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Analysis for Saturation Throughput Using Various Mechanisms for IEEE 802.11 WLAN'S

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Abstract---The IEEE has standardized the 802.11 protocol for Wireless Local Area Networks. The primary medium access control (MAC) technique of 802.11 is called distributed coordination function (DCF). DCF is a carrier sense multiple access with collision avoidance (CSMA/CA) scheme with binary exponential back-off algorithm (BEB). In this paper based on the two types of algorithms that is BEB and Constant Contention Window. In noisy channel, data packets become erroneous, and retransmission reduces the throughput. IEEE 802.11 allows for fragmentation tuning and rate selection to achieve highest throughput in bad channel conditions. If an error rate is known, the parameters like fragment size and contention window can be adjusted to obtain the maximum throughput. In this paper, an analytic model is developed to evaluate the throughput of IEEE 802.11 wireless networks over noisy channels using constant back-off window. The optimal Contention windows and optimal fragment size are calculated using this model.

Keywords---IEEE 802.11a, BEB, Fragmentation, Contention Window, Access Mechanisms.

I. INTRODUCTION

The 802.11a amendment to the original standard was ratified in 1999[1]. The 802.11a standard uses the same core protocol as the original standard, operates in 5 GHz band, and uses a 52-subcarrier orthogonal frequency division multiplexing (OFDM) with a maximum raw data rate of 54 Mbit/s, which yields realistic net achievable throughput in the mid-20 Mbit/s. The data rate is reduced to 48, 36, 24, 18, 12, 9 then 6 Mbit/s if required. The Wireless Local Area Network (WLAN) technology is defined by the IEEE 802.11 family of specifications. There are currently four specifications in the family: 802.11n, 802.11a, 802.11b, and 802.11g. They use the Ethernet protocol and CSMA/CA (carrier sense multiple access with collision avoidance instead of CSMA/CD) for path sharing.

The IEEE has standardized the 802.11 protocol for Wireless Local Area Networks. The primary medium access control (MAC) technique of 802.11 is called distributed coordination function (DCF). DCF is a carrier sense multiple access with collision avoidance (CSMA/CA) scheme with binary exponential back-off algorithm (BEB). DCF describes two techniques to employ for packet transmission, the two-way handshaking technique called basic access mechanism and an optional four way handshaking technique, known as request-to-send/clear-to-send (RTS/CTS) mechanism.

In the IEEE 802.11 standard MAC protocol, the Binary Exponential Back-off (BEB) is used. This algorithm functions in the following way when a node over the network has a packet to send, it first senses the channel using a carrier sensing technique. If the channel is found to be idle and not being used by any other node, the node is granted access to start transmitting. Otherwise, the node waits for an inter-frame space and the back-off mechanism is invoked. A random back-off time will be chosen in the range [0, CW-1][5]. A uniform random distribution is used here, where CW is the current contention window size.

The BEB algorithm is widely used in MAC layer protocols, in this algorithm each node doubles its CW value up to CW_{max} after a collision and resets CW to CW_{min} after a successful transmission [6]. In 802.11 DCF, the value of CW has

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the minimal value CW_{min}. After each collision, the CW will be doubled until reaching the maximum CW_{max}. After each successful transmission, the CW will be reset to CW_{min} regardless of the network conditions such as the number of current competing nodes, this method tends to work well when there are only a few competing nodes. When the number of competing nodes increases, it will be shown to be ineffective since the new collision can potentially occur and cause significant performance degradation. So even the number of nodes has increased to a very large value, the nodes will use the same initial CW. As a result lots of collisions occur and the throughput is deteriorated. Since a node uses CW to control the back-off window, the optimal setting of CW_{min} will affect the performance. In 802.11 DCF, the $CW_{min}$is fixed regardless of the number of contending nodes. In that for each number N of nodes, there is an optimal value of CW_{min}. Where, if it is decrease CW_{min} to a value less than the optimal value, there will be more collision, which will degrade the performance. At the same way, if increase CW_{min} to a value greater than the optimal value, the packet transmitted will suffer from a longer delay, which will also degrade the performance.

II. FRAGMENTATION IN IEEE 802.11

The process of partitioning a MAC service data unit (MSDU) or a MAC management protocol data unit (MMPDU) into smaller MAC level frames, MAC protocol data units (MPDUs), is called fragmentation [7]. Fragmentation creates MPDUs smaller than the original MSDU or MMPDU length to increase reliability, by increasing the probability of successful transmission of the MSDU or MMPDU in cases where channel characteristics limit reception reliability for longer frames. Fragmentation is accomplished at each immediate transmitter. The process of recombining MPDUs into a single MSDU or MMPDU is defined as defragmentation [7]. Each fragment is transmitted individually and acknowledged separately. Once a station has contended for themedium, it shall continue to send fragments with SIFS (short inter-frame space) gap between the acknowledgment (ACK) reception and the start of the subsequent fragment transmission until either all the fragments of a single MSDU have been sent, or an ACK frame is not received. If there is no acknowledgement, the failed fragment is retransmitted after a back-off procedure.

The basic access method

In 802.11, priority access to the wireless medium is controlled by the use of inter-frame space (IFS) time between the transmissions of frames. Totally three IFS intervals have been specified by 802.11 standards. short IFS (SIFS), point coordination function IFS (PIFS), and DCF-IFS (DIFS). The SIFS is the smallest and the DIFS is the largest. The station may proceed with its transmission if the medium is sensed to be idle for an interval larger than the Distributed Inter Frame Space (DIFS). If the medium is busy, the station defers until a DIFS is detected and then generate a random back-off period before transmitting. The back-off timer counter is decreased as long as the channel is sensed idle, frozen when the channel is sensed busy, and resumed when the channel is sensed idle again for more than a DIFS. A station can initiate a transmission when the back-off timer reaches zero. The back-off time is uniformly chosen in the range (0, w-1). Also (w-1) is known as Contention Window (CW), which is an integer with the range determined by the PHY characteristics $CW_{min}$and CW_{max}. After each unsuccessful transmission, w is doubled, up to a maximum value $2m'W$, where W equals to (CW_{min}+1) and $2m'W$ equals to (CW_{max}+1).

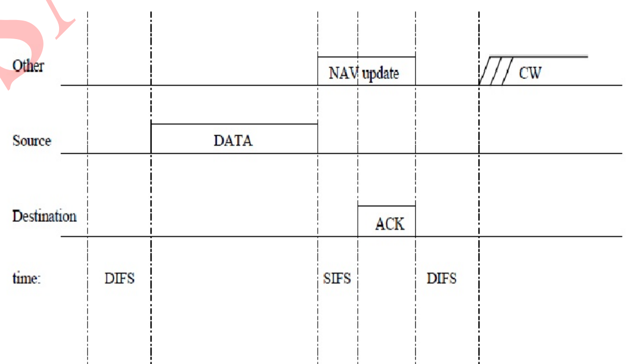

Figure 1.1 Basic access mechanism CSMA/CA protocol

Upon having received a packet correctly, the destination station waits for a SIFS interval immediately following the reception of the data frame and transmits a positive ACK back to the source station, indicating that the data packet has been received correctly. In case the source station does not receive an ACK, the data frame is assumed to be lost and the source station schedules the retransmission with the CW for back-off time doubled. When the data frame is transmitted, all the other stations hearing the data frame adjust their Network Allocation Vector(NAV), which is used for virtual CS at the MAC layer, based on the duration field value in the data frame

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received correctly, which includes the SIFS and the ACK frame transmission time following the data frame[3].

The RTS/CTS access method

RTS/CTS (Request to Send / Clear to send) are the optional mechanism used by the wireless networking protocol to reduce frame collisions introduced by the hidden node problem. Originally the protocol fixed the exposed node problem as well, but modern RTS/CTS include ACKs and do not solve the exposed node problem. A node wishing to send data initiates the process by sending a Request to Send frame (RTS). The destination node replies with a Clear to send frame (CTS). Any other node receiving the RTS or CTS frame should refrain from sending data for a given time (solving the hidden node problem). The amount of time the node should wait before trying to get access to the medium is included in both the RTS and the CTS frame. This protocol was designed under the assumption that all nodes have the same transmission range.RTS/CTS are an additional method to implement virtual carrier sensing in Carrier sense multiple access with collision avoidance (CSMA/CA). By default, 802.11 rely on physical carrier sensing only which is known to suffer from the hidden node problem.

RTS/CTS packet size threshold is 0-2347 octets. Typically, sending RTS/CTS frames do not occur unless the packet size exceeds this threshold. If the packet size the node wants to transmit is larger than the threshold, the RTS/CTS handshake gets triggered. Otherwise, the data frame gets sent immediately. RTS/CTS packets carry the expected duration of the data transmission, which will have some implications.

In 802.11, DCF also provides an optional way of transmitting data frames that involve transmission of special short RTS and CTS frames prior to the transmission of actual data frame. As shown in Fig.1.2, an RTS frame is transmitted by a station, which needs to transmit a packet. When the destination receives the RTS frame, it will transmit a CTS frame after SIFS interval immediately following the reception of the RTS frame. The source station is allowed to transmit its packet only if it receives the CTS correctly. Note that all the other stations are capable of updating the NAVs based on the RTS from the source station and the CTS from the destination station, which helps to combat the hidden terminal problems. In fact, a station able to receive the CTS frames correctly, can avoid collisions even when it is unable to sense the data transmissions from the source station. If a collision occurs with two or more RTS frames, much less bandwidth is wasted when compared with the situations where larger data frames in collision.

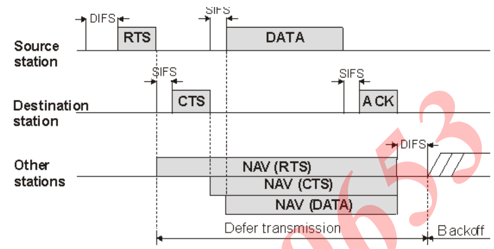

Figure 1.2 RTS/CTS access mechanism in DCF

III. THROUGHPUT ANALYSES

In this throughput analysis, analyze the performance measures of the IEEE 802.11 Distributed Coordination Function (DCF) in saturation in non-ideal channel conditions. Under DCF, data packets are transferred via two schemes. The default scheme is called the basic access mechanism, which transmits the data packet after deferring if the medium is busy. The 802.11 standard also provides an optional way of transmitting data packets, namely the Request to Send/Clear to Send (RTS/CTS) reservation based scheme. This scheme uses the small RTS/CTS packets to reserve the medium when large packets are transmitted in order to reduce the duration of a collision and to deal with the hidden terminal problem.

DCF is based on the Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) technique and adopts a slotted Binary Exponential Back-off (BEB) scheme to reduce collisions due to stations transmitting simultaneously. Each node with a packet to transmit first senses the medium to ascertain whether it is in use. If the medium is sensed to be idle for a time interval greater than the Distributed Inter-Frame Space (DIFS), the station proceeds with the packet transmission. If the medium is sensed busy, the station defers transmission and initializes its random back-off interval. This back-off timer is decremented when the medium is idle and is frozen when the medium is sensed busy. After a busy period the back-off resumes only after the medium has been idle for longer than DIFS.

For the purpose of this analysis is to determine the transmission probability τ of each station in a randomly chosen slot time. Consider the finite number of retransmission attempts $(m + f + 1)$ after which the frame is discarded from the transmit queue and a new frame is admitted in the queue. Let us consider

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finite number of stations in the network, n. it is reasonable to assume that after performing Carrier Sensing, the station will find the channel occupied, re-enter backlog condition, and immediately start executing Collision Avoidance procedure, i.e. the binary exponential back-off algorithm.

The random number for the back-off timer is chosen in the interval (0, *CW*-1), where *CW* is the contention window size. The value of *CW* depends on the number of failed transmissions of a packet.

Therefore,

$$\begin{Bmatrix} w_i = 2^{i'}.w, i \leq m' \\ w_i = 2^{m'}.w, i > m' \end{Bmatrix} \quad (3.1)$$

After the successful reception of a packet in the destination station, an immediate positive acknowledgment (ACK) is sent back after a time interval equal to Short Inter-Frame Space (SIFS). Since SIFS is shorter than DIFS, the station sending an ACK attempts transmission before stations attempting to send new packets and hence takes priority. If the source station does not receive an ACK, the data packet is assumed to have been lost and a retransmission is scheduled.

The probability τ is that a station transmits a packet in a randomly chosen slot time. Since a station transmits when its back-off timer reaches the value of zero, τ can be found as [2, 4]

$$\tau = \frac{2.(1-2p).(1-p)}{\left(1-(2p)^m\right).(wp) + (1-2p).(w+1)} \quad (3.2)$$

The probability τ is that a station transmits a packet in a randomly chosen slot time. Then the constant contention window is[6]

$$\tau = \frac{2}{w+1} \quad (3.3)$$

In this section is to analyze the saturation throughput and delay of the AFR scheme over noisy channels. Then a station is saturated if, whenever the MAC layer needs a frame to transmit, it can always fill a long enough frame without waiting. The saturation throughput S is defined as the expected payload size of a successfully transmitted frame $E\lfloor L_f \rfloor$ in expected slot duration $E[T]$, i.e. $S = \frac{E\lfloor L_f \rfloor}{E[T]}$. Where $E[T]$ is the expected state durationAltogether, there are three kinds of events in the AFR scheme.

• Idle duration T_I : When all STAs are counting down, no station transmits a frame then

$$T_I = \sigma \quad (3.4)$$

Where σ = PHY layer time slot

• Success/Error duration T_3: When a frame is successfully transmitted or it is corrupted due to channel noise, the slot duration is the sum of a frame, a SIFS, and ACK duration

$$T_3 = T_{hdr}^{phy} + T_f + T_{ack} \quad (3.5)$$

Where T_{hdr}^{phy} = Time duration to transmit the PHY header of one frame

T_{ack} = Overhead for transmitting an ACK frame

T_f =Time duration to transmit payload of one frame

• Collision duration T_C : When two or more stations transmit at the same time, a collision occurs. In this case, the sender waits for an EIFS before the next transmission, and so

$$T_C = T_{hdr}^{phy} + T_f + T_{EIFS} \quad (3.6)$$

Where T_{hdr}^{phy} = Time duration to transmit the PHY header of one frame

T_f =Time duration to transmit payload of one frame

T_{EIFS} =Time duration of EIFS

The expected state duration are $E[T] = P_I T_I + P_3 T_3 + P_C T_C$, where P_I, P_3, P_C are the probabilities of Idle, Success/ Error, and Collision events, respectively. Let τ denote the STA transmission probability and n the number of STAs in the system. Then

$$P_I = (1-\tau)^n \quad (3.7)$$

$$P_3 = \binom{n}{1}\tau(1-\tau)^{n-1} \quad (3.8)$$

$$P_C = 1 - P_I - P_3 \quad (3.9)$$

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Letting p_f denote the probability of doubling the contention window after a transmission, τ can be expressed as a function of p_f using a Markov chain similar to that of Bianchi's. In more detail, Bianchi's model assumes there are no errors in the channel, so

$$p_f = p_c = 1-(1-\tau)^{n-1} \qquad (3.10)$$

Where p_c is the STA collision probability.

However, the noisy channels occur. In this case, if the contention window is reset after an erroneous transmission, then $p_f = p_c$ if the contention window is doubled, then $p_f = p_c + p_e - p_c \cdot p_e$, where p_e stands for the frame error rate. In the AFR scheme, the receiver sends back the ACK frame in both successful and erroneous cases, thus $p_f = p_c$ and the Bianchi's formula [3] could in fact be applied without change. The Bianchi assumes a frame can be retransmitted infinite times, which is inconsistent with the 802.11 specification.

Then the saturation throughput S_{AFR} of the AFR scheme from [5]

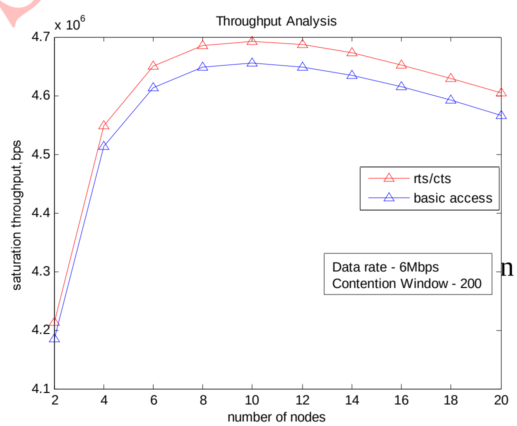
$$S_{AFR} = \frac{P_3 \cdot L_f \cdot \left(1 - p_e^{frag}\right)}{P_I \cdot T_I + P_3 \cdot T_3 + P_C \cdot T_C} \qquad (3.11)$$

4. Simulation Analysis

This section provides simulation parameter settings for the IEEE 802.11a, conventional multi-hop system and the PMCA based multi-hop system performance evaluation. For the IEEE 802.11a, the performance metric's models described. The complete set of simulation parameters [1] and their initial values are shown in table 4.1

Table 4.1 Simulation Parameters

Description	Range of Values
Slot	9 us
SIFS	16 us
DIFS	34 us
PLCP Preamble	144 us
PLCP Header	48 us
CW_{min}	15
CW_{max}	1023
Channel bit rate	6,9,12,18,24,36,48,57 Mbps
MAC header	28 us
Propagation delay, δ	2 us
PHY Header	48 us
MAC header	224us
ACK	14octets + PHYpre/hdr
RTS	20octets + PHYpre/hdr
CTS	14octets + PHYpre/hdr
packet payload	8184 bits



n the optimal value, the pack

Figure 5.1 Number of Nodes Vs Saturation Throughput

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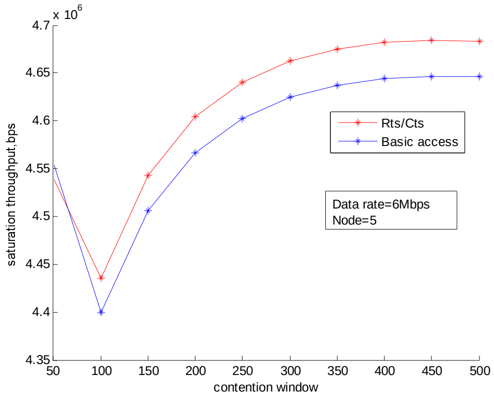

Figure 5.2Contention Window Vs Saturation Throughput

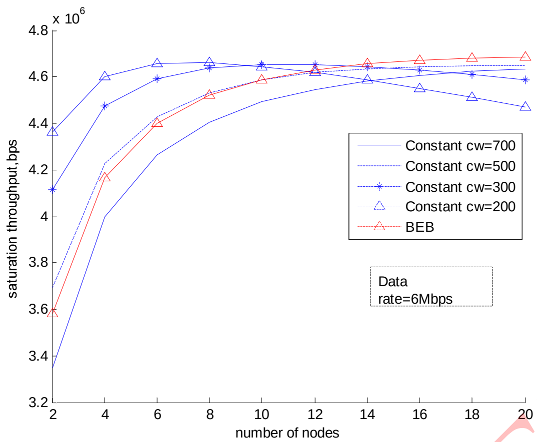

Figure 5.3 Number of Nodes Vs Saturation Throughput for various mechanisms

From the above figure 5.1, we analyze the Nodes vs saturation throughput for 6Mbps data rate. In this we compare the two mechanisms i.e Basic access and RTS/CTS mechanisms and from figure 5.2 analyze the Cw vs Saturation Throughput and figure 5.3analyze the Nodes vs saturation throughput here we observe the optimal window size.

Conclusion

In this thesis, the throughput analysis using the two different algorithms i.e. constant contention window and binary exponential back-off algorithm is analyzed. It can be used in both the basic access and RTS/CTS methods and with fragmentation and without fragmentation. In observing the throughput analysis comparing the BEB and constant CW algorithms, the throughput decreases in BEB compare to the constant CW algorithm. Comparing the basic access scheme and rts/cts scheme, the basic access scheme gets the lowest throughput for comparing the rts/cts scheme.

The throughput analysis is carried out using fragmentation for IEEE 802.11 networks. In this analysis constant contention window is used. In case of errors, only the corrupted fragments are retransmitted instead of retransmitting the whole frame. The analysis presented here is made for the data rate of 6 Mbps and can be applied to higher data rates. The optimal contention windows are determined to achieve the maximum throughput for the specified BER.

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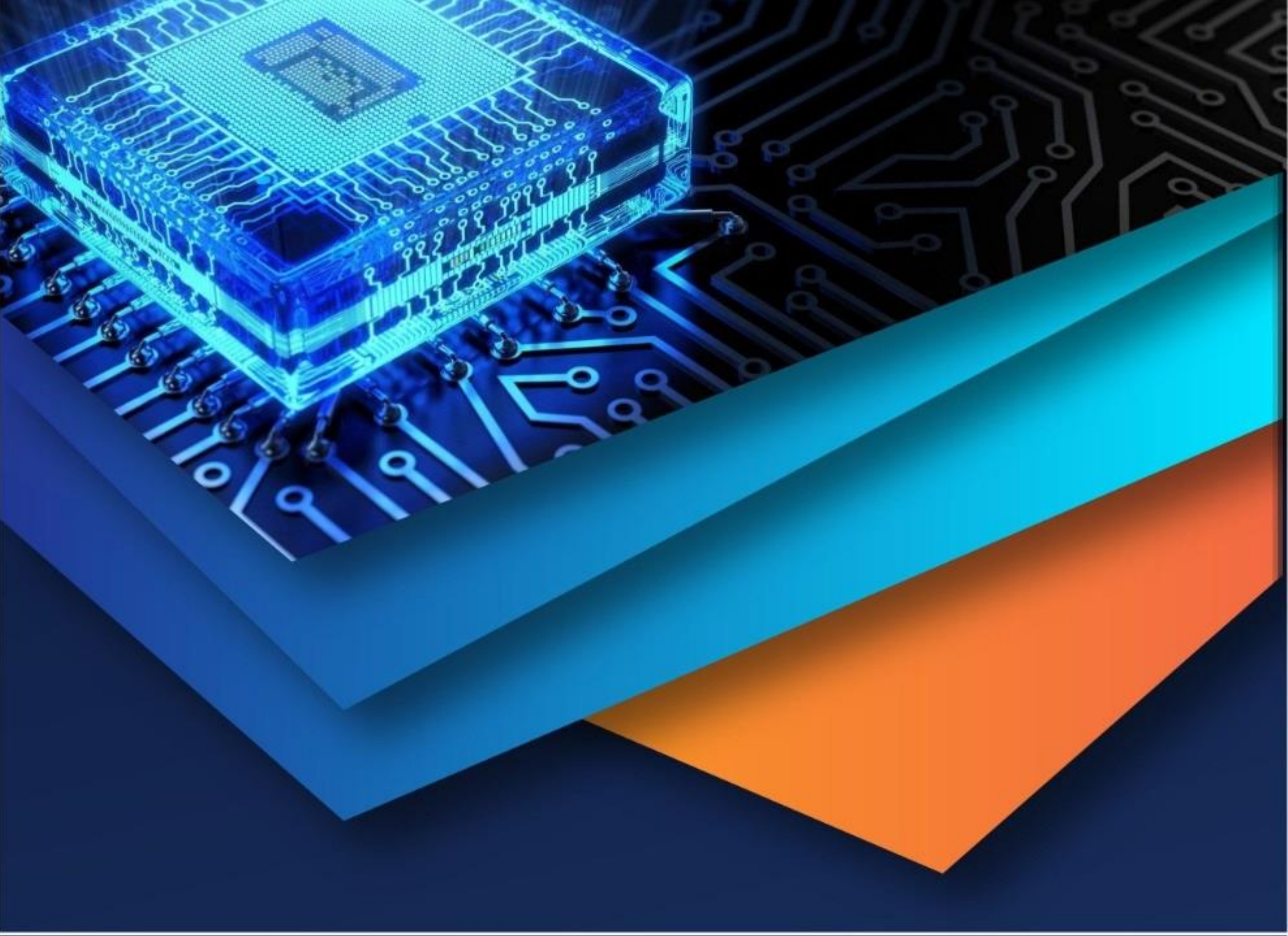

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