APPLICABILITY OF 5G SUBSCRIBER EQUIPMENT AND GLOBAL NAVIGATION SATELLITE SYSTEMS

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ABSTRACT

5G is the latest generation of mobile cellular technol-ogy, which is designed to significantly increase Internet speed, coverage and reduce the data packet transfer time in wireless networks. 5G brings together all latest and most advanced developments of mankind in terms of communications and IT. This is the limit of existing tech-nologies of microelectronics and data radio transmission. The new generation of 5G mobile communication has a number of fundamental advantages compared to 4G: higher data transfer rate; low signal delay; the abili-ty to connect more devices; high energy efficiency; multiply increased throughput; high user mobility. Another im-portant difference of 5G deserves attention — large-scale virtualization. The new technology goes beyond just hardware solutions. Many functions in it are imple-mented not at the level of physical infrastructure, but in a soft-ware way. This article covers the topic of applicability of GNSS and 5G mobile communications. The material of article will tell you why GNSS and 5G are interesting and how User Equipment developers can start shaping the 5G device market today.

KEYWORDS: *GNSS, 5G network, standards, MIMO, LTE.*

INTRODUCTION

Communication networks of the fifth generation (5G), together with Big Data and the Internet of things (IoT), are designed to become one of the digital economy foundations, the main driving force of which is artificial intelligence. Over the past 40 years, four generations of mobile networks have changed. If the first generation 1G cellular networks have long disappeared, then 2G, 3G and 4G networks still continue to be exploited. Moreover, a certain amount of the legacy infrastructure of 3G and 4G networks will organically become part of the fifth generation 5G mobile networks [5, 19].

Number of devices connected to the Internet and requirements of subscribers for the speed of mobile access are increasing every year. Developers of telecommunications equipment and telecom operators update the networks architecture and interaction regulations. 5G networks are emerging, which are the next stage in the 4G networks evolution. Geography of 5G application in the world is noticeably expanding. In 2021, we managed to find 5G practices in 14 new countries: France, Italy, Australia and New Zealand, the countries of South America. The largest number of new practices were found in China (22), Great Britain (17) and the USA (16), which became more visible on the global landscape largely due to the activity of local operators [8].

The internal geography of 5G is expanding - they are being actively implemented not only in capitals and megacities, but also in provinces, regions and small towns.

The key functional areas in which 5G practices are being most actively implemented are: industry, transport, entertainment, security, communications and medicine. In industry, there is a development of scenarios that were discovered last year. This is implementation at industrial facilities (at the level of infrastructure hubs), equipment management. In the transport segment, among other things, technically complex practices were implemented: for example, providing communications for high-speed transport routes. In most areas, another trend is noticeable – many new practices have become more narrow-profile, that is, within the framework of one practice, a narrower range of tasks is solved and a smaller range of technologies is used in addition to 5G.

Enterprises are actively using private 5G networks. As a rule, they are deployed by industrial enterprises - most projects in this direction were carried out in private networks. However, such practices are also found in the segments of transport, medicine, security, and agriculture [8]. Half of Russian practices are also implemented in private 5G and 5G-ready networks (that is, ready to be launched in fifth-generation networks after the approval of the relevant standards), also mainly in industrial enterprises [12-14, 16-17].

5G wireless communication networks require very tight time synchronization at every node to maximize spectrum usage efficiency and capacity throughput [18]. All Remote Radio Heads (RRH) must be time synchronized to +/- 1.5 us in their base mode of operation. If your RRH timing drifts outside of this range, it will shut down to avoid interfering with adjacent cells.

5G communications networks rely on high-precision source clocks that lock to the Global Navigation Satellite System (GNSS). If the GNSS timing reference is lost or impaired, calls will drop and data services will dramatically slow down or stop altogether. Highly dense 5G architectures often require a 10× increase in the number of nodes and GNSS traceable source clocks, but ideally, operators could avoid the expense and security exposure of installing GNSS receivers in every clock node [1].

This article covers the topic of applicability of GNSS and fifth generation (5G) mobile communications. The material of the article will tell you why GNSS and 5G are interesting how User Equipment (UE) developers can start shaping the 5G device market today [6].

GNSS & RTK

Let's look at the history of Global Navigation Satellite System (GNSS) and Real Time Kinematic (RTK). One technology that GNSS often relies on, RTK, is a global satellite positioning technique that helps GNSS improve the validity and accuracy of target data. In terms of positioning, positioning and maximum accuracy, the combination of GNSS with RTK increases the level of accuracy. RTK amplifies the phase signal exchanged between transmitter and receiver, providing centimeter-level accuracy and real-time signal correction.

Currently, GPS, GLONASS and Galileo are the main operating GNSS. With the advent of GNSS technology, many assistive technologies known as Regional Navigation Systems came into play. The technology concept is the same as GNSS, but covers less geographic areas.

GNSS satellites have two carrier waves fixed in the L band, namely L1 (1575.42 MHz) and L2 (1227.60 MHz). The main purpose of these two wavebands is to transmit the signals of the connected satellite to the surface of the earth. Using L-band technology can reduce overhead while providing a reliable connection that is less prone to interruptions. The introduction of L-band with the right antenna placement offers a number of benefits for agricultural drones, marine technology, remote monitoring, and more. On the other hand, GNSS receivers placed on the earth's surface consist of an antenna and a processing unit. The purpose of the antenna is to receive coded signals from connected satellites, and the task of the processing unit is to decode the signals into meaningful information.
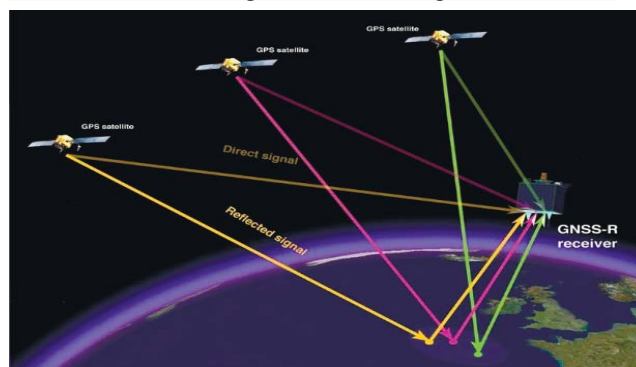
To determine the position of one receiver, GNSS must collect data from at least three separate satellites. Each GNSS satellite revolves around the Earth at an interval of 11 hours 58 minutes and 2 seconds. The time information transmitted by the satellite is transmitted using codes so that the receiver can determine the time interval during which the code was transmitted.

The signals transmitted from a satellite contain coded data that helps receivers pinpoint its location, and the receiver itself positions itself exactly according to the position of the satellite. The receiver IC calculates the time difference between the broadcast time and the coded signal reception time. Once the receiver is positioned accurately relative to the satellite, the processing unit translates the receiver's location in terms of latitude, longitude, and altitude.

The application of GNSS technology has led to a change in the concept of position tracking with a high degree of accuracy and a wide range of coverage. Recently, GNSS has been included in the automotive industry, now almost every car company is integrating GNSS technology into their car models. GNSS is also widely used in aircraft. Preliminary terrain mapping and real-time GNSS terrain updates allow pilots to avoid collisions in air traffic. What's more, the GNSS used in aircraft cockpits also uses technologies such as WAAS or GBAS (LAAS) to improve heading accuracy.

Unlike traditional ground-based navigation aids, the Wide Area Augmentation System (WAAS) provides navigation services across the entire National Airspace System (NAS), according to the Federal Aviation Administration. WAAS provides additional information to GPS/WAAS receivers to improve the accuracy and integrity of current position estimates.

In addition to the wide range of GNSS applications in automobiles and aircraft, GNSS is also used to navigate boats/yachts and ships on the surface of the water. Ships also use a GNSS functional block called the "Man Overboard" (MOB). This feature allows the ship's crew to accurately mark the location of a person who has fallen overboard.

Surveying and geological mapping is another important application of GNSS. Most GNSS receivers use signal data generated at the L1 wave frequency to perform geological mapping. It is equipped with an accurate crystal oscillator that helps the wave reduce clock errors when mapping. Researchers can also make highly accurate measurements by calculating the appropriate offset between GNSS sensors. For example, if an actively deforming area (volcano) is surrounded by multiple receiving stations, then GNSS can be useful to detect any kind of earth deformation or movement.

In addition to the above GNSS applications, important ones also include: mobile satellite communications, location-based emergency and accurate services, improved weather forecasting, photographic geocoding, marketing, etc.

The Inertial Measurement Unit (IMU) plays a vital role in global navigation satellite systems. If the signal is obstructed by something (trees, buildings, etc.), then the signal cannot provide accurate positioning. In tandem, GNSS and IMU provide end users with more powerful and accurate navigation solutions.

Thanks to recent technological advances, many concepts and technologies have significantly changed the playing field for robotics, satellite communications and navigation as we know them. The Global Navigation Satellite System is a key player among innovative technologies. Real Time Kinematic provides GNSS with centimeter-level accuracy with real-time signal correction capability. The combined use of GNSS and RTK ensures maximum accuracy and the highest tracking quality, making it the most powerful combination on the market today.

APPLICABILITY OF 5G SUBSCRIBERS

5G is not just a new standard for mobile communication, the introduction of 5G networks will transform our perception of the world in the long term and lead to the social transformation of society. At the same time, the economics of networks will change: the average transmission speed will increase by 40 times, while the cost of delivery, on the contrary, will decrease by 30 times. By 2024, according to analysts, up to 30% of mobile traffic will go through devices with 5G support. 5G technology will account for 15% of the global mobile telephony sector by 2025 (GSMA forecast, www.gsma.com); for Europe and China this figure will be 30%, and for the USA 50%.

5G standardization

The standardization of 5G technologies and solutions should be completed by 2021, so the term 5G so far refers to only fragmented solutions that will be part of the full-scale IMT2020 solution in the future. Such solutions are already being deployed in different countries, but they are still local and test in nature and do not provide all the planned functionality of IMT2020 networks.

Main standards organizations 5G

3GPP (3rd Generation Partnership Project) – an alliance of seven organizations that develop various telecommunications standards, which, in turn, include other partners. The task of 3GPP is to formulate specifications, evaluate proposals, and finally adopt standards. In addition to developing a common architecture, 3GPP is also developing 5G New Radio (NR) radio technology standards for new frequency bands dedicated to 5G.

ETSI (European Telecommunication Standard Institute), The European Telecommunications Standards Institute, which is a member of 3GPP and is most active in the development of 5G standards.

IETF (Internet Engineering Task Force) develops IP protocol upgrade solutions to support Network Fucntion Vitrualization (NFV) network functions virtualization. For example, the IETF has developed Service Function Chaining (SFC) technology that combines virtualized 5G architecture components such as base stations, service gateways, and data packets in a single path. This allows the dynamic creation and chaining of Virtual Network

Functions (VNFs). The IETF works closely with the 3GPP.

ITU (International Telecommunication Union) – a UN agency based in Geneva that standardizes a wide range of telecommunications technologies. In particular, it coordinates work on sharing the radio spectrum, including for 5G networks. In addition to these three main coordinating organizations, there are a number of others in which systematic practical work is underway to develop IMT2020 (5G) standards.

5GPPP (5G Infrastructure Public Private Partnership), is considered one of the leading 5G standardization partnerships. The organization sets ambitious goals for developing requirements for the 5G network, for example, capturing network capacity by 1000 times, reducing the power consumption of user devices by 90%, significantly reducing the time to create new services and services, complete and secure network coverage and with negligible data transfer latency, etc.

NGMN (Next Generation Mobile Networks) Alliance. The Next Generation Mobile Network Alliance is standardizing the full range of 5G solutions. The alliance includes the management of leading American operators: AT&T, U.S. Cellular and Verizon.

In addition to these, there are industry and regional organizations such as 5G Americas, Small Cell Forum, which also make a great contribution to the development and standardization of 5G solutions (Fig. 1, 2).
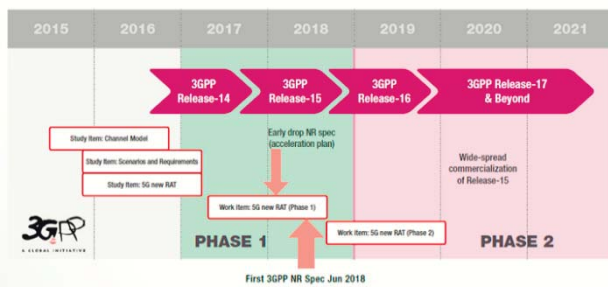

Figure 1. 5G standardization roadmap in 3GPP

Source: The ABC's of 5G New Radio Standards.
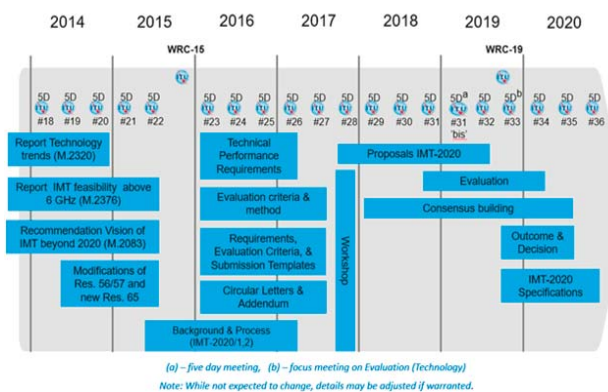*5992-3406EN © Keysight Technologies [10]*

Figure 2. Detailed timeline & Process for IMt-2020 in ITU-R

Source: www.itu.int [11]

Large telecom operators such as AT&T, Verizon, etc. also make a great contribution to the development of standards. They coordinate their work with ETSI and ITU, but sometimes they are ahead of these organizations. Therefore, the decisions of these operators often form the basis of ETSI and ITU standards.

The figure below shows the planned distribution of 5G low-frequency spectrum in various countries and regions of the world according to WRC-15 (Fig. 3).

Figure 3. 5G low-frequency band distribution in various countries and regions of the world

Source: Nokia [9]

Key indicators of the 5G standard and technology

5G (fifth generation) – a generation of mobile communications operating in accordance with telecommunications standards following the existing LTE (4G) technology.

The 3GPP consortium began the formation of the 5G-NR (NR – New Radio, radio access technology for 5th generation mobile networks) specification in 2015. Then plans for the preparation of specifications were announced. In accordance with these plans, the 1st phase of the specifications was to be completed before the second half of 2018 (as part of 3GPP release 15), and the 2nd phase – before December 2019 (as part of 3GPP release 16). At the moment, the 1st phase is completed with a delay of a year, and the 2nd is shifted to the third quarter of 2020 (Fig. 4).
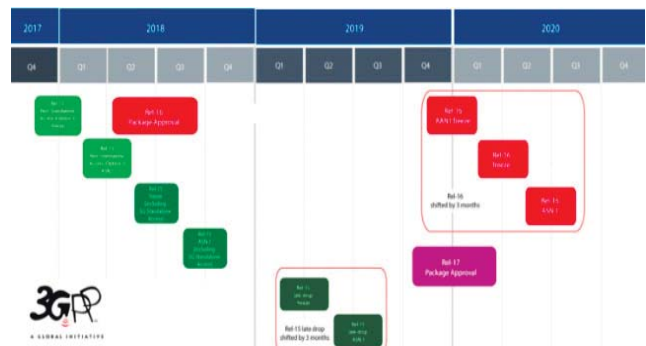

Figure 4. 3GPP Specification Release Plan

Source: https://www.3gpp.org

- The 3GPP standards and specifications are created by market participants and take into account a wide variety of business problems, each of which, of course, has its own specific requirements. Recommendation 3GPP TR 38.913 defined the following key indicators for next generation networks:
- 20 Gbps downlink peak data rate (spectral efficiency 30 bps/Hz);
- 10 Gb/s peak uplink data rate (spectral efficiency 15 bit/s/Hz);
- minimum delay in the radio access subsystem for URLLC services – 0.5 ms, for eMBB services – 4 ms;
- maximum density of devices from the IoT world connected to the network in urban conditions – 1'000'000 devices/km^2;
- autonomous operation of devices from the world of IoT without recharging the battery for 10 years;
- support for mobility at a maximum speed of 500 km/h.

And now briefly about some of the technologies through which the actual implementation of fifth generation networks becomes possible.

FREQUENCY AND BANDWIDTH

The 3GPP TS 38.211 V1.2.0 (2017-11) specification defined new radio frequency bands for 5G (Tabl. 1) and divided them into two frequency blocks: FR1 (frequencies up to 6GHz or sub6G) and FR2 (frequencies above 6GHz or mmWave). Working on higher frequency ranges allows you to eliminate various interferences in the network that distort data transmission. In addition, the higher the frequency, the higher the bandwidth, and the bandwidth of the channel directly depends on it. So, for the FR1 block, depending on the SCS used (Sub-Carrier Spacing, subcarrier radio frequency spacing option), the width of one radio channel is up to 100 MHz, for the FR2 block – from 50 to 400 MHz! Unlike LTE networks, which allow channels with a width of only 1.4, 3, 5, 10, 15 and 20 MHz. And if you combine channel width with frequency aggregation (CA), then for one connection you can achieve spectrum of 2 GHz and more (Tabl. 2).

Table 1

Frequency bands for 5G networks

RF Block	RF range
FR1	450 – 6 000 MHz
FR2	24'250 – 52'600 MHz

MASSIVE MIMO AND BEAM FORMING

Beamforming with MIMO antennas is not a new concept and already exists in the cellular market as AAS (Active Antenna System) [15, 20]. An AAS MIMO antenna mounted on a tower allows you to divide the coverage area into static cells, thereby increasing the efficiency of spectrum use, and therefore increasing the number of channels. But today's congested networks require dynamic digital beamforming to maximize spectrum efficiency.

The application of the concept of MIMO antennas in the FR2 millimeter wave becomes even more interesting because millimeter-wave radio waves have good directivity due to the increase in the number of antenna elements per antenna. An array of such antenna elements (256 or more) can be combined into one so-called. Massive MIMO antenna. By controlling the phase and amplitude of the signals, such an antenna is able to dynamically form many strong and sharp beams in the directions of specific users [25, 30]. With Massive MIMO we get:
– strong signal at the output in the direction of the UE;
– s rong signal/noise level in the direction from the UE;
– absence of intercellular interference;
– a signific nt increase in the number of communication channels per cell.

Thus, MIMO technology takes on different meanings in the sub6G and mmWave bands, as shown in Table 2.

Table 2

MIMO in sub6G and mmWave bands

	Sub6G	mmWave
MIMO order	up to 8x8	x2
Meaning	Static spatial multiplexing for multiple users	Dynamic beamforming for one user
Charac-teristic	Multipath, ideal for spatial multiplexing. Extended coverage area, indoor coverage	Distribution in line of sight. Bulk connections with ultra-wide bandwidth

Sounding Reference Signal (SRS)

Known since 3GPP Release 14, the technology is an important addition to Beamforming. It allows the base station to learn about the channel quality through a special packet sent from the UE. Typically, most UEs can only support sending SRS through their main transmit antenna. Therefore, the base station can only receive channel information for this antenna. However, using the transmit antenna selection technique, complete channel information of all UE antennas can be obtained. Therefore, the base station can generate a beam in the direction of the UE in the best way. As a result, the throughput of the UE will increase significantly, especially at points at long and medium distances from the base station (up to +40%).

SCENARIOS AND EXAMPLES OF THE PROVISION OF MOBILE SERVICES IN 5G NETWORKS

Some of the previously listed indicators, such as, for example, peak data transfer rate and autonomy, are simply incompatible and even mutually exclusive. But all these indicators at once should not be performed by one device at a time or, in principle, supported by the entire list. The idea is to distinguish between different types of mobile radio service scenario depending on the degree of importance (high, medium, low) of a particular indicator. In the concept of Network Slicing, the physical architecture of 5G will be divided into many virtual networks or layers, each of which is designed for a different use case.

Each of the scenarios will satisfy one or another set of previously indicated indicators and, accordingly, is aimed at its own market segment. The specification defines only three scenarios:

– e BB (enhanced Mobile Broadband), ultra-broadband mobile communications;

– U LLC (Ultra-Reliable Low Latency Communication), ultra-reliable, low-latency communications;

– MTC (Massive Machine-Type Communications), mass machine-to-machine communication.

NB-IoT and eMTC for mMTC

mMTC – scenario of machine-to-machine interaction, when human participation is minimal, and all processes are automated. mMTC devices include: water, gas, electricity meters; street lighting controllers; parking space sensors; GPS/GLONASS bookmarks; various smoke/fire sensors; burglary sensors; "smart" trash cans and other IoT devices. As you can see, high speed and ultra-low latency are not at all important here, but autonomy and a huge number of connections in the network are very important. We are talking about the so-called. LPWA (Low Power Wide Area) devices – about mass, simple and cheap devices with ultra-low consumption, capable of operating on a single battery up to 10 years.

Standards and specifications for LPWA networks were laid down in releases 13 (Cat.NB1 and Cat.M1) and 14 (Cat.NB2 and Cat.M2) of 3GPP and currently NB-IoT networks (aka LTE Cat.NB1/NB2) and eMTC (LTE Cat.M1/M2) are already in commercial operation. Networks for such devices are characterized by low transmission rates (up to 150 kbps in LTE Cat.NB2 and up to 1 Mbps in LTE Cat.M1), wide and "deep" coverage. It should be noted that the beauty of NB-IoT and eMTC is that the deployment of networks by mobile operators does not require huge investments and the allocation of separate frequency bands – these LPWA networks can operate in existing frequency bands and on existing network equipment, while one basic the station can serve a wider area than existing 2G, 3G or LTE networks.

Streaming video

Market participants predict a shift in such a classic application as "video streaming" to the right, towards increasing data transfer rates without special requirements for delays. The main driver for this will be the need for high-quality 8K video.

Today, there are TVs with 4K video support on the market and some providers provide video content of this quality. But reliable access to such content can only be obtained by those connected to the fiber-optic Internet, access to which is not available in all settlements. With the advent of 5G, 4K and even 8K video will become the norm for all residents of the city and suburbs, and in the field of film/photo production, such quality as detail will become even more important (Fig. 5).

Figure 5. Network bandwidth requirements of different video formats

Consumption of video content on a widescreen TV sets download bandwidth requirements. However, 5G opens up higher speeds for uploads as well. This will open the door to the introduction of urban video surveillance systems with intelligent face recognition on all continents. In such systems, the entire computing part with artificial intelligence is on the network, all that is required of CCTV cameras is to be able to transmit video of the proper resolution to the server. There are examples of implementation of such systems in the world.

The government of Shanghai (China) has been using such a system since 2015. More than 170 million "smart" video cameras are connected to it. For example [2], this system helped to detect a criminal in a crowd of 50,000 on the way from a concert of a popular singer. He came to the concert with his wife and, according to the detainee, he expected to get lost in the crowd.

In practice, such systems bring the city not only savings on security and operational-search activities, but also generate a positive socio-economic effect – citizens and tourists are not afraid to buy expensive things, visit public places at any time of the day, and business is not afraid of the safety of clients and property is now the task of the city. With the advent of 5G, this system has only become more efficient and less costly to deploy and maintain, and therefore more affordable.

Sky Office

In the early stages of commercial 5G deployment, with the exception of smartphones, it is expected that the laptop with Sky Office connectivity will be the key 5G product. Sky Office is the concept of moving laptop computing power to the cloud by equipping the laptop with a built-in 5G modem. The cloud can host not only user files (Cloud Drive), but also software such as MS Office 365 (Cloud Office) or gaming software products (Cloud Games). In this concept, the laptop becomes, simply put, a screen with a keyboard and a camera.

If cellular networks provide a delay of a few milliseconds and provide a dedicated reliable communication channel on an unlimited basis (Network Slice), then working with Sky Office in the future may become a popular way to use a laptop.

At the same time, the consumer will receive a number of interesting consumer qualities that are unattainable with conventional laptops:

- low consumption at the level of tablets with a battery life of 14 hours or more;
- "always ready", the laptop does not waste time downloading software, it is already running - in the cloud;
- "ready everywhere", losing a laptop no longer means losing data and licenses;
- thin and light body, the composition and structure of the notebook are simplified, and this entails a reduction in size and weight;
- passive cooling, the laptop no longer performs energy-intensive calculations and heats up slightly;
- communication is safer than Wi-Fi, because. 5G is almost impossible to hack, the communication channel is protected by the latest encryption algorithms.

Of course, turning the Sky Office concept into reality requires building an entire ecosystem with the participation of players from several industries at once, such as operating system and software manufacturers, laptop manufacturers, mobile operators, cloud service providers, chipset manufacturers, eSIM manufacturers and 5G modules. But despite the complexity of implementation, Sky Office is expected to have rapid growth in China and many other countries in the near future.

Virtual and augmented reality

The entertainment industry has always been a driving force in the development of consumer electronics. The highest performance requirements come from game console consumers. The most advanced, but also less common technologies in the gaming world are virtual reality (VR) and augmented reality (AR).

The well-known companies Sony and Microsoft have been offering accessories for VR and related 3D games for several years now.

Gradually, VR and AR will go beyond the gaming industry and will inevitably spread to education, medicine, industry – it is difficult to overestimate the potential. Figures 10-13 show some examples of the use of AR from the Microsoft Hololens 2 presentation materials. The next step in this industry will be the combination of AR and VR with 5G. Technically, this is already feasible thanks to the new Qualcomm Snapdragon XR2 chipset, which combines a 5G modem and a specialized XR (from VR + AR) processor with artificial intelligence support that responds to the facial expressions of the "pilot".

It is clear that online games will only be acquired with 5G. With the transfer of computing power to the cloud (Cloud Gaming), game consoles will become less loaded, this video will become smoother, more detailed and more dynamic. Having overcome the technological barrier with 5G, the AR/VR games market will become more in demand. Many will discover virtual travel to other cities, diving to the bottom of the ocean and even flying into space. It is a well-known fact that the perception of the world by a person strongly depends on what he sees, with XR + 5G the horizons of the average layman will significantly expand, change the approaches of society to the study of the world and creative activity in all areas.

Tactile internet

In continuation of the topic of XR and artificial intelligence, it must be said separately about the derivative direction, like the tactile Internet. Tactile Internet (hereinafter referred to as TI) is the transmission of tactile sensations, touches over any distance with a minimum, almost imperceptible delay. The name of the technology was proposed at the Dresden University of Technology, where back in 2012, work began on the creation of robotic systems capable of remotely transmitting sensations.

Now scientists are working on creating artificial touch by inserting sensors into soft robotic structures and the most sensitive touch sensors. Now sensors are already able to reproduce the force and nature of the touch, they distinguish between different materials: metal, wood, textiles, etc.

TI puts forward requirements that 5G networks will be able to do:

- delays less than 1 ms;
- reliability – to perform critical tasks (remote operation), network losses, equipment failure, etc. are unacceptable.;
- high data transfer rate – more than 10 Gbps;
- high network density – support for connecting more than 100 devices per 1 km^2.

To reproduce sensations, it is assumed that there are any devices that are in contact with the recipient, for example, clothing (t-shirts, jumpers, trousers), accessories (gloves), shoes, hats, exoskeletons or special devices, which are tactile displays with tiny actuators, which set moving elements (needles, pins) in motion.

With the help of TI, you can learn to draw, play musical instruments, perform remote surgical operations, i.e., everything that requires "fine motor skills". In e-commerce, you can use this technology to touch or try on a product before buying it. You can touch museum exhibits and even feel the weight of ancient artifacts in your hand. Multiplayer online shooters with XR + TI will become more realistic, it will be possible to feel pain, pushes, blows, heat and cold.

The first practical examples of the use of TI in surgery already exist today. In the USA, tests are being carried out for the introduction of the so-called. "telesurgery", when a surgeon performs a surgical operation remotely, via a 5G network. Telesurgery is very different from classical telemedicine – it's not about a simple video broadcast in conference mode, but about the "presence" of the surgeon during the operation. His movements, precision, personal skills, instant reaction to events - everything will be transmitted over 5G networks without a physical presence and without degrading the quality of the operation. Thus, the services of rare specialists will become more accessi-

ble, and patients will be able to choose a surgeon regardless of their country of residence.

Unmanned aircraft (drones)

Telesurgery places high demands on latency and communication reliability, but there is another area that requires, among other things, mass connectivity – unmanned aerial vehicles or "drones". Today, you will not surprise anyone with light unmanned drones for a variety of purposes – from entertainment to specialized military drones. With their help, they shoot spectacular videos, conduct reconnaissance, save people, transport goods, etc. But almost all of them are controlled directly by a person who has a direct wireless reliable contact on an unlicensed frequency.

In the context of the introduction of 5G, in progressive countries, regulatory authorities have already paid serious attention to this topic today, in connection with which work is underway to standardize and ensure security in this area. For example, in Europe there is a special expert group 5G PPP (5G Infrastructure Public Private Partnership, www.5g-ppp.eu/5gdrones) based on the European Commission and representatives of the information and communication technology industry (operators, providers, institutions, small and medium business) from Britain, France, Switzerland, Austria, Finland, Greece, Poland and Estonia. The 5G PPP public-private partnership will offer solutions, architectures, technologies and standards for drones. Through this state initiative, the European Union sees one of the ways to strengthen its technological leadership on the world stage.

With standards to regulate the mass circulation of drones, artificial intelligence systems, a reliable, constant and fast 5G wireless link for a whole drone hive, new markets and services can be opened in a variety of areas. Imagine: drone couriers delivering food from stores or important medicines to hard-to-reach places; rescue drones looking for people lost in the forest or the sea day and night; drones-firefighters, extinguishing fires at an early stage; agrocopters spraying crops – and all on a global scale, and not in particular cases.

Infrastructure C-V2X

Let's move from UAVs to unmanned vehicles. Many have seen the video presentation of Tesla (www.tesla.com), where an electric vehicle controlled by artificial intelligence moves around the city with minimal driver participation. Or another example is the Waymo service (www.waymo.com), which allows you to call a taxi using a mobile application and drive it to a selected point without a driver behind the wheel.

Both services are built on different principles of operation, under the control of powerful artificial intelligence built into the car. Auto makes a situational decision based on visual information and data from lidar (Waymo). A "smart" car is surrounded by "not smart", unpredictable cars controlled by a person.

There is an infrastructure approach to autonomous driving, enshrined in the 14th release of 3GPP – C-V2X. The abbreviation C-V2X stands for Cellular Vehicle-to-Everything, which is the concept of transferring information from a vehicle to any object that can affect the vehicle, and vice versa. This approach allows the vehicle to "communicate" with other cars (V2V), infrastructure (V2I), LTE network (V2N), power grid (V2G), pedestrians (V2P) and even houses (V2H). The 15th release of 3GPP also introduced the possibility of auto communication with the 5G network, which made the C-V2X more attractive thanks to the URLLC service.

Thus, vehicles connected to the C-V2X system will be able to "see" the whole picture of the road situation, "know" about the relative position, obstacles, dangerous areas, and the artificial intelligence located in the network will not just form a trajectory for them separately, but will do this taking into account the mutual influence on the transport system. Such systems will solve the problem of transportation better and safer than any driver, reduce travel time for each participant in the movement, make traffic predictable, safe and energy efficient.

The international consulting company Pricewaterhouse-Coopers (PwC) predicts that the first driverless cars will appear on public roads as early as 2021, and by 2040 all transport in megacities around the world will become unmanned. However, at first, such vehicles will require attention from the driver in certain situations along the way. During this period, legal issues related to unmanned and electric vehicles will also be resolved. In particular, legal and insurance aspects. A certain amount of time will be spent on creating a network of charging stations for electric cars.

Now, having listed many examples where 5G will come in handy more than ever, let's figure out what the state of 5G networks is today and what barriers need to be overcome on the way to a fantastic future.

State of 5G networks in the world

The process of introducing 5G networks into commercial operation has already begun in 2019, however, so far the coverage of such networks is very modest (Fig. 6). At the beginning of 2020, 5G networks were put into operation by 47 operators in 22 countries of the world, and together with those who planned to launch or are testing, there will be 279 operators in 109 countries (Fig. 7).

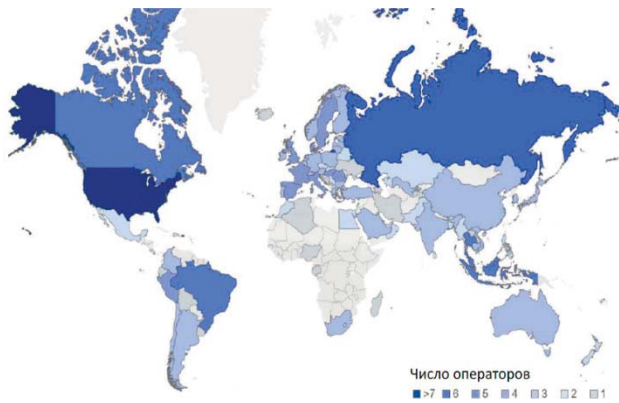**Figure 6.** Number of 5G-NR base stations in commercial circulation [3]

Figure 7. Commercial, planned and pilot 5G networks [6]

Figure 8. Scenarios for building a 5G network in the initial
and intermediate periods [6]

As for subscriber equipment, there are already many models of 5G smartphones, routers and CPEs on sale.

Early adopters are already seeing a significant increase in 5G transmission speeds. Qualcomm test results (May 2019) show a 3.3x increase in download speed for 5G devices compared to LTE devices. In the future, this figure will be higher due to denser coverage and the transition from the LTE EPC core to the packet 5G network core.

THE PATH FROM LTE TO 5G

As mentioned, current 4G networks are not up to the demands of new application scenarios. In the long term, full-fledged 5G networks, including those to support Network Slicing and URLLC, will require a new NGCN (Next Generation Converged Network) network infrastructure, as well as an upgrade of the radio access network. It is clear that it is impossible to perform such a volume of work at once.

4G network delays

The 3GPP consortium initially took into account the complexity of deploying new networks and adopted scenarios for moving from the standard configuration of LTE networks (# 1) to 5G. The introduction of 5G is proposed to be carried out first over the existing LTE EPC infrastructure in NSA (Non-Standalone, #3) mode, as cellular operators did throughout 2019. In such a configuration, the delays on the radio part will be reduced, but due to the restrictions of the EPC core LTE, the overall delay will be far from the requirements of the URLLC. The main meaning of this configuration is different – in the radio part we will get a significant increase in throughput sufficient for most existing eMBB applications, as well as connection stability with a large number of connected subscribers per base station (Fig. 8).

NSA's initial model (#3) aims to improve the quality of mobile broadband internet to improve reliability and data capacity by using EN-DC (E-UTRAN New Radio – Dual Connectivity) connectivity.
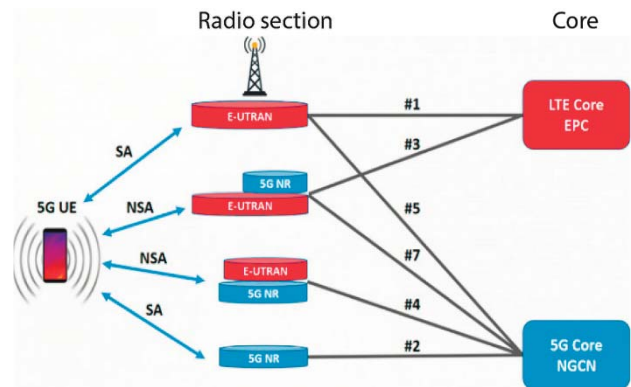
User terminals that support EN-DC can simultaneously connect to LTE and 5G base stations, while the LTE base station is an anchor (upgrading to ng-eNb, or new generation eNB is required). The user terminal (UE) initially registers with the network via E-UTRAN at low frequencies (<2 GHz) and starts broadcasting the measurements performed on the 5G-NR radio access network to the network. When the 5G "radio quality" is satisfactory, the LTE ng-eNb base station initiates a request to the 5G gNB base station to allocate network resources to the UE.

Upon completion of the procedure, the UE connects simultaneously to the LTE ng-eNB and 5G gNB base stations. Of course, the coverage area of a 5G base station will be much narrower than LTE. a high-frequency millimeter-wave signal has a higher attenuation coefficient (Fig. 9).
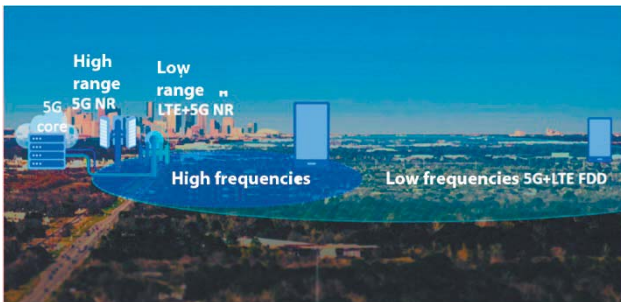

Figure 9. UE connectivity to LTE ng-eNB and 5G gNB
in EN-DC mode [6]

Further, through combined LTE + 5G-NR base stations, 5G coverage can be expanded by using DSS (Dynamic Spectrum Sharing, dynamic spectrum sharing) technology, when the lower frequency band of E-UTRAN (<2 GHz) is dynamically shared with 5G-NR . Prior to the introduction by operators of the 5G core, networks will be able to work like this (Fig. 10).
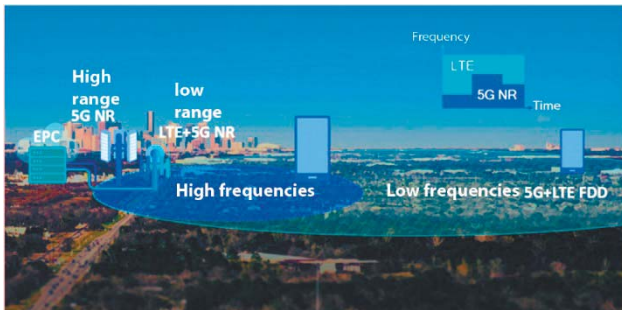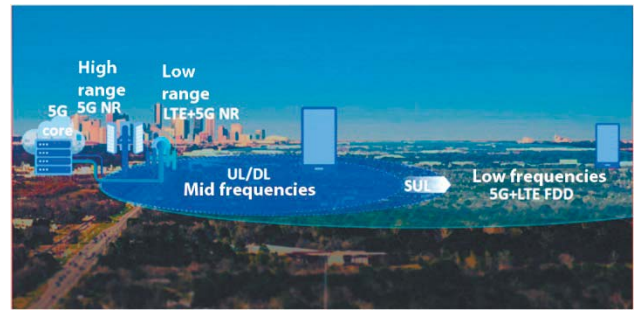
Figure 10. Expanding 5G Coverage
with Low Frequency LTE (DSS) [6]

Figure 12. Expansion of the coverage area of medium
frequencies due to an unpaired channel [6]

Further from step #3, when cellular operators integrate the 5G NGCN core, they can move to the target and final SA mode (options #2 and #5) when using one radio access technology – either E-UTRAN or 5G-NR. Below is the final view of the 5G network capable of providing URLLC services. (Fig. 11).

Figure 11. Final view of 5G network [6]

To meet the growing demand for eMBB, medium frequencies (2 GHz-7 GHz) can be used, thus increasing data rates, including through frequency aggregation. Lower frequency - more coverage, but less channel width. However, there is a way to increase coverage while maintaining a high upload speed using an additional uplink channel (SUL, Supplementary Uplink). How it works? The figure below shows how a UE's Medium Frequency Paired (UL/DL) radio resource is assigned a Supplemental Low Frequency Unpaired Uplink Channel (SUL). Then, in one cell, the UE receives 1xDL (mid frequencies) and 2xUL (low and medium frequencies) channels, the use of which will be controlled by the network. In this case, at the cell boundary, the DL channel uses a medium-frequency signal with increased power from the "paired" band, and the UL channel uses a low-frequency signal in the unpaired SUL band. As a result, the base station "sees" the UE at longer distances, and the download speed is maintained as with the use of medium frequencies (Fig. 12).

5G COVERAGE FORECAST

From the 5G network deployment scenarios and applied frequency bands, the logic of frequency band allocation for different scenarios follows, as shown in the table. Subject to this concept is the Network Slicing technology defined by the 3GPP specification; it will allow mobile operators to deploy networks isolated from each other, each of them can be allocated for specific needs (for the Internet of things, streaming video, etc.) (Tabl. 3).

Table 3

Application scenarios in different 5G frequency bands

| Frequencies	Bandwidth	Scenarios	C acteristic
above 7 GHz (FR2)	800 MHz	eMBB	Super high speed, small coverage and only on the streets
2 GHz … 7 ГГц (FR1)	100 MHz	eMBB, URLLC, mMTC	High speed, wide street coverage, satisfactory indoor coverage
< 2 GHz (FR1)	20 MHz	eMBB, URLLC, mMTC	Medium speed, ubiquitous street and indoor coverage

Given the feasibility of these scenarios in megacities, small towns and villages, it is possible to draw up a generalized network coverage scheme as in Figure 34. As you know, the world has either already abandoned 3G networks or has already announced plans to turn them off. Therefore, Figure 3G is shown as a dashed line. According to the plans of European operators, instead of slow 3G, fast LTE will come to the villages (scenario #5) while maintaining 2G for voice traffic. Suburban coverage will feature faster speeds and lower latency, while metropolitan areas will also boast more connections and ultra-fast internet in FR2 coverage areas. As you can see, in the coming years, 5G networks will not replace 4G networks, but will gradually integrate with 4G networks, significantly improving the overall situation (Fig. 13).
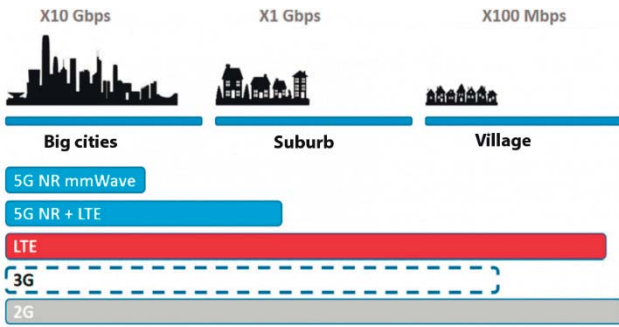
Figure 13. Generalized scheme of coverage
by 2G, LTE and 5G networks until 2025

Separately, it must be said that such a distribution of networks will give rise to a sharp growth in the FWA (Fixed Wireless Access) market. Manufacturers of CPE (Customer Premises Equipment, wall-mounted or in-house telecommunications equipment located in the subscriber's premises) will be able to provide high-speed Internet to residents of territories where high-speed and reliable 5G coverage for some reason "did not reach".

Typically, wired and fiber optic Internet providers come to such places. But 5G FWA will pose a serious threat to this business sector. Indeed, with 5G, FWA's broadband Internet quality will not be inferior to fiber-optic Internet, and the cost of connection will be completely out of competition, since fiber/cable installation, installation work and configuration for each subscriber individually are excluded. Installing the CPE is as easy as installing a Wi-Fi router and requires almost no maintenance (Fig. 14).
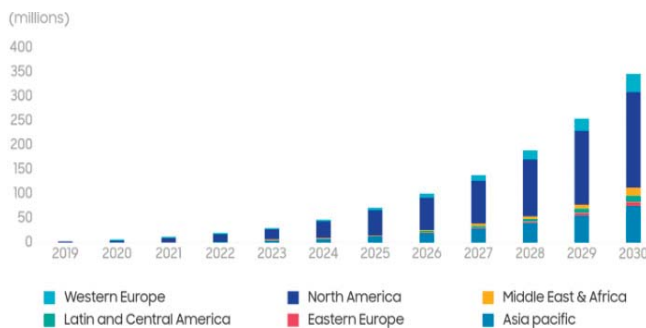
Figure 14. Number of FWA connections using 5G

Source: SNS Telecom

Perhaps, as a result, the fiber optic/wired Internet market will be greatly transformed, will find its specific application, but will never be as massive as it is today. On the contrary, according to the forecast of experts from SNS Telecom (www.snstelecom.com), by 2030, 345 million subscribers will be connected via the FWA service via 5G, and over 90 million units of CPE subscriber devices will be sold. In Russia, this service, due to the length of the territory, can be in great demand even at the initial stage of deploying 5G networks.

5G & GNSS

The virtual Primary Reference Time Clock (vPRTC) timing architecture uses a secure fiber network to provide bi-directional east and west timing flows to local source clocks in aggregation sites with 100 ns of accuracy. The protected PTP southbound timing flow is then sent to the 5G Remote Radio Heads (RRHs). A key benefit of this architecture is that the GNSS receivers are only required in the core enhanced Primary Reference Timing Clock (ePRTC) sites where they can be protected and monitored to shield the network from the risk of GNSS jamming or spoofing threats [7].

To support secure 5G network communications, the vPRTC is a highly secure and resilient network-based timing architecture that blends our secure GNSS firewall technology, high-precision atomic system clocks and a portfolio of trusted time solutions to meet the expanding needs for 5G deployment [21].

The combination of GNSS visibility and the vPRTC architecture provides 5G operators with a dual-purpose solution for the use of Positioning, Navigation and Timing (PNT) services as delivered by GNSS. It provides situational awareness about the health of GNSS reception by monitoring and evaluating key GNSS observables in real time to determine if there is risk in the use of PNT delivered by GNSS. Like a network firewall, this solution creates a dome of protection that strengthens the overall use of PNT services by GNSS for critical 5G communication infrastructures [22].

Prior generation wireless networks relied heavily on the Global Navigation Satellite System (GNSS) to provide a traceable time reference for all the source clocks in the Radio Access Network (RAN). Well-engineered GNSS-based clocks can easily provide +/- 100 ns Primary Reference Time Clock (PRTC) timing accuracy. Table 4 shows the timing accuracy for common source clocks as defined by the ITU for use in communications networks.

Table 4

Primary Reference Time Clock (PRTC) types
available for 5G [7]

Clock Type	Accuracy	ITU standard	Comment
PRTC – A	100 ns	ITU-T G.8272	Single band GNSS
PRTC – B	40 ns	ITU-T G.8272	Typically, dual-band GNSS
Enhance PRTC (ePRTC)	30 ns	ITU-T G.8272.1	Combines GNSS with a local Cesium Atomic Clock at core sites to provide an autonomous timescale that can maintain timing if GNSS is lost

5G Challenge with GNSS

5G operators face two major challenges with deployment of GNSS-based source clocks.

First, 5G networks are very dense, often requiring ten times as many source clocks compared to prior generation networks. That means ten times as many GNSS antennas to install and maintain. GNSS antennas are already installed in core/RAN sites, but not out in 5G aggregations sites. GNSS antennas are a headache you would rather avoid.

Second, GNSS is vulnerable to cybersecurity attacks such as jamming and spoofing. Your 5G radios have a minimum holdover time and will quickly begin interfering with other radios in the same spectrum if GNSS is compromised due to failures or other vulnerabilities such as jamming.

Are GNSS Cybersecurity Threats Real? In a word – yes. And, government agencies are finally stepping forward to do something about it [7]. If you don't believe GNSS threats are real, spend a few minutes searching them out on the internet. The below table shows some of the recent government actions to address this cybersecurity threat (Tabl. 5).

Table 5

Government initiatives to address GNSS cybersecurity

Action	
Executive order on strengthening national resilience through responsible use of Position Navigation and Timing (PNT) services	February 2020
US National Space Policy – Key initiatives to improve Cybersecurity for GNSS systems	December 2020
Department of Homeland Security (DHS) Resilient PNT Conformance Framework	December 2020

For example, Microchip's innovative new timing architecture – the virtual Primary Reference Time Clock (vPRTC) – uses protected core ePRTC timing sites as redundant area timing hubs for your network. The ePRTC achieves 30 ns accuracy when locked to GNSS and can maintain 100 ns accuracy for a minimum of 14 days if GNSS is lost. This architecture helps to deliver a new resiliency – which in turn helps network operators provide uninterrupted services to their clients (Fig. 15).
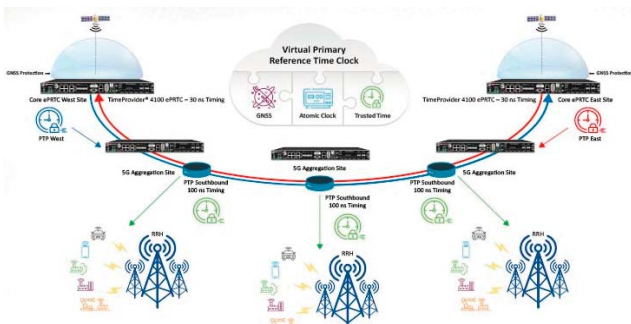

Figure 15. Bi-directional protected timing flows deliver required 5G timing accuracy without the need for GNSS at 5G aggregation sites [7]

The above diagram shows how redundant core ePRTC sites can be deployed for a 5G network. Bidirectional protected Precision Time Protocol (PTP) timing flows from the "west" and "east" core ePRTC sites to all 5G aggregation sites. Operators and optical equipment suppliers have presented technical papers on similar timing architectures at the International Timing and Synchronization Forum (ITSF) conference in November 2021 demonstrating field results supporting timing accuracy and resiliency [2-4].

Microchip's TimeProvider 4100 clocks at 5G aggregation sites are configured in High Performance Boundary Clock (HPBC) mode to receive timing from the core "east" and "west" sites with an error budget of less than 5 ns. If timing flow from the west is lost, the clock will instantly switch to the protected east flow to maintain required timing accuracy for the network without the need for a GNSS receiver at the aggregation sites.

The southbound PTP flow out to the RRHs is protected by the bi-directional timing flows from the core east and west ePRTC sites. Your core timing sites can also be protected with the BlueSky™ GNSS Firewall technology to monitor GNSS observables, detect potential jamming or spoofing threats and shield them from impacting core ePRTC sites.

CONCLUSION

The cost of passing ever-increasing traffic through the networks of telecom operators as of 2020 is not covered by income from traditional services. The search for new services, the so-called "killer application" of traditional telecom platforms, usually does not give the expected results. Meanwhile, the main growth in traffic and revenues is not in the human device sector, but in the IoT device sector, which is one of the basic goals of 5G functionality. Therefore, 5G networks can be considered one of the necessary components of digital transformation and the digital economy.

Unmanned vehicles can act as part of the Smart City service, however, they can be provided on their own platform. It includes not only driverless cars, but also unmanned tractors for Smart Agriculture, unmanned subway and commuter trains, drones and other types of public and special transport. In addition, the implementation of ADAS (Advanced Driver-Assistance Systems) driver assistance systems is possible on the 5G platform.

Unlike networks of previous generations, the range of services of which was severely limited and somewhat expanded in 4G, the services of the 5G platform are synergistic and scalable, and are not limited to once set functionality. 5G plays the role of a platform for the development mode of new DevOps services and applications, when new features are created by developers in close coordination with the teams responsible for their implementation and operation.

5G will not necessarily change the risk factors we have. But it will exponentially increase the threat vectors and opportunities that attackers can take advantage of.

In general, 5G network includes not only mobile, but also fixed communication services, as well as high-speed Internet access with low latency and specialized corporate networks for vertical sectors of the economy.

Due to fifth generation networks, it will also be possible to improve the quality of use of existing services, where large amounts of traffic are involved. The 5G network platform provides operators with significant benefits, primarily expressed in expanding the functionality and characteristics of the network and improving the User Experience [23, 24].

It is still too early to say that 5G networks have acquired their mature, final form. We need to wait for the 16th release, which, according to the consortium's plan, will close the second phase of the specifications and determine the beginning of the mass introduction of fifth-generation core networks. However, this does not prevent from starting work on the study of new technology today, which will lay the foundation for future projects. 5G networks will become our daily routine and the transition from NSA to SA mode will be smooth and imperceptible, and the achievements made today will not be wasted.

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