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ARCHITECTURE AND TECHNOLOGIES OF 6G NETWORK

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Abstract

The idea of integrating traditional terrestrial networks with emerging space, aerial, and underwater networks suggests a move towards a truly comprehensive and ubiquitous network infrastructure. This integration aims to provide seamless connectivity across diverse environments, addressing the limitations of current networks. The ultimate goal of this integration is to achieve ubiquitous coverage, ensuring that connectivity is available consistently across different geographical locations and technology platforms. Incorporating pervasive AI is highlighted as a crucial aspect. This likely involves embedding AI algorithms and capabilities throughout the network infrastructure to enhance efficiency, responsiveness, and adaptability. AI can play a key role in network management, resource optimization, and enabling advanced features for diverse applications. The mention of an enhanced network protocol stack suggests that 6G will likely introduce new or improved communication protocols to handle the complexities of integrated networks and meet the requirements of future applications. The statement emphasizes that the capabilities and requirements of future applications are driving the development of 6G. This could include applications in areas such as augmented reality, virtual reality, the Internet of Things (IoT), and other emerging technologies. The commendable focus on sustainable and socially seamless networks reflects an awareness of the importance of minimizing environmental impact and ensuring that technology benefits society as a whole. Exploring technologies such as terahertz and visible light communication can potentially contribute to achieving these goals by leveraging new communication paradigms. The integration of blockchain technology can enhance security, privacy, and trust in the network, which are essential for the success of future wireless systems. The symbiotic radio involves intelligent cooperation among different wireless systems, which optimizes resource allocation and improves overall network efficiency. The paper draws upon a comprehensive and up-to-date account of the architectural adjustments and potential technologies in the field of green 6G, along with a novel method for assessing efficacy that will foster innovation and propel wireless networking forward toward a more sustainable and efficient future.

Keywords: 6G, green networks, blockchain, Artificial Intelligence, Visible Light Communication (VLC)

I. INTRODUCTION

After commercial deployment of 5G networks, there is a growing focus on the development of 6G. This pattern of research and development for the next generation of mobile networks is not new, as previous generations have followed a similar timeline. Several countries, including Finland, the U.K., Germany, the United States, and China, have recognized the importance of 6G and have taken steps to invest in its development. The 6Genesis Flagship program in Finland, for example, is a significant initiative with substantial funding dedicated for building a complete 6G ecosystem. The involvement of different countries in 6G research indicates the global significance and potential impact of this future technology. Each country's investment in various technologies, such as quantum technology and terahertz-based networks, demonstrates the wide range of possibilities and avenues of exploration for 6G. The focus on 6G at this stage, while 5G is still in its early commercial phase, indicates the continuous drive for innovation and improvement in mobile communication technologies. It sets the stage for further research, collaboration, and exploration of new concepts and technologies that will shape the future of wireless networks and enable transformative applications and services which is described in Figure 1 [1].

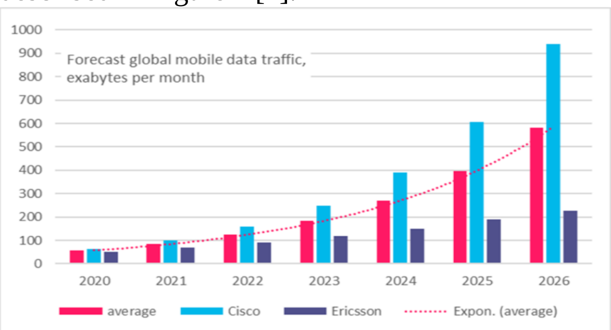

Figure 1: Global cellular data traffic forecast by ITU [3]

To address these evolving demands, 6G networks will need to achieve the following main technical objectives:

i) *Ultra-high data rate*: 6G networks are expected to support data rates of up to 1Tbps (terabits per second). This significant increase in data rate will enable seamless and high-bandwidth connectivity, supporting bandwidth-intensive applications and services.

ii) *Ultra-low latency*: The next-generation networks will aim to provide extremely low latency, ensuring near-real-time responsiveness for applications that require immediate and precise interactions. This will be crucial for applications like autonomous driving, remote robotic control, and immersive virtual reality experiences.

iii) *Ubiquitous global network coverage*: 6G networks aspire to provide ubiquitous coverage, extending connectivity to even the most remote and underserved areas. This global coverage will support seamless connectivity for users and devices anywhere in the world, enabling truly pervasive and universal access.

iv) *Trusted and intelligent connectivity*: 6G networks will emphasize the integration of trust and intelligence across the entire network infrastructure. This includes advanced security mechanisms to safeguard user data and privacy, as well as intelligent connectivity to optimize resource allocation, network management, and service provisioning.

By pursuing these technical objectives, 6G networks aim to push the boundaries of data rate, latency, coverage, and intelligence. These advancements will be critical to meet the future demands of emerging applications to enable transformative services that go beyond the capabilities of current wireless technologies. The motivation behind researching 6G networks highlights the need for improved wireless network architecture to meet future application demands [2].

the remainder of the paper is organized as section 2 presents the historical evolution of mobile communication networks which covers the timeline from concept research to commercial deployment and subsequent usage. section 2.3 elaborates on the detailed description of architectural changes of 6g considering ubiquitous 3d coverage, pervasive ai integration, and an enhanced network protocol stack. section 3 offers a brief overview of emerging technologies that may play a crucial role in 6g networks by mentioning specific technologies such as terahertz and visible light communication, new communication paradigms, blockchain, symbiotic radio, and unique 6g applications and limitations summarizes the paper followed by the conclusion and prospects in section 4.

II. ARCHITECTURES OF 6G NETWORK

The architectural changes associated with 6G can analyzed from three key dimensions:

i) *Connectivity Dimension*: This dimension focuses on the overall connectivity aspects of the network architecture. It includes advancements in wireless access technologies, network topologies, and the integration of various communication platforms such as satellite and underwater networks. The goal is to achieve seamless and ubiquitous wireless connectivity across different environments and geographies.

ii) *Intelligence Dimension*: This dimension highlights the increased intelligence and automation within the network architecture. It enables self-optimization, self-configuration, and intelligent decision-making within the network. The aim is to enhance network efficiency, adaptability, and the ability to handle complex network operations.

Sustainability Dimension: This dimension emphasizes the importance of green and sustainable network design. It involves energy-efficient solutions, the use of renewable energy sources, and the integration of energy harvesting technologies. The goal is to reduce the environmental impact of network operations and ensure long-term sustainability [3].

A. From Terrestrial to Ubiquitous 3D Coverage

To overcome the drawbacks of other generations of networks, 6G networks are envisioned to integrate non-terrestrial networks, enabling full wireless coverage in various environments. By incorporating space, air, ground, and sea communication, 6G aims to provide seamless connectivity across different domains. This integration of non-terrestrial networks has the potential to overcome the limitations of traditional terrestrial cellular infrastructure. Preliminary discussions and envisioning of Space-Air-Ground-Sea integrated communication for 6G have already taken place. This concept involves utilizing satellites for space communication, aerial platforms (such as drones and high-altitude platforms) for air communication, traditional terrestrial infrastructure for ground communication, and underwater communication systems for sea communication. The integration of these networks allows for comprehensive coverage, including remote areas, high-altitude regions, and underwater environments. The use of non-terrestrial networks in 6G expands the coverage and capabilities of the network architecture, enabling connectivity in scenarios that were previously challenging or impossible to reach. It opens up possibilities for various applications, such as remote sensing, disaster response, environmental monitoring, and maritime communications. It's important to note that the integration of non-terrestrial networks introduces new technical and operational challenges. These include managing handover and seamless connectivity between different network domains, addressing signal propagation and interference issues in space and underwater environments, and ensuring efficient coordination and resource allocation across the integrated network [4].

B. Towards Intelligent Network

Artificial intelligence (AI), particularly machine learning (ML), has gained significant attention in both industry and academia in recent years. The combination of AI and edge computing has also shown improved quality of experience and reducing costs. Edge learning performs AI computations at the network edge, opens up new possibilities for applications in areas like healthcare. The current application of AI in 5G networks is primarily focused on optimizing traditional network architecture. Since AI was not initially considered in the design of the 5G architecture, its full potential has not been fully realized in the 5G era. By integrating AI capabilities throughout the network, the 6G architecture can leverage AI algorithms and techniques to enable intelligent decision-making, adaptability, and optimization in various network functions. This will facilitate advanced features such as autonomous network management, intelligent resource allocation, dynamic network optimization, and enhanced user experience. This AI-driven approach will enable intelligence to become an intrinsic part of the 6G network, unlocking new levels of efficiency, adaptability, and performance. The initial intelligence in network entities represents a limited form of AI implementation that can make intelligent adjustments based on predefined options. However, as networks become increasingly complex and heterogeneous, with diverse service requirements and a rapidly growing number of connected devices, there is a need for a novel AI paradigm that goes beyond this initial intelligence. The vision of self-aware, self-adaptive, self-interpretive, and prescriptive networking is emerging as a requirement for future networks [5].

1] *Intelligent Radio (IR)*

The concept of Intelligent Radio (IR) goes beyond the initial intelligence implemented at the physical (PHY) layer. In the context of IR, hardware capabilities are estimated, and transceiver algorithms have the ability to dynamically configure themselves based on the available hardware information. This enables the system to optimize its performance by leveraging AI techniques. This means that as hardware evolves or diversifies, the transceiver algorithms can be adjusted and optimized accordingly, without requiring significant hardware changes. This flexibility allows for improved performance, adaptability, and future-proofing of wireless communication systems. Intelligent Radio extends the initial intelligence at the PHY layer by decoupling transceiver algorithms from hardware. This approach enhances the adaptability, performance, and evolution of wireless communication systems, leveraging AI techniques to optimize operations based on the available hardware resources [6].

2] *Real-Time Intelligent Edge (RTIE)*

Traditional centralized cloud AI, which primarily deals with static data, may not be sufficient to meet the real-time demands of these services. As a result, there is a growing need for Real-Time Intelligent Edge (RTIE) capabilities, where intelligent prediction, inference, and decision-making can be performed on live data. Collaborative research labs, such as the Berkeley RISE Lab, have been at the forefront of this research, focusing on the development of real-time AI systems that can process and analyze data in a timely manner. These efforts aim to enable intelligent interactions with the environment in real-time, allowing for applications that require immediate responses. In addition to software advancements, high-performance hardware is also a driving factor in realizing real-time AI capabilities. Specialized real-time AI processors have been designed to efficiently handle the computational demands of real-time AI processing, ensuring fast and responsive decision-making. By combining optimized hardware and software components, the goal is to enable real-time intelligent processing at the edge of the network, closer to the data source. The development of Real-Time Intelligent Edge (RTIE) capabilities is essential to meet the requirements of interactive AI-powered services, especially those that rely on real-time decision-making. Ongoing research and development efforts are focused on creating technologies, software components, and specialized hardware that can enable real-time processing, prediction, and inference on live data, enabling applications with low latency and intelligent interactions with the environment [7].

3] *Distributed AI*

Distributed AI plays a crucial role in distributed resources which enable parallel training processes that accelerate learning and enhance the reliability of inference. One prominent paradigm of distributed AI is federated learning. This approach has several advantages. First, it enables distributed learning while keeping the data at the network edge, thereby addressing privacy and security concerns associated with transmitting sensitive data to a centralized location. Second, federated learning reduces communication costs by minimizing the amount of data that needs to be transmitted. Third, it allows for personalized models and decision-making based on local data characteristics. By employing federated learning and similar distributed AI techniques, the future network can benefit from improved efficiency, reduced latency, enhanced privacy, and increased scalability. These approaches enable intelligent decision-making across distributed resources, promoting collaborative learning while respecting data privacy and security.

C. New Network Protocol Stack Architecture

The Internet protocol stack is based on TCP/IP, has been highly successful in data delivery over the past several decades. However, as the Internet faces new challenges and evolving application requirements, it has become apparent that the current architecture may not be sufficient to meet future needs. These challenges include the demand for deterministic throughput and latency, among others. While protocols like QUIC (Quick UDP Internet Connections) have been developed as enhancements to TCP/IP, they are more like patch-like solutions and do not completely address the inherent shortcomings of the Internet. They add complexity to the network and do not provide a comprehensive solution to the evolving requirements. This rethinking involves considering new approaches to protocol design and architecture to better accommodate futuristic application delivery constraints. Researchers and industry experts are actively exploring alternative protocols, architectures, and paradigms to enable the next generation of Internet services by incorporating application-specific metadata and commands into the IP protocol, the network can become more aware of the requirements and expectations of the applications it serves, leading to more efficient and effective network operations [8].

The traditional separation between the network layer and transport layer is being reconsidered, and a cross-layer transport layer has been advocated in some research. The cross-layer transport layer merges the functionalities of the network and transport layers, allowing them to work together more closely. This integration enables more effective congestion control, as the transport layer can make decisions based on a broader understanding of the network conditions. One of the advantages of the cross-layer design is the ability to break the strict end-to-end principle that has been a fundamental principle of the Internet. This allows for advanced network functions, such as flow multiplexing, where multiple flows can be combined and transmitted together, improving overall network efficiency and resource utilization. By considering these factors at the transport layer, it becomes possible to optimize the delivery of different types of data and ensure precise synchronization for applications that require it. So, the cross-layer transport layer design aims to provide more efficient and adaptive transport protocols that can better meet the diverse requirements of future applications and effectively utilize the available network resources.

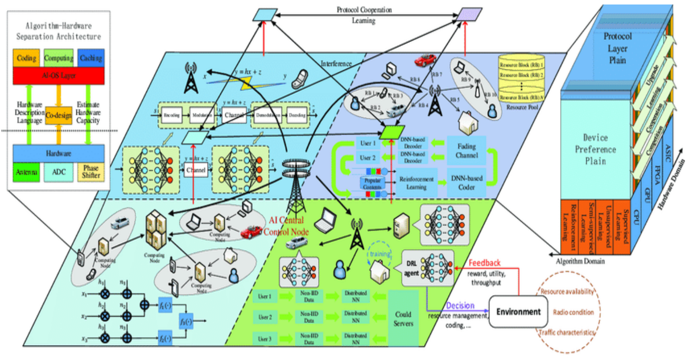

Figure 4: Architecture of Green 6G

III. METHODOLOGY

To assess the viability and implications of the Green 6G network on ubiquitous communication, this study uses a methodical methodology. A comprehensive literature review is conducted to gather up-to-date information on 6G technology, its benefits for green communication, and its possible applications.

A. Fundamental Techniques

1] *Flexible and Intelligent Materials*

Traditional semiconductor materials like silicon have certain limitations when it comes to high-frequency and high-temperature applications in ultrahigh-speed communication systems. As a result, novel materials came into existence to overcome these limitations and design next-generation communication devices with improved performance. Such materials can be listed as follows:

i) *Gallium Nitride (GaN)*: It has excellent high-frequency characteristics, making it suitable for applications in wireless communication systems operating at higher frequencies. It offers higher electron mobility and can handle higher power levels, resulting in improved efficiency and higher data rates.

ii) *Indium Phosphide (InP)*: It is another material that has gained attention for its superior high-frequency properties. InP-based devices have been used in various communication applications, including optical communications, due to their excellent electron mobility and high electron saturation velocity.

iii) *Silicon Germanium (SiGe):* It is a semiconductor material that combines silicon and germanium. It offers higher carrier mobility compared to pure silicon, enabling faster transistor switching speeds. SiGe is often used in high-speed communication devices, such as wireless transceivers, to improve their performance [9].

2] *Energy Harvesting and Management*

As we move towards 6G, where communication distances are expected to be shorter, energy-efficient communication technologies will become crucial. Efforts have been underway to address these energy challenges, and one such technology is symbiotic radio (SR). This approach combines the benefits of passive backscatter communication with active RF transmission. This enables battery-free communication, as devices can scavenge energy from ambient sources and use it to power their operations. By leveraging ambient RF signals, ambient backscatter communication can significantly reduce the energy consumption of communication devices. Smart energy management is another promising mechanism for improving energy efficiency in communication systems. The goal of smart energy management is to dynamically optimize the balance between energy demand and supply. This involves monitoring and adapting to the energy requirements of communication devices, considering factors such as data traffic, network conditions, and available energy sources. By intelligently managing energy resources, such as batteries, renewable energy harvesting technologies, and power grid connectivity, smart energy management techniques can ensure that communication devices operate efficiently while minimizing energy consumption and waste. The energy-efficient communication technologies are crucial for addressing the energy challenges posed by AI processing and the growing number of IoT devices. Symbiotic radio, including techniques like ambient backscatter communication, and smart energy management mechanisms offer potential solutions to improve energy efficiency, enable battery-free communication, and dynamically optimize the energy balance in future communication systems like 6G [10].

3] *Blockchain for Decentralized Security*

The decentralized, tamper-resistant, and anonymous nature of blockchain technology makes it suitable for various applications. It was made by FCC Commissioner Jessica Rosenworcel during the 2018 Mobile World Congress Americas (MWCA). Some potential use cases of blockchain in wireless networks include:

i) *Identity Management:* Blockchain can provide a secure and decentralized system for managing user identities, allowing for more reliable authentication and authorization processes.
ii) *Internet of Things (IoT)*: Blockchain can facilitate secure and transparent communication between IoT devices, enabling efficient data sharing and automation without the need for central control.
iii) *Network Security*: The decentralized nature of blockchain can enhance network security by mitigating the risk of single points of failure and providing an immutable record of network activities.

Micropayments and Smart Contracts: Blockchain-based micropayments can enable new business models in wireless networks, allowing for seamless and secure transactions between users and service providers. Smart contracts can automate and enforce the terms of agreements in a decentralized manner [11].

B. Spectrum Communication Techniques

To achieve higher data rates and accommodate the requirements of 6G, operations at higher frequencies become inevitable. This is because higher frequencies offer wider available spectrum and larger bandwidth, which are essential for achieving the target of Tbps (Terabits per second) aggregated bit rates.

Both terahertz and visible light spectrums offer the potential for achieving the Tbps data rates envisioned for 6G. The technical challenges associated with utilizing these spectrums are significant in terms of exploiting their potential for practical implementation in future communication systems.

1] *Visible Light Communication*

Optical Wireless Communications (OWC) is considered as a complementary technology to RF-based mobile communications, and its spectrum includes the infrared, visible light, and ultraviolet ranges. Among these, the visible light spectrum (430-790 THz) holds great premises for OWC with widespread adoption of light-emitting diodes (LEDs) for illumination purposes. One of the significant advantages of LEDs, distinguishing them from older illumination technologies, is their ability to switch rapidly between different light intensity levels. This property allows data to be encoded in the emitted light in various ways, enabling data transmission through intensity modulation techniques. By modulating the intensity of the light emitted by

LEDs, it becomes possible to transmit information, such as digital data or audiovisual content, wirelessly LED-based OWC systems offer several benefits. They can provide high data rates, especially in short-range communication scenarios, such as indoor environments. Visible light communication (VLC) systems utilizing LEDs can leverage existing lighting infrastructure, making them cost-effective and easily deployable. In addition to intensity modulation, other modulation techniques, including color modulation and polarization modulation, can also be employed in OWC systems to further enhance their performance and increase data transmission capacity. Multiple-input multiple-output (MIMO) configurations can be utilized as well to improve the robustness and reliability of OWC systems. the visible light spectrum, with its technological advancements and the widespread use of LEDs, offers significant potential for Optical Wireless Communications. LEDs' ability to switch rapidly between light intensity levels allows for various encoding methods, enabling high-speed data transmission through light. As a complementary technology to RF-based communications, OWC using the visible light spectrum can provide benefits in terms of data rates, cost-effectiveness, and immunity to electromagnetic interference. VLC takes full advantage of LEDs for both illumination and high-speed data communication, offering several attractive benefits over classical radio communication in certain scenarios [12].

VLC offers several advantages over classical radio communication for short-range links. These advantages include the availability of ultra-high bandwidth, unlicensed spectrum usage, enhanced information transmission security, reduced inter-cell interference, cost-effective deployment using existing illumination sources, and immunity to electromagnetic interference. VLC is particularly well-suited for applications that require high-speed data communication, security, cost-efficiency, and low electromagnetic radiation. The achievable data rate in visible light communication (VLC) is heavily influenced by the lighting technology utilized. Different lighting technologies offer varying levels of performance in terms of data rate capabilities.

Some of the examples of data rates achievable with different lighting technologies in VLC are as follows:

i) *Phosphor-coated blue LED*: VLC based on phosphor-coated blue LEDs can achieve data rates of up to 1 Gbps (Gigabits per second). These LEDs emit blue light, and the phosphor coating is used to convert a portion of the blue light into other colors, such as green and red, to achieve full-color illumination.

ii) *RGB LED*: VLC systems based on RGB (Red-Green-Blue) LEDs, which directly emit light in three primary colors, can achieve multi-Gbps data rates. By independently controlling the intensity of each color, higher data rates can be achieved compared to phosphor-coated LEDs.

iii) *Micro-LED*: Micro-LED is an advanced LED technology that consists of an array of miniature LEDs, typically with pixel sizes of less than 100 micrometers. Micro-LED has demonstrated impressive performance in the lab, achieving data rates of more than 10 Gbps. The small size of micro-LEDs enables high spatial resolution and allows for densely packed arrays, enabling higher data rates.

As LED technology continues to improve in terms of luminous efficiency, lifespan, and modulation capabilities, and with advancements in related technologies such as digital modulation techniques, VLC is expected to reach even higher data rates in the 6G era. Data rates in the range of hundreds of Gbps, or even Terabits per second (Tbps), are anticipated as VLC progresses. Achieving these high data rates are also dependent on various factors such as the modulation schemes, signal processing techniques, channel conditions, and the capabilities of the receiver equipment. Continued research and development in VLC technology will play a crucial role in unlocking its full potential for ultra-high-speed data transmission in the future [13].

2] *THz Communication*

The THz band falls between the microwave and optical bands and it offers several compelling reasons for its utilization which are as follows:

i) *High data rates*: THz communication provides a significantly larger bandwidth compared to the 9 GHz bandwidth available in the mmWave band. This abundance of spectrum resources enables the transmission of vast amounts of data, facilitating ultra-high-speed wireless communication.

ii) *Secure communication*: THz waves exhibit narrow beams and short pulse durations, which can significantly limit the probability of eavesdropping. The focused nature of THz beams makes it difficult for unauthorized parties to intercept the signal, enhancing the security of THz communication systems. This characteristic makes THz waves particularly attractive for applications that require secure and private communication.

THz wireless communication technology demonstrate significant progress in overcoming challenges and pushing the boundaries of high-speed wireless communication. Several key aspects that require efficient and reliable THz wireless communication systems is discussed below in details:

i) *Transistor and Hardware Materials:* To achieve high-frequency characteristics required for THz communication, the development of transistors and hardware materials is essential. Graphene, with its unique properties such as high thermal and electrical conductivities and plasmonic effects, holds great potential for hardware design in the THz frequency range. Further research is needed to explore and optimize the use of graphene and other materials for THz communication systems.

ii) *Beamforming and Scanning Algorithms*: Robust beamforming and scanning algorithms are vital for directing and focusing THz signals in desired directions. Hybrid beamforming approaches, which combine analog and digital beamforming techniques, show promise in achieving efficient and adaptive beamforming in THz systems. Research efforts should continue to refine and develop beamforming and scanning algorithms tailored to THz communication [14].

iii) *Low-Complexity, Low-Power Hardware Circuits*: THz communication systems demand low-complexity and low-power hardware circuits to address the challenges associated with high-frequency operation. Developing efficient circuit architectures, signal processing techniques, and power management strategies are crucial to minimize complexity and power consumption in THz hardware designs.

iv) *Channel and Noise Modeling*: Establishing accurate channel models for THz communication is a challenging task. THz waves are susceptible to various propagation effects and environmental conditions. Mixture models, which combine multiple channel models, can be a potential solution to capture the complex THz channel characteristics accurately. Similarly, accurate noise modeling is necessary to understand and mitigate noise effects in THz communication systems.

v) *Energy-Efficient Modulation Schemes and Low-Density Channel Codes*: Energy efficiency is a critical consideration for THz communication, especially given the high data rates and bandwidths involved. Developing modulation schemes and channel coding techniques that are energy-efficient and robust in THz channels is essential. Low-density channel codes, such as LDPC (Low-Density Parity-Check) codes, are known for their excellent performance and low decoding complexity, making them a suitable choice for THz communication systems.

vi) *Ultra-Massive MIMO Systems*: Ultra-massive MIMO (Multiple-Input Multiple-Output) systems, which utilize a massive number of antennas, can significantly enhance the capacity and performance of THz communication networks. Nano antennas, designed to operate at THz frequencies, will play a crucial role in implementing ultra-massive MIMO systems in THz communication [15].

vii) *Synchronization Schemes*: Accurate synchronization is vital for efficient THz communication systems. Developing powerful synchronization schemes that can handle the challenges of THz frequencies, including short wavelengths and high data rates, is necessary for reliable communication.

The parameters of THz and VLC can be compared as follows in below Table 1.

Table 1: Comparison of THz and VLC

Sl. No.	Parameter	THz	VLC
1	Data Rate	100 Gbps	10 Gbps
2	Transmission Energy	High	Moderate
3	Spectrum Precision	Licensed	Unlicensed
4	Bandwidth	100 GHz	100 THz
5	Tariff	High	Low
6	Cell Interference	High	Low
7	Transmission Rate	Non- Line of Sight	Line of Sight

C. NEW COMMUNICATION PARADIGM

1- *Quantum Communication*

Quantum communication (QC) is a paradigm that offers unconditional security. It differs from classical binary-based communication in terms of the ability to detect eavesdropping on-site, and providing a higher level of security. Here are some key points about quantum communication:

i) *Unconditional Security*: One of the most significant advantages of quantum communication is its unconditional security. The properties of quantum states allow for the detection of any attempt to intercept or eavesdrop on the transmitted information. Any tampering with the quantum state during transmission would be detectable, ensuring the security of the communication.

ii) *Superposition and Data Rates*: The superposition nature of qubits, the fundamental units of quantum information, allows for potential improvements in data rates compared to classical communication systems. Quantum superposition enables the simultaneous encoding of multiple states, leading to higher information capacity and potentially higher data transfer rates [16].

Branches of Quantum Communication: Quantum communication encompasses various branches such as:

2- *Molecular Communication*

In such cases, molecular communications (MC) offer a potential solution by leveraging biochemical signals to transfer information. We have listed some of the key points about molecular communications:

i) *Biochemical Signals*: In molecular communications, information is encoded and transmitted using biochemical signals instead of electromagnetic waves. These biochemical signals are typically composed of small particles, such as lipid vesicles, proteins, or other molecules, which can range in size from a few nanometers to a few micrometers. These particles propagate through aqueous or gaseous mediums, allowing for communication in specific environments.

ii) *Communication Principles*: Molecular communication systems rely on various mechanisms to encode and transmit information. Diffusion is one of the primaries means of signal propagation in MC, where molecules or particles move from higher to lower concentration regions, carrying encoded information. Other mechanisms, such as active transport or chemotaxis, can also be employed to control the movement and behavior of particles for communication purposes [17].

Molecular communications find potential applications in environments where traditional electromagnetic-based communication is challenging or not feasible. One prominent example is nanonetworks inside the human body, where MC can be utilized for targeted drug delivery, monitoring of biological processes, or communication between nanoscale devices. Other applications include environmental monitoring, chemical sensing, and synthetic biology. There are several challenges associated with molecular communications. Designing reliable and efficient encoding schemes, modulation techniques, and decoding algorithms for biochemical signals are areas of active research. Additionally, understanding and modeling the complex interactions between particles, diffusion dynamics, and noise sources in the communication medium are key challenges in realizing practical molecular communication systems. Molecular communications offer a unique approach to communication in environments where traditional electromagnetic-based methods may not be suitable. Ongoing research aims to advance the understanding and development of molecular communication principles, techniques, and applications to harness the potential of this emerging communication paradigm [18].

Several advantages of the molecular communication (MC) over the traditional radio communication are listed below:

i) *Nanoscale Compatibility*: At the nanoscale dimension, electromagnetic communication faces limitations due to the size of antennas relative to the electromagnetic wavelength. In contrast, MC signals are biocompatible and can propagate through biological environments without the need for large-scale antennas.

ii) *Energy Efficiency*: MC signals consume less energy which is beneficial for microscale applications, where power resources may be limited. The low energy requirements of MC signals make them well-suited for nanonetworks and other energy-constrained environments.

iii) *Mobile MC*: MC is highly dynamic, which has led to the exploration of mobile MC systems. Mobile carriers, such as particles or molecules, can be utilized to enhance network implementation and increase data transfer rates. This opens up possibilities for mobile MC applications and communication in dynamic environments [19].

iv) *Interface and Security Challenges*: As MC systems evolve and interface with the Internet and mobile networks, there are two significant challenges to address. The first challenge involves establishing interfaces between the electrical domain (traditional communication networks) and the chemical domain (MC systems). The second challenge is ensuring security in MC systems, as information is encoded and transmitted using biochemical signals. Developing secure and reliable interfaces, as well as robust security assurance methods, are important considerations for the integration of MC with existing communication infrastructure.

Hence, molecular communication shows promise in both micro and macro scale applications, offering advantages in terms of compatibility, energy efficiency, resilience in harsh environments, and potential for mobile communication. Recent development works are focused on addressing the challenges and realizing the full potential of MC systems in various domains [20]-[28].

Upgraded and new technologies will be included to enable new use cases and applications. This section demonstrates the intended applications that will be used after 6G networks are deployed. One unique feature of the 6G standard is its broad range of application situations.

D. UNIQUE 6G APPLICATIONS AND LIMITATIONS

Completely Sensitive Virtual Sensing and Truth: Sixth-generation wireless networks (6G) will make it possible to build fully sensorial digital environments by sending several sense modalities—including touch, smell, sight, and sound—over the internet. This will open up new avenues for social interaction, education, and entertainment applications.

- Industrial Network: 6G will help the industrial internet grow by enabling real-time industrial automation control and decision-making. New levels of production and manufacturing efficiency, accuracy, and safety will be made possible by this. Space Travel: 6G will enable new opportunities for space travel, with the ability to communicate with satellites and other space-based assets in real-time, with low latency and high reliability. This will enable new applications in space exploration, satellite communications, and space-based scientific research.
- Space research: 6G will open up new possibilities for space travel by enabling real-time, highly reliable, low-latency communication with satellites and other space-based assets.
- Fully autonomous vehicles: 6G will enable the development of these vehicles, which will have low latency, highly reliable communication, and sophisticated sensing capabilities.
- Precision farming: With its sophisticated sensing capabilities, 6G will enable farmers to monitor crops and soil conditions in real time, increasing crop yields and decreasing waste.
- Graphical Verticals and the Community: With the help of 6G, holographic communication will be possible, enabling the development of three-dimensional virtual depictions of people, things, and

settings. New applications in teleconferencing, entertainment, learning, and social interaction will be made possible by this. Tactile/Haptic Internet: 6G will support the development of the tactile internet, allowing for transmitting touch sensations over the internet. This will enable new applications in virtual and augmented reality, gaming, and remote control of robotic systems.

- Smart cities: 6G will help create these enhanced sensing and communication cities, opening up new applications like public safety, traffic control, and environmental monitoring. Remote surgery: 6G will enable remote surgery with ultra-reliable low-latency communication and advanced sensing capabilities, allowing medical professionals to perform surgeries from a distance.

The researcher only lists a few of 6G's limitations here to comply with research standards, albeit there are many. Among the study's drawbacks are its complexity, expensive cost, and ease of usage. Furthermore, several concerns are raised about compatibility, privacy, and usage; last but not least, the detrimental effects of high-frequency radiation on human health are among the primary drawbacks of 6G technology.

IV. CONCLUSION AND FUTURE PROSPECTIVES

The exponential growth of wireless data and the proliferation of smart devices create the need for the next wireless evolution. The evolution from 1G to 5G provides valuable context and insights into the development trend of 6G. The pervasive use of AI to enable truly intelligent connections enhances the network's performance and adaptability. The enhanced network protocol stack framework ensures efficient and optimized communication. Exploring emerging technologies is vital as it sheds light on potential advancements in data rates and the seamless society concept. THz communication and VLC (Visible Light Communication) are promising spectrum technologies that can significantly improve data rates. Molecular and quantum communication paradigms represent new communication approaches that can revolutionize wireless connectivity. The innovations in fundamental technologies like blockchain, flexible and intelligent materials, and ambient backscatter communication contribute to the development of green 6G networks. Researchers provide a comprehensive survey in this work that could be useful for future research on green 6G communications. A thorough understanding of the network of the future is guaranteed by its development, shift in the architectural paradigm, emerging technologies, and fundamental breakthroughs. It will promote further research and the long-term sustainability of wireless networks. In addition to discussing possible applications and network technologies, this document describes the additional features of 6G. The survey is made more worthwhile by comparing the VLC and THz. Our research focuses on several applications and constraints, offering a concise overview of future technological advancements.

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COVER LETTER

Title of the manuscript: Architecture and Technologies of 6G Network
Abstract The idea of integrating traditional terrestrial networks with emerging space, aerial, and underwater networks suggests a move towards a truly comprehensive and ubiquitous network infrastructure. This integration aims to provide seamless connectivity across diverse environments, addressing the limitations of current networks. The ultimate goal of this integration is to achieve ubiquitous coverage, ensuring that connectivity is available consistently across different geographical locations and technology platforms. Incorporating pervasive AI is highlighted as a crucial aspect. This likely involves embedding AI algorithms and capabilities throughout the network infrastructure to enhance efficiency, responsiveness, and adaptability. AI can play a key role in network management, resource optimization, and enabling advanced features for diverse applications. The mention of an enhanced network protocol stack suggests that 6G will likely introduce new or improved communication protocols to handle the complexities of integrated networks and meet the requirements of future applications. The statement emphasizes that the capabilities and requirements of future applications are driving the development of 6G. This could include applications in areas such as augmented reality, virtual reality, the Internet of Things (IoT), and other emerging technologies. The commendable focus on sustainable and socially seamless networks reflects an awareness of the importance of minimizing environmental impact and ensuring that technology benefits society as a whole. Exploring technologies such as terahertz and visible light communication can potentially contribute to achieving these goals by leveraging new communication paradigms. The integration of blockchain technology can enhance security, privacy, and trust in the network, which are essential for the success of future wireless systems. The symbiotic radio involves intelligent cooperation among different wireless systems, which optimizes resource allocation and improves overall network efficiency. The paper draws upon a comprehensive and up-to-date account of the architectural adjustments and potential technologies in the field of green 6G, along with a novel method for assessing efficacy that will foster innovation and propel wireless networking forward toward a more sustainable and efficient future.
Keywords 6G, green networks, blockchain, Artificial Intelligence, Visible Light Communication (VLC)

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