

An Overview of Mobile Network Communication Evolution (0G – 6G)

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Abstract

Communication systems play a crucial role in various industries and human life. Since the emergence of legacy communication systems, human lives have become more interconnected. At first, wired communication systems with short-distance connections were invented then evolved into wireless systems, which we now heavily depend on in our daily lives. Zero Generation (0G) (pre-cellular communication systems) was the beginning of Wireless communication, followed by the First Generation (1G), which introduced cellular networks using analog transmission. The Second Generation (2G) introduced Global System for Mobile Communication (GSM) systems with digital transmission technology which is regarded as more effective and robust than Analog technology. Later generations, such as Third Generation (3G) with Universal Mobile Telecommunications System (UMTS) and Fourth Generation (4G) with Long Term Evolution (LTE) evolved to meet new requirements. With each generation, communication capabilities have significantly advanced to break limitations of last one and meet requirements in current one. Fifth Generation (5G) has been in deployment since 2020 with many advanced technologies being leveraged due to the diverse scenarios of 5G, and research on Sixth Generation (6G) is currently in progress. In this work, we provide a thorough analysis of mobile communication systems to help researchers understand each generation specifically. Since 6G is still in the research phase and has not yet been deployed, we highlight key challenges and issues to assist researchers in identifying solutions and exploring potential 6G advancements.

Keywords: AMPS, GSM, WiMAX, LTE, eMBB, mMTC, URLLC.

Introduction

Over the years, wireless communication has been developing dramatically, and there are now various communication systems, such as infrared communication, Bluetooth, Wi-Fi, mobile communication, satellite communication, and microwave communication [1]. These technologies have been integrated with many other technologies to support many applications. For example, cellular systems play an important role in IoT technology by providing a seamless connection between a massive number of devices [2]. So, any advancements in wireless communication facilitate the advent of new technologies, services, and applications. Moreover, advancements in these systems are mainly related to the evolution of several technologies, such as antenna design, signal processing, embedded systems, software-defined networks, network function virtualization, artificial intelligence, etc.

In our study, we are focusing on mobile networks and their evolution over time. In the early stages of developing mobile communication systems, countries developed these systems independently. However, now several communities gather countries and unify their effort to make the world more connectable, such as the Third Generation Partnership Project (3GPP), the International Telecommunication Union (ITU), and the Institute of Electrical and Electronics Engineers (IEEE) communities [3-5]. Each section of this paper discusses one generation in sequence, starting from 0G, which is not defined in many studies because it was not a cellular system. That was the reason behind calling it the pre-cellular generation. Otherwise, cellular systems started to be deployed with the emergence of 1G, which had weak connections and low capacity. After that, the 2G was utilized by proposing the GSM system, which was used with digital transmission capability. Subsequently, 3G came over to break the limitations,

proposing new technologies such as packet-switched systems to handle new services, like multimedia services and video calls. Additionally, 4G proposed LTE, offering more efficiency and better capabilities to handle more data transmission and accommodate more devices. These days, we have witnessed the deployment of 5G, which is designed to deal with more scenarios and meet current usage requirements. The need to improve the network always exists because future requirements will differ from today's. Therefore, 6G is starting to take place in research and industry. It is also planned to be a terrestrial and non-terrestrial network with enhanced throughput and density, enabling more advanced services and applications. Moreover, the details will be mentioned in each section for each generation, and we will also provide some potential research challenges related to the 6G network development at the end of the study. Then, we have the conclusion of our work.

0G (Zero Generation)

0G refers to pre-cellular telephone technology that emerged in the 1970s. While some papers classify 0G alongside the 1G, in our paper, we will treat them as separate generations based on whether they utilize cellular systems. Both 0G and 1G rely on analog communication, which introduces several disadvantages.

These limitations ultimately led to their replacement by digital communication in later generations, as we will discuss further in this paper. 0G employed various technologies, as illustrated in Figure [1]. Each of these technologies, with its own unique features played a crucial role in the zero-generation system. PTT utilized half-duplex communication, allowing only one party to speak at a time. OLT enabled users to make and receive phone calls using mobile handsets connected to the public switched telephone network (PSTN) via base stations and mobile switching centers. MTS was one of the earliest mobile telephone standards, serving as the radiotelephone equivalent of landline dial-up phone service. IMTS, a pre-cellular VHF (Very High Frequency) and UHF (Ultra High Frequency) radio system, replaced MTS and improved upon it by offering direct dialing rather than operator-assisted connections and full-duplex operation, allowing both parties to speak simultaneously. AMTS, an early analog mobile telephone system developed in the 1970s and deployed in various countries during the late 1970s and early 1980s, it used analog frequency modulation (FM) for voice transmission and operated on relatively low-frequency bands such as VHF or UHF. Each successive technology represented a further improvement over its predecessor [6].

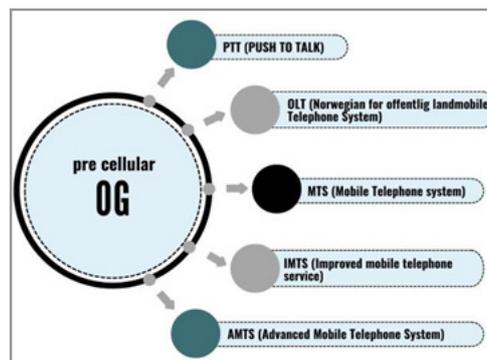


Figure 1: Technologies employed in 0G

1G (First Generation)

In the 1980s, numerous analog cellular systems were introduced, marking the first implementation of cellular systems. The first one was implemented in Tokyo, Japan, and was named Nippon Telephone and Telegraph (NTT) in 1979. Subsequently, many nations launched their systems, such as Advanced Mobile Phone System (AMPS), Total Access Communication System (TACS) and Nordic Mobile Telephone (NMT). The architecture of these first-generation systems comprised three main components: the mobile phone, the base station (BS), and the mobile switching center (MSC); at the end, these integrated components connect to PSTN as Figure illustrates [2, 7, 8]. The mobile phone communicates with the base station within its cell coverage area using a specific range of frequencies unique to the system.

The base station transfers the received radio signal to the MSC via wired (landline) or wireless (microwave communication) links. The MSC subsequently routes the signal to the intended recipient's phone.

For example, AMPS utilized the frequency range of 869- 894 MHz for the forward channel (transmitting signals from the base station to the mobile phone) and 824-849 MHz for the reverse channel (communicating from the mobile phone to the base station), and AMPS relied on analog technology with FM modulation. Additionally, the FDMA (Frequency Division Multiple Access) system was employed to manage the system's channels with a capacity of 30 KHz [7-8-9-10].

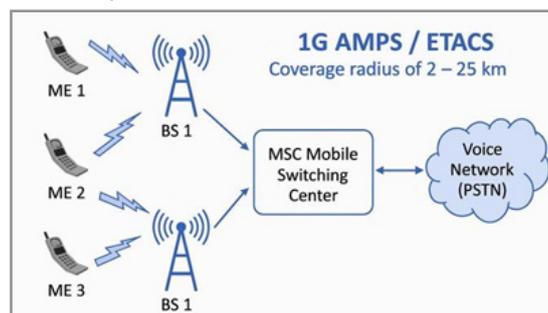


Figure 2: 1G AMPS architecture

2G (Second Generation)

This generation was the starting point of digital mobile communication, which enabled more than voice services, making it different from 1G, which used analog transmission. The advancements that came with this generation were not only using digital signals, which offered services other than voice communication; in other words, more services such as text messaging, picture messages, and MMS (multimedia messages) became available with 2G as long as digital communication used which means sufficient security transmission process and offering ability of digital encryption so desired users can only transmit and receive data [11], So digital traffic channels, error detection and correction techniques, cryptographic algorithms and incorporation of Code division Multiple Access (CDMA) and Time Division Multiple Access (TDMA) for dynamically managing and sharing available spectral resources were enabled owing to the adoption of digital technology [12].

To manage channels, several technologies have been proposed, like FDMA, which means each frequency in bandwidth is assigned for one user during the communication process, and this type is employed in the first generation; as we mentioned, we

have TDMA, which means time slots are allocated for each user over channel allowing many users could share the same channel, and CDMA also used to increase the user's number could utilize one frequency by giving each user unique code to be identified during transmitting and receiving the signal, Different TDMA technologies has been introduced in 2G such as GSM, PDC, iDEN and IS-136, as mentioned in [13] gaussian minimum shift keying (GMSK) has been utilized in GSM as modulation technique, on the other hand IS-95 using CDMA technology [10]. GSM was the most popular 2G wireless technology Standard using two bands of 25MHz, 890-915MHz, and 935- 960MHz for the transmit and receive bands of the mobile system, respectively. Also, it leverages FDD (Frequency Division Duplex) and TDMA. Furthermore, the receive band is divided into 128 channels with 200 KHz bandwidth; consequently, eight users could share one [14].

Figure [3] illustrate some features and challenges in 1G and 2G networks, demonstrating how the limitation of 1G were improved upon to pave the way for the advancement of 2G technology. Otherwise, GSM continues to be improved until even today [16].

1G	2G
✓ Analog system	✓ Digital system
✓ Data speed of up to 2.4kbps	✓ Data speed of up to 64 kbps
✓ Cordless telephone with voice services	✓ Improved system capacity and network coverage
✗ Data services	✓ Roaming capability
✗ High capacity	✓ Voice and data services
✗ Poor handoff	✓ Enhanced spectrum efficiency
✗ Good secure	✓ Better secure
✗ Good voice link	✗ handling complex data

Figure 3: Key differences between 1G and 2G

2G – GSM Architecture

In GSM Architecture, we have 4 subsystems as follows:

1. The Mobile station (MS): Equipment and tools used by the user to access the services, including Mobile equipment (ME), Subscriber identity module (SIM), International mobile station equipment identity (IMEI), Mobile subscriber ISDN number (MSISDN), International mobile subscriber identity (IMSI) and Mobile station roaming number (MSRN).
2. The Base Station Subsystem (BSS) is the central component connecting mobile phones to the network. It has two main parts: The base transceiver station (BTS) and the Base station controller (BSC).

3. Network switching subsystem (NSS): is responsible for switching calls between users, involving entities such as Mobile switching center (MSC), Gateway mobile switching center (GMSC), Equipment identity register (EIR), Home location register (HLR), Visitor location register (VLR) and Authentication center (AuC).
4. Operation and Support Subsystem (OSS): Responsible for supervising all components and entities of the GSM system and monitoring their performance. It maintains direct connections to the NSS and BSS [15-13].

Figure [4] shows GSM architecture and the connection of GSM network components.

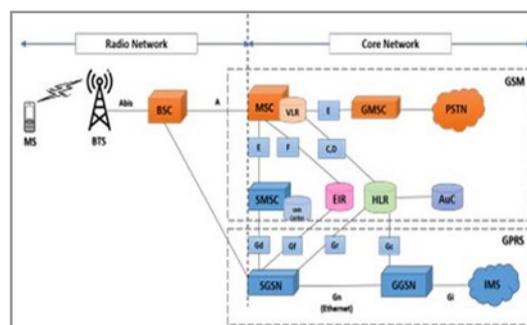


Figure 4: 2G - GSM architecture

3G (Third Generation)

The 3rd Generation Partnership Project (3GPP) was established in 1998 to oversee the evolution of 3G networks that originated and developed from GSM. 3GPP has played a crucial role in the development of several key technologies, including General Packet Radio Service (GPRS), Enhanced Data Rates for Global Evolution (EDGE), UMTS Wideband CDMA (WCDMA), High-Speed Downlink Packet Access (HSDPA), and LTE Evolved UMTS Terrestrial Radio Access (E-UTRA). GPRS deployments began in 2000, followed by EDGE in 2003. Although IMT-2000 standards define these technologies, they are sometimes classified as "2.5G" because they do not support multi-megabit data rates [10].

Three primary standards are generally utilized in 3G network systems: CDMA2000, WCDMA (UMTS), and TD-SCDMA [17].

1. CDMA2000: Deployed in North America and Developed from 2G Code Division Multiple Access, CDMA2000 features a 1.25 MHz channel width and supports speeds up to 144 Kbps.
2. WCDMA (UMTS): Deployed in Europe and considered an evolution of GSM, WCDMA operates with a 5 MHz channel width and supports speeds of up to 2 Mbps. UMTS consists of two main networks: The Core network and the radio access network; the system architecture is illustrated in Figure [5].
3. TD-SCDMA: Deployed in China and Utilizing time- divi-

sion duplexing (TDD) rather than frequency division duplexing (FDD), TD-SCDMA operates with a single channel width of 1.6 MHz [18].

The advancement of 3G technologies has enabled a diverse array of applications, including Global Positioning System (GPS), Video on Demand (VOD), Location-Based Services (LBS), Mobile TV (MTV), and Video Conferencing (VC) [19]. Additionally, challenges such as power consumption and cost must be taken into consideration when addressing 3G networks. 3GPP developed HSPA+ (Evolved High-Speed Packet Access), which is based on W-CDMA and utilizes MIMO (Multiple Input Multiple Output), enhancing data services in third-generation networks.

It is worth mentioning that WCDMA is The Most Widely Adopted Standard for Several Reasons, such as:

- Global Adoption: Operators worldwide use this standard, making it the most common choice.
- Advanced 2G Technology: WCDMA is an advanced evolution of second-generation (2G) technology. It allows compatibility with 2G devices, enabling seamless usage and adaptation.
- Wide Device Support: Many devices support this standard, unlike TD-SCDMA, which is primarily used in China, or CDMA2000, which is geographically limited to specific regions [20].

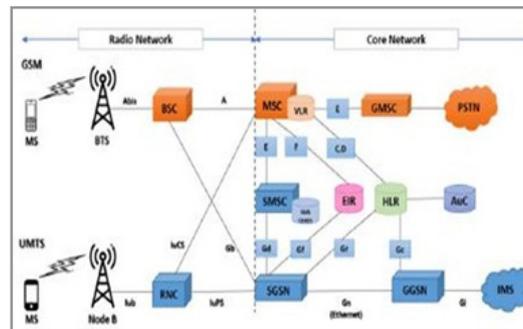


Figure 5: UMTS Network Architecture Connected with Legacy Network

4G (Fourth Generation)

4G aims to address the increasing demand for higher data rates and to break through the limitations of 3G by introducing new standards and technology to meet massive requirements and handle several scenarios. So, WiMAX, LTE, and LTE-A are posed as the 4G wireless communication technologies, each introducing advancements over the predecessor networks. By 4G technology, data transmission rates, IP-based architecture, lower latency, spectral efficiency, and reduced operational and capital costs are utilized. Furthermore, these three technologies are explored individually as follows:

1. WiMAX (Worldwide Interoperability for Microwave Access) is a wireless network that provides broadband transmission over a wide geographical area. It is a fixed wireless system and is part of the IEEE 802.16 family of standards. The IEEE 802.16e standard introduced flexible mobility for fixed WiMAX, allowing users to maintain connectivity while moving between cells. Orthogonal Frequency Division Multiplexing (OFDM) and Orthogonal Frequency Division Multiple Access (OFDMA) are considered as mod-

ulation technique and an access method, respectively, in WiMAX. Advanced MIMO schemes are also utilized [21].

2. LTE, developed by 3GPP, is a technology designed to offer high-speed data transfer, support many devices, and reduce access time and latency by efficiently utilizing bandwidth and ensuring interoperability with existing networks. LTE uses OFDMA for downlink, achieving data rates of about 300 Mbps, and Single Carrier FDMA (SC-FDMA) for uplink [22], achieving flows of about 75 Mbps, even for users traveling at speeds between 120 and 350 km/h. OFDM and MIMO technologies are employed in LTE, along with a new System Architecture Evolution (SAE) [23-24].
3. LTE-A is an enhanced version of LTE, offering data rates of up to 300 Mbps for uplink and 1 Gbps for downlink, with a bandwidth of up to 100 MHz. It provides lower latency than LTE and supports mobility at speeds up to 500 km/h while utilizing the same technologies and techniques as the LTE standard [25].
4. LTE is the predominant 4G network technology today, with operators favoring it over WiMAX due to its smoother tran-

sition to 5G and widespread adoption. Additionally, LTE demonstrates higher throughput efficiency than WiMAX, as explained in the work [26].

5G (Fifth Generation)

Global mobile subscriptions increased from 6.7 billion in 2013 to 10.7 billion in 2020, the year of the 5G network launch [27]. Moreover, global mobile data traffic has rapidly increased due to the services provided to users, such as high-quality video streaming, cloud services, low-latency applications, etc. Therefore, 5G must address the growing demand for new user services and applications. The requirements need to be addressed by 5G, such as handling massive data volumes, providing faster transmission speeds, increasing network capacity, delivering efficient performance in mobility scenarios, and supporting emerging service requirements. 5G technology introduces three primary enhancements to address these needs and handle different scenarios: eMBB (Enhanced Mobile Broadband), mMTC (Massive Machine-Type Communications), and URLLC (Ultra-Reliable Low-Latency Communications) [28, 29].

Enhanced Mobile Broadband (eMBB): Improving peak data rates with stable connections, superior user experience, and wide-area coverage to support bandwidth-intensive services such as 4K/8K video streaming, large-scale file transfers, cloud services, Augmented Reality (AR), Virtual Reality (VR), and high-definition video conferencing. Additionally, eMBB ensures stable connectivity for users when they move across cells, including those at the cell edge. Massive Machine Type Communications (mMTC): supports many IoT devices, each transmitting small amounts of data with low power consumption. mMTC plays a crucial role in industrial IoT, smart cities, and smart agriculture. To meet these requirements and handle the massive number of devices, 5G technology is designed to accommodate

4 devices/m², 200,000 devices/km², and 1 million devices/km² [30]. Ultra-Reliable Low Latency Communications (URLLC): Low Latency and High Reliability are required in many applications such as Autonomous Vehicles, Industrial Automation, Telemedicine and Remote Surgery, Mission-Critical Communications, Augmented Reality (AR) and Virtual Reality (VR), Drone Control and Management, Smart Grids, and Utilities. URLLC provides the necessary infrastructure for these applications which require real-time interaction, ensuring a high-quality, reliable communication channel.

5G networks involve various technologies, so efficiently utilizing new spectrum and bandwidth is important to accommodate many devices and handle required services. Moreover, it delivers services that address user demands. Consequently, a new network architecture and upgraded infrastructure are necessary. 5G utilizes MIMO (Multi-Input Multi-Output) with high-density antenna construct; connection pathways are enhanced by transmitting signals in multiple directions. Meanwhile, the receiver captures several copies of the transmitted data, which helps to strengthen the connection and improve throughput [31]. Therefore, the implementation cost of 5G presents a significant challenge for operators.

5G is implemented in two frequency ranges: sub-6 GHz and millimeter-wave (mmWave) [32]. The sub-6 GHz spectrum offers improved network performance with higher bandwidth, while mmWave provides extremely high-speed wireless communication and ultra-wide bandwidth. This combination of technologies allows 5G to meet the requirements of modern and future applications in many fields, such as Education, Automation and the IoT, Industry, Smart grid, Healthcare, Transportation, and Energy [31].

Table 1: Technology features comparison 1G To 5G

Technology / Features	1G	2G	3G	4G	5G
Deployment	1980 - 1990	1990 - 2000	2000 - 2010	2010 - 2020	2020 - 2035
Standards	NMT, AMPS, TACS, MTS	GSM, IS-95, D-AMPS, PDS	CDMA 2000, TD-SCDMA, W-CDMA	WiMAX, LTE	SINGLE UNIFIED STANDARD
Bandwidth	30kHz	200kHz	5 MHz - 20 MHz	20 MHz - 100MHz	Sub-1GHz, 1 GHz - 6 GHz, mmWave - 24 GHz to 100 GHz
Channel frequency	Analog Signal (30KHz)	1.8GHz	1.6GHz	2-8GHz	300GHz
Technology	Analog cellular Technology	Digital cellular Technology	CDMA 2000, UMTS, EDGE	WiMax, LTE, LTE-Advanced (LTE-A)	MIMO, mm Waves
Capabilities	Voice	Voice and Data	Voice, Data, and Video Calling	Voice, Data, Video Calling, HD Television, and Online Gaming.	Voice, Data, Video Calling, Ultra HD video, Virtual Reality applications

user cases (senarios)	Analog voice calls	Digital voice calls, Short Message Service	Mobile internet, video calling, and multimedia services.	eMBB with data streaming, and IoT support.	mMTC, eMBB, URLLC
Multiplexing	FDMA	TDMA, CDMA	CDMA	CDMA	OFDM/BDMA
Switching	Circuit switching	Circuit switching	Packet switching	Packet switching	Packet switching

6G (Sixth Generation)

Currently, 6G is still in the research and development phase, so the details about it may vary depending on different studies and perspective. 6G is expected to be deployed around 2030, integrating advanced technologies such as distributed ledger technologies, physical layer security, visible light communication, AI, terahertz communication, and quantum computing [33]. Additionally, its key verticals will include IoT, VR/AR/XR, smart cities, V2X (Vehicle-to-Everything communication), AI-driven networks, holographic communication, industrial automation, remote healthcare (telemedicine and haptic internet), Digital Twin, blockchain and Distributed Ledger Technologies and satellite & space communication. To manage these innovations, 6G must support a vast ecosystem of devices with diverse functionalities, ensuring seamless connectivity and automation. From this perspective several studies discuss 6G network architecture [34-36]. 6G will be enhanced more than 5G, having higher capacity, higher data rates, lower latency, more intelligible and automation, higher security, and better quality of service (QoS) to achieve and handle different scenarios and different technologies. Since each new generation must meet the demands and

requirements that the previous generation could not hold, the author in states that 6G capabilities will be 10 to 100 times greater than those of 5G. Additionally, the author expects that the data traffic volume in 2030 will be 670 times that of 2010. Despite enhancements in 5G, it will not be able to handle this massive data load, leveraging terahertz communication will influence the network positively from several aspects such as: ultra-high data rates, secure connectivity, energy efficiency, and massive device density through directional beamforming, supporting critical applications in mobility environments, small wavelengths, and advanced MIMO techniques [37, 38].

6G is planned to have a peak data rate of 1 TB/s, which necessitates a new spectrum, advanced chip architecture, alternative energy sources, and computer systems capable of transmitting and receiving such massive amounts of data while handling these frequencies, Figure [6] presents some key enhancements of the 6G network. According to, the 12GHz to 20GHz spectrum can support 6G services and intelligent 6G architecture proposed as shown in figure [7, 39].

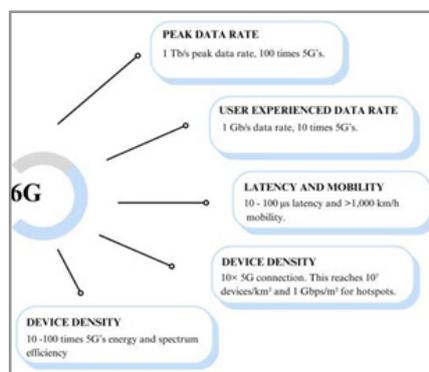


Figure 6: Key Enhancements of 6G

Authors in [36] mention some challenges encountered in 6G development, such as:

- AI-based adaptive transceivers
- Distributed and secure business models
- Intelligent wireless energy harvesting
- Intelligent cell-less architecture
- Distributed security models
- Reconfigurable smart reflecting surfaces enabled 6G



Figure 7: Intelligent 6G architecture

The author in [37] refers to challenges as follows:

- High Path Loss in THz Communication
- Need for Advanced THz Transceiver Architectures
- Energy Consumption and Cost Efficiency
- Challenges in Wireless Energy Transmission
- Scalability and Management of IoT in 6G
- Privacy vs. Intelligence Trade-off in 6G Networks
- THz Antenna Design and Performance Optimization
- Integration of THz Spectrum with Optical Fiber Networks
- Environmental Impact on THz Signal Transmission
- Health and Safety Concerns of THz Wave Propagation
- Understanding the Physical Nature of THz Signals.

Since 6G is still in the research and study phase, ongoing exploration will present many challenges that must be addressed.

Conclusion

Since the 1980s, a new generation of communication systems has emerged approximately every decade. Each generation of wireless communication technology emerges to meet the needs of its time in order to enhance the effectiveness of communication among users. Moreover, each new generation brings with it services and features that align with current technological advancements to meet the requirements and needs that could not be addressed by the previous generation. In other words, new wireless communication technologies are supposed to provide users with the ability to fully benefit from available services, contributing to their convenience and quality of life.

While 5G networks are currently deployed, future requirements vary from today's due to the emergence of new technologies and the diversity of services. Furthermore, 6G networks, which are currently in the research and study phase, aim to address the expected demands and needs by implementing novel technologies. This requires integrating advanced technologies with intelligent infrastructure to be able to handle different scenarios. However, this will pose many research areas for researchers to study and explore.

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