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6G Wireless Communications: Vision, Research Groups, and Future

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Abstract - *5G network has started rolling out and is commercially available in many parts of the world. This paper focuses on 5G evolution and 6G vision. It also presents an overview of the 6G application areas and research works of different major companies and universities. NTT Docomo published a white paper on 6G in 2019. After that research papers were published by Rhode & Schwartz, Finnish 6G Flagship, and Samsung. Further research groups were established such as Hexa-X, 6G@UT among key players including Ericsson, Nokia, Samsung, Qualcomm, Intel, AT&T, etc.*

***Key Words*: 5G, 6G, Hexa-X, AI/ML, Extreme Reality, AR/VR**

1.INTRODUCTION

The need of sharing information with others led to the invention of communication systems. The transmission of data from one place to another was made possible through a wired communication system. This led to the development of the Public Switched Telecommunication Network (PSTN) where users could communicate through fixed phones. However, it faced the challenge of increasing cost, attenuation, and maintenance with large distances. Then Wireless communication was invented, where data was transmitted through the air using electromagnetic waves such as radio waves, satellites, etc. This first-generation (1G) of mobile/cellular communication was launched in the 1980s. 1G used analog modulation techniques. Different 1G standards are Advanced Mobile Phone System (AMPS) in North America and Australia, Total Access Communications System (TACS) in the United Kingdom, and Nordic Mobile Telephone (NMT) majorly in Nordic countries, some parts of Europe and Russia. 1G laid the foundation for mobile networks that established mobile connectivity and provided voice services to the users. Then second generation (2G) was launched in the 1990s that introduced digital communications and increased the capacity of voice services. The 2G standard was known as Global System for Mobile Communications (GSM). Advancement in 2G led to the development of General Packet Radio Service (GPRS) and Enhanced Data for Global Evolution (EDGE) services. The core network in 2G was a circuit-switched network. The services provided by 2G were digital voice and simple data services. Further, 3G was released in the 2000s that provided mobile broadband along with voice services. 3G provided video services on the mobile using circuit and packet core network. Radio frequency utilized in 3G or UMTS was around 2 GHz and the available bandwidth in 3G is 5 MHz which is higher than 2G (i.e., 200 kHz). With the launch of 3G, web services became popular among users using smartphones. As the number of users increased, more capacity and bandwidth are required which led to the development of Long Term Evolution (LTE) i.e. 4G in the 2010s. The services provided by 4G were completely packet-based that provided a bandwidth of 20 MHz per channel. 4G LTE and 4G LTE Advanced standard revolutionized internet and video streaming services as it provided download speed up to 300 Mbps. Different standards were developed to meet the mobility and bandwidth demand. In 2G, users used to stand at a particular place and connect to a network for a voice call. The connectivity was maintained even while walking. In 3G, mobile connectivity could be maintained during a call even in moving cars, or other vehicles. Now with 4G services are even available in high-speed transport systems. The high download speed also made the internet plans affordable and cheaper. Now with the increase in the development of the Internet of Things and the development of other smart devices such as smart vehicles, robots, etc., there was a demand for communication between devices. Some services are critical that require dedicated bandwidth. All these and other demands led to the development of the next generation (5G). Now the research phase of 5G is complete and it is being commercially launched. Researchers have started working on 6G. This paper presents the 6G vision and explains different researches that are being kicked off. The first portion of this paper explains the need for 6G along with a comparison with 5G. The second portion discusses the 6G vision and potential application areas. The next portion presents the different research groups and the 6G works that they are carrying out.

2. 5G EVOLUTION and 6G

5G wireless communication network is developed for connecting machines and smart devices together. 3rd Generation Partnership Project (3GPP) members worked together for developing the 5G standard. 5G radio access network is also called 5G – NR or New Radio network. The architecture of 5G is distributed to fulfill different application areas. The main aim of developing 5G is human to machine and machine to machine connectivity. As mentioned earlier, the vision for 4G was faster communication compared to 3G and the vision for 5G is to develop an open and unified air interface that supports massive IoT and critical applications. Some of the major application areas identified for 5G are enhanced mobile bandwidth, mission-critical communications, and massive IoT. Consistent data rates with low latency will be required for augmented and virtual reality services. Mission-critical applications such as medical procedures, vehicle operations, drone services need ultra-

reliable and low latency remote links for proper functioning. With the automation of the industry, various sensors are deployed for monitoring and they are storing their data in the cloud. The network of sensors or small battery-operated devices in IoT is becoming dense with more and more advancement. This is also one of the major application areas for 5G networks. It is predicted that in 2020, customers will be consuming up to 11 GB of data per month on their smart devices. 5G works in different spectrum bands i.e., low bands (less than 1 GHz), mid bands (1 GHz to 6 GHz) and, high bands known as millimeter wave (mmWave). It also provides a bandwidth of approximately 200 MHz per channel. 5G will support 20 Gbps peak data rates and 100 times increase in network and traffic capacity.

For developing a next-generation standard, first of all, a need should be identified i.e., there must be a vision or the application areas for which that standard will be developed. Then once the vision is set then 3GPP works towards defining new radio technologies, new network platforms and tests them for different applications so that requirements are set. Thus, the major phases for any new generation are requirements that include framework and structuring, development of technical standards, and commercial launch that leads to the evolution of that generation. These are released as specifications and then they become standard for all the companies and manufacturers that are providing the equipment and services for that standard. The sixth generation or 6G will be using Tera Hz frequencies and Artificial Intelligence/ Machine Learning as a network or core platform.

Table -1: 5G vs 6G

Characteristics	5G	6G
Spectrum	GigaHertz	TeraHertz
Peak DL Rate	20 Gbps	100 Gbps-1 Tbps
Device Density (/m$^{2)}$	1	100
Network Platform	Cloud	AI/ML
Latency	1 ms	01. ms

3. 6G APPLICATION AREAS

5G focused on human and physical world interaction and 6G will focus on continuous connectivity between the human, physical and digital world. The 6G vision includes twinning between the physical and digital world, real-time control between the human and digital world, and synchronization between the human and digital world. With the massive scale deployment of sensing elements and AI/ML, it is possible for creating a digital world that is connected to the physical world and controls the physical world based on the collected sensor data. Another ever-advancing aspect is real-time control of the machines by a human. The new application area in 6G is synchronization between the human and digital world, e.g., virtual avatar, healthcare facilities, etc.

- Extreme Reality (XR) applications combine Augmented Reality (AR), Virtual Reality (VR), and Mixed Reality (MR) experiences.
- Creating digital versions of all the physical objects for inspection and using AI to make improvements in the physical objects.
- Enhanced communication services using terrestrial and non-terrestrial networks such as satellites.
- Internet of Everything (IoE) applications
- Network Services with advanced security features
- AI/ML based solutions that provide efficient and better services with the capability of predicting problems and providing corrective measures beforehand.

4. 6G RESEARCH GROUPS & KEY PLAYERS

The first white paper on 6G was published by NTT Docomo in 2019, then the next white paper was published by Rohde & Schwarz in 2020. The next set of white papers on 6G were published by Finnish 6G Flagship. The University of Oulu, Finland started 6G research and development work under the 6G Flagship project. Samsung also published a white paper on 6G in July 2020. Key players that are working towards the 6G vision are Ericsson, Nokia, Samsung, NTT Docomo, Huawei, LG, and ZTE.

1.1 NTT Docomo (2019)

This research paper discusses the 5G evolution and 6G. It presents the challenges that are being faced in 5G and the future research work direction for the optimization of 5G and the development of 6G. It explains the application areas. 6G will provide real-time solutions utilizing which users can access any device or information from anywhere eliminating the location and the time constraints. Another area would be human-machine interactions which have endless possibilities. Communication services would be available everywhere whether it's drones, aircraft, ground, or anyplace. Also, the AI and digital cloning of the real world will require low latency and high reliability. The paper categorizes 6G requirements into 6 sections i.e., extreme high data rate/capacity, extreme coverage, extreme low energy and cost, extreme low latency, extreme high reliability, and extreme massive connectivity. Paper also suggests technological areas for further studies including the glass antennas, antennas integrated with sensor and communications, distributed network topology, satellites for providing super coverage, high frequency range, terahertz frequency, spectrum utilization, massive MIMO, faster-than-Nyquist (FTN) signaling, AI/ML platforms, etc.

1.2 Samsung (2020)

The Samsung white paper titled "The Next Hyper-Connected Experience for All" presents Samsung's Vision on 6G. The paper focuses on the usage trends, demand for new services, requirements, identification of candidate technologies and it also presents the predicted timeline for the 6G standardization. The paper analyzes megatrends that will lead to 6G. Some of them are connected machines where the machine will become the dominant user of the 6G network. AI/Ml platforms will aid in developing better and efficient tools for network optimization and predicting solutions. The paper identifies three major areas of 6G services: Truly Immersive XR, High Fidelity Mobile Hologram, and Digital Replica. XR is a word used for combination AR, VR, and MR applications. This application requires a high amount of speed and network bandwidth. The next application area is wearable displays that are providing 3D hologram displays to the user.

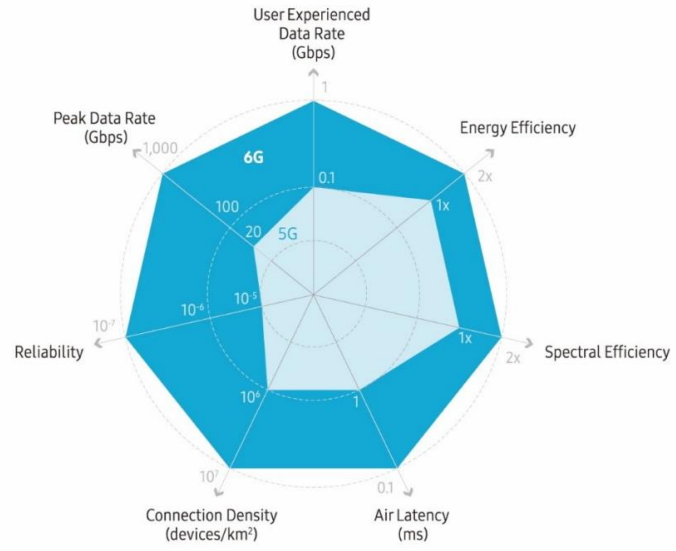

Fig -1: 6G Requirements based on Samsung Research [5]

AI will play a major role in managing data requirements efficiently for reducing bandwidth. Digital Replica services will provide a digital twin of people, objects, devices, etc., with which users can observe and interact virtually. This will be coupled with multiple sensors and AI platforms and if any problem is detected by AI in the digital twin of the object, the AI will process and reflect the changes in the physical world object. The paper further presents the 6G requirements that include extremely low latency, network coverage, seamless high-end services, etc. The 6G architecture should consider the limited capability of mobile devices for processing AR/VR applications. The multi-access edge computing server (MEC) should be integrated into the 5G core for bringing ultra-low latency networks closer to mobile phones. The 6G network nodes should have embedded AI capability. Another important aspect is trustworthiness i.e., the system should be designed with security in mind, and security measures should be deployed in the platform for protecting user data in the open access 6G network. The candidate technologies discussed in the paper are the Terahertz spectrum and its challenges, novel antenna technologies, duplex technology evolution, network topology evolution, spectrum sharing, comprehensive AI, split computing and, high precision network. Metamaterial that is constructed at scales smaller than the wavelengths by arranging multiple tunable elements such as varactor diodes, PIN diodes, in a repeating pattern. This can be used for developing novel antenna technology comprising metamaterial antennal and reconfigurable intelligent surface that will calculate propagation paths. Another promising area that can be explored is Orbital Angular Momentum. The network topology may include base stations along with satellites and HAPS for providing coverage in the mountains where a terrestrial network is not possible. The AI platform can be utilized for taking scheduling, traffic, and UE information and predicting collision, and making spectrum access decisions. Application AI is implemented as local AI, joint AI, and E2E AI. Local AI at each network node can help in optimizing the node requirements and when two nodes are coordinating, their operation is optimized by joint AI. E2E AI optimizes the whole network and implements corrective measures. As mobile computing capability is not enough for extreme reality applications, the computing can be split between a mobile phone, base station, and MEC servers. This enables high performance of mobile devices and saves battery. The software platform, low latency, and low power wireless communications, and data synchronization will help in achieving split computing. The 6G is currently in the research and requirement phase. It is predicted that ITU-R will start working on 6G specifications from 2022 and the commercial launch might happen in the 2030s.

1.3 Hexa-X (January 2021)

Hexa-X is a 6G Flagship research group of Europe comprising 25 members from top companies and universities. Nokia is leading this research group and Ericsson is playing the role of technical manager. Other members are Intel, Orange, Telefonica, etc. The agenda is to frame the 6G research and lay the foundation for the development of future and digital

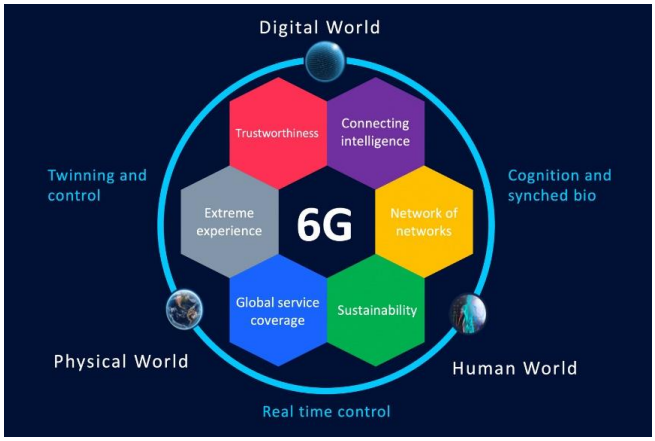

Fig -2: Hexa-X 6G Vision [7]

technologies. Their vision is to connect the human, physical world with 6G technology. Six goals for 6G are connecting intelligence, a network of networks, sustainability, global service coverage, extreme experience, and trustworthiness. This project's focus is on the interaction between three worlds: the biological or human world of intelligence, bodies, values; the physical world of things, devices, and the digital world of data, information, and computing. The interaction between the human and physical world in the form of real-time control of objects such as controlling robots, vehicles, medical operations, etc. with high reliability and extremely low latency requirement. The digital world can communicate with the physical world where different sensing elements are uploading data to the digital world, which will be processed by AI/ML platforms and feedbacks will be provided back to the physical world. Another is human-machine interface applications that provide synchronization between the human and digital world. This area can include all kinds of AR/VR solutions that will be helpful in various scenarios, such as operating on avatar first to analyze the results, etc. The application areas and corresponding network requirements are being researched upon.

1.4 6G@UT (July 2021)

AT&T, Samsung, Qualcomm, nVIDIA, and interdigital founded 6G research at the University of Austin in 2021. Other industry partners are Intel, Western Digital, Honda R&D America Inc, etc. This research group aims to develop new technologies for 6G, providing 6G training and education to a future generation. The research areas include deeply embedded machine learning, pervasive sensing, new spectrum, and network slicing or spectrum sharing. Pervasive sensing will provide data to the ML platform through sensors incorporated in the physical world.

1.5 Others

LG Electronics is another major player that started research on the 6G network. In June 2021, LG in collaboration with Fraunhofer-Gesellschaft (Europe research lab) demonstrated successful transmission and reception of signals over 100 meters using the THz band. LG also partnered with the Korea Advanced Institute of Science and Technology and established LG-KAIST 6G Research Center. Huawei is also working toward the development of a roadmap for 6G. It is working towards advancement from 5G to 5.5G and is expecting to develop 6G after 2030. ZTE announced in 2020 that ZTE R&D will be collaborating with global partners, universities for 6G research.

4. CONCLUSION

The paper presents an overview of the different research work carried out towards the development of 6G. It discusses the evolution of 5G networks and the differences between 5G and next-generation, 6G. Further, the paper presents different 6G application areas. It then discusses details of all the research activities on which major companies and universities are working. It also covers studies on 6G goals, network requirements, and candidate technologies.
The present stage of 6G wireless communication is the research phase in which different topologies, network architecture are proposed. The next phase will be the development of 6G specifications. The research phase for the 6G will be complete by 2023. Researchers are hoping to start 6G commercialization by the 2030s.

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