Overview of 6G Network & Technology

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Abstract -- **Sixth Generation (6G) research commenced in 2019. There are a number of conceptual papers on 6G and its related technologies available with some research groups working actively on this new wireless communication generation. Commercial deployment is expected from 2030. 6G networks will be able to use higher frequencies than 5G networks and provide substantially higher capacity and much lower latency.**

Since 2020, telecom operators around the world started deploying 5G technology in their networks. Mindboggling growth in advanced technologies such as artificial intelligence, robotics, IoT and automation is poised to bring unprecedented shift in the wireless communications. 6G technology, where India has filed significant number of patents will become the fulcrum of unheard of applications to make industrial as well as domestic operations more productive.

India now has the second largest 5G network in the world, on the back of the fastest rollout, the government has set a target to lead in 6G technology by developing global 6G standards. This article provides overview of 6G network and technology.

Keywords: 6G standards, Massive machine-type communications, Ultra-reliable and low-latency communication, Edge computing, High performance computing, Energy efficiency

I. INTRODUCTION

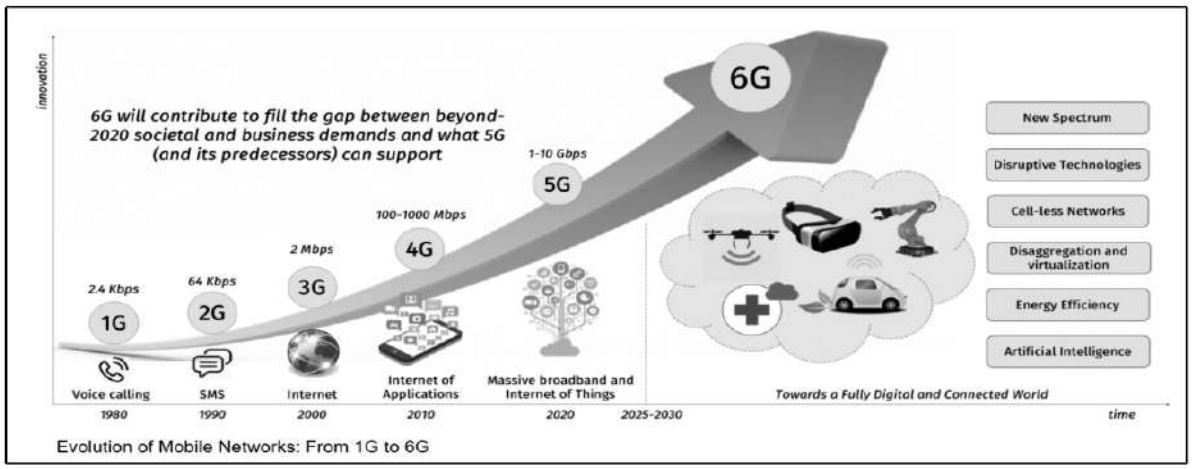
EVERYDAY technology is evolving; computers are getting faster, cars are getting smarter, and communications are more accessible than ever before. Network connection plays a primary role in the development and growth of all technology. Without advanced network connections, Virtual Reality (VR) and Artificial Intelligence (AI) technology would not exist or would be largely inaccessible to the public.

Starting with 2G in early 90s, successive decades saw emergence of 3G, 4G and now 5G, promising peak speed of 1 Gbps (1,000 Mbps) compared to 20-100 Mbps on 4G. However, 6G holds promise of 1 Tbps (1,000 Gbps). Interestingly, India has significant number of global patents for 6G technology, and the government has set a target to lead in 6G technology by developing global 6G standards.

Table 1 -- THE TOP COUNTRIES LEADING THE RACE TO 6G

Rank	*Country*	*6G Patents*	*Fastest 5G Speed*	*6G Ready Score*
1	South Korea	760	814	8.75
2	India	265	465	7.50
3	United States	2,229	363	6.88
4	China	4,604	142	5.00
4	United Kingdom	115	392	5.00
6	Japan	155	298	3.75
6	Finland	12	452	3.75
8	Germany	77	330	3.13
9	Australia	55	296	1.25

Historically, new technology emerges every 10 years in the domain of wireless communications.



Evolution of Mobile Networks: From 1G to 6G

5G has an end-to-end delay of 1 to 5 ms, while 6G is designed to have substantially lower latency, which will result in almost instantaneous data transfer. In addition to the high-speed requirement in the range of 1 Tbps in the form of enhanced Mobile Broadband, two more features are needed:

(*i*). Ultra-reliable and low-latency communication (URLLC)
(*ii*). Massive machine-type communications (mMTC).

Also, with almost every device being connected and sporting an internal antenna, one square kilometre area may connect 10 million devices using 6G compared to a million in case of 5G. Applications that take advantage of wireless communications are expanding from connecting humans to connecting various things. Wireless communication is becoming an important part of social infrastructure. In addition to this, tremendous growth in advanced technologies such as AI, robotics, IoT and automation is poised to bring unprecedented shift in the wireless communications.

Less than two years ago, 5G or fifth-generation networks seemed impossible. From airplane interference to updating cell towers, 5G was considered light-years away. Nevertheless, it is now reality. With 5G technology, humans around the world can connect with one another faster than ever before.

If 5G was so hard to accomplish, then how are we already considering the transition to 6G, and what is 6G?

The answer is quite simple: we need to. If we want to continue this fast-paced upward trajectory of growth in technology, then the networks need to match that pace. 6G will allow for technology—specifically in communications—to grow with the needs of our societies.

China has launched a 6G test satellite equipped with a terahertz system. Technology giants Huawei Technologies and China Global reportedly plan similar 6G satellite launches in near future. Many of the problems associated with deploying millimeter wave radio for 5G must be resolved in time for network designers to address the challenges of 6G.

The race to 6G is drawing the attention of many industry players. Test and measurement vendor Keysight Technologies has committed to its development. Major infrastructure companies, such as Huawei, Nokia and Samsung, havesignaled that they have 6G R&D in the works.

It is yet to be seen that what benefits 6G will bring for society, however, one thing is sure that Machine Learning and Artificial Intelligence in smart cities will play key roles in 6G technology.

II. BRIEF ABOUT 6G

6G (sixth-generation wireless) is the successor to 5G cellular technology. 6G networks will be able to use higher frequencies than 5G networks and provide substantially higher capacity and much lower latency. One of the goals of the 6G internet is to support one microsecond latency communications. This is 1,000 times faster -- or 1/1000th the latency -- than one millisecond throughput.

The 6G technology market is expected to facilitate large improvements in the areas of imaging, presence technology and location awareness. Working in conjunction with artificial intelligence, the 6G computational infrastructure will be able to identify the best place for computing to occur; this includes decisions about data storage, processing and sharing.

It is important to note that 6G is not yet a functioning technology. While some vendors are investing in the next-generation wireless standard, industry specifications for 6G-enabled network products remain years away.

III. SPECTRUM

Spectrum is—and will continue to be—an obviously essential resource for wireless connectivity. While 5G ensured the mainstream adoption of mmWave spectrum, the need for higher data rates and consequently larger channel bandwidths will necessitate the incorporation of terahertz (THz) and sub-THz spectrum within 6G.

Among emerging research and development trends in wireless communications, terahertz band (0.1-10 THz) communications has been envisioned as one of the key enabling technologies for the next decade. As of now, the THz band is available in abundance and due to the ultra-wide spectrum resources, the THz band can provide terabits per second (Tbps) links for a plethora of applications, ranging from ultra-fast massive data transfer among nearby devices in Terabit Wireless Personal and Local Area Networks to high-definition video conferencing among mobile devices in small cells.

The lower frequency bands (up to about 6 GHz) are currently used by 4G/5G and will remain important in the 6G era, especially to provide wide-area coverage for 6G services. Since very little new sub-6 GHz spectrum is expected to be made available, it is essential that a 6G radio access technology will be able to share lower-frequency spectrum with previous generations. The millimeter wave frequency bands in the 24 GHz to 52 GHz range, pioneered by 5G and likely to soon be extended up to 100 GHz, will naturally be used by 6G as well.

The 7–24 GHz range is currently being used for other purposes than cellular communication but can be exploited for 6G by deploying advanced sharing mechanisms. Above 100 GHz, there are opportunities for relatively large amounts of spectrum, but, given the very challenging propagation conditions, it is

mainly of interest for very specific scenarios requiring extreme traffic capacity and/or data rates in a dense network deployment condition.

Federal Communications Commission (FCC) has released the frequency bands above 95 GHz to 3000 GHz for experimental use and unlicensed applications to encourage the development of new wireless communication technologies. Considering the advancements, it is expected that 6G band would require up to 3000 GHz.

IV. IMPLICATIONS OF 6G

The exact working of 6G is not yet known, as the specification is yet to be fully developed, finalized, and released by the ITU. However, depending on previous generations of cellular networks, one can expect several core functionalities. 6G will have big implications for many government and industry approaches to public safety and critical asset protection, such as the following:

- threat detection;
- health monitoring;
- feature and facial recognition;
- decision-making in areas like law enforcement and social credit systems;
- air quality measurements;
- gas and toxicity sensing; and
- sensory interfaces that feel like real life.

Improvements in these areas will also benefit smartphone and other mobile network technology, as well as emerging technologies such as smart cities, autonomous vehicles, virtual reality and augmented reality.

V. NEED OF 6G TECHNOLOGY

There are a number of reasons that we need 6G technology. They include the following:

- *Technology convergence*: The sixth generation of cellular networks will integrate previously disparate technologies, such as deep learning and big data analytics. The introduction of 5G has paved the way for much of this convergence.

- *Edge computing*: The need to deploy edge computing to ensure overall throughput and low latency for ultrareliable, low-latency communications solutions is an important driver of 6G.

- *Internet of things (IoT):* Another driving force is the need to support machine-to-machine communication in IoT.

- *High-performance computing (HPC)*: A strong relationship has been identified between 6G and HPC. While edge computing resources will handle some of the IoT and mobile technology data, much of it will require more centralized HPC resources to do the processing.

VI. WHAT ARE THE ADVANTAGES OF 6G VS. 5G?

6G, the sixth-generation wireless technology, is still in its developmental phase, and there is currently no standardized definition for what 6G will ultimately encompass. However, researchers and experts predict that 6G will bring significant benefits over the current 5G technology. Some potential benefits of 6G include:

- *Increased data speeds:* 6G is expected to provide significantly faster data transfer speeds than 5G which will facilitate faster downloads, smoother streaming, and quicker access to information.

- *Lower latency:* 6G is expected to offer lower latency, or the delay between sending and receiving information which will make it possible to create new applications, such as remote control of machinery, that require real-time communication.

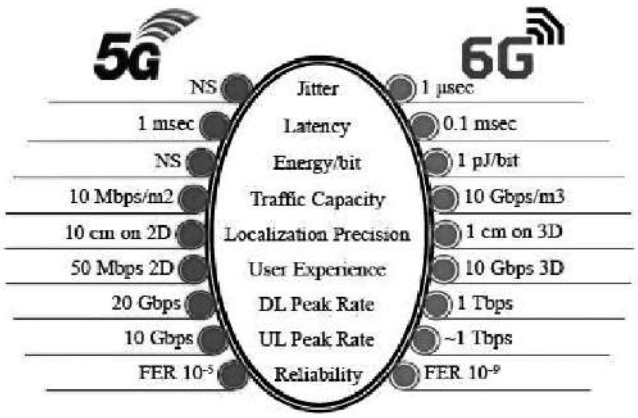
- *Higher bandwidth:* 6G is expected to offer higher bandwidth, which will allow for more devices to connect simultaneously and increase the amount of data that can be transferred at once.

- *Improved reliability:* 6G is expected to provide more reliable connectivity, even in challenging environments such as crowded cities or remote areas.

- *Improved energy efficiency:* 6G is expected to be more energy-efficient than 5G, which will help to reduce energy consumption and increase battery life.

- *New applications and services:* 6G could enable new applications and services that are not possible with current technology, such as immersive virtual and augmented reality experiences, advanced machine learning, and intelligent automation.

VII. TECHNOLOGY COMPARISON OF 6G WITH 5G



VIII. SECURITY ISSUES IN 6G AND POSSIBLE REMEDY

6G is a rapidly evolving technology and new security issues may emerge in the future. However, based on current understanding of the technology, here are some probable security issues in 6G and how to address them:

- *Increased Attack Surface:* 6G is expected to use a variety of new technologies and components, such as artificial intelligence, virtual and augmented reality, and machine learning, which could lead to an increase in the attack surface for cybercriminals. To address this issue, it will be important to design 6G networks with security in mind, including implementing advanced authentication and authorization mechanisms, secure encryption, and intrusion detection systems.

- *Supply Chain Risks:* As 6G networks will be composed of a complex array of hardware and software components from various vendors, there is a risk of supply chain attacks. Such attacks could occur when a malicious actor infiltrates a supplier's systems and introduces malware or other malicious code into the network components. To address this issue, 6G network operators need to implement a robust supply chain risk management program and work closely with their suppliers to ensure the security of the components they use.

- *Network Slicing Risks:* 6G networks are expected to be highly flexible and customizable, with the ability to create multiple virtual networks, known as network slices. However, network slicing could create new security risks, as malicious actors could use a compromised slice to launch attacks on other parts of the network. To address this issue, 6G network operators need to implement strong isolation mechanisms between different network slices and carefully monitor network traffic to detect and respond to any anomalous activity.

- *Privacy Concerns:* 6G networks will enable the collection and analysis of large amounts of data, including location data, biometric data, and other sensitive information. As such, there is a risk of privacy breaches, which could occur when data is mishandled, misused, or stolen. To address this issue, 6G network operators need to implement strong data protection mechanisms, such as data encryption, secure storage, and access controls, and work closely with regulators to ensure compliance with relevant data privacy regulations.

In summary, 6G networks will bring a new set of security challenges, including increased attack surface, supply chain risks, network slicing risks, and privacy concerns. To address these issues, network operators need to take a proactive approach to security, implementing a range of technical and organizational measures to mitigate risks and protect against cyber threats.

IX. SUPPORT REQUIRED FOR 6G

6G, the next generation of wireless communication technology, is still under development, but it will require significant advancements in various areas to meet its ambitious goals. Here are some key support areas for 6G:

- *Higher Bandwidths:* 6G aims for terabit-per-second (Tbps) speeds, requiring significant upgrades to existing infrastructure. This require deploying more cell sites, using higher frequency bands (potentially in the terahertz range), and leveraging new antenna technologies like massive MIMO.

- *Network Densification:* Denser networks with smaller cells will be crucial to handle the increased traffic and enable ultra-low latency. This includes deploying small cells, femtocells, and exploring new network architectures like fog computing.

- *Artificial Intelligence***:** Integrating AI into the network will be essential for dynamic resource allocation, self-optimization, and network management in a complex 6G environment.

- *Enhanced Security:* With the growing number of connected devices and the critical nature of 6G applications, robust security measures will be paramount. This may involve new authentication methods, intrusion detection systems, and secure communication protocols.

- *Privacy Considerations***:** Protecting user privacy in a hyper-connected world will be crucial. Advancements in anonymization and data minimization techniques will be needed.

- *Energy Efficiency***:** 6G networks are expected to handle a massive amount of data traffic, necessitating energy-efficient solutions. This requires advancements in chip design, power-saving protocols, and utilizing renewable energy sources.

- *Sustainable Materials:* Developing environment-friendly materials for network infrastructure will be important to minimize the environmental impact of 6G deployment.

- *Global Standards***:** Collaboration between industry players, governments, and research institutions will be crucial to establish clear and unified standards for 6G technology, ensuring global compatibility and interoperability.

- *Quantum Technologies:* While still in its early stages, quantum communication holds promise for ultra-secure communication and potentially revolutionize cryptography in 6G networks.

- *Regulatory Frameworks:* Regulatory bodies will need to adapt existing frameworks to address the unique challenges and opportunities presented by 6G, such as spectrum allocation and data privacy regulations.

By providing robust support in these areas, we can pave the way for a successful 6G rollout that delivers on its promise of revolutionizing communication, enabling new applications, and fostering innovation across various sectors.

X. 6G AND ENVIRONMENTAL CONCERNS

As climate change brings rising temperatures and extreme weather, global citizens are demanding urgent action. NASA reports that increased carbon emissions have raised the planet's average surface temperature 2.12 degrees Fahrenheit (1.18 degrees Celsius) since the late 19th century — and the seven most recent years have been the warmest on record.

135 countries and hundreds of companies worldwide have pledged carbon neutrality. The technology sector is poised to create long-term solutions toward environmental sustainability. In particular, electronic design can support the development of clean energy systems, data analytics for environmental applications, and machine technology advancements that reduce carbon emissions.

By focusing on sustainability as a key driver of 6G research, we will discover new ways to combat climate change in the following industries and beyond.

a. *Transportation*: The US transportation industry is currently the largest contributor (29%) of greenhouse gas emissions, according to the EPA. 6G will enable innovations in smart transportation and logistics, including connected vehicles and transit infrastructure. The growth in driverless electric vehicles will not only promote clean energy but will also reduce emissions by optimizing traffic flow. These outcomes will be made possible by applying wireless connectivity to sensor technology, distributed computing, and AI. This combination of new technologies will allow vehicles, traffic cameras, and roads to communicate and coordinate in real time.

   The Global System for Mobile Communications Association (GSMA)'s 2020 Mobile Industry SDG Impact Report found that the increase in vehicle monitoring, route optimization, and fuel efficiency through telematics helped avoid approximately 105 million tons of greenhouse gases in 2018 — equivalent to taking 23 million cars off the road. In Toronto, a smart traffic management system that enables traffic lights to self-learn and recognizes patterns shortened travel times by up to 25% and reduced emissions by 13%.

b. *Manufacturing:* 6G will build upon 5G's ability to modernize all stages of manufacturing — from product design to the factory floor to the warehouse. Connected machines and cooperative robotics will be able to orchestrate all manufacturing and supply chain management activities, automating once-manual processes to enable more efficient and resilient supply chains.

   6G-enabled manufacturing plants will also advance our ability to monitor and manage energy and water usage, reduce carbon emissions, and leverage renewable energy to power operations. For example, Ericsson's Smart 5G Factory reduced waste by 5%, saved 5% on energy costs, and increased overall energy efficiency by 24%.

c. *Agriculture*: One of the main benefits of 5G and eventually 6G is expanding wireless access to rural areas. This opens new sustainability opportunities for the agricultural sector, where chemical fertilizers, pesticides, and animal waste release harmful greenhouse gases into the atmosphere.

   Smart agriculture unlocks new ways to optimize crop production, conserve resources, improve soil health, and monitor livestock — all helping farmers reduce their carbon footprint. The same GSMA report revealed that in California — where agriculture accounts for 80% of all water use — solar-powered sensors and an LTE-served network reduced water consumption by 6% and emissions by 5%. And a recent Qualcomm study found that real-time data collected by IoT-enabled drones and sensors resulted in more efficient and accurate pesticide spraying that could reduce overall pesticide use by 50%.

e. *Energy:* As the world's population grows, so does the need to manage and reduce fossil fuel consumption. 6G will help the critical transition to renewable energy, as well as further advance the development of smart grids. Smart grids will enable communities to better monitor increasing energy demands, optimize electrical distribution, and use automation to manage large variations in loads. The same Qualcomm report found 5G-connected smart grids will reduce gas and electricity consumption by 12% — and 6G will accelerate that progress.

f. ICT (Information and Communications Technology): It is to be recognized that the telecommunications and

technology sectors have considerable influence on the economy as a whole, thus have significant influence on energy consumption. AT&T for example estimates that in 2018, its technologies have enabled greenhouse gas (GHG) emission reductions that are twice as large as AT&T's own entire GHG footprint.

The ICT industry already has a large footprint (about 1/10th of global electricity consumption), and is projected to rise significantly. The wireless communication industry, which is a big part of the ICT sector, has made it a primary 6G objective to reduce its energy usage and incorporate sustainability in its operational processes and lifecycle management.

Currently, the Radio Access Network (RAN) consumes a major share of the energy (>50%) of the wireless network architecture. The move towards cloudification is shifting more of the usage to data centers, where there is already tremendous momentum towards 'greening'.

XI. INTERNATIONAL STATUS OF 6G

The international status of 6G is as mentioned below:

- Unlike 5G, which has already seen large-scale deployments, 6G is still in its early stages of research and development.
- There's no commercially viable 6G technology available yet.
- Several countries, including China, South Korea, Japan, the United States, and the European Union, are actively funding research initiatives on 6G technologies.
- Research focuses on core technologies like higher bandwidths, lower latency, network densification, and integration with advanced technologies like AI and quantum communication.
- International standardization bodies like the 3rd Generation Partnership Project (3GPP) are yet to define the technical specifications for 6G.
- Discussions and preliminary studies are ongoing to identify potential use cases, requirements, and key performance indicators (KPIs) for 6G.
- There's a growing international collaboration among research institutions, universities, and telecom companies to accelerate 6G development.

Estimated Timeline: While there's no exact timeline for commercial 6G deployment, it could happen sometime in the late 2030s, following the widespread adoption of 5G.

XII. TAKEAWAY

6G networks will be able to use higher frequencies than 5G networks and provide substantially higher capacity and much lower latency.

Even as the 5G rollout continues worldwide, leading research consortiums and mobile companies are busy working on the sixth generation of mobile connectivity. 6G networks aim to connect the physical and virtual worlds through faster M2M communication and better support for immersive technology. Organizations/Institutes should know about the working and importance of 6G networks to prepare for the future and fully use the wireless infrastructure available to them.

Lately, India's indigenously developed 5Gi standard has been formally merged with the 3GPP 5G Standard. The technology enables the deployment of 5G cell sites with long range, which is required for improving cellular and IoT connectivity in rural India.

Tilak Raj Dua is the Director General, Digital Infrastructure Providers Association and Chairman ITU-APT. An engineering graduate with diploma in business management and export marketing, he has over 35 years' experience in the telecom sector. His experience includes all facets of telecom be it product development, business development, telecom licensing, regulatory issues with respect to interconnection / roaming / unified licensing and infrastructure sharing / mobile number portability, spectrum management, spectrum related issues like spectrum pricing, efficient utilization and spectrum reframing, finalization of joint ventures, technical collaboration, introduction of new product, launch of cellular services in india and finalization of licence agreements / interconnect agreements etc. Served as Deputy Director IAF - from 1967 to 1989, Director, Shyam Telecom Ltd. (Regulatory) – from1994 to 2000, Director, Bharti Airtel Ltd (Corporate Affairs & Regulatory) – from 2000 to 2005, Deputy Director General: COAI – from 2006 to 2011, Executive Director Augere Mobile Broad Band Wireless Pvt. Ltd. – 2011, Director General Tower and Infrastructure Providers Association: since Jan 2015 till date. Has many firsts to credit like finalization of joint ventures, technical collaborations, introduction of new products, launch of cellular services in India and finalization of licence agreements/interconnect agreements. Works with institutions like ITU, APT, WWRF for spectrum/ regulatory matters.