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6G Revolution: Exploring the Next Frontier in Wireless Communication

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Abstract: ***The 5G communication system has developed far more features than the previous generation, enabling new technologies. But it is predicted that by the year 2030, this communication system will fail to provide the growing demands of emerging technologies such as Holographic calls, Avatar robotics applications, Nanonetworks, Teleoperated Driving (ToD), e-health, Tactile Internet, Internet of Everything (IoE), etc., So it is important to develop a ubiquitous communication system which will provide low latency, high data rate, more capacity with secure and efficient transmission of information which is named as the 6G communication system. This paper briefly reviews the 6G communication system, its architecture, requirements, and emerging technologies and applications in the 6G communication system.***
Keywords: 6G, Next Generation Communication System, Quality of Services, THz band, Artificial Intelligence.

I. INTRODUCTION

According to the International Telecommunication Union's (ITU) global data traffic prediction, data traffic will increase exponentially by the year 2030. The global mobile volume traffic has significantly increased due to emerging applications such as AI, VR, 3D Media, and the Internet of Things (IoT). It is predicted that the global mobile volume traffic will increase to 5016 EB/month by the year 2030 which is 670 times that of 2010 [1]. After completing the third-generation partnership project (3GPP) Release 15 of the 5G standard in June 2018 researchers shifted their focus to 6G. In the year 2018, ITU's Telecommunication Standardization Sector (ITU-T) Study Group 13 established a Focus Group technology for Network 2030(FG NET-2030) which will study the requirements of Network 2030 [2]. The world of Information Technology evolving rapidly towards a completely automated and intelligent system that is beyond the limits of the current communication system, so it is important to develop a communication system having advanced value-added services and high Quality of Services (QoS). 6G, the Sixth-Generation communication system promises to provide a high data rate, low latency, and intelligent, and secured services resulting in a ubiquitous communication system.6G is going to enable new technologies such as tactile internet, extended reality (XR), avatar robotics, holographic calls, teleoperated vehicles, e-health, blockchain, artificial intelligence (AI), and machine learning (ML) that will revolutionize the future of mankind.

This paper gives a brief review of the 6G Communication system. Section Ⅱ explores the Evolution of the Communication system while the requirements and KPI targets of the 6G cmmunication system, are explained in section Ⅲ. The architecture of 6G communication is explained in section Ⅳ and emerging technologies and applications are explained in section Ⅴ.

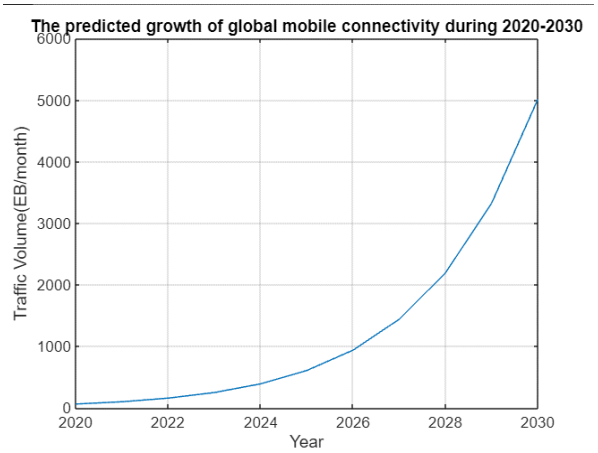

Fig. 1: The predicted growth of global mobile connectivity during 2020-2030

II. EVOLUTION OF COMMUNICATION SYSTEM

In the age of rapidly changing technology, communication systems play a vital role. Since the initial development of the Advance Mobile Phone System (AMPS) which was later termed as First-Generation mobile communication(1G) evolution [3], the modern wireless communication system came into existence in the early 80s. since then communication systems have evolved.

The First Generation (1G) mobile communication system used analog signals to transmit the information and this system was able to provide only voice services having data rates up to 2.4 Kbit/s [3]. still, then there was not any universal wireless standard to govern communication across the world. By the year 1991 the second generation (2G) communication system was launched. this system was based on the digital modulation technique for signal transmission and offered data rates up to 384 kbits/s. along with the voice service, this system was able to provide data services such as Short Message Service (SMS) and used a Global System for Mobile Communication (GSM) as a standard [3]. The Third-Generation mobile communication system (3G) brought revolutionary changes in wireless mobile communication systems. This system had the capability to provide data rate up to 2Mbit/s, which was approximately four times of previous generation [3]. The advancements brought by 3G were not only confined to increased communication speed but also provided some value-added services such as internet access, e-mail services, live streaming facilities, GPS (Global Positioning System) Internet Protocol Television (IPTV), etc. [3]. Third-Generation mobile communication system followed International Mobile Telecommunication -2000(IMT-2000) standards as stated by ITU (International Telecommunication Union). The Fourth-Generation mobile communication system (4G) had an IP (Internet protocol) based communication network that provided high data speed of up to 1Gbit/s, this system overcame the limitations of the 3G wireless communication system by integrating additional enhanced technologies with the features of 3G, which lead to raise in QoS (Quality of Services). 4G provided greater spectral efficiency, increased peak data rates, increased throughput, and reduced latency which resulted in advanced services such as digital video broadcasting, high-definition (HD) Television (TV) content, etc. LTE-A (Long Term Evolution- Advanced) was the dominant standard for 4G communication systems [3].

The Fifth Generation (5G) wireless communication system is being deployed worldwide; this generation aims to achieve a data rate of up to 10Gbit/s. The use of a millimeter wave (mm Wave) band along with the microwave band for communication will be a key factor in achieving the aim [4]. International Telecommunication Union's (ITU) International Mobile Telecommunication-2020(IMT-2020) standard proposed three major 5G usage scenarios:

1) enhanced mobile broadband(eMBB), 2) ultra-reliable low latency communication (URLCC), and 3) massive machine type communication(mMTC). Internet of Things (IoT), Internet of Vehicles (IoV), Machine to Machine (M2M) communication, and Device to Device(D2D) communication [4] will be the main applications of the 5G wireless communication system. 5G technology is an enabler of a fully digitalized world, but it seems that even 5G technology might face several limitations shortly [4].

Any new generation system does not emerge from the vacuum but it follows the industrial and technological trends from previous generations, so with the Sixth Generation(6G) communication system. 6G will require the support of technologies that played a key role in 5G communication systems such as enhanced Mobile Broadband(eMBB), ultra-reliable low latency communication (URLCC), massive machine type communication (mMTC) along with new technologies such as computation-oriented communication (CoC), contextually agile eMBB communication (CAeC) and Event defined URLCC(EDURLCC) [5].

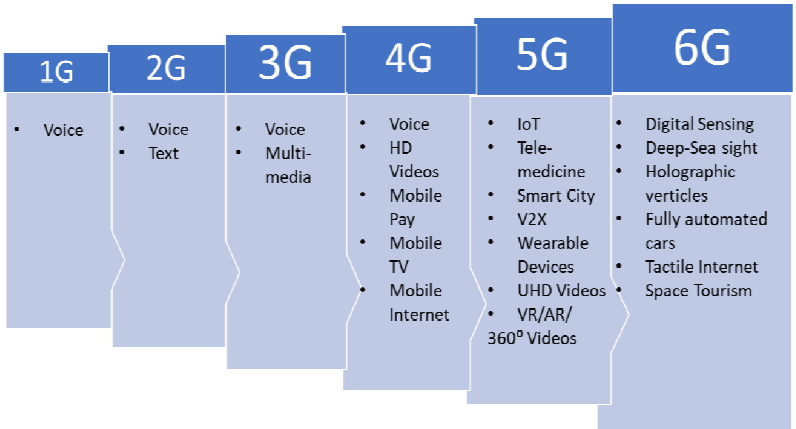

Fig. 2: Evolution of Communication System and their Services

6G will go beyond mobile internet and will be able to support ubiquitous AI services from core to end devices of the network and it will revolutionize wireless communication from "connected things" to "connected intelligence" [5]. The traditional key performance indexes (KPI) will not be able to completely define all aspects of the 6G communication system as new technologies are emerging, so it is important to come up with new KPIs for the 6G communication system, such as situation awareness, learning ability, storage cost, computational capacity, etc.

To achieve these KPI's 6G communication system requires new services which are, ubiquitous Mobile ultra-broadband (uMUB), the ultra-high speed with Low Latency communication (uHSLLC), massive Machine type communication (mMTC), and ultra-High Data Density (uHDD) [6].

According to [7] smartphones were central to 4G and 5G communication systems but the increase in smart wearable devices in recent years indicates that these wearable devices are replacing the functioning of smartphones, indicating the end of the smartphone era in next-generation communication systems.

From the evolution, it can be observed that the communication system has evolved from a device-centric approach to a human-centric approach. 6G will provide an information and communication technology (ICT) infrastructure that will provide virtually zero latency services, unlimited storage, and immense cognition capabilities which will enable end users to perceive themselves as surrounded by a huge artificial brain [8]. The 6G communication will play a significant role in responding to fundamental human and social needs and in helping realize visionary scientist Nikola Tesla's prophecy that "When wireless is perfectly applied, the whole Earth will be converted into a huge brain" [8].

III. OBJECTIVES AND KPI TARGETS OF 6G COMMUNICATION SYSTEM

The current communication network is not capable of providing new application delivery services in terms of Quality of Services (QoS), For Example, for any Internet of Things (IoT) application a delay can be up to 25 ms but for Vehicle-to-Vehicle communication(V2V) required delay is 5-10 ms to make the drive safe, which is impossible with current cellular network [9]. Also, the current communication system is not able to fulfill the requirements of emerging applications such as Holographic Calls, Avatar and Robotics, Nanonetwork, Tactile Internet, etc. because of factors such as network delay, instability of the network, and the incompletion of overall architecture.

The current communication system fails to provide the demands of the market and the emerging technologies. Low data rates, increase in global network traffic, low throughput, energy efficiency are some of the key issues which needs to be addressed in the 6G communication system [6].

Researchers have proposed main objectives for the 6G communication system those are,

1) Extremely high data rates per device.
2) Very large numbers of connected devices.
3) Global connectivity.
4) Very low latency.
5) Lowering energy consumption with battery-free IoT devices.
6) Ultra-high reliable connectivity.
7) Connected intelligence with Machine Learning capabilities.

To assess the performance of any communication system the key performance indicators (KPIs) play an important role. Researchers have set the traditional KPIs with new targeted values for the 6G communication system which will help to monitor the performance of the 6G communication system ubiquitously. Those are given in Table 1. [6]

TABLE I
Target KPI values for 6G communication system [6].

KPI	Target Value	Description
Peak Data Rate	Up to 1 Tbps	Maximum theoretical data transfer speed.
Radio Latency	0.1 ms	Time delay between sending and receiving a signal.
Battery	20 years	Expected operational

Lifetime		duration without needing a recharge.
Device Connectivity	100 devices/m^3	Number of devices that can connect per cubic meter.
Traffic Increase	10,000 times	Projected growth in network traffic compared to current levels.
Energy Efficiency	10 times	Improvement in energy consumption per unit of data transferred.
Maximum Outage	1 out of 1 million	Probability of network service interruption.
Indoor Positioning Precision	10 cm	Accuracy of location determination indoors.
Outdoor Positioning Precision	1 meter	Accuracy of location determination outdoors.

IV. E2E 6G COMMUNICATION ARCHITECTURE

The 5G PPP architecture working group has proposed a high-level view of the 6G communication system Architecture, according to them the architecture will consist of three layers those are Infrastructure layer, the Network Service layer, and the Application layer as shown in Fig 3.

This architecture provides easy and flexible adaptation to new topologies to meet requirements beyond what 5G was capable of both extreme performance and global service coverage, by incorporating different (sub)network solutions in a network [10].

A. Infrastructure Layer

The infrastructure layer comprises network RAN, network CN, and transport network which consist of radio equipment, distributed units (DU), classical base stations, switches, routers, communication links, data centers, cloud infrastructure, etc. Physical resources to host the network services and application layer elements are provided by this layer.

This layer is capable of accommodating new enablers such as localization and sensing which are the result of the introduction of new applications like smart cities, connected cars, etc. As discussed, earlier 6G communication system requires KPIs such as extremely low latency, high reliability, high data rate, high capacity, etc. to fulfil the needs of emerging applications, this layer consists of advanced improvements in Radio Access Network (RAN) which will enable all required KPI's for 6G communication system [10].

B. Network Service Layer

It is proposed that the network service layer of the 6g communication system will be cloud and micro-service based in which functions and microservices are expanded from the central cloud to the extreme edge cloud as shown in Fig. 3.

Extreme edge cloud refers to all the devices beyond RAN, which can be personal devices (smartphones, laptops) or a huge variety of Internet of Things (IoT) devices (wearables, sensor networks, connected cars, etc.) extreme cloud will act as a key technology enabler for the network service layer.

To have a software, intelligent, and efficient network architecture, in the 6G communication system all network functions, operations, and applications are implemented as microservices. 6G architecture will support AI, AI as a Service (AIaaS), programmability, and network automation to be an intelligent network. this layer will also provide exposure to the framework and integration fabric which will establish communication channels that will enable continuous interoperation and networking across different domains [10].

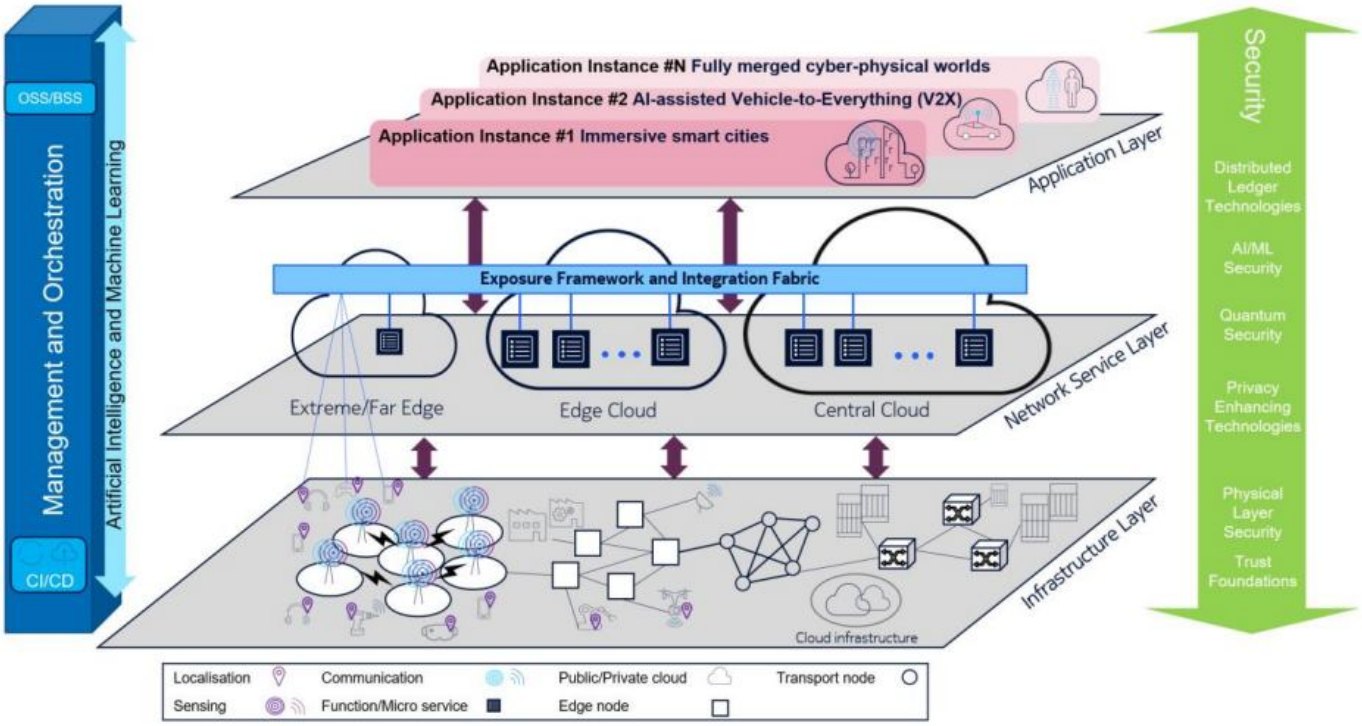

Fig.3: High-level view of 6G architecture [10]

Network management and orchestration is an important part of this communication architecture and it will be fully automated closed loop control and support based by adopting advancements in AI/ML technology which will result in a highly reliable, flexible, resilient framework. Another important and integral part of the 6G communication system architecture is the architecture of security and privacy [10].

V. EMERGING TECHNOLOGIES AND APPLICATIONS

The 5G communication system came with new applications such as AI, Automation, and Smart City but 5G is not capable of fully integrating these technologies based on the vision and architecture of the 6G communication system it will be able to integrate all partially integrated technologies of 5G and will introduce more technologies and applications providing high data rates, high reliability, low latency, secure and efficient transmission. some of those technologies and applications are discussed below

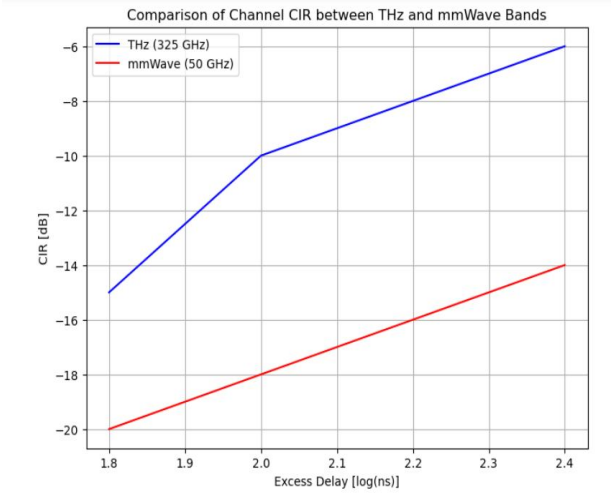

Fig. 4. Simulation results of channel CIR at THz frequency band (325GHz) and mm Wave frequency band (50 GHz).

A. *Terahertz communication*

The Terahertz (THz) band constitutes the gap band between microwave and optical spectra. It ranges from 0.1 THz (100 GHz) to 10 THz (10,000 GHz). Deployment of a terahertz communication system faces a major challenge which is to design a new transceiver module as the current designs are not capable of handling THz band frequencies. [11]. Current communication systems use the Radio Frequency (RF) band for the transmission of data but this band is now almost full and it is not capable of supporting the increasing growing demand for wireless communication system technology. The terahertz (THz) band will play a crucial role in the 6G communication network. Due to this 6G communication system will be the first to provide Tbits/s high-speed communication [1].

The graph shown in Fig. 4 gives an analysis of terahertz communication. It is the Channel Impulse Response (CIR) of two distinct frequency bands commonly encountered in wireless communication systems: Terahertz (THz) at 325 GHz and Millimeter Wave (mm-Wave) at 50 GHz [12].The graph showcases the comparative advantage of the THz band over mm Wave in terms in terms of reliability, speed, capacity excess delay which results in better performance in a communication system.

B. *Artificial Intelligence and Machine Learning*

Artificial Intelligence (AI) and Machine Learning (ML) were partially supported by the 5G communication system but 6G will fully support it for automation. It is the most important technology in the 6G communication system, with the help of this technology network handover, network selection, and resource allocation will result in improving the performance of the communication system especially in delay-sensitive applications, as self-driving cars and voice assistance are possible only because of advancements in this technology. The 6G wireless network is more complex and requires smarter methods to handle the losses, detect anomalies, handle network features, and understand the KPI trends which can be possible by introducing advanced ML solutions [13].

Extended Reality (XR)

The term Extended Reality (XR) is referred to a system consisting of Virtual Reality (VR) Augmented Reality (AR) and Mixed Reality (MR). VR is a computer-simulated reality in which a person can experience the simulated reality with the help of a headset generating sound and images creating an imaginary world. At the same time, AR uses the real world and adds to it using a specific device. Audios, videos, and GPS could be used to create an interactive environment. But XR comprises both real and virtual worlds, for a genuine XR high data rate, low latency, and highly reliable wireless connectivity is required which can be provided by 6G. To make this possible ultra-high speed with low latency communication i.e. uHSLLC a key service of 6G will play an important role. To make its deployment successful in the future [6].

C. *Blockchain*

This is the method of recording information that makes it impossible or highly difficult for a system to be changed or manipulated or to be hacked. In this method, data is represented as distributed blocks and connected chain and the whole chain is secured with cryptography.

In 6G it will be used to manage and organize big data also integration of blockchain with AI and deep reinforcement learning will help to increase the Quality of Service (QoS). This technology has the potential to solve the problem of spectrum requirement in 6G communication systems by allowing users to share the same spectrum providing a guarantee of secure, low-cost, smart, and efficient spectrum utilization [13].

D. *Quantum Communication*

Quantum technology uses properties of quantum physics such as the interaction of molecules, atoms, and even photons and electrons to create devices such as ultra-accurate clocks, Medical- imaging, and Quantum computers.

This technology is not completely developed but it is expected that it will evolve parallelly with the 6G communication system. In the year 2018, European Communication launched a Quantum flagship program to promote Quantum research having the goal to create a quantum internet by developing Quantum Computer Infrastructure (QCI) across Europe. QCI will make it possible to implement Quantum Cryptography a part of conventional communication networks, increasing the security of information exchange. Quantum Key Distribution will be the first service to run QCI which will provide an encrypted message with an intrinsically secure random key to the sender and recipient in such a way that the attacker cannot control the system. It can play a key role in 6G communication systems by providing solutions in the domain of increased channel capacity e.g., multiple access technologies such as NOMA, RSM which demand high power on runtime for computation of Successive Interference Cancellation (SIC) [13].

E. Tactile Internet

The evolution of the mobile internet has resulted in the introduction of new services such as the sharing of data, and videos on mobile, similarly highly evolving IoT devices will enable communication between smart devices, which will integrate real-time interaction of Machine-to-Machine (M2M) and Human-to-Machine (H2M) by adding new dimension of haptic sensation and Tactile. the word tactile means touching sense and the Tactile Internet means transmission of touching sense over long distance that's why many researchers have termed it as "Internet of Senses". This technology will enable communication between humans and machines in real-time with the environment [13].

VI. CONCLUSION

5G communication system is being deployed worldwide. Still, it will not be able to support growing demands of wireless communication so the introduction of 6G is much needed in upcoming years. Which will provide extremely high data rates, a large number of connected devices, global connectivity, low latency, and secured communication. Though 6G is in the research phase it can be concluded that the 6G communication system will be able to fulfil the network requirements of emerging technologies and applications and will provide a human-centric communication system.

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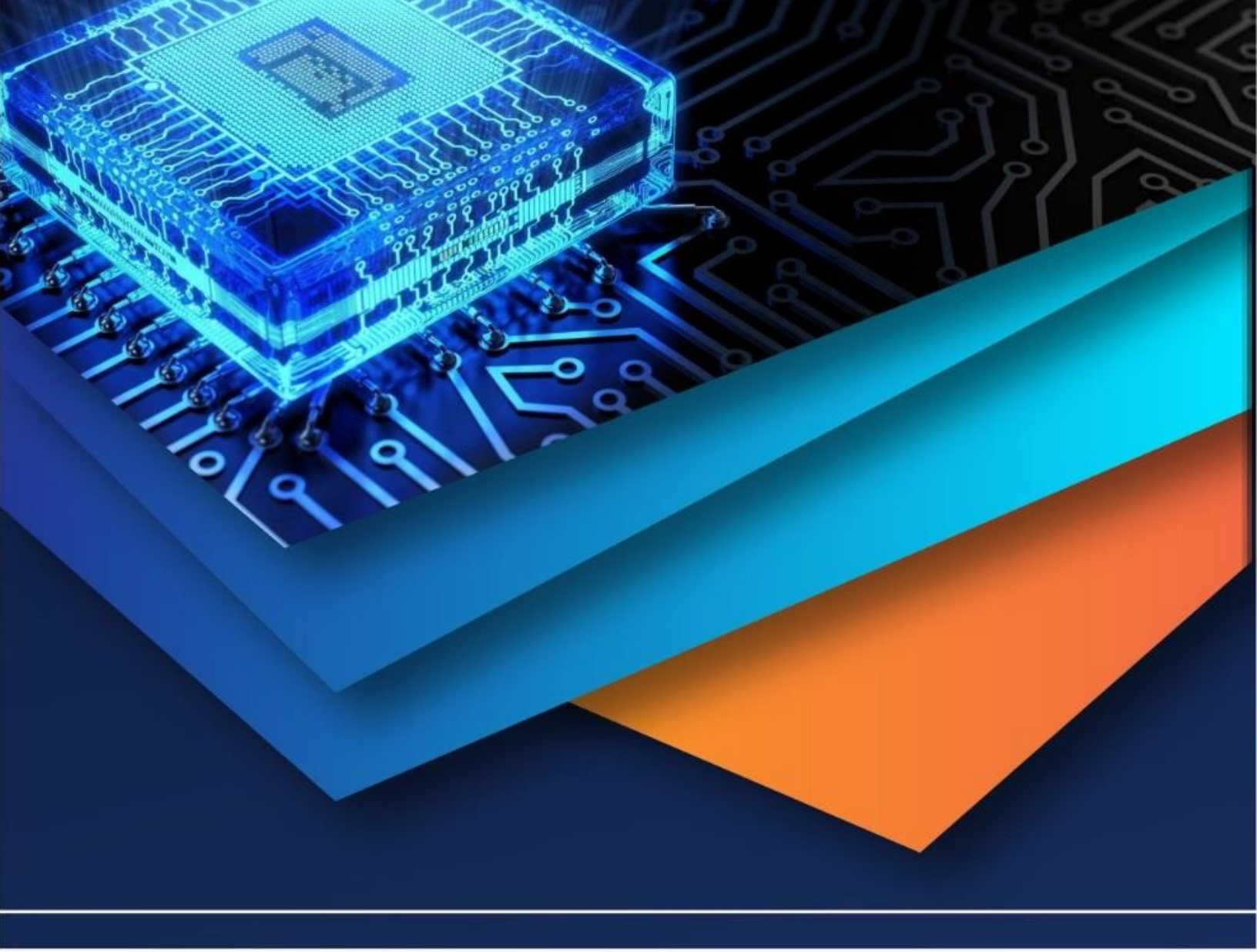

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