iJRASET
International Journal For Research in Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH
IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 14 Issue: II Month of publication: February 2026

DOI: https://doi.org/10.22214/ijraset.2026.77163

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 14 Issue II Feb 2026- Available at www.ijraset.com

Development of an Improved Smart Healthcare Applications Through Visible Light Communication Networks

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Abstract: Visible Light Communication is an emerging technology that leverages the visible light spectrum for wireless communication. As medical sensing technologies and smart healthcare operations continue to progress, hospitals' needs for wireless communication are growing. The increasing demand for efficient and reliable healthcare services Due to the large number of wirelessly connected devices and data-rate-hungry applications, the available Radio Frequency spectrum is limited and getting more crowded. As a result, Radio Frequency based wireless networks are unable to support the low-latency and broadband requirements of applications in future hospital. The widely used open-source network simulator ns-3 is used to construct our simulation testbed. We compare two simulated networks in order to assess the suggested protocol. One network uses the conventional Time Division Multiple Access protocol without enabling Quality of service. Regardless of the priority level of their data, all users in this network share the same amount of time slots. To meet user demands for quality of service, we implement the priority-aware Time Division Multiple Access protocol in the second network. The results confirm that VLC, when optimized through the Development of an Improved Smart Healthcare Application through Visible Communication Network Scheme, offers a transformative solution for hospital wireless communication networks. By achieving ultra-low latency less than one millisecond, high throughput (up to 10 Gbps), and superior packet delivery ratios (95%), Development of an Improved Smart Healthcare Application through Visible Communication Network addresses the critical demands of smart healthcare applications.

I. INTRODUCTION

As medical sensing technologies and smart healthcare operations continue to progress, hospitals' needs for wireless communication are growing. For instance, real-time patient monitoring is becoming more and more crucial in hospitals as it can help medical professionals quickly identify and respond to changes in a patient's condition. Researchers are also interested in robot-assisted wireless networks because they can be used for precision surgeries, medication delivery, or assistance in high-risk environments (like the COVID pandemic) Tian et al., (2019). In the future, medical holography will likely be used for surgical planning and guidance, medical education and training, and medical simulations. All of these applications will require wireless communication in hospitals. Thus, it's important to make sure hospital networks can handle this quick expansion while maintaining the best possible standard of care. Hospital settings and upcoming smart health applications, however, present serious design issues for wireless networking systems because of the following features Mbunge et al., (2021):

A. Electromagnetic Interference Limitation

Hospitals are in charge of managing the amount of electromagnetic interference (EMI) brought on by wireless communication since they must adhere to electromagnetic compatibility (EMC) regulations. This is due to the fact that hospitals house vital medical equipment that is susceptible to electromagnetic fields, such as magnetic resonance imaging (MRI), electrocardiograms (ECG), and electroencephalograms (EEG) Wang et al., (2023)

B. High Demand Limitation

Healthcare networks are desired to have high bandwidth and low latency in addition to worries about EMC. One program that is frequently used in medical settings is real-time video conferencing, which is infamous for being extremely data-hungry. Coordination between the several doctors, medical professionals, and surgeons who work together is made possible by video conferencing, which is a vital tool to enable the provision of excellent care.

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In addition, a lot of people in rural areas rely on remote telemedicine conferences to communicate and receive medical advice along with their medical staff Verma et al., (2023). Large volumes of data are also produced by medical imaging, some of which may require wireless transmission. As regular hospital treatments become more convenient and quicker thanks to portable imaging equipment like cordless ultrasound devices, this is becoming more and more common. The increasing sophistication of smart healthcare operations is another factor contributing to the burden on hospital wireless networks. Hospitals are seeing an increasing number of linked, internet-enabled medical devices and data-driven patient care apps, as is the case in many other sectors Aminizadeh et al., (2024).

II. PERFORMANCE EVALUATION METRICS

The metrics used to evaluate the efficiency of the EMDAPP-scheme were Network Latency, Packet Delivery Ratio (PDR), and Network Throughput.

1) Network Latency: Network latency is the amount of time it takes for a packet of data to go from its source to its destination inside a network. The time it takes for a data packet to go from a sender to a recipient and back is known as "ping time," and it is measured in milliseconds (MS). Latency and ping time are frequently used interchangeably. By calculating the average of all messages that are delivered correctly, the network latency can be determined. Consequently, the latency is influenced by the packet delivery ratio. As the distance between the source and the destination grows, so does the likelihood of a packet drop. All network latencies, including buffering route discovery latency, are included in the network latency Zhou et al., (2021). The following formula is used mathematically to determine the network latency

$$Latency = \frac{R*T - S*T}{Packets\ Sent}$$

Eq-1

Where Latency is the network latency, ST is the time packets are sent from the source node and RT is the time packets are received at the destination node.

2) Packet Delivery Ratio (PDR): PDR, which is a network metric, is the proportion of total packets delivered to total packets sent from source nodes to destination nodes expressed in percentage. The goal is for the greatest amount of data packets possible to arrive at the intended location. The network's performance rises in connection with the value of PDR. Kheradmand et al., (2022). The PDR can be expressed as follows:

$$PDR\ (\%) = \frac{\Sigma Packets\ Deliverd}{\Sigma Packets\ Sent}\ x\ 100$$

Eq-2

3) Network Throughput: A VANEs throughput is measured in terms of the number of packets that are successfully sent over the network during a given period of time. The total number of packets that have been successfully delivered to the desired nodes is counted as part of the process of measuring the throughput put for a link that connects two nodes. An excellent sign of improved performance is an increase in the values of the throughput. A bit per second (sometimes written as bps) is the unit of measurement for this quantity Deng et al., (2022). The throughput of a system can be mathematically described as in the following equation:

$$Throughput = \frac{Packet\ size}{Total\ tramsmission\ Time\ (bps)}$$ Eq-3

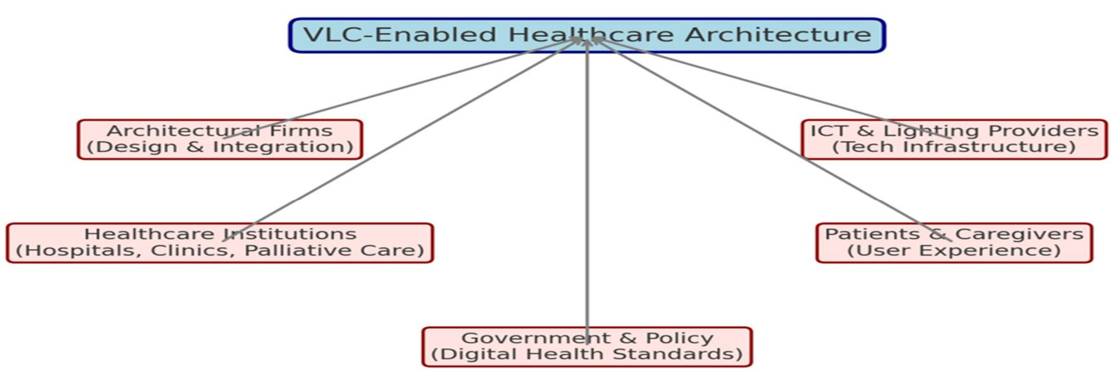

Figure 1: Improved VLC smart healthcare architecture

Figure 1. illustrates how VLC technology connects lighting and ICT providers, healthcare institutions, patients and caregivers, and government bodies setting digital health standards. This integration enables architects to design healthcare environments that are not only functional and human-centered but also digitally intelligent, sustainable, and innovation-driven.

Strategically, this model illustrates an innovation-driven market entry pathway for architectural firms. By positioning themselves as orchestrators of VLC-enabled smart healthcare environments, firms can differentiate their services, build cross-industry partnerships, and access the rapidly expanding smart healthcare sector. The figure thus reinforces how digitalization enables new entry strategies in the architectural services business ecosystem.

A. Existing Algorithm in ESHAVCON

Algorithm
Parameters: slot time t, guard time G, inter-frame spacing I, total slots Ts
Start TDMA Frame
Initialize transmission array, low priority slots LPS = SI I I
for (User associated with AP) do
if User AC == Type I then
Offer transmission slots based on equation 3.5
else if User AC == Type II then
Offer transmission slots based on equation 3.6
else
if $LPS \neq 0$ then
Offer $AI\ I\ I$ transmission slots based on equation 3.7
LPS = LPS - $AI\ I\ I$
else
Defer user to next frame
end if
end if
end for
Broadcast synchronization packet
for (Index in transmission array) do
Select transmission unit TU
Transmit data TU
Wait for guard time G
end for
Wait for inter-frame spacing I
Advertise AP with beacon packet
for (Beacon response) do
if Respondent not associated with AP then
Associate new user
end if
Assign user AC based on traffic type
end

B. Improved Algorithm in ISHAVCOMN

Algorithm
Parameters: slot time t, guard time G, inter-frame spacing I, total slots Ts
Start TDMA Frame
Initialize transmission array, low priority slots LPS = SI I I
for (User associated with AP) do

if User AC == Type I then
Offer transmission slots based on equation 3.5
else if User AC == Type II then
Offer transmission slots based on equation 3.6
else
if $LPS \neq 0$ then
Offer $AI\,I\,I$ transmission slots based on equation 3.7
LPS = LPS - $AI\,I\,I$
else
Defer user to next frame
end if
end if
end for

Modifies area

```
// Receiver Function
std::string receiveData(int num_bytes) {
    std::string received_data = "";
    for (int byte_count = 0; byte_count < num_bytes; ++byte_count) {
        char current_byte = 0;
        for (int i = 0; i < 8; ++i) {
            bool received_bit = readPhotodiode();
            current_byte = (current_byte << 1) | received_bit;
            std::this_thread::sleep_for(std::chrono::milliseconds(50)); // Simulate reception time
        }
        received_data += current_byte;
    }
    return received_data;
}
int main() {
    std::cout << "VLC Simulation Started" << std::endl;

    std::string message = "Hello, Healthcare!";
    std::cout << "Transmitting: " << message << std::endl;
```

C. Broadcast Synchronization Packet

for (Index in transmission array) do
Select transmission unit TU
Transmit data TU
Wait for guard time G
end for
Wait for inter-frame spacing I
Advertise AP with beacon packet
for (Beacon response) do
if Respondent not associated with AP then
Associate new user
end if
Assign user AC based on traffic type
end

III. PERFORMANCE EVALUATION RESULTS

Based on the network latency, packet delivery ratio (PDR), and network throughput measurements covered in Chapter Three, the ISHAVCOMN Scheme's performance evaluation is presented in this section.

A. The Network Latency

Network latency is shown in Figure 4.1, which indicates that as the number of nodes in the network increased, so did the network latency. However, the latency decreases when the numbers of nodes are reduced in the network.

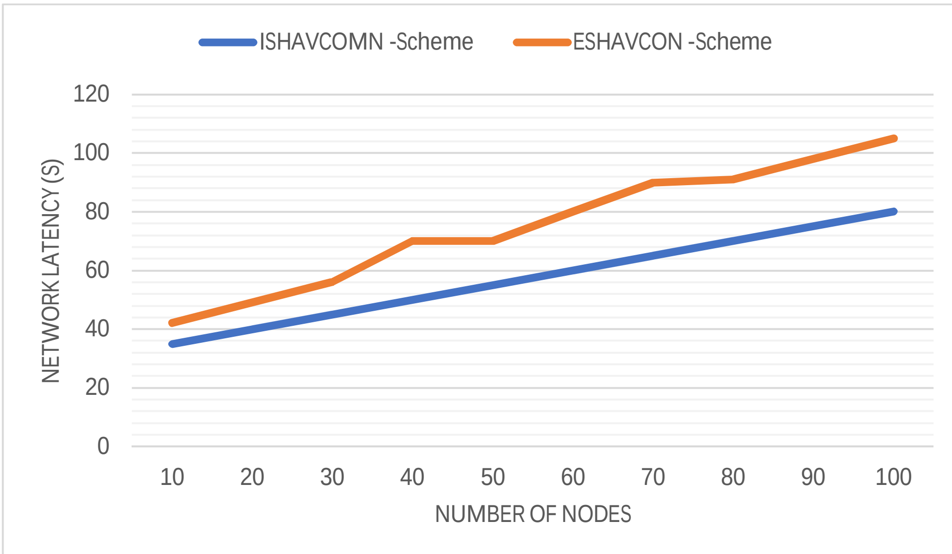

Figure 2: Network Latency Results

Figure 4.1's network latency result demonstrates that the ISHAVCOMN-Scheme outperforms the ESHAVCON-Scheme in terms of performance (low latency) due to the modification of the existing algorithm, which saves time by preserving the history of previously validated and untrusted nodes. However, as more nodes are added to the network, the latency rises, and vice versa.

B. Packet Delivery Ratio (PDR)

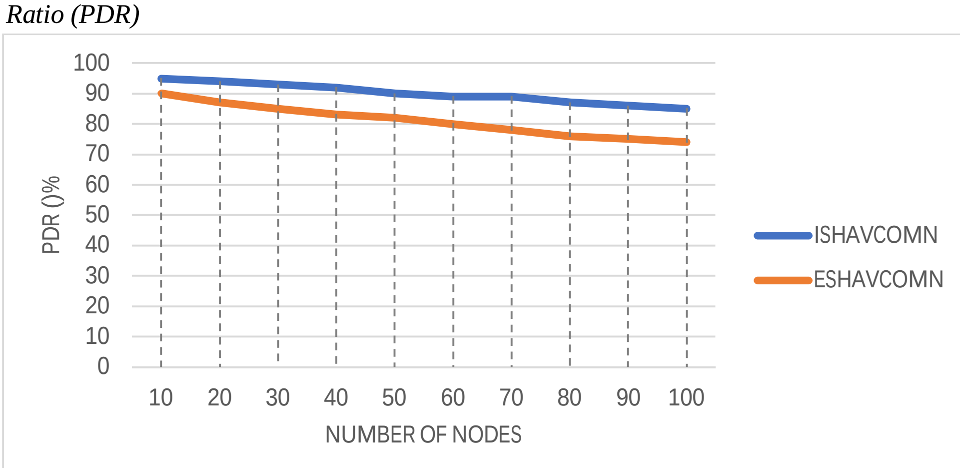

Figure 3: Packet Delivery Ratio

The packet delivery ratio for different node counts is shown in Figure 4.2. According to the statistics above, it has been seen that the percentage of packet delivery decreases as the number of nodes in the network rises and vice versa. However, the modification of the exixting algorithms, which maintains historical data on previously validated and untrusted nodes, improves efficiency, and saves time, is the reason why the ISHAVCOMN -Scheme has a larger percentage of delivery ratio. Since the ISHAVCOMN -Scheme yields the best outcomes and, hence, the best packet ratio, we may conclude that it was more efficient than the ESHAVCON -Scheme.

C. Network Throughput

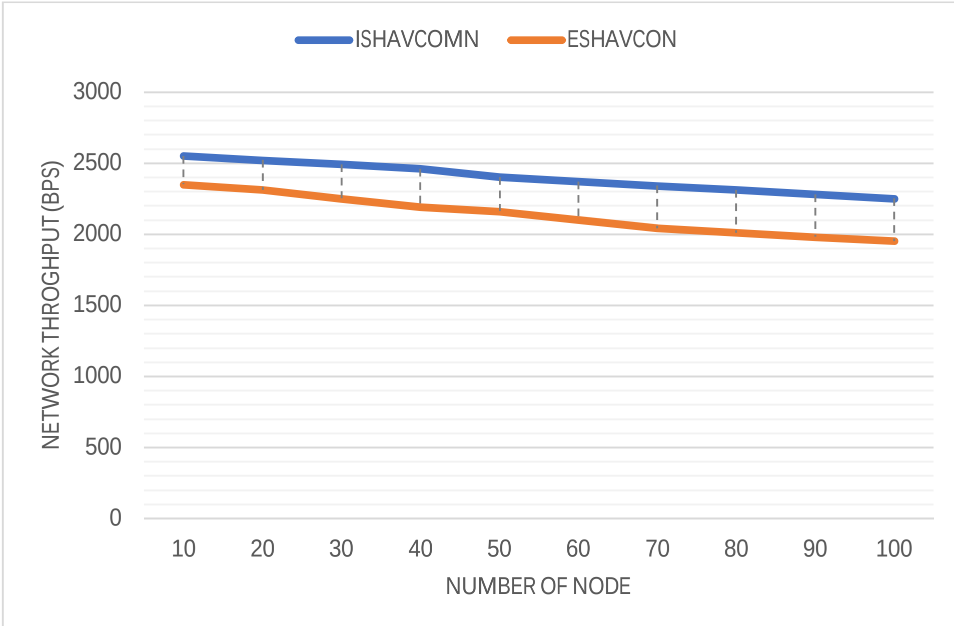

Figure 4: Network Throughput

As can be seen from the result in Figure 4.3, the throughput of the network decreases with the number of nodes in the network; in other words, as the number of nodes in the network increased, the network throughput declined, and vice versa. This lowers processing time and boosts delivery ratio since the network preserves the history of previously verified and untrusted nodes.

D. Overall Network Performance and Improvement

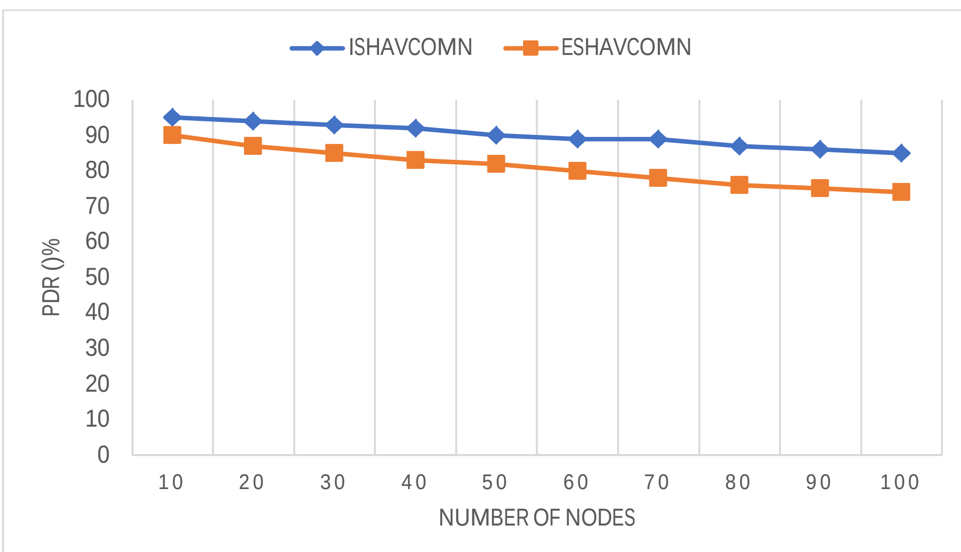

Figure 5. Overall Network Performance and Improvemen

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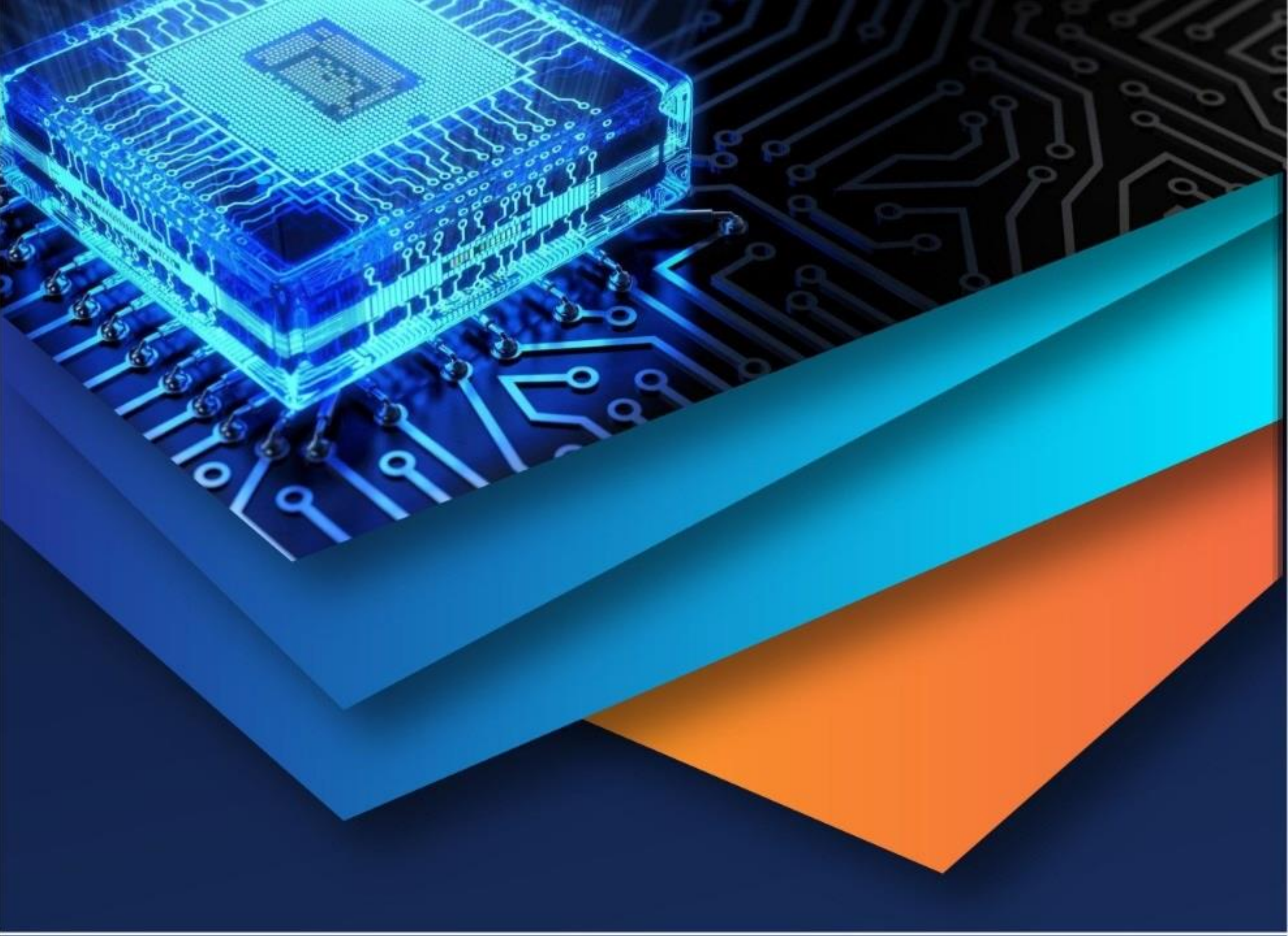

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