Open issues and beyond 5G

Marco Chiani, Enrico Paolini, Franco Callegati

Abstract
Fifth generation mobile networks (5G) will change our life and society, thanks to the introduction of recently developed technologies which will enable the development of new services and applications. While 5G is appearing with her novelties, we need to start thinking about the next steps that wireless cellular systems have to tackle, always keeping in mind that the final goal is the benefit of humanity. In this chapter we discuss some issues that 5G will still leave open, and the possible evolution towards the next generation (6G) of wireless communication systems.

1 Introduction

The last two decades have witnessed an extremely fast evolution of mobile cellular network technologies, from 1G to 4G, with 5G networks expected to be operational by 2020. This chapter will briefly review the path from the first to the latest generation of mobile cellular systems, will discuss some issues not fully addressed in 5G systems, and finally will sketch a vision of what we may expect beyond 5G. For the path beyond 5G, we envision that the mobile network will become more intelligent, with learning mechanisms to modify itself based on users' experience; situation-awareness will lead decision making and networking; this will allow fast and flexible spectrum reallocation, with consequent large bitrates available to the users; other human senses will be communicated, and 3D / holographic type communication will improve the quality of the tele-interaction; users will not necessarily need to bring a smartphone but will benefit of wireless-devices-as-a-service, with distributed devices available to anyone; the devices battery life will be substantially extended.

Among the technologies to reach these goals we count machine learning, dynamic spectrum allocation, wireless energy transfer, free-space optical communication, use of bands beyond 100 GHz, massive use of multiple antenna systems, new access

CNIT/University of Bologna, e-mail: {marco.chiani, e.paolini, franco.callegati}@unibo.it

Fig. 1 The network will learn from experience.

schemes allowing an increase in node density, cybersecurity for quantum attacks, high accuracy indoor localization, massive virtualization of network functionalities and novel, software driven, network control architectures.

2 The evolution from 1G to 5G

Table 1 provides an overview of the main features of each cellular network generation, from the first generation to the fifth one, including regulation, services, innovation with respect to the previous generation, and some ancillary information.

Concerning regulation, we witnessed a profound paradigm shift across the several generations, from 1G state-owned monopoly operators, very often obtaining the use of spectrum free of charge, to open-market auctions starting with 3G, to 5G spectrum sharing. Concerning open-market auctions, 3G systems spectrum was licensed at extremely high prices, with up-front payments years before the first universal mobile telecommunications system (UMTS) terminal appeared on the market. This regulation model contributed to late (and in some cases limited) profits seen by operators and, consequently, to a limited availability to excessive up-front payments for 4G spectrum licenses. The possibility of extending spectrum licenses up to 25 years, to apply spectrum sharing mechanisms, and to benefit from some regulatory flexibility in new millimeter wave (mmWave) frequency bands, are new regulatory aspects characterizing 5G.

In terms of services, the initial basic voice-only calls featured by 1G mobile systems evolved into a multitude of different services with the subsequent generations, from simple text messaging and basic high-latency data exchange to high-quality video streaming and chatting services, to radically new services supported by 5G networks. Services evolution was enabled by several factors, including ever-rising supported bit rates, advances in air interface design, signal processing at physical layer, and MAC layer procedures, technological advances in mobile terminals manufacturing, evolution of mobile internet protocols, cloud computing, advanced networking control paradigms.

Second generation global system for mobile communications (GSM) cellular networks initially provided digital voice service at bit rate 9.6 kbps. General Packet Radio Service (GPRS) and ultimately Enhanced Data Rates for GSM Evolution (EDGE) data services were subsequently introduced, with bit rates of a few tens of kbps and up to 200 kbps, respectively. Push email was also introduced for the first time on Blackberry devices. These bit rates were largely increased in next generations. Third generation UMTS offered up to 2 Mbps bit rate (often 364 kbps) initially, and then several tens of Mbps in downlink with High Speed Packet Access (HSPA). Fourth-generation LTE features up to 300 Mbps in downlink, with a target of 1 Gbps, and up to 50 Mbps in uplink. Fifth generation cellular networks are expected to increase the bit rate significantly, up to 20 Gbps. These bit rates, end-to-end latencies down to 1 ms, ultra reliability (packet error rate 10^{-5} or less), and massive multiple access, will foster services such as enhanced mobile broadband, device-to-device (D2D) communication, ultra-reliable and low-latency Internet of Things (IoT) and machine-type communication (MTC), e-health, augmented reality and tactile Internet, industrial control for the Industry 4.0, automated driving and flying. D2D communication, consisting of establishing a direct link between nearby devices without relaying information through a base station (BS), is emerging as a key technology to achieve efficient resource allocation, higher spectral efficiency, reduced latency.

Each generation of wireless cellular networks came with its own technical innovations, both on the network, air interface, and user terminal side.

Multiple access. Multiple access schemes were constantly enhanced, from single carrier per channel frequency division multiple access (FDMA), to frequency-and-time division multiple access (FDMA/TDMA), code division multiple access (CDMA), up to orthogonal frequency division multiple access (OFDMA) and non-orthogonal multiple access (NOMA), with a progressive explosion of the network capacity in terms of the number of users served at the same time with an adequate quality of service (QoS).

PHY layer enhancements. Fundamental innovations at the physical layer contributed to the above-reviewed ever-increasing bit rates. Among them we can count multiple-input multiple-output (MIMO), evolving into massive MIMO in 5G, as well as advanced channel coding schemes such as 3G/4G turbo codes and 5G New Radio traffic channel low-density parity-check (LDPC) codes and control channel polar codes.

Frequency bands New frequency bands were exploited by each generation. First generation advanced mobile phone system (AMPS) and total access communication system (TACS) were operated in the 800 MHz and 900 MHz bands, respectively, while second generation GSM was initially operated in the 900 MHz band, and then also in the 1800 MHz and 1900 MHz (in North America) ones. Frequency bands around 2 GHz were for the first time used by UMTS networks, while a number of frequency bands are available worldwide for long term evolution (LTE), based on regulatory aspects in different geographical areas (e.g., 450/800/900 MHz, 1800/2100 MHz, 2600 MHz in Europe). From a spectrum allocation viewpoint, the main breakthrough introduced by 5G is the use of licensed, shared, and unlicensed frequency bands in the mmWave band, above 24 GHz. The one around 60 GHz is of particular interest for indoor very-high data rate applications, wireless backhaul, and femtocell implementation.

Evolution of switching and networking The 1G network was fully circuit based, resembling the traditional telephone network, a choice motivated by being voice calls the target service of the networks. In 2G and 3G systems data oriented services progressively became more important and a packet switched network dedicated to the transport of data was set aside the existing circuit switched network. From 4G the evolved packet core (EPC) concept is adopted meaning that the transport network is based on packet switching only and that such packet switching is IP based. Therefore the transport technology of the mobile networks converges with the transport technology of the Internet. The EPC definition brings along another concept fundamental for the evolution to the 5G: the separation of the control and data plane. The technologies to control the transport of the user data are logically separated from the transport itself, which is essential to allow a separate evolution path to guarantee the required network scalability.

Network softwarization The emergence of the cloud computing paradigm and of the related virtualization technologies brought forward a key innovation in the 5G. Complex networking functionalities, traditionally requiring dedicated hardware and management may be virtualized as pieces of software into the cloud. This is the network function virtualization (NFV) paradigm, defined and standardized by ETSI in the recent years. Meanwhile software defined networking (SDN) also emerged, a novel approach that allows a very effective separation of the network control and data plane, thus further extending the ideas behind the EPC. The OpenFlow protocol is the key component of SDN, supporting the implementation of a communication channel between the controller (the brain of the network) and the network nodes (that carry data). NFV exploits virtualization, cloud computing and SDN to define an architecture which supports the implementation of network services as subsets of software functionalities, with an unprecedented degree of flexibility and adaptation capabilities. Network programmability and split of control and data plane are key enabling technologies towards a full implementation of the 5G. NFV and SDN fulfill such expectation and are now getting into a state of advanced validation.

3 5G Issues

This section points out some issues and challenges that, at present, have not been fully addressed in 5G mobile networks and that are attracting further research efforts.

Coverage issues. With the advent of 5G we will witness a site densification process as a primary means to increase network capacity. Site densification necessarily poses economical issues that may slow down considerably spatial and temporal 5G deployment, unless a substantial BS cost reduction is achieved over the time. It has been reported how SDN and network virtualization may contribute to cut costs, but there remains uncertainty about to what extent this will speed up 5G rollout. Recent studies have shown that, under a *business-as-usual* model, in UK 90% of the population will be covered with 5G not before 2027 and the that 100% coverage will be extremely hard to reach due to prohibitively increasing deployment costs in less populated areas [7]. Similar expectations have been reported for other countries during discussions at the 2018 IEEE 5G World Forum.

Emerging applications challenges. Super-hype of 5G contributed to create unprecedented expectations about the levels of QoS these mobile networks will be able to provide. It is becoming clear, however, how some emerging applications will push the required QoS to extreme levels that appear very challenging for currently envisioned 5G architectures. Among them, driverless cars and vehicles and the tactile Internet. For example, the set of requirements imposed by the tactile Internet (end-to-end ultra-low latency not exceeding 1 ms, outage probability 10^{-7} or less, network intelligence to support predictive actuation) to deliver actuation and senses such as hearing, touching, and seeing, is still considered a 5G challenge especially over long ranges beyond 100 km [9].

D2D challenges and vulnerabilities. There are aspects of D2D communication in 5G that have not yet been addressed in a totally satisfactory manner. One is coexistence of cellular users (CUs) and D2D pairs, particularly, mitigation of D2D links interference on CUs, when downlink resources are shared with D2D devices, and also on the BS when uplink resources are shared. D2D interference management is still a subject of research efforts, since existing interference mitigation techniques (interference cancellation based on coding and signal processing, interference avoidance based on orthogonal resource allocation, and interference coordination based on scheduling and power control) are expected to be insufficient in ultra-dense node deployment scenarios. Other issues concern D2D security and privacy. Direct or relay-assisted communication may be established on device controlled links with no control of the core network, a trusted party providing identification, authentication, and encryption. This makes D2D links potentially more vulnerable to privacy violation, besides suffering from all of the attacks affecting other networks.

Mobile edge computing issues. It is foreseen that moving computing, storage, and networking resources to the edge of the radio access network (RAN) will be a key ingredient to alleviate backhaul and core network and to allow executing delay-sensitive and context-aware applications in the proximity of end users. This paradigm, referred to as mobile edge computing (MEC), poses however concerns [10]. Among them, the limited computing and storage resources per each MEC platform, the necessity for MEC platforms of different provider to collaborate, challenges in user mobility support in small cells, problematic applicability of centralized authentication protocols.

An open and smart RAN? We are currently witnessing efforts towards open, interoperable interfaces, RAN virtualization, and RAN intelligence.There is a trend to incentivize the use of commercial off-the-shelf (COTS) hardware, to explore open source and open whitebox network by introducing virtualized network elements with standardized open interfaces, to push embedded machine learning systems and artificial intelligence back end modules for an enhanced network intelligence. These are the main objectives of the ORAN Alliance. This trend is taking the first steps and it is clear to what extent the envisioned features will be implemented in 5G networks.

Network orchestration and slicing. The NFV-SDN technologies, as briefly mentioned above, promise to support the implementation of a large variety of services by means of softwarized functionalities hosted into cloud computing platform over data centers implemented with standard hardware (COTS). In terms of Capex and Opex this is a real revolution for network operators, that can move into the direction of more effective procurement and simplified operations. Moreover the same resources (both and hardware and software) may be shared among different subsets of customers, while keeping full isolation of the data paths and of the quality of service thanks to the native capabilities of cloud computing platforms. This is the "slicing" concepts, different subsets of customers may subscribe a service contract with different operators (either real or virtual) and share in the end the same infrastructure, which paves the way to novel business models and opportunities for the network providers. An effective management of NFV requires an orchestration platform that will automate the deployment of the required functionalities and manage operations. Some opensource implementations of such an orchestration platform are currently under implementation, for instance Open source MANO (OSM)[1], and the open network automation platform (ONAP)[2], and running proof of concepts are also available such as the central office re-engineered as a data-center (CORD)[3]. These technologies are not at the production level and some issues like multi-domain orchestration support are still open. Similarly, the slicing paradigm has still to be fully understood and experimented to validate some critical aspects such as full quality of service isolation and security guarantees.

[1] https://osm.etsi.org

[2] https://www.onap.org

[3] https://opencord.org

4 A Vision of 6G

Some possible facts which will arise are summarized below.

More and more data. As of today (2018), about one million Terabytes (i.e., 1 Exabyte = 10^{18} bytes) of data per day are exchanged over the mobile networks all over the world (see Fig. 2). The amount of data exchanged by mobile users will continue to increase, on one side due to the increasing number of non-human devices connected (including vehicles, UAVs, and autonomous systems), and to the enhanced quality 3D video / holographic type communication that will be used by humans.

Network Intelligence. To deal with increased traffic, the mobile network will become more intelligent, with learning mechanisms to autonomously modify itself based on users' experience, and situation-aware decision making and networking.

Fast spectrum reallocation. Network intelligence will be used to allow fast and flexible spectrum allocation/reallocation, with consequent large bitrates available to the users.

Enhanced senses. Other human senses will be communicated to improve the quality of the tele-interaction, including 3D / holographic type communication, taste, smell, touch.

Wireless-devices-as-a-service. Users will not necessarily need to bring a smartphone but will benefit of wireless-devices-as-a-service, with distributed devices available to anyone. All information being in the cloud, users will just need to be authenticated and then access the network by using any available device.

Battery duration & energy. The need to put devices on recharge will be dramatically reduced, so that the battery life will be substantially extended.

Quantum computers & quantum networks. We will see the appearance of quantum computers, capable to solve problems that are not solvable with non-quantum computers. Also, quantum communication and networks will be available, e.g., for cryptographic key exchange, also from satellites.

Privacy, security, data manipulation. The need for privacy and security for a proper management of personal data will be of paramount importance. The appearance of quantum computers will force to re-think the cryptography and security mechanisms.

Security and safety. The IoT and the Industry 4.0 will bring the network very close to the real infrastructures. Therefore a security breach on the networking side may quickly become a very important safety issue in the real life. This already happened with the failed attack to a petrochemical plant in Saudi Arabia in August 2017, that is widely believed was aimed to make the plant explode by attacking the IT control infrastructure.

Virtual Operators explosion. The NFV-SDN technologies and the related slicing capabilites will boost the emergence of virtual operators that will compete by providing added values services to the users by deploying innovative network functionalities in the cloud. This may lead to a significant innovation also in the business models and commercial strategies in the field.

5 Technologies

Among the technologies in the evolution path, we cite the following.

Machine Learning & AI. The complexity of the network and the number of connected devices will lead to a network which will learn from the experience to modify itself and accomodate new services. A suitable policy should be investigated to avoid the "Skynet" of the movie "The Terminator".

Dynamic spectrum allocation. The precious radio spectrum in the lower bands will be used more effectively by allocating the frequencies every second or so, based on the context.

Wireless energy transfer. This could be in some situations a viable way to extend the battery life, avoiding frequent recharges.

Free-space optical communication. Optical free-space communication will allow high data rate, for both outdoor and indoor scenarios, so releasing the lower band radio spectrum for long range uses.

Sub-Terahertz and Terahertz communications. The availability of large bands beyond 100 GHz (D-band, 110 GHz to 170 GHz,...) will lead to transmission systems at high data rate over short distances, so releasing the lower band radio spectrum for long range uses (see Fig. 3).

Massive use of multiple antenna systems. The increase in the frequency will require multiple antenna systems able to exploit the multi-rays propagation, for larger throughput but also for precise localization and for energy transfer.

High accuracy indoor localization. Context awareness needs a precise user's localization. For this item see the chapter about localization in this book.

Access schemes for massive wireless networks. New access schemes will be needed to handle a massive number of non-orthogonal users (more than 10 devices/m^2) in an efficient and scalable way.

Cybersecurity. The possibility to use non-personal devices for personal communication will impose new challenges on biometric authentication and privacy. New schemes for wireless security, capable to deal with attacks of quantum computers, will be needed.

References

1. IEEE Future Networks Initiative. URL: https://futurenetworks.ieee.org/.
2. Ericsson Mobility Report, Q2, 2018. URL: https://www.ericsson.com/en/mobility-report.
3. IEEE 5G World Forum, July 2018. URL: http://ieee-wf-5g.org/past-events/2018-2/.
4. ITU Focus Group on Technologies for Network 2030. URL: https://www.itu.int/en/ITU-T/focusgroups/net2030.
5. K. David and H. Berndt. 6G Vision and Requirements: Is There Any Need for Beyond 5G? *IEEE Vehicular Technology Magazine*, 13(3):72–80, 2018.
6. S. Kim, W. T. Khan, A. Zajić, and J. Papapolymerou. D-Band Channel Measurements and Characterization for Indoor Applications. *IEEE Transactions on Antennas and Propagation*, 63(7):3198–3207, July 2015.

7. E. J. Oughton and Z. Frias. The cost, coverage and rollout implications of 5G infrastructure in Britain. *Telecommunications Policy*, 42(8):636–652, 2018.
8. P. H Pathak, X. Feng, P. Hu, and P. Mohapatra. Visible light communication, networking, and sensing: A survey, potential and challenges. *IEEE communications surveys & tutorials*, 17(4):2047–2077, 2015.
9. M. Simsek, A. Aijaz, M. Dohler, J. Sachs, and G. Fettweis. 5G-enabled tactile Internet. *IEEE J. Sel. Areas Commun.*, 34(3):460–473, March 2016.
10. T. X. Tran, A. Hajisami, P. Pandey, and D. Pompili. Collaborative mobile edge computing in 5G networks: New paradigms, scenarios, and challenges. *IEEE Commun. Mag.*, 55(4):54–61, April 2017.
11. Y. Xing and T. S Rappaport. Propagation Measurement System and Approach at 140 GHz-Moving to 6G and Above 100 GHz. *arXiv preprint arXiv:1808.07594, to appear in IEEE Globecom 2018*, 2018.

GENERATION	REGULATION	SERVICES	INNOVATIONS	NOTES
1 G	monopoly	voice	lightweight mobile terminals	humans, $\ll 10\%$ popul.
2 G / GSM	competing operators chosen by regulators	voice, SMS, data 9.6 – 200 kbps (GPRS-EDGE), push email (Blackberry)	FDMA/TDMA, smaller mobile terminals, first cameras, GPS, content (iPhone), access to WWW (WAP, not great succ.)	humans, $> 90\%$ popul., M2M
3 G / UMTS	granting licenses, open-market auction	high data rates 364 kbps - 10 Mbps, email, file/image	CDMA, camera, GPS	superhype, limited success due to competition with cheaper WiFi, mobile devices too heavy, low battery duration compared to GSM
4 G / LTE	less up-front money from operators, elimination of roaming charges in Europe	downlink ~ 300 Mbps, uplink up to ~ 50 Mbps, mobile video, multimedia messaging (WhatsApp, Instagram, Telegram, Twitter,...)	OFDM, MIMO, D2D	competitive with WiFi, elimination of roaming charges in Europe
5 G	spectrum licenses up to 25 years, spectrum sharing, reuse, new frequency bands mmWave	bit rates ~ 20 Gbps, lower latencies ~ 1 ms, D2D, massive M2M for IoT	frequencies up to 60 GHz for extremely high-speed transmission, massive MIMO, LDPC, Polar Codes, network function virtualization, software-defined networking, network slicing	superhype

Table 1 Evolution from 1G to 5G

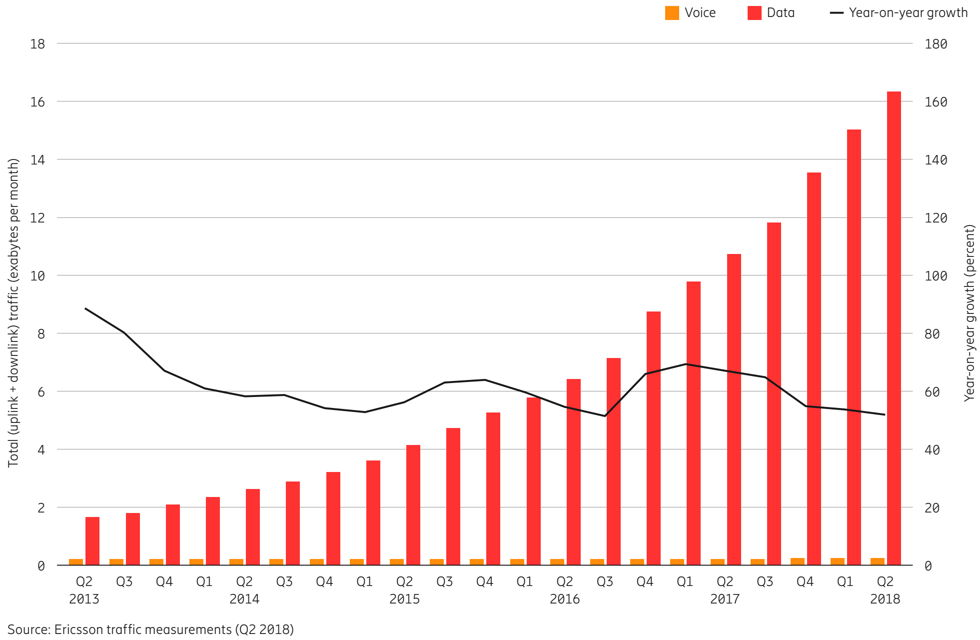

Fig. 2 Mobile data traffic (does not include DVB-H, Wi-Fi) [2].

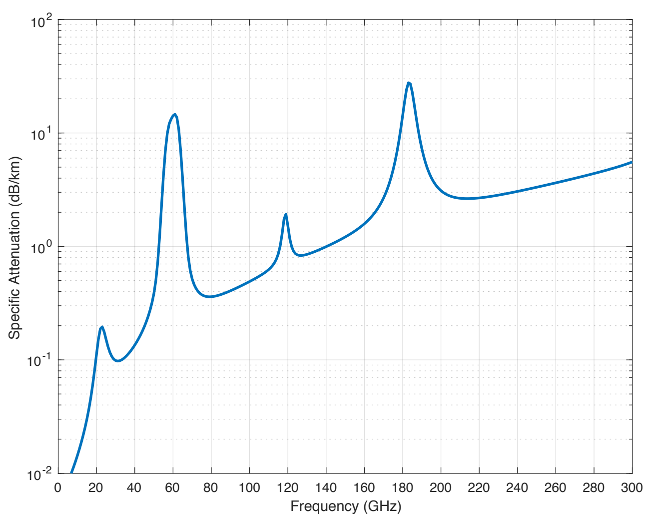

Fig. 3 Specific attenuation of atmospheric gases at sea-level.