

Advancements in Communication Technologies: Cellular Networks, Broadband, Cloud Computing, and their Security

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Abstract

This paper explores modern communication technologies, focusing on the evolution of cellular networks from 1G to 5G, comparing their architectures and advancements. Broadband solutions, including DSL and fiber-optic FTTH, are examined alongside cloud computing models—public, private, hybrid, and community—and service models like SaaS, PaaS, IaaS, and FaaS. Security challenges across these technologies, including cellular, broadband, and cloud systems, are analyzed with proposed countermeasures. The study highlights the importance of innovation and robust security to ensure the reliability of these interconnected systems.

Keywords: Mitigation Strategies, Networking Technologies, Security Vulnerabilities.

1. Introduction

Wired and wireless networking technologies are essential for modern connectivity. Wired and Wireless each serve unique purposes. Wired options like Local Area Networks (LANs) and broadband technologies such as DSL (Digital Subscriber Line), cable, and fiber provide reliable, high-speed connections, while Wide Area Networks (WANs) cover larger distances, often using leased lines. Wireless technologies such as, Wi-Fi (WLAN), cellular networks (1G to 5G), and Fixed Wireless Access (FWA) offer flexibility and mobility. Short-range solutions like Bluetooth and Zigbee support close-proximity communication. Satellites enable connectivity in remote areas. Virtual networks and hybrid systems combine local and cloud infrastructure for versatile networking. Table 1 summarizes these prominent wired and wireless in different categories.

Table 1: Overview of Prominent Wired and Wireless Technologies

Wired Networking	Wireless Networking	Other Categories	Cloud Computing (part of several categories)
Local Area Network (LAN): Typically used within a single building or campus	Wireless Local Area Network (WLAN): Commonly known as Wi-Fi, used for local wireless connectivity.	Metropolitan Area Network (MAN): Connects multiple LANs within a city or metropolitan area.	Wide Area Network (WAN): Cloud services often rely on WANs to connect users to data centers over large geographic areas.
Wired Broadband: Includes technologies like DSL, cable modem, and fiber optic.	Wireless Broadband: Includes cellular networks like 4G, 5G, and fixed wireless access (FWA).	Wide Area Network (WAN): Covers a large geographic area, often using leased telecommunication lines.	Data Center Networking: Within cloud providers' data centers, various networking technologies are used to manage and route data.
	Short-range Wireless: Technologies like Bluetooth and Zigbee for close-proximity communication.	Personal Area Network (PAN): Very short-range network, typically for personal devices like smartphones and tablets.	Virtual Networks: Cloud providers offer virtual networking services that allow users to create isolated networks within the cloud environment.
	Satellite: Used for internet access in remote or rural areas where other types of connections are not available.		Hybrid Networks: Combining on-premises infrastructure with cloud services, often involving both LAN and WAN components.

This paper covers a wide array of communication technologies, spanning from the first to the fifth generation of cellular networks. The paper also explores wired broadband solutions, focusing on both copper-based and fiber optic mediums. Additionally, the paper discusses cloud-based computing, examining various aspects and applications.

In Section 2, the paper explores the evolution of cellular networks from 1G to 5G, focusing on the architectural developments of each generation, along with a detailed comparison between 3G, 4G, and 5G. Section 3 delves into wired broadband technologies, specifically DSL and FTTH, discussing their respective architectures and comparing their advantages and limitations. Section 4 explores cloud computing, highlighting the distinctions between public, private, hybrid, and community clouds, as well as key cloud service models. Section 5 covers security threats across all discussed technologies and outlines the countermeasures to mitigate these risks. The final section summarizes the paper with a conclusion.

2. Cellular Wireless Technologies

Cellular wireless communication has evolved significantly since the first generation (1G). Evolving from analog radio systems of the mid-20th century, to today's advanced 5G networks. 1G introduced analog cellular calls, while 2G transitioned to digital signals, enabling Short Message Service (SMS) and basic data.

3G expanded internet access and multimedia capabilities, and 4G revolutionized connectivity with high-speed internet and streaming. Now, 5G delivers ultra-fast speeds, low latency, and massive device connectivity, driving innovations like the internet of things, autonomous vehicles, and smart cities. Each generation has advanced communication, transforming how people connect and paving the way for future innovations in global wireless technology.

2.1. First Generation (1G)

1G is based on analog signalling. North America used Analog Mobile Phone Systems (AMPS) while Europe uses Total Access Communication Systems (TACS). The analog systems used in 1G was primary designed for voice and was based on circuit-switched technology [1].

2.2. Second Generation (2G)

2G improved on forerunners by using digital signals with speeds up to 64kbps. 2G had the facility to support SMS. 2G used Global System for Mobile Communications (GMS) standard which comprised of **Base Stations (BS)** and a **Network Switching Subsystems (NSS)** [1].

2.3. Third Generation (3G)

Universal Mobile Telecommunications Service (UMTS) is the European version of 3G [2]. Frequency bands originally for UMTS are 1885–2025 MHz uplink and 2110–2200 MHz downlink [3]. 3G initially had maximum speed around 2 Mbps downlink for stationary/walking users and 384Kbps while in a moving vehicle [4]. International Telecommunication Unions (ITU) set the specifications for 3G in the International Mobile Telecommunications-2000 (IMT-2000) standard. Third Generation Partnership Project (3GPP) provides the work, development, and maintenance of UMTS [5].

UMTS CN can be divided into two switching networks: Voice and Data [6]. Figure 1 displays the architecture of a UMTS network. UMTS comprises of three components: UE, UMTS Terrestrial Radio Access Network (UTRAN) and the Core Network (CN).

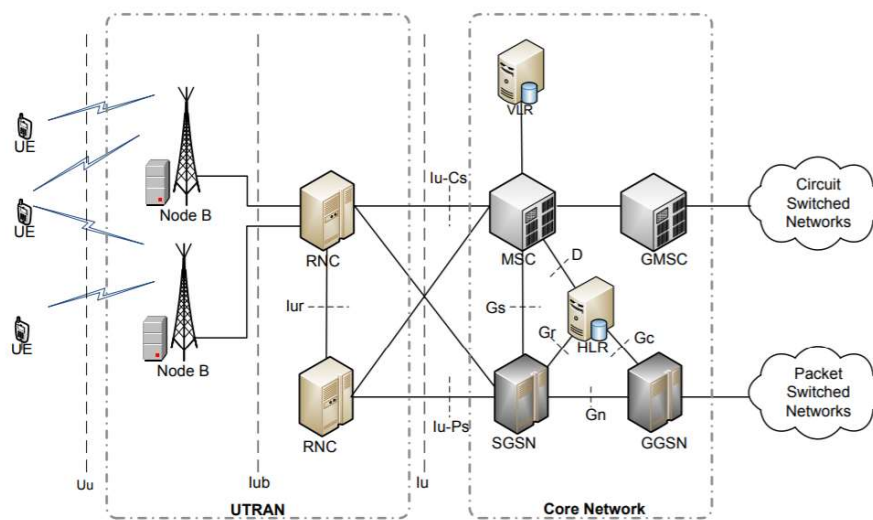


Figure 1: Architecture of UMTS [6]

User Equipment (UE) is End-user device which connects to a Radio Access Network (RAN) using an air interface. UE may include universal Subscriber Identity Module to store subscription information [7]. UMTS widely adopts WCDMA radio interface standard technology. WCDMA supports voice and Data [8]. **UTRAN** has two elements: Node Bs provides cellular radio coverage and air interface. [6]. RNC (Radio Network Controller) manages and connects to number of Node Bs [6]. **CN** can be divided into two parts: circuit Switching and packet switching [6]. **Circuit Switch Network** manages voice and SMS [6]. One of the most integral parts of the UMTS network is the **Mobile Switching Centre (MSC)** that manages calls, SMS, and UE location management [2]. **Gateway MSC (GMSC)** manages Connections to external networks [2].

The **Home Location Register (HLR)** plays a vital role in mobility and roaming which holds the database with information on UE authentication and UE location along other critical pieces of information about the subscribers [9]. **Visitor Location Register (VLR)** also plays an important role in mobility and roaming. VLR holds the database containing visiting UE roaming information [9]. **Packet Switching** manages data traffic, connectivity, and authentication [6]. **Serving GPRS Support Node (SGSN)** is responsible for the authentication of users, management of data connection between UE and **Packet Data Network (PDN)** [10]. **Gateway GPRS Support Node (GGSN)** works in tandem with the SGSN to manage connectivity of the users to the external data networks [10].

2.4. Fourth Generation (4G)

LTE (Long Term Evolution) is the current standard of 4G. 4G is similar to 3G but speeds are much faster [11]. The frequency range utilised by 4G spans from 2000 MHz to 8000 MHz, with a spectrum allocation of 5 Mhz to 20 Mhz. In LTE systems, this enables maximum downlink speeds of approximately 100 Mbps and uplink speeds of roughly 50 Mbps [4]. 3GPP provides the technology for LTE using IMT-Advance requirements issued by ITU. LTE Networks transitioned to a packet switching network only [12]. LTE offers Voice over LTE (VoLTE) which enables high-definition voice calls over a packet network. VoLTE provides up to three times more capacity for voice and data compared to UMTS [13]. Figure 2 shows a 4G architecture.

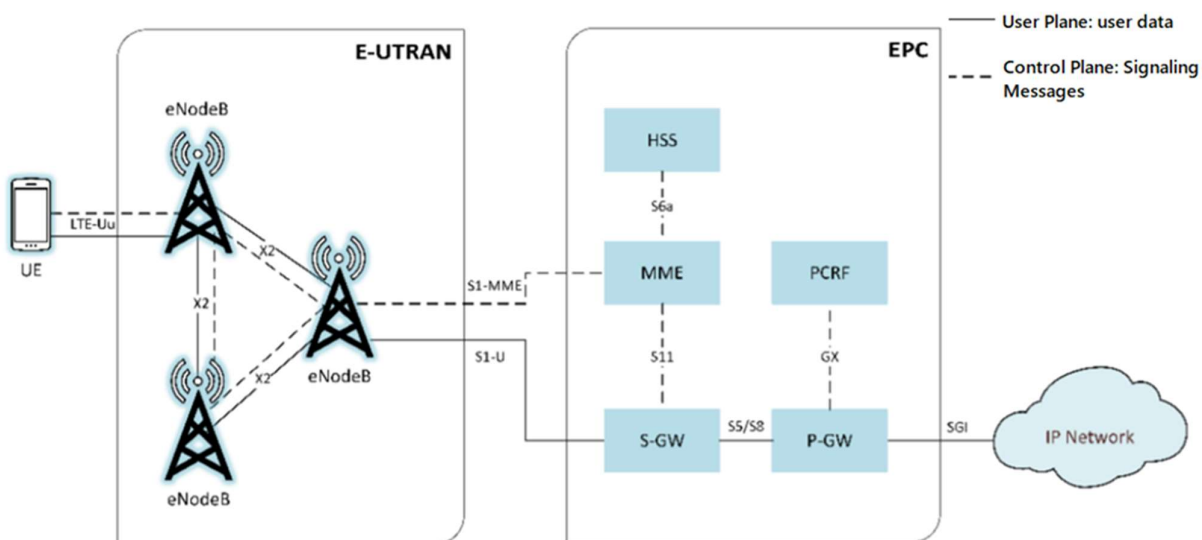


Figure 2: LTE Network Architecture [14]

The 4G LTE network is built on two primary components: the Evolved Universal Terrestrial Radio Access Network (E-UTRAN) and the Evolved Packet Core (EPC). The **E-UTRAN** provides the air interface and comprises User Equipment (UE) and eNodeBs (Evolved Node B). **eNodeBs** are advanced base stations responsible for network control functions, network coverage, managing handovers, scheduling, and dynamically allocating resources to UE [14]. The LTE air interface employs Orthogonal Frequency Division Multiple Access (OFDMA) for downlink communication, which transmits data in parallel across multiple subcarriers, and Single Carrier-Frequency Division Multiple Access (SC-FDMA) for uplink, which transmits data sequentially using multiple subcarriers [15].

The **EPC** serves as the framework for converging voice and data traffic in the network. Key components of the EPC include the **Mobile Management Entity (MME)**, which authenticates and tracks UE while selecting the appropriate Serving Gateway (S-GW) and Packet Data Network Gateway (P-GW) for connectivity [14]. The **S-GW** facilitates the transfer of user data between eNodeBs and P-GWs, acting as an anchor point when the UE transitions between eNodeBs [14]. The **P-GW** serves as the interface between the LTE network and other packet networks, ensuring seamless connectivity [7]. Supporting the EPC are the **Home Subscriber Server (HSS)**, which stores user subscription data, and the **Policy and Charging Rules Function (PCRF)**, a

real-time software node responsible for enforcing policy rules [7]. The network operates across two planes: the **Control Plane**, which handles signalling messages to manage UE data sessions, and the **User Plane** where the nodes exchange user data [14]. Additionally, the **IP Network** interconnects devices, using Internet Protocol to facilitate communication [16].

2.5. Fifth Generation (5G)

5G is the fifth generation of wireless telecommunications. Minimum standards for 5G is set by ITU's IMT2020 specification [17]. Frequency band and Data Bandwidth specification is 3-300GHz and download speeds 1Gbps & higher [18]. 5G is capable of virtualising CN components to provide network slicing for data communications [19]. Figure 3 shows the overall concept of a 5G standalone network architecture. The architecture can be divided into UE, RAN, Multiple Access Edge Computing (MEC) and CN.

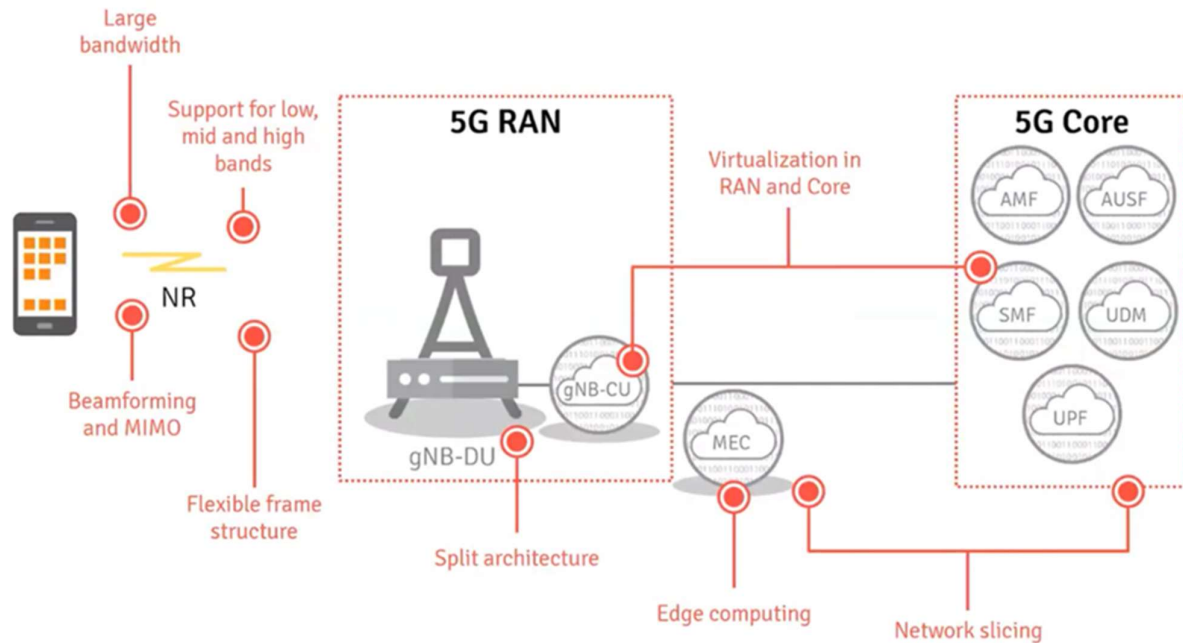


Figure 3: 5G Network Architecture [20]

The 5G network introduces advanced technologies and components to support high-speed, low-latency, and highly scalable communication. User Equipment (UE) includes devices such as mobile phones, autonomous vehicles, and Internet of Things (IoT) devices [20].

5G **New Radio (NR)** operates on two key frequency spectrums: sub-6GHz, which offers better range and penetration through solid objects, and **millimetre waves (mmWaves)**, which operate above 6GHz and provide significantly more bandwidth in the 30GHz to 300GHz range [21]. Although mmWaves cannot travel as far or penetrate objects as effectively as sub-6GHz, they enable massive device connectivity and can deliver download speeds of several gigabits per second, supporting up to one million devices per square kilometre [21]. To maximise mmWaves performance, 5G networks use technologies such as **Massive Multiple-Input Multiple-Output (MIMO)**, which deploys large numbers of antennas to improve network efficiency and allow multiple users to share resources, and beamforming, which creates highly directional links by focusing signals directly at the UE [22].

The **Radio Access Network (RAN)** features Next Generation NodeB (gNB), which is divided into the Centralised Unit (CU) and Distribution Unit (DU) [20]. The **gNB-DU** handles tasks such as scheduling and broadcasting system information, while the **gNB-CU** manages user data transfer, mobility control, session management, and network sharing [23]. Dense deployment of gNBs with directional antennas enhances mmWaves communications [24]. **Multi-access edge computing (MEC)** further enhances 5G by bringing cloud services closer to the network edge, reducing latency and congestion [25]. MEC supports the virtualisation of 5G Core Network (CN) functions, enabling features like **Network Slicing** for tailored service

segmentation, **Network Function Virtualisation (NFV)** for real-time management of network functions, and **Software Defined Networking (SDN)** for centralised network control and programmability [26].

The **5G Core Network (CN)** integrates several critical components to ensure seamless functionality. The **Access and Mobility Function (AMF)** regulates connectivity, reachability, and location management of UE, while the **Session Management Function (SMF)** oversees session management and IP address allocation [27]. The **User Plane Function (UPF)** manages packet routing, quality of service (QoS), policy enforcement, and serves as an anchor point for mobility within the Next Generation RAN (NG-RAN) [27]. **Unified Data Management (UDM)** handles user registration, data storage, and authorisation, while the **Authentication Server Function (AUSF)** authenticates servers and provides encryption keys to ensure secure communications [20]. Together, these components power the advanced capabilities and scalability of 5G networks.

The popularization of smart devices is creating a demand for improved video, audio, graphic and data services [11]. Current spectrum bands are becoming increasingly congested, causing service disruptions, especially when large numbers of people in the same area attempt to use mobile online services simultaneously [28]. 5G challenge is to satisfy user experience by offering higher transmission rates and latency than currently available while improving the support of device connectivity per square kilometer [29].

Benefits of 5G is to enjoy greater transmissions with lower latency. 5G can offer new services from robots, autonomous vehicles, real time communication, glitch-free video conferencing, gaming in real time, to services that that we cannot foresee [28]. New Generations of wireless communication is approximately deployed every 10 years [30]. 6G is already in the research phrase [31]. If history repeats itself the telecommunications may be ready for 6G in 2030.

2.6. Comparison of 3G, 4G, 5G Technologies

Table 2 compares the key features and advancements of 3G, 4G, and 5G cellular wireless technologies. It highlights their development timelines, ITU requirements, architectures, air interfaces, data bandwidths, frequency bands, switching types, applications, advantages, and disadvantages.

Table 2: Comparison of 3G, 4G, and 5G Technologies

Technology/Features	3G	4G	5G
Start/Development	1990's	2000's	2019+
ITU Requirements	IMT-2000	IMT-Advance	IMT2020
Architecture	UMTS	LTE	mmWaves, MIMO
Air Interface	WCDMA	OFDM	NR
Data Bandwidth	Up to 2 Mbps	Up to 100 Mbps	1Gbps and Higher
Frequency Bands	1885-2200 MHz	2000 MHz to 8000 MHz	Sub-6GHz; 30 - 300 GHz
Switching Type	Circuit Switching (Voice & Data)	Packet Network	Virtualized CN
Applications	- Voice, SMS & MMS - Video Conferencing - GPS - Mobile TV - Open Mobile Architecture	- Video Conferencing. - High-Definition Video Streaming - Online game multiplayer. - VoLTE	- 8K Video Streaming - Autonomous vehicles - Robots - Unforeseen Applications

Advantage over predecessor	- Interoperability between ISPs - Backward compatibility - Always-online devices - Global Roaming - Improved Data rates - Internet Services - Improved Security [4]	- Data Rates are improved - Packet only network - Improved Security - Clearer calls on VoLTE - Lower latency - Improved Security [4]	- Improved Data Speeds - Manageable with predecessors - Edge Computing - Lower Latency [28]
Disadvantage over predecessor	- Upgrading Radio Network is expensive - Requires a new 3G handset - UE Subscriptions more expensive - UE requires more power [4]	- Time and Money to roll out infrastructure - UE More expensive - 4G Technology consumes more UE battery [4]	- Time and Money to roll out infrastructure - UE More expensive - 5G Technology consumes more UE battery - Security to be solved - Obstruction penetration with mmWaves [17]

3. Wired Broadband Technologies

DSL (Digital Subscriber Line) and FTTH (Fiber-To-The-Home) are 2 mainstream and most-widespread wired broadband technologies. They use different types of technology and offer different capabilities. In this section, we have a deeper look into these technologies.

3.1. Digital Subscriber Line (DSL)

DSL provides data communications over copper telephone lines. Variants of DSL, such as Asymmetric DSL (ADSL), offer greater downlink speeds by splitting traffic into two isolated frequency bands, allowing simultaneous data and voice transmission. DSL works by splitting traffic into two isolated frequency bands which allows a single line to transmit data and voice simultaneously [32]. DSL architecture comprises two components: Premises and Central Office [33].

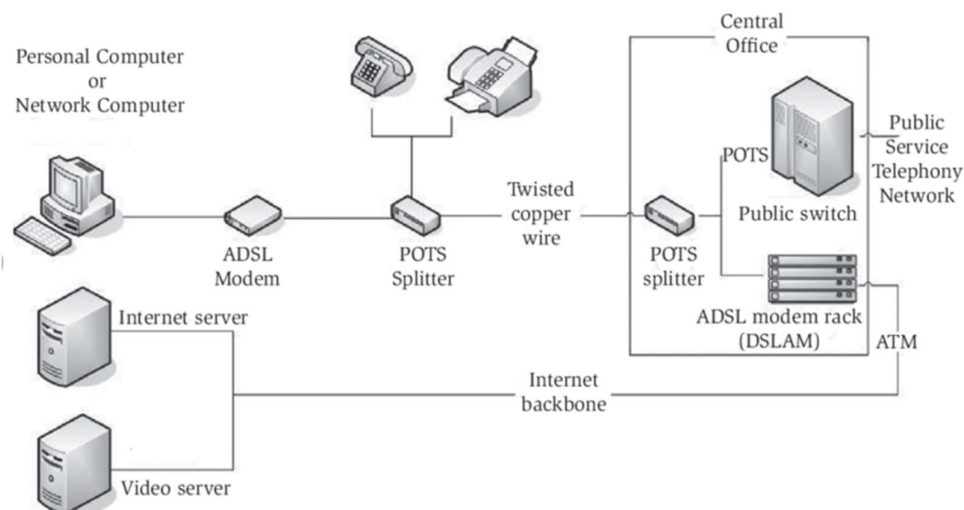


Figure 4: Architecture of DSL [33]

In the context of DSL architecture, **Premises** refer to the location where the DSL service is delivered, typically a home or business. DSL arrives at a property using **twisted copper wire**. The line connects to a **Plain Old Telephone Services (POTS) Splitter**. The splitter separates the channels for voice and data. The data line connects to an **ADSL Gateway**. ADSL gateway combines the functions of a **modem, router, and wireless**

access point. The gateway provides data communications. The voice line connects to the telephone system [33].

Central Office/Telephone Exchange receives signals from multiple DSL connections and separates the signal using POTS splitters. The Data signal is sent to the DSLAM. A DSLAM issues multiplexing techniques to signal data to the internet backbone. Internet Service Providers (ISP) may use several DSLAMS to route traffic. The voice is signaled to a public switch which connects to the Public Switched Telephone Network (PSTN) [32].

ITU- G.991 is a standard for ADSL from Telecommunication Standardization Sector of the International Telecom Union [34]. The system supports downstream speeds of about 6 Mbit/s and upstream speeds of around 640 kbit/s, with performance varying based on deployment conditions and noise levels [34]. Full-rate ADSL offers service at a maximum distance of 12,000 feet (approximately 2 miles) from the telecommunication provider's central office to the end user [35].

3.2. Fiber-To-The-Home (FTTH)

FTTH is a broadband network which uses optical fiber to provide network coverage. FTTH brings fiber connectivity to the home. Other fiber optic deliveries include Fiber to the Cabinet (FTTC) and Fiber to the Node (FTTN) [36]. There are several Passive Optical Network (PON) options available for FTTH. A PON system broadcasts one signal into many by using passive splitters. Options of PON include Broadband PON (BPON) using the ITU-T 9.983 standard, Gigabit capable PON (GPON) using the ITU-T G. 984 standard and Ethernet PON using IEEE-802.3ah standard [37]. FTTH architecture as seen in Figure 5 can be divided into three components: Central Office (CO), Distribution Fiber Hub (FDH), and Optical Network Terminal (ONT) [38].

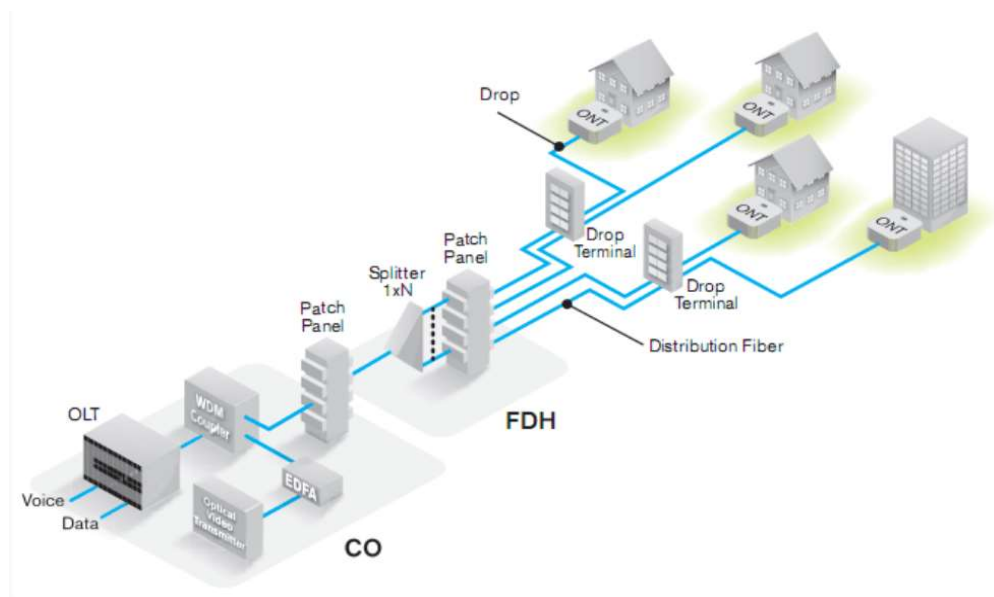


Figure 5: Network Architecture of FTTH [39]

Central Offices (CO) play a crucial role in distributing fiber optic connections to end users, using a variety of essential components. The **Erbium-Doped Fiber Amplifier (EDFA)** boosts the intensity of optical signals, ensuring strong signal transmission [40]. The **Optical Video Transmitter** converts digital signals into optical signals, while the **Wavelength Division Multiplexing (WDM) Coupler** distributes optical signals, allowing them to travel either from one source to multiple destinations or vice versa [41]. The **Optical Line Terminal (OLT)** performs the critical function of converting electrical signals from the network into fiber optic signals used by the Passive Optical Network (PON) [41]. A **Patch Panel** provides multiple connection points for routing circuits, and the **Drop Terminal** links the Optical Network Terminal (ONT) to the Fiber Distribution Hub (FDH). The **FDH** acts as the intermediary between the CO and the ONT, connecting fiber optic cables to passive optical splitters [42]. The **ONT** converts optical signals into electrical signals and vice versa, enabling the modem to broadcast fiber optic internet within premises [41].

Fiber to the Home (FTTH) is a future-proof solution for delivering broadband services like video on demand, online gaming, HD TV, and VoIP. Passive Optical Networks (PON) are designed to handle various speeds, such as Broadband PON (BPON) offering data and voice at up to 155 Mbps, Ethernet PON (EPON) at up to 1.25 Gbps, and Gigabit PON (GPON) at up to 2.5 Gbps. FTTH networks take advantage of the low attenuation (0.2–0.6 dB/km) and extremely high bandwidth (>30,000 GHz) of single-mode optical fibres, providing significantly more bandwidth than other broadband technologies like DSL. Furthermore, these networks are capable of delivering all communication services including data, voice, and video on a single, unified platform [43].

3.3. Comparison of DSL and FTTH Technologies

This section compares the advantages and disadvantages, as well as the key features of DSL and FTTH.

Table 3: Advantages and disadvantages, and Key Features of DSL and FTTH

	Advantages	Disadvantages
DSL	- Ability to talk on the phone while browsing the internet simultaneously [33]. - DSL uses existing infrastructure (telephone network) [32]. - DSL provides data speeds much higher than narrowband [44]. - Copper may be more robust. - DSL is widely available within the United Kingdom	- The connection performs better the closer the connection from the premises to the central office [33]. - Sending information is much slower than receiving information [32]. - Copper-based transmissions currently max out at 40 Gbps [45].
FTTH	- Data speeds far faster than offered by DSL. - Fiber optics can carry data at close to the speed of light [45] - Fiber can virtually carry unlimited bandwidth with long reach [43]. - Fiber is resistant to electromagnetic interference [46]. - Fiber optics do not radiate signals which improves security from eavesdropping [47].	- Fiber optic cables are thinner and lighter than metal wiring, making the system more fragile. Additionally, their small size makes them prone to accidental damage during building renovations or rewiring [47]. - Installation costs are expensive if the infrastructure is not yet available within the desired area [47].

4. Cloud Computing

Network technology devices such as routers, switches, bridge, modems, repeaters, access points, servers, and workstations allow data to be exchanged through physical nodes on a network. Traditional networks provide full control over network infrastructure at the cost of network administration resource and physical network devices [48]. Cloud services have become a fundamental part of the Internet, establishing themselves as a modern infrastructure. Cloud Services are designed to offer users access to the necessary computing resources, such as servers, storage, and applications owned and managed by the cloud service provider [49].

A deployment model in the context of cloud computing refers to the specific environment and configuration in which cloud services are deployed. There are four deployment models for cloud services [50]: **Public Cloud** provides entire infrastructure services to everyone over the internet, **Private Cloud** provides dedicated infrastructure which is private and not shared by other users, **Hybrid Cloud** combines public and private cloud characteristics where data can be stored on private cloud while using the benefits of public cloud, and **community cloud** that is shared by a variety of users which have common goals.

Table 4: Comparison of Cloud Deployment Services

Attribute	Public Cloud	Private Cloud	Hybrid Cloud	Community Cloud
Reliability	Moderate	High	Moderate to High	Very High
Scalability	Very High	Limited	Very High	Limited
Upfront Cost	Inexpensive	Highly Expensive	Dynamic (base plus pas you go)	Dynamic (base plus pas you go)
Data & Application Integration	Easier	Easier	Most Difficult	East to Moderate
Security	Low	High	Moderate	Moderate
System Management	Easier	Easier	Most Difficult	Moderate
Portability	Easier	Easier	Difficult	Easy
Data Security Solutions	Encryption Techniques, Authentication Techniques (Username & Password).	Encrypted Data on Private Servers	Personal Encrypted data. Sensitive/Confidential data should be on Private.	Personal Encrypted data. Sensitive/Confidential data should be on Private.
Performance	Low to Moderate	Very Good	Good	Very Good
Workload	Normal Workload	Mission-critical workload	Highly dynamic or changeable	Collaborative Large workload
Users	General Public, Organizations	Organizations	Organizations	Community Members, Multiple Organizations
Owner	Service Provider	Enterprise	Enterprise	Community

In the context of cloud computing, a service is a resource provided over the internet that allows users to access and utilize software, infrastructure, or platforms without managing the underlying hardware or software directly. There are four types of service in cloud computing: Software as a Service (SaaS) delivers software on demand through cloud services, Infrastructure as a Service (IaaS) provides virtual and physical network IT infrastructure, Platform as a Service (PaaS) offers tools to develop, test, deliver, and manage software applications, and Functions as a Service (FaaS) allows users to execute code in response to events without the complexity of infrastructure [50].

Figure 6 gives an overview of SaaS, PaaS and IaaS and the vendors supplying those services [51]. Table 5 summarizes the advantages and disadvantages of these cloud technologies as argued by Rani & Ranjan [52].

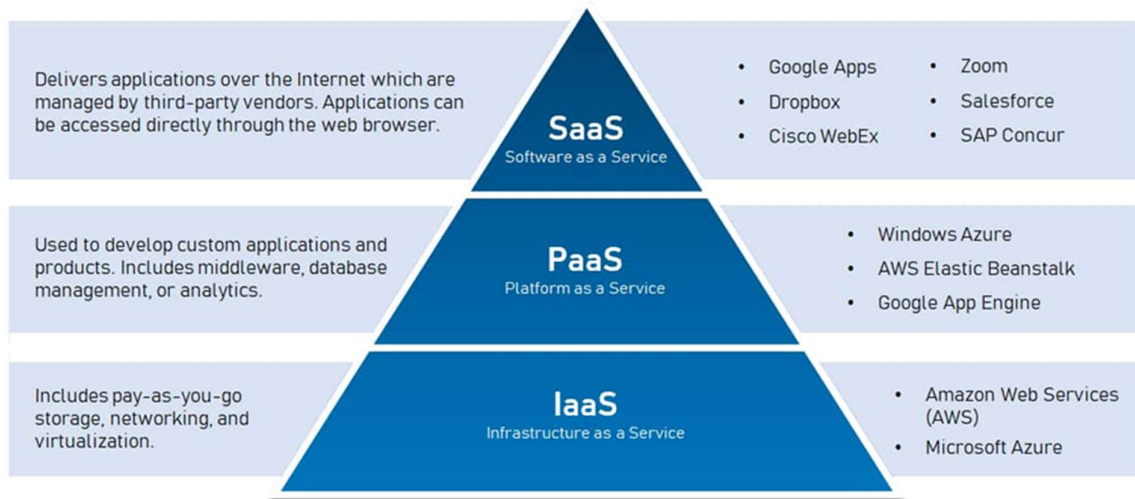


Figure 6: cloud Services [51]

Table 5 compares the advantages and disadvantages of SaaS, PaaS, and IaaS cloud computing models. It highlights key points such as availability, control, infrastructure costs, and complexity.

Table 5: Comparison of Cloud Services [52]

	SaaS	PaaS	IaaS	FaaS
Advantages	- Available through web browsers - Available on desktop or mobiles - No Requirements for installation - reduction in local administration - Improved Usability; Users just need to sign in to use the service	- Provides Control over the platform software - Supports Multiple programming languages	- Lower infrastructure costs - Improved scalability	- Cost Efficiency - Scalability - Simplified Code
Disadvantages	- No control over the traditional infrastructure	- No control over the infrastructure - Fundamental Coding knowledge required by users	- In-house specialist knowledge requirement of IaaS computing resources - Added complexity and management - Unnecessary workloads may result in unforeseen costs.	- Vendor Lock-In - Cold Starts - Security Concerns

Figure 7 provides a comparison of cloud services, including IaaS, PaaS, FaaS, and SaaS, and indicates which services are managed on-premises, by the customer, and by the provider. It visually represents the division of responsibilities between the customer and the cloud service provider for each type of service.

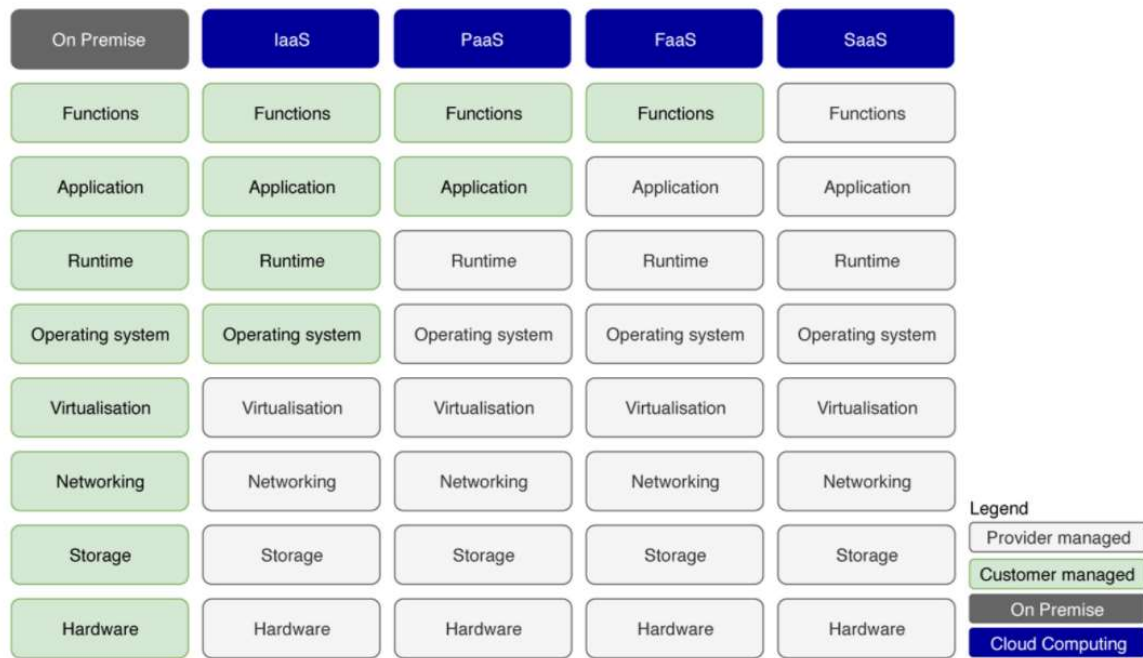


Figure 7: Traditional v Cloud [53]

Cloud computing can provide users and organizations services over the internet which provides a pay-as-you-go service when compared to traditional on-premises infrastructure that can be costly to install with limited stability. 2020 has been a year of tumult and turbulence because of Covid-19. The Covid-19 pandemic provided an increased and accelerated demand for cloud services [54]. Post Covid-19 could be a pivotal moment in the history of cloud computing in which organizations can improve on networking infrastructure by employing cloud services. However, organizations are still dependent on the infrastructure used by ISPs to deliver Internet Services.

Content Delivery Networks (CDNs) are a crucial component of cloud infrastructure, and they work together to enhance the delivery of content and services over the internet. CDN works by storing cached replications of content to multiple geographical locations around the world. The replication reduces the physical distance for data to travel which improves latency and reduces congestion [55]. CDNs are enabling more efficient content delivery over the internet and help maximize bandwidth, improve accessibility, and maintain correctness through content replication [56].

5. Security Threats and Countermeasures Pertinent to the Technologies

After an in-depth discussion on the features and characteristics of different networking technologies in sections 2, 3, and 4 of this paper, in this section we will have a look at the security threats, and related countermeasures pertinent to those technologies. There could be numerous security threats pertaining to each networking technology, however, in favor of space, we will focus on top 5 (most current) security threats pertaining to each technology, and their relevant countermeasures.

Table 6: Security Threats and Countermeasures

Technology	Security Threats	Relevant Countermeasures
3G	1. Eavesdropping on communications	1. Implement strong encryption protocols like A5/3 and end-to-end encryption for user data.

	2. Man-in-the-Middle (MitM) attacks	2. Use mutual authentication between User Equipment (UE) and base stations.
	3. SS7 signalling vulnerabilities allowing unauthorised tracking and interception	3. Upgrade SS7 to Diameter protocol and deploy firewall solutions to prevent unauthorised signalling.
	4. Fake base station (IMSI catcher) attacks	4. Implement base station authentication and alert mechanisms to detect rogue base stations.
	5. Malware injection through unverified apps	5. Educate users and enforce stricter app verification policies for app stores.
4G	1. Exploitation of signalling protocols like Diameter for denial of service (DoS) attacks	1. Deploy Diameter firewalls and monitoring solutions to detect and mitigate abnormal traffic.
	2. IMSI catching through fake eNodeBs	2. Use randomised temporary IMSI numbers to protect user identity.
	3. Radio jamming to disrupt communication	3. Deploy advanced interference detection and mitigation systems.
	4. Packet sniffing over unencrypted IP traffic	4. Implement IPsec for secure communication.
	5. Malware targeting mobile devices	5. Encourage security patch updates and implement robust device security solutions.
5G	1. Supply chain vulnerabilities in 5G hardware	1. Conduct regular hardware audits, enforce secure supply chain standards, and use trusted vendors.
	2. Network slicing attacks, exploiting vulnerabilities in isolated virtual networks	2. Use isolation techniques, robust access controls, and constant monitoring for slices.
	3. Misuse of Massive MIMO and Beamforming for unauthorised access	3. Deploy AI-based monitoring systems to detect anomalous beamforming activities.
	4. Data interception through weak encryption in edge computing	4. Implement strong encryption protocols and ensure secure communication between edge nodes.
	5. DDoS attacks on 5G core networks	5. Deploy advanced DDoS mitigation solutions like AI-based detection and traffic filtering.
DSL/ADSL	1. Man-in-the-Middle attacks over unencrypted data streams	1. Use VPNs and implement end-to-end encryption.
	2. Phishing attacks exploiting less secure internet browsing	2. Educate users about phishing and enforce web filters at ISP level.
	3. Router-level vulnerabilities	3. Enforce strong passwords and firmware updates on routers.

	4. Data sniffing over unprotected Wi-Fi used alongside ADSL	4. Use WPA3 for secure Wi-Fi encryption.
	5. Malware distribution via infected websites	5. Deploy ISP-level threat intelligence to block malicious websites.
FTTH	1. Physical tapping of fiber cables	1. Use fiber monitoring systems to detect and mitigate physical tampering.
	2. Optical network terminal (ONT) vulnerabilities	2. Regular firmware updates and endpoint security for ONTs.
	3. DDoS attacks on FTTH networks	3. Employ network-wide DDoS detection and mitigation solutions.
	4. Insider threats from service providers	4. Use role-based access controls and audit logs to track insider activity.
	5. Data exfiltration through compromised routers	5. Implement network-wide intrusion detection systems (IDS) and endpoint monitoring.
Cloud Computing	1. Data breaches due to misconfigured cloud environments	1. Use automated configuration management tools and enforce compliance monitoring.
	2. Insider threats within cloud providers	2. Enforce strict role-based access controls and enable activity logging.
	3. Ransomware attacks on cloud-stored data	3. Regularly back up data and implement strong disaster recovery mechanisms.
	4. API vulnerabilities exploited for unauthorised access	4. Secure APIs with strong authentication mechanisms and regular penetration testing.
	5. Shared tenancy risks where multiple customers share the same hardware	5. Use hypervisor security measures, such as isolation and sandboxing, to prevent cross-tenant attacks.

6. Conclusion

This paper explored modern communication technologies, covering the evolution of cellular networks from 1G to 5G with advancements in architecture and functionality, a comparison of 3G, 4G, and 5G, as well as broadband technologies like DSL and fiber-optic FTTH, focusing on their architectures and capabilities. Cloud computing was analyzed, highlighting deployment models—public, private, hybrid, and community—and service models like SaaS, PaaS, IaaS, and FaaS, emphasizing their advantages and limitations. Security threats and countermeasures for these technologies were also discussed, addressing vulnerabilities in cellular networks, broadband solutions, and cloud environments. As these technologies evolve, their integration will foster greater connectivity and innovation, but robust security measures are crucial to maintaining trust and reliability.

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