A Limit of Digitalization in 5G Technology Period

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Abstract— For data transmission in 5G there is a lower limit of 4G LTE parameters and an upper limit of 6G parameters. We observe a tendency to measure parameters from spatial to volumetric, spectral and energy efficiency in the process of developing mobile systems. We build in infrastructure 3 types of small, medium and large cells to achieve the parameters characteristic of 5G technology. We do not use them for wireless data transmission between stationary objects in order not to degrade network parameters by increasing network traffic. Networks in the 5G technology at the initial stage interact with LTE, at the last - with 6G. The author in the work shows an evolutionary shift in the frontier of digitalization with the development of technologies from 4G to 5G and therefore 6G. We are seeing an increase in artificial intelligence and cyber security in the telecommunications infrastructure, which is being introduced for mobile digital data transmission as we move from the old to the new generation.

***Аннотация*—Для передачи данных в 5G есть нижний предел параметров 4G LTE и верхний предел параметров 6G. Мы наблюдаем тенденцию измерения параметров от пространственной до объемной, спектральной и энергетической эффективности в процессе разработки мобильных систем. Мы строим в инфраструктуре 3 типа малых, средних и крупных ячеек для достижения параметров, характерных для технологии 5G. Мы не используем их для беспроводной передачи данных между стационарными объектами, чтобы не ухудшать параметров сети за счет увеличения сетевого трафика. Сети в технологии 5G на начальном этапе взаимодействуют с LTE, на последнем - с 6G. Автор в работе показывает эволюционный сдвиг границы дигитализации по мере развития технологий от 4G до 5G и следовательно 6G. Мы наблюдаем рост искусственного интеллекта и кибербезопасности в телекоммуникационной инфраструктуре, которая внедряется для мобильной передачи цифровых данных при переходе от старого к новому поколению.**

***Keywords*—LTE, 5G, 6G, telecommunications infrastructure, limit of digitalization**

***Ключевые слова*—LTE, 5G, 6G, телекоммуникационная инфраструктура, предел дигитализации**

I. Introduction

The development of telecommunications infrastructure construction technology is faster than the development of other areas of human activity, as generations that have not used this infrastructure are dying out. In their place they come a generation that cannot imagine life without access to the Internet anywhere, anytime. Additionally, you should secure the possibility to exchange data between smart objects, vehicles and implement the telemetry and telecontrol. Changing the parameters of the existing infrastructure proved insufficient to meet the demand for quantity and quality of the transmitted data. Data transfer via fixed networks is more efficient because in FTTH, fiber to the home, the carrier frequency is 10e15 Hz, and in mobile transmission it is approaching only to the frequency of 10e12 Hz [6]. As we know, the width of the transmitted bandwidth may be greater if we increase the frequency of the carrier wave. Both stationary and mobile transmission of digital data is subject to globalization. To enable mobile networks to integrate with landline networks, we change technology from LTE to 5G and then 6G in an evolutionary way. For the process to proceed in a predictable way, the old FCC, UKE, ETSI, ITU and new 3GPP organizations issue standardization documents that streamline the globalization process of digital data transmission [8].

II. Research method

The current 4G and LTE cellular networks have gone through a long evolutionary path to meet the growing expectations of telecommunications market participants. To a limited extent, we can forecast the limits of digitization of new generations based on knowledge and experience gained in the past. Changes in mobile telecommunications technology were taking place more or less every decade. We make the assumptions made in this way based on the experience gained from the implementation of pilot installations in selected cities, university campuses, airports, stadiums, highways, and ships. The implementation technique is as follows. If the network in a small area meets the planned parameters, it is built in a larger area. Theoretical considerations are conducted in accordance with the rules developed by the development of mathematics, physics and medicine. The most unpredictable and difficult to model is the economic side of mobile network development. We cannot predict the purchase price of carrier waves by telecoms, because governments announce the proposition to determine it. We cannot predict how many people will use the net for profit, and how much for pleasure. We most likely forecast that ensuring secure data transfer will generate higher costs in each newer generation.

III. 1G

The first radio networks operating on the basis of the division of cells, which are areas controlled by different base stations, built in the early 80s of the last century. 1G cellular system was not compatible with each other. The 1G system initially used the 450 MHz band, but after reaching its maximum capacity its modernized version using the 900 MHz band was launched. 450 MHz band provided the good coverage of the radio signal of a large area within a single cell. In this way, the cellular network providing services along the coast, highway, or in the vast rural areas require fewer cells than in the higher radio frequency bands. On the other hand, the cell capacity counted by the number of simultaneously serviced subscribers remained unchanged, which in areas with high population density resulted in the lack of access to services along with the growing number of subscribers. For this reason, operators have also begun to implement a version that uses the 900 MHz band, forming cells with smaller sizes. 1G network used the principle of FDMA, frequency division multiple access. This means that at the time of the call terminal receives a channel for the exclusive use of a segment in the radio frequency band, generally 25 or 30 kHz. This method of use of the radio channel was ineffective because it was occupied for the duration of the entire call, regardless of whether the user is talking or silent. With the increasing number of telephone calls initiated by subsequent users, the capacity of the base station was exhausted, because the number of radio channels per base station remained unchanged.

IV. 2G

At the core of the development of second-generation mobile network 2G or GSM, the Global System of Mobile Communications laid your goal, the network allowed to use the services of a much larger number of users than ever before. In addition, the new standard was based on the digital transmission of the talks also guarantees much better protection against eavesdropping and better call quality. An important improvement was also to be the compatibility of 2G networks built by various operators, and consequently the possibility of roaming users, that is, telecommunications services provided outside the home operator's network. The standard describing the functioning of the GSM system was finally developed by the European Telecommunications Standards Institute ETSI, the European Telecommunications Standards Institute in 1991. Although initially the GSM system was only intended for Europe to work in the 900 MHz band, then the 1800 MHz band was also included. For the USA, a system version was developed that works also in the 1900 MHz band. Unlike the 1G network, in the 2G system, the information sent is previously digitized. This allowed the use of mechanisms that reduced the amount of information and how they were transmitted by the user in the radio channel. The first mechanism is the compression of the voice, thanks to which digital recording corresponding to the conversation transmitted in the radio channel requires less data to be transmitted than in the case of an uncompressed signal. This procedure, although it leads to a decrease in the quality of the telephone connection noticed by users, significantly reduces the load on the radio channel. The second mechanism consists in dividing the digital signal broadcast by users into fragments and then their cyclical transmission in the radio channel. This takes place in time slots, which are periodically repeating transmission windows in which a given user sends or receives data. The use of this access method, known as TDMA, Time Division Multiple Access, has allowed to significantly increase the number of users using radio access in a given frequency band. Further work on the development of the 2G standard resulted in the 1997 specification of the GSM system under the name Phase 2+, which included HSCSD data transfer technologies, High Speed Circuit Switched Data, GPRS, General Packet Radio Service, EDGE, and Enhanced Data rates for GSM Evolution. The former technology used the same radio channels that were used in the GSM system for voice transmission. This meant that these channels are occupied for the entire duration of the connection, even when the data is not transmitted. Newer technologies: GPRS and EDGE, often referred to as the 2.5 G network, introduced into the 2G network packet switched transmission, one in which users send and receive packet data, sharing physical channels among themselves. The consequence of using this type of transmission is also another tariffing rule, based on the volume of transmitted data, and not for the duration of the connection, when the data was transmitted, as was the case with HSCSD technology [6].

V. 3G

Introduced by operators in the first years of this century, the third generation of cellular systems used the 2.5G network concept in the field of packet data transmission, but unlike the GSM system, the 3G system would immediately provide various services: audio and video transmission and packet data transmission. As a consequence, it meant the need to expand the backbone network connecting base stations. However, the biggest changes compared to the 2G network were introduced in the radio part. ITU, International Telecommunication Union, as an organization established in order to standardize and regulate the telecommunications and radio-communications market in the world, has allocated to use in 3G networks the frequency bands: 790-960 MHz, 1710-2025 MHz, 2110-2200 MHz, 2300-2400 MHz and 2500-2600 MHz, some of which were used by GSM systems. In 3G networks, a radio access method other than GSM has been used, which enables the service of even more users and offers a higher data transmission speed. Although it was not possible to create a globally uniform 3G system, a system family called IMT-2000 was defined that could work together and offer similar capabilities. It also included the UMTS standard, Universal Mobile Telecommunications System proposed by ETSI and implemented in the majority operators in the world. Patrons of this and subsequent development the standards of mobile networks were covered by the 3GPP, 3G Partnership Project, which brings together the largest standardization organizations in the world of telecommunications.

VI. 4G

The progressive development of Internet services has placed increasing demands on the efficiency of data transmission. As a result, the further development of cellular technologies has focused on developing a standard that improves the speed and reliability of data transmission, based on the existing 3G network infrastructure. As a result, at the end of 2008, the 3GPP consortium developed the first version of the 4G LTE standards, Long Term Evolution, operating initially in the 1800 MHz band with channel band widths from 1.4 MHz to 20 MHz, which included improved coding, optimized data rates and better performance. In addition to the increased transfer capabilities, the 4G LTE standard is characterized by the rare occurrence of stoppages and transfer errors and a significantly shorter response time to 3G. The transmission in the 4G network supports speeds up to 150 Mbps in the case of data transmission to the end user, and sending packets at speeds up to 50 Mbps. Due to this, the 4G LTE network enables users to quickly access the Internet wirelessly, personalized telephony and provides the possibility of using mobile broadband applications for mobile phones, laptops and other electronic devices. Many foreign and domestic operators have implemented mechanisms extending the capabilities of LTE technology in their networks. LTE-Advanced technology, using the so-called aggregation of bands, connection of several carrier frequencies into one channel with a greater width, enables reaching the data download speed even up to 1 Gbps and sending up to 500 Mbps [3].

VII. 5G

Using the new technical solutions, the 5G network meets the growing demands of users, including the growing number of devices, as well as the quality requirements imposed by the applications. It is a development of today's 4G network and is characterized by solutions that allow both to handle the fast-growing amount of data transferred, as well as to meet the need for data exchange between the growing numbers of devices of the Internet of Things [10]. As in the case of each of the next generation networks implemented so far, it is assumed here that until the coverage and possibilities offered by the existing cellular network are provided, the 5G network will initially function together with the existing networks. In addition to the existing areas of use of cellular networks, in the case of the emerging 5G network, three scenarios are foreseen applications that will be particularly important to users, while at the same time differentiating this network from networks of previous generations. Extended mobile broadband Internet access eMBB, enhanced Mobile Broadband, which provides quick access to 1 Gb Internet and will be the main feature distinguishing this generation of networks from previous ones, especially at the initial stage of its implementation. Using this advantage of 5G, the efficiency and quality of communication in society will increase. As the flagship potential use case for 5G, it will include services based on delivering high-definition multimedia, attractive forms of communication, video and enhanced conversation, and virtual reality, as well as smart city services, material transfer from high-resolution cameras. The second area is based on mMTC, massive Machine Type Communications, under which 5G will offer to connect to the mobile network a very large number of devices with low power consumption, referred to as IoT, Internet-based devices. By using a cellular network for communication, these devices exchange data in an asynchronous manner. In this scenario, it is assumed that many types of devices may be included, but their common feature is the sporadic use of the cellular network and the exchange of small data volumes. URLLC Ultra-Reliable Low Latency Communications will be a technology providing minimum 1-ms delay, which will enable data exchange via a cellular network for critical applications such as drones control. In previous generations of cellular networks, the achieved delay values were longer and amounted to about 100 ms in the 3G network, and in 4G LTE - about 30 ms. The most important new 5G technology solutions in the field of radio network include technologies such as: Massive MIMO, Massive Multiple Input, Multiple Output, radio beam shaping, Multi-RAT, Multi-Radio Access Technology [5]. While in the previous solutions sector antennas were most often used, in 5G networks antennas in Massive MIMO technology will be used. It is an extension of MIMO technology, which is currently used in the LTE-Advanced network. In MIMO technology, each antenna consists of several elements, which allows for a more stable transfer and allows to achieve a higher data transfer rate, and at the same time enables the service of more users in the area of a single cell. In turn, Massive MIMO assumes the use of antennas with a much larger number of components (e.g. 64 × 64), which will significantly increase the efficiency of communication in the serviced area. Another element allowing increasing the efficiency of radio transmission in 5G networks is the use of radio beam shaping. Beam shaping is a technology that allows, using antennas in Massive MIMO technology, to direct the radio signal only towards the receiving device and not to disperse in all directions. This technology uses advanced signal processing algorithms to determine the best route of a radio signal reaching the user. This increases transmission efficiency because the signal susceptibility to interference is reduced caused by the interference phenomenon, i.e. the overlapping of radio waves. The use of Multi-RAT technology, i.e. radio multiple access, will allow users, depending on their requirements, as well as the current network load, to be able to automatically connect using the optimal interface / interfaces at the moment (e.g. Wi-Fi, 4G, 3G). The use of new technological solutions in the 5G radio network requires the development of antenna infrastructure and the construction of new antenna installations. They will use new, higher frequency bands, while serving smaller cells. Thus, the power necessary to transmit signals using these devices will be correspondingly smaller, as in the case of end devices, e.g. smartphones [1].

VIII. 6G

The digitization limit for 5G technology in the direction of 6G is exceeded in the following points:

- More Bits, More spectrums, More Reliability: Most of the applications of 6G require higher bit rates than 5G. To cater for applications such as XR, eXtended reality and BCI, Brain Computer Interaction 6G must deliver yet another 10e3 times increase in data rates yielding a target of around 1 Tbps. This motivates a need for more spectrum resources, hence motivating further exploration of frequencies beyond sub-6 GHz. Meanwhile, the need for higher reliability will be pervasive across most 6G applications and will be more challenging to meet at high frequencies [9].

- From Spatial to Volumetric Spectral and Energy Efficiency: 6G must deal with ground and aerial users, encompassing Smartphone and XR/BCI devices along with flying vehicles. This 3D nature of 6G requires an evolution towards a volumetric rather than spatial bandwidth definition. We envision that 6G systems must deliver SEE, high spectral and energy efficiency requirements measured in bps/Hz/m3/J. This is a natural evolution that started from 2G bps to 3G bps/Hz, then 4G bps/Hz/m2 to 5G bps/Hz/m2/J.
- Emergence of Smart Surfaces and Environments: Current and past cellular systems used base stations (of different sizes and forms) for transmission. We are currently witnessing a revolution in electromagnetically active surfaces (e.g., using met materials) that include man-made structures such as walls, roads, and even entire buildings. The use of such smart large intelligent surfaces and environments for wireless communications will drive the 6G architectural evolution.
- Massive Availability of Small Data: The data revolution will continue in the near future and shift from centralized, big data, towards massive, distributed small data. 6G systems must harness both big and small datasets across their infrastructure to enhance network functions and provide new services. This trend motivates new machine learning and data analytics techniques that go beyond classical big data.
- From SON, Self-Organizing Networks to SSN, Self-Sustaining Networks: SON has only been scarcely integrated into 4G/5G networks due to a lack of real world need. However, CRAS, Connected Robotics and Autonomous System and DLT, Distributed Ledger Technologies motivate an immediate need for intelligent SON to manage network operations, resources, and optimization. 6G will require a paradigm shift from classical SON, whereby the network merely adapts its functions to specific environment states, into SSN that can maintain its KPIs, key performance indicators, in perpetuity, under highly dynamic and complex environments stemming from the rich 6G application domains. SSNs must be able to not only adapt their functions but to also sustain their resource usage and management (e.g., by harvesting energy and exploiting spectrum) to autonomously maintain high, long-term KPIs. SSN functions must leverage the recent revolution in AI, artificial intelligence technologies to create AI-powered 6G SSNs [7].
- 3CLS, Convergence of Communications, Computing, Control, Localization, and Sensing: The past five generations of cellular systems had one exclusive function: wireless communications. However, the convergence of various technologies requires 6G to disrupt this premise by providing multiple functions that include communications, computing, control, localization, and sensing.
- We envision 6G as a multi-purpose system that can deliver multiple 3CLS services which are particularly appealing and even necessary for applications such as XR, CRAS, and DLT where tracking, control, localization, and computing are an inherent feature. Moreover, sensing services will enable 6G systems to provide users with a 3D mapping of the radio environment across different frequencies. Hence, 6G systems must tightly integrate and manage 3CLS functions.
- End of the Smartphone Era: Smartphones were central to 4G and 5G. However, recent years witnessed an increase in wearable devices whose functionalities are gradually replacing those of smartphones. This trend is further fueled by applications such as XR and BCI. The devices associated with those applications range from smart wearables to integrated headsets and smart body implants that can take direct sensory inputs from human senses; bringing an end to Smartphone and potentially driving a majority of 6G use cases [2].

IX. Conclusion

Note the SEE parameter, Spectral and Energy Efficiency, which best describes the change in the approach to the digital border for subsequent generations of cellular data transmission. We have for 2G-bps, 3G-bps/Hz, 4G-bps/Hz/m2, 5G-bps/Hz/m2/J, 6-Gbps/Hz/m3/J. We do not have generations in fixed networks, because these networks already have 10e3 times more bandwidth, because in FTTH, the frequency of the carrier wave is 10e15 Hz and in mobile networks 6G only 10e12. Another difference is that in comparison to mobile networks, landlines have access to an unlimited amount of energy, and in mobile we must always remember to minimize its consumption.

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