Engineering and Technology Journal for Research and Innovation (ETJRI)
ISSN 2581-8678, Vol. VII, Issue II, July 2025

Factors Affecting Deployment of Advanced Communication Techniques (6G And Beyond) In Indian Scenario

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***Abstract*— In the evolution era of communication technology, wireless networks (6g and beyond) are going to be revolutionized the real time connectivity, data rates and processing, sub milli second latency a many more. The transition to 6G and beyond offer transformative capabilities in wireless communication, but its deployment in India faces several challenges. This paper explores key factors such as spectrum allocation, infrastructure readiness, policy support and socio-economic condition impacting the rollout of the advanced communication technologies. A comparative analysis of 4G,5G and 6G is represented along with the MATLAB based BER simulation to access performance. The study highlights the need for strategic investment, robust Infrastructure and inclusive policy reforms to ensure India's readiness for next generation networks.**

***Keywords*— BER, QPSK, MIMO, FDMA**

I. INTRODUCTION

As the telecommunication network transition from 5G to 6g or beyond is more than just an improvement in the telecommunication network, it signifies a fundamental shift in the connectivity of people, machine and the environment. With a large population, a developing digital economy, and a strong IT sector, India has a enormous potential for advanced telecommunication but it also faces several obstacles such as inadequate infrastructure, high costs, a lack of local manufacturing and fragmented R&D. With rapid expansion of communication techniques introduces significant cybersecurity challenges due to attacked surfaces from IOT, edge computing and virtualization. A comprehensive cyber defense strategy that integrates proactive measures (network segmentation, encryption, intrusion detection, AI-driven threat intelligence) with reactive strategies (incident response, forensic analysis) [1].

The development of wireless communication technology from 1G to 5G has changed the way individuals communicate, access data and interact with digital services dramatically. Ahead lie 60 and beyond as we are stepping into an error that will deliver record-breaking data speed, ultra-low latency and intelligent adaptive network powered by artificial intelligence, terahertz communication and quantum technologies. While international efforts are being made to delineate 6G’s framework and capabilities, the Indian communication landscape offer a distinct scenario characterized by extensive geographical diversity, socio economic inequality, and infrastructural constraints.

India's being one of the largest consumers of mobile data has potential to be key player in next generation wireless innovation. However, the deployment of advanced communication techniques faces multiple challenges including spectrum, spectrum scarcity, inconsistent policy implementation, digital divide between rural and urban region and the high cost of restructuring modernization. Furthermore, technical preparedness in terms of human capital, R&D spending and global cooperation continues to be a determining criterion. This paper tries to critically examine the determinants of the adoption and rollout of 6G and feature technology in India, comparing some major performance parameters such as BER over 4G,5G and 6G. The paper also presents simulation results to gauge the performance gap and policy suggestion for filling it. By recognizing the roadblocks and opportunities, this study helps build a holistic study for India's future ready digital infrastructure.

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II. Literature Review

[1] Author emphasizes Russian defense mechanism with increased complex challenges in cyber security because of widened attack surfaces. Existing literature emphasizes the efficiency of sophisticated encryption algorithms such as AES and RSA, which assist in safeguarding data, with AES being more efficient and suitable for real time operations. Network segmentation provides better performance and restricts the effects of breaches. Intrusion detection system proved to be very accurate and threat detection. Additionally, for future communication networks, combining these proactive defenses with reactive strategies such as AI based threat detection is essential. Together, these approaches provide a comprehensive defense to secure next generation communication networks.

[3] 5th generation wireless technology is a major leap in wireless communication, providing higher data capacity, ultra-low latency and vast connective capabilities. Research highlights the importance of 5G as a software defined networking convergence platform and IoT ecosystem and high-speed Internet access. Dense device network architecture is supported for seamless integration with wired and wireless infrastructure, allowing for smartphone support. While 5G complete deployment is ongoing, it is capabilities from ultra-high data rates to enormous device support plays it's as a foundation of future communication infrastructure.

[5] Fizzy provides society and industry with transformative potential without adding materially new physical danger. Unless there is public concern, it is not different from earlier generations. Adaption of regulation is needed for infrastructure rollout, especially regarding electromagnetic field (EMF) exposure restriction. Remarkably, Poland implements EMF limits (0.1 W/m^2) much stricter to 10 times higher compared to many other EU nations (1-100 W/m^2). Misinformation about the novelty and danger of 5G technology is baseless and contrary to existing scientific opinion.

[6] 6G marks the new evolution of ICT, expanding beyond 5G with spatial, interstellar and intelligent network capabilities. It aims to enable ultra-high speed, low latency communication through terahertz band, AI integration and multidimensional connectivity (Land, air, sea space and micro worlds). Emerging applications include digital twins, holographic communication and air-based internet.

[7] 6G communication aims to overcome the limitation of 5G by introducing intelligent, decentralized technologies. Key advancements include blockchain based spectrum sharing for real-time secure allocation. Reconfigurable intelligent surfaces (RIS) to enhance signal control and energy efficiency and delay aware transmission using edge computing and AI based user prediction. Wireless distributed computing enables privacy preserving, location aware task processing across network nodes, making 6G more adaptive, efficient and responsive to future service demands.

III. History From 1G Onwards

Wireless communication has experienced swift and transformative evolution since its inception, with each successive generation- from 1G to 5G, and now the emerging 6G represents substantial advancements in technology, network architecture, and serve capabilities.

A. 1G (First Generation) (analog voice communication)

First generation (1G) mobile systems introduce in the early 1980s, first generation(1G) cellular system marked the advent of commercial mobile communication utilizing analog transmission technologies. It introduced analog mobile telephony using frequency Division Multiple Access (FDMA) for channel access and used a cell frequency reuse pattern to maintain an 18dB signal to interference ratio with 120° directional antennas. key systems included AMPS, NMT, and TACS. AMPS operated in the 800-900MHz band with a total of 40MHz allocated by FCC, using 869-894 MHZ for downlink and 824- 849 MHz for uplink [2]. It supported only voice calls, with no data or text services. However, 1G suffered from poor voice quality, low security (no encryption), limited capacity to 9.6 kbps, and high noise susceptibility. With large cells(2-20km) and no support for data,

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MIMO or carrier aggregation, 1G was eventually replaced by digital 2G system [4]. Despite its limitations, 1G established the foundation for future mobile communication systems.

B. 2G (Second Generation): digital voice and basic data

Second – Generation(2G) mobile systems emerged in the late 1980s introducing digital multiple access technologies like TDMA and CDMA(IS-95), which significantly improved spectrum efficiency, voice quality, increased capacity, improved security through digital encryption and international roaming. 2G introduced basic data services including SMS, GPRS, and EDGE supporting limited internet access [2]. GSM became the dominant global standard employing digital signal processing and efficient spectrum utilization. The evolution of 2.5G introduced GPRS, enhance GSM with packet-switched data services paving the way for mobile internet.it supported speed of 64-144 kbps and marked the transition toward mobile internet use, through still limited for rich media like video [3].

C. 3G (Third Generation): Mobile Broadband and Multimedia

Third generation launched in the early 2000s, 3G marked a shift to data centric mobile communication, enabling services like video calls, mobile internet and streaming. It utilizes technologies such as UMTS (W-CDMA) and CDMA2000 offering data rates from 384 kbps to few with Mbps. With IMS architecture, 3G supported VoIP, multimedia and IP based services, laying the foundation for smartphones. It uses circuit and packet switching, turbo codes for error correction, and operates in 1800-2400 MHz bandwidth [4]. Despite enhanced capacity and global roaming, 3G faced challenges like high latency and limited spectrum, but played a crucial role in the transition to mobile broadband and rich app ecosystems.

D. 4G (Fourth Generation): IP based high speed broadband

The fourth generation(4G) launched around 2010, marked a shift to all-IP networks using LTE and WiMAX, enabling broadband level speeds (10 Mbps to 1 Gbps) a low latency (22-50 ms). Key technologies include OFDMA, MIMO and 64 QAM, enhancing spectral efficiency and supporting HD video, online gaming and real time services [3]. 4G eliminated circuit switching, integrated internet service seamlessly and enabled rapid mobile app growth. While offering superior speed and mobility, it faced challenges in infrastructure cost, spectrum availability and indoor coverage. 4G laid the foundation for the data centric mobiles era.

E. 5G (Fifth Generation): ultra-fast, ultra reliable and massive connectivity

5th generation (5G) launched in the late 2010s represents a major leap in wireless technology offering ultra-high speed (up to 10 Gbps), ultra-low latency (~1 ms), downlink speeds ≥ 20Gbps and massive device connectivity for IoT [5]. Core technology includes New Radio (NR), mmWave spectrum, Massive MIMO, beamforming, network slicing and edge computing. It supports applications like autonomous vehicles, smart cities and AR/VR. While mmWave enables high bandwidth, it faces range and penetration issues needing dense base station deployment. Despite high costs, 5G enables real time, high capacity, energy-efficient communication, transforming industries and paving the way for future innovations.

Key enabling technologies include:

1) *Millimeter-Wave(mmWave) Communication*
   Utilize This spectrum allows 50 Ghz for wider bandwidth (1-2Ghz) though with reduced range and penetration.
2) *OFDMA*:
   Efficient multiple access scheme supporting simultaneous users.
3) *Massive MIMO with beamforming*:
   Enhance coverage and throughput using large antenna array with dynamic beam steering.
4) *Dense Small Cell Networks*:
   Improves spectrum utilization and network capacity in high demand areas.

F. 6G(sixth generation) wireless systems

Research into 6G focuses on integrating AI-driven networks, terahertz communication, and ubiquitous connectivity with unprecedented data speeds and intelligence. Expected around the 2030s, 6G aims to create a fully immersive, intelligent wireless

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ecosystem blending human and machine communications seamlessly.

Different generations of networks are shown in table 1.

Generation	Key Feature	Data Rate	Latency	Technology & Architecture	Primary Use Cases
1G	Analog voice	~2.4 kbps	High	FDMA, Analog Cellular	Voice calls only
2G	Digital voice + SMS	Up to 384 kbps	Moderate	GSM (TDMA), CDMA	Voice, text messaging, limited data
3G	Mobile broadband	384 kbps – few Mbps	~100-500 ms	W-CDMA, CDMA2000	Internet, video calls, multimedia
4G	IP-based broadband	100 Mbps – 1 Gbps	~20-50 ms	LTE (OFDMA, MIMO), All-IP	HD video, apps, online gaming
5G	Ultra-fast, low latency	Up to 10 Gbps	~1 ms	NR, mmWave, Massive MIMO, Slicing	IoT, AR/VR, autonomous vehicles, smart cities
6G (future)	AI-integrated wireless	>100 Gbps (predicted)	<1 ms (predicted)	Terahertz, AI, Quantum	Immersive, intelligent networks, holographic communications

TABLE I DIFFERENT GENERATION NETWORK

IV. ADVANCED TECHNIQUES

The division and beyond stands for a change in wireless communication that goes beyond speed or latency to include sophisticated sensing and network contextual adaptability. Several new technologies will influence how people communicate in the future. The development of the future generation is centered on these cutting-edge methods, and their integration will present both opportunities and difficulties, particularly in the Indian context.

1) *Terra Hertz Communication:*
Terahertz frequencies (100 GHz to 10 THz) offer enormous bandwidth, enabling ultra-high speed data rates exceeding 100 Gbps. However, these waves suffer from high Path loss and atmospheric absorption, requiring innovation in transceiver design, antenna miniaturization, and short-range cell development strategies. For India, this will demand dense infrastructure, especially in urban clusters.

2) *Reconfigurable Intelligent Surfaces (RIS):*
RIS are programmable meta surface that manipulate electromagnetic waves to dynamically controlled propagation. They can extend coverage in dense urban or obstructed environments, reducing dependency on high powered base stations. Their cost-effective potential aligns well with India's need for energy efficient and affordable deployments.

3) *Massive MIMO and Holographic MIMO*
Moving beyond conventional Massive MIMO holographic MIMO inventions ultra large intelligent antenna arrays that can capture and manipulate electromagnetic fields in three dimensions. This offers special multiplexing gains and beamforming precision essential for 6G. Adoption in India would require localized antenna manufacturing and AI assisted optimization.

4) *AI driven Network Orchestration*
6G network will be inherently autonomous, relying on artificial intelligence for real time resource allocation, fault detection, user behavior prediction and energy optimization. India's growing area research ecosystem provider strong base, but integration into telecom networks needs edge AI hardware and massive datasets, both of which are in early deployment stages domestically.

5) *Integrated Sensing and Communication (ISAC)*
Future networks will not just communicate but also sense the environment enabling applications such as radar like imaging, health monitoring and gesture recognition. ISAC leverages shared hardware for both functions, reducing latency

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and energy consumption. Indian deployment would need regulatory alignment, especially in areas like health, data and privacy.

6) *Quantum Communication and Post Quantum Cryptography*
Quantum Key Distribution (QKD) and post quantum cryptographic methods will be crucial to secure future networks. While India has initiated quantum research missions, the integration of quantum safe techniques into communication protocols remains at a nascent stage.

7) *Cell Free Massive MIMO*
Unlike traditional networks with well-defined cell boundaries, cell free massive MIMO removes intercell interference by distributing many small access points that corporate centrally. This offers seamless connectivity but requires high speed backhaul and synchronized network architecture for an area where India must invest heavily in fiber and software defined infrastructure.

V. Simulation And Results

Bit error rate is the key performance metric in wireless communication system representing the number of bit error per unit times or number of bits transmitted. In general, as we move from 4G to 5G and towards 6G, there is a notable improvement in BER performance due to advancement in modulation scheme, channel coding techniques antenna technologies (like MIMO) and error correction algorithm. The bit error rate comparison from the simulation highlights the progressive improvement in communication reliability across 4G,5G and 6G system under identical modulation (QPSK) and AWGN channel condition. As observed in the BER versus E_b/N_o plot, 6G consistently achieved the lowest BER at all SNR levels, followed by 5G and then 4G. This performance gain is attributed to the assumed advancement in coding efficiency and signal processing techniques in newer generations, modeled through reduced noise scaling factors. At an E_b/N_o of 10 dB, for instance the 6G system shows a significantly lower BER compared to 4G indicating that future network will offer much more robust and error resilient communication. These results validate the anticipated improvement in data integrity and signal quality with each generation's evolution. Overall, the BER decreases from 4G to 6G, with 6G accepted to deliver near zero BER in optimal condition, supporting applications like real time holographic communication and autonomous system. The simulation of BER comparison of 4G, 5G and 6G using QPSK under AWGN is shown in fig 1.

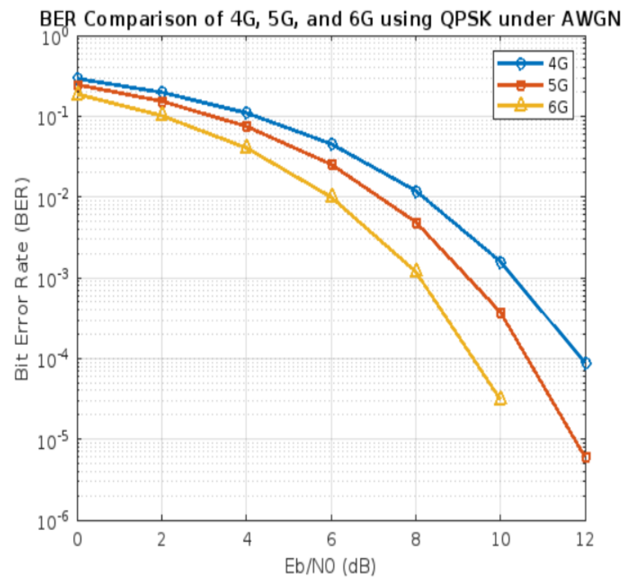

Fig.1. BER comparison of 4G,5G and 6G using QPSK under AWGN

VI. Factors Affecting Deployment Of Advanced Communication Technique (6G and Beyond) In India

1) *Spectrum ability and allocation*
The spectrum resources available in India are limited and subject to strict regulations. Availability and economical distribution of these high frequency bands will be crucial for 6G, which is anticipated to use terahertz (THz) and sub-THz channels. Harmonizing international norms while maintaining equitable domestic access is the difficult part.

2) *Infrastructure readiness*
6G network demand ultra dense small cell deployments, fiber backhaul and advanced core networks. India's existing telecom infrastructure, especially in rural and semi urban areas is not uniformly equipped to support this. Significant

investment in base stations, data centers and power infrastructure is required.

3) *Power and energy efficiency*
With 6G's reliance on massive MIMO, AI and edge computing, energy demand will soar. In a country where power supply is still inconsistent in many regions, the energy efficiency of network components and reliance on renewable energy sources will be a critical deployment factor.

4) *Economic viability and ROI concerns*
The telecom sector in India operates on thin margins and companies are still recovering from 5G investments. Hide deployment cost of 60 technology combined with one peer. Short term return on investment can slow down adoption without strong government or industry support.

5) *Skilled workforce and R&D capacity*
India's push toward Atmanirbhar Bharat (self-reliance) must be matched by increased investment and research and skilled human capital. Indigenous 6G development will need interdisciplinary expertise in AI, terahertz electronics, quantum communication and hardware-software co-design which are currently limited.

6) *Policy, Regulation and Bureaucratic Bottlenecks*
The speed of policy making often lags technological evolution. Streamlined spectrum policy, ease of regulatory approvals and updated national telecom frameworks will be necessary to avoid deployment delays.

7) *Digital divide and social readiness*
India's digital divide across urban, rural, linguistic and economical lines poses a unique challenge. A significant portion of the population still lacks access to 4G/5G. For 6G to be meaningful, deployment must be inclusive and address affordability and accessibility from the outset.

8) *Security and Data Sovereignty*
With 6G enabling ultra-low latency and real time intelligence, cybersecurity, encryption and data localization concerns becoming even more critical. India will need robust framework to ensure secure data transmission and user privacy in a hyperconnected environment.

9) *Global technological dependence*
India imports most of its advanced telecom hardware. Reduced dependency on foreign vendors and building domestic semiconductors and hardware manufacturing capacity will be key to achieving a sustainable 6G ecosystem.

10) *Global technological dependence*
A fragmented industry approach could lead to inefficiencies. Strong collaboration among government, academia, starter and telecom players will be necessary to align standards, innovation priorities and commercialization timelines.

VII. FUTURE SCOPE

In India, the introduction of 6G and subsequent has the prospect to revolutionize several sectors such as intelligent transportation e-health, education, disaster management, smart infrastructure and precision farming. The convergence of communication technologies will facilitate AI driven services, smart cities and digital society for all of this development is in line with projects such as Digital India and Made in India.

During the next decades, India is expected to be a both a contributor and a consumer of 6G technologies and standards. The role played by the government departments, including the Department of Telecommunication (Dot) and MeitY industry leaders like BSNL, Reliance Jio and Bharti Airtel and national institution like IITs and IISc in 6G research is evidence of a change in direction of telecommunication technology towards self-reliance. Also, India's geographical and demographic diversity will offer a special setup to create scalable, reliable, and affordable 6G solutions.

The future is also:

1. Expanding to create cheap and energy savings 6G infrastructure for both urban and rural settings.
2. Employing terahertz power and spectrum for intelligence and communications services.
3. Introducing satellite and terrestrial hybrid networks to increase coverage, especially in hilly and isolated areas.
4. Artificial Intelligence native networks that facilitate real time disaster recovery and health production decisions.

5. Policy framework and regulations that enhance cybersecurity, sustainable use of the spectrum and private research and development incentives.

VIII. CONCLUSION

Sixth generation communication technologies like 6G can potentially transform India's landscape. Realizing this vision, however, is fraught with numerous challenges that include spectrum availability, infrastructure scalability, energy efficiency, regulatory preparedness, and harmonized urban and rural integration. India's socio-economic heterogeneity and population density necessitate customized deployment strategies in conformance with leading edge innovation with respect to local imperatives.

To facilitate a smooth 5G to 6G transition, a forward-looking approach through the interventions of the government in policies, research and development investments, academia-industry collaboration, and global collaboration is required. Wit concerted efforts, India can adopt and contribute substantially to the worldwide 6G arena fostering smart governance, inclusive growth and sustainable digital progress.

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