Journey of Wireless Communication

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Abstract Development of mobile communication is rapid, with different methods and techniques being introduced in wireless communications. The next few pages will deal with the detailed study of wireless cellular technologies—first, second, third, and fourth generations eventually leading to the fifth generation as well. This will visualize the evolution from analog system transmissions to digital transmissions which brought the usage of audio, graphics, video, etc. The evolution also gave rise to Internet on the cellular mobile phones which were once realizable only in computers through broadband connections. With improved technologies, we saw the development of fourth-generation cell phones which harnessed the use of LTE. The world is moving very fast, and the corporates involved in mobile communications are in a strong tussle to achieve the fifth generation of mobile networks which will shift the world's entire way of functioning from autonomous vehicles to IoT and many other things which could be seen only as part of sci-fi movies.

1 Introduction

The exchange of data which can be in any form between points that are not connected physically is wireless communication. It helps us avoid the recurring cost incurred in setting up physical means of communication such as cables. It is the fastest developing field in the world today. This development has been triggered by the need of employing the major use case of wireless communication—voice transmission, to be accompanied by video, packet, and data transmission on the air. There was a time when there used to be research conducted to increase the capacity of wired lines. This has reached a point wherein the world is researching on increasing the capacity

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of the wireless modes [1] of communication to accommodate the fifth generation of wireless communication so-called 5G. As there are limitations in increasing the bandwidth and maintaining power requirements, research is widely carried out on the types of signal transmission and the signal processing methods used in receiver. Due to rapid increase in the number of mobile subscribers, many issues such as congestion, low speed, and low bandwidth are faced. But above all this there are many advantages of wireless communication as well which include saving cost of installation of cables, saving time of installing the same, and at the time, instance creating mobility of devices connected to a network. But wireless communication is not only restricted to the cellular communication part. It also includes radio satellites which are used to communicate across the world as well as the networks which work inter-continentally. Even though we have come this far in the evolvement, there is still scope for perfection. The journey of coming to the fifth generation of networks is very long, and many researchers and companies have had to give in to the needs of the present world. Those who could not adapt were left back. For instance, Nippon Telegraph and Telephone (NTT) were the first to start a commercial cellular network which was automated in 1979 creating huge popularity which went to become the first nationwide 1G network in Japan. NTT is still at the forefront in the world in revenue terms. Nordic Mobile Telephone (NMT) was an early 1G network mostly used in Nordic countries. As the NMT specifications were free and open, many companies tried their recipes and companies like Nokia, Ericsson, and Motorola [2] came to the fore in manufacturing communication equipment. Some of these companies, however, could not survive the retail market beyond the 2G networks because they could not adapt to the changing needs of the people in cellular phones. And then came many other mobile operating systems which were all outclassed by Android and IOS. Chip manufacturing companies like Qualcomm, MediaTek, Broadcom, etc. have had their share of successes till date. As 2G evolved into 3G, people started expecting more and eventually came 4G which changed the outline of the cellular market. The corporates involved in the development of 4G dished out all companies surviving on 2G and 3G, and it has come to a stage where service providers like AT&T, Verizon, Jio, etc. have either completely shut down the GSM network-related infrastructure or are in the process of phasing it out soon. As companies started cashing on the success of 4G, a survey claims that more than 54% of the companies involved in technology and as service providers have started developing technologies for 5G with 16% already partially deployed.

2 Evolution of Mobile Cellular Networks

Wired communication using landlines and setting up public switched telephone network (PSTN) is considered the most reliable source of communication wherein we see very good speech quality and high-speed broadband services. Cable television providers still use wired systems from their control room because of the quality and reliability in spite of being costly. The evolution of the mobile cellular networks has been phenomenal, and lots of scene changing episode have made this field evergreen. It was presumed that satellite phones first used for communication between boats will become a sensation, but this vision was proved wrong by the upcoming discoveries in the wireless ocean.

2.1 First Generation

This generation of wireless mobile communications supported communication which was only analogue in nature. They were used predominantly for voice. They improved on earlier systems by providing automatic switching, handover of calls to different cells thus using the cellular concept. Japan's NTT paved way to different adaptations by different operators in various countries. NMT was the first system to support automated handover and international roaming. This was used in most parts of Europe. AMPS from USA and total access communication system (TACS) from Europe (ETACS) and Japan (NTACS) were more successful. These systems had only a major difference in channel bandwidth with AMPS deploying a 30 kHz channel whereas NTACS deployed 12.5 kHz and ETACS used 25 kHz [3]. A quick summary can be seen in Fig. 1.

AMPS used frequency division multiple access (FDMA). Subscribers were assigned a pair of voice channels (forward and reverse) for the duration of their call. AMPS had a coverage of 2100 square miles. It had only ten base stations. Each of them had height of antenna tower around 150–550 ft. They mostly deployed a frequency reuse pattern of 7 cells with 3 sectors for each cell. The Federal Communications Commission (FCC) allocated the spectrum to two operators per market in USA. Each operator supported a total of 416 AMPS channels and assigned 20 MHz of spectrum, in each market. Of the 416 channels, control information was sent in 21 channels and the remaining 395 channels for voice traffic. Control information was

	AMPS	ETACS	NTACS	NMT-450/ NMT-900
Year of Introduction	1983	1985	1988	1981
Frequency Bands	D/L:869-894MHz U/L:824-849MHz	D/L:916-949MHz U/L:871-904MHz	D/L:860-870MHz U/L:915-925MHz	NMT-450:450-470MHz NMT-900:890-960MHz
Channel Bandwidth	30kHz	25kHz	12.5kHz	NMT-450:25kHz NMT-900:12.5kHz
Multiple Access	FDMA	FDMA	FDMA	FDMA
Duplexing	FDD	FDD	FDD	FDD
Voice Modulation	FM	FM	FM	FM
Number of Channels	832	1240	400	NMT-450:200 NMT-900:1999

Fig. 1 Major first generation cellular systems

sent using frequency-shift keying (FSK) and frequency modulation (FM) at higher frequencies typically 150 MHz and above was used for the transmission of analog voice. Such typical systems had a lifetime of a decade from 1980 to 1990. The rate at which data was sent was around 2.4 Kbps. When such 1G phones started getting popular, the number of people who started using it rose to 20 million by 1990 which meant an astonishing growth rate of around 40%. It has bad voice links, less capacity, more noise interference, not so reliable handoff, and susceptibility to eaves dropping by hackers. Also the phones were big in size and had a poor battery life. Even after 2G came into picture, such systems were used as a fallback network by service providers and also for providing roaming between different operators with incompatible 2G systems.

2.2 Second Generation

This generation evolved mainly due to hardware platforms depicting increased processing abilities. It also aimed toward efficient voice communication only but adapted digital modulation in contrast to 1G systems. This shift also increased the system capacity through use of digital speech codes which were efficient spectrally, thus deploying time or code division multiple access to multiplex many users on the same frequency channel. It could also realize frequency reuse due to better digital modulation, coding, and equalization techniques. Better speech codecs and signal-level processing also improved voice quality. Security was also worked upon in 2G to prevent eavesdropping through simple encryption techniques which differed for every channel access and known only to mobile station and the infrastructure.

Global System for Mobile Communications (GSM), IS-136 TDMA, and IS-95 CDMA systems were the prominent cellular systems in this generation among many others. IS-95 was used mostly in some parts of Asia and North America. IS-136, touted as a digital improvement over AMPS using 30 kHz channels, was a TDMA-based system. However, GSM was the most used technique and widely adapted which went on to become a standard. GSM is also based on TDMA, and one 200 kHz channel is time shared between 8 users in different time slots [4]. It used Gaussian minimum-shift keying (GMSK) for modulation because of its ability to provide constant envelope and providing efficient use of the spectrum along with good power characteristics [5]. GSM did not stop here and went on to provide numerous services. Short messaging service (SMS) was one of them, and this does not describe at all. Besides voice and SMS, circuit-switched properties started to get imbibed. Around middle of the 1990s, European Telecommunications Standards Institute (ETSI) that had taken charge of the GSM standard introduced GSM Packet Radio Systems (GPRS) as a stepping stone toward increasing the data rates. The architecture for GSM and GPRS was almost the same in the signaling links and also usage of the same bands as well as slots in time. GPRS could garner average data rate of 30 kbps. GSM also got a further push during the early part of 1997 in the data domain with the innovation of Enhanced Data Rate for GSM Evolution (EDGE). EDGE could increase the data rate to around 59 kbps per slot by addition of the 8 PSK scheme of modulation. This was almost 3 times as that of GPRS. Practically EDGE could provide average user rates around 100 Kbps.

CDMA was claimed by Qualcomm in 1989 as a more efficient and higher quality technology. The unique property which it provided was the usage of same frequency at same time by many users. It used a 12.5 MHz bandwidth to transmit a voice signal at around 9.2 Kbps. Other advantages include every cell using same frequency channel in turn simplifying the planning for frequency and increasing the capacity. It was also instrumental in the innovation of a mobile station able to connect to a new base station before the disconnection from the previous one which was referred to as soft handoff [6]. It also was able to provide one dedicated channel for data at 9.6 kbps which went on to become around 14.4 kbps later on. CDMA was instrumental in the fast transition to 3G through newer versions like CDMA2000-1X and EV-DO thus challenging GSM which was undertaking a subtle evolution through GPRS and EDGE to 3G.

2.3 Third Generation

The second generation improved voice capacity and quality and began data support for Internet. But the circuit-switched way was inefficient for data providing low data rate. Hence, the need for third-generation systems to provide increased data rate and advanced services and applications was felt thus triggering the International Telecommunications Union (ITU) to invite proposals for such systems. It laid out criteria such as 2 Mbps in fixed, 384 Kbps in pedestrian, and 144 Kbps in wide area vehicular environments. There were parallel evolutions going on in the GSM and CDMA track which were carried out by consortium bodies for standards called Third-Generation Partnership Project (3GPP) and 3GPP2 (spearheaded by Qualcomm), respectively [7].

CDMA2000-1X was 3GPP2's first bet (here 1X implied that it uses same bandwidth as IS-95). As it provided specifications less than the standards set, it was referred to as 2.5G. CDMA-1X increased capacity by doubling the number of forward channels as compared to previous 64. In contrast, 3GPP was created as a consortium of 6 regional standards in telecommunication. The 3G system based on the evolution of GSM was Universal Mobile Telephone Service (UMTS), indigenously developed by ETSI. The characteristics of UMTS were a core network (CN) which provided routing, user management in addition to switching. It also comprised of UMTS Terrestrial Radio Access Network (UTRAN) and the User Equipment (UE). UMTS was consistent with the architecture used for GSM/GPRS. It is described in Fig. 2. The air interface used was Wide-band CDMA (W-CDMA) inspired by IS-95. The system supported 100 voice calls at the same time and maximum data rates from 384 to 2048 kbps due to bandwidth of 5 MHz.

Further additions to 3G family included EV-DO which was the first system to deliver speeds comparable to broadband developed by Qualcomm (the 3GPP2 group)

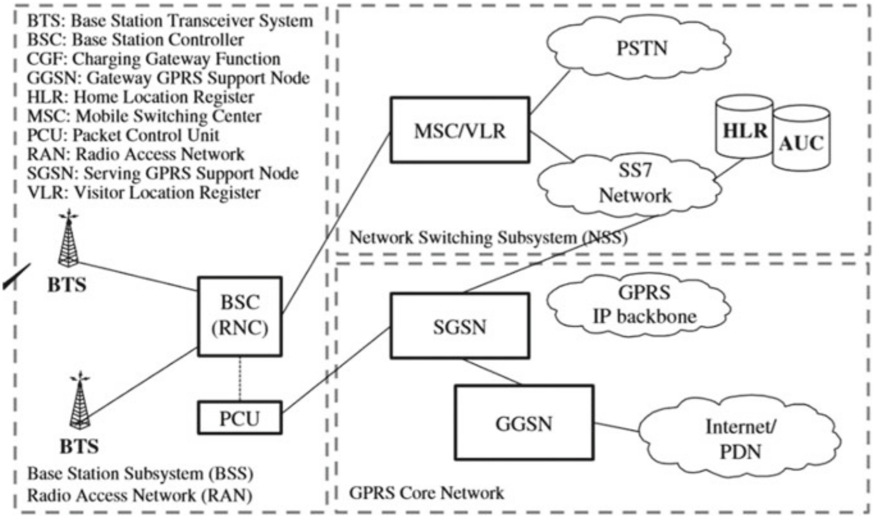

Fig. 2 GSM network architecture

in 2002, 3 years ahead of HSDPA deployed by GSM. It provided up to 2.4 Mbps downstream and up to 153 kbps upstream. The modulation and coding could be dynamically adapted according to conditions by EV-DO. High-Speed Data Access (HSPA), a combination of HSDPA and HSUPA (downlink and uplink), was additional enhancement to the 3GPP standard. It introduced new advanced techniques such as adapting modulation and coding according to channel conditions, fast dynamic scheduling of packets, and hybrid automatic repeat request (H-ARQ), an improved retransmission technique, to soft-combine multiple erroneous retransmissions to recover from errors more quickly. Various other additions occurred to the family which are considered as part of 4G or 3G by different explanations which will be seen further as part of 4G here.

2.4 Fourth Generation

This generation has lots of arguments of technologies not meeting the standards set by ITU for 4G. HSPA+, WiMAX, and LTE are some of the most prominent ones. HSPA+ uses higher order modulation such as 64QAM and 16QAM, in addition to multiple-input multiple-output (MIMO) wherein two transmit and receive antennas each are used to enhance diversity, beamforming, and spatial multiplexing. It uses dual-carrier downlink operation for doubling data rates and could enhance capacity in addition to data rates. It also gave attention to the draining batteries of the devices using discontinuous transmission and reception. WiMAX has many features adapted by LTE, the most prominent one being orthogonal frequency division multiplexing

(OFDM) [8]. OFDM can operate even when not in line of sight and can resist multipath. Its peak data rate is 74 Mbps. Support for advanced antenna techniques and dynamic allocation of resource to a user are other characteristics of OFDM.

LTE, referred to as Long-Term Evolution, has many features inherited from HSPA+ and WiMAX. When 3G was at its peak, the world was moving rapidly to high bandwidth applications such as music downloads, video streaming, and IPTV. It was the time when smart devices started proliferating. We started using laptops, netbook computers, large screen devices, devices for gaming, camcorders and projectors with built-in wireless interfaces, portable media players, cameras, and other machine-to-machine communication devices. Also service providers and device manufacturers started cashing in on this and the need was felt for bringing the performance on wireless devices on par with broadband in addition to lowering the cost per megabyte of data for the users to make the market competitive. But this had to be done using the already existing spectrum taken up by 2G and 3G. OFDM had many advantages. It had reduced computational complexity due to use of known FFT/IFFT techniques, frequency diversity, was robust against narrowband interference, and had graceful degradation of performance under excess delay. Advanced multi-antenna solutions [9] such as beamforming, spatial multiplexing, and transmit diversity in addition to MIMO that made the spectrum efficient, increased capacity, and made a robust link were provided by the LTE standard. The core design to support LTE is called Evolved Packet Core (EPC) which can be seen in Fig. 3. LTE has a capability of data rate up to 150 Mbps. LTE-Advanced has been targeted to obtain 1 Gbps downlink and 500 Mbps uplink [10]. With such capability, the existing 2G and 3G systems are being planned to be phased out to free the spectrum which is captured by them. But it is not an easy task because LTE alone cannot guarantee service in every nook

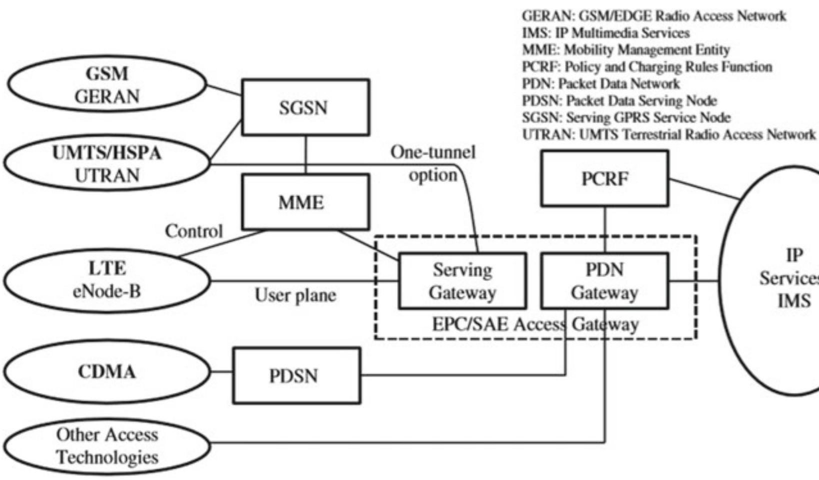

Fig. 3 Evolved packet core architecture

and corner of the world. 2G is the best fall back network option available in this fast-evolving industry of wireless networks.

2.5 *Fifth Generation*

The world has started becoming greedy. From the smart handheld devices to more advanced use cases such as online gaming, virtual reality, artificial intelligence, 3D 4K–8K cloud and video streaming, autonomous cars, big data [11], and the most important one which will drive all the previous, Internet of Things (IoT), the vision forward has been just like some sci-fi movie. The extent of people realizing technology to aid in surgery and medical tracking proves the fact that we humans have progressed to unimaginable levels. To envisage this vision, IUT has aimed for a standard peak data rate of 20 Gbps and latency of 1 ms for 5G systems. Basically, IUT has defined 3 categories of service. They are enhanced Mobile Broadband (eMBB) or handsets, Ultra-Reliable Low-Latency Communications (URLLC) including industrial applications and autonomous vehicles, and Massive Machine Type Communications (MMTC) or sensors. As the throughput requirements have increased enormously, a large number of new spectrum called the 5G NR frequency bands have been allocated which work in the GHz range and some particularly in millimeter wave bands. In addition to this, multiple access schemes, modulation methods, Future PHY/MAC, flexible duplexing methods, and massive MIMO have all been under research for 5G [12]. Corporates like Qualcomm, Intel, and Huawei are actively involved in modem technology while Nokia, Cisco, ZTE, Samsung, and Ericsson are involved in infrastructure of 5G. Companies have left no stone unturned to safeguard their architecture or design for the 5G systems due to which details on the architecture are only an imagination.

3 Conclusion

Every generation of wireless mobile communication intended to raise the bars set for that particular decade. 2020 is seen as a revolutionary year in this field where we will be able to experience some technologies which were imagined only in movies. The journey so far has been fantabulous and will continue to be. No generation can be considered as a winner as all of them satisfied the needs of that decade very well in their own way and own limitations.

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