TOWARDS CONVERGED 5G MOBILE NETWORKS-CHALLENGES AND CURRENT TRENDS

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ABSTRACT

With the rapid development of wireless technologies, the concept of the Fifth Generation (5G) wireless communication system started to emerge and it is foreseen that it will be a result of standards convergence. The expectations towards 5G are set much higher in terms of capacity and maximum throughput when compared with Fourth Generation (4G). There are also some new technical challenges the system will need to face, like Machine to Machine (M2M) communication, energy efficiency, complete ubiquity and autonomous management. This paper analyses new technologies that could enable 5G networking, discusses potential standardisation and development directions, and presents recent research efforts in the area of future mobile networks.

Keywords— 5G, M2M, C-RAN, HetNet, SON

1. INTRODUCTION

We observe tremendous changes within the field of wireless communications nowadays. It could be best described as an accelerating evolution of wireless networks together with significantly growing user demands. Previous generations of mobile systems set the foundation for their successors. Current technologies go far beyond traditional telephony and basic data service that was offered by Second Generation (2G) standards. Some key features of future mobile networks include increased capacity, lower Capital Expenditure (CAPEX) and Operational Expenditure (OPEX), complete ubiquity provided by full multistandard interworking, as well as spectrum and infrastructure sharing.

The 5G of mobile networks is seen as an agnostic technology, i.e., one global unified standard that will allow completely seamless connectivity without barriers among both, existing standards, e.g., High Speed Packet Access (HSPA), Long Term Evolution (LTE) and Wireless Fidelity (WiFi), and new wireless systems that are about to come. It will offer a wide variety of new multimedia services at very high data rates. Some emerging services and future applications can be already envisioned, such as augmented reality and tactile Internet providing very rich multimedia experience. Other examples include the emerging concept of a smart city, steering the traffic of driverless cars or telecommunication support for advanced healthcare systems, where patients can be instantly monitored at their homes.

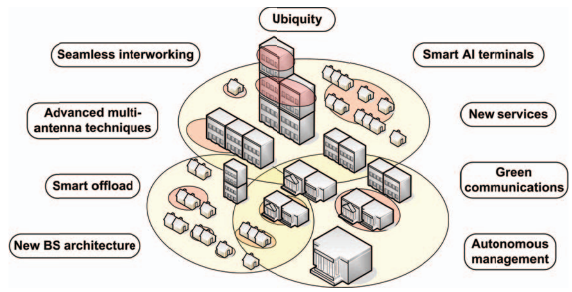

Figure 1. 5G scenario characteristics

The expectations are that 5G will surpass 4G in terms of achievable throughput, higher spectral efficiency, fully ubiquitous service and finally better energy efficiency. Consequently, it will go beyond requirements defined by the International Telecommunication Union-Radiocommunications Sector (ITU-R) under International Mobile Telecommunications Advanced (IMT-Advanced) term. Before that happens, however, a number of technical and standardisation challenges will have to be solved.

In this paper we present key research topics and review the main directions related to 5G development. We start with a mobile technology overview and define 5G requirements in the next section. Later on we discuss the research and development challenges from a network perspective. Finally, we summarize the paper by highlighting the presented topics and challenges to be solved in 5G mobile networks.

2. MOBILE TECHNOLOGY OVERVIEW AND 5G REQUIREMENTS

In this section we describe the mobile networks' development and give an overview of a set of requirements for the upcoming 5G wireless systems. Since the beginning of 1980s and the first analog mobile telephony systems such as Nordic Mobile Telephony (NMT) or Advanced Mobile Phone System (AMPS) we have been observing continuous development of wireless communications, as summarized in Table 1. Widely deployed Time Division Multiple Access (TDMA) based 2G mobile networks introduced Short Message Service (SMS) and data enhancement in subsequent technologies (General Packet Radio Service (GPRS) and Enhanced GPRS (EDGE)). Third Generation (3G) family of Wideband Code Division Multiple Access (WCDMA) standards offers much higher data rates when compared with predecessors, and therefore enables such services as video streaming or

Table 1. Mobile Generations Comparison

Generation	Technology	Type	Key Characteristics
1G	NMT, AMPS	Analog	Voice services only
2G	GSM/EDGE	TDMA	Voice services accompanied by SMS, widely deployed around the world, data enhancement to GSM, simple multimedia services (MMS, web browsing)
3G	UMTS/ HSPA	CDMA	Data service of UMTS network, enhanced multimedia and streaming video services, new type of devices
4G	LTE-A, WiMAX 2.0	OFDMA	New flat IP-based architecture, data service of very high throughput, dedicated applications
5G	Emerging	CDMA, OFDMA, new proposals, e.g., SCMA[1], NOMA[2]	Seamless heterogeneity, agnostic access, advanced services and applications (e-health, M2M)

podcasting, and makes data services more common. Finally, Orthogonal Frequency Division Multiple Access (OFDMA) based Long Term Evolution-Advanced (LTE-A) and Institute of Electrical and Electronics Engineers (IEEE) 802.16m known better as WiMax 2.0 are classified as 4G technologies, as they meet ITU-R requirements set to IMT-Advanced mobile systems. They offer high data rates (peak throughput 100 Mbps and 1 Gbps in high and low mobility scenarios, respectively) and support a wide variety of dedicated applications from a rapidly growing market. 4G introduces the concept of connectivity any time, anywhere from any kind of device and it is indeed observed in users' behaviour. Online life has gained a lot more importance with boosting content sharing, blogging and social networking. Day by day wireless communications becomes an integral part of our society and as a consequence, our technological expectations grow continuously. Fig. 1 presents the major characteristics and challenges of 5G development.

The official requirements towards 5G have not been defined yet and many operators, vendors as well as academic institutions take the initiative in defining the case scenarios. The expectations are that it will provide uniform throughput of 1 Gbps and the peak in the range of 10 Gbps with couple of milliseconds of latency providing highly reliable service. New multiple access techniques have been recently proposed, such as Sparse Code Multiple Access (SCMA) [1] and Non-orthogonal Multiple Access (NOMA) [2], and they can be considered in the 5G scenario.

In Europe the Mobile and wireless communications Enablers for the Twenty-twenty Information Society (METIS) consortium [3] focuses on setting the foundation of 5G systems. It is forecasted that 5G will provide truly ubiquitous unlimited mobile experience through terminals enhanced with Artificial Intelligence (AI) capabilities. A number of new applications is foreseen facilitating such domains as Electronic health (e-health) and M2M. From a network perspective, it requires very tight and seamless interworking among existing and future standards. Furthermore, rising mobile traffic demand will enforce new ways of capacity enhancements such as dense deployment of small cells, as well as intelligent traffic steering and offload schemes. Ever-growing energy consumption in wireless networks imposes new mechanisms of energy control and reduction. Finally, there is a high need for autonomous network management due to its complexity and high degree of heterogeneity.

We are currently facing the first steps towards the goals presented above. They will be discussed more in detail in the following sections.

3. CHALLENGES AND DEVELOPMENT DIRECTIONS

In this part we outline some observed research challenges and directions in the mobile network development as well as highlight the future trends and solutions that may lead to improved network performance while meeting the constantly increasing user demands. They are summarized in Table 2.

3.1. Machine to Machine Communication

Besides network evolution, we observe also device evolution that become more and more powerful. The future wireless landscape will serve not only mobile users through such devices as smartphones, tablets or game consoles but also a tremendous number of any other devices, such as cars, smart grid terminals, health monitoring devices and household appliances that would soon require a connection to the Internet. The number of connected devices will proliferate at a very high speed. It is estimated that the M2M traffic will increase 24-fold between 2012 and 2017 [17].

M2M communication is already today often used in fleet monitoring or vehicle tracking. Possible future usage scenarios include a wide variety of e-health applications and devices, for instance new electronic and wireless apparatus used to address the needs of elderly people suffering from diseases like Alzheimer's, or wearable heart monitors. Such sensors would enable patient monitoring and aid doctors to observe patients constantly and treat them in a better way. It will also reduce the costs of treatment, as it can be done remotely, without the need of going to a hospital.

Table 2. Summary of Challenges and Trends

Area	Challenge	Proposals and Trends
Ubiquity	Need for a truly seamless wireless experience, connectivity any time, anywhere, from any kind of device	Tight interworking of mobile standards, IEEE 802.11u for seamless WiFi experience
M2M communications	High QoS requirements for e-health applications, advanced security mechanisms	New rules regulating access to BANs [4]
Green communications	Reduced energy consumption by telecommunication networks	Adjusting transmission power to actual traffic load, new green Radio Access Network and base station architectures [5, 6, 7]
Capacity requirements	Growing traffic demands	Small cell deployment, phantom cell concept [8], visible light communication [9], offload to WiFi, extensive work on IEEE 802.11 standard family
Spectrum bottleneck	More spectrum bands and higher spectral efficiency needed to meet capacity requirements	New spectrum bands in 2015, mm-waves [10], spectrum sharing techniques [11], HSPA and LTE carrier aggregation [12], relaxed orthogonality requirements [13]
Autonomous management	Minimisation of management effort, lowering OPEX	Self-Organising Network and cognitive behaviour [11], new self-reparing chips [14], core network virtualisation [15, 16]

Remote patient monitoring using a Body Area Network (BAN), where a number of wireless sensors, both on-skin and implanted, record the patient's health parameters and sends reports to a doctor, will soon become a reality and an important part of 5G paradigm. Therefore, in order to offer e-health services, 5G will need to provide high bandwidth, meet extremely high Quality of Service (QoS) requirements, e.g., ultra low latency and lossless video compression for medical purposes, and implement enhanced security mechanisms. Furthermore, extended work will need to be done to efficiently manage radio resources, due to high diversity of traffic types, ranging from the reports sent periodically by the meters, to high quality medical video transmission.

3.2. Capacity Crunch

With the new broadband services and high demand for mobile data, future wireless systems will require much higher capacity than can be provided today. There are three major ways of capacity enhancement, namely dense deployment, additional spectrum bands and higher spectral efficiency.

The spectrum used by mobile communication systems today becomes congested and alternatives are needed to meet the future capacity demands. One of the novel proposals includes using visible light bands, where LEDs can be both a source of illumination and a hotspot [9]. This technology is not mature yet but attracts more attention from the very dense small cell deployment and vehicular communication scenarios. This concept would make wireless service available in areas that nowadays have limited service, such as hospitals and aircrafts, and significantly improve indoor data coverage in general. Due to its very local character it has a great advantage when compared to radio communication, which is security and privacy, as the communication cannot be eavesdropped unless the attacker gets into visual contact with the transmitter.

There is also enormous potential in very high spectrum bands, e.g., 28 or 60 GHz that provide also wider bandwidth and can support higher data rates. Millimetre waves greatly facilitate massive antenna solutions, thus also enabling higher speeds. The recent extensive feasibility study of using 28 and 38 GHz frequencies for mobile communication was reported in [10]. Furthermore, the possibility of using unlicensed spectrum around 2.4 and 5 GHz, as well as refarming 900 and 1800 MHz bands could also increase the spectrum available for broadband data. It is expected that new bands will become available after ITU-R World Radiocommunication Conference in 2015.

However, new spectrum bands alone will not be sufficient to satisfy the future traffic demands. Hence, spectral efficiency should be significantly increased, where novel multiple access schemes, like [1, 2], advanced multi-antenna techniques, such as beamforming and massive Multiple Input Multiple Output (MIMO) together with spectrum sharing are the key enablers to achieve higher spectral efficiency.

Techniques such as Carrier Aggregation (CA) and Coordinated Multipoint (CoMP) increase the network capacity but require very tight synchronisation and strict orthogonality of fragmented spectrum. Fifth Generation Non-Orthogonal Waveforms for Asynchronous Signalling (5GNOW) [13] is a European project that addresses these challenges by relaxing stringent requirements. A new transmission scheme allowing non-orthogonal waveforms and asynchronous traffic can be expected as its result. It will be suitable for a wide variety of services, e.g., those related to M2M communication, reducing both the related signalling overhead as well as power consumption.

Cognitive radio [11] is an intelligent radio capable of automatic reconfiguration. Secondary cognitive users are able to intelligently adapt their radio parameters to observed radio environment with for example the support of Software Defined Radio (SDR), and to access licensed spectrum when its primary users are inactive. Dynamic Spectrum Access (DSA) can be perceived as an example of cognitive radio, which is a much broader concept [18]. Challenges and implementation directions are widely covered in [19]. Finally, one of the recent proposals considers spectrum sharing among different technologies, through for example CA between LTE and HSPA [12, 20].

3.3. Enhanced Local Area Access

Small cell solutions and further network densification are perceived as means to cope with the exponential traffic growth in the coming years. Heterogeneous Networks (HetNets), where the macrocell overlays a number of smaller cells, e.g., metrocells, picocells, femtocells have already demonstrated a great increase of capacity, as the small cell sites proliferate at a high speed. The tier of Low Power Nodes (LPNs), referred also as local area access [21, 22], can significantly enhance the coverage and boost the capacity of mobile networks and it has become of a great interest in 3^{rd} Generation Partnership Project (3GPP) LTE Release 12.

Higher network densification poses numerous challenges, mainly in terms of mobility. The phantom cell concept is one of the key enablers to efficiently integrate both network tiers and address current research challenges related to mobility. It tackles this issue by separation of data and control plane at small cells and redirecting the latter one towards the overlaying macro site [8]. The concept proposes also using different frequency bands for the different cell tiers (3.5 GHz and higher for small cells), so that interference problems can be mitigated in ultra-dense deployments. Further directions include studying ideal, as well as non-ideal backhaul solutions for the small cells [21, 22, 23].

Since LTE does support interworking with both 3GPP and non-3GPP based technologies, the IEEE 802.11 standard with some of its amendments can become a great enhancement to mobile networks and help balance the traffic through efficient offload techniques. Cisco estimates that there are 800 million new WiFi devices every year [24], and an average user is surrounded by numerous hotspots that could potentially provide a service. Therefore, extensive research work on tighter interworking with WiFi can be expected. From that perspective, two amendments to IEEE 802.11 may be of particular interest.

3.3.1. IEEE 802.11u

IEEE 802.11u is a new amendment to 802.11 family that offers automatic authentication and handoff of WiFi enabled devices to WiFi networks. The choice of the best available network, obtaining user credentials and finally connecting may become cumbersome. The new standard overcomes it by automating access network discovery and selection, and supporting invisible authentication. It ensures always best connectivity based on a set of policies and preferences defined by both, a user and network operator.

Hotspot 2.0 is an industry initiative, whose goal is to provide seamless WiFi connectivity using the new amendment. The more recent initiative of the Next Generation Hotspot focuses also on WiFi-mobile networks interoperability challenges. Both may be of a great support to mobile operators to offload their traffic and to provide a service as close to today's 3G experience as possible thanks to smooth and seamless connection establishment.

3.3.2. Mesh Networking

IEEE 802.11s is an amendment concerning Wireless Mesh Networks (WMNs). WMN is defined as a wireless multi-hop network formed by the static mesh routers providing a distributed infrastructure for mesh clients over a full (each node communicates with all the nodes in the network) or partial mesh topology. Due to high popularity of devices equipped with WiFi it may be nowadays used to easily extend WiFi coverage of public wireless access, provide adaptive and flexible wireless Internet connectivity and offload mobile traffic.

WMNs are easy and inexpensive to deploy, as low cost nodes with free software can be used. Furthermore, they are characterized by Self-Organising Network (SON) properties. This makes them an attractive alternative especially within organised communities, as the network is scalable and can grow spontaneously. WMNs can be used in a multiple different scenarios and set-ups, from a metropolitan and community networking, transportation means networking through building automation, public safety, emergency, surveillance systems to simply entertainment [25].

Today the standard can be a base and inspiration for a mesh network cell, where some of the User Equipments (UEs) behave as a Base Station (BS), which is feasible as UEs become more powerful. Wireless mobile backhaul can also greatly benefit from the mesh architecture and its self-organising features.

The coexistence of LTE and WiFi is now observable more as a cooperation rather than competition. A multimode small cell working in licensed as well as license-exempt spectrum band is available on the market. The recent proposal includes a SON based traffic steering mechanism for small cells [26]. Similarly as in Joint Radio Resource Management (JRRM) [27], the delay sensitive traffic is sent over the mobile network, whereas delay tolerant data over WiFi.

The evolution of WiFi itself has led to the proposal of IEEE 802.11ac known better as *WiGig* offering the rates of several Gbps in the 5 GHz band. Other new standards include 802.11ad operating in 60 GHz and 802.11af using TV white spaces. With the fast development of LTE and attractive WiFi amendments, much research and standardisation efforts of 3GPP and IEEE can be expected to address the challenge of ensuring seamless interworking of these two Radio Access Technologies (RATs).

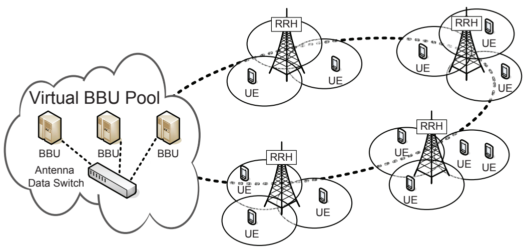

Figure 2. Cloud RAN Architecture

3.4. New Radio Access Network Architectures

With the increased data traffic, need for more capacity and flat plans offered to the end users, operators need to seek their benefit in reduction of CAPEX and OPEX to lower the cost per bit. Within a mobile network, it is the BS that generates the most expenses due to such factors as cooling, site rental and signal processing and it has been the main focus for cost reduction [5, 6]. As a result, novel approaches to radio access network architectures and advanced multi-antenna configurations were proposed recently and we summarize them briefly below.

3.4.1. Cloud RAN

Cooperative, Centralised, Clean (Green) Cloud Radio Acces Network (C-RAN) concept [5, 6] evolved from a Distributed Base Station (DBS) architecture where a BS server responsible for Baseband (BB) processing is connected over a fibre link to a number of antennas, so-called Remote Radio Heads (RRHs). In C-RAN multiple Baseband Units (BBUs) are gathered in one central physical location to enable resource aggregation and pooling. A BBU pool serves a particular area with a number of RRH of macro and small cells. The topology of BBU pool- RRH connections is scenario and implementation specific. C-RAN supports wide variety of architectures, for example chain deployments for railway and other transportation networks, as well as star and ring topologies depending on the needs. There is also a flexible enhancement to interconnect RRHs (daisy chaining) for further coverage enhancement. An example C-RAN architecture is presented in Fig. 2.

This clear separation of BBUs from antennas has multiple advantages. Together with smart antenna systems it has the potential to significantly increase overall system capacity while keeping low energy consumption. Furthermore, thanks to BBU aggregation, the number of BS sites can be greatly reduced, which results in much lower cost of operation. Since BBU resources are virtualised, some of the processing power can be reduced during off-peak traffic hours. Moreover, in such a set-up locally centralised collaborative management can be employed, which leads to improved adaptability to dynamic and non-uniform traffic across all connected RRHs. It also makes network upgrades fast and easy. Finally, C-RAN supports multistandard operation, and centralisation makes inter-RAT management relatively easy enabling joint processing in such areas as scheduling, interference coordination or traffic steering.

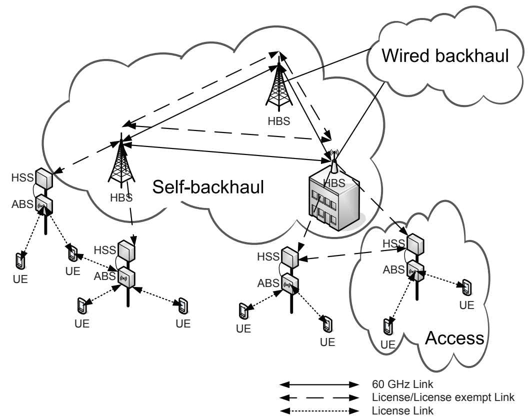

Figure 3. Simplified BuNGee Architecture

Cooperation and network virtualisation will become one of the main trends in saving OPEX and leading to better resource utilisation. C-RAN architecture facilitates resource sharing, e.g. spectrum, hardware, among many operators. In [28] the theoretical aspects of such cooperation are studied and benefits of resource sharing for different partners are evaluated. The study shows that the benefits highly depend on the initial network dimensioning and amount of resources they wish to share.

3.4.2. BuNGee Approach

BuNGee project aimed at proposing an architecture facilitating increase of capacity density up to 1 Gbps/km^2, which is well beyond IMT-Advanced requirements (ten fold). Another goal was to drastically lower CAPEX and OPEX when compared to traditional BS deployments. It was achieved with the architecture presented in Fig. 3 adopted from [7].

The key idea is to gather all the core functionalities in an intelligent and very powerful platform called Hub BS (HBS) and mount it over rooftops serving a large amount of light access points- Access BSs (ABSs) comparable to relay nodes that are placed below rooftops. HBS is the most expensive part of the system, but thanks to local centralisation, similarly to C-RAN it reduces the overall cost of network deployment and maintenance. What is more, the project further reduces the cost of infrastructure by introducing wireless links between HBSs. The optical fibre link between HBSs is replaced by a microwave link at 60 GHz, which requires line-of-sight (LOS) but significantly reduces the cost per bit. Each HBS is connected to regular wired backhaul and has a number of narrow beams in licensed or unlicensed spectrum to communicate with ABSs. This connection is realised through additional subscriber stations (HSS). Similarly to daisy chaining in C-RAN, a direct connection between ABSs is also possible. Finally, ABSs provide the broadband service to UEs using licensed spectrum.

The proposed architecture allows to increase network capacity at a very low cost. It is very generic, can be applied to any wireless technology, and has already been under standardisation process by European Telecommunications Standards Institute (ETSI) [7].

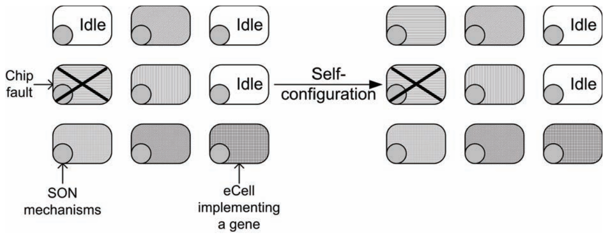

Figure 4. Self-healing of eDNA

3.5. Self-Organising and Cognitive Networks

Due to increasing network complexity with new standards, network architectures, and multiple cell tiers, network management has become very complex and it is one of the major challenges in mobile networks. The tendency and one of the main focuses in LTE Release 12 is to automate most of the management procedures so as to make it faster and lower the cost of operation.

SON have three distinctive features, namely self-organisation, self- optimisation and self-healing. A number of different algorithms can be implemented to supports SON behaviour, for example those responsible for load balancing or coverage optimisation. If resource utilisation in a cell becomes too high, it triggers a handover for some connections so as to move them to a neighbouring cell. Similarly, if too high interference is detected, a BS may adjust its transmission power. These procedures can be performed in all the cells leading to a more uniform traffic distribution and improved network coverage.

When self-healing is concerned, network faults such as a coverage hole are considered. However, hardware errors for example in BBUs are not that uncommon in telecommunication infrastructure. So far, these kind of faults need to be repaired manually, which is usually expensive, time consuming and causes losses to an operator due to downtime. A revolutionary concept of self-healing hardware has been recently proposed in [14]. The proposal of electronic DNA (eDNA) for hardware is inspired by biological properties and processes, in particular self-healing ability.

The eDNA architecture consists of a number processing units, so-called electronic cells (eCells). Some of them implement an independent part of a program called a gene, whereas others remain empty. Furthermore, every cell has a copy of a program which is responsible for SON functionalities. In case of a failure, piece of code from a faulty cell is mapped to one of the idle ones. It triggers self-configuration behaviour of the cells, as depicted in Fig. 4, so that the execution can be continued. Thanks to this approach chips become self-aware and are able to control themselves autonomously by incorporating SON principles, thus increasing robustness of a system and prolonging its lifetime. This technology can be applied to numerous use cases and clearly the next generation telecommunication scenario is one of them.

A next step in self-organisation is introduced by cognitive approaches [11], where management modules are able to learn based on current and past observations. This way self-organisation is not limited by the predefined algorithms and a system is able to adjust to any unexpected situations. Recently a new docitive approach has been introduced [7], where network nodes have also a teaching ability. By implementing machine learning algorithms, they are able to exchange information and teach each other which accelerates their learning process and leads to faster convergence.

3.6. Core Network Virtualisation

Moving towards 5G imposes changes not only in the Radio Access Network (RAN) but also in the Core Network (CN), where new approaches to network design are needed to provide connectivity to growing number of users and devices.

The trend is to decouple hardware from software and move the network functions towards the latter one. Software Defined Networking (SDN) being standardised by Open Networking Foundation (ONF) assumes separation of the control and data plane [15]. Consequently, thanks to centralisation and programmability, configuration of forwarding can be greatly automated.

Moreover, standardisation efforts aiming at defining Network Functions Virtualisation (NFV) are conducted by multiple industrial partners including network operators and equipment vendors within ETSI [16]. Introducing a new software based solution is much faster than installing an additional specialised device with a particular functionality.

Both solutions would improve the network adaptability and make it easily scalable. As a result of simpler operation, one can expect more dynamic and faster deployment of new network features.

4. SUMMARY

In this paper we presented the current trends in mobile broadband network development. 5G will be a result of standards convergence, where various technologies complement each other to reach the common goal of providing ubiquitous service. We analysed important concepts facilitating the growth of the next generation 5G mobile networks, as well as underlined future directions and research activities in this field. Clearly, there is an enormous potential in small cell development, followed by technologies leading to reduction of power consumption and carbon footprint, such as new BS and RAN architectures. Due to increased traffic demands, we will observe rapid WiFi development, since it has great potential as supportive technology. Significant changes are observable also in CN, where software based solutions start to play a major role.

Most of the solutions presented in this paper are in their early development stadium. In the next decade significant research and standardisation efforts will be taken to meet the new network requirements and challenges of 5G. It will lead to a simpler network architecture, increased network efficiency, reduced power consumption, and standard-agnostic solutions providing truly ubiquitous access, thus creating a new fully integrated wireless future.

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