The 5G Architecture for Scientific and Academic Computer Network

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Abstract. The search architecture design paradigm for computer network made in the technology 5G started from manual execution of the project. Theoretical knowledge obtained from organizations working on editing standards and norms was used. Practical knowledge was obtained from companies producing elements and devices for building telecommunications infrastructure in 5G technology. Searching for the optimal solution, the demand for services and their quality reported by end users was taken into account. The equipment has been adapted to the architecture of the buildings located in the network area. Carrier frequencies for digital data transmission were obtained from a telecommunications operator operating on the campus. The backbone network was built on fiber optics. The radio access network has used cognitive radio. The services were performed using SDN, software-defined networks. Architecture has been tested in a prototype scientific and academic network. The new network is gradually taking over traditional network services. Replacing the traditional network with a new one reduces operating cost and reduce adverse for environmental impact.

Keywords: Enhanced Mobile Broadband. Massive Machine Type Communication. Ultra Reliable. Low Latency. 5G Network.

1 Introduction

Designing architecture for a computer network in 5G technology involves two difficulties. First of all, there are no automatic design systems or even computer aided design systems for 5G technology. Secondly, there is not all the knowledge gathered in one place so you could not design architecture based on tested methods. The developed standards and recommendations are prepared on the basis of theoretical considerations. Proposed by the author collecting and organizing this knowledge, began by manually designing architecture for a prototype scientific and academic computer network. The whole burden of solving this task has been reduced to ensuring that all data obtained from the 5G ecosystem is included. An important feature of the design is this, in order not to miss anything when choosing and adjusting the network architecture. The purpose of this was to find 5G architecture paradigms that were used to gather functional assumptions for the construction of CAD systems.

The 5G technology is characterized by the paradigm that for all applications of digital data transmission there is one telecommunications infrastructure. Specialized services are installed on this infrastructure, tailored to the requirements of all end users. The most popular services are high-quality mobile TV, broadband Internet access and device-to-device communication (Internet of Things). The designed architecture should have such features to secure 5G services and scenarios requirements presented in Fig. 1. The data shown in the figure are from a company producing elements and devices for new telecommunications infrastructure [1]. New architecture features are theoretically defined by ITU in [2, 3].

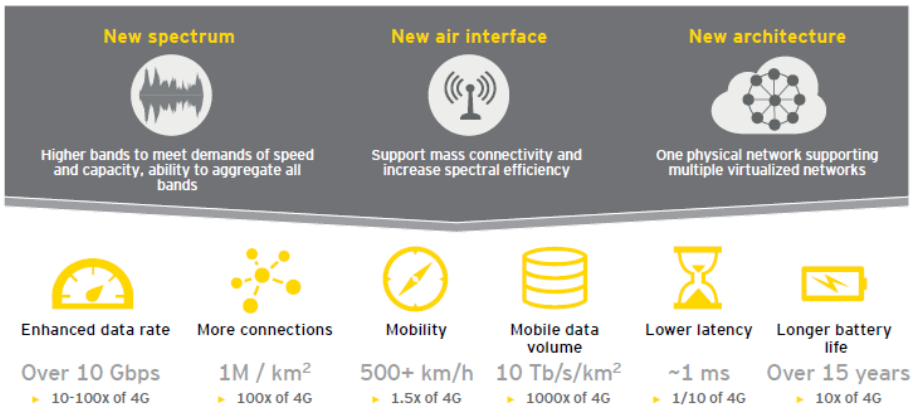

Fig. 1. 5G service and scenario requirements [4]

The design of telecommunications infrastructure has the basic characteristics of 5G technologies: [5]

- EMBB (Enhanced Mobile Broadband) - access to broadband data transmission for both mobile and fixed users (Fixed Wireless Access). This bandwidth is achieved by using 26 GHz mm carrier wave. The bandwidth down to the terminal is 20 Gbps and up to the network is 10 Gbps.
- ULLRC (Ultra Low Latency Reliable Connection) - at the same time to achieve very low latency (<1ms) and very high reliability (error level 10^{-5}).
- MMTC (Massive Machine Type Communications) - simultaneously providing network access for one million users per 1 km^2.
- These parameters are obtainable by using the spectral efficiency of 30 bps / Hz.
- Massive MIMO (Massive Multiple Input Multiple Output) - communication using a narrow radio beam covering only the receiver, no omnidirectional PEM radiation of the transmitting station, bandwidth duplex point-to-point communication.
- Cognitive radio with FQAM modulation - performing digital data transmission on the channel where SNR has the highest value, this gives the largest data bandwidth.
- C-RAN (Cloud-RAN), sometimes referred to as Centralized-RAN, is architecture for cellular networks. It was first introduced by China Mobile Research Institute in April 2010 in Beijing, China, 9 years after it was disclosed in patent applications

filed by U.S. companies. Simply speaking, C-RAN is a centralized, cloud computing-based architecture for radio access networks that supports 2G, 3G, 4G and future wireless communication standards. Its name comes from the four 'C's in the main characteristics of C-RAN system, "Clean, Centralized processing, Collaborative radio, and a real-time Cloud Radio Access Network.

- AAU (Active Antenna Units) - An active antenna is an antenna that contains active electronic components such as transistors, as opposed to most antennas which only consist of passive components such as metal rods, capacitors and inductors. Active antenna designs allow antennas of limited size to have a wider frequency range (bandwidth) than passive antennas, and are primarily used in situations where a larger passive antenna is either impractical (inside a portable radio) or impossible (suburban residential area that disallows use of large outdoor low-frequency antennas).
- LOS (Line of Slight) - Line-of-sight propagation is a characteristic of electromagnetic radiation or acoustic wave propagation which means waves travel in a direct path from the source to the receiver. Electromagnetic transmission includes light emissions traveling in a straight line. The rays or waves may be diffracted, refracted, reflected, or absorbed by the atmosphere and obstructions with material and generally cannot travel over the horizon or behind obstacles.
- Smart antennas (also known as adaptive array antennas, digital antenna arrays, multiple antennas and, recently, MIMO) are antenna arrays with smart signal processing algorithms used to identify spatial signal signatures such as the direction of arrival (DOA) of the signal, and use them to calculate beam forming vectors which are used to track and locate the antenna beam on the mobile/target. Smart antennas should not be confused with reconfigurable antennas, which have similar capabilities but are single element antennas and not antenna arrays.

In order to increase the performance, scalability and capabilities of 5G networks, a number of technologies have been used, such as: [2]

- SDN (Software Define Networking) - is a programmable computer network that allows you to control the network in a completely programmable way.
- NFV (Network Function Virtualization) - distributed cloud infrastructure increasing the efficiency and reliability of network services.
- MEC (Mobile Edge Computing) - mobile edge computing, is an ETSI-defined network architecture concept that enables cloud computing capabilities and an IT service environment at the edge of the cellular network and, more in general at the edge of any network.
- FC (Fog Computing) - or fog networking, also known as fogging, is an architecture that uses edge devices to carry out a substantial amount of computation, storage, and communication locally and routed over the internet backbone.
- SON (Self-organizing Network) -a self-organizing network is an automation technology designed to make the planning, configuration, management, optimization and healing of mobile radio access networks simpler and faster. SON functionality and behavior has been defined and specified in generally accepted mobile industry recommendations produced by organizations such as 3GPP (3rd

Generation Partnership Project) and the NGMN (Next Generation Mobile Networks) [6,7].

2 Methods

Automatic design systems for computer networks made of 5G technology have not yet been published. Prototype, pre-commercial installations are designed manually, in cooperation with specialists from investors, telecommunications operators, equipment suppliers. This collaboration develops as the size and complexity of the network increases. The academic computer network was designed in this way. The contracting authority, the university is the owner of the area and building infrastructure. The owner of masts and telecommunications channels is usually a telecommunications operator, although these installations are located on the campus of the university. The functional assumptions of the designed network are defined by the university. The non-functional assumptions together define the three interested parties: the university, the operator and the hardware supplier. The owner of the frequency on which the radio part of the network works is the telecommunications operator. Telecommunications operators have been obliged by the laws of the countries in which they operate to purchase licenses for used carrier frequencies from governments. The third co-designer was a supplier of telecommunications infrastructure equipment. He has the knowledge and experience in installing and operating his own devices.

Frameworks for designers are saved in release 15, 16, 17 published by ITU [8]. Release 16 and 17 are not yet binding standards or norms, are waiting for approval. They are just draft recommendations. There have been made public standards, norms and recommendations for 5G technology. 5G Toolbox has been released for the States of European Union [9]. It contains additional recommendations, although it is not a valid standard. The European Electronic Communications Code applies in the European Union. In 2020, it was implemented into national telecommunications law in the Member States. The project includes resources for building an extended virtual world. They were currently used to maintain social distance during the corona virus epidemic period. The second application is the construction of a twin technological process in emerging industry 4.0. With webinars as part of the extended virtual world also uses distance learning via the network 5G.

In all universities there are computer networks built in traditional technologies. They carry out tasks imposed on them by designers and users. Investing in these networks in order to improve the quality of data transmission was done by exchanging equipment and software. These investments did not change the architecture of the network based on new technology. Such modernizations were economically not optimal. They used more and more energy to improve data transmission parameters. Designing the next generation of network architecture takes into account the existence of traditional networks in the prototype area. Gradually, new networks take over the functions of the old ones, leading to the natural death of the former. New generations of computer networks are designed in accordance with the objectives of

environmental protection. In traditional radio networks, to improve the quality of transmitted data, the power of transmitters was increased. This improved the relationship between signal strength and noise power. A larger SNR value gave a wider bandwidth of transmitted data, because instead of QAM 16, QAM 64 could be used. This caused an increase in PEM power in the area covered by the range of such a radio network. PEM is not indifferent to human health. The new generation of networks deviates from this principle. Three cell sizes are introduced to reduce the distance between the transmitter and receiver during data transmission - connection duration. In the smallest cell, the carrier frequency and bandwidth are the highest. In the largest cell carrier frequency and the bandwidth of the transmitted data is the smallest. The paradigm has changed in the design of radio computer networks in the new technology. Therefore, the power of the transmitters was replaced with an increase in the carrier frequency and a reduction in the distance between the transmitter and receiver in order to improve the parameters of the transmitted data.

On the assumption, 5G technology is a radio technology developed for moving users and wired technology for stationary (among others: base stations). The core network connecting base stations and stationary end users (servers for cloud computing, edge computing, supercomputers) is made on FTTx (Fiber To The) fiber optic links. It is not recommended to use radio communication by stationary users in order not to overload the occupancy of the radio data transmission bandwidth and not to introduce additional power into the electromagnetic field. The exceptions are building structures that cannot be connected to the network via fiber 5G or buildings that do not perform internal cable installation. Such buildings are the rector's office located in a former tenement house, the international department placed in the manufacturer's villa. In these cases, an internal radio network is built up to which the digital data signal is also fed via radio. Signal passage through the building structure is done by cable to save on the power of the transmitted signal. This technology is called WTTx (Wireless To The).

In addition, resources should be provided for adding new functionalities that have not been possible to date (autonomous transport, internet of things, mobile TV, twin reality, software for industry 4.0, smart buildings). 5G networks increase the security of transmitted data and facilitate identification of the end user. They encrypt the channel and content and record the parameters of end users. This makes it possible to send sensitive data over the network. It reduces the risk of storing your own data on network servers [9].

Another aspect that was taken into account when deriving the CAD method is the need for internal and external openness of the network architecture. At the design stage, the services that will be needed by the end user and with which external networks our systems will communicate are unknown. Because on one hardware structure in the proposed architecture is implemented several SDN, therefore, it shall be forwarded to the internal user API to connect to an existing network software and its installation. The internal end user also gets the option to define and install own SDN. The API was also provided to the external end user, of course after fulfilling the conditions set out in the contract. Opening prototype networks for a commercial user

made it possible to gather experiments and move to designing network architecture in the pre-commercial variant.

During architecture design has taken into account to minimize energy consumption. When choosing devices, not only reliability, price of the device, but also energy consumption was taken into account. To operate radio access network has been applied cognitive radio. In addition, 5G technology uses massive MIMO antennas. They do not emit waves omnidirectionally and only a beam in the direction of the receiving antenna (devices which exchange data). Optimization of energy consumption is also carried out by designing the program part of the network, minimizing the amount of data transferred in cloud and edge processing.

3 Results

The result of the research is a 5G network meta architecture project that has replaced the existing computer network structure on the campus of a technical university. It will satisfy the needs of end users regarding the demand for high quality digital data transmission. The architecture was designed for a prototype network, which after conducting operational tests has become the architecture of the pre-commercial network. It transmits digital data in the channel with the best SNR and which reduces the power of the emitted signal in the absence of data transmission.

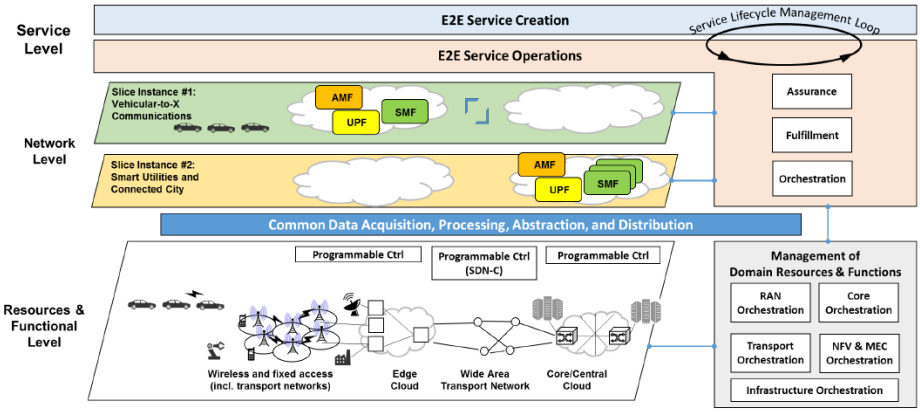

Fig. 2. Overall architecture [5]

The project complies with the 5G PPP recommendations presented in Fig. 2 in the form of meta architecture. It contains various architectural designs and their subsequent versions. They arise as a result of the emergence of new users and the demand for new services. Prototype testing also modifies the structure and parameters of the architecture used. In the proposed solution, the physical layer allows the transmission of digital data in a wired and wireless way between end users and intermediary installations and directly between end users. In the field it is very difficult to separate round cells, because the soil is not perfectly flat, there are plants,

ubiquitous objects on it. Even if we take into account these values in the design, there are still dynamically changing parameters that affect the propagation of electromagnetic waves. These are low-flying planes, drones, riding cars, trams and even for propagation of mm waves have influenced pedestrians and animals.

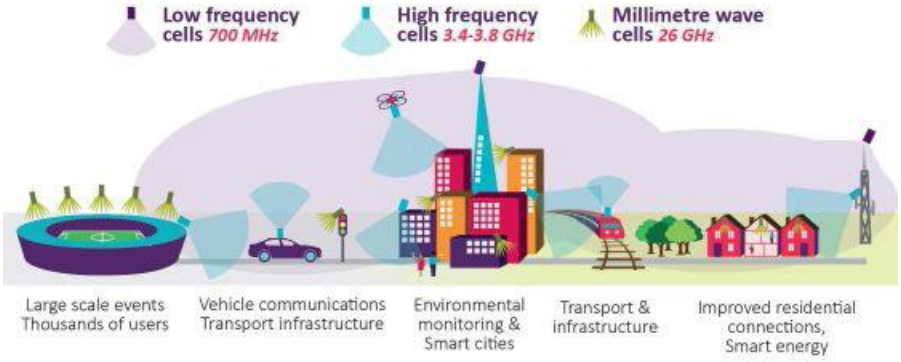

Fig. 3. Three dimension of cells [4]

The campus area was divided into cells of three different dimensions. All cells are rounded to a circle. In the smallest the radius is about 10 m, in the medium about 1 km and in the largest 20 km, accordingly, the carrier frequency in cells: 26 GHz picocells, 3.5 GHz microcells and 700 MHz macrocells. Between base stations, located in the center of all cells, digital data is transmitted in most cases by wire. However, in areas of cells data transmission is by radio. University buildings, masts of older technology, fences, lanterns and new constructions were used to build the passive part of the physical layer. The carrier frequency manager in the entire network is a telecommunications operator who has leased them from the government of the state in which the university is located. Technological channels for routing optical fibers and copper wires have been located in the infrastructure supplying basic utilities (gas, electricity, sewage) to the university premises.

In the university buildings, the lightning protection system has been supplemented to protect the active elements of the physical layer. It uses data redundancy flow paths so that in spite of everything, in case of failure of one other took its movement. Software has been launched at the network nodes to provide basic 5G network parameters, i.e. wide bandwidth, low latency, high reliability and high density of end users. For the network layer, it is the control software that manages the movement of the frames. It also provides encryption of the channel and content of the transmitted data. Another feature of smart nodes is network diagnostics. This module validates the operation of the equipment, logs errors and reconfigures the network in the event of a failure, and forwards appropriate messages to the network administration staff. Active physical layer device has been chosen so that on the basis of signals from the network layer smartly diagnose and optimize their work. Cognitive radio selects the data transmission channel, in which the SNR is greatest. Which, in turn, broadening the width of digital data transmission channel to the maximum size by choosing the optimal modulation. Above the network-control layer, the service layer was

implemented in the cloud technology. End-user services are attached via edge applications.

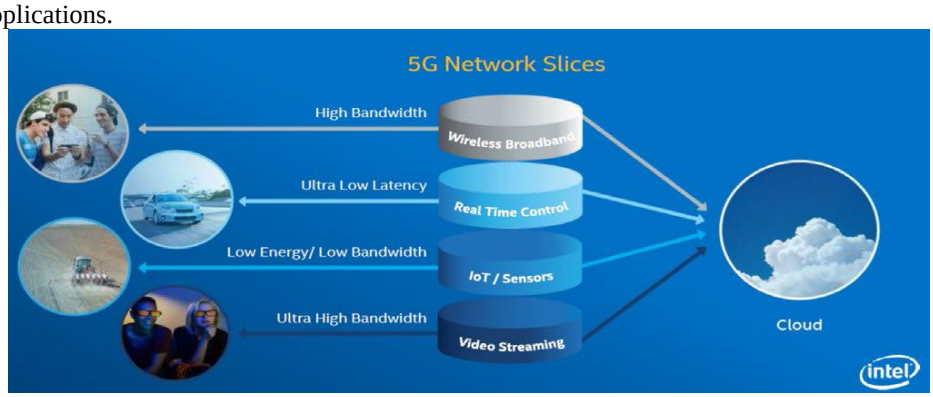

Fig. 4. 5G network slice [4]

Of course, the network stands out slices of end-user access by giving full hardware and software interface. Services performed by the end user:

- network administration (ensuring security),
- conducting 5G research,
- conducting implementations transforming the prototype network into a commercial one,
- absorption of a classic computer network,
- administration of the university,
- support for computer-aided teaching,
- support for scientific work in computer science,
- internet of things,
- clever transport management,
- smart building, campus, city,
- electronic banking,
- entertainment services,
- support for live video,
- distance learning,
- commercial user approval,
- launching a portal enabling exchange of experience in the area of 5G technology (impact of a pandemic, demand for social distance).

The network provides a variety of services both meeting and not meeting 3gpp recommendations. Each service is carried out thanks to the use of appropriate software and separation of the SDN module in the network structure. Each such module also has a feature to identify the user. The software for the network can be provided by the end user or can be made on commission by a team of programmers included in the network administration. The academic network has its own servers for data processing and storage. The 5G network also provides external services via the Internet if requested by an internal user. Financing the construction of the prototype was carried out from the state budget, because the university budget did not have the

funds to implement such an investment. After overcoming all adversities, from 14/05/2020 in the Lodz University of Technology began to work in the physical layer in the first variant of the project, having a full range of features defined in 5G technology. The implementation of this project showed that the developed paradigms for the physical layer reduce the costs of network construction and for higher layers the costs of operation. Modification of the physical layer involves the replacement of hardware and higher layers of software. The experience gained was based only on the implementation of the 5G network in one university. The next stage is sharing knowledge and experience with designers from other universities and then developing design paradigms for all 5G networks.

4 Conclusion

The universal architecture cannot be designed for all scientific and academic computer networks in 5G technology, because in every university the physical layer of the network is different and the need for network services is different. For the same reason, there is no universal architecture for commercial 5G networks. Designing and implementing a system for computer-aided design of such architecture is a natural solution to the problem. The knowledge to perform such a system has always consisted of theoretical knowledge and practical tests carried out in the prototypes being built. Only a pilot physical layer of the 5G network was designed and launched at the Lodz University of Technology. The basic network paradigm was analyzed that the conditions for launching traditional and new services were prepared on its telecommunications infrastructure. Conditions for testing various architectural concepts on the physical layer prototype were prepared. The experience gained develops functional assumptions for CAD design for designing network architecture in 5G technology. It opens the possibility of testing solutions, which is carried out in the form of engineering, masters, doctoral dissertations in computer science and telecommunications. The study shows that the manual architectural design is the first step in building a system of computer-aided design. This process is iterative. Based on a hand-made design, a prototype scientifically academic computer network was built. In the first stage of launching the prototype, it coexisted with traditional networks working on the university campus. Designers gained knowledge and experience to build another version of the submitted architecture. Ultimately, architecture design will be carried out using the agile method, because on the physical layer, the higher layers are software-defined networks. Knowledge of the principles and limits gains also iteratively. First of all, on the server in the traditional network a portal [10] was organized to exchange experiences between designers from various academic centers, telecommunications operators and equipment suppliers. A database has been designed and constructed to which end users report the demand for the amount and parameters of digital data transmitted. At the stage of the designed prototype network, significant hardware resources were left for development by the architectural designer in the future. The physical layer allows end users to communicate not only via network servers but also directly. This is new in 5G technology; previous generations of

telecommunications infrastructure did not allow such transmission. The use of knowledge acquired from the designers of commercial 5G networks has been used to a limited extent. The reason was that commercial 5G networks only perform some functions from 5G technology, not comprehensive solutions. Commercial 5G networks operate on one frequency carrier wave, rather than three frequencies as is defined in ITU [5, 8]. Launched commercial networks provide only a physical layer with a small number of services, because there are no end users on the market yet reporting the demand for the full range of 5G network capabilities. Having a prototype telecommunications infrastructure fully compliant with the 5G standard will enable end users to be offered all services offered by 5G technology. This applies to autonomous air and ground transportation (cars, drones), mobile transmission of video signals in HD quality at least, the Internet of things (smart buildings, smart campus), mobile and fixed broadband internet and many other proposed by end users. The author of this work proposed that the pre-commercial CAD system be implemented by joint work of many academic centers, telecommunications operators and equipment suppliers. Earlier papers [11, 12] published in Abeokuta and Odessa have shown that interest in the subject of designing computer network architecture in 5G technology is real and international cooperation is possible.

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