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Reliable and Fast Future Communications with Millimeter Waves: A Review

Aditi Thakur[1], Dhawan Singh[2]
[1, 2] Department of Electronics and Communication Engineering, Eternal University, Baru Sahib, Sirmour-173101, India

Abstract: This review article focuses on a variety of ways that show how and why millimeter waves (mmW) could be interesting, beneficial, and acquitting utmost attention when configuring steerable directional antennas at base stations and handheld communication devices. Comparisons among various wireless communication links have been focussed and discussed in this research work. Although mmW can travel only a few distances as compared to the short frequencies, this does not make mmW disadvantageous or inefficient. Because mmW makes possible more densely packed communication links, therefore permits very efficient and effective spectrum utilization, even in the absence of Line of sight (LOS) connectivity. Hence, this can be used to enhance and heightened the security of communication transmission systems and offer wider opportunities and thus, require more near future exploration.
***Keywords*: 5G, Millimeter wave (mmW), MIMO, Steerable microstrip patch antenna, WLAN.**

I. INTRODUCTION

The recent demand for cellular data has been springing at such a tremendous rate so that within next decade we will require a network having capacity thousands of times greater than we are having right now. To overcome the massive demand of the customers we need to design a compact, low cost and efficient antenna. One of the solutions to this problem is the design of steerable microstrip patch antenna at mmW range, which has various advantages at short range communication as we go through its propagation characteristics.

Recent studies investigated and suggested that mmW range of frequencies could be employed as an alternative to replace the currently congested and saturated 700 MHz to 2.6 GHz radio frequency spectrum in the wireless communication systems [1]. Cellular capacity, coverage, and data rate analysis have been done by various researchers, concluding to the fact that mmW communication is good in terms of capacity, coverage as well as data rates [2]. A lot of research is going on 5G networks using these properties of millimeter waves [3, 4]. Z. Pi and F. Khan discussed that for broadband communication we have to move towards 3-300 GHz band [5].

II. NEED OF MILLIMETER WAVE COMMUNICATION

For high data rates, both the signal bandwidth and dynamic range must be taken into consideration. As the capacity of single input and single output (SISO) connection is totally relied and dependent on bandwidth and signal-to-noise ratio (SNR), thus limits the data rates over such link. Such as,

$$C = B.W \times \log_2(1 + SNR). \qquad 1$$

Thus, for the rate of transmission to be high with low bandwidth, *SNR* must be high. High *SNR* can be achieved either by reducing the distance between transmitter and receiver or by using high gain and efficient antenna arrays configuration.

This is explained by the Friis equation [6]:

$$P_{signal} = P_{trans.} \times G_{rec.} \times G_{trans.} \times \left(\frac{\lambda}{4\Pi d} \right)^{\alpha}. \qquad 2$$

As given in the equation (2), $P_{trans.}$ is the transmitted signal power, P_{signal} is the received signal power, $G_{trans.}$ and $G_{rec.}$ is the transmitting and receiving gains of the antennas, and *d* is the distance between two antennas. Here α varies from 1.8 to 5.2.

One more noise component associated with the receiver can be written as:

$$N_{in} = k \times T \times N.F \times B.W. \qquad 3$$

Where, *T* = absolute temperature, *N.F.* = noise factor, and *k* = Boltzmann constant. By combining above (1), (2), and (3) equations, we have:

$$C = B.W \times \log_2 \left(1 + \frac{P_{trans.} \times G_{rec.} \times G_{trans.} \times \left(\frac{\lambda}{4\Pi d} \right)^{\alpha}}{k \times T \times N.F \times B.W} \right). \quad 4$$

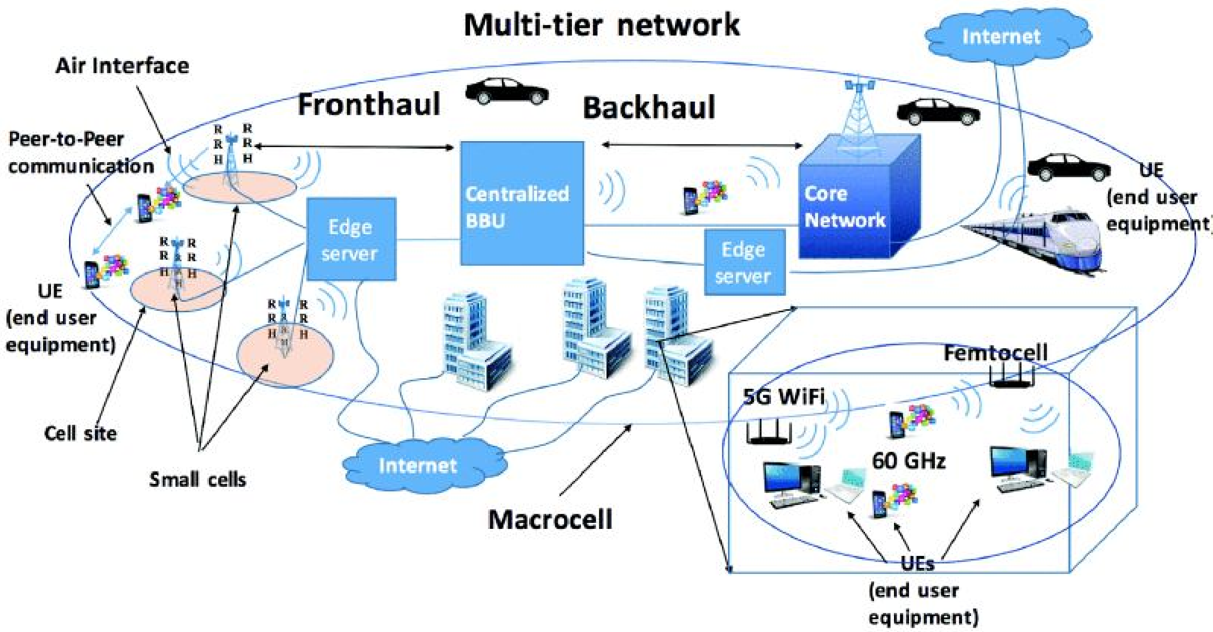

Fig. 1 peer-to-peer communication, cell sites, edge servers, front haul, and backhaul 5G multitier architecture [8].

From the equation 4, it is quite obvious and clear that with the increase in B.W, the channel capacity can be increased, but it also results in an increase of the noise level in the links and consequently brings down the SNR at a defined signal grade. Thus, increase in B.W is only possible when the SNR is sufficiently prominent [6]. Because α varies with the frequency, which is appropriate for lower frequencies. This shows how and why radio communication is most popular at relatively lower frequencies. However, this leads to the fact that if all high data rate communication systems choose the B.W at low frequencies, and then lower frequency radio spectrum would be congested, filled up, and consumed very rapidly. This further would results in a quest, focus, and attention towards higher frequency spectrum because more B.W would be available to use at higher frequency spectrum.

One of the major advantages of mmW communication is that we can reuse frequency very often, thus the proper utilization of the spectrum offered. However, when we consider wireless communication, it is commonly said that rain and atmospheric characteristics make it useless and less important for long distance communication. But as we come across urban areas where the cell size reduces to 200 meters, this effect will become negligible. Presently, 4G LTE latencies are very high but with 5G this can be reduced using wireless mmW communication. From Fig. 1 it can be seen that the network can be made more reliable by making use of edge servers to enable new signals with low latencies [7].

III.ADVANTAGES OVER OTHER COMMUNICATIONS LINKS

Millimeter waves have a large bandwidth, with help of which we can achieve high data rates of about 10 Gbps. This makes mmW communication more advantageous over lower RF frequency communication. Millimeter waves have narrow beamwidth as compare to the lower frequency microwave region. This provides better security and less interference. Moreover, density in the given area is very high which is very helpful to boost point-to-point communication. Licensing cost for millimeter wave is less as compared to microwave region.

In the mmW frequency spectrum, the service providers have significant flexibility and it offers wider opportunities in terms of allocating more bandwidths per channel. Therefore, they can extend the channel bandwidth far beyond the current 20 MHz channels, this is presently used for communication by 4G service provider [8]. With the further increase in the radio channel bandwidth, the data efficiency and capacity would be greatly enhanced. Whereas, the response and reaction time for digital signal transmission would greatly reduce. Hence, this would result in much better and supportive wireless data transmission

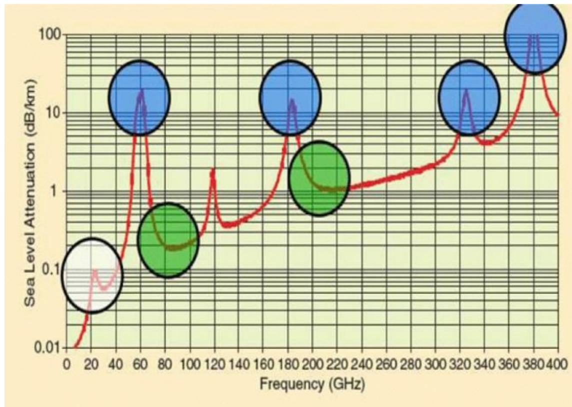

Fig. 2 Atmospheric absorption of electromagnetic waves [8].

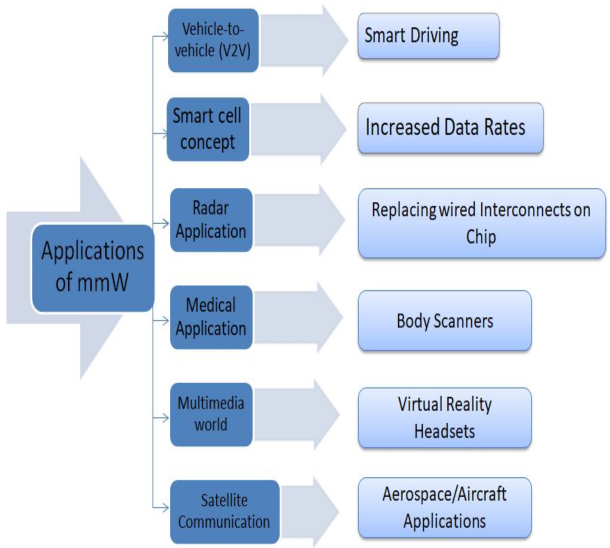

Fig. 3 Applications of millimeter waves.

with the minimal latency required. Recent researches in wireless communication have been deployed in mmW band (especially in 57GHz-64GHz). Attenuation values for the mmW are shown in Fig. 2, which is good to reduce interference.

This wireless mmW frequency band is increasing in popularity with the time and drawing the attention of researchers because of the monolithic universal unlicensed frequency spectrum has been available around 60GHz and obtainable for short-range wireless communications [9]. The high attenuation in mmW band reduces interference, while directionality (narrow beamwidth) offered by mmW backings wireless backhauling within several base stations [10].

Therefore, mmW is suitable for dense heterogeneous communication environment. With the developments of efficient and high gain, steerable antennas along with much reliable, readily available and cheaper CMOS technology, which can function and operates well within the mmW frequency range, a reliable mmW communication system could be transformed and converted into reality with proper functionality. These factors all together influence and strengthen the possibility of mmW based wireless communication systems [11, 12].

Many of the existing solutions either do not have beam-steering capabilities or have limited beam-steering properties with limited transmitting power. One of the suitable and most efficient solutions is the mmW antenna array, which can be accomplished in a low form factor. Such antenna arrays consisted of a number of elements are capable of effectively utilizing the spatial properties of the communication channel and organizing MU-MIMO transmissions. Certainly, transmission using mmW communication is a distinguish enabling technology for the coming 5G multi-tier large-scale antenna system, where high beamforming gains could be achieved within small areas using mmW antennas composed of small size with dense antenna packaging [13].

Many of the researchers are working on GHz and THz frequencies from past few years [14, 15]. Keeping this in consideration, several antenna designs exploitation and practical execution feasibility remained exposed and their solution would perhaps bring drastically change towards our understanding of future mmW radio communications. Thus, Wireless mmW radio systems would require employing antenna arrays with a large number of elements both at the base station and at the user end terminal. This would result in high directivity, gains, beam-steering capability, and possibly low noise communication, all to overcome the propagation challenges in this range.

However, there are still some classical design constraints, issues, new objectives and available degree of freedoms, which has yet to be fulfilled for mmW radio systems as compared with the traditional communication systems [16].

IV. VARIOUS APPLICATIONS AREAS OF MILLIMETER WAVES

There are many applications in which mmW communication has appeared in past few years as shown in Fig. 3. MmW frequencies are used in commercial applications such as automotive radar, satellite, and mobile communication etc. The advancement of wireless radio communication engineering over the last two decades has increasing rapid growth and become an eye-catching in the domains like tunnels, underwater, and mines beneath the surface of earth. These environments are supposed to be inadequate, troublesome, hazardous, and unmanageable. Thus wireless communication becomes necessary in these areas for various consequences such as human safety, protection, and productivity [9].

A. Vehicle-to-Vehicle (V2V)

The intelligent transportation system is an application operating at millimeter wavelength established for vehicle to vehicle communication and vehicle to wayside communications. To improve the significant road safety, technologies like short-range radar (SRR) systems and long-range radar (LRR) systems have been identified and developed. With the recent adbvancement with respect to the advanced and sophisticated transportation systems, millimeter wavelength might play a crucial character facilitating high data transfer rate between vehicles. This is due to the reason that mmW is already playing an achor role in the automotive radar system technology, which has been developed and deployed over the past one decade [17].

B. Smart Cell Concept

Fiber optic data transfer links have been employed in today wireless communication, which offer data transfer at the rates of multi gigabyte-per-second (Gbps). However, it comes at the expense of difficulty in deployment, extra cost in term of manpower and fiber optics, and physical constraints because of some terrain areas. Whereas, wireless radio communication could avail a cost-effective substitute to interlink the remote terrains and that will remain abundant without the fiber rollout. Taking all these considerations into account, there are enormous challenges in terms of further increasing demand of multi-Gbps data transfer rates, fiber replacement and mobile backhauling for the next-generation wireless technologies [18].

The high attenuation reduces the chances of signal interference, while beam steering capability backup wireless backhauling among various base stations [19]. Therefore, mmW radio services are most worthy for dense heterogeneous communication environment. Small sized cells would not only decrease the congestions and data trafficking among several base stations by rolling out a layer of multiple access points of small cell but also results in achieving lower distance between the transmitters and end devices. Thus, this would produce and results in more reliable and fast communication with low signal loss, high data transmission rate, and efficient energy management.

This is worthwhile to mention that, the lower wavelengths support reduction in antenna size so it is possible to design multiple antenna elements for designing antenna arrays on a relatively small and compact physical platform at the communication end. Also, the small cell configuration ascertains and guaranteed that the signal attenuation and rain fading should remain low and up to the optimum level.

C. Radar Application

The alliance of mmW radio communication with radar [20] is also quite interesting and challenging. The mmW radars are useful in a number of applications for radio astronomy, imaging and analyzing upper atmosphere through satellites, studying climate changes and examining the effects of global warming on earth atmosphere. Older mmW radars based techniques were made up of large and bulky components with difficulty in handling and calibration, whereas new mmW radars consist of small components which cover less space, more user-friendly and equipped with sophisticated technology.

D. Medical Application

The mmW based communication offers plenty of applications in the areas of medical science such as multi-Gbps communication and mm-wave imaging. For the treatment of a variety of diseases mmW therapy is a low intensity, millimeter wavelength electromagnetic treatment. This is because, mmW does not have enough photonic energy to cause ionization. Hence, mmW is not capable of producing chromosomal alterations in the human body, which are responsible for cancer. In short mmW therapy is helpful in detection of a brain stroke, bone fracture, breast cancer etc., through mmW tomography.

E. Multimedia World

This frequency band can be used in indoor communications, WLAN and PAN because of mmW radio band substantial edge and support over delivering sufficient bandwidth signal transmission capabilities for the purpose of various multimedia supported applications. It is also imperative for high-speed wearable devices that include applications like cell phone connectivity, smart watches, garments, glasses, handheld and other wireless electronics wearable devices [21].

F. Satellite Communication

In satellite communication repeaters can be used at mmW frequencies. Uplink frequency to receive signal is 36 GHz or 96 GHz or 62 GHz and downlink frequency to re-transmit signal, in this case, is 34 GHz or 94 GHz or 60 GHz. These satellites make use of low power amplifiers to have proper utilization of solar energy available on the board of the satellite. For this high gain and high directional antennas are required. Carrier frequencies of 94 GHz/60 GHz/30 GHz must be used keeping in view of the smaller size of all the system components because of which there is less power requirement [22].

Modern mmW radio systems for indoor as well as for most outdoor areas require beam steering with high gain capabilities antenna arrays to support beam switching for reconfigurable backhauling along with freely user mobilization [23].

V. FUTURE SCOPES AND CHALLENGES

With the demand and requirement of new frequency band for wireless communication systems, mmW emerges out to be an alternate for short and long range communications. However, there are few challenges that should be tackle and require immediate attention before any further progress made. In this section, we shall highlight the scope of mmW and the challenges that we would face in near future.

A. High Data Rate Transmission

With mmW band with a large unexploited B.W, we can cope up with future challenges of high data rates [13]. The idea of mmW communication is to release the 30-300 GHz frequency band with the possibility of mobile broadband over new 100 GHz spectrum. This idea would enable costly fiber replacement and mobile backhauling for the next-generation wireless technologies This mmW communication would results in low-interference, highly dense heterogeneous communication environment of small cells, low-latency, uncompressed high-definition data for various multimedia supported applications, and wireless approach to the cloud network. The necessity of mmW radio communications due to congestion and high trafficking have brought forth the demand for new signal processing units, sophisticated circuitry requirement, antenna arrays with beam-steering capabilities and high gain, and other wireless communication technologies.

B. Non-Line of Sight Transmission (NLOS)

The entire life cycle of every cellular generation generally last for a decade or less. This is because of the advancement and evolution of latest computer aided software and sophisticated hardware technology [24]. Researchers are focussing towards increasing data transmission range and spatial ability in the millimetre frequency bands with paying special attention in non-line of sight (NLOS) transmission. This ultimately requires highly been steering capability, which can compensate for the propagation loss due to rain fading and attenuation. In addition to the very high gain, the antennas small cells should be able to provide fast adaptive beam steering and create multiple beams for simultaneous service of several mobile users in multiuser (MU) environment and multiple-input multiple-output (MIMO) systems.

C. 5G Communication

MmW communication has become thrust area of importance by researchers, scholars, and scientist for the next generation 5G cellular systems. This is because of the limited, high trafficking, and congested frequency spectrum availability at lower frequency band [24]. However, latest signal processing approaches such as cognitive radio technique freed more frequency spectrums. Even though, this technique is still not much matured and quite efficient, if we want to obtain Gbps data transfer rates [25, 26].

Earlier research work has accomplished the practicality and feasibility of 5G cellular system by way of signal propagation analyses and system capacity studies. Amazingly, there is much initial research work on mmW cellular system, which supports the propagation and desegregation of wireless communication at 60 GHz [10]. From all above discussion, it is quite certain that the succeeding time is shining and hopeful for the communication with millimetre wave.

D. Antenna Designing and Signal Processing

An Antenna is a key factor in mmW systems or in any communication system. To keep the antenna aperture constant, the antenna designing and increase in antenna array elements should be accomplished carefully. This should eliminate the possibility of frequency dependency on path loss, as the scenario exists with the omnidirectional antennas. It must also compensate the larger thermal noise bandwidth by providing a net array gain. This is possible with Adaptive antenna arrays technique with steering beams capability that also reduces the impact of interference.

The system based on mmW frequencies more often work under noise-limited conditions instead of interference-limited conditions that leads to more secure communication. Because, the reliable communication might only occurs under the conditions of adequate antenna array gain, high directivity, and signal processing access protocols. Adaptive array processing algorithms are imperative and mandatory for mmW radio communication as it accommodate rapidly when signals are halted by people, surrounding or some other device antennas. Also, the signal beams might become obscured and blurred by the user's own structure [27].

VI. CONCLUSION

The main advantages of moving towards mmW communication are to provide larger spectral bands/channels. For example, 2 GHz bandwidth channels are quite common and standard for communication systems operating at 60 GHz, This will provide high data rates output. Communications using mmW are not only just a change of frequencies, but it also offers challenges for the prior developments in signal processing, antenna designing, and hardware techniques. As analogues to the counterparts at the lower radio communication links, transceiver architecture at mmW frequencies would have to meet with dissimilar demands and requirements. With the objective of achieving an adequate SNR, less B.W efficient modulation schemes become attractive. At these mmW frequencies, large sized antenna arrays might be used for both transmission and reception with enhanced radiation performances. Moreover, MIMO systems could be employed for this purpose.

So, there are various challenges and research issues which are absolutely essential and imperative to resolve at mmW communication. Such as, channel modeling, precoding, beamforming, transceiver design, channel estimation, antenna designing and even though many areas which are application specific. Hence, there is bright future and scope hereafter in the antenna designing, signal processing, and other wireless communications areas at mmW.

In this paper, it is concluded that how mmW is useful for fulfilling the demand of today's world in each area because of its wider applications.

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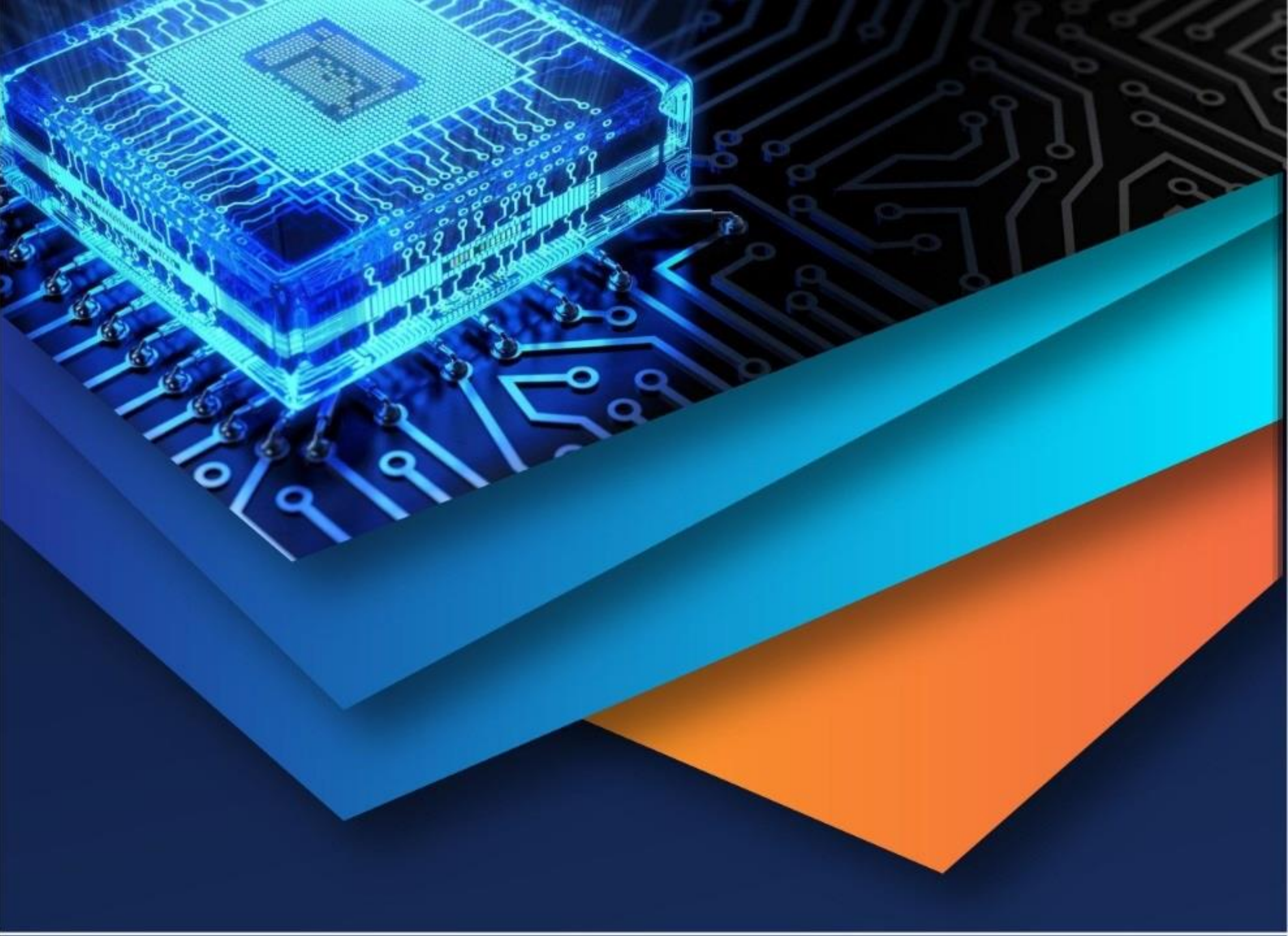

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