

# Transforming digital communication through fiber-based broadband infrastructure

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## ABSTRACT

Fiber to the home (FTTH) is a broadband internet delivery technology that utilizes optical fiber cables to provide high-speed internet access directly to residential homes or buildings. Unlike traditional internet connections that rely on copper or coaxial cables, FTTH employs optical fibers, which are made of glass or plastic and transmit data as light pulses. The paper discussed the evolution of communication technologies such as satellite, Ethernet, wireless communication, asymmetric digital subscriber line (ADSL), and 5G. In an FTTH network toward FTTH broadband, the fiber optic cables are connected from the service provider's central office or point of presence directly to the subscriber's home, hence the term "FTTH". This direct connection allows for extremely fast and reliable internet speeds, capable of delivering high-bandwidth services such as high-definition video streaming, online gaming, and large file downloads/upload.

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## 1. INTRODUCTION

The internet has become an essential component of our daily lives. The internet is a global network that connects people, devices and information. As a result of improvements in technology, the internet has evolved significantly since its inception, with increases in speed and bandwidth; in addition to better connectivity. The purpose of this paper is to examine the development of the internet from its origins through to the present day. This paper will examine the key technologies that have influenced the development of the internet. Each type of technology is unique in its characteristics, advantages and disadvantages, as well as its response times, bandwidths, noise levels, costs and scalabilities, and thus, a more detailed analysis of these may demonstrate how the internet has developed and what path it could take in the future. Fiber to the home (FTTH) is viewed as one of the largest developments in communication technologies due to the following reasons.

**Fast internet:** compared to the more traditional copper-based technologies of cable and digital subscriber line (DSL), FTTH provides much faster internet speeds. Due to FTTH's higher bandwidth capabilities, customers now find it easy to utilize bandwidth intensive applications including streaming HD videos, playing online games, and retrieving large files.

**Future proof infrastructure:** FTTH technology is designed to be able to adapt to changes in technology and to rising bandwidth requirements. In fact, FTTH is scalable, allowing users to grow to meet the changing demands of bandwidth and to be able to continue with the latest developments in technology without the need for a large-scale upgrade of the users infrastructure. Equal bandwidth for uploading and down loading: most FTTH technology allows for symmetrical uploading and downloading rates. Many

internet protocols offer asymmetric upload/download speeds, in which the upload and download rates are different. This is especially beneficial for cloud storage, file sharing, and video conferencing. Fiber-optic cables are resistant to interference, electromagnetic noise and signal degradation compared to copper-based connections, making them reliable and of good quality. Therefore, they provide a reliable and durable internet connection especially over long distances. Real-time applications, including voice-over-IP (VoIP), video conferencing, online gaming, and benefit greatly from the low latency (delay) provided by FTTH technology. Low latency, in conjunction with FTTH technology, enhances the speed of response and user experience of these types of applications. The availability of FTTH makes many cutting-edge services and applications dependent upon fast, reliable internet connections possible, such as telemedicine, internet of things (IoT) devices, augmented reality (AR), and virtual reality (VR) all of which enhance innovation and improve the quality of life for those who use them. In today's society, high-speed internet is a requirement for innovation, social growth, education, and economic success. With FTTH technology, communities, organizations, and individuals will have the ability to connect to each other in an increasingly connected world, provide access to educational resources, reduce the digital divide, and capitalize on the digital marketplace.

## 2. RELATED WORKS

### 2.1. Satellite

Satellite-based technology offers a method of delivering internet services via communication satellites, and it is especially useful for providing service to remote or sparsely populated locations where there are very few (if any) wired connections available to consumers. Figure 1 shows the typical satellite network physical architecture, the connection between terminals, satellites, and hub through service link and feeder link to the data network, that is mean the importance of satellite technology for providing internet access in remote or underserved areas. However, since data has to travel over long distances using this technology, there are significant delays associated with using satellite links to connect the consumer to their chosen service provider; although these services do cover wide geographic areas. The bandwidth for satellite internet is typically between 1 and 50 Mbps, and the cost of service depends upon the service provider being used.

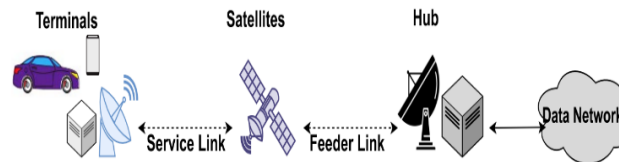


Figure 1. Typical satellite architecture [1]

### 2.2. Ethernet

Wired Ethernet is an extensively utilized form of wired networking technology. Figure 2 shows the Ethernet segment with switches and hosts, the MAC table for bb:bb switch with addresses cc:aa, cc:dd, dd:dd, dd:ee, that is mean the importance of MAC addressing in managing Ethernet network traffic efficiently. Wired ethernet allows for rapid data transfer over cable. Wired ethernet allows for rapid data transfer over cable. Wired ethernet is frequently used in local area networks (LANs) and in data centers. Wired Ethernet provides low latency with reaction time that may vary between 1 and 10 ms. Wired ethernet's bandwidth will depend upon the network design and may vary between 10 and 10,000 Mbps. Wired Ethernet is also recognized for its cost, scalability, and endurance.

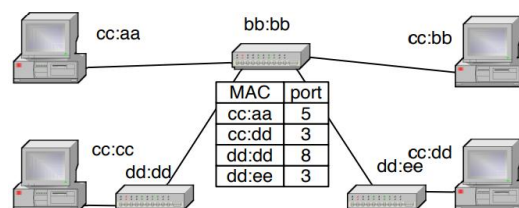


Figure 2. An ethernet segment with switches and hosts [2]

### 2.3. Asymmetric digital subscriber line

Asymmetric digital subscriber line (ADSL) is digital subscriber line technology that provides internet access via current phone lines. Figure 3 shows the ADSL modem block diagram, the internal components that enable high-speed data transmission over existing telephone lines, that is mean the importance of ADSL technology in delivering broadband internet through traditional copper infrastructure. In comparison to dial-up connections, it provides faster data transmission speeds. Response times over ADSL range from 10 to 50 ms, while bandwidth is available in increments of 1 to 20 Mbps. Due to its affordability and widespread availability, ADSL is a preferred option for both home and small business users.

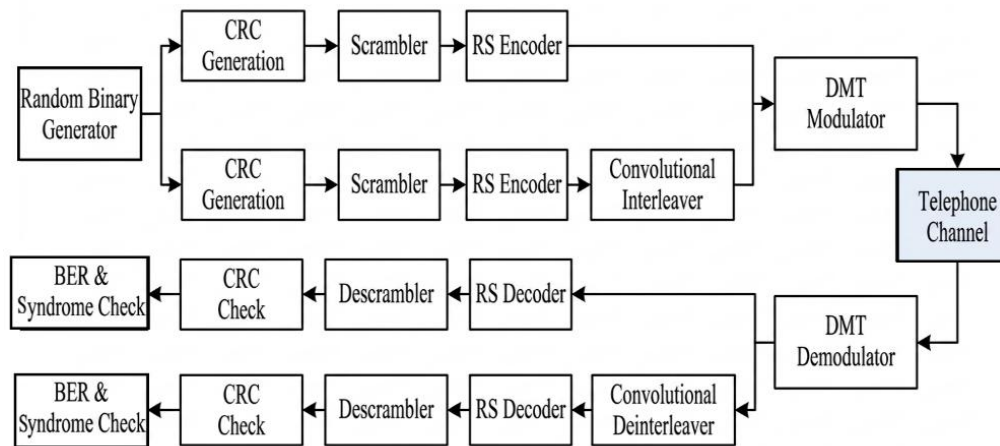


Figure 3. ADSL modem block diagram [3]

### 2.4. Wireless technology trends

With their ease of use and portability, wireless technologies have completely changed how people use the internet. Wi-Fi is a widely used wireless technology that can be found in homes, workplaces, and public areas for local wireless networking. Cellular networks allow mobile devices to access the internet wirelessly. These networks include 2G, 3G, 4G, and now 5G. Figure 4 shows the wireless communication evolution from 1G to 6G, the development of mobile network generations with improved speeds, latency, and capacity, that is mean the importance of continuous innovation in wireless technology. Wireless technologies can have response times between 10 and 100 ms and bandwidth between 1 and 9,600 Mbps, contingent on the network standard and circumstances. Digital cellular networks were created and basic data services were made possible by 2G technology. Although it mostly concentrated on voice communication, it set the stage for mobile internet access. 2G networks have response times between 100 and 500 ms and comparatively low bandwidth, usually between 0.01 and 0.24 Mbps [4], [5].

But the introduction of 3G networks represented a major improvement in mobile internet access. Now that mobile clients could transport data more quickly, they could send emails, access the web, and watch basic videos. Average response times range from 50 to 150 ms, and average bandwidth is between 0.38 and 2 Mbps. Thanks to 3G networks, mobile devices can now handle more multimedia material, opening up new possibilities for mobile services and apps [6].

Mobile access to the internet was significantly altered by 4G networks, which offered fast connectivity and made it possible for cutting-edge services like cloud apps, online gaming, and video streaming. While bandwidth may vary from 2 to 100 Mbps, response times might range from 10 to 50 ms. Smartphone and tablet users can enjoy the best potential internet experiences because 4G wireless networks have minimal latency and low interference [7].

5G technologies, the most recent version of mobile network technology, delivers significant gains in capacity, speed, and connectivity. Users may stream and download more quickly and seamlessly thanks to 5G's ultra-high bandwidth of up to 10 Gbps and reaction times as low as 1 ms. Additionally, it supports more recent technologies like the IoT, autonomous automobiles, and VR. 5G networks are highly dependable, have very little latency, and can link a lot of devices at once [8]–[11].

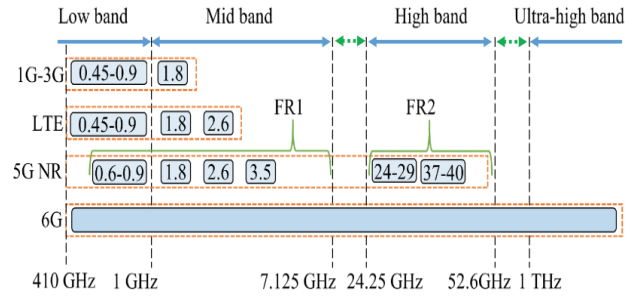


Figure 4. Wireless communication evolution from 1G to 6G [12]

## 2.5. Fiber to the X/fiber to the home

FTTH, commonly known as Fiber to the X (FTTX), is a broadband technology that gives homes and businesses high-speed internet access. Figure 5 shows the FTTH architecture, the direct fiber optic connection from the service provider's central office to the subscriber's home, that is mean the importance of FTTH in providing ultra-fast and reliable internet connectivity. It uses fiber optic connections. It includes variations such as fiber to the curb (FTTC) and fiber to the building (FTTB). FTTX offers unrivaled dependability, speed, and bandwidth. While bandwidth can reach up to 1 Gbps, response times range from 1 to 10 ms. The limitations of copper-based solutions are eliminated with FTTX, providing a dependable long-term solution to the expanding bandwidth requirements of homes and businesses [13].

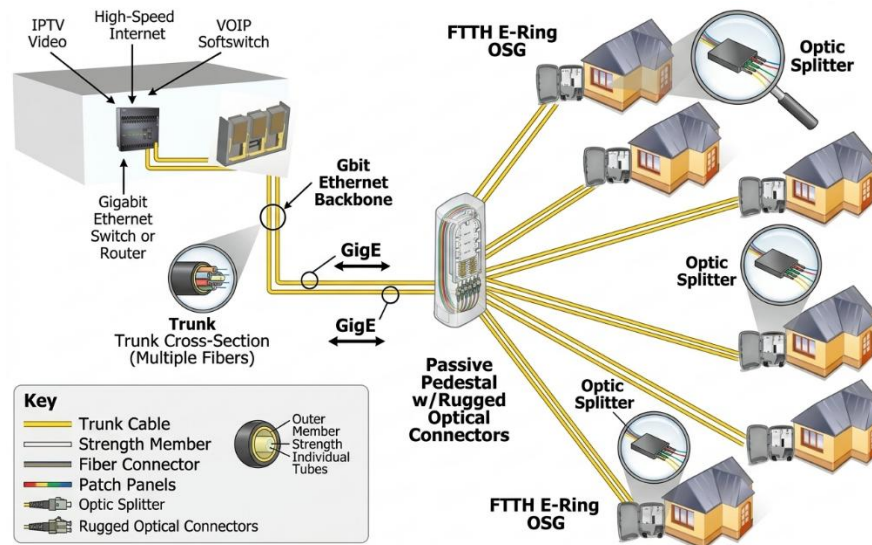


Figure 5. FTTH architecture [13]

FTTH offers advantages over all other ways of getting an internet connection due to the number of factors listed below:

- Speed and bandwidth: FTTH is faster and offers greater bandwidth than older ways of connecting to the internet as you get both fast download and upload rates with virtually unlimited bandwidth.
- Reliability: due to its resistance to outside interference and degradation of signals, FTTH provides a more stable and reliable connection to the internet compared to older methods of providing broadband connectivity.
- Future proof: as new technologies emerge and bandwidth requirements continue to grow, FTTH will be able to adapt to meet those needs without needing to make major upgrades to existing infrastructure.
- Low latency: in comparison to most other types of broadband technology, FTTH has low latency (time delay) and this is important for applications such as video conferencing and on-line gaming.

Although there are many advantages to FTTH, the availability of FTTH services vary greatly depending on your local area and your internet service provider (ISP). While FTTH offers many benefits, the cost of installing FTTH infrastructure may be too expensive for FTTH to become widespread in certain areas. A number of significant advances have been made in the development of FTTH installations.

#### **2.5.1. Fiber to the curb**

The stage of transition that divides broadband to the cabinet (FTTH) networks from more established copper-based networks is known as fiber to the cabinet (FTTC). Fiber optic cables are attached to curbs, also known as street cabinets, using existing copper or digital lines. They are then expanded to encompass specific houses or structures. It has some important advantages over typical copper-based connections, while being slower than FTTH [14].

#### **2.5.2. Gigabit passive optical network**

Gigabit passive optical network (GPON): is a widely used FTTH technology that allows multiple consumers to share optical lines. Passive splitters divide the fiber optic signal, allowing several customers to connect to a single fiber. GPON's high-speed support allows it to offer high-bandwidth goods or services, with symmetric rates of up to 2.5 Gbps upstream and 1.25 Gbps upstream [15].

#### **2.5.3. 10 gigabit passive optical network**

A GPON development that provides even faster speeds is called XG-PON. Users' usable bandwidth is considerably boosted with its capability for symmetric speeds up to 10 Gbps downstream and 10 Gbps upstream. The backward compatibility of XG-PON with GPON allows for a smooth transition and an upgrade route [16].

#### **2.5.4. Next-generation passive optical network**

Next-generation PON (NG-PON2) is the most recent PON technology generation. It provides considerably faster speeds and more wavelength division multiplexing (WDM) versatility. Up to 40 Gbps or more in symmetrical rates can be achieved with NG-PON2, enabling future scalability and supporting newly developed bandwidth-intensive applications [17].

#### **2.5.5. Fiber deep**

Fiber deep is a deployment approach that involves extending fiber optic cables farther into the network, hence bringing the fiber closer to the end consumers. Higher speeds and better performance are made possible by fiber deep, which shortens the distance between the fiber and customers.

#### **2.5.6. Full fiber**

A full switch to fiber optic connectivity, when all network connections are built on fiber, is symbolized by the idea of "full fiber." It entails switching out all outdated copper or coaxial cables for fiber optic cables in order to get rid of all restrictions and bottlenecks related to previous technology. The supply of innovative services and the growing demand for high-speed internet access in home and corporate environments have been supported by these improvements in FTTH technology, which have resulted in faster speeds, more bandwidth, and improved connection [18].

### **3. RESULTS AND SUMMARY**

#### **3.1. Comparison of fiber to the home with other internet technologies**

The comparison between FTTH and various other internet technologies explained as below:

##### **3.1.1. Ethernet**

FTTH when compared to ethernet connections, fiber optic cables provide larger bandwidth and faster speeds when delivering internet to homes. Conversely, wired connections made with ethernet cables are referred to in ethernet. Its service area may be limited, but it can offer dependable and fast connections.

##### **3.1.2. Wireless technologies**

FTTH are used to transport internet via physical fiber optic cables, which offer quicker and more reliable connections than wireless alternatives. While satellite internet, cellular networks, and Wi-Fi are examples of wireless technologies. Although wireless technologies are convenient and mobile, they could not be as fast, latency-free, or have as wide a coverage as fiber-thread technologies.

### 3.1.3. Toward next generations (2G, 3G, 4G, and 5G)

FTTH are superior than mobile network technologies like 2G, 3G, 4G, and 5G in terms of speed and latency. Newer mobile network technologies like 2G, 3G, 4G, and 5G offer wireless internet access. Although they provide mobility, 5G offers higher speeds and reduced latency than previous generations. However, their speeds and reliability may vary [19], [20]. Overall, compares favorably to previous mobile network technologies, Ethernet, wireless technologies, satellite internet, and ADSL in terms of speed, dependability, and latency.

## 3.2. Future enhancements of fiber to the home

### 3.2.1. Increased speeds

Even though FTTH already provides fast access, future communication engineering research attempts to increase speed even more. Technologies that provide multi-gigabit or perhaps terabit per second speeds over fiber optic networks are being developed by researchers and engineers. This would enable even quicker download speeds, real-time data streaming, and the smooth incorporation of cutting-edge technology such as 8K/16K video streaming and VR and AR. Figure 6 shows the important increasing values across years, the increased speeds of FTTH from 2010 to 2024 about 100 times from 2010, that is mean the importance the FTTH technologies in the network applications.

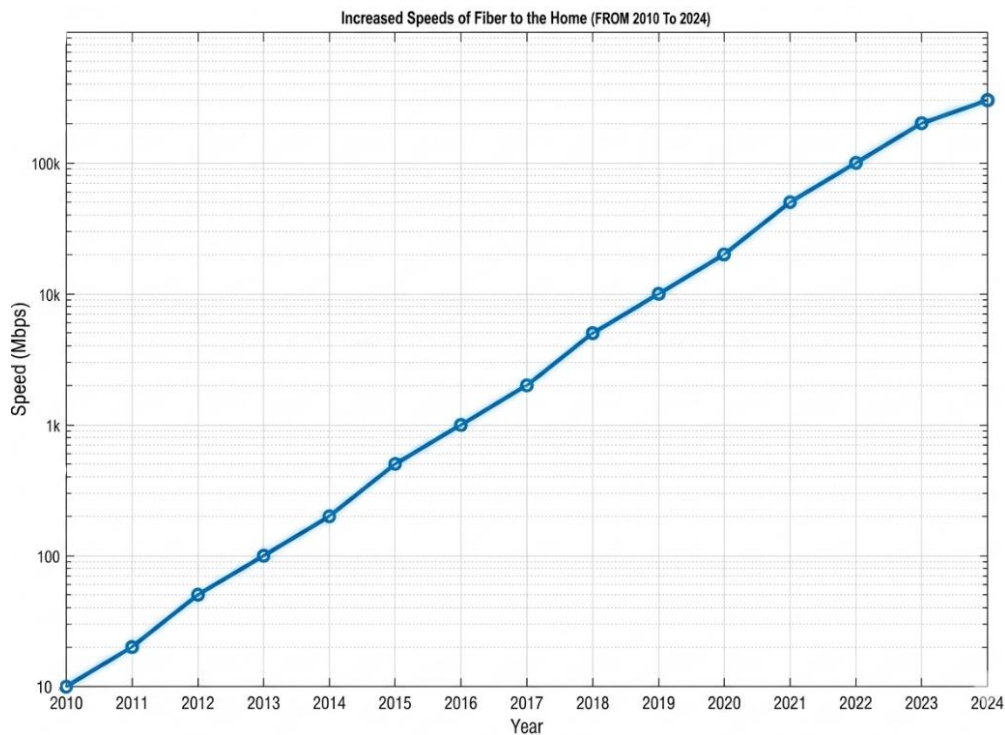


Figure 6. Increased speeds of FTTH (from 2010 to 2024)

### 3.2.2. Enhanced reliability

Even though FTTH networks are typically very dependable, future research can concentrate on enhancing their resilience and fault tolerance. This entails improving network management and monitoring systems, putting in place redundancy and backup plans to guarantee continuous connectivity, and creating sophisticated fault detection and self-healing processes to reduce service interruptions.

### 3.2.3. Seamless integration with 5G and beyond

Research is currently underway to determine how to seamlessly integrate FTTH with upcoming wireless technologies and 5G. Combining the high-speed, low-latency capabilities of FTTH with the mobility and ubiquity of 5G can enable a seamless and integrated communication experience. Real-time immersive experiences, ultra-low latency gaming, and flawless multi-device communication are just a few of the innovative services and apps this mix might produce.

### 3.2.4. Energy efficiency

The main focus of next research initiatives could be enhancing the power efficiency of FTTH networks. To run network infrastructure in a way that reduces power consumption, energy-saving components have to be developed; network design and protocols have to be optimized; and renewable energy sources have to be investigated. Running costs and environmental impact of fiber-to-the-thrust (FTTH) installations can be lowered by energy-efficient designs.

Figure 7 shows the energy efficiency of FTTH proposed system design and we can note the relationship between distance and energy consumption, when the distance is 1 km the higher energy consumption fix in 8 kWh while when increase the distance to the 5 km the values decrease until save power consumption to zero. Moreover, Table 1 presents a comparison of the internet technology that are being discussed, with a focus on pricing, scalability, bandwidth, and response time.

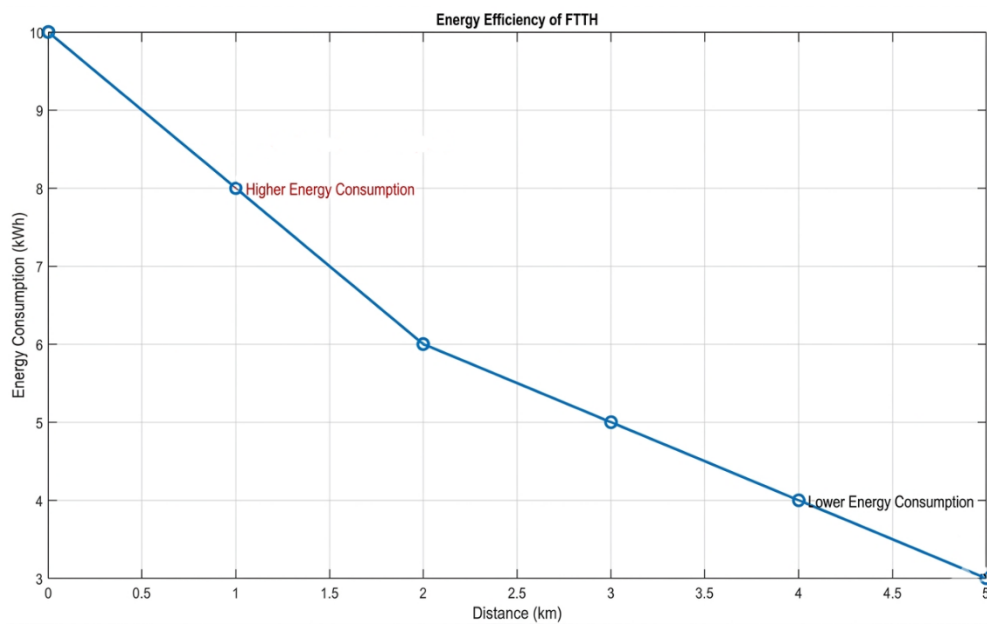


Figure 7. Energy efficiency of FTTH

Table 1. Comparison between FTTH and other technologies with different factors

Technology	Response speed (ms)	Bandwidth (Mbps)	Noise	Cost	Scaling flexibility
Satellite internet	500-700	1-50	High	High	Limited
Ethernet	0.1-10	10-10,000	Low	Moderate	Excellent
Wireless technologies	10-100	1-9,600	Moderate	Varies	Moderate to high
ADSL	10-50	1-20	Moderate	Moderate	Limited
2G	100-500	0.01-0.24	Moderate	Low	Limited
3G	50-150	0.38-2	Moderate	Moderate	Moderate
4G	10-50	2-100	Low	Moderate	High
FTTH	1-10	100-1,000	Low	High	Excellent

## 4. CONCLUSION





The growth of internet transmission technologies has allowed for increased speed, dependability, and scalability of connectivity. From satellite and ethernet to wireless, ADSL, 2G, 3G, 4G, FTTH, and 5G, each technology has brought its own set of advantages and limitations. As demands for high-speed data transmission continue to grow, the transition towards advanced technologies like 5G and FTTH is crucial to meet the needs of an increasingly connected world. The evolution of FTTH has undergone several advancements over the years to enhance its capabilities and provide even faster and more efficient internet connectivity. These are just a few examples of the future work that can be undertaken in the field of communication engineering to further enhance and advance FTTH technology. Continued research, innovation, and collaboration among industry, academia, and policymakers are crucial for driving these advancements and realizing the full potential of FTTH in the future.

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