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Sixth Generation (6G) to the Waying Seventh (7G) Wireless Communication Visions and Standards, Challenges, Applications

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ABSTRACT

The increasing need for next-generation wireless networks becomes apparent as the Internet of Everything (IoE) gains prominence in smart services, projecting widespread popularity in the future. While sixth-generation (6G) networks have the capability to support a diverse range of IoE services, their potential limitations in meeting the demands of innovative applications prompt consideration for seventh-generation (7G) wireless systems. This article seeks to compare the characteristics of 6G and the planned 7G wireless systems. The commercial development of fifth-generation (5G) mobile communication systems is currently underway, introducing new services and enhancing user experiences. Despite these advancements, 5G encounters challenges that require on-going improvements. With the International Telecommunication Union Radio communication Sector (ITU-R) actively envisioning 6G and anticipating a consensus on 7G by October 2024, numerous unresolved questions persist in global discussions. This paper delivers a comprehensive overview of the current understanding of 7G, exploring the vision, technical requirements, and application possibilities. It presents a critical evaluation of the 7G network architecture and essential technologies. Furthermore, the article provides an in-depth examination of advanced 7G verification platforms and existing test beds, unveiling these aspects for the first time. Future research directions and lingering issues are emphasized to contribute to the on-going global discourse on 7G networks. Discussions on lessons learned from 7G networks culminate in the suggestion that 7G systems signify the pinnacle of mobile communication technology. The ongoing research on 7G, an intelligent cellular technology, holds promise for the future of wireless communication.

Introduction:

Beginning in 2020, the fifth generation (5G) of wireless communication networks will be standardized and implemented globally. Massive machine type communications (mMTC), ultra-reliable and low latency communications (uRLLC), and enhanced mobile broadband (eMBB) are the three main 5G communication scenarios. In comparison to fourth-generation (4G) wireless communication systems, the primary features include 20 Gbps peak data rate, 0.1 Gbps user experienced data rate, 1ms end-to-end latency, support for 500 km/h mobility, 1 million devices/km2 connection density, 10 Mbps/m2 area traffic capacity, three times spectrum efficiency, and one hundred times energy efficiency. Numerous pivotal technologies, including millimeter-wave (mmWave), massive multiple-input multiple-output (MIMO), and ultra-dense networks (UDN), have been suggested to realize the objectives of 5G **[1].** The standardization of 5G communications has concluded, and the global deployment of the system is currently underway. Fig. 2 illustrates the worldwide coverage map of commercial 5G networks, encompassing field testing, trials, and research efforts. South Korea emerged as a pioneer, implementing extensive 5G deployment across approximately 85 cities with a network of 86,000 5G base stations by April 2019 **[4].** However, six cities—Seoul, Busan, Daegu, and others—were home to 85% of the 5G base stations. There, a distributed architecture using 3.5 GHz (sub-6) spectrum with deployed data rate speeds evaluated between 193 and 430 Mbit/s **[5].** By the end of 2025, it is anticipated that over 65% of the world's population will have access to 5G ultrafast 5G Internet coverage **[6].** These difficulties have spurred business and academics to begin developing the sixth generation of wireless communication networks, or 6G, to meet the demands of the 2030s for communication services **[11]** and maintain the sustainability and competitiveness of wireless communication systems. Due to the unconventional technologies that 6G communication systems will adopt, such as an extremely large bandwidth (THz waves) and high AI that includes the operational and environment, it is anticipated that the 6G communication systems will offer a large coverage that enables subscribers to communicate with one another everywhere at a high data rate speed.

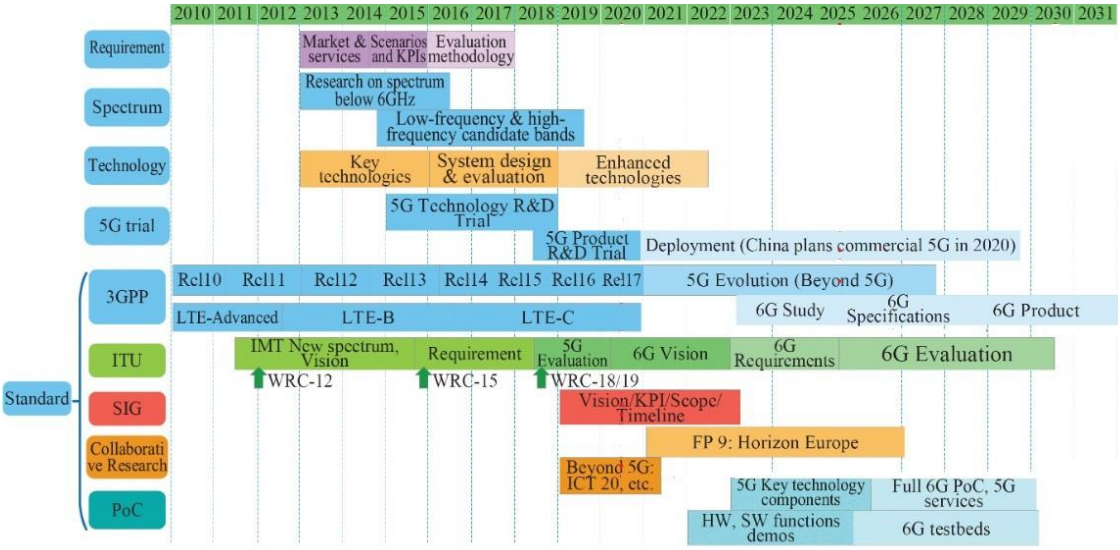

Figure 1. Timeline of 6G wireless networks

Similar to 6G in terms of worldwide coverage, the 7G mobile network will also specify the satellite functions required for mobile communication. The global positioning system (GPS) will be provided by the navigation satellite, the earth imaging satellite will provide additional information such as weather updates, and the telecommunications satellite will handle voice and multimedia communications. Numerous services and local voice coverage will be supported via the 6G mobile wireless network. The next generation of mobile communication will be called 7G. Only until all standards and procedures are specified will the 7G dream come true. Perhaps this will be achievable in the generation that follows 7G and 7.5G. New paradigms in 6G wireless communication networks will be introduced. We envision a 6G network, as shown in Fig. 1. In order to offer total worldwide coverage, 6G wireless communication networks will first be integrated space-air-ground-sea networks. The coverage range of wireless communication networks will be significantly increased by satellite, unmanned aerial vehicles, and marine communication. Every spectrum will be thoroughly investigated, including the sub-6 GHz, mmWave, THz, and optical frequency bands, to offer a better data rate. AI and ML technologies will be effectively integrated with 6G wireless communication networks to enable complete applications and improve network automation and management. Moreover, the performance of next-generation networks can be enhanced by the dynamic orchestration of networking, caching, and computing resources made possible by AI technology. The last but certainly not least trend in network development is the use of robust or endogenous security for both the physical and network layers. 6G wireless communication network development will be significantly aided by industry verticals such as cloud virtual reality (VR), Internet of Things (IoT) industry automation, cellular vehicle to everything (C-V2X), digital twin body area network, energy-efficient wireless network control, and federated learning systems. Fig. 2 provides an overview of 6G wireless networks, including performance indicators, industry verticals, supporting technologies, new paradigm shifts, and application scenarios.

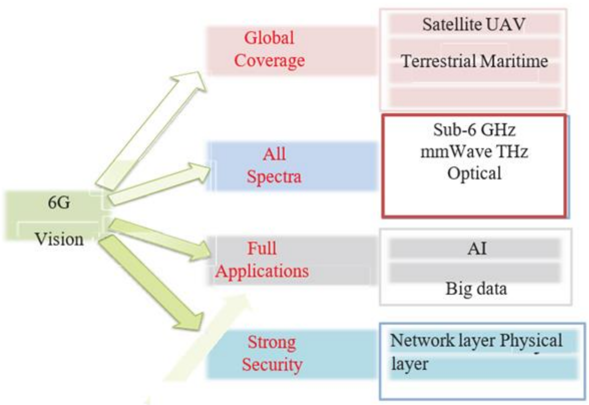

Fig 2 An illustration of wireless networks with 6G speed.

6G WIRELESS SYSTEMS:

The next generation of wireless technology is called 6G, or sixth-generation wireless. In comparison to 5G networks, which offer significantly increased capacity and significantly lower latency, 6G networks will be able to use higher frequencies. Supporting communications with a latency of only one microsecond is one of the objectives of the 6G network. The speed difference between this and a millisecond throughput is 1,000. It is anticipated that the market for 6G technology will enable significant advancements in location awareness, presence technologies, and imaging. Combining artificial intelligence with the 6G computational infrastructure will enable it to determine the optimal location for computing. Decisions about data processing, sharing, and storage will fall under this category. The fact that 6G is not yet a working technology is crucial. Although some suppliers are making investments in the next-generation wireless standard, the industry standards for network components that support 6G remain unchanged for years.

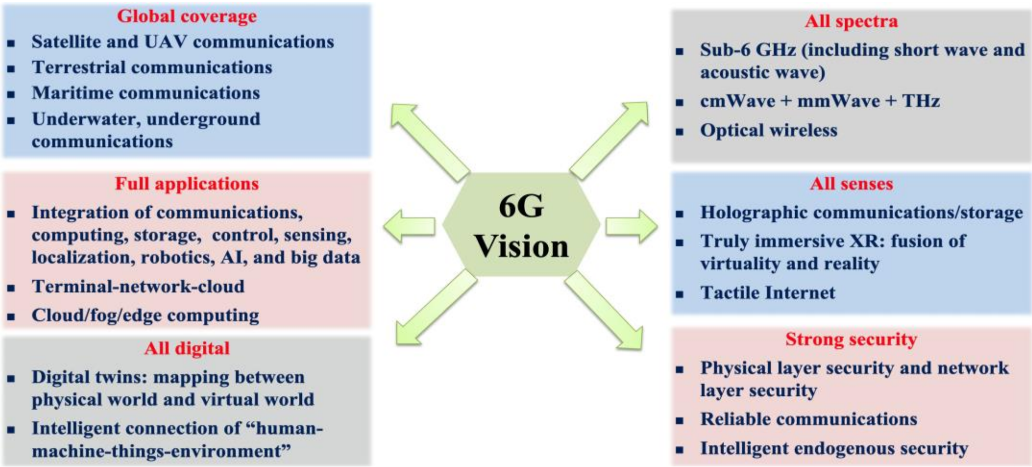

Figure 3. The 6G network's concept includes strong security, worldwide coverage, full applications, all spectrum, and all senses.

6G MARKET STATISTICS AND RESEARCH ACTIVITIES: -

While 5G wireless systems are still in the early stages of deployment, 6G wireless systems are anticipated by extensive research to meet the demands of anticipated revolutionary IoE smart services shortly. The 6G industry is expected to reach 4.1 billion US dollars by 2030, growing at a compound annual growth rate of 70% between 2025 and 2030 [17]. Out of all the 6G components—edge, cloud, and AI—communication infrastructure is expected to have the biggest market share, perhaps reaching USD 1 billion. By 2028, there will be more than 240 million AI chipsets, another essential 6G component.

6G: STATE-OF-THE-ART

The cutting-edge developments that make 6G possible are outlined in this section and are summed up in Table 3. Federated learning at the network edge was examined by **Khan et al. [30].** For federated learning at the network edge, resource efficiency, and incentive mechanism design were taken into consideration. Initially, important design elements that facilitate federated learning at the network edge were showcased. The design of learning algorithms, hardware–software co-design, incentive mechanisms, and resource optimization are among these crucial design aspirations. Secondly, an incentive mechanism based on the Stackelberg game was suggested. They also provided some numerical results to support their Stackelberg game-based reward system. Lastly, several open-ended research difficulties and potential future study avenues were discussed. It is advised to further suggest an incentive mechanism based on contract theory, even though the Stackelberg game-based incentives mechanism yields reasonable results.

TAXONOMY: -

We take into account emerging machine learning techniques, networking technology, communication technologies, and important enablers.

Edge intelligence, hemimorphic encryption, blockchain, network slicing, artificial intelligence, photonics-based cognitive radio, and space-air-ground integrated networks are the main components that enable 6G wireless systems. While network slicing was suggested as a crucial networking technology enabler for 5G, its actual implementation is anticipated for 6G.

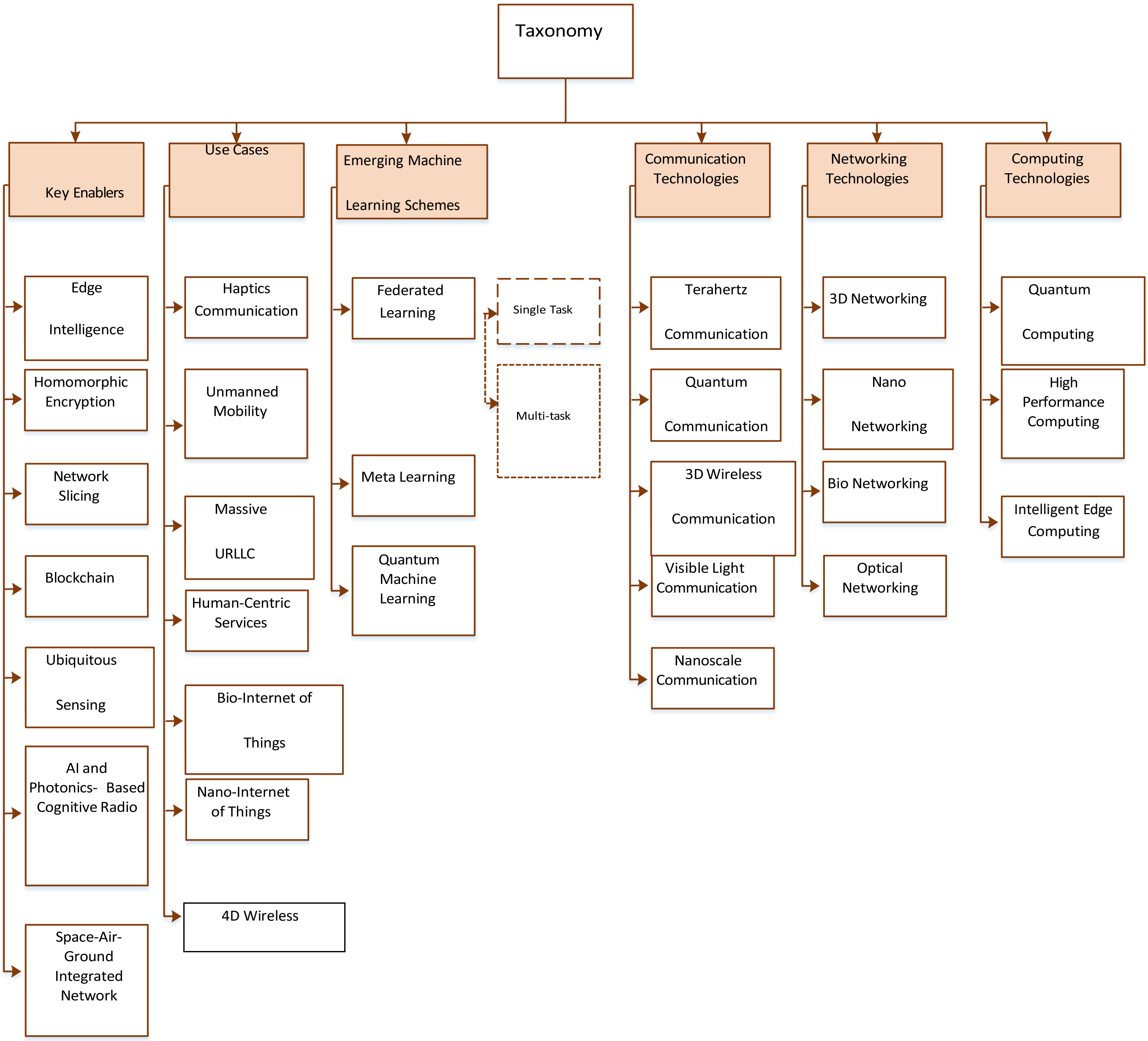

Figure 4: Taxonomy of 6G wireless systems.

AI and ML Technologies: An Overview

The quality of the upcoming wireless network can be enhanced by the scalable and potent forthcoming AI and ML technologies. The combination of mobile computing and big data has given rise to a new field of study called mobile big data (MBD), which presents significant issues in terms of source, analytics, applications, characteristics, and security. The fact that AI and ML are data-driven is one of their main advantages. It is said that creating precise mathematical models for the majority of scenarios in 5G networks is difficult. Instead of using pre-established set rules, AI and ML techniques learn features from huge amounts of data, which improves network efficiency and latency. Furthermore, when next-generation wireless networks develop, they can become complicated systems with diverse service requirements for various networks and applications. AI and ML algorithms that are predictive and adaptable can create intelligent, self-aware networks. Both feed-forward and recurrent ANNs can process the huge amounts of data that are transmitted between the device and server, according to the taxonomy of ANNs.

Because AI and ML are so powerful, they may be used to different layers of networks. Apart from large data, the three most important uses of AI and ML approaches are resource allocation, proactive caching, and adaptive BS. The future wireless ultra-dense.

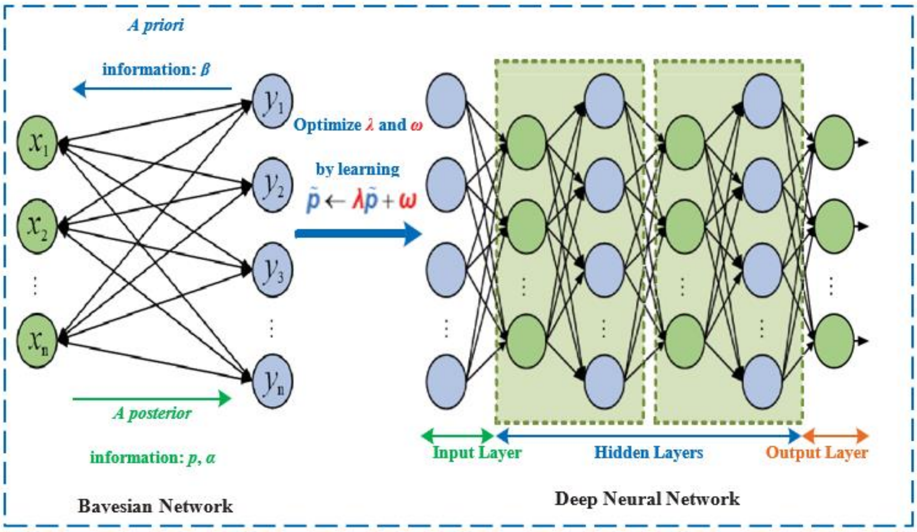

Fig. 5 DL-assisted Bayesian optimum estimators for communications at the physical layer

Both data traffic and energy consumption are increased by the network. Energy efficiency can be increased by using AI and ML techniques to provide more effective scheduling and allocation. Wireless network physical layer optimization is another use for machine learning techniques. The greater needs of next-generation wireless systems cannot be addressed by the traditional model-based approaches, which are unable to manage some complex and unknown channels. The decoding and detecting modules of the existing BB system can be redesigned by leveraging the potential of machine learning.

Physical Layer Applications

Spectral and energy efficiency needs will rise beyond 5G because of the rapid expansion of wireless communications. Unlike 5G, the new era's physical layer will only get more complex, presenting a host of brand-new difficulties. First of all, a communication system is too complex and has too many real-world flaws to be accurately modeled by a mathematical model. Second, cooperation between various physical layer blocks is required to remove barriers and attain global optimality. Third, new techniques for implementing the algorithms are needed to make them more realistic due to the sharply rising hardware complexity needed to handle novel performance difficulties.

KEY 6G TECHNOLOGIES

We have an attractive roadmap for future communications systems in the form of the ambitious 6G ambition. The meaning of the communication system will be further developed to actualize intelligent services that combine computing, sensing, and communication with security assurance, based on utilizing all available spectra and offering users worldwide coverage. In this sense, the previously indicated 6G concept cannot be supported by the essential 5G technology. Although numerous studies have been conducted on prospective 6G essential technologies, current systems are not up to par with the fast-rising demand for 6G data services. The final undiscovered spectrum gap between the optical and mmWave frequency ranges is THz (0.1–3 THz). substantial frequency, wide bandwidth, substantial path loss, strong molecule absorption, a lot of diffuse dispersion, and an incredibly narrow beam are the characteristics of THz. Because of its strong support for ultra-high data rate services, THz is considered one of the most promising technologies for 6G, even though actual applications are still some way off.

A. New Spectrum

1) THz: By 2024, it's expected that mobile data traffic will have increased five times. According to the earlier mentioned 6G vision, there is a growing need for high data rate transmission and low latency services due to the quick expansion of video services and the introduction of new applications like VR/AR, autonomous driving, and IoTs. The majority of current 5G solutions are limited to average rates of up to 1 Gbps and are trapped in the mmWave spectrum. overcoming issues with non-negligible spectrum congestion, 5G communication,

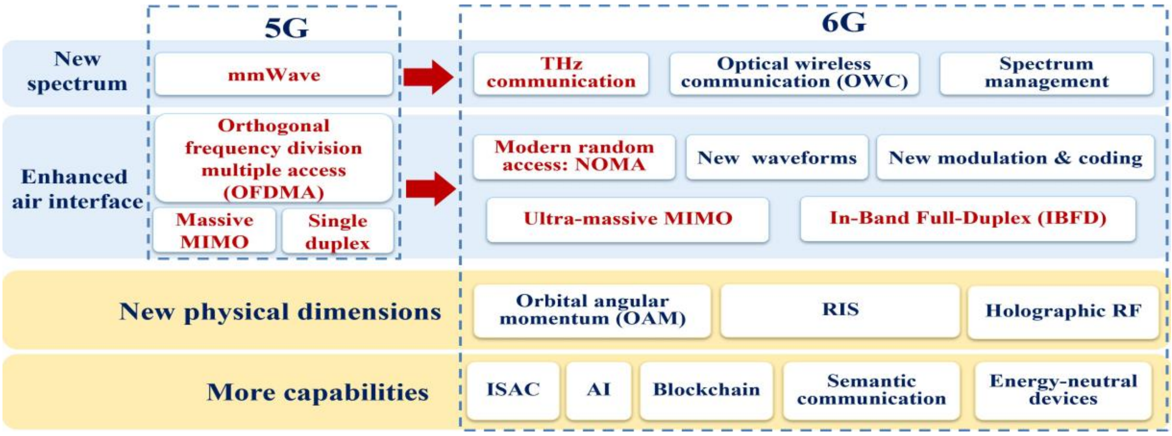

Fig. 6. Potential 6G key technologies.

2) Novel Channel Research: The four steps of traditional channel research are typically channel measurement, channel modeling, channel characteristic analysis, and channel parameter estimation. There are various drawbacks to this passive method of channel recognition. The measurement of the channel requires a lot of labor, money, and time. Furthermore, not all frequency ranges or scenarios can ever be covered by channel measurements in practice. The estimation of the channel parameter is further complicated by the substantial volume of data and the high computational complexity. Analyzing the channel characteristics is limited to known circumstances and frequencies.

3) Space channel capacity: The wireless propagation channel modeling theory and antenna theory link these two ideas. In particular, the wireless propagation channel connects the information theory with the EM theory since it originates from antennas and uses EM waves to carry information. Figure 12 illustrates how these traditional views relate to one another. Since electromagnetic waves (EM waves) are the source of the channel capacity constraint, EM theory is a crucial part of wireless communication systems. However, academics studying wireless communication have not given significant attention to information theory research. It should be noted that while 6G's core technologies present opportunities and challenges for the fusion of various theories, they also confront the limitations of individual theories. 6G must achieve continuous full-space CSI in order to meet new technical criteria. The near-field range is expanding with the introduction of 6G new antenna technology due to the growth in antenna size and number of units. For instance, short-wave communication antennas can reach tens of meters in size, and they are inextricably linked to their communication environment. Furthermore, when signal sources tend to shift from discrete to continuous, the antenna's unit spacing decreases, putting additional demands on how channels are represented. The number of users of the 6G wireless communication network is expected to increase as it grows from local terrestrial coverage to global space-air-ground-sea integrated network coverage. In order to inform generalized antenna design and the creation of continuous full-space wireless channel maps, 6G wireless communication networks exhibit a trend of evolution from discrete space to continuous full space. To that end, CSI at any point in continuous full space must be obtained, and channel capacity must be calculated.

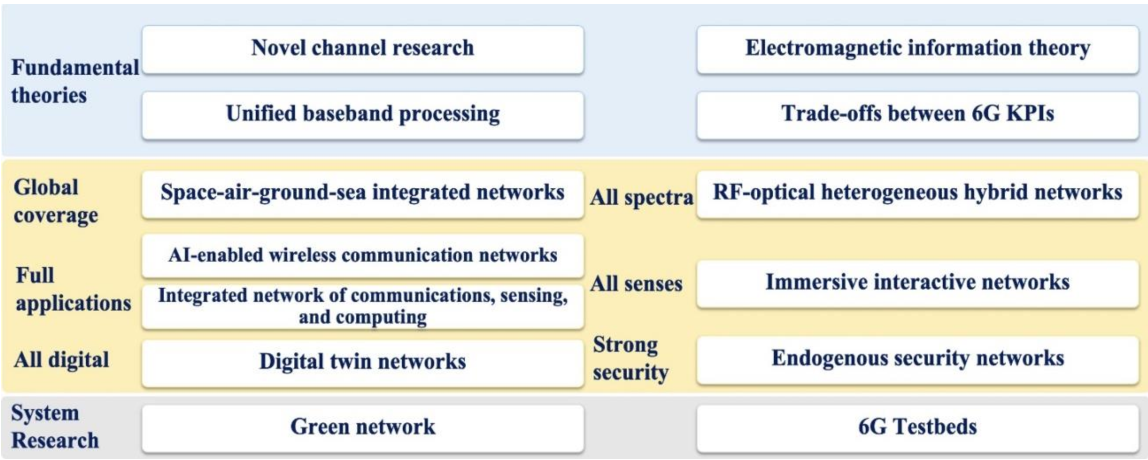

Fig 7 Challenges and Future Research Directions for 6G.

CONCLUSIONS: -

To meet the upcoming challenges posed by the sharp rise in wireless data traffic, industry, and academic collaboration has begun to design the next generation of wireless communication systems, or 6G, during the global deployment of 5G networks. Along with a host of new services, 6G technology enables bitrates of up to Tbps with a latency of less than 1ms. To promote future 6G in the following areas: energy efficiency, intelligence, spectral efficiency, security, secrecy, privacy, affordability, and customization, this study began by outlining a vision and the essential elements. Subsequently, we talked about the various possible obstacles linked to 6G technology and the possible ways to support future 6G. International research initiatives that seek to develop a vision for future 6G round out this work. Examine the 5G and 6G wireless technologies and create a chart outlining the key distinctions between them. Lastly, introduces the 7G wireless technology, which can operate at higher frequencies and offer significantly more capacity and reduced connection latency. The seventh generation of wireless technology, or 7G, will focus primarily on research on mobile communication networks. Future research on the 7G technology must focus on identifying its advantages over existing wireless systems.

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