A Comparative Study on the Generations of Mobile Wireless Telephony: 1G - 5G

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Abstract : ***This paper discusses how the mobile telephony generations have come up over the years along with what is in-store in the future generations. The paper highlights each generation's features and drawbacks. It brings forth the different technologies and standards used in each generation. Finally, considering all the generations, observations are made.***

IndexTerms - 1G, 2G, 3G, 4G, 5G, B5G, FDMA, TDMA, CDMA, OFDMA.

I. INTRODUCTION

Mobile Wireless Telephony is a wireless network that enables communication between people using mobile communication devices. This allows people from any part of the world to communicate with each other, even in mobility. Such communication is made possible by Telecommunication Service Providers (TSPs), which transmits all types of voice, data and video over significant distances [1]. The need for human communication comes just after the requisites of survival [2]. This need led to the increase in demand of mobile wireless communication, which can be seen from the growing number of mobile customers over the years as projected in Ericsson Mobility Report June 2018, as shown in Figure 1 [3]. In the first quarter of the year 2018 alone, mobile subscriptions are in the millions as shown as Figure 2 [3]. Initially, TSPs started with only voice transmissions and over time, they transmitted data and video as well. These changes evolved the communication in mobile wireless telephony. With each evolution, a new generation of mobile telecommunications came about. Overcoming the limitations of a previous generation gave rise to the next generation. The generations in mobile wireless telephony are First Generation (1G), Second Generation (2G), Third Generation (3G) and Fourth Generation (4G). Evolution is a continuous process and hence, generations beyond 4G are expected in the coming years.

This paper is divided into nine sections. Section II to VI highlights features such as standards, switching techniques, channel access methods, speed, frequency, services and many more from 1G to 5G. Section VII discusses on upcoming generations beyond 5G. Section VIII mentions the observations made in the study. Finally, section IX, concludes the paper.

	2017	2023	CAGR
Worldwide mobile subscriptions	7.8bn	8.9bn	2%
Worldwide smartphone subscriptions	4.3bn	7.2bn	9%
Worldwide mobile broadband subscriptions	5.3bn	8.3bn	8%
Worldwide LTE subscriptions	2.7bn	5.5bn	12%
Worldwide monthly data traffic per active smartphone	3.4GB	17GB	31%
Worldwide total monthly mobile data traffic	15EB	107EB	39%

Figure 1: Mobile Subscriptions over the years along with Compound Annual Growth Rate (CAGR)

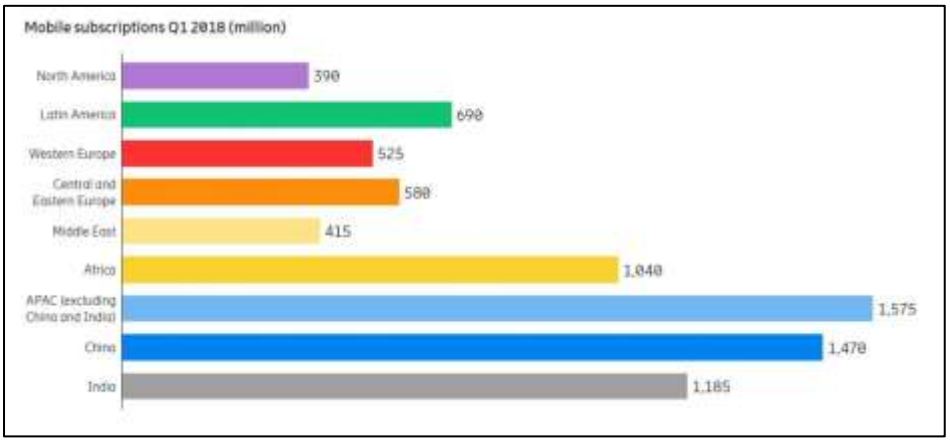

Figure 2: Mobile Subscriptions in First Quarter (Q1) in 2018 (million)

II. First Generation (1G)

1G came about in the 1980s. It was able to transmit only voice as analog signals by implementing circuit-switching technique. Circuit-switching is a technique whereby the end-devices are able to communicate by first establishing a connection, then communication begins which is carried over a dedicated path between them, finally when communication ends, the connection is released making the path available for other communication. A dedicated path implies that all voice traffic will follow only this path, congestion may arise only at the time of establishing connection, the usable bandwidth is fixed for the entire session and in the path a failure of even a single switch will lead to loss of connection. There were many standards used in this generation such as Advanced Mobile Phone System (AMPS) in North America, Nordic Mobile Telephone (NMT) standard of Nordic Countries, Total Access Communications System (TACS) which was based on AMPS was a standard in the United Kingdom [4]. In AMPS, 30 KHz bandwidth was supported with frequency 824 to 894 MHz and a speed of 2.4 kbps [5]. 1G also used Frequency Division Multiple Access (FDMA) as a channel access method. In FDMA, the available bandwidth is first divided into frequency bands. Then each terminal is allocated a specific band for usage. In order to prevent station interferences, FDMA separates allocated bands from one another by small guard bands [6].

For about ten years, 1G was the standard but it suffered from certain demerits like poor voice quality with very low spectrum efficiency and no security [7]. This brought about an opportunity for growth which led to the next generation.

III. Second Generation (2G)

In the 1990s, 2G emerged with the transmission of voice using digital signals along with data, which was not there in 1G. This was made possible since 2G introduced packet-switching along with circuit-switching technique. Unlike circuit-switching which uses a dedicated path for communication, packet-switching dynamically allocates different paths for communication in a single session. A packet is a data unit in packet-switching. In a session, packets can take different paths thus making it dynamic. In such a case, possible congestion may occur on every packet during transmission. The use of dynamic path made the usable bandwidth dynamic. Also, failure of switches is not fatal to the transmission. The data services which started in 2G were SMS (Short Message Service), MMS (Multimedia Message Service), Email, as well as, World Wide Web access. There were many standards used in this generation such as Global System for Mobile communications (GSM) in Europe. With GSM, better voice quality was achieved by digital modulation and an increased speed of up to 64 kbps [8]. Also, GSM provided the much needed security by firstly authenticating the user and then encrypting both voice and data transmission [9]. GSM used Time Division Multiple Access (TDMA) channel access method. In TDMA, all terminals use the entire bandwidth but they take turns to use based on the allotted time slots [6]. Further, this generation had undergone developments which led to the conception of 2.5G and 2.75G. 2.5G had General Packet Radio Service (GPRS) as a standard which increased speed to 115 kbps, and 2.75G had Enhanced Data rates for GSM Evolution (EDGE) as its standard which further increased the speed to 384 kbps [10]. GSM, GPRS and EDGE all operate in the frequency of 850 – 1900 MHz.

2G was a landmark in bringing in packet-switching which provided digital transmission that started data services in mobile telecommunication. 2G drew more users with more features, increased speed and security than 1G. A major drawback was that it provided limited data services.

IV. Third Generation (3G)

Before 3G, standards were defined based on regions and nations, also any organisation that carried out developments owned the development thus creating a divide in the market. To overcome this, a specialized agency for Information and Communication Technologies (ICTs) known as International Telecommunications Union (ITU), through its Radiocommunication Sector (ITU-R) developed IMT, International Mobile Telecommunications system, framework of standards for world-wide interference free communication in Mobile Telephony [11]. For this purpose, World and Regional Radiocommununication Conferences (WRCs) are held every three to four years. WRCs are held to ensure performance and quality in operating radiocommunication systems, conserve spectrum, and ensure flexibility for future expansion and new technological developments [12]. IMT2000 was framed and came to be marketed as 3G, which was deployed first in Japan in the year 2001[13].

3G is a hybrid network, like 2G, which used circuit and packet switching techniques and their comparison is shown in Figure 3 [14]. It is an improvement over 2G as it provided additional data services like video calls, live streaming, video conferencing, navigational map, 3D gaming, mobile television, to name a few. With these services, Internet Protocol (IP) technology became an accepted norm. 3G also increased its speed up to 2 Mbps, which was considerably faster than 2G. The speed of 3G was comparable to broadband connections. 3G operates in the frequency 1.8 – 2.5 GHz [15]. 3G used three different channel access technologies which were FDMA, TDMA and CDMA [6]. In Code Division Multiple Access (CDMA), all terminals use the entire bandwidth and each pair can communicate simultaneously with a different code. 3G also had many standards such as Wideband Code Division Multiple Access (WCDMA) or Universal Mobile Telecommunications System (UMTS).

Item	Circuit switched	Packet switched
Call setup	Required	Not needed
Dedicated physical path	Yes	No
Each packet follows the same route	Yes	No
Packets arrive in order	Yes	No
Is a switch crash fatal	Yes	No
Bandwidth available	Fixed	Dynamic
Time of possible congestion	At setup time	On every packet
Potentially wasted bandwidth	Yes	No
Store-and-forward transmission	No	Yes
Transparency	Yes	No
Charging	Per minute	Per packet

Figure 3: Comparison between Circuit switched and Packet Switched Techniques

3.5G, 3.75G and 3.9G

The data services in 3G demanded higher speeds which led to 3.5G, then 3.75G and ended with 3.9G. 3.5G used High Speed Downlink Packet Access (HSDPA) in WCDMA which offered downlink speed of 8 – 10 Mpbs.3.75G used High Speed Uplink Packet Access (HSUPA) in WCDMA which offered uplink speed of 5.8 Mpbs. HSDPA and HSUPA were together incorporated as High Speed Packet Access (HSPA) [16]. HSPA further developed as Evolved High Speed Packet Access (HSPA+) which was used in 3.9G. HSPA+ gave a download speed of 168.8 Mbps and upload speed of 23.0 Mbps [17].

The transition from 2G to 3G happened smoothly for mobile subscribers. It provided increased speed, as well as, supported a variety of data services compared to 2G; however, it had its disadvantages. For 3G networks, TSPs had to financially bare much more in the infrastructure, license and agreements. 3G also suffered from higher power consumption [18].

V. Fourth Generation

4G started in the year 2010 and was also known as IMT-Advanced. It implements only packet-switching technique which sets it apart from all the previous generations. A 4G network is integrated with one Core Network and several Radio Access Networks (RANs) [19]. 4G is also known as MAGIC where M stands for Mobile Multimedia, A for Anytime Anywhere, G for Global mobility support, I for Integrated wireless solution and C for Customised Personal Service. It provided a complete IP-based network with a speed of 100 Mbps to 1 Gbps using frequency of 2 – 8 GHz. With higher speed, the range of coverage was smaller compared to 3G. Hence, to support long range communication, multiple smart antennas were incorporated in 4G networks [20].

4G ensured Quality of Service (QoS) and data rates which could support services with more clarity such as Mobile Television, High Definition Television (HDTV) content, Digital Video Broadcasting(DVB), Video Chat, Multimedia Newspapers and High Quality Live-streaming. 4G offered ultra-low latency compared to 3G [21].

4G dominant technologies are Long Term Evolution (LTE) and WiMAX (World Wide Interoperability for Microwave Access). LTE provides downlink data rates of 100 Mbps and uplink of 50 Mbps whereas WiMAX offers downlink data rates of 75 Mbps and uplink of 25 Mbps [22]. A different channel access method was introduced in 4G's LTE known as Orthogonal Frequency Division Multiple Access (OFDMA) for downlink. OFDMA was brought in to make use of the spectrum more efficiently as seen in Figure 4 [23]. This efficiency was achieved by OFDMA as it eliminates the need of guard bands. A remarkable feature of OFDMA is that it does not suffer from interferences since it uses orthogonal subcarriers. The entire available bandwidth is first spilt into multiple subcarriers, each equally spaced at 15 KHz. Users are then provided a subset of these carriers for data transmission [24]. Unlike FDMA or TDMA, OFDMA allows users to access variable bandwidth depending upon available resources. 4G had to address spectrum efficiency because with 4G, many applications came up which used the same frequency band and making it crammed [25].

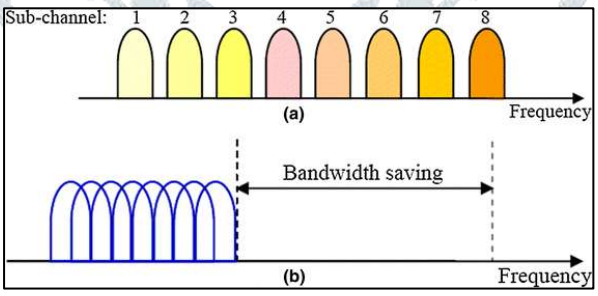

Figure 4: Effect of using orthogonal subcarriers on spectral efficiency

VI. Fifth Generation (5G)

The future generation after 4G is IMT-2020 which is marketed as 5G. This generation is expected to start by the year 2020 as given by the detailed timeline in ITU-R as shown in Figure 5 [26]. 5G will also be implementing packet-switching technique only.

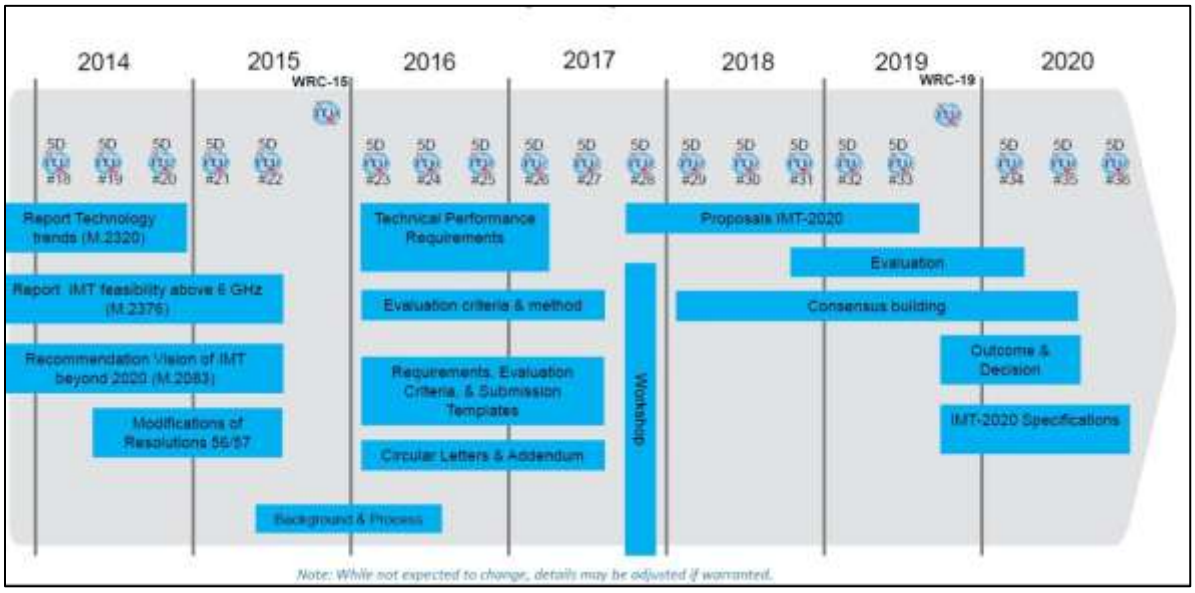

Figure 5: Detailed timeline and process for IMT-2020 in ITU-R

Wen Tong [27] mentions the three major developments upcoming in 5G are ultra-fast access speeds, massive connections and lower latency. 5G is expected to provide increased speed of over 1 Gbps with a peak data rate of 10 to 20 Gbps [28]. Some of the features of 5G are real World Wide Wireless Web (WWWW), made possible in 5G as it's an enhanced mobile broadband network, enhanced QoS, smart devices will be more in use and it will embody green technologies and infrastructure. Figure 6 shows some of the services which can be expected in 5G [26].

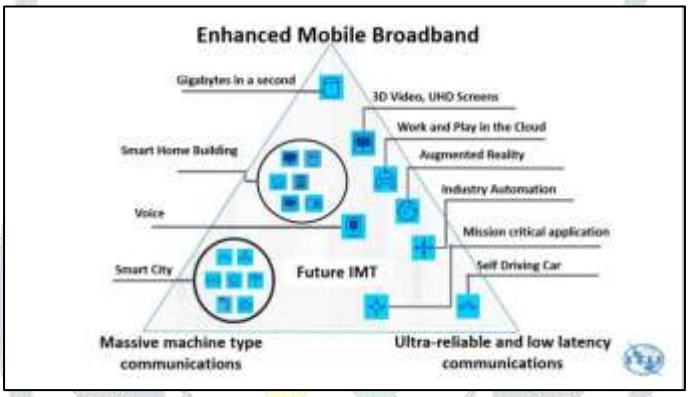

Figure 6: Expected Services in 5G

With regards to 5G technologies, there are many research groups working on them such as Mobile and Wireless Communications Enablers for the twenty-twenty Information Society (METIS), a European Union's research and innovation programme, 5G Infrastructure Public Private Partnership (5G-PPP) a joined initiative between the European Commission and European ICT Industry[29], 5th Generation Non-Orthogonal Waveforms for Asynchronous Signaling (5GNOW), Enhanced Multicarrier Technology for Professional Ad-hoc and Cell-Based Communications (EMPhAtiC), Network of Excellence in Wireless Communications (NEWCOM#), NYU WIRELESS, 5GIC (5G Innovation Centre) at the University of Surrey, GIGA 5G Project of Electronics and Telecommunications Research Institute (ETRI) of Korea, 5Gforum of Korea, E3Network, PHYLAWS, PUPLO, CROWD, MAMMOET, LEXNET and in India, Tejas Network of IIT Hyderabad [30, 31].

The expected technologies in 5G:

- Millimeter-Wave (mm-wave): 5G will experience a massive growth in the number of subscribers, applications and devices connected to it but 4G applications saturated the frequency bands which were in use for communication. Therefore, 5G required to look for another range of frequency known as Millimeter-Wave. In 5G, the existing bands along with Millimeter-Wave will be used for communication. Millimeter-Wave is a new band of spectrum ranging from 3 GHz to 300 GHz [31]. The use of existing bands required 5G to be adaptive, unlike its predecessors. When accessing shared spectrum, 5G will have the capability to use previous generation's access technologies [32]. This is how 5G achieves the expected speed as mentioned earlier. Millimeter wave provides higher speed but with smaller range of coverage than the previous generations. This is because it is susceptible to absorption by obstacles along its path. Therefore, to provide longer range of communication, multiple numbers of small cells will be introduced in 5G networks.
- Modulation Techniques: 5G has many candidate modulation techniques such as Orthogonal Frequency Division Multiplexing (OFDM) used in 4G, Filter Band Multi Carrier (FBMC), Universal Filter Multi Carrier (UFMC), Orthogonal Frequency Band Multi Carrier (OFBMC), Generalized Frequency Domain Multiplexing (GFDM) and Bi-orthogonal Frequency Division Multiplexing (BFDM) [30, 31]. FBMC is an advancement of OFDM. It is found that OFDM is less efficient in terms of spectrum and performance than FBMC. Most likely, OFDM will no longer be used in 5G [30].
- Web Technologies: 5G will become the driving force in the growth of Cloud Computing and Internet of Things (IoT). Services of these technologies will become more eminent in day to day lives and creating massive global networks.
  With the growth of Cloud Computing services, even infrastructure of mobile networks will undergo a revolution in form of a virtualised mobile network. Cloud-RAN or RANs-as-a-service is one such endeavor which aims to cut-down power consumption and

ensure network sustainability. To further save power consumption, virtualization of base station, as well as, the core network is being looked into since a base station consumes three fourth of the entire mobile network energy consumption [33].

In 5G, IoT is also expected to play an important role. One of the communication platforms of IoT is Device-to-Device (D2D). D2D services will use mm-wave for communication between devices within the range of 500 m. Unlike Wi-Fi and Bluetooth technologies, it allows data sharing between devices in a secure and energy efficient manner [30]. D2D will also help subscribers in attaining high speed, even if they are near the edge of the cell [19].

After 5G has been standardized, it may take time to be deployed every country since TSPs need to overhaul the infrastructure of 5G to provide its services. Also to access 5G, subscribers would require compatible devices.

VII. BEYOND 5G (B5G)

5G with all its advancement still has room to grow. Mobile telephony networks will incorporate three different satellite communication networks which are telecommunication satellite networks, earth imaging satellite networks and navigation satellite networks [34]. Telecommunication satellite networks have been around the longest providing voice, data, internet and video broadcasting. Through earth imaging satellite networks, national security, disease and natural disaster tracking has been improved [35]. Lastly, navigation satellite networks provide Global Positioning System (GPS). With global coverage, we can expect automation services in a larger scale. The generation beyond 5G will strive to provide features of a satellite phone in a cellular phone bringing the world in your fingertips. Various issues may emerge with the inclusion of satellite communication networks such as the lack of standardisation in satellite communication as felt before IMT frameworks [34]. ITU, therefore, will continue to play a crucial role because it is also responsible for regulating the use of satellite orbits for radiocommunication.

VIII. OBSERVATIONS MADE IN THE STUDY

- It was observed that the progression from one generation to the next took around ten years.
- The main focus of 1G, 2G and 3G networks was on better transmission of voice, unlike 4G and 5G revolved around data.
- The transition from 1G till 3G was seamless but this was not so from 3G to 4G, as well as, from 4G to 5G.
- It was found that the speed is inversely proportional to the range of coverage in each generation, from 1G to 5G, increasing in speed but decreasing in range.
- Generations having lower range of coverage needed new infrastructure to be incorporated as part of their network to propagate signals just like smart antennas in 4G and small cells in 5G.
- Each generation out did its predecessor by having more features, better security, enhanced quality of service, higher spectrum efficiency and achieving lower latency.
- Each generation experienced a growth in the number of subscribers and devices connected to each network.
- Based on the Ericsson Mobility Report June 2018, it was found that even when countries have deployed 5G networks, its predecessors will still be in use, as shown in the Figure 7 [3]. This may happen due to various reasons such as mobile subscribers still using older technologies and countries with many constraints may not be able to adopt 5G immediately. These networks can co-exist as ITU ensures full interoperability and internetworking between them [13].
- ITU-R is monitoring that the technologies and infrastructure developed in 3G and above are environmentally friendly so that it does not have a negative impact on the life on Earth. Yet social implications are reasons of concern such as social impairment with increased accessibility of technology. This requires further examination.

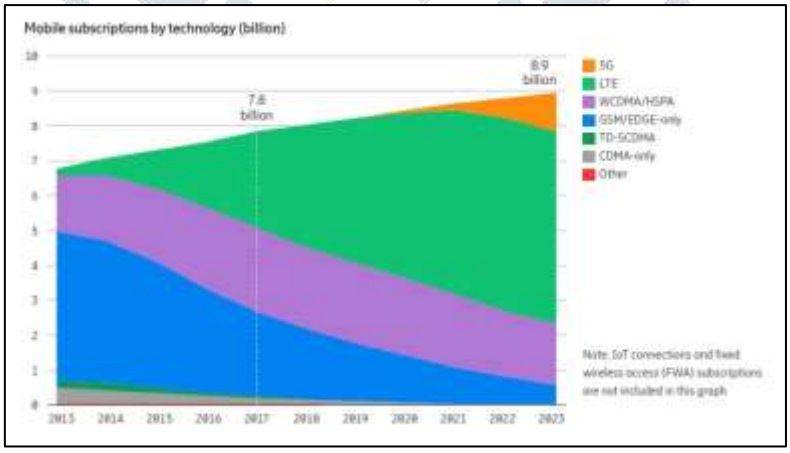

Figure 7: Mobile Subscriptions by Technology (billion)

Table 1 Comparison between 1G to 5G

Parameters	Generations				
	1G	2G	3G	4G	5G
Year	1980s	1990s	2000	2010	Expected in 2020
Peak data rate	2.4 Kbps	64 Kbps (2G)	2 Mbps (3G) Downlink 8 – 10 Mbps (3.5G using HSDPA)	1 Gbps (4G)	10 – 20 Gbps

Parameters	Generations				
	1G	2G	3G	4G	5G
		115 Kbps (2.5G)	Uplink 5.8 Mbps (3.75G using HSUPA)	Downlink 100 Mbps, Uplink 50 Mbps (LTE)	
		384 Kbps (2.75G)	Downlink 168.8 Mbps, Uplink 23 Mbps (3.9G using HSPA)	Downlink 75Mbps, Uplink 25 Mbps (WiMAX)	
Frequency	824-894 MHz	850-1900 MHz	1.8-2.5 GHz	2-8 GHz	3 GHz – 300 GHz
Standard Framework	Nations, Regions, Proprietary etc.	Nations, Regions, Proprietary etc.	IMT-2000	IMT-Advanced	IMT-2020
Standards	AMPS, NMT, TACS	GSM (2G)	WCDMA/UMTS (3G)	LTE, WiMAX	IMT – 2020 proposals
		GPRS (2.5G)			
		EDGE (2.75G)			
Channel Access Method	FDMA	TDMA	FDMA,TDMA,CDMA	OFDMA	FBMC, UFMC, OFBMC, GFDM, BFDM (Candidates)
Switching Techniques	Circuit – Switching	Circuit – Switching and Packet – Switching	Circuit – Switching and Packet – Switching	Packet-Switching	Packet-Switching
Services	Voice only	Digital voice , SMS,MMS, Email, WWW	Video calls, live streaming, video conferencing, navigational map,3D gaming, mobile television etc.	Mobile Television, HDTV, DVB, Video chat, Multimedia Newspapers, High Quality Live Streaming etc.	UHD screen, Work and Play in the Cloud, Augmented Reality, Industry Automation, Mission critical application, Self Driving Car etc.

IX. Conclusion

In this study, the merits and demerits of mobile telephony generations from 1G to 5G are shown. The need for better communication drove the development in mobile telephony. Due to its growth, its impact is felt in many other areas of our life. It made areas such as e-learning, telemedicine, online banking, e-commerce and entertainment, more accessible. Certainly, due to its demand and necessity, many more generations with varied possibilities are in-store as discussed.

References

[1] SearchTelecom.com. (2016). Telecommunications. Retrieved July 15, 2018, from searchtelecom.techtarget.com: https://searchtelecom.techtarget.com/definition/telecommunications.

[2] Cisco Neworking Academy (2014, January 14). Introduction to Networks: Exploring the Network. Retrieved July 5, 2018, from Cisco Press Website: http://www.ciscopress.com/articles/article.asp?p=2164577&seqNum=4.

[3] Ericsson. (2018). Ericsson Mobility Report. Stockholm, Sweden: Fredrik Jejdling, Executive Vice President and Head of Business Area Networks.

[4] International TeleCommunication Union. (2011, April 4). All About the Technology. Retrieved July 25, 2018, from International TeleCommunication Union Website: https://www.itu.int/osg/spu/ni/3G/technology/index.html.

[5] Gawas, A. U. (2015, May). An Overview on Evolution of Mobile Wireless Communication Networks: 1G-6G. International Journal on Recent and Innovation Trends in Computing and Communication, 3(5).

[6] Fourouzan, B. A. (2013). Data Communications and Networking (Fifth ed.). New York: The McGraw-Hill Companies, Inc.

[7] Baba, M. I., Nafees, N., Manzoor, I., Naik, K. A., & Ahmed, S. (2018, April 25). Evolution of Mobile Wireless Communciation Systems from 1G to 5G: A Comparative Analysis. International Journal of Scientific Research in Computer Science, Engineering and Information Technology, 4(1), 1-8.

[8] Yadav, R. (2017). Challenges and Evolution of Next Generation Wireless Communication. International MutiConference of Engineers and Computer Scientists. 2. Hong Kong.

[9] Rhee, M. Y. (2009). Mobile Communication Systems and Security. Singapore: John Wiley and Sons (Asia) Pte Ltd.

[10] Shruti. (2018, January-February). A Sneak Peek into Future Generation, 7G: A Survey. International Journal of Advanced Research in Computer Science, 9(1), 399-402.

[11] International Telecommunication Union. (2018). Welcome to ITU-R. Retrieved July 15, 2018, from International Telecommunication Union Website: https://www.itu.int/en/ITU-R/information/Pages/default.aspx.

[12] International Telecommunication Union. (2018). World Radiocommunication Conferences (WRC). Retrieved July 15, 2018, from International Telecommunication Union Website: https://www.itu.int/en/ITU-R/conferences/wrc/Pages/default.aspx.
[13] International TeleCommunication Union. (2011, April 4). All About the Technology. Retrieved July 25, 2018, from International TeleCommunication Union Website: https://www.itu.int/osg/spu/ni/3G/technology/index.html.
[14] Tanenbaum, A. S., & Wetherall, D. J. (2011). Computer Networks (5 ed.). Massachusetts: Prentice Hall.
[15] Lakshitha, V., Reddy, R., Jayanth, G., Raju, C. J., & Manikandan, K. (2018, March). 3G, 4G AND 5G: A Comparative Study. International Research Journal of Engineering and Technology, 5(3), 2911-2913.
[16] Bhalla, M. R., & Bhalla, A. V. (2010, August). Generations of Mobile Wireless Technology: A Survey. International Journal of Computer Applications, 5(4), 26-32.
[17] Du, K.-L., & Swamy, M. N. (2010). Wireless Communication Systems:From RF Subsystems to 4G Enabling Technologies. Cambridge: Cambridge University Press.
[18] Theebendra, C., Yuvabarathi, S., & Pavithra, M. K. (2014, December). Network Evolution in 3G / 4G: Applications and Security Issues. International Journal of Computer Science Engineering and Technology, 4(12), 371-375.
[19] Sahoo, S. S., Hota, M. K., & Barik, K. K. (2014). 5G Network a New Look into the Future: Beyond all Generation Networks. American Journal of Systems and Software, 2(4), 108-112.
[20] Agarwal, A., & Agarwal, K. (2014). The Next Generation Mobile Wireless Cellular Networks - 4G and Beyond. American Journal of Electrical and Electronic Engineering, 2(3), 92-97.
[21] Baba, M. I., Nafees, N., Manzoor, I., Naik, K. A., & Ahmed, S. (2018, April 25). Evolution of Mobile Wireless Communciation Systems from 1G to 5G: A Comparative Analysis. International Journal of Scientific Research in Computer Science, Engineering and Information Technology, 4(1), 1-8.
[22] Yadav, R. (2017). Challenges and Evolution of Next Generation Wireless Communication. International MutiConference of Engineers and Computer Scientists. 2. Hong Kong.
[23] El-Gohary, N.M., El-Bendary, M.A.M., Abd El-Samie, F.E. et al. Wireless Pers Commun (2017) 96: 5555. https://doi.org/10.1007/s11277-017-4248-6.
[24] Joshi, Alok. Peak to Average Power Ratio Reduction in Orthogonal Frequency Division Multiplexed Systems. Thesis. Jaypee University of Information Technology, Solan. Shodhganga. Web. 18-Mar-2015. < http://shodhganga.inflibnet.ac.in//handle/10603/3732>.
[25] IEEE Spectrum. (2017, January 27). Everything You Need To Know About 5G. Retrieved August 10, 2018, from IEEE Spectrum Website: https://spectrum.ieee.org/video/telecom/wireless/everything-you-need-to-know-about-5g.
[26] International Telecommunication Union. (2017, July). 5G roadmap: challenges and oppurtunities ahead. Retrieved July 15, 2018, from International Telecommunication Union Website: https://www.itu.int/en/ITU-D/Conferences/GSR/Documents/GSR2017/IMT2020%20roadmap%20GSR17%20V1%202017-06-21.pdf.
[27] Tong W. (2018, February 20). Wen Tong: 5G will be the neural network of the physical world. (W. Zhao, Interviewer)
[28] Ancans, G., Bobrobs, V., Ancans, A., & Kalibatiene, D. (2017). Spectrum Considerations for 5G Mobile Communication Systems. Procedia Compuiter Science, 104, 509-516.
[29] 5G PPP. (2014). The 5G Infrastructure Public Private Partnership. Retrieved August 2, 2018, from 5G PPP website: https://5g-ppp.eu/.
[30] Kumar, A., & Gupta, M. (2017). A review on activities of fifth generation mobile communication system. Alexandria Engineerign Journal, 1-11. http://dx.doi.org/10.1016/j.aej.2017.01.043.
[31] Mitra, R. N., & Agrawal, D. P. (2015). 5G mobile technology: A survey. Information and Communications Technology Express, 1(3), 132-137.
[32] Pradeep, M., & Kumar, M. V. (2017, February). A Study on Next Generation Mobile Communication. Asian Journal of Applied Science and Technology (AJAST), 1(1), 30-33.
[33] Karani, K. P. (2018). A Text Book of Research Papers On 4G & 5G Technologies and its Applications on Online Learning and Banking. In K. P. Karani, A Text Book of Research Papers On 4G & 5G Technologies and its Applications on Online Learning and Banking (pp. 84-96). India: Karani, Krishna Prasad; Retrieved from https://www.researchgate.net/publication/324728113.
[34] R, S. N., Shetty, S. C., C. S, S. S., & N, M. (2017, May). Evolution of 5G and Future - Enabling Technologies. International Journal of Engineering, Basic sciences, Management and Social studies, 1(1), 299-305.
[35] Space Foundation. (2018). Commercial Earth-Imaging Satellites. Retrieved August 18, 2018, from Space Foundation website: https://www.spacefoundation.org/what-we-do/space-technology-hall-fame/inducted-technologies/commercial-earth-imaging-satellites.