Advancements and Challenges in Energy-efficient 6G Mobile Communication Network

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Abstract. The arrival of 6G mobile communication networks is anticipated to revolutionize the technological landscape, bringing about profound innovations. This research paper explores the various technological advancements that will pave the way for the advent of 6G networks, with a particular focus on addressing energy consumption. It is widely recognized that energy efficiency plays a crucial role in the evolution of 6G networks. To enhance network performance, user experience, and resource management, the integration of Artificial Intelligence (AI) is expected to be a pivotal technology. AI-based solutions can effectively optimize energy usage and contribute to the overall efficiency of 6G networks. Furthermore, the incorporation of wireless communication systems, telecommunication, and the Internet of Things (IoT) will be integral to the infrastructure of 6G networks. The need for significant enhancements in 6G networks is also examined in this study. Ensuring the safety and protection of 6G networks from cyber threats becomes increasingly important due to the growing reliance on networked communication and the sensitive nature of transmitted information. Cutting-edge security methods such as homomorphic encryption and blockchain technology may be essential in this regard. Moreover, this research paper explores the impact of 6G networks on various domains and discusses the challenges that must be overcome to unlock the technology's full potential. To ensure responsible adoption and usage of 6G networks, the development of new business models and regulatory frameworks may be necessary to support their implementation while addressing energy consumption concerns.

Index Terms— 6G, AI, energy consumption, mobile communication, NGN, IoT.

1 Introduction

Software-defined collaboration, network function software as a service, and fifth-generation wireless (5G) are just a few of the cutting-edge technologies that make Next Generation Networks (NGN) possible. When compared to the previous communication infrastructure, NGN is a radical departure. The NGN is based on the concept of convergence, where a single network carries all forms of data and services (including voice, data, and various forms of media) in packet form [1-2]. Its multi-tiered design is meant to encourage rapid service expansion and technological progress. NGNs are built on a more adaptable and scalable architecture that can accommodate the technological change and services so that they become available.

Technology has changed the face of mobile communication, whether we're talking about voice/data commuters or the fundamental structure of cellular networks [3-4]. Over time, cellular technologies have undergone continuous evolution, progressing from the first generation to the current fifth generation (5G), in order to cater to the escalating demands for bandwidth, throughput, and latency. However, each successive generation has witnessed a proportional increase in energy consumption, primarily due to the incorporation of new hardware to support additional applications. Notably, 5G already consumes four times more energy than its predecessor, 4G, and is poised to contribute to a significant surge in the conventional energy consumption trajectory. Consequently, the advent of 5G has raised substantial concerns regarding energy efficiency. Looking ahead, the forthcoming sixth generation (6G) presents an unprecedented challenge to energy efficiency and sustainability, given its even greater technical and network complexity. A steady increase in data transfer rates from 1G to 6G has been noted over the years (see figure 1).

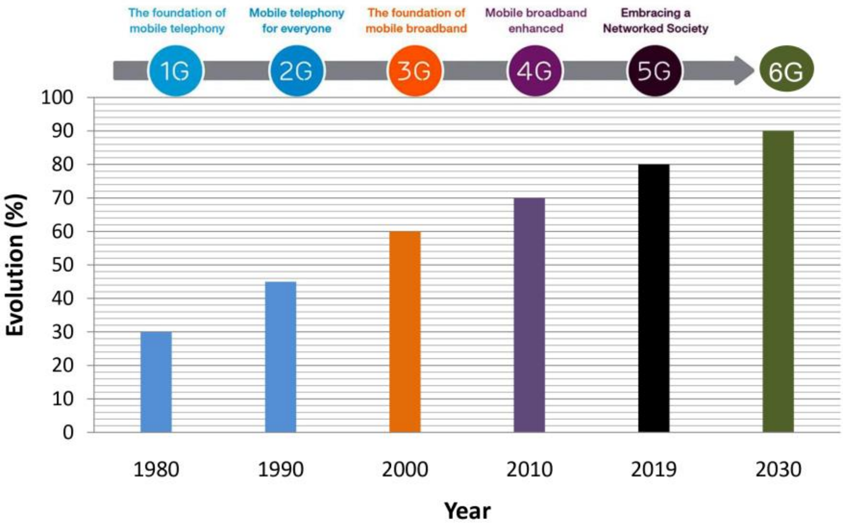

Fig. 1. Mobile technology evolution per decade.

NGNs are able to offer more adaptable and scalable networks thanks to these developments, meaning they can better accommodate emerging technologies and services. They can be used in many different contexts, such as smart cities, the IoT, and multimedia services. On the other hand, there are a few obstacles that must be overcome before NGNs can be widely adopted, such as security, interconnection, and the need for standardized protocols. Despite these difficulties, NGNs have a bright future because of the increasing need for sophisticated communication networks and the general trend towards digitalization [5]. Moreover, NGNs offer the potential for significant energy savings and improved efficiency compared to traditional communication systems. With their advanced network architecture and intelligent routing algorithms, NGNs can optimize energy consumption by dynamically allocating resources and reducing unnecessary data transmission. This energy-efficient approach not only contributes to cost savings but also aligns with the global efforts to reduce carbon emissions and promote sustainable development. Therefore, NGNs are positioned to play a pivotal role in directing the development of future communications and technology while addressing the pressing challenge of energy consumption.

2 NGN architecture and its Advantages

The Next Generation Network (NGN) is an architecture that enables the convergence of voice, data, and video communication services over a single IP-based network [6-7]. The

NGN architecture is designed to provide flexible and scalable services to end-users, reduce operational costs for service providers, and support innovative new services. The NGN architecture is composed of three essential layers: the Access layer, the Transport layer, and the Service layer (see figure 2).

- → The **Access layer** provides connectivity between the end-user devices and the network, using various access technologies such as wireless or fiber-optic.
- → The **Transport layer** provides transport of traffic between the Access layer and the Service layer, using packet-switched technology such as IP, MPLS, or Ethernet.
- → The **Service layer** provides various communication services such as voice, data, and video, using a variety of protocols such as SIP, H.323, or RTP.

The NGN architecture supports both circuit-switched and packet-switched technologies [8], enabling service providers to offer traditional voice services over the same network as new IP-based services. One of the key advantages of the NGN architecture is its flexibility and scalability. Service providers can easily add new services and features to the network without having to make significant changes to the underlying infrastructure. The NGN architecture also enables service providers to reduce operational costs by consolidating their network infrastructure and reducing the number of network elements needed to provide services [9]. Another advantage of the NGN architecture is its support for Quality of Service (QoS) mechanisms [10]. QoS mechanisms enable service providers to prioritize traffic based on its type and importance, ensuring that critical traffic such as voice and video receive the necessary bandwidth and latency to ensure a high-quality user experience.

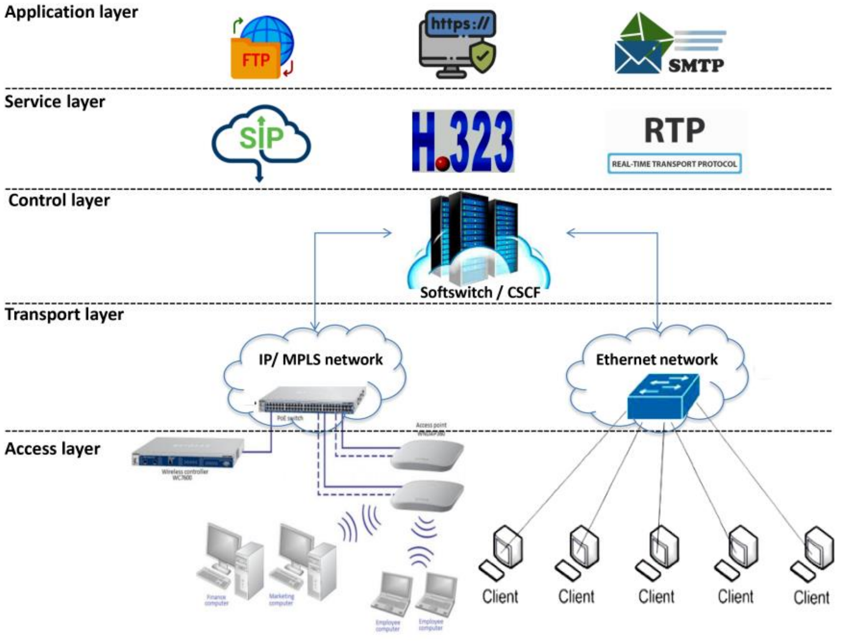

Fig. 2. NGN architecture

Overall, the NGN architecture is a flexible, scalable, and energy-efficient solution for delivering a wide range of communication services over a single IP-based network. Its support for QoS mechanisms and ability to converge different communication services onto a single network not only reduce costs for service providers but also contribute to significant energy savings. By consolidating various services onto a unified infrastructure, NGNs eliminate the need for multiple physical networks, reducing the energy consumption associated with their maintenance and operation. This energy-conscious approach aligns with the growing global focus on sustainable practices and positions NGNs as an environmentally friendly choice for service providers aiming to offer innovative new services while minimizing their environmental footprint.

3 Methods

Next Generation Networks (NGNs) may significantly alter the way we communicate with electronic devices [11]. These network-centric approaches, including NGNs, play a crucial role in the development of "smart cities" [12], where they bring residents cutting-edge communication services that elevate their standard of living. Moreover, NGNs are instrumental in facilitating the expansion of the Internet of Things (IoT) by enabling secure and reliable data exchange between connected devices [13]. By leveraging NGNs, cities can optimize their infrastructure, enhance efficiency, and ensure seamless connectivity, all while minimizing energy consumption and promoting sustainability. Through their ability to support advanced communication services and enable safe and efficient data transmission, NGNs are driving the evolution of smart cities and paving the way for a more connected and sustainable future.

The utilization of NGNs to support communication services, including high-definition audio, has opened up new opportunities for communication and collaboration. However, despite their numerous advantages, NGNs are not without challenges during deployment and implementation. Confidentiality poses a major concern, as these structures must be safeguarded against computer security threats. Integration is also a critical consideration, as NGNs need to seamlessly collaborate with other network systems and various technologies. Additionally, NGNs should be built on clinical guidelines to ensure their ability to adapt to emerging technologies and infrastructure, as they become more widely accessible.

4 Result and discussion

NGNs usher in a new era of communication systems, providing advanced capabilities and enhanced services compared to older networks. They have been utilized to support a wide range of applications, including pervasive computing, the Internet of Things (IoT), as well as incorporating cutting-edge technologies such as AI and emotions recognition, and are positioned to have a significant impact on the success of information and communications technology, encompassing:

- ✓ The rise of the smart city, where millions of sensors are installed in infrastructure including roads, homes, automobiles, buildings, and factories. 6G will be the dependable wireless high-speed connectivity that enables apps to collaborate and interface with one another, making it ideal for data-oriented tasks [14-15].

- ✓ The integration of AI and emotions in NGNs has the potential to revolutionize communication experiences by enabling systems to understand and respond to human emotions, resulting in more personalized and empathetic interactions [16-17].

- ✓ Cyber robots and driverless cars are becoming increasingly popular, with the 6G system allowing for widespread use of things like aerial vehicle mail delivery systems and robots and even the implementation of self-driving cars [18].

- ✓ The other major development is the creation of smart objects and environments, which will further the 6G architectural growth, by facilitating wireless communications in settings that include huge, intelligent displays. Transmission in cellular networks occurs at base stations, which come in a wide range of shapes and sizes depending on the situation [19-20].

The evolution of software, from Smart manufacturing to Industry 5.0, relies on the interconnectivity between machines, particularly in dynamic environments. Therefore, it becomes crucial to assess the features offered by phone carriers [21] to ensure seamless integration and efficient communication within the NGN framework.

The primary consideration in evaluating 5G and 6G cellular services is the data rate they offer. Comparing the mobility services of both generations, we observe that 5G achieves a maximum speed of 500 km/hr, while 6G reaches 1000 km/hr. However, the noteworthy distinction lies in the maximum data rate, with 5G capable of achieving 1 Gbps, while 6G surpasses it by a factor of 100. Consequently, 6G exhibits superior potential in providing more satisfying services to users/devices moving at speeds of 500 km/hr or higher, such as those on airplanes or high-speed trains [22-23]. Regarding spectral efficiency, 5G offers a rate of 30 bps/Hz, which is approximately, double that of LTE (15 bps/Hz). In contrast, 6G holds the potential to deliver an impressive rate of 100 bps/Hz, indicating significantly faster data transfer. However, it is worth noting that 6G communication exhibits relatively higher U-plane latency and C-plane response time compared to 5G communication in transmitting information (one way) at the IP layers.

While 5G technology does not encompass true artificial intelligence, 6G stands out by offering the capability for machines to exhibit human-like behavior. Genuine artificial intelligence depends on the synergy of computers operating collectively as an "AI cluster" to learn and enhance their performance. Moreover, 6G's inclusion of authentic artificial intelligence brings about not only advanced functionalities but also the potential for energy-efficient AI processing, enabling more sustainable and intelligent systems. The network resembling a mobile-phone network's base station consists of small cells that combine to form extensive networks of communication algorithms. This setup enables IoT devices to enhance their learning capabilities through cluster-based schemes and self-training algorithms. The high-speed data support offered by 6G technology will enhance system performance, albeit with an inevitable increase in computational complexity and throughput [24-25].

The 6G standard not only enhances security compared to its predecessor, 5G, but also prioritizes energy efficiency. It achieves this by incorporating cryptographic algorithms at both the physical and application levels, providing an additional layer of protection for user data while minimizing energy consumption. One key distinction between 6G and 5G lies in the utilization of satellites for signal transmission rather than traditional base stations. This satellite-based approach enables extensive mobile coverage, leading to a substantial increase in volume spectral efficiency, measured in bits per second per square meter (bps/Hz/m3). This enhanced spectral efficiency signifies a significant improvement in the amount of data that can be transmitted within a given frequency spectrum and physical space. Furthermore, the integration of smart cities components in 6G facilitates the seamless connection of sensor nodes in smart city environments. This integration streamlines the deployment and operation of sensor nodes, contributing to the overall efficiency and effectiveness of smart city systems.

In summary, 6G not only enhances security and enables satellite-based signal transmission but also places a strong emphasis on energy efficiency. Through the integration of cryptographic algorithms, satellite communication, and streamlined connectivity for smart cities, the 6G standard paves the way for a more secure, sustainable, and energy-efficient wireless communication future.

5 Conclusion

This research study highlights the significance of Artificial Intelligence, advanced analytics, 5G, and the Internet of Things (IoT) in the development of next-generation networks. The paper emphasizes the need for enhanced speed, dependability, and security in these networks, with a particular focus on energy efficiency. Furthermore, the paper explores how next-generation networks have the potential to revolutionize various fields, by optimizing energy consumption and minimizing wastage, these networks have the potential to revolutionize various industries. The article also addresses the current limitations of existing networks and the challenges that must be overcome to fully harness the potential of future generation networks.

Looking ahead, the focus will shift towards the exploration of 5G mmWave Positioning for Vehicular Networks, which will contribute to a deeper understanding and advancement of next-generation networks. As research and development continue, it is expected that these networks will continue to evolve and shape the future of communication technology.

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