5G Mobile Technologies and Early 6G Viewpoints

Ivan Petrov, Toni Janevski

Abstract — **Design of each successor mobile technology assures improved and advanced functionality features compared to its predecessor. Machine Learning and generally Artificial Intelligence (AI) is becoming necessity for further expansion of the beyond 5G mobile world. AI-assisted IoT services, data collection, analytics and storage should become native in the beyond 5G era. 5G introduces New Radio (NR) in sub-6 GHz bands and also in mmWave bands above 24 GHz, network virtualization and softwarization, which means that Next Generation Core and 5G NR access network are built by using different functions in split user and control planes that introduces the network slicing approach. Enhanced Mobile Broadband (eMBB), massive Machine Type Communication (mMTC) and Ultra-Reliable Low-Latency Communication (URLLC), that are provided via separate network slices as logically separated network partitions are the key 5G services that constantly will increase the traffic volume and the number of connected devices. Terahertz and visible light communication and fundamental technologies like compressed sensing theory, new channel coding, large-scale antenna, flexible spectrum usage, AI-based wireless communication, special technical features as Space-Air-Ground-Sea integrated communication and wireless tactile network are few of the novelties that are expected to become a common network standard available beyond 2030.**

Index Terms — **5G, 6G, mobile networks, mobile technologies.**

I. INTRODUCTION

This paper covers the technological aspects of 5G mobile networks and gives early 6G viewpoints, toward the next generation networks. Mobile technologies evolution is based on so-called generations which include, [1]-[3]:1G to 5G and beyond 5G. The First Generation represented an analog system introduced in early 1980s that used analog radio signal at frequency of 800 MHz and 900 MHz and bandwidth of 10 MHz based at analogue switching with Frequency Modulation (FM) and Frequency Division Multiple Access (FDMA) as access technique. Main disadvantages of this system were poor voice quality due to interference, poor terminal battery life, large sized mobile phones (not convenient to carry), less security (calls could be decoded using an FM demodulator), limited number of users and cell coverage, not possible roaming between similar systems and etc. All of these disadvantages were inspiration advanced mobile system to be designed.

Digital system named as Global System for Mobile communication (GSM) was introduced in early 1990s. GSM used digital signals for voice transmission with speed in range of 14.4 up to 64Kbps and bandwidth of 30 up to 200 KHz. SMS and MMS as a service were announced along with call and text encryption. Key features of 2G were digitalization, SMS services, roaming, enhanced security, encrypted voice transmission and internet provision at low data rate. Disadvantages of 2G were low data rate, limited mobility, less features of mobile devices, limited number of users and hardware capability. 2.5G and 2.75G systems were predecessors of 3G, they supported higher data rate.

General Packet Radio Service (GPRS) as a service was deployed successfully. GPRS was assuring user data rate up to 171kbps. EDGE – Enhanced Data GSM Evolution was developed to improve data rates of GSM networks. The system was capable to support up to 473.6kbps. Another popular technology CDMA2000 was introduced to support higher data rate for CDMA networks. This technology has ability to provide data rate up to 384 kbps (maximum).

Third network generation arrived in late 1990s. Operated at range of 0.8-2.1 GHz and had a bandwidth of 5 MHz used for High Speed internet and data demanding services. It uses CDMA, Turbo channel coding. Maximal speed of 3G is defined to be around 2Mbps for static devices and 384Kbps if we have moving vehicles. Some of the key features of 3G system were that it provides higher data rates, enables video calling, enhances security, supports increased number of users and coverage, mobile app support, multimedia message support, provides location tracking and maps, better web browsing, TV streaming, high quality 3D games. In order to enhance data rate in existing 3G networks, other two technology improvements were presented. HSDPA – High Speed Downlink Packet access and HSUPA – High Speed Uplink Packet Access were developed and deployed to the 3G networks. 3.5G network can support up to 2Mbps data rate. 3.75 system is an improved version of 3G network with HSPA+ High Speed Packet Access plus. Later this system evolves in powerful 3.9G known as LTE (Long Term Evolution). Disadvantages of 3G were expensive spectrum licenses, costly infrastructure, equipment and implementation, compatibility with older generation of 2G system and frequency bands.

LTE (Long Term Evolution) and LTE advanced is considered as 4G technology. 4G systems are enhanced version of 3G networks that offer enhanced data rate and are capable to handle advanced multimedia services. It operates in spectrum of 0.4 up to 6 GHz with Turbo channel coding in bandwidth of 1.4 up to 20 MHz. OFDM modulation was used as downlink waveform and SCFDMA as uplink waveform. It has compatibility with previous network versions that makes it easier to deploy and upgrade. 4G assure higher data rates up to 1Gbps, enhanced security and mobility, reduced latency for mission critical applications, support of high definition video streaming and gaming, voice over LTE network, VoLTE (use IP packets for voice)

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and at the end like every technology it has some disadvantages as expensive hardware and infrastructure, costly spectrum (in most countries, frequency bands are too expensive) and etc.

Fifth Generation is the last standardized generation of mobile systems (the first 5G standard, 3GPP Release 15, is frozen in June 2019), which increases the data rates of 4G by more than 10 times with new radio interface called NR (New Radio) and allocation of new spectrum, providing possibilities for many new emerging services in different verticals. Compared to 3G and 4G, 5G uses OFDA/SCFDMA in up and downlink waveform, LDPC/Polar is used as channel coding technique and provides full support of beamforming in spectrum of 0.4 up to 90 GHz and bandwidth of 100 MHz. Network slicing (Multiple slices) is one of the key features together with flow based QoS in built cloud support and connectionless small packet support. 5G supports multiple RAN core interfaces compared to 4G when one per device was common. 5G network is defined to use modern modulation techniques and network technologies like carrier aggregation, common in LTE advanced to improve system efficiency. Intra-band noncontiguous allows two carriers to be transmitted with channel spacing while inter-band allows different LTE bands to be used for transmission simultaneously. Incensement of network efficiency with help of micro and Pico cells is assured. (cell is sub divided). Spectrum reusability allows more connected users in small area and allows network handling more efficiently.

Usage of MIMO concept is common as a transmission technology with help of multiple antennas for transmission and reception. This technology enables simultaneous data transfer with efficient data rate. WiFi offloading allows user to be connected using WiFi network and cellular network to be allocated to other users. This technique is especially suitable for regions with poor cellular network quality and possibility to connect without cellular reception. Usage of device-to-device communication is common. It is technique where network authorize two adjacent devices communicate each other directly.

Sixth Generation is expected to be standardized till 2030 and to assure and integrate advanced AI based services as terahertz communications, optical wireless technology (OWC), blockchain, dynamic network slicing, integration of sensing and communication, unmanned aerial vehicle users, holographic telepresence, integration of access-backhaul networks, 3D networking, holographic beamforming, big data analytics, augmented and virtual reality, cell-free communications, quantum communications. AI-enabled intelligent architecture of 6G networks is expected to be implemented to realize knowledge discovery, smart resource management, automatic network adjustment and intelligent service provisioning. Self-evaluation at any level as availability effectiveness, security, efficiency, scalability, portability, flexibility is expected to be driven by AI that will introduce the first self-sustain network provisioning. 6G decade is expected to be 2030. With each new mobile generation, the speed (i.e., bitrate) is increased, the latency (i.e., delay) is decreased and such trend is not going to change toward the 6G.

II. 5G (FIFTH GENERATION) IN SHORT

5G requirements are specified in IMT-2020 (a.k.a. 5G) by the ITU, [4-6]. According to them, latency in the air link (5G New Radio) should be lower than 1ms (for certain critical services), end-to-end (device to core) latency to be lower than 10ms, connection density to be 100x compared with LTE, area capacity density to be 1Tbit/s/km2, system spectral efficiency to be 10bit/s/Hz/cell, peak throughput (downlink) per connection to be 10Gbit/s and energy efficiency to be >90% improvement over LTE.

5G uses OFDMA/SCFDMA in uplink and downlink with different numerologies (the NR is in fact extension of the LTE radio interface), and provides full support of beamforming in spectrum of 0.4 up to 90 GHz and carrier bandwidth of up to 100 MHz in sub-6 GHz bands (and 400 MHz for bands above 24 GHz, the mmWave bands). 5G extends further the efficiency of radio access by using higher order MIMO (e.g., 64 x 64, 128 x 128) and higher order modulation and coding schemes. The 5G base stations are called gNodeBs, and have the same architectural aspect as eNodeBs in 4G (being connected between themselves and with the core), with further split of Control Plane (CP) and User Plane (UP) functions.

High-level view of 5G network architecture is presented in Fig. 2 and expected service functionalities in Fig. 1. One may notice unification of all known access technologies with enhanced fronthaul and backhaul networks. Unlike 4G networks which use gateway nodes (e.g., Serving Gateway – S-GW, Packet Data Network Gateway – P-GW), 5G defines many functions that can be combined together for provision of different functionalities in user, control and management planes (Fig. 2). That is referred to as network softwarization and virtualization, based on SDN (Software Defined Networking) and NFV (Network Function Virtualization). This leads to network slicing approach, which is in fact provision of logically isolated network parts, targeted to different group of services. However, network slicing is just another term for LINPs (Logically Isolated Network Partitions) which were defined in NGN (Next Generation Networks) umbrella standards by the ITU, [3]. Network slice can provide functionality of complete network including radio access network and core functions. One 5G mobile network can support one or several network slices. 5G systems should enable users to obtain services from more than one network slice simultaneously.
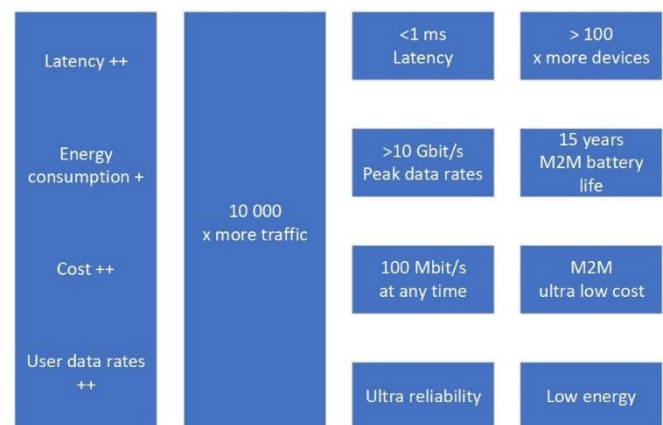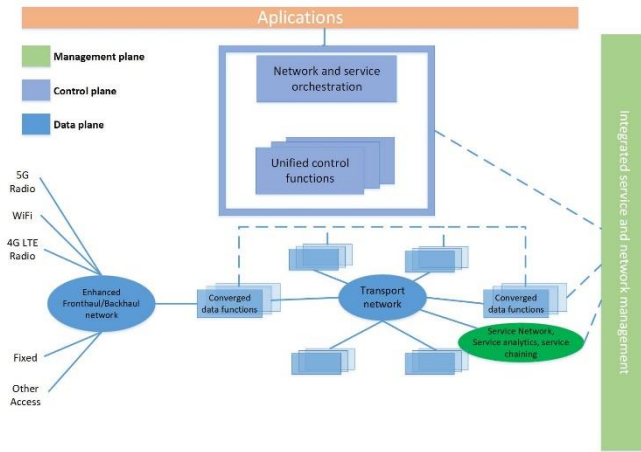

Fig. 1. Capabilities of 5G.

Fig. 2. Network architecture of IMT 2020/5G.

3GPP defines two types of 5G network architectures: Standalone (SA) and Non-Stand-Alone (NSA), which should be accepted as main 5G standards by the ITU in February 2020.

Non-Stand-Alone (NSA) network architecture (Fig. 3) is a concept that allows operators to deploy 5G cells that will depend entirely on existing LTE network for all control functions and add-on services. This concept works in master-slave structure where 4G access node (eNodeB) is the master and 5G access node (gNodeB) is the slave. On the other side, 5G Stand-Alone (SA) architecture (Fig. 4) means that independent 5G network is implemented including both New Radio (NR) in the access part and 5G Core (5GC). This architecture model provides end to end 5G user experience directly used by 5G device. However, the 5G SA architecture also interoperates with existing 4G LTE mobile networks to provide service continuity especially at areas that are not covered with 5G (which is the usual case for each new mobile generation when it starts with the commercial deployments) providing connectivity for both 5G users and non-5G users (e.g., 4G).
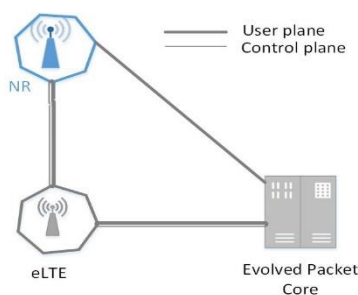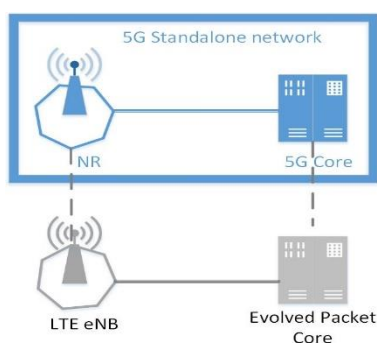

Fig. 3. 5G NSA architecture.

Fig. 4. 5G SA architecture.

Both 5G architectures NSA and SA have their advantages depending upon the observing perspective. From technological points of view the NSA provides clear win on the 5G "scene" for the 3GPP regarding the 5G standards, because NSA establishes in fact smooth evolution from LTE/LTE-A/LTE-A Pro (4G standards from 3GPP), which have become dominant 4G mobile technologies in 2010s (the second 4G standard, Mobile WiMAX 2.0, is decaying and disappearing). Although there are also 5G proposals from other countries, it is undoubted that 5G standard from 3GPP (in both NSA and SA modes) will be in fact the unified new mobile generation (something similar that happened in the past with Ethernet or WiFi standards from IEEE, which are also unified standards in the LAN segments).

The core network in SA is 5G Next Generation Core (it is used interchangeably with 5G Core in this paper) while in NSA it is initially 4G EPC (Evolved Packet Core) or 5G Core. One may say that SA provides high performance 5G environment while NSA leverages the existing 4G deployments. However, today (in year 2020) telecom operators (i.e.,telcos) introduce the 5G network functionalities with the NSA. Both deployment strategies have as the final goal the deployment of standalone 5G network. One of the main moves towards that end goal is optimizing 5G investment and achieving near-soon market leadership position in new verticals (e.g., industry 4.0, various smart services, automotive industry for vehicle to anything communication i.e., V2X, and so on). The time scale of 5G deployments is directly influenced by the availability of sub-6GHz spectrum bands for enhanced Mobile Broadband (eMBB) services (which are the expected front "runner" for the 5G), availability of affordable 5G handsets which support the 5G bands as defined by the ITU's WRC (World Radiocommunication Conference) 2019, as well as user adoption of 5G technology (which is mainly driven by the telcos and end-user equipment availability and process), and operator's ability to deploy nationwide 5G coverage.

End to end 5G requires new architecture, with NR in the access part and 5G Core. However, the evolution from 4G to 5G starts from the LTE networks with add-ons of 5G compatible functionalities such as dynamic experience management, self-organizing network and analytic driven orchestration.

III. EVOLUTION OF 5G

Today we have LTE core and radio access networks. Step 1 is to add 5G radio in dual connectivity mode with LTE as an anchor. This architecture provides LTE core plus 5G compatible functionality.

5G control plate is established via LTE while 5G user plane is provided via LTE or directly via 5G NR. Next step is to assure 5G core network and standalone 5G radio accesses without need for an LTE anchor. This approach provides distributed radio and core architecture required to deliver low latency. The aim is to evolve from today's silos to cognitive network built for automation. Today's legacy networks are consisted of many silos and complex automation that's why we need consolidation that offers

integrated analytics, management, orchestration and dynamic experience management. Dynamic experience management refers to automated Quality of Experience (QoE) optimization of each application session with fully automated management orchestration based on use of Artificial Intelligence (in fact, that is Machine Learning). One has to point to the evolution of 5G network slicing which is available also in 4.9G networks. Network slice represents composition of adequately configured network functions, network applications and underlying cloud infrastructure, physical access and core network resources and virtual (or emulated) resources that are bundled together to meet the requirements of specific use case with predefined bandwidth, latency, processing and resiliency coupled with a business purpose. Network slicing must enable flexible creation, placements of network functions to assure separate manageability on per slice basis that enable flexible partitioning and sharing of radio resources in the 5G RAN (radio Access Network) as well as 5G Core network. 5G network slicing assures each slice to be tailored to a specific use case that enables mobile network as a service business model.

In order to deliver best QoE by steering traffic across multiple air interfaces and also using multiple air interface aggregation (e.g., 3GPP has introduced the WiFi carrier and LTE carrier aggregation even in pre-5G releases).

Multi access environment with aggregation on protocol layer 4 (with TCP – Transmission Control Protocol) is created. Just for comparison purposes, LTE-Advanced has introduced aggregation on layer 3 by having protocol layers 1 and 2 to be different on different frequency carriers which are being aggregated. One possibility for aggregation on layer 4 is with Multipath TCP (MPTCP) which is still in information and draft forms at the IETF, [13]. It allows all bands to aggregate and utilize effectively with flexible policy control. MPTCP allows seamless integration and operation of 5G NR access and other access networks connected to the 5G core. For control of multiple access networks there is required intelligent network-controlled traffic steering. Mobile user equipment connects to WiFi, 4G or 5G access nodes and multipath manager in cloud connects to the mobile client (the user equipment - UE) and instantiates the multi-link scheduler function in the network, splitting the user traffic over the WiFi, 4G and 5G paths and aggregating the traffic at the UE (in the downlink direction), and vice versa in the uplink (by using the 5G QoS flow based approach with reflection of the downlink setup also in the uplink). QoS model of the 3GPP 5G system architecture, enables differentiated data services to support diverse application requirements while using radio resources efficiently. Service Data Flows (SDF) denote user plane data with certain QoS. QoS model is designed to support different Access Networks, including fixed accesses where QoS without extra signaling may be desirable. Standardized packet marking informs QoS enforcement functions what QoS to provide without any QoS signaling.

IV. 5G EXPECTATIONS

It is expected 5G to build trusted and secure application and service ecosystems based on machine learning, converged edge cloud, multi technology access and to promote openness like open APIs (Application Programming Interfaces), open source SW for the HW, and developing 5G applications open source communities. In later stages of 5G deployments (e.g., after 2025), [14-15], 5G enhancements are tailored toward lower latencies, such as latencies up to 5ms that should assure process automation (in industry) with help of mission critical sensors. Also, AR (Augmented Reality), VR (Virtual Reality) and generally speaking XR (Any Reality), require high bandwidth, secure and very low latency communications (especially AR). On the other side, the expectations of mobile trends, [14], is that the video is the dominant type of traffic in all environments, fixed and mobile ones. Overall, around 70-75% of all IP traffic in public Internet including also managed IP networks (which are normally isolated from the public Internet, with guaranteed QoS), is video traffic. One may expect, with eMBB networks slices in 5G, video traffic even further to increase its traffic shares due to expectations of larger data caps in mobile networks with 5G (in 2020s) and higher resolutions of the video (e.g., 2k, 4k, 8k video).

One of the key expectations from 5G (due to its much larger bandwidth) is to promote fixed wireless access to home (FWA) via 5G in all areas with none or very low fiber penetration. On the other side 5G hotspots is expected to provide AR/VR streaming from different events to user devices. We can notice that different service request different SLA and network capabilities.

5G Core is designed to be cloud native based on many functions in user plane and control plane. It is expected to support ultra-reliable low latency communications and massive machine type communication. 5GC enables new level of service quality especially notable with network slicing capability, and it is something that can help the operators to enter new markets (i.e., new verticals).

Fig. 5 shows a high-level view of 5G architecture and one can notice universal adaptive core that provide unified authentication and access control, unified session and mobility mgmt, unified user plane. The generalized design of the functionalities and a forward compatible Access Network – Core Network interface enable the 5G common Core Network to operate with different Access Networks. In 3GPP Release 15 these are the 3GPP defined NG-RAN and the 3GPP defined untrusted WLAN access. Cloud strategy is assured with logically centralized state and user data layer for cloud ready operations established with help of shared data layer meaning that all data will be in one plane which is cloud optimized. The RESTful API, [8], in 5G core is intended to provide programmability of 5G networks in the similar manner as socket API provides that to applications in Operating System (OS) of a single machine. Such APIs will be possible to be used for docking the OTT services over the mobile operator's networks, thus providing possibility for QoS-enabled provision of some such services to the end-users via different network slices, which in such case will not be part of the global Internet for which the network neutrality rules are in force. That means also - the mobile business logic will not be locked by the 5G equipment
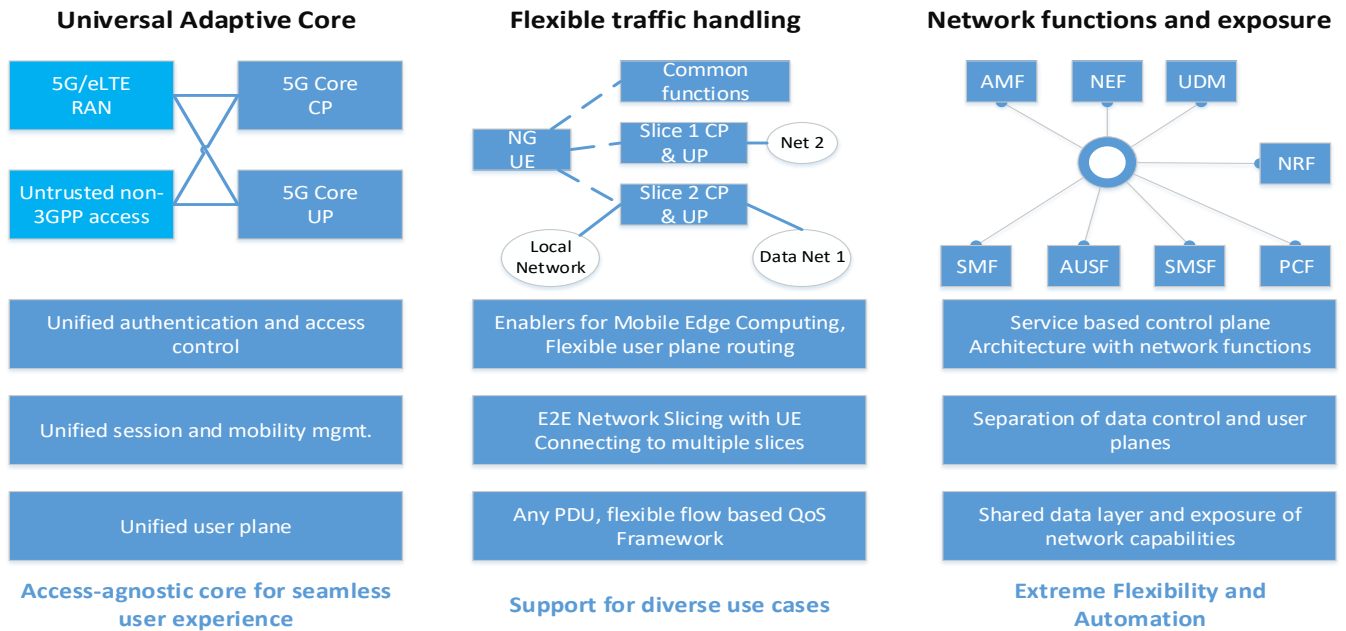
vendors.

Universal Adaptive Core

Flexible traffic handling

Network functions and exposure

Fig. 5. 5G architecture High level view

V. EARLY 6G VIEWPOINTS

Academia has already started to look beyond 5G and to conceptualize 6G. Machine learning based on Big Data and clouds is promising to enter later into the 5G world. Considering the AI momentum again in the telecom/ICT world, one may expect AI to be used for design and optimization of future 6G network, including the protocols and their operations. Vision of 6G is evolution from connected things to connected intelligence with possible requirements of aggregate data rates up to 1 Tbit/s or perhaps less (it is not early for exact estimations), high-energy efficiency that will support battery free IoT devices (e.g., use of energy harvesting), massive low latency control (as contrast to 5G where it is just emerging) and connected intelligence with machine learning capability. Some expectations go beyond the 5G use cases (eMBB, URLLC and mMTC) and some possible beyond 5G use scenarios include computation-oriented communication, [19], contextually agile eMBB communication targeted to provision of eMBB services more agile and adaptive to the network context.

Software Defined Network (SDN) and Network Function Virtualization (NFV) shall continue to be main approaches also in 6G, together with network APIs for network programmability regarding the creation of new services by third parties (i.e., parties different than mobile operators). In 5G network slicing provides powerful virtualization capability to allow multiple logically isolated/separated networks to be created on top of a shared physical infrastructure. In that manner 6G may continue towards massive network slicing, with numerous network slices (each slice defined for each micro or macro service). With such developments, the complexness of the network increases beyond the traditional computational approaches used in past mobile generations (and also used for 5G, at

least in the first deployments). So, the use of AI based on Big Data collected from different network functions in different contexts (e.g., provider, service, users, time, location, quality, security, etc.) will become necessity with aim network entities to support diverse capabilities for different services. Looking into the radio part, and considering that NR is in fact extension of the LTE radio approaches with additional numerologies for different frequency bands, one may expect such further extensions of the numerologies to result into, let name it here, 6G Radio (6GR) access (based on many new numerologies in different frequency bands, from MHz to hundreds of GHz and even THz, based on massive MIMO with hundreds of antennas, and new modulation and coding schemes). AI-assisted IoT services, data collection, analytics and storage should be native in 6G era. One may say that the late 5G (e.g., "real" URLLC services and many network slices on the ground, together with massive use of mmWave bands) will in fact be the early 6G. If we want to stay connected at any place and time maybe this is the network that will incorporate low orbit satellites as access technology so we could stay connected at any globe location. Integration of VLC (IEEE 802.15.7) as complement of RF access by piggybacking on the wide adoption of Light Emitting Diode (LED) luminaries for indoor communication is estimated to be used by 6G. Collaborative AI which differs from AI network management will be in use of advanced services. Mobile data traffic is expected to reach 5 zettabytes (ZB) per month. This traffic will be enabled by advanced techniques and services like: artificial intelligence, terahertz communications, optical wireless technology (OWC), blockchain, dynamic network slicing, integration of sensing and communication, unmanned aerial vehicle users, holographic telepresence, integration of access-backhaul networks, 3D networking, holographic beamforming, big data analytics, augmented and virtual reality, cell-free communications, quantum communications. Integration of

wireless information and energy transfer (WIET) in communication will be one of the most innovative technologies used in 6G. In particular, sensors and smartphones will be charged by using wireless power transfer during communication. It is optimistic to say that underwater communication can be for sure part of the future 6G but is grate challenge that if engaged will assure space air ground and sea connectivity and integration of advanced technologies that will provide ubiquitous connectivity. It is interesting to notice that today's traditional Internet uses interaction of information content but IEEEP 1918.1 Standard Working Group defines Tactile Internet as network for remote access, operation and control in real time. This actually changes the nature of the traditional Internet mainly because Tactile Internet is not only used for transmission of information content but also for remote control and response. Integrated Space and Terrestrial Network (ISTN) is expected to describe 6G in certain way.

These network modifications will require improved TCP protocols optimized with help of AI (each TCP phase must be optimized starting from flow control and congestion control protocols in case of high bit error and point to multipoint communication established in parallel with help of variety access technologies, case that will introduce virtually increased network data transfer speed).

VI. CONCLUSION

Mobile technology rapidly evolves with a new mobile generation in each decade, going from 1G in 1980s to 5G in 2020s. Different mobile generations are available on the telecom market, starting with 2G (e.g., GSM), via 3G (e.g., UMTS) and 4G (e.g., LTE/LTE-Advanced/LTE-Advanced Pro) to 5G deployments. The main and probably the only one that will be massively deployed in 2020s is coming from 3GPP, starting with 3GPP release 15. 5G introduces New Radio (NR) by adding new numerologies to existing LTE radio interfaces in sub-6 GHz bands and also in mmWave bands above 24 GHz. The main novelty is network function virtualization and network softwarization, which means that 5G Next Generation Core and 5G NR access network are built by using different functions in separated user and control plane. That provides the network slicing approach, with three main service types seen for the 5G era, eMBB, mMTC and URLLC, which may be provided via separate network slices as logically separated network partitions. Higher speeds and higher capacity in mobile networks with 5G and beyond results with constantly increasing mobile traffic and number of connected devices. This triggers the need for use of Machine Learning and other Artificial Intelligence (AI) in 5G and future mobile networks, such as 6G in 2030s. Self-evaluation at any level as availability effectiveness, security, efficiency, scalability, portability, flexibility will be driven by AI that will evolve and introduce the first self-sustain 6G network.

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