggregated with previously collected data (as in some sensor networks) or directly send into a communication network. The communication network routes the data to the Data Integration Point (DIP). This DIP then stores and processes the data, e.g. by integrating it with data from other systems. Since the objective is to automate some sort of business process by automatically providing needed information to the appropriate entities, in the last step the available information is forwarded by the DIP to the corresponding receiver. The receiver of those information will then react to it accordingly.

One of the reasons M2M is getting more and more attention in the last few years, is that MTC devices get smaller and more power efficient, while gaining more computing power. But all of these properties would be of no use without a network to link those devices together. The cellular networks may be the answer to this problem. By providing high mobility, easy deployment and most important a very high coverage cellular networks gained attention as an attractive solution. Alternative solutions are satellites or medium range wireless networks (IEEE 802.15.4 (ZigBee) and IEEE 802.11 (WiFi). While cellular networks seem to be a eligible candidate, there are lots of challenges to be conquered:

Power supply

Most of the M2M endnodes don’t have access to a wired power connection, but instead a limited battery. While most relevant technologies (storage, mobile data rates, etc.) showed an exponential growth in the past, the battery capacity did not. To deal with this fact a very careful handling [8] of this resource is necessary, since a transceiver is often the most power expensive component. One proposed solu-

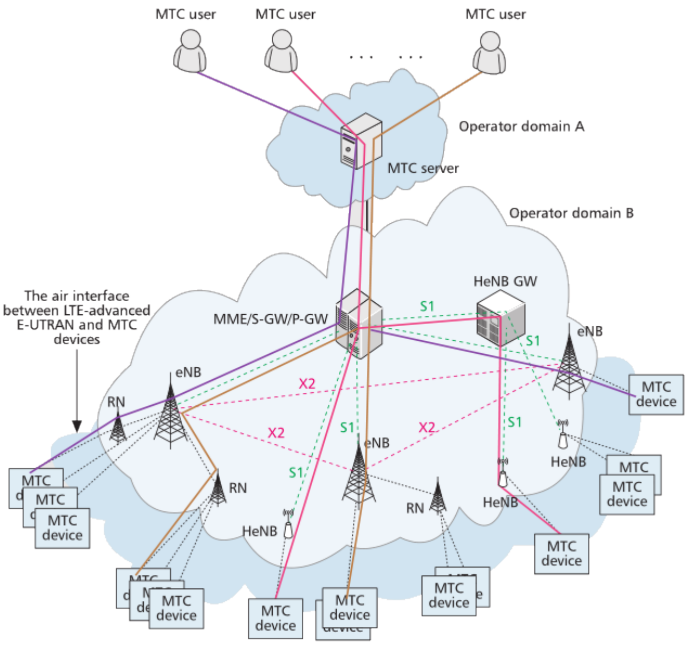

Figure 6: The communication scenario with MTC devices communicating with the MTC server. Dotted lines denote physical connections; solid lines denote logical connections. [33]

tion is to actively harvest energy from the environment [29].

Latencies

To provide realtime measurements through M2M systems the human reaction times have to be considered. For example when presenting live information of a sensor network through an augmented reality software we have to take in account how fast the human body can respond to the presented data. While the sensing to an unprepared muscular reaction is around 0.5 – 1 s, our eyes have a resolution of 100 Hz, which results in a 10 ms latency requirement. In tactile sensing humans even proved to be able to distinguish latencies around 1 ms, which is by far much lower than the RTT of current cellular networks [13]. Far reaching enhancements through all layers are needed to provide such latencies (see Figure 5).

Data rates

While bursts in data transmission rates are very common for H2H driven mobile networks (web-pages, file downloads, etc.), a M2M network typically features a periodic low data rate flow. This is due to the fact that the devices reside in hibernation most the time to save energy, e.g. sending 100 bytes in a duty cycle of 50 s.

Network congestion

Another problem that would occur in todays mobile networks is a congestion of the Uplink random access channels. In LTE a user equipment typically uses random access mechanisms to register within a eNB (due to the change of the cell or loss of the Uplink timing synchronization). Therefore it is possible that those random access channels get overloaded when a very high number of MTC devices begin to send at once (e.g. during a global event like an earthquake). This leads to an overload on the Random Access Channels, which cannot be handled by current cellular networks [25].

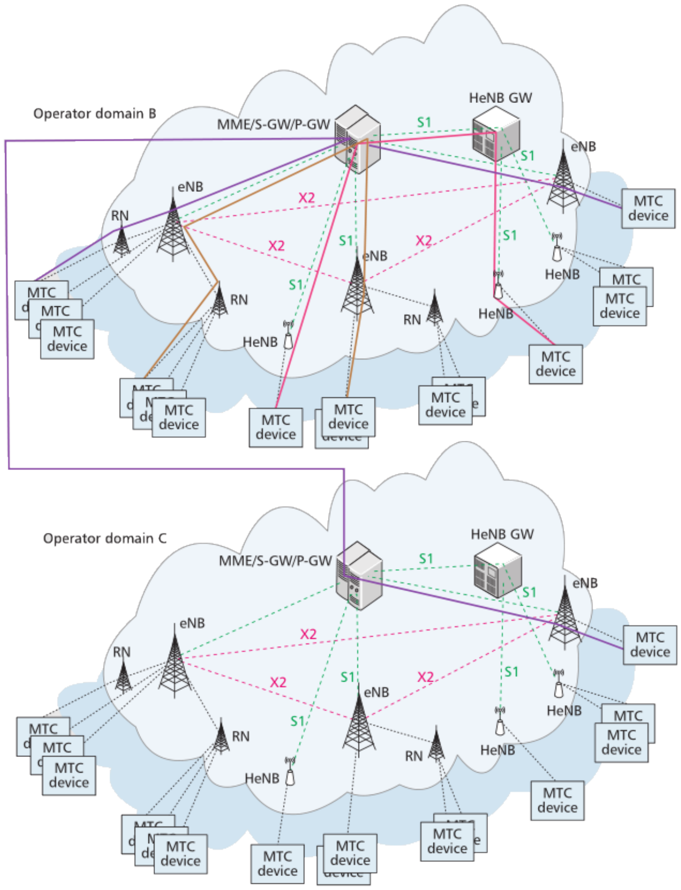

Figure 7: The communication scenario of MTC devices communicating with each other without intermediate MTC server(s). Dotted lines denote physical connections; solid lines denote logical connections. [33]

Some solutions have been proposed to address the problems that are caused by characteristic properties of M2M networks such as the very high amount of machines inside a cell and the low but constant traffic per machine. For example an improvement would be to use slotted aloha for the random access channels or to adopt a self-optimizing overload control mechanism as proposed by [25]. To find common standardized solutions to those problems a global initiative for M2M standardization was formed by multiple standardization bodies (ETSI, ARIB, etc.). There are aso some proposals to be found in the Literature concerning the realization of M2M networks, e.g. over Bluetooth (IEEE 802.15.1) or other medium range networks (WiFI, ZigBee). Despite these proposals no common standard could be formed until today. Recently the 3GPP started to address those requirements, by proposing a concept for providing M2M service over a cellular network.

The 3GPP depicts two different communication scenarios for MTC networks [4]. In the first scenario (see Figure 6) the MTC Devices connect to the MTC Server(s) through an LTE-Advanced Public Land Mobile Network (PLMN). This MTC Server(s) may be located in the same domain as the PLMN, but can also be run by a different operator. This can even be the MTC User (e.g. a car or a power plant in the smart grid) himself, who utilizes the services that are supplied by the MTC Server. The MTC User can access the collected data of the vast number of MTC devices through an API of the MTC Server. Through various interfaces within the LTE-Advanced network (e.g. X2, S1) the MTC Devices that are connected to an eNodeB, an Relay Node or to an Femtocell (HeNB) can be controlled by the MTC User via the MTC Server. In the second scenario the MTC devices directly communicate without the need for such a server. This communication can take place over a single operator domain or through multiple domains, as depicted in Figure 7. While the two approaches differ in the way MTC Devices are organized on higher layers, both have in common that the underlying network is provided by an LTE-Advanced network. In contrast to this proposal by the 3GPP, that solely favors LTE, studies take place that consider other mobile networks as feasible foundation (e.g. GSM as well-adopted solution with good coverage [26]). One of the many problems that need to be dealt with to serve a very large number of MTC devices is the fact that the E.164 telephone numbers are scarce. Multiple regulars in different countries noted that there are not enough mobile telephone numbers available. The 3GPP estimated that there will be up to 100x more MTC devices than H2H communication devices. While some want to temporarily assign longer dedicated number spaces (e.g. 14 digits) to MTC devices, others tend towards a long term solution as no longer providing E.164 numbers to M2M applications [27].

Regarding the limited nature of the electromagnetic spectrum, [33] propose to make use of cognitive radio technology for M2M communication. A cognitive radio (CN) is an intelligent radio, that is self-adjusting and able to dynamically access inactive radio spectrum of the primary system (PS) [24]. The cognitive radio is one of the end goals of the software-defined radio platform, which is a programmable radio that is usually powered by a digital signal processor (DSP) or a Field Programmable Gate Array (FPGA). While the ISM-Bands are usually fully allocated and under heavy use, licensed band are often inefficiently utilized. CN technology could help to make use of this unused gaps, without interfering with current users of those frequency bands. One approach is to use a database (e.g. from Spectrum Bridge) of the white space coupled to the geographic location. By querying this database the CN is able to avoid the parts of the spectrum which are in local usage [12]. Most of the CN technology is developed by startups such as Spectrum Bridge. Those startups propagate that by getting rid of the high costs of auctioning spectrum licenses the CN technology will boost wireless innovation such as M2M communication.

4. CONCLUSIONS

In this paper the drivers of future networks are identified. By investigating the evolution of commercial cellular PLMNs, core technologies could be determined that will most likely be reused in the coming generations of mobile networks. Those core technologies included a cellular network topology, digital transmission, a relocation of network logic closer to the edges of the network and a shift to ALL-IP communication. Besides enhanced data rates, future networks are expected to focus on latencies and a decentralized heterogeneous topology. It is anticipated that Machine-to-Machine communication and the ”Internet of Things” will be a major driver of future networks, impacting the way we receive and process information about our environment. The introduction of billions of machine type communication devices will require a revision of current mobile networks (network congestion, cognitive radio). We can conclude that those involved in the market of mobile networks are facing new requirements, which are already worked on to some extent. Yet many questions remain open especially on the air interface and the integration of opposing requirements resulting from H2H communication and M2M communication.

5. REFERENCES

[1] 3rd Generation Partnership Project. 3GPP TR 21.905: ”Vocabulary for 3GPP Specifications”, 2008.

[2] 3rd Generation Partnership Project. Release 8, 2008.

[3] 3rd Generation Partnership Project. Release 10. 2011.

[4] 3rd Generation Partnership Project. 3GPP TR 23.888 v12.2.0 ”System improvements for Machine-Type Communications (MTC)”, 2013.

[5] 4G Americas. Mobile Broadband Explosion, 2013.

[6] ABI Research. M2M Dream Challenged by Alarming Security Concerns - Spurs $198 Million Market by 2018, 2013. URL: `https://www.abiresearch.com/press/m2m-dream-challenged-by-alarming-security-concerns` [cited 19.11.2013].

[7] ABI Research. More Than 30 Billion Devices Will Wirelessly Connect to the Internet of Everything in 2020, 2013. URL: `https://www.abiresearch.com/press/more-than-30-billion-devices-will-wirelessly-conne` [cited 17.11.2013].

[8] H. Chao, Y. Chen, and J. Wu. Power saving for Machine to Machine communications in cellular networks. In *2011 IEEE GLOBECOM Workshops (GC Wkshps)*, pages 389–393. IEEE, Dec. 2011.

[9] Cisco. Cisco Visual Networking Index : Global Mobile Data Traffic Forecast Update, 2012 – 2017, 2013.

[10] Cisco. Connections Counter: The Internet of Everything in Motion, 2013. URL: `http://newsroom.cisco.com/articleId=1208342` [cited 10.11.2013].

[11] J. Engel. The effects of cochannel interference on the parameters of a small-cell mobile telephone system. In *19th IEEE Vehicular Technology Conference*, volume 19, pages 110–116. IEEE, 1968.

[12] Farpoint Group. Rethinking Spectrum Scarcity: Database-Driven Cognitive Radio. Technical report, Ashland, 2010.

[13] G. P. Fettweis. A 5G Wireless Communications Vision. *Microwave Journal*, 2012.

[14] R. L. Freeman. *Telecommunication System Engineering*. John Wiley & Sons, Inc., Hoboken, NJ, USA, fourth edition, May 2004.

[15] R. Frenkiel. A high-capacity mobile radiotelephone system model using a coordinated small-zone

approach. *IEEE Transactions on Vehicular Technology*, 19(2):173–177, May 1970.

[16] H. Holma and J. Reunanen. 3GPP Release 5 HSDPA Measurements. In *2006 IEEE 17th International Symposium on Personal, Indoor and Mobile Radio Communications*, pages 1–5. IEEE, Sept. 2006.

[17] H. Holma and A. Toskala. *LTE Advanced: 3GPP Solution for IMT-Advanced*. Wiley, 2012.

[18] IEEE. News Releases, 2012. URL: `http://www.ieee.org/about/news/2012/5september_2_2012.html` [cited 14.11.2013].

[19] ITU. New ITU radio interface standards to revolutionize mobile communication, 2009. URL: `http://www.itu.int/newsroom/press_releases/2009/48.html` [cited 25.10.2013].

[20] ITU. ITU World Radiocommunication Seminar highlights future communication technologies, 2010. URL: `http://www.itu.int/net/pressoffice/press_releases/2010/48.aspx` [cited 28.10.2013].

[21] ITU-R. Requirements related to technical performance for IMT-Advanced radio interface(s). Technical report, 2008.

[22] ITU-R. IMT-Advanced standards announced for next-generation mobile technology, 2012. URL: `http://www.itu.int/net/pressoffice/press_releases/2012/02.aspx` [cited 19.11.2013].

[23] M. Jurvansuu, J. Prokkola, M. Hanski, and P. Perala. HSDPA Performance in Live Networks. In *2007 IEEE International Conference on Communications*, pages 467–471. IEEE, June 2007.

[24] S.-Y. Lien, C.-C. Tseng, and K.-C. Chen. Carrier Sensing Based Multiple Access Protocols for Cognitive Radio Networks. In *2008 IEEE International Conference on Communications*, pages 3208–3214. IEEE, 2008.

[25] A. Lo, Y. Law, M. Jacobsson, and M. Kucharzak. Enhanced LTE-advanced random-access mechanism for massive machine-to-machine (M2M) communications. *in 27th World Wireless Research Forum (WWRF) Meeting*, 2011.

[26] G. C. Madueño, C. Stefanovic, and P. Popovski. How Many Smart Meters can be Deployed in a GSM cell? In *Proceedings of IEEE International Conference on Communications (ICC 2013). IEEE, 2013.*, 2013.

[27] D. Minoli. *Building the Internet of Things with IPv6 and MIPv6: The Evolving World of M2M Communications*. Wiley, 2013.

[28] A. R. Mishra. *Advanced Cellular Network Planning and Optimisation: 2G/2.5G/3G...Evolution to 4G*. Wiley, 2006.

[29] D. W. K. Ng and R. Schober. Energy-efficient power allocation for M2M communications with energy harvesting transmitter. In *2012 IEEE Globecom Workshops*, pages 1644–1649. IEEE, Dec. 2012.

[30] D. Niyato. Machine-to-machine communications for home energy management system in smart grid. *IEEE Communications Magazine*, 49(4):53–59, Apr. 2011.

[31] Nokia Siemens Networks. Long Term HSPA Evolution - Mobile Broadband evolution beyond 3GPP Release 10, 2010.

[32] J. Schiller. *Mobile Communications (2nd Edition)*. Addison-Wesley, 2003.

[33] Shao-Yu Lien, Kwang-Cheng Chen, and Yonghua Lin. Toward ubiquitous massive accesses in 3GPP machine-to-machine communications. *IEEE Communications Magazine*, 49(4):66–74, Apr. 2011.

[34] B. Yin, K. Amiri, J. R. Cavallaro, and Y. Guo. Reconfigurable multi-standard uplink MIMO receiver with partial interference cancellation. In *2012 IEEE International Conference on Communications (ICC)*, pages 4766–4770. IEEE, June 2012.