CZECH TECHNICAL UNIVERSITY IN PRAGUE
FACULTY OF ELECTRICAL ENGINEERING
DEPARTMENT OF TELECOMMUNICATIONS ENGINEERING

BACHELOR THESIS

Budoucnost fixního a mobilního internetového připojení a jeho vliv na rozvoj sítí

The future of fixed and mobile Internet and its influence on the development of networks

By

Zifan Han

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Prague, August 2022

Zifan Han

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Guidelines:

Analyze the current state and the expected development of mobile and fixed Internet connections in the European Union. Include the overview of technical factors and predict their future changes. Focus also on the consequences related to the expected development of networks considering the capacity and technology issues (VHCN, 5G).

Bibliography / sources:

[1] Body of European Regulators for Electronic Communications. BEREC Guidelines on Very High Capacity Networks [online]. Riga: BEREC, 2020 [viewed date: 11 October 2020]. Available from: https://berec.europa.eu/eng/document_register/subject_matter/berec/regulatory_best_practices/guidelines/9439-berec-guidelines-on-very-high-capacity-network

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Abstract:

With respect to the development of modern society and the increasing importance of communication means, this thesis analyzes the status of mobile and fixed network connections and outlines their development in the past. It looks at the current architecture of 4G networks and the problems faced by traditional fixed networks, proposing the necessity and advantages of the future development towards 5G mobile networks and next-generation fiber-based F5G fixed networks. The need for future IoT for VHCN and high-speed stable mobile networks is also discussed. In addition, this thesis reflects the current network infrastructure deficiencies in Europe in order to better understand the future development of mobile and fixed networks and propose possible solutions based on the current situation and future trends. This shall be the way to real changes and development in human lives.

Index Terms: Fixed network, Mobile network, 5G, VHCN, IoT

Anotace:

Tato práce nastiňuje dosavadní vývoj mobilních a pevných sítí a analyzuje jejich současný stav s ohledem na potřeby moderní společnosti a rostoucí význam komunikačních prostředků. Zabývá se architekturou 4G sítí, reflektuje problémy, kterým čelí tradiční pevné sítě, a zdůrazňuje nezbytnost i výhody budoucího vývoje směrem k 5G mobilním sítím a F5G pevným sítím nové generace na bázi optických vláken. Reflektovány jsou zde také potřeby dané rozvojem internetu věcí, konkrétně VHCN a stabilní vysokorychlostní mobilní sítě. Dále tato práce vysvětluje aktuální nedostatky síťové infrastruktury v Evropě s cílem lépe porozumět budoucímu vývoji mobilních a pevných sítí a navrhnout vhodná řešení na základě současné situace i očekávaných trendů. Zde se otevírá cesta ke skutečným změnám a rozvoji lidských životů.

Klíčová slova: pevná síť, mobilní síť, 5G, VHCN, IoT

Contents

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List of abbreviations:

- 5GC – 5G Core Network
- ADSL – Asymmetric Digital Subscriber Line
- AMPS – Advanced Mobile Phone System
- CDMA – Code Division Multiple Access
- CDPD – Cellular Digital Packet Data
- CO – Center Office
- D2D – Devices to Devices
- DOCSIS 3.1 – Data Over Cable Service Interface Specification 3.1
- eFBB – Enhanced Fixed Broadband
- eNB – Evolved Node B
- EPC – Evolved Packet Core
- ETSI – European Telecommunications Standards Institute
- F1G – First Generation Fixed Network
- F2G – Second Generation Fixed Network
- F3G – Third Generation Fixed Network
- F4G – Fourth Generation Fixed Network
- F5G – Fifth Generation Fixed Network
- FFC – Full-Fiber Connection
- FMC – Fixed Mobile Convergence
- FTTP – Fiber to the Premises
- GPRS – General Packet Radio Service
- GRE – Guaranteed Reliable Experience
- GSM – Global System for Mobile Communications
- HFC – Hybrid Fiber-Coaxial
- ICT – Information and Communications Technology
- IMS – IP Multimedia Subsystem
- IoT – Internet of Things
- ITU – International Telecommunication Union
- LTE – Long Term Evolution.

- MIMO – Multi-Input Multi-Output
- MME – Mobility Management Entity
- MMS – Multimedia Messaging Services
- MTC – Machine Type Communication
- NFV – Network Functions Virtualization
- NGA – Next-Generation Access Networks.
- NMT – Nordic Mobile Telephone
- NSA – Non-Standalone Architecture
- ONU – Optical Network Unit
- PGW – Packet Data Network Gateway
- RTMI – Radio Telefono Mobile Integrato
- SA – Standalone Architecture
- SDN – Software Defined Networking
- SGW – Signaling Gateway
- SMS – Short Message Service
- TDMA – Time Division Multiple Access
- VDSL – Very High-speed Digital Subscriber Line
- VHCN – Very High Capacity Network
- WiMAX – Worldwide Interoperability for Microwave Access

Chapter 1: Introduction and goal of the thesis

This thesis will discuss the status of fixed and mobile Internet and its future development, mainly focusing on the European Union to explain why the development of next-generation fixed and mobile Internet is needed, as well as to show the advantages brought by next-generation fixed and mobile networks, The challenges, and issues facing the development will also be discussed. The impact of their development on existing networks will be fully dissected to anticipate the future development trend of the European Union.

As we can see, the rapid development of modern society is inseparable from the network, both for the convenience brought by mobile networks and for the high speed and stability of fixed networks, which provide a fundamental guarantee for our modern development. According to the European Commission's study on broadband coverage in 2020, the overall fixed broadband coverage in Europe has reached 97.4%, with the largest growth occurring in the coverage of next-generation access networks (NGA).

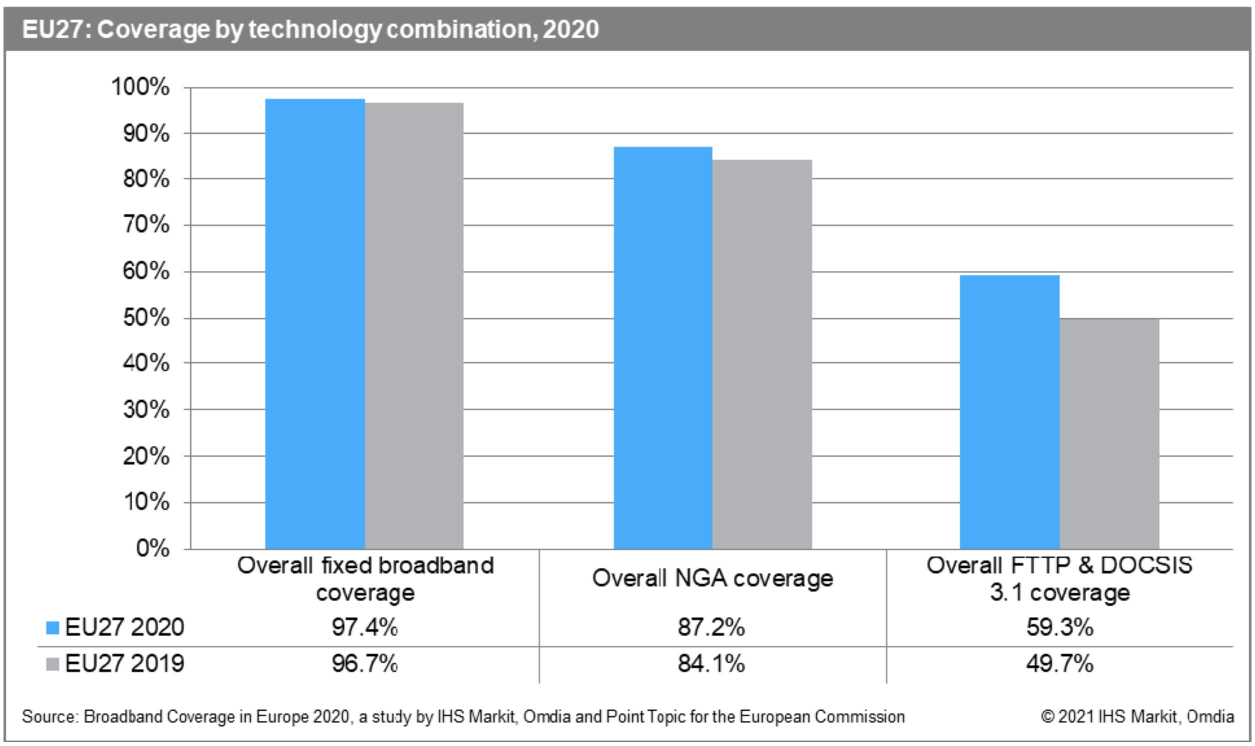


Figure 1: EU27: Coverage by technology combination 2020. [1]

In terms of mobile network (cellular data) coverage, Europe ranks first among the eight continents in the world with a high coverage rate of 99.8%.

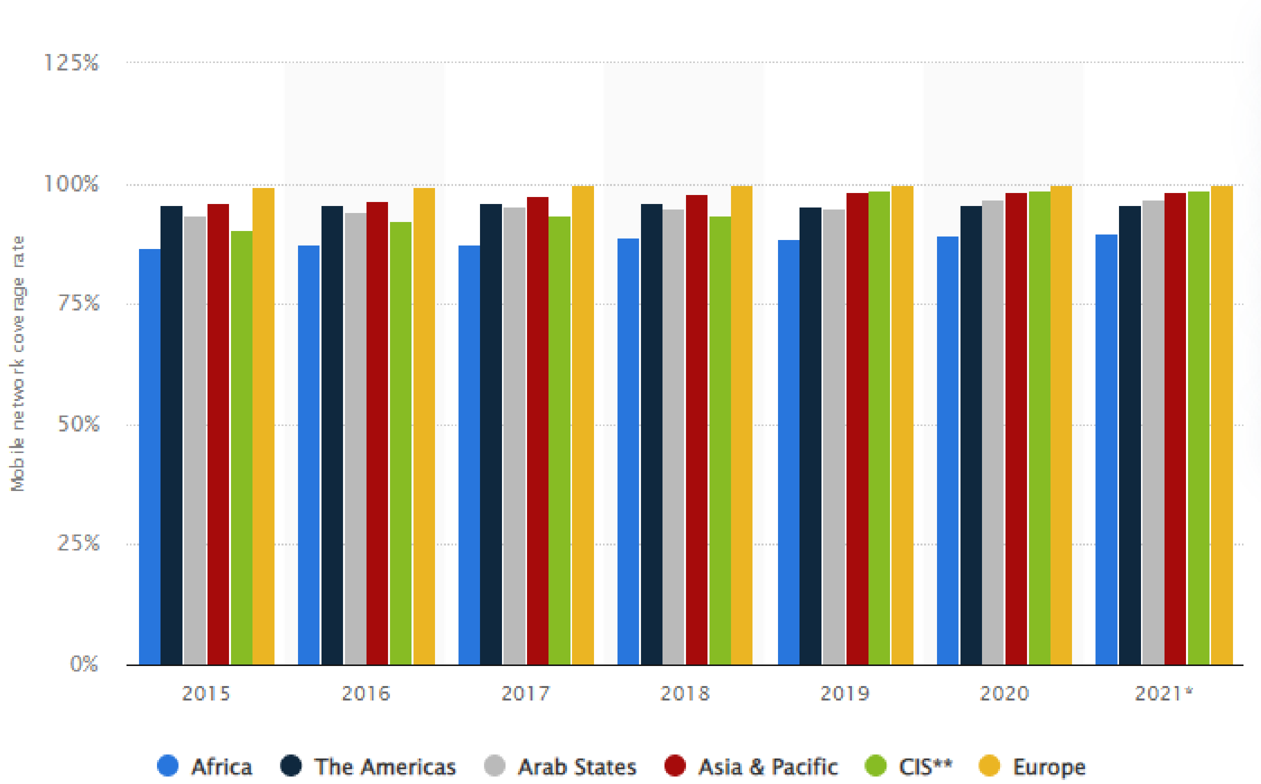


Figure 2: Coverage rate of mobile network worldwide 2015-2021 by region. [2]

However, increasing the coverage of primary cellular data and basic fixed broadband access technologies is not enough for Europe. Then based on the higher average LTE coverage of operators in each EU country and the overall coverage of 97% in the EU-27.

Country	Average Operator LTE Coverage
AT	99.30%
BE	100.00%
BG	80.80%
HR	98.30%
CY	98.30%
CZ	99.70%
DK	100.00%
EE	98.20%
FI	99.10%
FR	99.10%
DE	94.30%
EL	98.00%
HU	98.50%
IS	99.60%
IE	99.00%
IT	98.00%
LV	99.80%
LT	99.50%
LU	98.30%
MT	100.00%
NL	99.40%
NO	99.90%
PL	99.30%
PT	96.60%
RO	93.90%
SK	89.60%
SI	99.50%
ES	95.30%
SE	99.60%
CH	98.60%
UK	99.30%
EU27	97.00%

Table 1: Average operator LTE coverage for each country [3]

The LTE infrastructure in Europe has reached a certain peak. the demand for mobile data from personal and large business devices is no longer the most basic GSM data connection. Cell phones, tablets, and other portable mobile devices have come into people's lives. The fast-paced era of fragmented information access requires high-speed mobile Internet as basic support. Since 2012, European countries have rapidly adopted 4G/LTE services, and by 2020, 86% of the European population had subscribed to mobile Internet services.[4]

In terms of fixed Internet, the overall fixed broadband coverage in Europe is high, with FTTP & DOCSIS 3.1 coverage accounting for 59.3%, while the growth of next-generation access networks (NGA) is relatively good, but the use of fixed Internet is not only for basic fixed Internet needs such as homes and companies. Industries as large as national scientific research and rapid emergency response need high-speed and stable fixed Internet as a foundation.

Chapter 2: Status of the fixed and mobile networks

2.1 Status of mobile network

2.1.1 The first generation of mobile networks

Since 1979, the first generation of mobile Internet appeared, the mobile Internet has evolved rapidly from the first generation to the current fifth generation in just over 40 years. Each generation of mobile Internet development has changed the way we communicate with each other and further improved our lifestyles.

The first-generation mobile network appeared in 1979, launched by Nippon Telegraph and Telephone Corporation, and by 1984, the first-generation mobile network covered all of Japan. The first generation of mobile networks relied on analog radio systems, meaning that users could only make phone calls, not send, or receive text messages, and countries used to build cell towers so that they could get better signal coverage. Different standards were used in different regions, with Japan using JTAGAS, the UK using Total Access Communications System, the US using Advanced Mobile Phone System (AMPS), Germany using C-Netz, France using Radiocom2000, and Italy using RTMI, Nordic Mobile Telephone (NMT) used in Northern Europe, Eastern Europe, and Russia, etc. But the unreliability of the first-generation mobile network is also reflected in some problems, such as the coverage of the cell back down, and ease to receive interference from other radio signals. The most important is the security issue, which is easily hacked due to the lack of confidentiality. This means that anyone with a radio scanner could receive calls, although the first generation of mobile networks was groundbreaking at the time, there was still a lot of room for improvement. The first generation of mobile networks is now discontinued in most countries and regions.

2.1.2 The second generation of mobile networks

The second generation of mobile networks was introduced in 1991 in the Malaysian market, based on the GSM standard. The second generation of mobile networks runs on digital signals instead of analog signals and offers some important improvements. Encrypted calls were introduced, and the sound quality was improved. The radio spectrum was used more efficiently, allowing more users per band. With General Packet Radio Service (GPRS), the 2.5G mobile network can provide data transfer, GPRS was established by the European Telecommunications Standards Institute (ETSI) for the earlier Cellular Digital Packet Data (CDPD) and i-mode technologies. The provision of GPRS extends the GSM packet circuit interaction data capabilities to bring some new services. For examples, SMS and Radio, Multimedia Messaging Services (MMS), and Peer-to-Peer services: interconnection with the Internet, the ability to check and read e-mails sent via POP3 or IMAP protocol, etc. According to the ETSI Phase 2 proposal, GPRS is divided into two development phases: Phase1 and Phase 2. Phase 1 of GPRS supports TCP/IP and X.25 services, the new GPRS air interface encryption technology, GPRS add-on services, and enhanced SMS service. Since GPRS uses packet data billing, the most significant of these services are TCP/IP and X.25 services, which can be used to provide users with e-mail, WWW browsing, private data, LAN access, etc., depending on the amount of data.

With the introduction of 8PSK coding, the GPRS evolved into Enhanced Data rates for EDGE often referred to as EGPRS. EDGE uses a high-speed coding scheme of 98PSK that can represent 3 bits of information per symbol, while GMSK can only represent 1 bit of information per symbol, allowing EDGE to theoretically provide 3 times more data than GSM. Enhanced EDGE was later introduced, called Evolved EDGE, which improved EDGE in several ways, by increasing the transmission interval to approximately 10 ms to 20 ms to reduce latency. Peak bandwidth is increased to 1 Mbit/s and latency is reduced to 80 ms with dual carriers, using higher symbol rates and higher-order modulations, such as 32QAM and 16QAM instead of 8PSK, signal quality is improved with dual antennas, and average bit rate and spectral efficiency are improved as a result. Evolved EDGE leverages existing advantages through progressive software upgrades to experience mobile Internet connectivity equivalent to 500 kbit/s ADSL service at the user level. As text messaging, downloads and phone calls became increasingly popular, the mass adoption of cell phones by consumers and businesses alike. However, as more and more people start using cell phones, the demand for data is growing.

2.1.3 The third generation of mobile networks

Then 3G came in 2001, it has 4 times more data transfer capacity than 2.5G, 3G is a new generation mobile communication system which combines wireless communication with multimedia communication. It is capable of handling images, music, video, web browsing, telephone conferencing, e-commerce information services. The wireless network must be able to support different data transmission speeds, that is to say, at least 2 Mbps, 384 kbps, and 144 kbps in indoor, outdoor, and driving environments respectively. Due to the higher frequency band and more advanced wireless (air interface) access technology, the communication quality of 3G standard mobile communication network has been greatly improved compared with 2G and 2.5G networks, such as soft switching technology, when the mobile users move at high speed during the journey and no longer have dropped calls when driving out of one cell and entering another cell. The higher frequency band range and user classification rules make the network capacity per unit area greatly improved, while the call allowance is greatly increased. One of the most important aspects of 3G wireless technology is the ability to unify existing cellular standards such as CDMA, GSM, and TDMA under one umbrella. The following three air interface models achieve this result: Wideband CDMA, CDMA2000, and Universal Wireless Communications (UWC136). Wideband CDMA (W-CDMA) is compatible with the 2G GSM networks currently popular in Europe and parts of Asia. W-CDMA required bandwidth between 5MHz and 10 MHz, making it suitable for higher-capacity applications. [5]

2.1.4 The fourth generation of mobile networks

In March 2008, the International Telecommunication Union - Radiocommunications Sector (ITU-R) specified a set of requirements for the 4G standard, named the IMT-Advanced specification, which sets the peak speed requirements for 4G services at 1 Gbit/s for high-speed mobile communications and 100 Mbit/s for fixed or low-speed mobile communications. LTE and WiMAX (a wireless broadband access standard developed and maintained by the IEEE under the 802.16 designation) support peak bit rates much less than 1 Gbit/s. On December 6, 2010, the ITU-R announced that these two technologies, as well as other 3.9G technologies, do not meet the requirements of IMT-Advanced and can still be considered 4G, but only if they are first movers and to the extent that IMT-Advanced version of the standard and improved performance and features make it only equivalent to the 3G networks deployed today. The reason behind the strong industry support for LTE is the relative ease of upgrading from the world's current 3G networks to LTE mobile broadband, compared to the significant infrastructure build-out that WiMAX has taken so far. In the 700 MHz spectrum used by LTE, there are fewer cellular base stations to build and better penetration into buildings. Many of the world's leading carriers and mobile companies were supporting LTE in the 4G mobile broadband race, including Vodafone, Orange, T-Mobile, LG Electronics, Ericsson, Nokia, Siemens, NTT Docomo, and others. [6]

LTE technology is finally moving away from its GSM roots as a circuit-switched network and moving to all-IP planar network architecture. In simple terms, this means that LTE will treat everything it transmits, even voice, as data. Another major change is the use of MIMO technology, or the use of multiple antennas at the transmitter and receiver ends to improve communication performance.

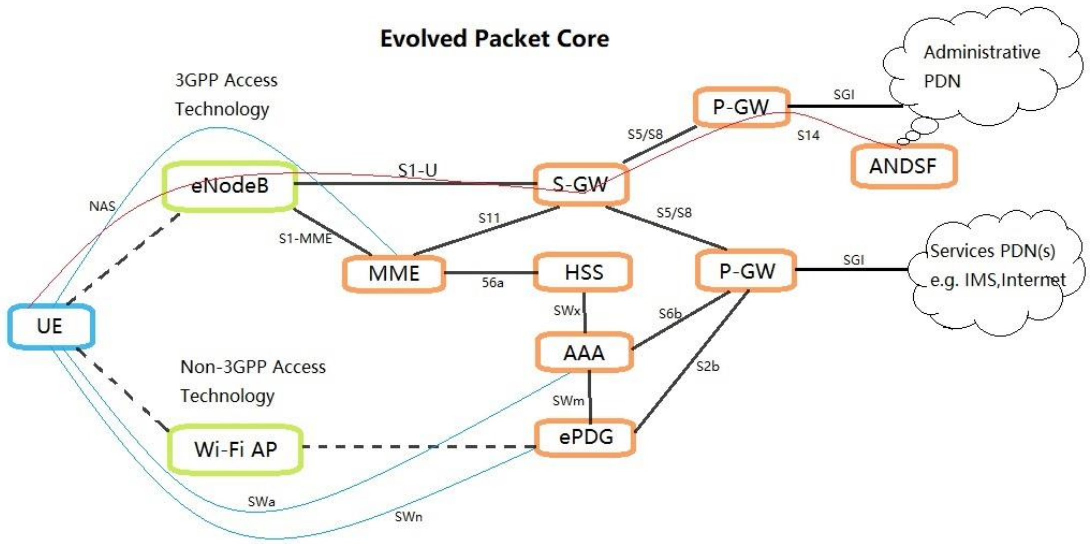


Figure 3: Evolved Packed Core [7]

The basic LTE network is mainly composed of eNB, MME, SGW and PGW. eNB is responsible for air interface signaling and data transmission, signaling surface interaction with MME, data forwarding with SGW; MME, as the control surface node in LTE network, is responsible for mobility management and session control plane node in the LTE network, also for the control of mobility management and session management; SGW and PGW have both control plane function and user plane function. Control plane function being the main one, which includes the establishment and management of data transmission tunnel, while the user plane is responsible for data transmission. The LTE network adopts a centralized control plane management mechanism, and all the signaling for mobility management, session management and session management signaling needs to be handled by the centralized control node in the network All signaling for mobility management and session management needs to be handled by the MME in the network. [8]

2.1.5 The fifth generation of mobile networks

In 2019, the fifth generation of mobile networks (5G) is officially launched. 5G is the latest generation of mobile communication technology, and 5G performance targets high data rates, reduced latency, energy savings, reduced costs, increased system capacity, and massive device connectivity. The evolution of the cellular network generation is primarily influenced by the continued growth of wireless user devices, data usage, and the need for a better quality of experience. By the end of 2020, more than 50 billion connected devices will be using cellular network services. [9] This will lead to a significant increase in data traffic and subscriber volume, so 4G capacity is not sufficient to meet this challenge. So, the corresponding major issues are addressed by the following features of the 5G mobile network. So 5G mobile networks are considered to have the following characteristics:

- For users 5G ubiquitous links, uninterrupted communication services, and smooth experience.
- For providers by providing connected intelligent systems, more advanced service units, and IoT possibilities.
- For operators more energy-efficient, scalable, programmable, and secure communication infrastructure.

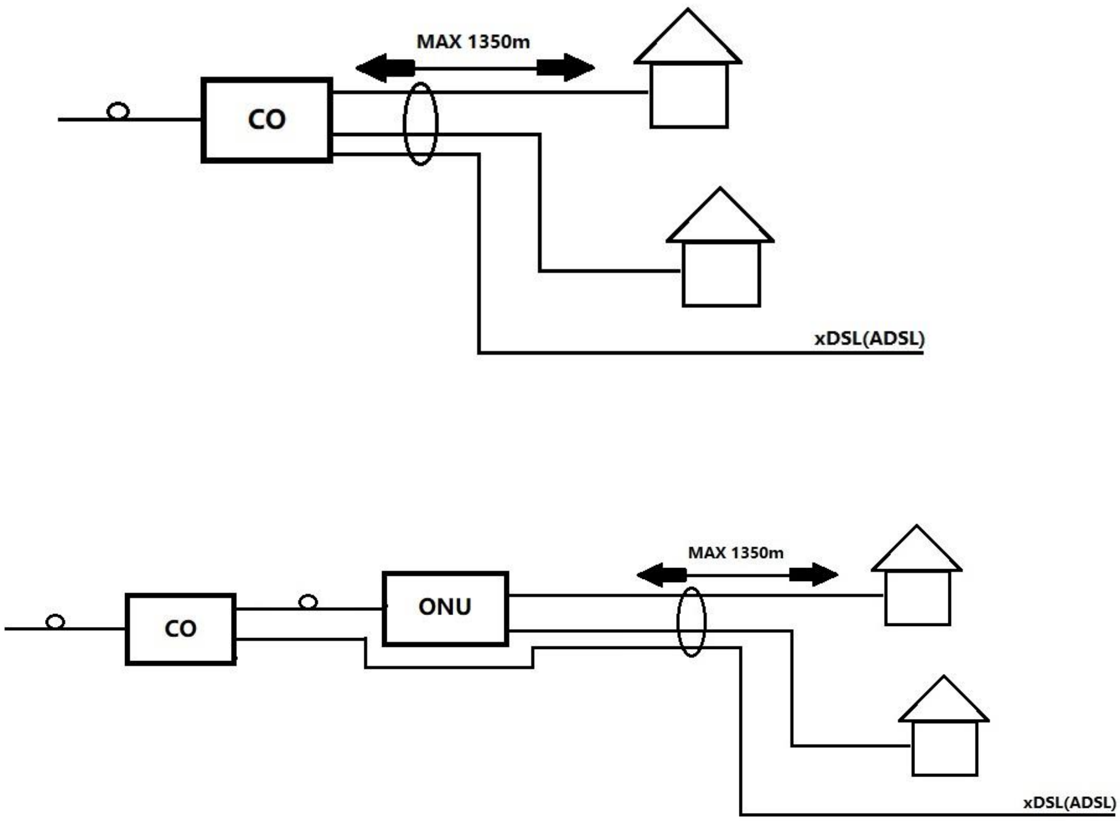
2.2 Status of fixed networks

According to the number of fixed network access technology statistics from 2011 to 2021 in the EU, [10] in the last decade Asymmetric Digital Subscriber Line (ADSL) access technology is gradually replaced by Very high-speed digital subscriber line (VDSL), and the number of FTTP technology uses has increased significantly, while the traditional cable access technology has not changed significantly.

Although ADSL is better built as more places are covered by basic telephone lines, it has benefits such as allowing users to talk while using the internet as uses a different frequency band compared to the phone line, But the disadvantage is its limited-service quality. In the last decade, ADSL, for example, no longer meets the current bandwidth requirements and it has been gradually replaced by VDSL technology because VDSL:

- Uses the existing telephone infrastructure
- Quick to install
- Has a small range of efficiencies due to the wire resistance of the copper connection and many times faster than its predecessor

In terms of actual deployment, the proportion of VDSL is gradually increasing and the actual deployment of VDSL is limited to within 1350m from the signal source due to the high attenuation of high-frequency signals over twisted-pair lines, as shown in Figure 4, and those close to CO (Center Office) can be deployed through the copper lines. Further away will be through the ONU (optical network unit), as shown in Figure 5, and then using the existing infrastructure to distribute signal.



Figures 4: FTTEx configuration and FTTCab configuration [11]

The development of fixed networks depends on a large extent of the infrastructure and the choice of materials for transmission lines. Different network operators use a variety of different configurations to provide connectivity.

	Core	Distribution	Last Mile
PSTN	Fiber /Copper	Twisted pair	Twisted pair
Cable TV	Fiber	Coax	Coax
Hybrid fiber coax	Fiber	Fiber	Coax
Fiber to the node	Fiber	Fiber	Twisted pair
Fiber to the home	Fiber	Fiber	Fiber

Table 2: Categories of fixed networks [12]

Twisted pair / FTTN

Twisted-pair networks are built for voice telephony services and most countries have extensive twisted-pair networks. These networks carry Internet data traffic at broadband speeds but have limited capacity. Capacity distribution points can be increased by connecting fiber optics to intermediate equipment, often used within communities. Although the final connection is still made by twisted pair, shorter copper wires allow for higher FTTN throughput.

Cable Internet/ HFC

The-second last-mile technology is a coaxial cable. It uses thicker copper bundles to provide higher capacity than twisted pair and started out to provide more channels to simple TV lines but turning a one-way cable network into an Internet access system requires more investment than basic DSL and twisted pair networks. The higher capacity of a cable network means increases higher broadband speeds. This upgrade is more for cable TV to be able to provide on-demand capabilities than access a cable broadband network. So, most countries do not use coax cable systems as the primary way to access broadband.

Fiber

Fiber, as the foundation for next-generation fixed network. The carrying of light using laser pulses is virtually unlimited, and studies have demonstrated that speeds can exceed 100 terabits per second over 100 kilometers. [13] This is 10 to 100 times faster than most fixed broadband, but the challenge with fiber is the deployment costs involved. The cost of equipment and electronics for fiber-optic networks has fallen, but the construction costs associated with laying them through underground or aerial ducts are still very high.

Next Generation Access (NGA) networks, the high-speed broadband infrastructure that resides in fiber, and the rollout of NGA across the EU is one of the goals of the European Commission's Digital Agenda strategy. Telecom operators must accelerate network speeds to meet the growing demand for bandwidth for new, interactive multimedia services, such as cloud computing.

In addition to this, the construction of the very high capacity network (VHCN) is also very important, regarding the very high capacity network (VHCN), an electronic communication network consisting entirely of fiber optic components, at least to the distribution point of the service location or an electronic communications network capable of providing similar network performance in terms of available downlink and uplink bandwidth, resiliency, error-related parameters, latency, and its variation under usual peak time conditions. [14]

Chapter 3： The future of fixed and mobile internet.

3.1 The future of mobile internet

Through chapter 2.1 on the current state of mobile networks, including the shortcomings of the current LTE network, it can be found that the different communication scenarios that exist in future mobile networks, mainly 5G mobile networks, have different performance requirements, which the LTE network is unable to meet because of its own working principle. Therefore, the future needs to redefine the 5G network architecture and the key technologies that support it. The future development of 5G stems from the demand for 5G network characteristics. The network architecture and key technologies for 5G revolve around both the needs of the services themselves and the needs of the network operations, and as there are many different types of services in the 5G network, the network architecture for 5G should not be static and uniform. Instead, it should be able to take on different forms according to the characteristics of the services and communication scenarios, to achieve a user-centric and improved user experience. For example, for mobile cloud computing services, a layered architecture is used to enable edge computing, thereby reducing signaling overheads and service transmission delays.

For IoT services, a more simplified architecture is used to reduce the complexity of network management, thereby reducing network costs and hence the cost of IoT users. If considered from the perspective of the needs of network operations, achieving the matching of user needs and network resources in 5G networks, ensuring user experience and reducing operating costs, strengthening network openness, etc., is also an important development trend for 5G networks. A comprehensive analysis of the future trends in 5G network technology is as follow.

A. The use of SDN and NFV as the platform architecture process technology

SDN has had a transformative impact on network technology. The control plane and forwarding plane of traditional mobile communication networks are not completely separated, and the control platform cannot be centralized, which makes it impossible for the network to unify the control and scheduling of network hardware resources through a centralized platform so, it is difficult to achieve dynamic adjustment of network resources and programmable operation according to user needs, and it is impossible to make open innovation based on the characteristics of the network. This makes it difficult to allocate network resources on-demand and results in long deployment cycles for new services in the network. On the other hand, SDN has three main features: separation of control and forwarding, centralized control logic, and network programmability. Therefore, it is expected to be one of the supporting technologies for the new network architecture.

In traditional mobile communication networks, the logic and hardware of network equipment are tightly coupled, resulting in poor network scalability, difficulty in expanding and reducing capacity, and high deployment costs of new services. To solve these problems, the telecom industry has started to borrow the technical ideas of SDN. In November 2012, AT&T, Deutsche Telekom, China Mobile and 13 other major carriers in the world formed an NFV industry specification group at ETSI to study the use of IT virtualization technologies to transform carrier networks, using technologies such as Virtual Network Functions (VNF), Network Functions Virtualization Infrastructure (NFVi) and Management Automation Network Orchestration (MANO) in the NFV architecture. [15]This enables the functions of the nodes in the network to be implemented in software and enables functional reconfiguration and network orchestration only, allowing the network hardware infrastructure to use industry-standard high-capacity servers, switches, and storage devices.

SDN and NFV have no dependencies; SDN separates network forwarding functions from network control functions with the goal of creating centrally manageable and programmable networks, while NFV abstracts network functions from hardware. But using NFV and SDN creates a network architecture that is more flexible, programmable, and efficient in its use of resources.

B. Network implementation of dynamic slicing

Diverse communication scenarios put forward diverse performance requirements for 5G networks, and these diverse performance requirements obviously cannot be ensured by a unified network architecture so, 5G networks need to have the ability to virtualize slicing, so that each network slice can be adapted to different services and communication scenarios. Network slicing refers to the partitioning of a physical network into multiple independent virtual networks through virtualization technology, with each virtual network referred to as a network slice. The network functions in each network slice can be customized and trimmed to form a complete instantiated network architecture with dynamic network functions. This allows the network to adopt different network architectures according to different service characteristics, thus ensuring the performance requirements of communication scenarios, such as the introduction of localized control management mechanisms and data transmission mechanisms in ultra-dense scenarios, reducing the signaling overhead and the number of transmission paths in the network.

Satellite communications remain an indispensable tool in today's world because of several outstanding advantages such as wide coverage, low dependence on infrastructure and cost independent of distance. The 3GPP, ITU and the Sat5G Alliance have been working on the research and standardization of related technologies.

As a major infrastructure for space information networks, satellite communication systems can make up for the shortcomings of terrestrial 5G communications with their wide coverage, good communication quality and low operation and maintenance costs. [16]

- **Integrated satellite 5G convergence architecture research**

At present, based on satellite forwarding and on-satellite processing, whether the terminal and satellite access need to relay and other different, integrated satellite and ground architecture to achieve different ways, however, with the improvement of on-satellite processing capacity, the wireless access and other functions in the on-satellite implementation is the future development trend, including on-satellite access control, autonomous intelligent resource management, reducing service delays and other aspects. In line with the direction of 5G development on the ground, it is of great significance to carry out satellite function virtualization, satellite SDN, etc., which can make the unified orchestration and resource management of star-ground resources.

- **Research on the sharing of satellite and terrestrial dynamic spectrum**

As the most valuable resource for wireless communications, frequency resources are the first factor for network deployment and capacity enhancement, so the use of on-satellite only multibeam technology, inter-satellite frequency planning and frequency multiplexing technology, high spectrum efficiency of multiple access and other air interface transmission, as well as dynamic spectrum sharing, will be the key development in the future. For the user terminals in the network, realizing undifferentiated access to and obtaining seamless services for both terrestrial and satellite nodes within the network is the direction in which the future network needs to evolve.

Mobile communication through the development of 5G technology is a key goal for future development, although the current 4G network and the multiple standards included under it are very good in terms of both network rates and coverage. But looking ahead, 4G will not be able to meet the demand for new applications in the coming years, and we will be witnessing many applications related to the Internet of Things (IoT) and D2D (Devices to Devices). The European Commission say that the timely deployment of 5G networks will provide important economic opportunities in the coming years as a key asset for Europe competitiveness and sustainability, as a key enabler of future digital services. [17] Currently, in the case of the EU, as of March 2021, 5G commercial services have been deployed in 24 EU-27 countries: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Estonia, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Luxembourg, The Netherlands, Poland, Romania, Slovakia, Slovenia, Spain, and Sweden. [18] Based on the commercialization of 5G, big data generated by IoT applications will become the norm, as well as the cloud for computing, storage, and virtualized network functions. Figure 5 depicts the overlapping of these five major ICT trends.

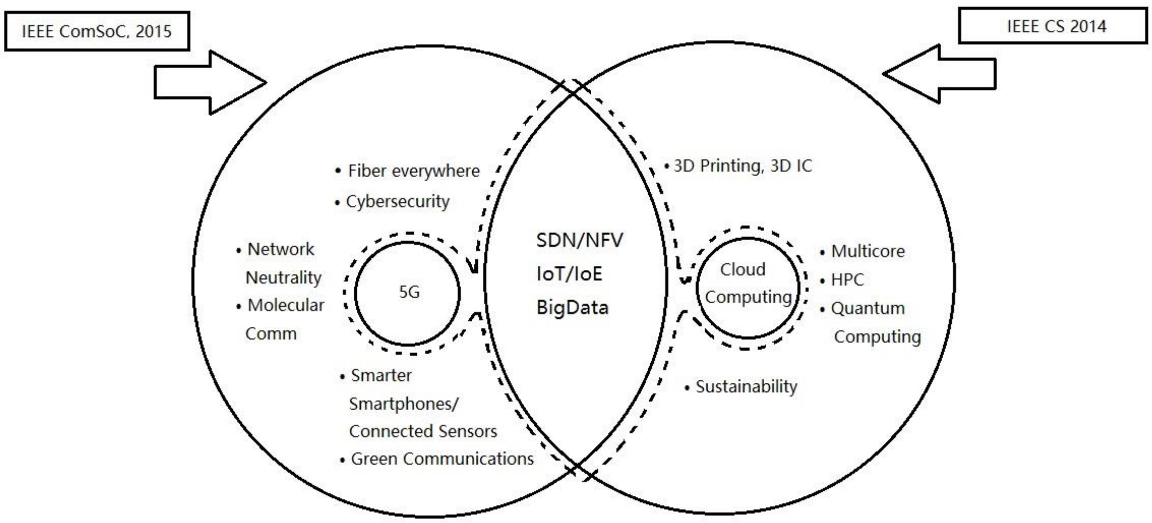


Figure 5: ICT major trends for 2015-2020 [19]

For the development of 5G, it should be more applicable to all kinds of wireless access technologies to have better gains at the economic level. For EU operators, 5G is a complete wireless communication with almost no limitations. And with 5G it is possible to send data faster than previous generations, bringing a truly wireless world where wearable devices using artificial intelligence are no longer limited by access and area issues. Creating a unified global standard network that provides ubiquitous computing, users can connect to multiple wireless access simultaneously and switch seamlessly between them directly, with access technologies that can be any access technology such as previous generations of mobile networks or Wi-Fi. 5G is not only the current generation of networks but more importantly, the revolutionary technological field of information and communication [20] with innovative network capabilities. [21]

Among them we can mention:

- The native support for MTC, according to which ad-hoc transmission processes are defined to efficiently handle cellular transmissions by reducing latency and energy to achieve small packet consumption.
- Small cell deployments, envisaging large-scale deployments of femto, pico, and relay units to extend coverage and capacity and reduce energy consumption.
- Interoperability, i.e., seamless integration between 3GPP and non-3GPP access technologies to enhance reliability and coverage.
- Access/core segment optimization, enabled by novel paradigms such as software-enabled and virtualized capabilities for network entities.

These features make D2D a very attractive solution to meet the stringent requirements of IoT for 5G network solutions.

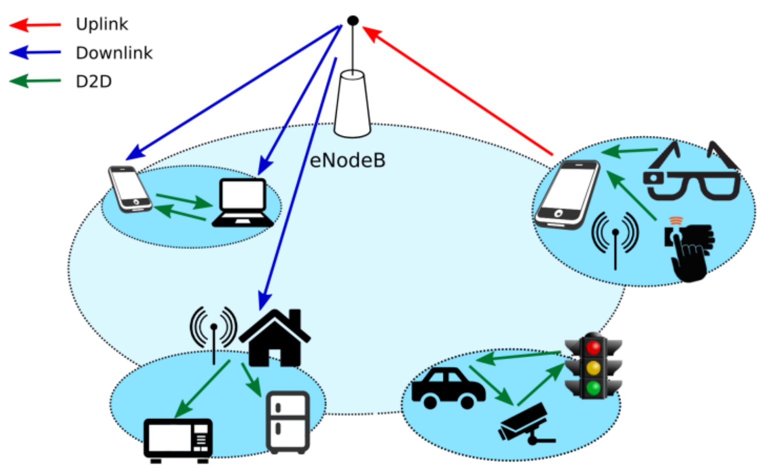


Figure 6: D2D communications in 5G IoT networks [22]

Currently, we have 10 billion IoT devices connected and 24 billion to 50 billion total connections expected within the next five years. In [23] the current situation in the IoT space has been compared to the Wild West centuries ago, with its vast, largely unexplored territory, with no clear boundaries, where all current technologies could work and where ad hoc solutions were usually the norm.

- For 6G thinking

5G does not primarily meet the need of human-to-human communication, but for the interconnection of everything from human to machine and machine to machine. In the long run, 5G is not the end. Its inability to solve problems such as global coverage in deserts, oceans, and other uninhabited areas will be a problem that 6G needs to explore and solve.

- Key technologies that need to be developed for 6G

6G will use the terahertz band of 100 GHz-10 THz to meet the demand for higher speed. Terahertz communication requires not only the development of communication technology but also high requirements for high-performance devices. For example, the preparation of high-power terahertz diodes, high-power rate terahertz solid-state electronic amplifiers, development of terahertz high-speed baseband devices, etc. [24]

Huge access to high-speed full coverage will lead to 6G networks and base stations densification It is expected that in the 6G era, the density of connected devices reaches more than a hundred per square meter, and 6G base stations need to meet the simultaneous access to hundreds and thousands of wireless devices, so more efficient and scalable ways to handle the large number of accesses need to be explored.

- Higher security technology

When everything people do is through their cell phones or stored in them. The current encryption technology can no longer meet all the new security, the development of biometric authentication technology, quantum computing, quantum encryption, etc. is an essential part of the development of 6G.

Relying on 6G technology, the future 6G may reach the framework of intelligent connection, deep connection, and holographic connection. A satellite communication network with seamless global coverage can be formed to enable any remote area to communicate with the outside world. 6G will drive the creation of new services and bring humanity into the "post-smartphone era". It will bring humanity into the "post-smartphone era", where everything will be connected.

3.2 The Future of fixed networks

In the global digitalization process, the fixed network is a strategic public infrastructure. In recent decades, communication technologies have undergone five epochs of evolution. (as shown in the Figure 7). However, there are still non-uniform standards for fixed networks such as those of ITU, IEEE, ETSI, BBF, etc., which make it difficult to unify and collaborate. ETSI launched the F5G online launch in February 2020 and announced the establishment of the F5G Industry Working Group for the world. [25]

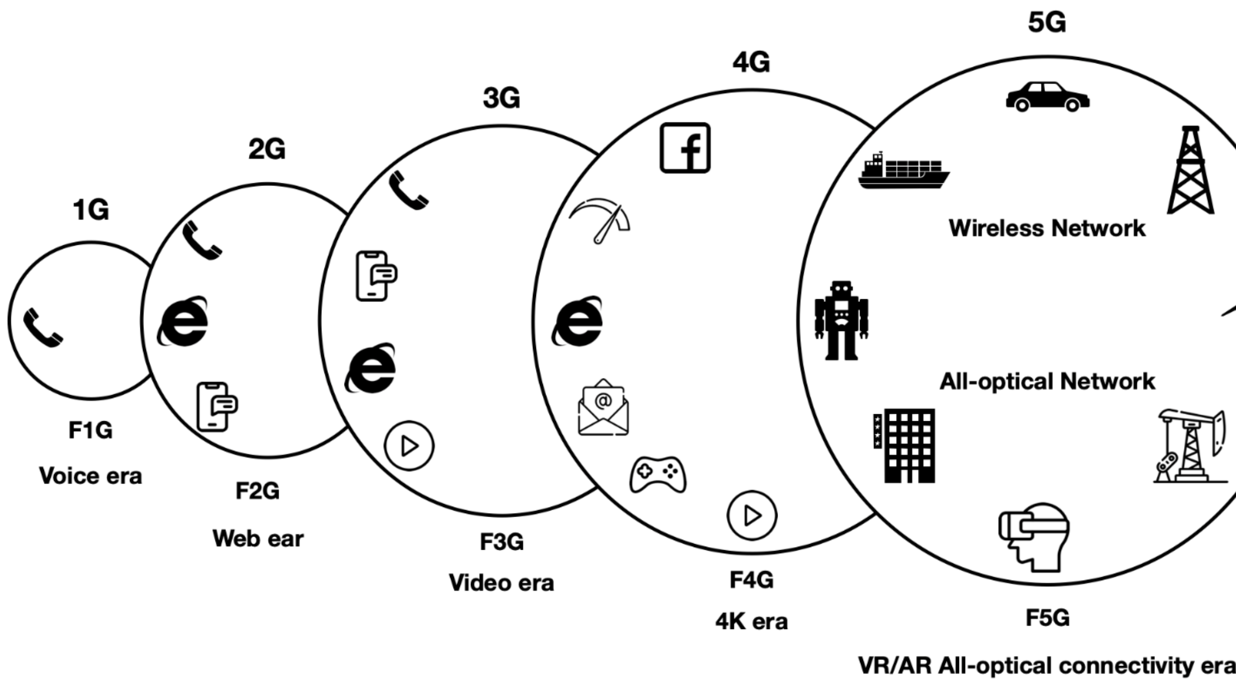


Figure 7: Intergenerational evolution of communication technology [26]

ETSI is an independent, not-for-profit European standardization organization for the telecommunications industry. ETSI collaborates closely with the European Commission and the European Free Trade Association. Based on ETSI's research, the design principles of F5G network are mainly the following.

- **Multi-Service Network Platform**

The currently deployed broadband network architecture, while allowing for the deployment of multiple services for different customer types but it is not flexible.

Multi-service network platform can be achieved by migrating from a fixed network architecture to an F5G network architecture that supports SDN and NFV. to achieve flexible service deployment. SDN centralizes the control plane function and provides a concentrated network management functions. NFV uses the virtualization technologies and cloudification to virtualize entire classes of network node functions into functions that are either stand alone or chained together to provide the desired communication service.

- **Dynamic and Flexible Service Creation**

F5G is expected to support enhanced fixed broadband (eFBB), full-fiber connection (FFC) and guaranteed reliable experience (GRE), which means a tenfold increase in speed, density of connections, etc. With respect to required basic, the F5G architecture is expected to support SDN and NFV. It focuses more on flexible service enablement, reliable network performance assurance and autonomous service deployment.

- **Decoupling Service Plane and Network Plane**

Broadband services should be decoupled from the underlying network infrastructure. This decoupling allows for independent upgrades to the network infrastructure without any impact or change to the service plane. However, certain interdependencies remain, especially in terms of which resources at the underlying layer can be used to provide specific services. Also, in the event of a failure of the underlying network, the quality of service may be affected. [27]

F5G network covers 10G PON, Wi-Fi 6-based gigabit access network with large bandwidth, low latency, and continues the high stability of fixed networks performance. At the same time F5G meets the requirements of VHCN:

In general, a VHCN-compliant network is an electronic communication network composed entirely of fiber optic elements, at least to the distribution point of the service location or an electronic communications network capable of providing similar network performance in terms of available downlink and uplink bandwidth, resiliency, error-related parameters, and latency and its variability under usual peak time conditions

For fixed network development, it is not enough to discuss the network aspect alone. Unlike mobile networks, fixed networks need a strong infrastructure as a driving force for their development. The European Commission noted that the COVID-19 crisis demonstrates that connectivity is essential for individuals and businesses and that high-capacity networks have been enabling remote work and schooling, healthcare, personal communication, and entertainment. [28] The European Commission said the pandemic has changed the economic outlook for the coming years. More than ever, investment and reform are needed to ensure convergence and a balanced, forward-looking, and sustainable economic recovery. The EU also recommended that countries should build on the Broadband Cost Reduction Directive to facilitate the rollout of high-speed networks by reducing deployment costs and ensuring that network providers and operators can share infrastructure. The EU's strategic goal of achieving a gigabit society by 2025 is based on the foreseeable connectivity needs of Europe digital society in the coming years [29] The goals for the 2025 Gigabit Society are:

1) Gigabit connectivity for all major socio-economic drivers (e.g., schools, transport hubs and major public service providers, as well as digitally intensive businesses).

2) 5G coverage in all urban areas and all major land transport paths.

3) Internet connectivity with at least 100 Mbps downlink, scalable to Gigabit speeds in all European households. [30]

3.3 Fixed and Mobile Convergence

The rapid development of both mobile and fixed access is based on the concept of user-centric services. The needs of users are ever-changing, and the development of multiple access methods allow users to access a wide range of telecom services across time, space, and access methods; it is impossible to cover everything with just one technology. Therefore, mobile, and fixed access technologies should be converged. Many international standardization organizations have proposed their views on FMC (Fixed Mobile Convergence) in the 5G era and have developed standards based on fixed-mobile convergence; the ITU awareness great importance to FMC, which is seen as a-must for 5G in ITU-T Y.3130. [31] The drivers for fixed-mobile convergence include business level and network level. The business-level drivers have mainly unified user accounting and authentication, unified billing, business continuity assurance, and service experience consistency. The drivers for the network include network construction and operation and maintenance cost reduction under the unified network architecture.

In the 4G era, access to a unified EPC converged core network enables interoperability between Wi-Fi and LTE. But the actual deployment by the operators is very rare, and the main application scenario is to provide VoWi-Fi to provide users with voice service mobility between LTE and Wi-Fi. In the 5G era, the range of fixed access has been expanded. In addition to the traditional meaning of Wi-Fi access, it also includes other fixed access methods. The above mentioned access enables mobile-fixed convergence by converging 5GC (5G Core Network). Compared to previous generations, 5G deployments can carry both EPC and 5GC in actual implementation. This is achieved by introducing 5GC in SA (Standalone Architecture) mode and EPC or 5GC in NSA (Non-Standalone Architecture) mode in 5G deployments.

The main scenarios for FMC services using converged 5GC are as follows:

- **Fixed network services via fixed or/and mobile access**

Endpoints of fixed broadband services (e.g., subscriber terminal equipment, or home gateways) can be controlled by Converged 5GC across the domain and connected to the Internet or to the cloud via fixed and mobile access. For example, users can have a portable home gateway that allows them to access fixed broadband services when they are at home. When going out, they can take this home gateway with them and connect to the network via mobile access. The users can use the same identity to connect to the Internet at the terminal of the Wi-Fi hotspot created by the home gateway, and the home gateway can access the 5GC network provided by the same operator.

- **Mobile network services via fixed or/and mobile access**

Endpoints for mobile broadband services (e.g., cell phones) can be performed by converged 5G controlled throughout the domain and can be accessed via fixed and mobile access to Converged 5GC for Internet access and access to the cloud. For example, subscribers to mobile broadband services are being served via 5GC based on IMS for voice calls. When the subscriber walks into his house, the cellular overlay coverage is too weak to provide enough bandwidth for this call. Converged 5G detects this situation and can seamlessly switch the mobile device to a home gateway in the home Wi-Fi hotspot at home. The voice call continues, and all packets of this conversation are not lost. packets of this conversation are not lost.

With the FMC offered by 5GC, subscribers can enjoy a seamless service experience and ubiquitous service availability, and service providers can provide seamless service implementation for both fixed and mobile access networks.

Chapter 4: Conclusions and discussion

In this thesis, I have analyzed the current status and future perspectives of fixed and mobile networks. Fixed networks still exist based on ADSL/VDSL, but they cannot meet the increasing bandwidth demands due to new interactive multimedia services, cloud computing and IoT. The importance of fixed networks with high capacity, high speed and high stability could be seen in the COVID-19 crisis. In the context of global development, fixed networks represent the strategic public infrastructure. My conclusion is that the future development should be seen in unified collaboration through further deployment of fiber and unification of fixed networks in the F5G.

For mobile networks, I have briefly outlined the evolution from 1G to 5G. 5G is now mostly in NSA (Non-Standalone Architecture) mode, still dominated by 4G-era architecture, as 4G capacity can no longer meet the significant increase in the number of users accessing the network in the future. 5G future development stems from the demand for new 5G network features; therefore I believe that SDN and NFV should be used as the key promising technologies which, along with dynamic network slicing, shall give the 5G networks the ability to virtualize slices to adapt to different services and scenarios, allowing more flexible, programmable and efficient use of network resources. The satellite 5G converged architecture should also be integrated to achieve dynamic spectrum sharing between the satellite and terrestrial segment in the future to complement terrestrial 5G communications.

In the long-term perspective, it is necessary to consider the 6G technology as well. It is assumed that in the future, the terahertz band can be developed to meet the demand for higher speeds. Relying on the 6G technology, the framework of intelligent connectivity, deep connectivity and holographic connectivity can be reached in the future to form a communication network with seamless coverage in key regions around the world, bringing humanity into the “post-smartphone era”.

Through specific analysis of fixed and mobile networks, I believe that the important future development trend will be the convergence of fixed and mobile networks, based on a user-centric concept to form a converged network under a unified network architecture. The converged network with unified billing and consistent service experience from the service aspect will reduce the network construction, operation and maintenance costs.

Finally, this thesis on the current state of fixed and mobile networks reflects the insufficiency of the current network infrastructure in the EU for all aspects of future development, for better understanding and prediction of the development and the real changes it will bring to people’s lives, based on the future trends, the envisaged challenges and their possible solutions. I assume that the future development will bring 6G mobile network and a fixed network with full fiber access as a base, supplemented by a satellite network as a full-coverage type of network. It is not just a simple breakthrough in network capacity and transmission rate, it is to narrow the digital divide and achieve the goal of interconnection of everything, which will also meet the future demands for new applications such as holographic communication and metaverse. It will realize efficient and intelligent interconnection of people with people, people with things, and things with things in the physical world, and create a ubiquitous and fine, real-time and reliable, organically integrated digital world.

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