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Fiber To The 5G Small Cell – FTT5G: A Survey

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Abstract

The deployment of 5G networks requires high-capacity, low-latency connectivity to support the increasing demands of modern communication services. Fiber to the 5G small cell (FTT5G) has emerged as a crucial solution, enabling efficient small cell deployment by leveraging fiber-optic networks for reliable backhaul and fronthaul connectivity. This paper provides a comprehensive survey of FTT5G architectures, deployment strategies, and technical challenges, with a focus on Fiber-to-the-Home (FTTH) and Fiber-to-the-X (FTTx) solutions. The study highlights the role of fiber in addressing the bandwidth and scalability challenges of 5G small cell networks, ensuring seamless data transmission for next-generation applications. Additionally, the paper examines the economic and regulatory aspects of fiber deployment and explores strategies for cost-efficient network expansion. By offering insights into the integration of optical and wireless technologies, this survey serves as a valuable resource for researchers, industry professionals, and policymakers aiming to optimize fiber-based 5G infrastructure and enhance network performance.

Keywords: 5G, Fiber to the 5G, FTT5G, FTTx, Wireless Technology, Optical Communication, PON.

1. Introduction

“Fiber optics are the backbone of 5G” This is a recurrent quote in recent blog posts. Said to be a crucial enabling technology for efficient initial 5G rollouts, significant optical network improvements have been widely expected in the near decade [1]. However, more recently, the prominent industry news sources, analyst opinions and presentations of industry insiders have created an impression of being much more conservative. Cignal AI says that, amid early claims that 5G must be upgraded to understand its capabilities, network providers are building the radio network before improving the optical network. A recent post on Light Reading summarizing an OFC panel discussion titled “5G Applications and Networks: Real World Operator Case Studies” revealed that operators are not offering vendors too much to be excited about [2].

A new generation of optical networks is required to unleash the full potential of 5G communications and to prepare the network for beyond 5G. In 5G, the basic requirements of the new class of modern, ultra-reliable and low-latency services (such as autonomous driving, or virtual reality) are influencing the evolution not only of the wireless/radio category but also of the higher-tier optical wired segments, ranging from access to heart

Several daunting opportunities emerge which can fundamentally alter users' network experiences (to name a few, multi-sensorial and holographic communication, pervasive machine learning,

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coordination of heterogeneous access technologies, and quantum communication). Although this is just a "vision" of the future, definitely optical communication networks in the future are going to be greater than ever. Based on technological advancements that feature in-built hardware protection, the lower latency, sub-linear bandwidth scalability and reconfigurability of devices would be necessary. We must never neglect the need to explore potentially disruptive solutions at both control and data plane [3].

2. Global Mobile Data Growth

The rapid growth of mobile data usage is shaping the evolution of communication networks worldwide. As digital services expand and user demand for high-speed connectivity increases, mobile networks must adapt to accommodate this surge in traffic. This section explores the trends in mobile data growth and broadband efficiency across different regions.

2.1 Traffic Growth in Mobile Networks

According to [4] based on new estimates, smartphone accounts for nearly half of all web traffic. 50% of the global website traffic are generated by mobile devices (excluding tablets) in the first quarter of 2019. Some countries have a higher number of internet browsing using mobile than other devices. Lots of developing countries grew as cell phones became more expensive. The African nation, Nigeria, leads the world with mobile web traffic being more than the global average.

Mobile video and game updates are only a couple of the mobile Internet practices that need adequate speed. Norway was named as the first country in the world that had the highest overall mobile Internet speed. Nevertheless, network quality remains a crucial concern when it comes to mobile Internet. In 2018, 98% of the European population had mobile broadband access and just 2% of the population did not. There was a major absence of digital connectivity standards in Sub-Saharan Africa. Figure 1 represent the growth of data traffic between 2017 and 2022 measured in exabytes [5].

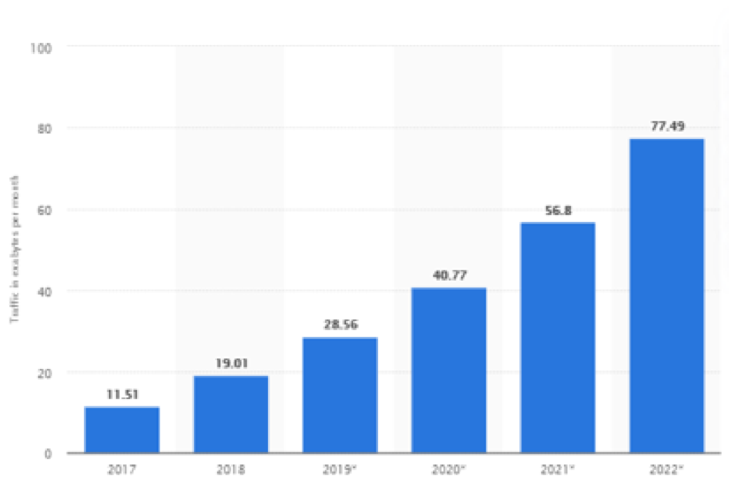

Figure 1: Mobile data traffic between 2017 and 2022

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Most of the traffic to and from Asia Pacific will come from mobile devices in the upcoming decades, rendering Asia Pacific the largest consumer by far by 2022. Traffic will be less controlled by North America by 2022, and this will happen primarily because Asia will be passing the region to become the largest traffic network. The Middle East and Africa will benefit more in terms of development due to projects undertaken in this area. As the Asia Pacific economy's growth rate looks highly promising, a major upturn in investment is expected to be reported as shown in Figure 2 [5].

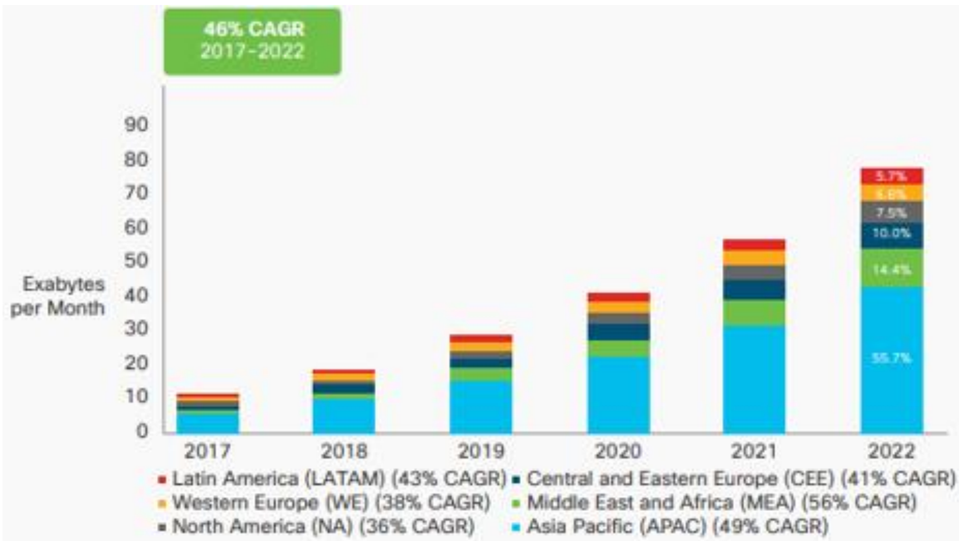

Figure 2: Global mobile data traffic forecast by region

2.2 Comparing Broadband Efficiency in Different Countries

In 2017, the world's average cell connectivity speed was 8.7Mbps. In this way, average broadband download speed will begin to rise at 26.7% CAGR, and hits 28.5 Mbps by 2022. Mobile is expected to have been completely on par with the global average pace by 2022. The cell phone speed will increase, in term of data package speed, tripling by 2022.The findings on behavioral dimensions of time utilization strongly reinforce the belief that use improves with time savings. In developed markets, evidence has shown that speed increase would not have an impact on mobile data use. The Cisco Visual Networking Database, or VNI, is one of the more recent inventions in that area. Many of the patterns in the subsequent traffic forecast can be found in the speed forecast. For example, strong development rates are seen for emerging nations and regions compared to industrialized countries and regions as it represented in Table1[5][6].

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Table 1: Mobile data speeds of 2G, 3G, 3.5G, 4G and 5G through 2022

	2017	2018	2019	2020	2021	2022	CAGR 2017–2022
Global							
Global speed: All Connections	8.7	13.2	17.7	21.0	24.8	28.5	26.7%
Global speed: Smartphones	13.5	14.9	22.1	25.9	34.8	41.6	25.2%
Global speed: Tablets	22.6	24.5	25.9	32.9	40.5	57.2	20.4%
By Region							
Asia Pacific	10.6	14.3	18.0	21.7	25.3	28.8	22.1%
Latin America	4.9	8.0	11.2	13.0	15.3	17.7	29.6%
North America	16.3	21.6	27.0	31.9	36.9	42.0	20.9%
Western Europe	16.0	23.6	31.2	37.2	43.8	50.5	25.8%
Central and Eastern Europe	10.1	12.9	15.7	19.5	22.8	26.2	21.0%
Middle East and Africa	4.4	6.9	9.4	11.2	13.2	15.3	28.0%

3. Optical Access Network Evolution Towards FTTH and FTT5G

This section explores the historical development and transformative journey of optical access networks, from the early stages of optical communication technology to the current advancements in Fiber to the Home (FTTH) and Fiber to the 5G (FTT5G), highlighting key innovations that have paved the way for the high-speed, high-capacity networks of today and tomorrow.

3.1 Optical Access Network Evolution

The history of optical communication dates back to the 1790s which the first optical semaphore telegraph was created by a French inventor. In 1880, Alexander Graham Bell invented the Photophone which was the first optical telephone device. Moreover, his earlier invention, the telephone, was more appropriate and had a concrete structure. The Photophone was never a practical invention, and ceased to exist. In the 1920s, John Logie Baird and Clarence W. Hansell pioneered the concept of using clusters of hollow plastic pipes or transparent rods to relay images for television or facsimile systems.

Abraham Van Heel is further remembered for his significant added contributions. Inspired by an analogy by the American physicist Brian O'Brien, Van Heel invented the cable cladding technique. All prior fibers were bare and lacked any sort of cladding, until now that fiber was invented. Abraham Van Heel applied a lower refractive index transparent coating to a bare fiber or glass or plastic. This provided the defense against contamination while significantly reducing cross-talk between fibers. Glass-clad fibers were able to attenuate 1 dB of signal power per meter in 1960, adequate for medical imaging, but too powerful for communications. In 1961, Elias Snitzer of American Optical Inc. proposed a theoretical model of a fiber with a center small enough to have only one mode of propagation. Snitzer's idea for the construction of an optical fiber was acceptable for a medical instrument looking inside the person, but its attenuation was only 1 dB per meter. Communication devices for long-distance communications required a loss of no more than 10 dB per kilometer and were light in weight.

In 1960s the begin of optical communication but Only a few modern scientists used them for optical communication. The biggest issue was that a few decades ago, optical fibers were so inefficient that only 10% of light entering at one end of a fiber exited at the other end of a fiber

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that was only a few meters long. Most engineers rejected them for communication applications because only light had to be transported over a minimum distance. In 1966, it was suggested that impurities in silica could be minimized to minimize losses in optical fibers. It was also suggested that such low-loss optical fibers could be the best option for optical communication [7].

Indeed, Charles Kao was awarded one-half of the 2009 Nobel Prize for his ground-breaking work on light propagation in fibers. The concept of using glass fibers for transmitting optical signals was innovative because they could direct light like the confinement of electrons inside copper wires. Therefore, electric wires may be used similarly as they are now.

The first generation of near-infrared laser diodes was designed to work at 45.2 Mbit/s since GaAs semiconductor lasers are used for making them emit light at wavelengths near 850 nm. Since the signal loss at that wavelength was close to 3dB/km, the opto-repeater was used to regenerate the signal every 10km or so. Before optical cables the waves are transmitted via air which allows people to watch TV or listening to radios. The main problem in airwaves that the receiver device must be near or visible by the infrared region. Optical fibers transmit light over long distances, irrespective of environmental conditions, by confining light to a microscopic cylindrical center through a process known as complete internal reflection [7].

3.2 Fiber To the X (FTTx) Development

The development and implementation of photonic technology, optical techniques, and fibre-optic networks has dramatically increased the transport system's potential. This was followed by the seeming increases in capability at the end user side making possible handling of high bandwidth resources like symmetric peer-to-peer, HDTV broadcasting, remote storage, e-services and grid computing[8]. FTTx (fibre to the home/ curb/ building/ premises) is just one of the technologies now explored to spread these broadband networks, employing wireless and wired technologies both fibre and copper-based [1]. Using FTTx is the most future-proof technology available for delivering triple-play services, employing all forms of technologies, such as active Ethernet and traditional Passive Optical Networks (PONs). FTTP has become the world's standard for internet connectivity introduced mainly by major carriers and local governments. Among the separate two forms of PON technologies EPON and the GPON are the often deployed standards[9].

3.3 Fiber To the Home (FTTH)

FTTH allows providers to provide optical signals to supply networks in the building, thereby facilitating contact between devices within the home or business. Fibre for home is a modern, fast-growing means of increased speed for telecommunications, cable TV, and Internet use. In this technique, the standard systems used are EPON and GPON. This means that users have an expanded ability of bandwidth over the public Internet. Present fiber optic infrastructure allows for speeds up to 100 megabits per second on both the transmitting and receiving ends. In addition, as cable modem and DSL technology suppliers are devising more ways to gain greater bandwidth from their techniques, fiber optic equipment are continuously enhancing without having to patch the fiber [10].

FTTH concept originated in the US with test implementations in 1989. In 1994, a corporation in Japan also carried out trials. This experiment showed that this technology is justifiable for

Pakistan. These are the new functional methods, not tests or research. Canada and Japan. Optical fiber cable was commonly used in the core network. Service providers are implementing IPv6 because of its capabilities for the future [11].

3.4 Fiber To The 5G (FTT5G)

Fibre-optic communication networks will continue to develop in the future because they will provide higher capacity and broader application space, particularly in interworking with the next-generation wireless networks. Incredibly wireless.

The connection has undergone dramatic breakthroughs in recent years. 1G, 2G, 3G, and 4G broadband technologies were usually used from the 1980s through the 2010s [12] .The cell phone and mobile connectivity have affected our culture tremendously by offering vital means of conversation and information sharing such as mobile voice communication, instant messages, mobile internet and smartphone communication. This is especially important since the fifth-generation wireless technologies will be launched by 2020.

There is one major problem for fixed broadband providers. This is why they are offering a Gigabit speed to all. It can be difficult to provide high-speed data since the fiber does not go to the house itself. Although 5G FWA technology can fill the complete distance, fixed wireless access (FWA) allow for a fast connection to serve the last mile where fiber optic connectivity cannot exist. For telecommunications companies, FWA would encourage them to try rising money outside of their primary phone markets, such as landline revenues [13].

Communities of fibre-to-the-home FTTH have already shown their ability to handle the rise in access points while connecting 5G cell sites. 5G offers a strategic, long-term option for bandwidth-intensive networks while FTTH operators will complete their Gigabit broadband projects by extending beyond premises that Fiber can't penetrate.5G is supposed to have a major effect on our daily lives, starting in personal usage to innovative new applications, ranging from autonomous cars, first responder systems, to smart cities. But it can't do it on its own: the key to a high-performance 5G network is a high-performance FTTH network [13].

4. Evolution of Mobile Communication

This section traces the remarkable progression of mobile communication technologies, from the early analog systems of the first generation (1G) to the advanced, high-speed, and low-latency networks of fifth-generation (5G). We explore the technical advancements that have shaped each generation, the rise of new access techniques, and how these innovations have enabled the connected world we live in today.

4.1 Wireless Technologies Evolution

One of the most successful and influential technology advances in modern history has been mobile communication [14]. More than a few decades have passed since the first generation of mobile wireless communication, with voice systems only, was initiated. The world has seen a gradual, but steady development of mobile wireless communications towards second, third and fourth-generation wireless networks during the last couple of decades[15], and recently fifth generation has been deployed in various parts in different cities around the world and is growing gradually. The following is an overview of wireless communication technologies evolution.

4.1.1 First Generation (1G)

The first generation launched in early 1980, it is analogue-based technology which provides basic voice communication services [16]. The primary subscribers of 1G were from North America, the United Kingdom, Scandinavia and Japan. The data rate was up to 2.4 kbps, bandwidth of 30 kHz and it used FDMA (Frequency Division Multiple Access) transmission technology. It has different disadvantages related to security, limitations in subscribers and voice services, also it lacked to a united international standard, etc. [14].

4.1.2 Second Generation (2G)

In the late 1990's the second generation was established. 2G is based on digital transmission, in which the Global System for Mobile Communication (GSM) stand has been used [17]. Voice communication quality improved and other services such as SMS (Short Message Service) and email were provided in 2G. Furthermore, Code Division Multiple Access (CDMA) technique is utilized. Later 2.5G was introduced which was enhancement of 2G, added some features and combined with GPRS (Global Packet Radio Services). Moreover, it employed circuit switching with packet switching. The data rate assisted up to 144 kbps[18].

4.1.3 Third Generation (3G)

3G is initiated in the late of 2000. In this generation system, high-speed services are provided which based on IP (Internet Protocol). The transmission rate was up to 2Mbps. Which enhanced capabilities of audio and video streaming services, global roaming services, (MMS) Multimedia Message Services and QoS. 3G utilized technologies like W-CDMA (Wide-Code Division Multiple Access) and HSPA (Higher Speed Packet Access) which is merging of HSPUA for Uplink packet access and HSPDA as Downlink packet access. The third generation has some disadvantages such as energy efficiency, and compatibility with previous cellular technology generations [14] [16] [18].

4.1.4 Fourth Generation (4G)

The fourth generation is the successor and the descendant of 3G and 2G standards. LTE (Long Term Evolution) advanced standardized as 4G by 3GPP (3^{rd} Generation Partnership Project) along with WIMAX (Mobile Worldwide Interoperability for Microwave Access) [18]. 4G is an IP-based system network which doesn't support circuit switching [17]. OFDM (Orthogonal Frequency Division Multiplexing) technology which radio access based utilized which provided transmission up to 20MHz bandwidth, with advanced transmission of multi-antenna. Higher spectrum efficiency enabled by multi-stream transmissions a high data rate that is supported by the major technology MIMO (Multiple-Input Multiple-Output) [14]. Many applications with 4G compatibility were created such as DVB (Digital Video Broadcasting), (HDTV) High-Definition TV, video chats, and MMS [18]. In LTE the peak mobile data rates has been increased up to 100Mbps, and as the wireless communication technology in development continuously, the demand increases every year. However, the continuously growing traffic in mobile data leads towards the fifth generation of cellular communication [14]. Figure 3 summarizes and illustrate the key evolution of the four generations (1G to 4G) of cellular communication systems [14].

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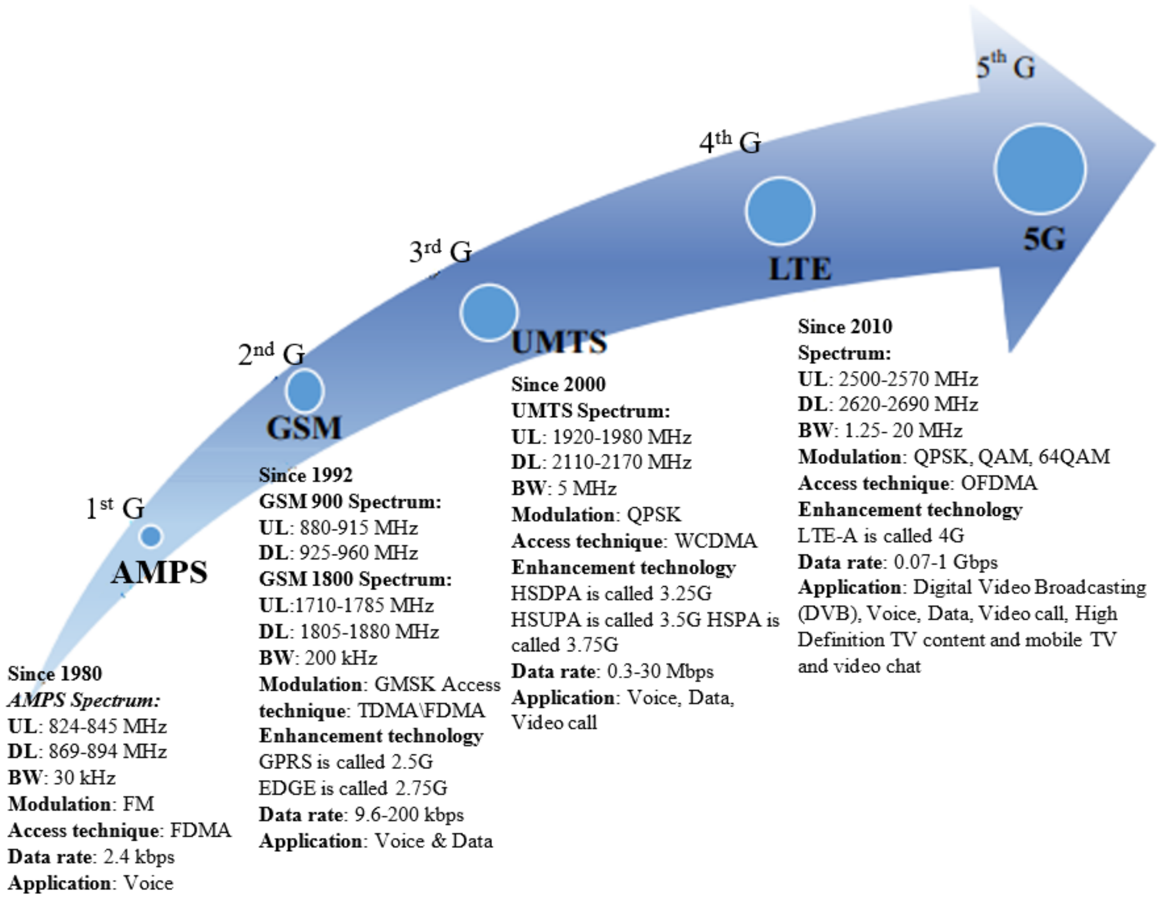

Figure 3: The key evolution for the four generations of cellular communication networks [14]

4.1.5 Fifth Generation (5G)

The number of people using cellular communication services has steadily increased as technology has improved and expanded into more areas of people's lives. In addition, to meet the demands of all users for a smarter, safer, and quicker wireless network, more bandwidth is required to carry more data at a greater pace [19]. 5G is considered as an important evolution of 4G networks. 5G is designed to accommodate today's modern society's wide increase in data and communication, the Internet of Things with billions of connected devices, and tomorrow's innovations [20]. Intense 5G experience, efficiency, and performance standards, along with the vision of "everything connected," [21] are driving the gradual implementation and deployment of 5G cellular communication technology in different parts of different cities around the world. The opportunities it offers are promising. With 5G, massive machine connectivity is achieved through the use of the NOMA (Non-Orthogonal Multiple Access) method [22].

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A. 5G System Architecture

The 3GPP 5G system, similar to earlier cellular communication networks, specifies an architecture of functional blocks rather than a method for establishing communication between end points and user equipment. In terms of functionality, Figure 4 represents the 5G core architecture or system architecture [23] [24].

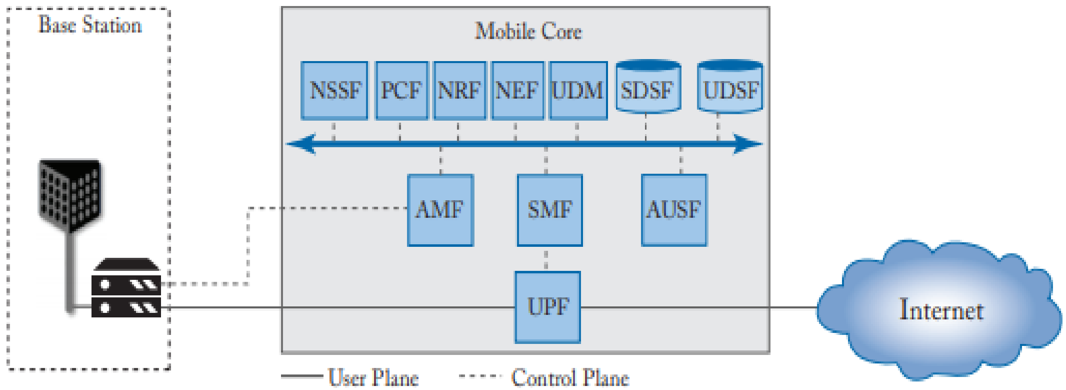

Figure 4: 5G Basic System Architecture

There are three categories into which the set of functional parts is classified. The first set of features, found in the Control Panel and their EPC counterparts, consists of the following: AMF, SMF, PCF, UDM, and AUSF, or Core Access and Mobility Management, Session Management, and Unified Data Management, respectively. The second set of functions is NSSF (Network Slicing Selector Function), SDSF (Structured Data Storage Network Function), NEF (Network Exposure Function), NRF (NF Repository Function), and UDSF (Unstructured Data Storage Network Function). However, these functions do not exist in CP. As for the final set, they're all User Plane Function (UPF) implementations [23].

Due of its heterogeneity, 5G cellular design must incorporate microcells, macrocells, tiny cells, and relays. When seen in this light, the importance of both the front end and the backhaul networks is equal. Operate within 4G networks until 5G fully develops to standalone networks. Figure 5 describes the various emerging technologies interconnectivity such as MIMO (Multiple Input Multiple Output), RN (Radio Networks), NFV (Network Function Virtualization), etc., [20].

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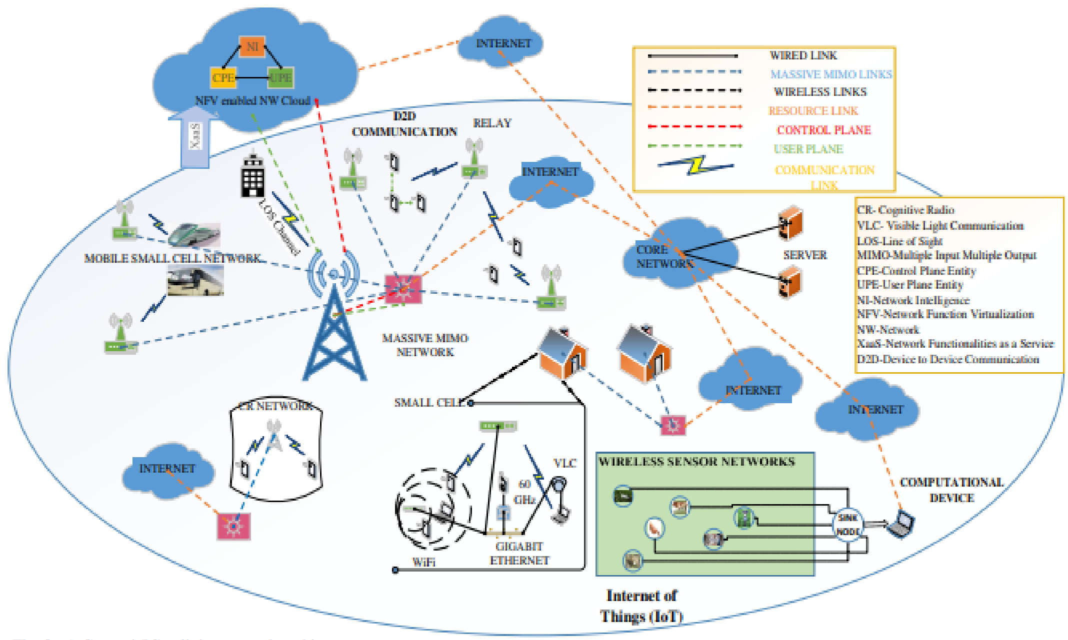

Figure 5: General 5G Cellular Network Architecture [20]

B. 5G Spectrum Utilization

Figure 6 depicts a radio frequency range of 3-100 GHz, with the new 5G spectrum above 6 GHz. This indicates that 5G will increase the utilization of spectrum resources, leading to larger bandwidth. Additional radio services (Wi-Fi, Satellite, TV, and Fixed Links) are also shown for convenience [20].

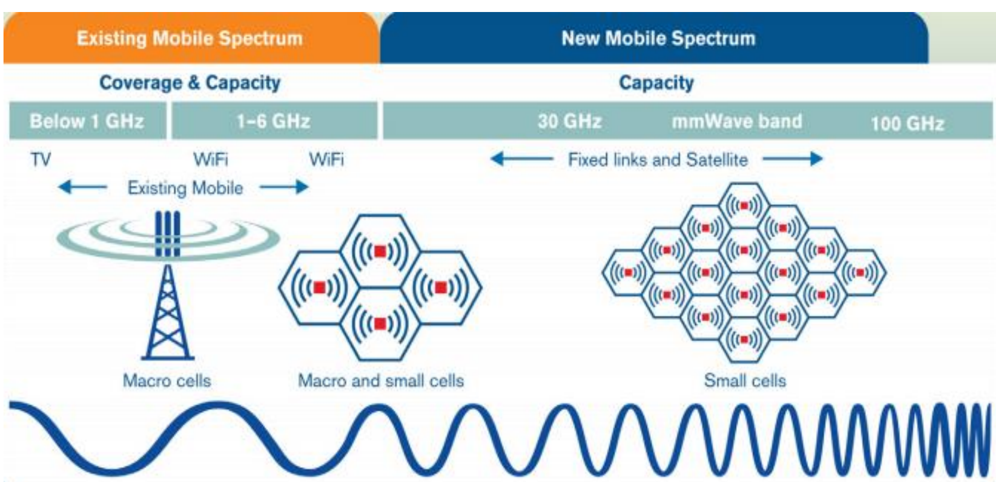

Figure 6: 5G spectrum shows frequency range from 3-100GHz

One of the most significant points in 5G even upgrading in earlier generations to understand is bandwidth. With 5G, customers will have access to limitless networking capabilities, large data bandwidth, increased data rates, more capacities, faster speeds, gigantic connectivity, improved quality of service, extensive signal coverage, and a plethora of other high-quality services. In addition, 5G has achieved low latency, which means faster response time compared to previous generations. Ultra-Reliable Low Latency Communications (URLLC) systems have less than 1 MS of latency, and improved mobile broadband has roughly 4-5 MS of latency [25]. From sub-3 GHz, which is used in 4G, to 100 GHz and beyond, the spectrum was stretched. Ultimate capacity, low latency, and multi-Gbps throughput can be achieved by operating in both mmWave (e.g., 24GHz and higher) and lower bands (e.g., sub-6GHz) [26].

C. Multiple Access Techniques in 5G

Wireless communication systems rely on multiple access as a foundational component. It makes a huge difference when considering latency, available spectrum, and system throughput. In the context of cellular radio, multiple access refers to a strategy where multiple users establish communication links to the base station (BS) by sharing radio resources [27].

In 4G, the uplink channel uses Single Carrier - Frequency Division Multiple Access (SC-FDMA) to control the greater peak-to-average power ratio [19], while the downstream channel uses Orthogonal Frequency Division Multiplexing (OFDMA). The enormous overhead caused by orthogonal transmission will result in unacceptable delay, but 5G's massive interconnectedness and the proliferation of connected devices will make this tolerable. In 5G, the NOMA technology is used to provide massive machine access [22].

The NOMA system efficiently takes advantage of the channel gain differential between users to achieve great spectral efficiency. In a multiple-user access (NOMA) network, numerous users can use the same spatial-time-frequency resource for uplink transmission, or for downlink transmission, multiple users can utilize the same resource for eNB [28]. There are two basic types of NOMA schemas: power-domain and code-domain. Due to the BS's computationally expensive decoding, uplink NOMA in power-domain NOMA is better suited to serve numerous users than downlink NOMA [27].

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The user is given a specific degree of power, and several users send out signals using that power, all while sharing the same time-frequency-code resources [29]. Nomadic orthogonal multiplexing (NOMA) power multiplexing, downlink, and uplink are illustrated in Figure 7 [30].

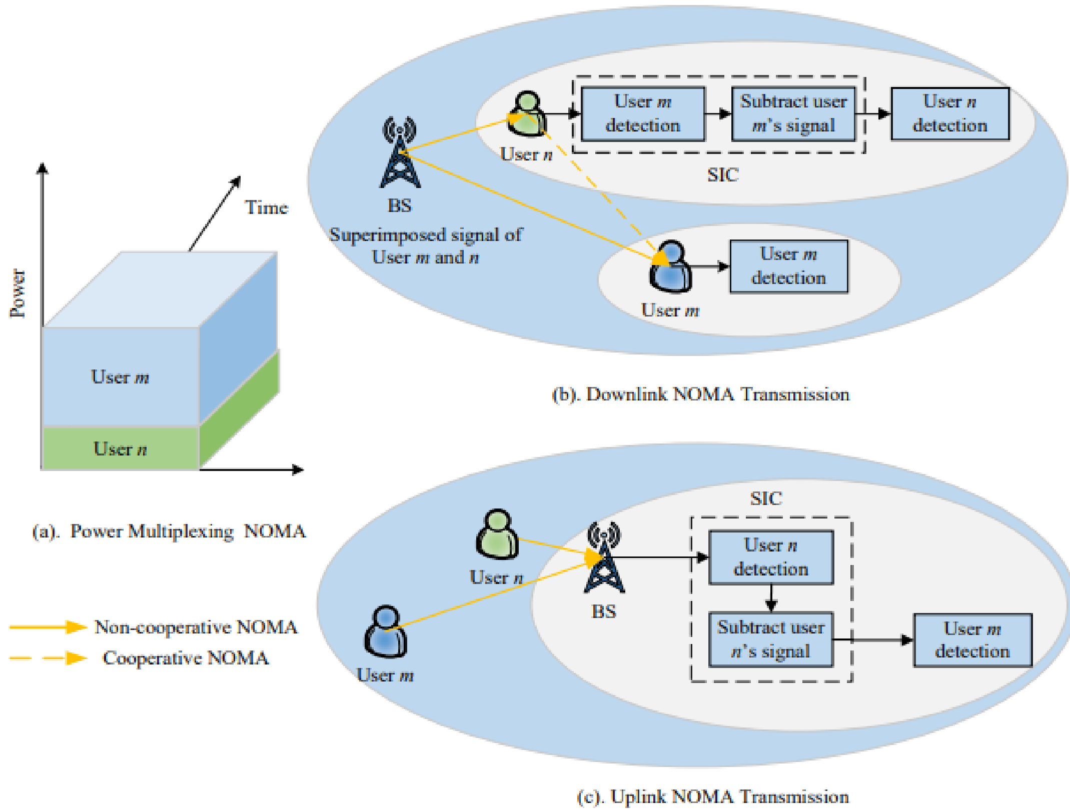

Figure 7: Illustration of NOMA transmission

D. Opportunities and New Services Provided by 5G

In order to provide a wide variety of use cases and the efficient dissemination of the idea of smart city (everything is connected), 5G wireless communication systems are the fundamental technology. Depending on the specifications and type of devices, 5G technology is expected to provide a diverse range of services that extend beyond human-type communications. There will be demonstrations of 5G's new macro-application services in areas including industrial automation, home digitalization, telepresence, public safety, and other public utility systems [22].

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Improving bandwidth is just one of many things that 5G is all about. The potential of 5G lies in its ability to expand broadband connectivity to include a broader range of edge services and devices. These include support for immersive user interfaces (e.g., AR/VR), the IoT, and mission-critical applications (e.g., autonomous vehicles, public safety). Users should expect 5G to facilitate not only smartphone Internet access, but also the coordinated actions of swarms of automated machines, including but not limited to household appliances, industrial robots, and autonomous vehicles. For all of this, a completely new architecture is required [23]. Figure 8 presents the applications and services supported by 5G [24], while Figure 9 shows an example of a 5G application in terms of everything connected [21].

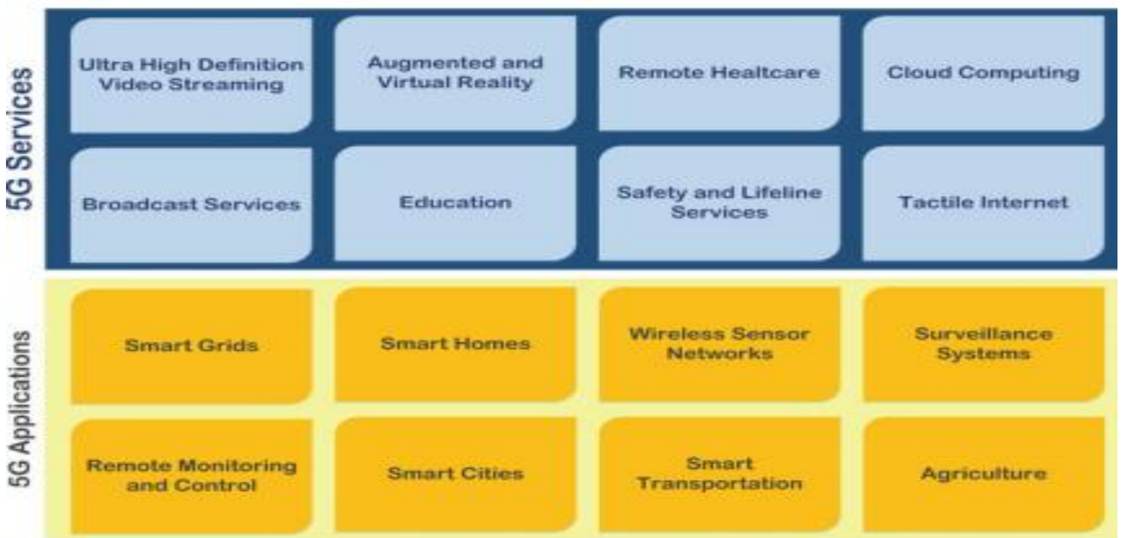

Figure 8: 5G Market Applications and Services

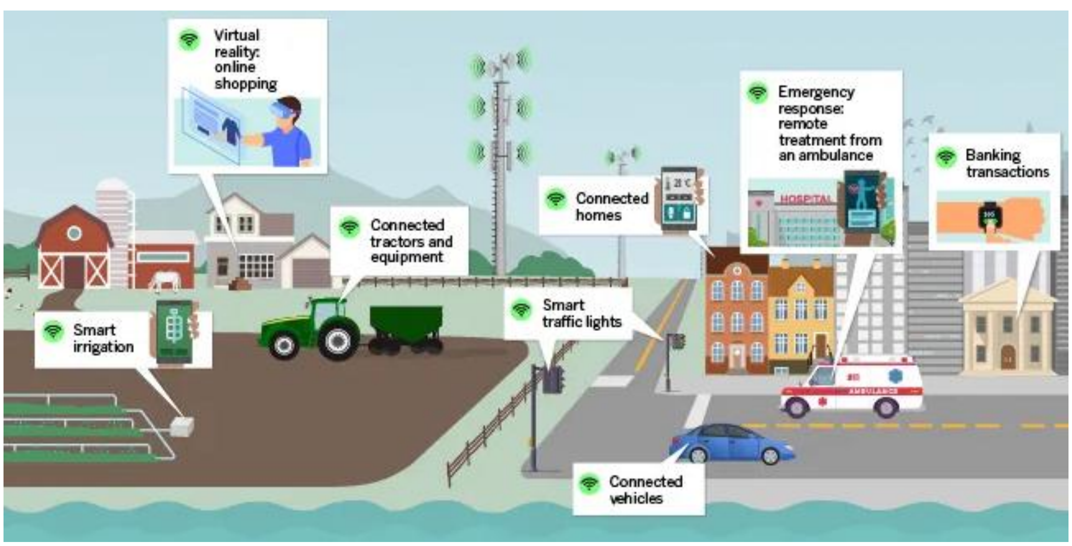

Figure 9: 5G Market Applications and Services

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5. Fiber to the Home (FTTH) and Fiber to the 5G (FTT5G)

Fiber-optic technology has revolutionized high-speed broadband networks, offering vastly improved internet performance compared to traditional copper cables. Fiber to the Home (FTTH) and Fiber to the 5G (FTT5G) are two key technologies transforming how internet and telecommunications services are delivered. FTTH connects fiber-optic cables directly to individual homes, enabling high-speed internet, television, and phone services with minimal latency. FTT5G, on the other hand, plays a critical role in enabling 5G connectivity, as fiber networks are necessary to support the high speeds and low latency demanded by next-generation mobile networks. This section will explore the architecture, benefits, and growth of FTTH networks, as well as the role optical fiber plays in the deployment and advancement of 5G technologies.

5.1 Fiber to the Home (FTTH)

Racing with 4G, 3.9G and also satellite technology, terrestrial broadband networks are developing high-speed fiberoptic network that require speed in communication. This happens to you, too. How much data does your high-speed broadband provide you? Usually, it is about 1.0 MB and 10 MB. FTTH technology would offer at least 100Mbps per residence if Point to Point technologies are used. this is possible because of the development of Internet bandwidth speed worldwide. about 0.1Gbps access to our homes Whatever are you going to do with so many things at once That's a small detail, but it is an interesting story for some subscribers.

The cost of deploying high-bandwidth networks such as the FTTx networks has been reduced substantially through the creation of modern network architectures. These include FTTC for fibr to the curb, also known as FTTN or fiber to the node, FTTH for fiber to the home and FTTP for fiber to the premises, use of "premises" to include houses, apartments, condos, small businesses, etc. Recently [31] .

There are two main architectures for FTTH. The point-to-point (P2P) architecture and the other architecture technology is using PON connectivity. It is known as (P2M) point to multi-point connectivity.

5.2 Point to Point architecture (P2P)

A Point-to-point architecture has more edges than hubs. A hub-and-spoke network has a main central office switch, which links over optical fiber cables to a distribution point usually at a street corner. Switches have several fiber ports, which directly link to OTN, which are located indoors or outdoors the customer's premises. Figure 10 represents the structure of P2P deployment.

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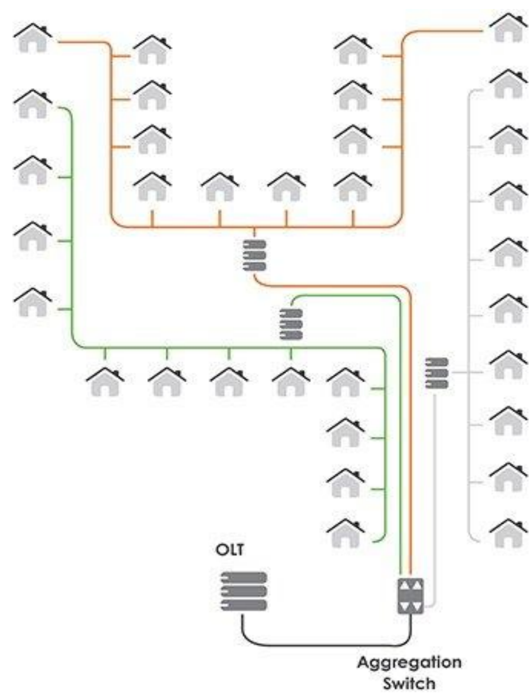

Figure 10: FTTH P2P Architecture [32]

5.3 FTTH Architecture

Fibre is immediately laid from a switching office to consumers. The central office infrastructure is connected to the public telephone network, data network, cable TV, broadband Internet, and even an antenna for satellite. Different signals obtained from different sources are mixed using a wavelength division multiplexing (WDM) method. Consumers may receive all the telecommunication facilities of voice, data, and video over a single fiber. The optical electric converter at the customer end offers interfaces for phone, fax and high-speed files. Figure 11 shows a standard structure of PON on FTTH architecture.

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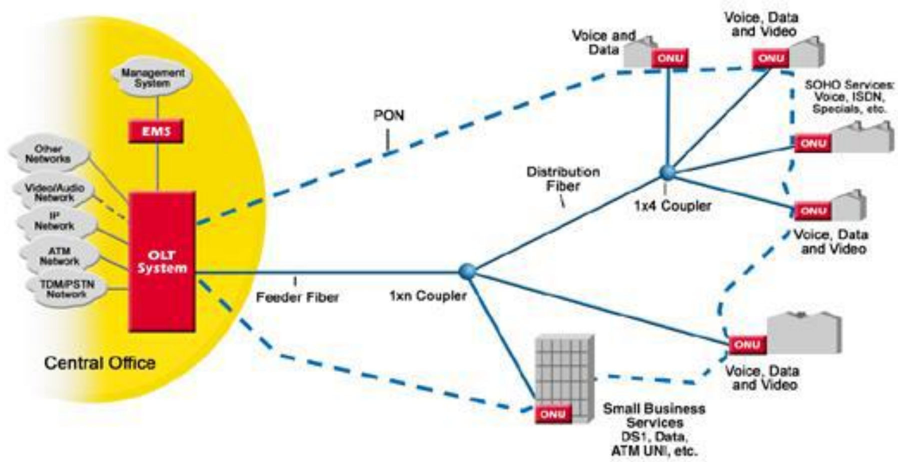

Figure 11: A standard structure of PON on FTTH architecture [33]

Most of the characteristics of the broadband infrastructure are that it is backwards compatible. All the original equipment, including the Printers, PC's, telephones, fax machines, and TV's are still maintained by this method, as standard interfaces are accessible. While current equipment also needs upgrades, it can be used for his purposes. Getting channels in ONT enables subscribers to have varied choices over a number of interfaces available on the ONT unit. Some programs are.

- Expand of phone line, that will mean can provide multiple phone line in a single cable including other services.
- High bandwidth and speed that can reach to hundreds of Mbps.
- Extend the private network (VPN) bandwidth and allows to share huge amount of data and large files.

A. Optical Line Terminal

The starting point of the Internet is the optical transmission terminal (OLT). The entire backbone of the carrier network is transformed into optics. It also receives and integrates ("multiplexes") the customer's network endpoint – the Optical Network Unit or ONU[34]. In many of the commercial systems, the customers do not want to be hardwired to an OLT. Some people may have to change service providers or re-route their phone line while the network is upgraded or repaired. These companies would use an ODF installation to provide complementary or piecemeal connections between fiber rings. OLT have many equipment such as CPU, Gateway router, NIC Network card, and Transceiver (SFP). Also, OLT have two main operations to perform:

- Translating the communications signals that have been used on the local loop of the FiOS cable system to the communication symbols used by the optical network.
- There is communication between the transceivers (STAs), and the customer premises equipment (CPE) on the optical network terminal (ONT) located at the customer premises.

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B. Optical Network Unit (ONU)

It is also known as an optical network terminal (ONT). ONU works by translating the optical signals transmitted through fibers into electrical signals. The electrical signals are sent before any person can apply to receive them. There is a Wi-Fi connection point some distance away from the user's home where the wirelessly transmitted information is received. Furthermore, the ONU blocks unblock the stream of data coming from the user, aggregate it as part of the public IP block, and then groom the IP block upstream to the OLT. Grooming is the process of refining and reorganizing the data stream in order to streamline distribution and reach the right audience, strengthening the message and build credibility. OLT supports bandwidth allocation that allows allowing smooth transmission of data floats to the OLT, which normally arrives in bursts from the customer. Any one of the ONU could be connected by different methods and cable types, including cheap twisted-pair copper wire, coaxial cable, optical fiber, or using Wi-Fi [35]. P2P has many advantages including:

- In each port of aggregation switch is allocated to individual homes and there is no shared bandwidth. Higher bandwidth per home can be achieved with this new technology.
- The bandwidth offered by this technology is symmetrical, meaning that you have equivalent upstream and downstream bandwidth. This technology offers symmetrical bandwidth, which is currently very useful for 2 different types of uses.
- Peer-to-peer (P2P) technology is a common technology that is restricting and can be modified and set up per port. Each home can have a restricted bandwidth plan that is adjusted to their individual specifications.
- P2P technology (peer-to-peer) can carry information over a longer distance using fiber (100+ Km).

Also, P2P has some drawbacks including:

- Limit bandwidth up to 100Mb for download.
- Asymmetric bandwidth. Upload is slower compared to download.
- PON is difficult to upgrade, especially if the bandwidth changes.

5.4 Point to Multi-Points Architecture (P2M)

The Point to Multi-point (P2M)/ Passive Optical Network (PON) architecture is the same, but delivery outlets vary. Instead of Active Switches with Fiber Ports, Passive Splitters are used. Optical splitters can eliminate the long and costly lines passing through optical fibers as they can break the optical fiber connecting through half-duplex. The house identity is retrieved by decrypting the signal received after the splitter. Nonetheless, P2P has P2M over P2P's P2P variants and P2M over P2P2M M's versions. This function allows each system in a chain to use all available bandwidth from the host. Different types of PON will not be the concern of this report [34][35][36]. Figure 12 shows the difference between P2P and P2M.

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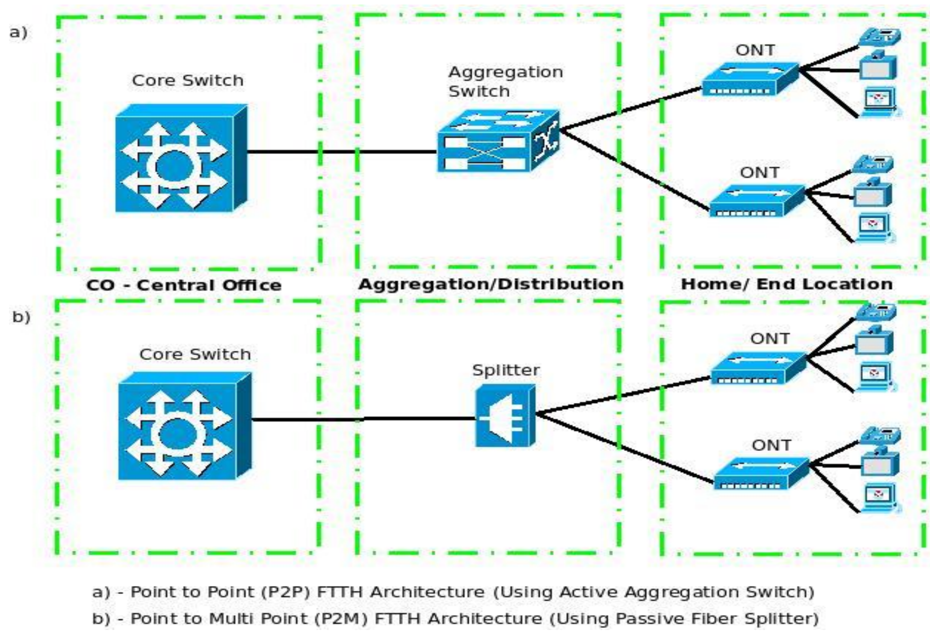

Figure 12: P2P vs P2M FTTH architecture [35]

Splitters are passive devices that split optical signals in one direction. The PON splitter offers the same data as from OLT to all ONUs/ONTs. The signal is being applied over the N output fibers. PON is typically using equipment that includes a splitter/coupler in a single unit. P2M has several advantages including:

- Less expensive by using a single fiber cable.
- No power is required for the splitter also it can be placed anywhere according to need.
- Higher downstream bandwidth for example in GPON the bandwidth for downstream can reach up to 2.5 Gbps.
- High downstream for shared users reach to 1Gbps for about 32 to 64 users.
- Splitter can be fixed anywhere unlike switch need an air conditioning or coolant system.

However, P2M has drawbacks such as:

- Cost is not efficient, more components required to implement.
- Large number of cabinets and cables.

5.5 FTTH Growth

According to FTTH Council, the number of subscribers increased rapidly in 2018 for about six times compared to 2011. The number of subscribers in 2011 was 16 million and in 2018 reached 60 million FTTH/B [9]. By September 2018, half of all FTTH/B deployments took place within the EU28 countries: a growing trend in contrast with most past years. In Italy itself the statistic increase shows that more than 43.1% increases in subscribes in 2018. Approximately 55% of total homes in the area have been linked to alternative ISPs, and approximately that same the

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incumbents prevailed by a 41% margin (as compared to 21% by incumbents in 2011). Figure 13 shows the breakdown of FTTH/B deployment in between 2011 and 2018 [9].

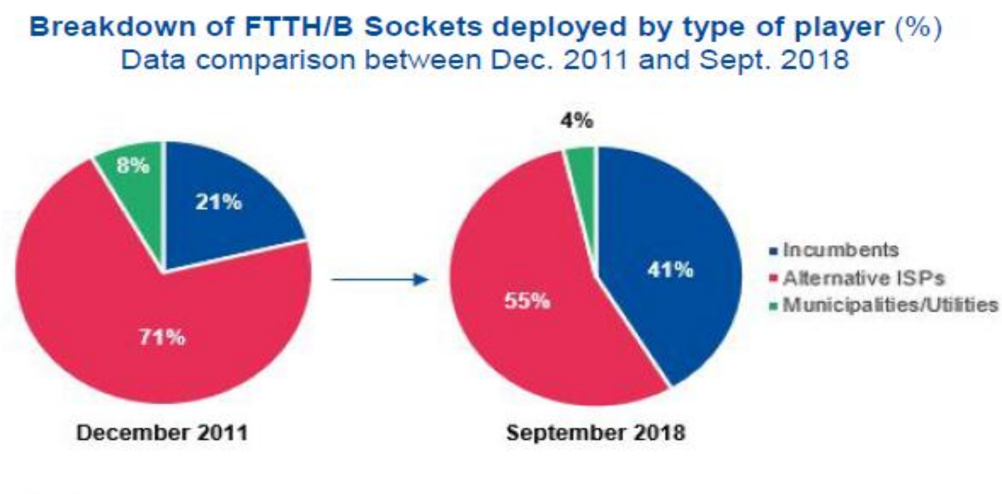

Figure 13: Breakdown of FTTH between 2011 and 2018 [9]

5.6 Optical Fiber on 5G

Optical fiber networks can play a crucial role in 5G rollout. Scientists agree that fifth-generation networks can provide customers with high-speed and low-latency service with more stable and stronger connections. To allow Internet access within cities, more 5G base stations have to be installed due to the higher 5G frequency band and reduced network coverage. Over the next few years, the number of 5G base stations will exceed six and a half million. Since this is greater than expected base station numbers, it will need more of the optical fiber that composes 4/10Gb [37].

5.6.1 Technology of 5G optical networks

From Figure 14 The optical module is an essential device to be included in the 5G-Optical Transponder Network. For 5G transport networks, the throughput from 5G backhaul links is shown in Figure. Each network often includes various types of optical modules that are faced with different kinds of challenges. In the optical networks, the PON networks represented in mid-haul and backhaul whether in front of the ONU to AAU connection required using fiber cable and wireless connection to home, or cell phones.

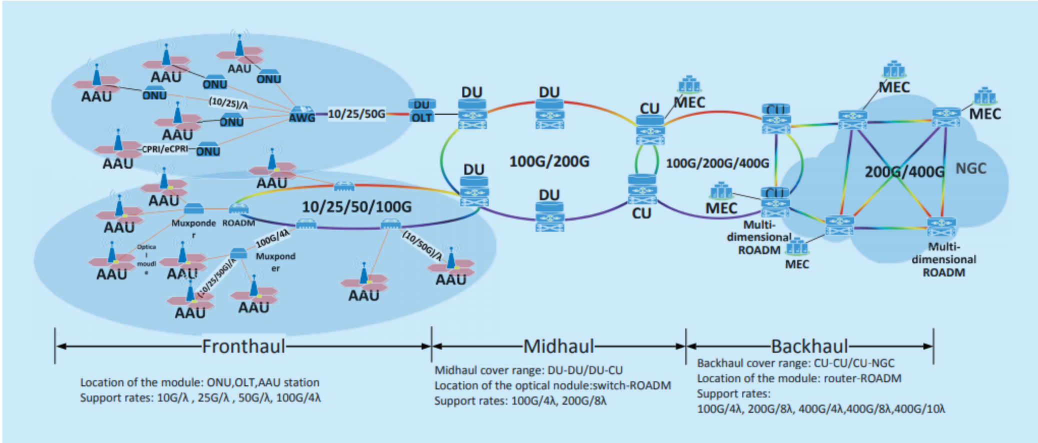

Figure 14: 5G network structure

In an Active Antenna Unit (AAU) the integrated radio system utilizes all of these functions into one complete unit. This antenna can mostly simplify the construction of radio ranges and has significantly improved efficiency. It also enables the creation of radio solutions with individual antenna components, making it the perfect architecture to implement Massive MIMO with advanced beamforming Figure 15 shows the ability of AAU.

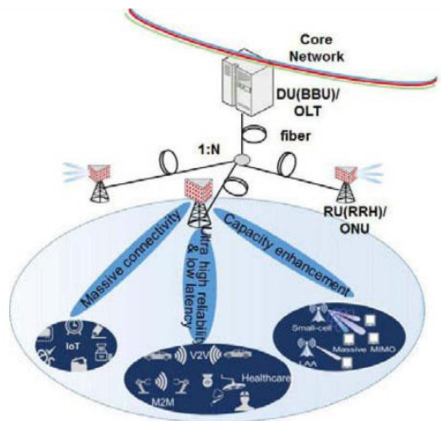

Figure 15: 5G network structure

5.6.2 Characteristics of FTT5G

FTT5G technology offers key benefits for 5G networks, including reduced latency, higher connection density, improved energy efficiency, and cost savings. These features are critical in supporting the performance and scalability required for widespread 5G deployment, making FTT5G a key enabler of the next generation of mobile networks.

A. Latency in 5G

There would be a major effect on new software application creation that would take less than 10 nanoseconds. 5G is supposed to reduce latency between endpoints from nearly 100ms to 6ms or

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less and offer even faster internet speed (for instance, for real-time mobile control facilitated by mobile edge computing). [9][38].

B. Connection density

It should have a significant impact on data rates with peaks in the region of 10 Gbps. On the other hand, "peak data rates" are considered less important than "user-experienced data rates" actually achieved. If this works, it will be great for both companies and customers. The target rates of user experiences are [38]:

- more than 10 Gbps throughput speeds for indoor and outdoor channels.
- dense and naturally occurring.
- Generally, more than 100Mbps speeds can be reached in urban and suburban areas.
- more than 10Mbps data would be widely available as it is a significant target of the Governments.

C. Network energy in5G

The performance of a network often directly depends on the computing energy consumption. Network energy efficiency is the capability of a radio interface technology to minimize the network energy required for the flow of traffic. Lowering operating costs would benefit electricity and utility companies. This would be beneficial for those who are living in the remotest places, since they will be connected to the internet even at night [38].

D. Cost efficiency

Compared to FTTH the FTT5G is efficient. The Figure 16 represents the amount of cabling in both FTTH and FTT5G the cost almost one by four ¼ for FTT5G compared to FTTH.

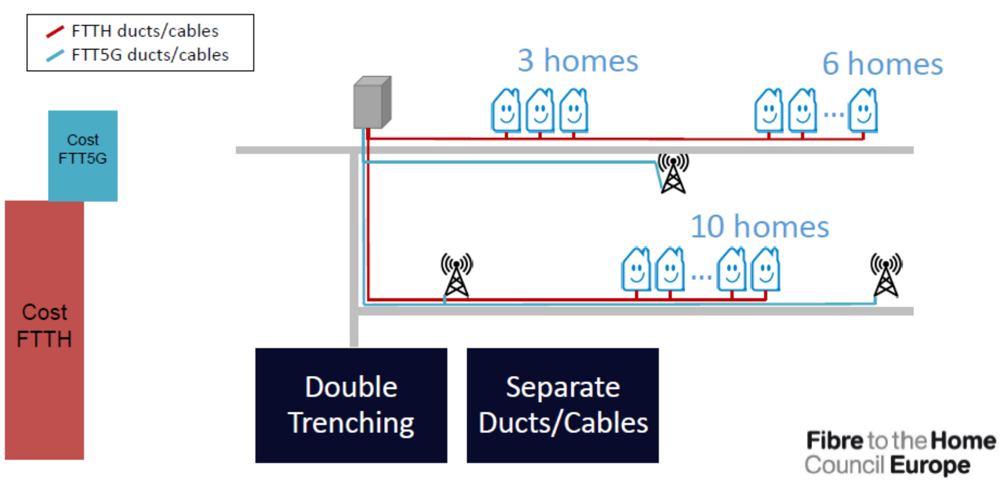

Figure 16: FTTH vs FTT5G fiber cable [9]

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Also, Figure 17 summarize the technical capabilities of 5G networking.

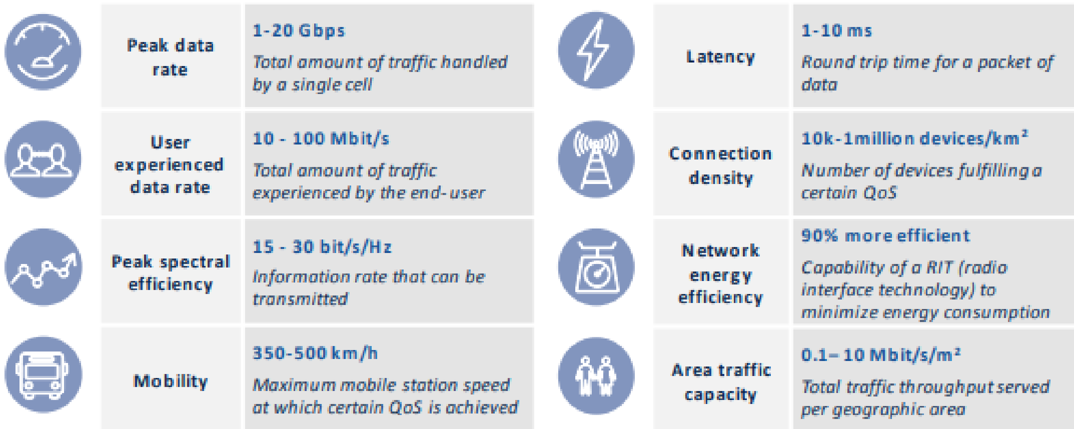

Figure 17: Technical capabilities in 5G network [38]

6. Deployment of 5G, FTTH and FTT5G

The deployment of 5G, FTTH, and FTT5G represents a major shift in global communications infrastructure, driving forward the digital transformation. While 5G promises to deliver ultra-fast, low-latency mobile connectivity for a wide range of applications, FTTH offers a reliable and high-speed broadband solution directly to homes, ensuring better performance for internet, television, and phone services. FTT5G, which integrates fiber-optic networks with 5G infrastructure, forms the backbone of future 5G deployments, providing the necessary bandwidth and capacity for next-generation wireless networks. This section explores the ongoing global efforts and strategies for deploying these technologies, highlighting the challenges, opportunities, and future growth potential.

6.1 Deployment of 5G

Implementing and deployment of 5G cellular communication technology in various parts of different cities around the world is growing gradually and its opportunities are promising, due to the intense 5G experience, efficiency and performance criteria, as well as the vision of "everything connected,". 5G can achieve higher performance in term of higher data rate, low latency, connection density, and etc. However, there are risks such as public health and challenges such as managing the spectrum, and wireless infrastructure regulations that come with its deployment and adaptation [21] [28]. Figure 18 is the world map that shows the 5G networks launched, 5G technology deployed and the investment in 5G.

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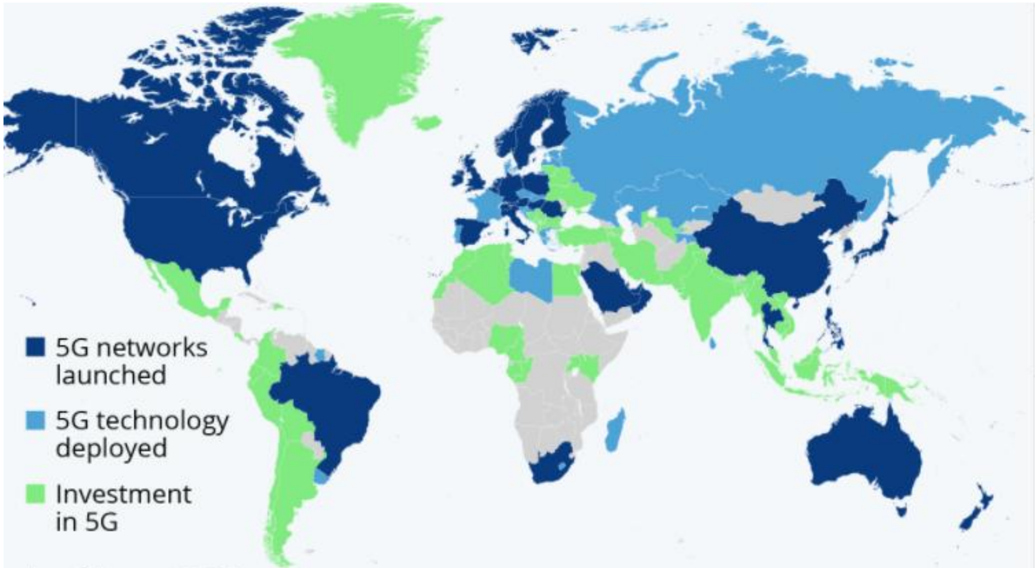

Figure 18: World Map of 5G Launch, Deploy, Investment [39]

6.2 Deployment of FTTH

Growing the need for bandwidth and data steadily and continuously, moving operators in the direction of FTTH technologies. Many incumbents are changing business models instead of copper-based technology to concentrate on FTTH. Actively engaged in FTTH deployments, leaving behind DSL. The deployment is growing gradually around the world. To concentrate on fibre and 5G, governments have updated their Digital Infrastructure policy, leading to greater availability of public funds committed to expanding fibre-based networks [40]. Figure 19 shows the mature market's global ranking in those countries with up to +200 households and FTTH/FTTB subscribers at least represent 1% of the total households until September 2018. While Figure 20 shows the global ranking in those countries that has penetration of less than 30% with up to +200

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households and FTTH/FTTB subscribers at least represent 1% of the total households until September 2018 [41].

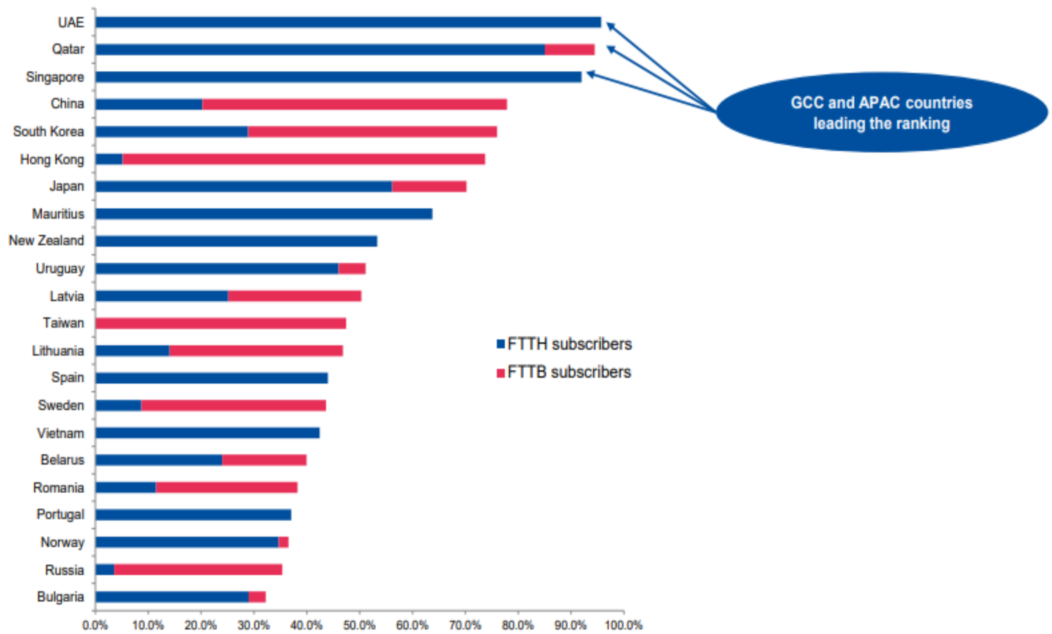

Figure 19: Global ranking deployment of FTTH/B related to Mature markets [41]

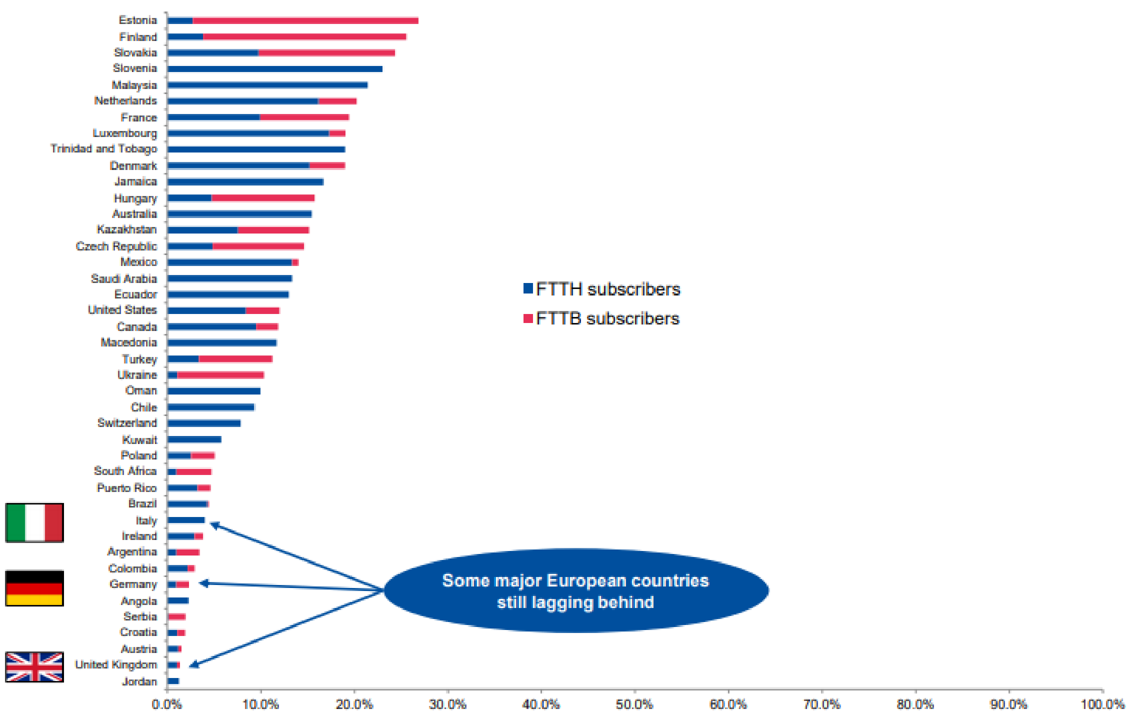

Figure 20: Global ranking deployment of FTTH/B with less 30% penetration

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6.3 Deployment of Fiber to the 5G

For future 5G applications, the implementation of FTTH today should have enough spare capacity. Since it would result in substantial extra costs for potential 5G with little spare space. By installing an integrated and future-proof converged fibre network, between 65%t and 96% of fibre costs for 5G xHaul can be eliminated. In certain cases, it is possible to virtually remove the cost of fibre to 5G, which would theoretically reduce the overall cost of 5G by 50%. Densification, fiber and convergence led to FTT-5G. Figure 21 shows the relation and combination between the FTTH and FTT-5G, while Figure 22 represents the FTT5G network cost which can be saved through convergence [41].

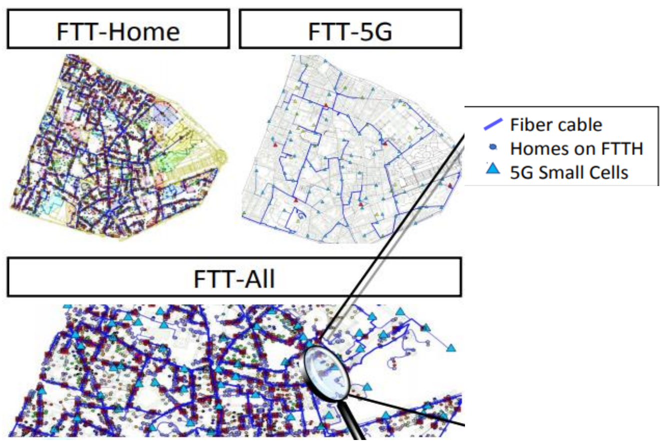

Figure 21: Combination and relation between FTTH and FTT5G [41]

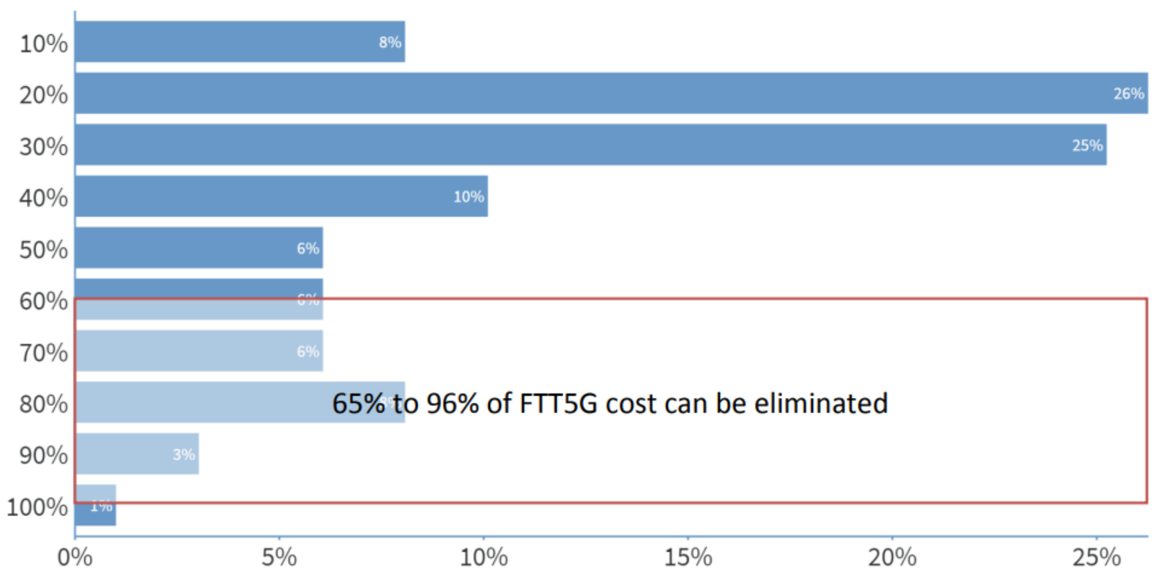

Figure 22: FTT5G cost saving through convergence [41]

7. Conclusion

This survey provides an in-depth examination of the evolution of mobile data growth, the development of optical access networks, and the integration of fiber optics with 5G small cell

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networks. The findings highlight that FTT5G architectures are pivotal in ensuring the high-speed, low-latency, and ultra-reliable connectivity required for 5G and beyond. By analyzing the architectural principles, deployment strategies, and operational challenges of FTTH and FTT5G, this study underscores the necessity of fiber-based infrastructures in meeting the increasing demands for bandwidth and seamless connectivity. Furthermore, the convergence of fiber optics and 5G presents opportunities to optimize network efficiency while significantly reducing deployment costs through shared infrastructure models. However, challenges such as scalability, investment requirements, and regulatory frameworks must be addressed to ensure the widespread adoption of FTT5G networks. As 5G technology continues to evolve, future research should focus on enhancing fiber deployment strategies, leveraging AI-driven network optimizations, and integrating advanced security protocols to safeguard next-generation communication infrastructures. By bridging the gap between fiber-optic technology and 5G connectivity, this paper contributes valuable insights for telecom operators, network architects, and policymakers striving to build resilient, future-proof, and cost-efficient fiber-to-5G solutions. The ongoing advancements in fiber technology, network virtualization, and automation will play a critical role in shaping the future of high-speed, ultra-reliable mobile communication networks.

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