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A Fault Tolerant Priority-Based Scheme for Channel Allocation in Cellular Wireless Networks using Quorum

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Abstract- **The effective use of channels is crucial for the performance of cellular wireless networks. The issue of fault tolerance is significant in cellular wireless networks because of mobility, poor quality of wireless links and other constraints. The quorum system has been used effectively in distributed system to handle fault tolerance. In the present exposition, a new quorum system suitable for cellular wireless network has been proposed. The proposed quorum system has been used in a priority-based fault tolerant channel allocation algorithm. The algorithm can be used for any reuse distance and for cells of regular/irregular shapes. The dynamic analysis of the algorithm has also been presented in the paper.**

Key words- **Channel, quorum, reuse, cellular, bandwidth**

I. INTRODUCTION

In cellular networks, effective and efficient use of available bandwidth is utmost important in order to meet the Quality of Service (QoS) requirement of the continuously increasing number of users, especially in developing countries. Additionally, the newer applications are more bandwidth hungry. Hence, the available channels have to be used in an efficient manner. A frequency channel can be reused; between two cells provided that these cells are non-interfering. The minimum distance which must exist between two non-interfering cells is known as the minimum channel reuse distance.

The researchers have proposed several channel allocation schemes for cellular wireless networks. These schemes can be put in to following two categories: centralized schemes and distributed schemes [1]. Since, the centralized schemes suffer from single point of failure these are neither reliable nor scalable and distributed schemes are a preferred option. The distributed schemes can be further divided in to static schemes and dynamic schemes. In static schemes, the number of channels allocated to each cell is fixed. The static schemes are simple in nature, however, despite due to non-uniform call distribution, these schemes normally do not perform well. In dynamic channel allocation schemes, any channel can be used by any cell. A hybrid approach is a combination of dynamic schemes and static schemes. In Hybrid channel allocation schemes, few channels are allocated statically to cells and other channels are available for dynamic sharing between cells.

The search based schemes and update based schemes [1] are the two most important categories of dynamic channel allocation schemes. In search based schemes, a base station starts searching all neighboring cells to compute the set of

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currently available channels whenever it requires a channel. In update based schemes, each cell maintains up to date information about available channels. Whenever a cell acquires or releases a channel, it informs its neighbors, and neighbors update their information. The update based schemes are faster where as the search based schemes shows better message complexity. Therefore, search based schemes are considered better as far as channel utilization is considered, however this efficiency comes at the cost of call setup time.

The cellular wireless networks suffer from link failure (wireless links are less reliable in comparison to wired links), message loss and other faults. The fault tolerance is another desirable feature for a channel allocation scheme in order to handle above mentioned failures. The quorum has been used effectively in distributed systems [2], [3] to handle failure. In the present paper, a quorum system suitable for channel allocation problem has been proposed. Additionally, a search based dynamic channel allocation scheme using proposed quorum system has also been proposed. The scheme is able to handle link failure and message failure and adaptive to satisfy Quality of Service requirements. The rest of the paper can be divided as follows. The section 2 and section 3 contains the related work and the system model respectively. The new quorum system and its properties have been discussed in section 4. Section 5 and section 6 contains the channel allocation algorithm and its correctness respectively. The fault tolerant capabilities of the proposed quorum system have been discussed in section 7. Section 8 finally concludes the paper.

II. RELATED WORK

A comprehensive survey for dynamic channel allocation protocol has been presented by Boukerche-El-Khatib-Huan [1]. Prkash-Shivartri-Singhal [3], proposed the first fault tolerant channel allocation algorithm in 1999. However, the algorithm presented by Prakash-Shivratri-Singhal [3] was only able to handle the failure of MHs and MSSs. Additionally; the failure of MSSs is fail-stop in nature. In 2005, Yang et al. [4] presented a channel allocation algorithm able to handle link failures, network congestion, and/or MSS failures. The authors assumed hexagonal cells and the reuse distance 2r (where r is the radius of hexagonal cell). They divided the 6 cells in to 5 groups of varying size and the request for a channel can be granted if the requesting cell receives the reply from all members of a group. However, this algorithm ceases to work if the replies received by the requesting cell do not satisfy the above mentioned criteria. The algorithm is successful in the scenarios when the area of coverage is divided in to hexagonal cells and the reuse distance is fixed to be r (radius of the cell). The algorithm cannot be applied when the cellular network is divided in to cells which are not hexagonal in shape and the reuse distance is more. Additionally, a cell requesting for channel need to send control messages to all interfering neighbors even if there is no fault. In [5] Yang-Manivannan, proposed a fault tolerant algorithm in which the cells are divided in to k disjoints subsets such that any two cells in the same group do not interfere with each other. The channels are also divided in to k disjoint group PC_0,PC_1--PC_{k-1}. The channels in PC_i are considered as Primary channels for group i and are considered secondary channels for all other cells. A cell requesting for channel gives priority to primary channels and tries for secondary channels in case no primary channel is available. The timeout mechanism has been used by Yang-Manvinnan [5] for detecting a failure. Boukerche-Abrougui-Huang [6] proposed a Quality of Service aware channel allocation protocol. The protocol uses the mutual exclusion model in which the channels are grouped in to three equal sized groups and each group of channels cannot be shared concurrently with the same cluster. The algorithm is handles communication link failure as well as the failure of MH/BS. Chen-Huang [7] proposed a fault tolerant strategy for channel allocation. The strategy is adaptive in the sense that it is capable of handling traffic variation and able to achieve some degree of fault tolerance. The resource allocation technique has been used by Kim [8] to solve the channel assignment problem in cellular network. Cho et al. [9] used eccentric fault tolerant path grouping scheme in order to present a fault tolerance channel allocation scheme.

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The use of quorum system has been used extensively to solve the resource allocation problem in distributed system. The researchers have used quorum to solve the various resource allocation problem such as mutual exclusion [2], group mutual exclusion [10], k-exclusion [11], and extended group mutual exclusion problem [12]. Although, quorum system has been used earlier to solve channel allocation problem in mobile computing systems by Skawratananond-Garg [13], the proposed algorithm was an update based algorithm and because of that the message complexity was still high. Moreover, they assumed hexagonal cells, fixed reuse distance, and six neighbors of each cell and fixed request set. Kumar-Singh-Swaroop[14] presented a quorum system designed specifically for solving channel allocation problem in cellular wireless networks and presented a fault tolerant algorithm based upon proposed quorum system. Additionally Swaroop [15, 16] presented an adaptive general scheme to solve the group mutual exclusion in wired distributed system. The quorum system proposed in [14] was not adaptive and was not able to reduce the message complexity. In the present paper a new quorum system specially designed for channel allocation problem in cellular wireless networks has been proposed. Moreover, a fault tolerant QoS aware channel allocation scheme using the proposed quorum system has also been presented.

III. SYSTEM MODEL

The whole geographical area under consideration is assumed to be divided into cells of any shape (even different shape and size is permissible). Each cell has a BS (base station) at the center serving the MHs (mobile hosts) which are present in the cell. The channel reuse distance is assumed to be d. The frequency spectrum is divided in to frequency channels which can be used for setting up calls. A channel can be reused in two non-interfering cells; however, a channel cannot be used in two non-interfering cells simultaneously. The channels are also required for sending control messages which are also necessarily required in channel allocation algorithm.

A MH wishing to communicate forwards its request to its base station (via a control message). On receiving the request, BS tries to find a channel to support this call. If BS is having any free channel it allocates it to MH else it tries to borrow a channel from the neighboring cells (search mode). However, If BS is not able to find a channel for the requesting MH the call has to be dropped.

When a mobile host moves from cell C_i to cell C_j, this is called as handoff. During a handoff, the mobile host has to surrender the channel received in cell C_i Moreover, cell C_j has to allocate a channel to support this call. If BS at cell C_j is not successful in allocating the channel to the MH the call has to be dropped. In order to reduce the number of calls dropped during handoff, some channels may be reserved for handoff purpose only. The control channels are assumed to be FIFO. The messages may be lost in transit.

IV. NEIGHBORHOOD QUORUM SYSTEM

The use of quorum system helps in reducing the message complexity and achieving fault tolerance in various synchronization problems because a requesting node need not to send the request message to all the nodes of the system but to the members of the selected quorum. The size of quorum can be $O(\sqrt{n})$ if designed properly. The quorum system has fault tolerance capacity because if a member of the selected quorum fails to respond the requesting node may select another quorum from the system.

Let $IN(C_j)$ be the set of interfering neighbors of a cell C_j then a quorum system C for cell C_j is a set of subsets of $IN(C_j)$. Let $C= \{Q_1,Q_2….Q_k\}$ .The proposed quorum system named as *neighborhood quorum system*, must satisfy following three properties:

(a) non-intersection property :

$$\forall Q_i, Q_j \in Q \rightarrow Q_i \cap Q_j = \emptyset \quad ,$$

(b) Covering property: $Q_1 \cup Q_2 \ldots \cup Q_k = IN(C_j)$

(c) Neighbor covering property:

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$$\forall Q_i \in C \rightarrow Q_i \cup IN(Q_{i1}) \cup IN(Q_{i2}) \ldots = IN(C_j) \text{ where } Q_{i1}, Q_{i2} \ldots \text{are the members of } Q_i$$

The non-intersection property and covering property ensures that each interfering neighbor of Cj is the member of one and only one quorum (contrary to normal quorum system in which there must be at least one common element between any two quorums). The neighbor covering property ensures that if a base station C_j requiring a channel receives permission from all members of quorum Q_i then none of the interfering neighbors of Cj has any problem in fulfilling the request of C_j.

The proposed quorum system can be utilized for designing fault tolerant channel allocation algorithms in cellular wireless networks with arbitrary cell shapes and arbitrary reuse distance. In the next section, it has been shown that the new quorum-based algorithms can be used to design a QoS aware channel algorithm location with better message complexity and fault-tolerant capabilities.

V. ALGORITHM

5.1 BRIEF DESCRIPTION OF THE ALGORITHM

In this section, we present the brief description of a search based algorithm using neighborhood quorum system for channel allocation in cellular wireless system. To the best of our knowledge, the quorum systems have not been used in search based algorithms for channel allocation by the researchers till date. The brief description of the algorithm is given below.

When a call is generated in a cell C_i, it first checks whether any channels allocated to C_i is available, if such channels exists it select a channel from these channels. Otherwise, the cell enters in search mode; C_i selects one or more quorums from the quorum system Q and sends a request message to all members of the selected quorum(s). The number of quorums selected presents a tradeoff between the number of control messages required and call setup time. After sending a request message to the neighbors in the selected quorums C_i sets a timer. Let us assume that C_i selects following i quorums (i is at least 1) $Q_1, Q_2, \ldots Q_i$. Now, there are following two possibilities:

(a) C_i receives replies from all members to which reply was sent: In this case, C_i calculates the set of channels which have not been allocated to any of its selected neighbors or itself, if such channels exist; it selects a channel from this set and adds this channel to the list of its allocated channel. Otherwise, it tries to find the set of channels which have been allocated to one of its neighbors but not in use currently. If this set is not empty, C_i selects a channel from this set and consults with the cell C_j to which the selected channel was previously allocated and uses the selected channel on receiving permission from C_j. However, if both the above mentioned sets are empty, C_i checks whether there are quorums which were not selected previously. If yes, it selects quorum(s) out of the unselected quorums and sends again the request message to selected neighbors and waits. Otherwise, it drops the call.

(b) C_i did not received replies from all selected neighbors: On expiry of timer, if C_i has not received reply from all of its neighbors, it may still be able to borrow a channel from its neighbors provided that the following condition is satisfied.

Let R be the set of neighbors from which the cell C_i has received reply on expiry of timer. Let Q_m be the any quorum out of quorums selected by Ci. If $Q_m \subseteq R$ then C_i is still able to borrow a channel from neighbors provided that there is a set of channels that have been allocated to all members of Q_m but is not being used by any member of Q_m. Q_m selects a channel from this set, however, before using this channel C_i has to consult all members of quorum Q_m because any member of Q_m may start using this channel just after sending the reply to C_i. Therefore, C_i can only use these channels after all members of Q_m confirms that they are still not using this channel and allows C_i to use the selected channel. If C_i fails to receive permission from all members of Q_m, it selects another channel from the set if such a channel exists. Otherwise, C_i tries to find another quorum Q_n satisfying the above mentioned condition and the above procedure is repeated with Q_n . However, if $Q_m \subseteq R$ is not satisfied for any selected quorum and the timer expires, it is checked whether some unselected

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quorums are available. If yes another set of quorum different from previously selected is selected and the whole procedure is repeated again. Otherwise, the call is dropped.

When a cell C_i receives a request from cell C_j, it immediately sends its channel uses information to C_j, if C_i is not in search mode or its priority is lower than that of C_j's priority (Priorities may decided using Lamport's logical time stamps [17]). A cell can allow several borrowers' request for the same channel concurrently provided that no two of them are neighbors. Once a cell has allowed to requesting cell (s) for a particular channel, it can no longer use this channel for its own purpose and the borrower does not return the channel to the lender.

5.2. AN EXAMPLE

Without loss of generalization, let us consider an example system with hexagonal cells and reuse distance of 2d.

IN(1)={2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19}

Now, let us consider the possible quorums satisfying neighbor covering property. Quorums with members which are at distance d with 1.

(i) Q1={2,4,6} satisfy the neighbor covering property because 2 covers {2,3,4,5,6,7,8,9,10,11,12} 4 covers {13,14,15,16} and 6 covers {17,18}. Hence IN(2) U IN(4) U IN (6) U Q1=IN (1)
(ii) Q2={3,5,7} also satisfies neighbor covering property.

These two quorums are shortest possible quorums with only three members each.

Quorums with members at distance 2d

(iii) Q3={8,12,16} satisfy neighbor 8 covers {9,10,7,6,2,3,19,18} 12 covers {11,13,14,4,5} and 16 covers {17}. Hence, IN(8) U IN(12) U IN (16) U Q3=IN (1)
(iv) Q4={9,13,17}, {10,14,18} and {11,15,19} also satisfies neighbor covering property.

Fig.1: An example of cellular system

Now, there are 6 quorums each having a size of three and covering all 18 neighbors of cell 1 as shown in figure 1. Let us consider, 1 require a channel and selects 3 quorums {{9,13,17} , {10,14,18}, {3,5,7}} and 1 receives reply from following neighbors R= {3,5,7,9,10,13,17} and could not receive reply from {14,18} because of some fault. Now {9,13,17} and {3,5,7} are subset of R. Hence, 1 tries to calculate a set of channels that have been allocated to all members of either {9,13,17} or {3,5,7} but is not being used by any member. If such a channel exists, 1 consults the neighbors which have replied to 1 and start using it on receiving the reply. On the contrary, suppose, no channel is available with {9,13,17} and {3,5,7}. In such case, 1 selects another quorum(s) (say {{2,4,6}, {8,12,16}, {11,15,19}} and sends a request to all selected neighbors and the algorithm is executed again.

VI. PERFORMANCE AND CORRECTNESS

6.1. PERFORMANCE OF THE ALGORITHM

The number of quorums selected per iteration directly affects the number of control messages required and the waiting time. For example, in the example discussed in section 6, if we select one quorum only 3 control messages will be required in the first iteration. However, if no channel could be selected in the second iteration may be required. The number of control messages required in this case is 3*n where n is the number of

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iterations required (the value of n lies between 1 to 6). The waiting time increases linearly with the number of iterations. The number of possible iterations will depend upon the number of quorums selected, for example, if we select one quorum in each iteration there are 6 possible iterations, if we select 2 quorums per iteration, 3 iterations are possible and so on.

The proposed algorithm is adaptive in the sense that the number of quorums selected can be dependent upon Quality of Service requirement or priority of the incoming call. For example, for a low priority call, one can select only one quorum at a time and thus reducing the number of control messages required at the expanse of possible delay in setting up the call (In case, more than one iteration are required). On the other hand for a high priority call, the cell may select multiple (or even all) quorums in order to reduce the call set up time even if it increases the number of control messages required to setup the call. Since, the number of control messages required in proposed algorithm, number of control channels can be reduced and these channels can also be used for setting up calls.

6.2. CORRECTNESS

Lemma: Two cells are not allowed to borrow the same channel if these are neighbors.

Let us assume the contrary that two cells C_i and C_j have successfully borrowed a channel n_k. Now, there are four following four possibilities:

(a) C_i and C_j have received reply from all their neighbors: Now, C_i must have sent reply to C_j and C_j must have sent reply to C_i regarding n_k. However, due to time stamping of request message these two events cannot be true simultaneously. Hence, case (a) is infeasible.

(b) C_i has received reply from all its interfering neighbors and C_j has received reply from a quorum say Q_i. Because C_i has received reply from all neighbors; C_i must have received reply from C_j. Now, C_j may allow C_i to use the channel n_k only when it is not using or willing to use n_k. Therefore, case (b) is not possible.

(c) C_j has received permission from all neighbors and C_i has received permission from a quorum Q_i: The arguments similar to case (b) are applicable here.

(d) C_i has received permission from all members and channel n_k is allocated to all members of Q_l as well as that of Q_m. Due to neighbor covering property, either Q_l or Q_m may contain in its set of permissible channels, hence, only one cell may borrow the channel n_k. Therefore, case (d) is also not possible.

Our assumption is wrong in all the four cases; hence, it is proved that two cells are not allowed to borrow the same channel, if these are neighbors.

6.3. *FAULT TOLERANT CAPABILITIES*

The issue of fault tolerance is more relevant in cellular wireless systems because the wireless links are more error prone in comparison to static distributed systems. Hence, the fault tolerant capabilities of a distributed algorithm to be used in wireless systems become more desirable. In search based algorithm, Yang-Jiang-Manvinnan [4] used the concept of group in order to allow a cell to borrow a channel even if it has not received the replies from all neighbors. However, there approach is specific to the networks in which cells are hexagonal in nature and reuse distance is R (where R is the radius of a hexagonal cell).

The division of the cellular networks in to hexagonal cells of equal area is not always possible. For example, in urban/semi urban areas the concentration of users per unit is much higher in comparison to rural areas. Hence, the area of a cell in rural area may be larger than the area of a cell in urban area. Moreover, the shape of the cells may not be actually hexagonal because of geographical problems. Therefore, in the present paper, a quorum system has been proposed which can be used for any shape (or irregular shape) of cells and for any reuse distance. Additionally, the quorum system is deadlock free because of the intersection property and provides low message complexity.

The neighbor quorum system is fault tolerant because of the fact that a cell C_i is successfully available to borrow a channel from its neighbors even if it has not received replies from all members due to link failure or base station failure. A

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cell is able to borrow a channel correctly, if it has received replies from all members of a quorum (say Q_l). This is possible because of the quorum system used in the algorithm satisfies the neighbor covering property which requires that the quorum Q_l covers all interfering neighbors of the cell C_i.

VII.SIMULATION

7.1 SIMULATION SETUP

In order to perform dynamic analysis of the proposed priority based scheme we assumed that the system is divided in to hexagonal cells as described in fig. 1 and the reuse distance is 2d. The quorum system is designed according to the properties mentioned above and its details have been given in section 5.2. The results are compared with the scheme proposed by Kumar-Swaroop-Singh [14]. The performance metrics considered are number of messages required to setup a call and the call setup delay. The simulation experiments are performed using a network simulator NS2. The message propagation delay between MH-BS, BS-BS message propagation, average call time all are assumed to be exponentially distributed with average 20ms, 100ms and 10s respectively. Total 100 channels and 1000 Mobile hosts distributed throughout the area under consideration have been assumed.

7.2 SIMULATION RESULTS

For the purpose of simulation, the calls have been divided in to four priority levels (level 1 to level 4) which have been described in table 1. Level 1 is assigned highest priority call and level 6 is assigned to lowest priority call). The following policy
is assumed as far as selection of number of quorums to be activated initially for a call setup purpose.

Table.1: Priority level vs. no. of quorums selected

S. No	Priority level	Number of quorums selected
1	Priority level 1	6
2	Priority level 2	3
3	Priority level 3	2
4	Priority level 4	1

If a call has priority level 1 and cell requires a channel, all 6 quorums will be selected and message will be broadcast to all neighborhoods. However, for priority level 2 calls, initially only three quorums will be selected and if a free channel is not acquired in this attempt only then the other three quorums will be selected in second phase.

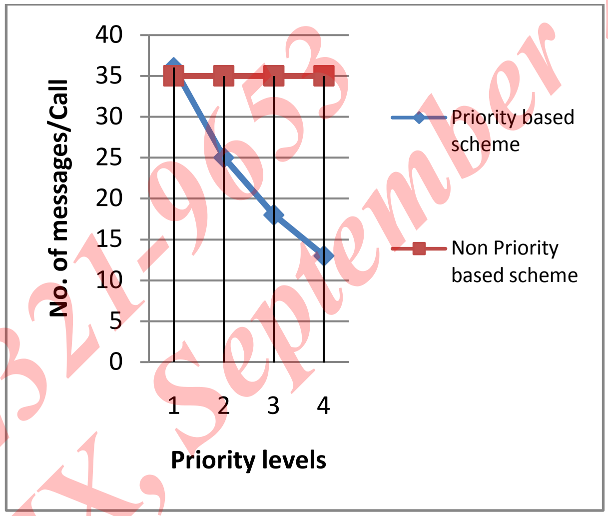

Fig.2: Number of messages per call

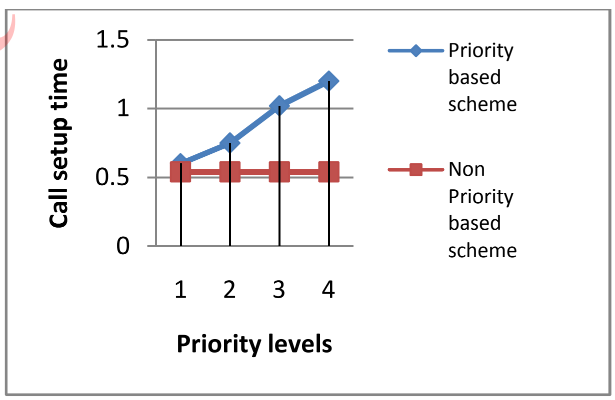

Fig.3: Call setup time

As expected, when we move from higher priority (level 1) to lower priority (level 4) the number of control messages (Fig. 2) required to set up a call decreases significantly. The reason is that when priority level is 1 the request messages will be sent to all neighbors. On the other hand, for lower priority levels selected neighbors (depending upon priority level) will be requested and remaining neighbors will be requested only when previous attempts fails to provide any free channel. The call setup time (Fig. 3) increases when we move from priority level 1 to priority level 4. This is because for lower priority levels some time the free channel may not be available with neighbors initially selected and multiple rounds of requests need to be made.

VIII.CONCLUSION

The present exposition presents a fault tolerant QoS aware scheme for channel allocation in cellular wireless network. The most striking feature of the scheme is that depending upon the user's requirement a priority level may be assigned to each user's call. There is a tradeoff between call setup time and number of control messages required. A high priority user is assigned higher priority to provide better call set up time at the cost of more control messages required. The scheme works even if some of the neighbors fail to respond. As a future work we plan to develop a self adaptive scheme which takes feedback on QoS violations after certain time interval and adjusts itself accordingly to reduced/eliminate QoS violations.

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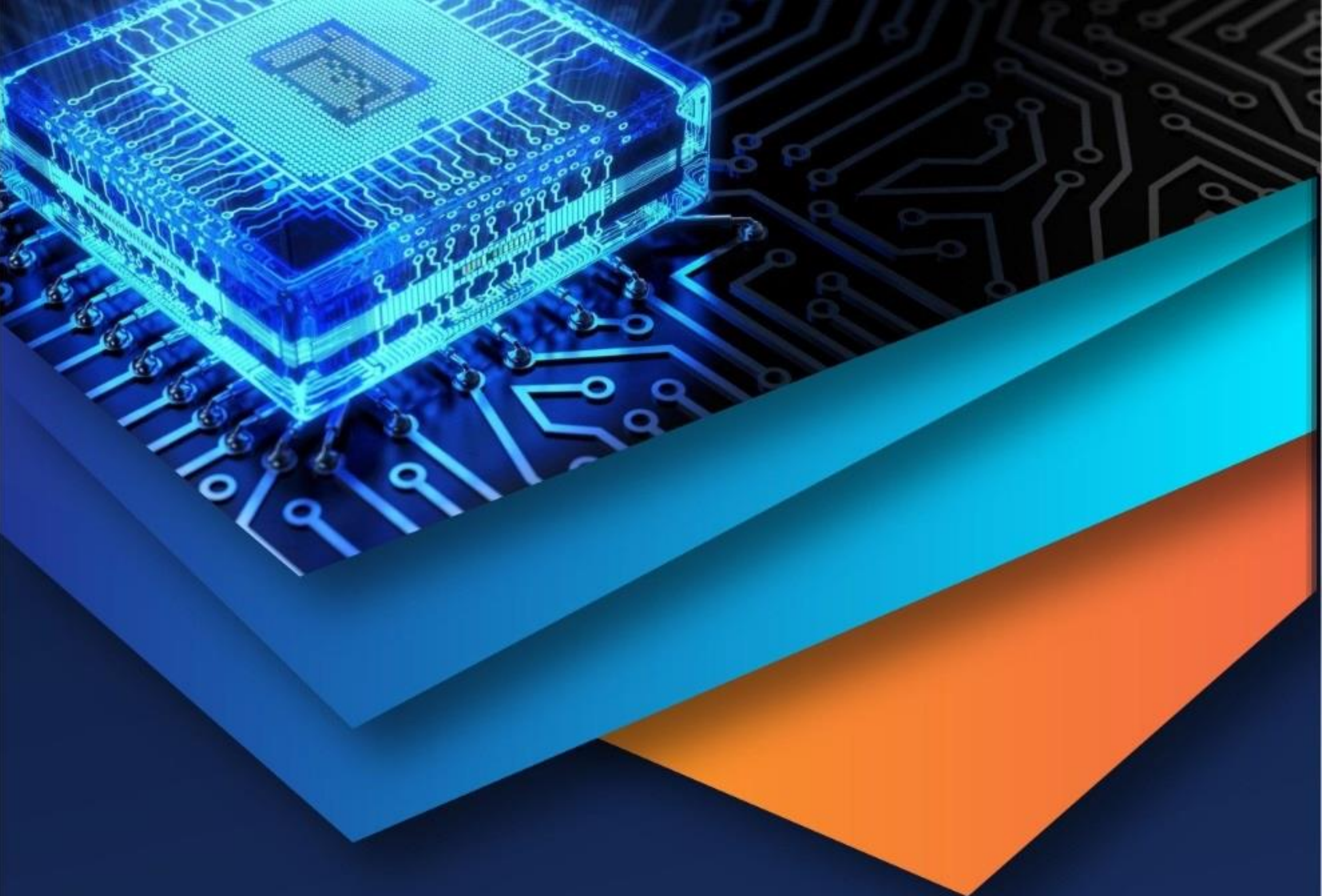

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