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Advancement in 6G: A Comprehensive Review of Technologies, Applications, and Challenges

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Abstract:- As the world becomes increasingly connected, the demand for faster and more reliable wireless communication continues to grow. With the successful deployment of 5G networks, attention has shifted towards the development of the next-generation wireless technology, known as 6G. This paper provides a comprehensive review of the advancements and key features of 6G, focusing on its potential to revolutionize various sectors, including telecommunications, healthcare, transportation, and beyond. We delve into the anticipated technical requirements, challenges, and potential solutions for 6G implementation. Furthermore, we explore the envisioned applications, architectural considerations, and the expected impact on society. This review paper aims to provide a holistic overview of the emerging 6G technology landscape, shedding light on the path forward.

Keywords:- *6G, AI, Latency, Spectrum, MIMO, QKD, Iot.*

I. INTRODUCTION

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 (AI), 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.

Literally, every single improvement in network connectivity that 5G will bring to the end-user will get further perfected with 6G. Whether it’s smart cities, farms or factories, and robotics, 6G will take it to the next level. Much of that will be facilitated by 5G-Advanced, the next standard enhancements for 5G. It comes with improved efficiency and extended capabilities and improved user experience.

Looking at the past, it’s clear that each generation optimizes the use cases of the previous generation and introduces new ones. This will continue to be the case. 6G will build on top of 5G in terms of many of the technological and use case aspects, driving their adoption at scale through optimization and cost-reduction. At the same time, 6G will enable new use cases.

We will connect the physical world to our own human world, thanks to the massive scale deployment of sensors and artificial intelligence and machine learning (AI/ML) with digital twin models and real-time synchronous updates. These digital twin models are crucial because they allow us to analyse what's happening in the physical world, simulate possible outcomes, anticipate needs and then take productive actions back into the physical world.

Digital twin models are already being used with 5G. With 6G, we can expect these technologies to operate at a much larger scale. Digital twins will be found not only in factories but also in wide area networks of cities and even digital twins of humans which will have a major impact on the network architecture.

While the smartphone will remain a key device in the 6G era, new man-machine interfaces will make it more convenient to consume and control information. Touchscreen typing will gradually get replaced by gesture and voice control. Devices will come embedded into clothing and even transform into skin patches. Healthcare will be an important benefactor as wearables facilitate 24/7 monitoring of vital parameters.

The maturing of AI and machine vision and their capacity to recognize people and objects will turn wireless cameras into universal sensors. Radio and other sensing modalities like acoustics will gather information on the environment. Digital cash and keys may become the norm. We may even start relying on brain sensors to actuate machines.

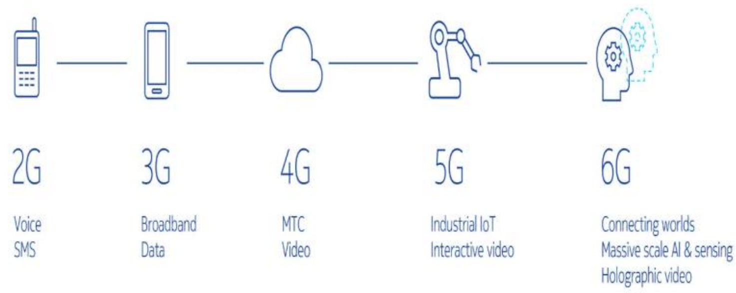

Fig. 1: Evolution of Wireless Technology

6G will also promote sustainability in a variety of ways. By enabling faster and lower cost per bit connectivity, it would be able to support data collection and closed-loop control of numerous appliances. The data can be analyzed using sophisticated tools to improve energy efficiency in industries. The advanced multi-sensory telepresence that is created with very high data rates will reduce the need for travel through the introduction of multi-modal mixed reality telepresence and remote collaboration.

6G will be significantly more energy-efficient, turning off components and scaling down capacity when the demand is lower. Energy efficiency will be a major design criterion in 6G along with the other metrics such as capacity, peak data rate, latency, and reliability.

II. OBJECTIVES

While 6G is still in the early stages of development, it represents a significant leap forward in wireless communication systems. Here's an overview of key aspects and potential objectives of 6G:

- **Data Speed and Capacity**: 6G aims to deliver unprecedented data speeds and capacity compared to its predecessors. It is projected to provide data transfer rates in the terabits per second (Tbps) range, enabling ultra-high-definition video streaming, virtual and augmented reality experiences, and advanced applications driven by artificial intelligence (AI) and machine learning (ML).
- **Low Latency:** Reducing latency, or the time it takes for data to travel from source to destination, is a crucial goal for 6G. It is expected to achieve ultra-low latency, potentially reaching the sub-millisecond range. This will be essential for latency-sensitive applications like autonomous vehicles, remote surgery, industrial automation, and immersive gaming.
- **Connectivity and Ubiquity:** 6G aims to provide seamless and ubiquitous connectivity by expanding coverage to remote areas and enhancing connectivity in challenging environments. It will support massive Internet of Things (IoT) deployments with billions of connected devices, enabling the realization of smart cities, intelligent transportation systems, and advanced industrial automation.
- **Enhanced Spectrum Utilization:** 6G is expected to utilize a wider range of frequencies, including higher frequency bands such as terahertz (THz) frequencies. These higher frequencies offer significantly greater bandwidth, enabling faster data transmission. However, they also present technical challenges due to higher propagation losses, requiring innovative technologies for efficient signal transmission and reception.
- **Intelligent and Adaptive Networks:** 6G networks will be characterized by advanced intelligence and adaptability. They will leverage AI and ML techniques to optimize network performance, manage resources efficiently, and adapt to changing user demands and environmental conditions. Self-configuring, self-healing, and self-optimizing network capabilities will be integral to 6G.
- **Novel Network Architectures:** 6G is expected to introduce new network architectures, such as cell-free networks, network slicing, and mesh networks. These architectures aim to improve coverage, capacity, and overall network performance while accommodating diverse use cases and applications.
- **Enhanced Security and Privacy:** Addressing security and privacy concerns will be a fundamental aspect of 6G. It will incorporate robust security mechanisms, including advanced encryption algorithms, authentication protocols, and privacy-enhancing technologies. As 6G networks connect a vast number of devices and handle sensitive data, ensuring secure and private communication will be crucial.
- **Sustainability and Green Initiatives:** 6G will emphasize sustainability and energy efficiency. It will strive to minimize energy consumption through innovative technologies, such as intelligent power management, energy harvesting, and eco-friendly infrastructure. By reducing the environmental impact, 6G aims to align with global sustainability goals.

It's important to note that 6G is still in the research and development phase, and its specific features and capabilities will continue to evolve as technological advancements progress. Standards bodies, research institutions, and industry stakeholders are actively working on defining the requirements and shaping the vision for 6G networks, with commercial deployments expected to occur in the 2030s.

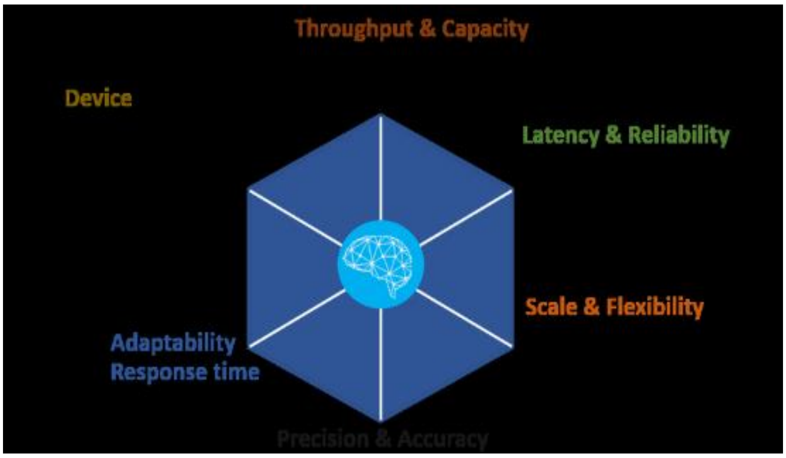

Fig. 2: Features of 6G

III. SCOPE

The scope of 6G is dynamic and subject to evolution as research and development progress, industry requirements emerge, and societal needs evolve.

- **Technical Development:** The development of 6G will involve advancements in wireless communication technologies, including new frequency bands, modulation schemes, antenna technologies, and network architectures.
- **Applications and Use Cases:** 6G will support a wide range of applications, such as augmented reality (AR), virtual reality (VR), holographic communication, autonomous systems, healthcare, and smart cities. The scope of 6G extends to various sectors that will benefit from high-speed, low-latency, and massive connectivity.
- **Network Architecture:** The design and deployment of 6G networks will involve new network architectures, such as cell-free networks, network slicing, and mesh networks. These architectures aim to improve coverage, capacity, and overall network performance.
- **Security and Privacy:** 6G will address security and privacy concerns by implementing advanced encryption algorithms, authentication protocols, and privacy-enhancing technologies. The scope includes protecting user data, securing network infrastructure, and preventing unauthorized access.
- **Standardization and Regulation:** The standardization and regulatory aspects of 6G involve global efforts by standardization bodies and organizations to establish common specifications and guidelines. The scope includes ensuring interoperability, harmonization, and adherence to legal and regulatory frameworks.
- **Societal Impact:** The scope of 6G also extends to the societal impact of wireless communication. It includes considerations of ethical implications, digital divide, employment effects, and social equality.

IV. TECHNOLOGICAL FOUNDATIONS OF 6G

The technological foundations of 6G are expected to encompass several key advancements that will shape the future of wireless communication. While 6G is still in its early stages of research and development, here are some potential technological foundations that are being explored:

- **Spectrum Exploration and Utilization**: 6G is likely to leverage new frequency bands and explore underutilized portions of the electromagnetic spectrum. This includes the use of higher frequency bands, such as millimeter-wave and terahertz frequencies, to achieve significantly higher data rates and capacity.
- **Millimeter-Wave and Terahertz Communication**: Building on the foundation laid by 5G, 6G is expected to further enhance millimeter-wave communication and explore terahertz communication. These higher-frequency bands offer even greater bandwidth and data rates, enabling ultra-fast wireless connectivity and supporting emerging applications.
- **Massive MIMO and Beamforming:** Multiple-Input Multiple-Output (MIMO) technology and beamforming techniques will continue to evolve in 6G. These technologies improve spectral efficiency, increase network capacity, and enhance coverage by utilizing large-scale antenna arrays and advanced signal processing algorithms.
- **Cell-Free Network Architecture:** 6G is likely to embrace cell-free network architectures, where traditional cell boundaries are dissolved, and access points are distributed more densely. This approach eliminates handover and interference issues, improves coverage and capacity, and enables seamless connectivity.
- **Cognitive Radio and Dynamic Spectrum Sharing**: 6G is expected to leverage cognitive radio technologies to intelligently access and share spectrum resources. Dynamic spectrum sharing techniques will enable efficient allocation of spectrum, allowing different services and devices to coexist and utilize available spectrum dynamically.
- **Artificial Intelligence and Machine Learning:** AI and ML will play a crucial role in 6G networks, enabling intelligent network management, resource allocation, and optimization. AI-powered algorithms will enhance network performance, energy efficiency, and user experience, supporting the diverse requirements of various applications and devices.
- **Quantum Communication and Computing:** 6G may incorporate advancements in quantum communication and computing, which offer enhanced security, ultra-fast processing, and novel cryptographic techniques. Quantum key distribution (QKD) and quantum-resistant algorithms may be utilized to ensure secure and private communication in 6G networks.

- **Energy Efficiency and Sustainability:** 6G will emphasize energy efficiency and sustainability. Technologies such as energy harvesting, smart power management, and green communication solutions will be integrated to reduce power consumption, minimize carbon footprint, and support sustainable development.

These technological foundations represent potential areas of focus for 6G development, but it's important to note that the field is still evolving, and new innovations and discoveries may shape the ultimate technological landscape of 6G networks. Research and standardization activities are ongoing to explore and define the precise technological foundations of 6G.

V. 6G: CELL-FREE NETWORK ARCHITECTURE

The cell-free network architecture is an innovative approach that has been proposed for 6G wireless communication systems. Unlike traditional cellular networks where communication is based on cells and base stations, cell-free networks aim to provide a more flexible, scalable, and efficient wireless connectivity paradigm. Let's explore the key aspects and benefits of the 6G cell-free network architecture:

- **Distributed Access Points (APs):** In a cell-free network, a large number of distributed access points are deployed densely throughout the coverage area. These access points, also known as APs or access nodes, are typically smaller and have lower transmit power compared to traditional base stations. They can be placed indoors, outdoors, or even on moving platforms like drones or vehicles.
- **Coordinated Signal Transmission:** In a cell-free network, multiple APs collaborate to transmit signals to user devices. This coordinated transmission, known as joint transmission or cooperative transmission, aims to mitigate interference, improve signal quality, and enhance overall system capacity. The APs coordinate their transmissions through advanced signal processing algorithms and protocols.
- **Massive MIMO:** Cell-free networks heavily rely on massive multiple-input multiple-output (MIMO) technology. Each AP is equipped with a large number of antennas, allowing for simultaneous transmission to multiple user devices. Massive MIMO enables spatial multiplexing, beamforming, and interference cancellation techniques, resulting in improved spectral efficiency and higher data rates.
- **User-Centric Approach**: Cell-free networks focus on providing a user-centric approach to wireless communication. Instead of associating users with specific cells or base stations, user devices are dynamically served by the APs that can provide the best signal quality and capacity at any given time. This approach aims to ensure better fairness, load balancing, and quality of service for individual users.
- **Spatial Resource Allocation:** In cell-free networks, spatial resource allocation is a crucial aspect. The system dynamically allocates radio resources, such as time, frequency, and power, based on the spatial demand and channel conditions. Advanced algorithms and machine learning techniques are employed to optimize the resource allocation process and maximize system performance.

Benefits of Cell-Free Network Architecture for 6G:

- **Improved Coverage and Capacity:** The dense deployment of APs in a cell-free network architecture enhances coverage, especially in areas with high user density or challenging propagation environments. The coordinated signal transmission and massive MIMO technology increase system capacity and support a large number of simultaneous connections.
- **Increased Spectral Efficiency:** The joint transmission and resource allocation techniques employed in cell-free networks improve spectral efficiency by mitigating interference and maximizing spatial reuse of radio resources. This leads to higher data rates and improved overall network performance.
- **Flexibility and Scalability:** The cell-free network architecture offers flexibility and scalability in terms of network deployment. The distributed APs can be easily added or removed, allowing for dynamic adaptation to changing user demand and traffic patterns. This flexibility facilitates the deployment of 6G networks in diverse scenarios, including urban areas, indoor environments, and remote locations.
- **Lower Latency:** The proximity of distributed APs to user devices in a cell-free network reduces signal propagation delays, resulting in lower latency. This is particularly important for latency-sensitive applications like autonomous vehicles, augmented reality, and real-time communications.
- **Energy Efficiency:** Cell-free networks have the potential to improve energy efficiency by reducing transmit power and optimizing resource allocation based on user demand. The distributed APs can also leverage energy harvesting techniques, such as solar or kinetic energy, to further enhance sustainability.

Overall, the cell-free network architecture presents an innovative and promising approach for 6G wireless communication systems, offering significant improvements in coverage, capacity, spectral efficiency, latency, and energy efficiency.

VI. KEY APPLICATIONS AND USE CASES

6G is expected to unlock a wide range of transformative applications and use cases that will revolutionize various industries and enhance user experiences. While the specific applications and use cases of 6G are still evolving, here are some potential areas where 6G is anticipated to have a significant impact:

- **Enhanced Mobile Broadband**: 6G will provide unprecedented data rates and capacity, enabling immersive experiences, high-resolution streaming, and ultra-fast downloads on mobile devices. This will enhance the quality of multimedia content, virtual reality (VR), augmented reality (AR), and gaming applications.
- **Internet of Things (IoT):** 6G will support massive connectivity and provide a scalable infrastructure for IoT devices. It will enable the deployment of large-scale IoT applications, including smart cities, smart homes, industrial

automation, connected vehicles, and smart he althcare systems, leading to improved efficiency, automation, and connectivity.

- **Holographic Communication:** 6G is expected to enable advanced holographic communication, allowing users to project realistic holograms of themselves for remote collaboration, teleconferencing, and virtual presence. This technology has the potential to transform the way people communicate and collaborate across distances.
- **Tactile Internet:** 6G aims to enable real-time, haptic communication, also known as the tactile internet. This will enable users to remotely control and interact with objects or environments, such as performing remote surgery, operating robots, and experiencing touch and physical sensations in virtual environments.
- **Autonomous Systems:** 6G will support the deployment of autonomous systems and vehicles by providing ultra-low latency, high reliability, and seamless connectivity. This includes autonomous vehicles, drones, robots, and intelligent transportation systems, enabling efficient and safe operation in various domains.
- **Smart Energy and Sustainability:** 6G can play a vital role in energy management and sustainability. It will enable smart energy grids, efficient energy distribution, and optimization, facilitating the integration of renewable energy sources. 6G can also contribute to environmental monitoring, precision agriculture, and smart resource management, reducing waste and enhancing sustainability.
- **AI-Driven Applications:** 6G will leverage the power of artificial intelligence (AI) and machine learning (ML) to enable intelligent networks, smart services, and personalized experiences. AI algorithms will be integrated into various aspects of 6G, including network optimization, context-aware applications, predictive analytics, and intelligent automation.
- **Critical Communications and Public Safety:** 6G is expected to enhance critical communication systems, providing ultra-reliable, low-latency connectivity for public safety agencies, emergency services, and disaster management. It will enable faster response times, improved situational awareness, and resilient communication in critical situations.

These are just a few examples of the potential applications and use cases of 6G. As research and development progress, new opportunities and innovative applications will continue to emerge, shaping the full potential of 6G technology.

VII. EMERGING TECHNOLOGIES & RESEARCH DIRECTIONS

The development of 6G is driven by a variety of emerging technologies and research directions that are poised to shape the future of wireless communication. These include the exploration of terahertz (THz) frequencies for ultra-high-speed communication, with ongoing research focused on understanding their unique properties and developing THz transceiver technologies. Another area of focus is the design of antennas for sub-THz and THz frequencies, where novel approaches such as metamaterials and phased arrays are being investigated to enable efficient and high-gain communication links. Intelligent Reflective Surfaces (IRS) are also gaining attention, offering the potential to enhance coverage, capacity, and energy efficiency by manipulating electromagnetic waves. Non-Orthogonal Multiple Access (NOMA) techniques are being explored to improve spectral efficiency and support massive connectivity, while full-duplex communication is being researched for doubling spectral efficiency by allowing simultaneous transmission and reception. Edge intelligence and computing are poised to enable low-latency processing and real-time decision-making at the network edge. Quantum technologies, such as quantum communication and computing, are being investigated for enhanced security and computational capabilities. Energy harvesting techniques and wireless power transfer are being explored to support sustainability and energy efficiency in 6G networks. These emerging technologies and research directions are collectively driving the evolution of 6G, opening up new possibilities and paving the way for innovative applications and services in the future.

VIII. SUMMARY & OUTLOOK

6G Wireless Communication: A Comprehensive Review of Technologies, Applications, and Challenges" provides a thorough examination of the key aspects of 6G, including its technologies, potential applications, and the challenges that need to be addressed. The paper highlights the emerging technologies that are expected to shape 6G networks, such as terahertz communication, intelligent reflective surfaces, and edge intelligence. It also explores the potential applications of 6G in various domains, including enhanced mobile broadband, IoT, holographic communication, and autonomous systems. Furthermore, the paper addresses the challenges that need to be overcome, such as spectrum exploration, network architecture design, security, and energy efficiency.

Overall, the review paper provides a comprehensive understanding of the current state of 6G research and development, shedding light on the potential technological advancements and their implications for future wireless communication. It offers valuable insights into the ongoing efforts to explore the possibilities of 6G and identifies the challenges that researchers and industry professionals need to address. With its comprehensive coverage, the paper serves as a valuable resource for researchers, practitioners, and decision-makers in the field of wireless communication.

Looking ahead, the outlook for 6G is promising, but several research and development efforts are required to transform the envisioned capabilities into practical implementations. The paper emphasizes the need for continued exploration of emerging technologies, standardization efforts, and collaboration among various stakeholders. As 6G evolves, it is expected to redefine wireless communication, enabling ground-breaking applications, enhancing user experiences, and driving innovation across industries. However, it is crucial to address the challenges associated with spectrum, network architecture, security, and energy efficiency to realize the full potential of 6G. With ongoing research and collaborative efforts, 6G is poised to shape the future of wireless communication, revolutionizing connectivity and enabling transformative applications that will benefit society as a whole.

REFERENCES

[1.] H. Nam, C. J. Lee, D. Kim, S. -K. Kim, D. Y. Lee and I. Na, "A D-Band High-Linearity Down-Conversion Mixer for 6G Wireless Communications," in IEEE Microwave and Wireless Technology Letters, vol. 33, no. 5, pp. 579-582, May 2023.

[2.] C. -X. Wang et al., "On the Road to 6G: Visions, Requirements, Key Technologies, and Testbeds," in IEEE Communications Surveys & Tutorials, vol. 25, no. 2, pp. 905-974, Secondquarter 2023.

[3.] M. Maier, A. Ebrahimzadeh, A. Beniiche and S. Rostami, "The Art of 6G (TAO 6G): how to wire Society 5.0 [Invited]," in Journal of Optical Communications and Networking, vol. 14, no. 2, pp. A101-A112, February 2022.

[4.] D. Serghiou, M. Khalily, T. W. C. Brown and R. Tafazolli, "Terahertz Channel Propagation Phenomena, Measurement Techniques and Modeling for 6G Wireless Communication Applications: A Survey, Open Challenges and Future Research Directions," in IEEE Communications Surveys & Tutorials, vol. 24, no. 4, pp. 1957-1996, Fourthquarter 2022.

[5.] F. A. Pereira de Figueiredo, "An Overview of Massive MIMO for 5G and 6G," in IEEE Latin America Transactions, vol. 20, no. 6, pp. 931-940, June 2022.

[6.] M. A. Uusitalo et al., "6G Vision, Value, Use Cases and Technologies From European 6G Flagship Project Hexa-X," in IEEE Access, vol. 9, pp. 160004-160020, 2021.

[7.] S. Seppo Yrjölä, P. Ahokangas and M. Matinmikko-Blue, "Value Creation and Capture From Technology Innovation in the 6G Era," in IEEE Access, vol. 10, pp. 16299-16319, 2022.

[8.] S. Kukliński, L. Tomaszewski, R. Kołakowski and P. Chemouil, "6G-LEGO: A framework for 6G network slices," in Journal of Communications and Networks, vol. 23, no. 6, pp. 442-453, Dec. 2021.

[9.] P. Zhang, L. Li, K. Niu, Y. Li, G. Lu and Z. Wang, "An intelligent wireless transmission toward 6G," in Intelligent and Converged Networks, vol. 2, no. 3, pp. 244-257, Sept. 2021.

[10.] K. Wang, P. Xu, C. -M. Chen, S. Kumari, M. Shojafar and M. Alazab, "Neural Architecture Search for Robust Networks in 6G-Enabled Massive IoT Domain," in IEEE Internet of Things Journal, vol. 8, no. 7, pp. 5332-5339, 1 April1, 2021.

[11.] W. Jiang, B. Han, M. A. Habibi and H. D. Schotten, "The Road Towards 6G: A Comprehensive Survey," in IEEE Open Journal of the Communications Society, vol. 2, pp. 334-366, 2021.

[12.] P. Porambage, G. Gür, D. P. M. Osorio, M. Liyanage, A. Gurtov and M. Ylianttila, "The Roadmap to 6G Security and Privacy," in IEEE Open Journal of the Communications Society, vol. 2, pp. 1094-1122, 2021.

[13.] F. Kooshki, M. A. Rahman, M. M. Mowla, A. G. Armada and A. Flizikowski, "Efficient Radio Resource Management for Future 6G Mobile Networks: A Cell-Less Approach," in IEEE Networking Letters, vol. 5, no. 2, pp. 95-99, June 2023.

[14.] https://en.wikipedia.org/wiki/6G_(network).

[15.] M. Wang, Y. Lin, Q. Tian and G. Si, "Transfer Learning Promotes 6G Wireless Communications: Recent Advances and Future Challenges," in IEEE Transactions on Reliability, vol. 70, no. 2, pp. 790-807, June 2021.

[16.] M. A. Khan et al., "Swarm of UAVs for Network Management in 6G: A Technical Review," in IEEE Transactions on Network and Service Management, vol. 20, no. 1, pp. 741-761, March 2023.

[17.] https://timesofindia.indiatimes.com/blogs/voices/introduction-to-6g-technology-how-will-india-develop-6g-network/

[18.] https://www.researchgate.net/figure/An-overview-of-6G-wireless-communication-networks_fig2_347799507

[19.] L. Xu, X. Zhou, Y. Tao, X. Yu, M. Yu and F. Khan, "AF Relaying Secrecy Performance Prediction for 6G Mobile Communication Networks in Industry 5.0," in IEEE Transactions on Industrial Informatics, vol. 18, no. 8, pp. 5485-5493, Aug. 2022.

[20.] M. P. McGarry and M. Lee, "Broadband Dielectric Properties of Integrated Circuit Packaging Materials Across the 6G Spectrum," in IEEE Transactions on Components, Packaging and Manufacturing Technology, vol. 12, no. 9, pp. 1575-1582, Sept. 2022.

[21.] C. She et al., "A Tutorial on Ultrareliable and Low-Latency Communications in 6G: Integrating Domain Knowledge Into Deep Learning," in Proceedings of the IEEE, vol. 109, no. 3, pp. 204-246, March 2021.

[22.] https://www.spiceworks.com/tech/networking/articles/what-is-6g/

[23.] https://www.techtarget.com/searchnetworking/definition/6G

[24.] L. Wang, D. Han, M. Zhang, D. Wang and Z. Zhang, "Deep Reinforcement Learning-Based Adaptive Handover Mechanism for VLC in a Hybrid 6G Network Architecture," in IEEE Access, vol. 9, pp. 87241-87250, 2021.

[25.] L. Zhu, Z. Xiao, X. -G. Xia and D. Oliver Wu, "Millimeter-Wave Communications With Non-Orthogonal Multiple Access for B5G/6G," in IEEE Access, vol. 7, pp. 116123-116132, 2019.

[26.] https://telecomtalk.info/6g-what-is-it-advantages-and-disadvantages/632346/#:~:text=Disadvantages%20of%206G&text=Additionally%2C%20the%20costs%20associated%20with,surveillance%20and%20other%20nefarious%20purposes.

[27.] Q. Qi, X. Chen, C. Zhong and Z. Zhang, "Integration of Energy, Computation and Communication in 6G Cellular Internet of Things," in IEEE Communications Letters, vol. 24, no. 6, pp. 1333-1337, June 2020, doi: 10.1109/LCOMM.2020.

[28.] https://www.spiceworks.com/tech/networking/articles/what-is-6g/

[29.] https://arxiv.org/pdf/2212.07902.pdf

[30.] 125981872.pdf.

[31.] IMT Traffic Estimates for the Years 2020 to 2030, document ITU-RM.2370-0, 2015.

[32.] K. Tekbiyik, A. Ekti, G. Kurt, and A. Gorcin, ‘‘Terahertz band communication systems: Challenges, novelties and standardization efforts,’’ Phys.Commun., vol. 35, pp. 1–18, Aug. 2019.

[33.]] S. Yamasaki, A. Yasui, T. Amemiya, K. Furusawa, S. Hara, I. Watanabe, A. Kanno, N. Sekine, Z. Gu, N. Nishiyama, A. Kasamatsu, and S. Arai, ‘‘Optically driven terahertz wave modulator using ring-shaped microstripline with GaInAs photoconductive mesa structure,’’ IEEE J. Sel. Topics Quantum Electron., vol. 23, no. 4, pp. 1–8, Jul. 2017.

[34.] C. Han and I. F. Akyildiz, ‘‘Three-dimensional end-to-end modeling and analysis for graphene-enabled terahertz band communications,’’ IEEE Trans. Veh. Technol., vol. 66, no. 7, pp. 5626–5634, Jul. 2017

[35.]] O. Blanco-Novoa, T. M. Fernandez-Carames, P. Fraga-Lamas, and M. A. Vilar-Montesinos, ‘‘A practical evaluation of commercial industrial augmented reality systems in an industry 4.0 shipyard,’’ IEEE Access, vol. 6, pp. 8201–8218, Feb. 2018.

[36.] J. M. Jacinto-Villegas, M. Satler, A. Filippeschi, M. Bergamasco, M. Ragaglia, A. Argiolas, M. Niccolini, and C. A. Avizzano, ‘‘A novel wearable haptic controller for teleoperating robotic platforms,’’ IEEE Robot. Autom. Lett., vol. 2, no. 4, pp. 2072–2079, Oct. 2017.

[37.] R. Perez-Jimenez, J. Rufo, C. Quintana, J. Rabadan, and F. J. Lopez-Hernandez, ‘‘Visible light communication systems for passenger in-flight data networking,’’ in Proc. IEEE Int. Conf. Consum. Electron. (ICCE), Las Vegas, NV, USA, Jan. 2011, pp. 445–446.

[38.] D. Iturralde, C. Azurdia-Meza, N. Krommenacker, I. Soto, Z. Ghassemlooy, and N. Becerra, ‘‘A new location system for an underground mining environment using visible light communications,’’ in Proc. 9th Int. Symp. Commun. Syst., Netw. Digit. Sign (CSNDSP), Manchester, Jul. 2014, pp. 1165–1169.

[39.] N. Lawrentschuk and D. Bolton, ‘‘Mobile phone interference with medical equipment and its clinical relevance: A systematic review,’’ Med. J. Aust., vol. 181, no. 3, pp. 154–159, Aug. 2004.

[40.] D. R. Dhatchayeny, A. Sewaiwar, S. V. Tiwari, and Y. H. Chung, ‘‘Experimental biomedical EEG signal transmission using VLC,’’ IEEE Sensors J., vol. 15, no. 10, pp. 5386–5387, Oct. 2015.

[41.] M. Song, K. Baryshnikova, A. Markvart, P. Belov, E. Nenasheva, C. Simovski, and P. Kapitanova, ‘‘Smart table based on a metasurface for wireless power transfer,’’ Phys. Rev. A, Gen. Phys. Appl., vol. 11, no. 5, pp. 1–9, May 2019.

[42.] A.-A.-A. Boulogeorgos, A. Alexiou, T. Merkle, C. Schubert, R. Elschner, A. Katsiotis, P. Stavrianos, D. Kritharidis, P.-K. Chartsias, J. Kokkoniemi, M. Juntti, J. Lehtomaki, A. Teixeira, and F. Rodrigues, ‘‘Terahertz technologies to deliver optical network quality of experience in wireless systems beyond 5G,’’ IEEE Commun. Mag., vol. 56, no. 6, pp. 144–151, Jun. 2018.

[43.] C. Han, A. O. Bicen, and I. F. Akyildiz, ‘‘Multi-ray channel modeling and wideband characterization for wireless communications in the terahertz band,’’ IEEE Trans. Wireless Commun., vol. 14, no. 5, pp. 2402–2412, May 2015.

[44.] M. Obeed, A. M. Salhab, M.-S. Alouini, and S. A. Zummo, ‘‘Survey on physical layer security in optical wireless communication systems,’’ in Proc. 7th Int. Conf. Commun. Netw. (ComNet), Hammamet, Tunisia, Nov. 2018, pp. 1–5.

[45.] S. Naser, L. Bariah, W. Jaafar, S. Muhaidat, P. C. Sofotasios, M. Al-Qutayri, and O. A. Dobre, ‘‘Optical rate-splitting multiple access for visible light communications,’’ Feb. 2020.