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Equal Power and Channel Sensing Over Multiuser OFDM Systems

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Abstract: ***As wireless communication develops rapidly, the value of frequency spectrum increases. Sometimes the spectrum bands are underutilized since the spectrum bands are not always occupied by the licensed users. Cognitive users try to transmit data using spectrum holes. Interference introduced by unlicensed secondary users to primary users makes power and channel allocation problem more complex in nature. It necessitates the need for minimum signal-to-interference-plus-noise ratio (SINR) in cognitive radio. In this project, investigation of joint power and channel allocation problem for the Orthogonal Frequency Division Multiplexing (OFDM) based multi-user cognitive radio systems are performed. Multiuser orthogonal frequency division multiplexing (MU-OFDM) is a reliable technique to achieve high downlink capacities in future cellular and wireless local area network (LAN) systems. Here, the water filling algorithm is used to provide the equal power and channel allocation over the secondary users with respect to the primary users by utilizing the network and data efficiently. Quality-of-service (QoS) in terms of signal-to-interference-plus-noise ratio (SINR) and proportional rate constraints are achieved through the proposed method.***
Keywords: Frequency spectrum, cognitive radio, signal-to-interference-plus-noise ratio, water filling algorithm, Quality-of-Service

I. INTRODUCTION

The wireless spectrum demand has been growing very fast with the enormous development of the mobile telecommunication industry in the past years. In the wireless traffic as assumed by the providers of the wireless service, it seems even larger than 15-fold might possibly increased by the year 2017. This is mainly due to the development and advancement of the devices which are easily handled and accessible such as smart phones, tablets, computers, etc to be able to access wireless network [1]. Application of wireless increases more and more leaving the radio spectrum more crowded which leaves very little room for a new application particularly in the band below 6GHz. Some studies reveal that however, certain portions of spectrum are underutilized very high because of the conventional regulatory policies inefficiently. Cognitive radio (CR) can be viewed as a useful model with a possibility to amend the spectrum utilization. Secondary users (SUs) are permitted in cognitive radio system to be able to sense the registered spectrum which is done by a system which is licensed and if any licensed user is detected by a secondary user in a channel, it then unloose the channel and change it to an empty channel or may wait whether any empty channel is available. Nevertheless, considering the feedback delays, licensed user may face a large interference due to the errors in wireless systems which are not possible to avoid.

SU generated interface should be controlled in a regular manner so as to keep off from the performance degradation of the licensed user which are not possible to avoid. Thus, the CR systems physical layer should be flexible so as to meet these requirements [2]. Cognitive Radio (CR) is a technology which is used commonly, it is capable of accessing to the vacant radio spectrum resource, thus solve the shortage of resource problem also increases the efficiency of frequency spectrum.

A suitable modulation candidate for CR system is considered to be Orthogonal Frequency Division Multiple (OFDM) technology. In this system, the frequency band is divided into a large number of small bands which are called subcarriers and use a particular frequency so that they are absolutely orthogonal to each other which are capable of reducing the mutual interference between the subcarrier and improve the spectral efficiency as well.

Mutual interference is the factor for limiting the performance of both CR and PU since both the systems have the nature of existing in side-by-side bands in cognitive radio network. So, the total power which is assign to the CR users and the total interference which is introduced to the PU band is to be considered during the resource allocation to guarantee that all users are possible to coexist effectively [3].

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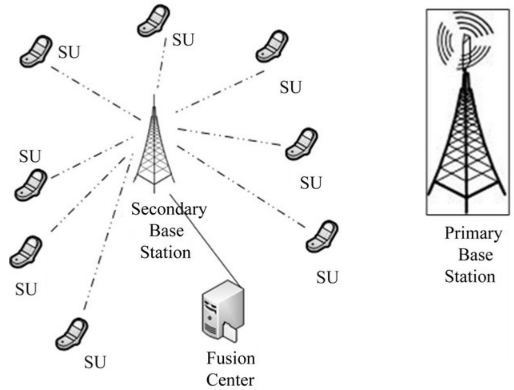

Fig. 1: Primary user and SU distribution

The U.S Federal Communications Commission (FCC) reported in 2002 that several licensed spectrums are temporarily failed to utilize for which the spectrum utilization is in the range of 15% to 85%. A cognitive radio (CR) which can be adapted for wireless transmission on licensed spectrum through sensing and dynamic spectrum access has been proposed so as the spectrum utilization to be improved [4]. In order to improve the utilization of spectrum, cognitive radio has been proposed for wireless transmission on licensed spectrum through spectrum sensing and dynamic spectrum sensing access. Thus, cognitive radio technology advancement helps to be more efficient and intensive spectrum access possible. The FCC starts considering more flexible and inclusive use of spectrum which are available and the definition adopted by [5] FCC about cognitive radio is defined as a system that senses its operational electromagnetic environment and can positively and independently adjust its system operating parameters to modify system operation, such as maximize throughput, mitigate interference, facilitate interoperability, access secondary markets. Cognitive radio (CR) systems make appearance of wireless communication systems that acknowledge efficient utilization of spectrum. This could possible because of the use of transceivers that can detect the presence of primary users which we considered the licensed users. The SUs use the frequency bands initially assign for the PUs for their own transmission as shown in figure 1. Once the activity of the PU's is detected on some frequency channel, the SU avoid any other transmission in this particular channel and may leads to disconnection of service for the SUs, hence degrade the quality of service (QoS) [6]. Opportunistic spectrum access using cognitive radio technology turns out to be a concept for an efficient utilization of RF spectrum by allowing unlicensed secondary users to access the licensed spectrum without causing harmful interference to the licensed primary users. In opportunistic dynamic spectrum access, secondary users are required to either sense the channels then identify the idle bands or search them on the geo-location database to access licensed bands opportunistically [7]. Hence, one main characteristics of cognitive radio is related to autonomously exploiting locally unused spectrum to provide new paths to spectrum access.

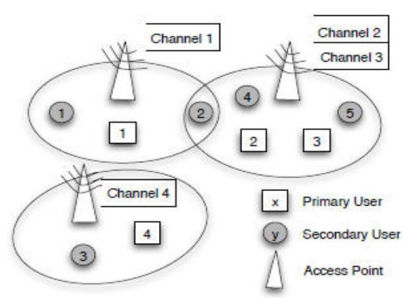

Fig.2: Network structure of the cognitive network

An important factor influencing the efficiency of communication is power allocation, for wireless network because power allocation will influence the interference among different channels and the consumption of energy. In cognitive radio networks, a well-organized power allocation is necessary with large numbers of secondary users communicating with each other. It builds a model as N secondary user pairs (SU) with strategy [si, pi] and one primary user with the strategy which is fixing when it is accessible to the network. The main issue in the design of wireless networks is how to use the resources which is very limited such as bandwidth

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including power most efficiently so as to face the quality-of-service requirements of applications in the field of bit rate and loss. So for that, lots of efforts have been given to develop more advanced physical layer communication skills. A remarkable conviction of task has been on developing multiuser receiver structures which diminish the intrusion between users in spread-spectrum systems [8].

For next-generation wireless broadband networks, multiuser orthogonal frequency division multiplexing (MUOFDM) [9], is one of the auspicious multiple access techniques where several users' signals are transmitted at the same time that is simultaneously over different subcarriers on each OFDM symbol. OFDM technology has been considered as an appropriate modulation candidate for cognitive radio system. In OFDM system, the frequency band is divided into a large number of small bands called subcarriers that use specific frequencies so as to be completely orthogonal to each other, which can not only reduce the mutual interference between the subcarriers, but also improve the spectral efficiency [10]. The optimal power allocation algorithm for conventional OFDM systems that maximizes the channel capacity is the well known water-filling, which is derived by solving a convex optimization problem subject to the sum transmit power constrain. Water filling algorithm provides an optimal solution for the problem of maximizing the throughput of a time varying channel by adjusting the transmitted power based on channel gain. In OFDM-based cognitive radio systems, the band of the SU can be divided into several sub channels, each of which is corresponding to a licensed band of one PU system. Since the interference limit of each PU introduces the sub channel transmit power constraint for the SU, the power allocation in OFDM-based cognitive radio systems should not only satisfy the sum transmit power constraint but also the sub channel transmit power constraints. Therefore, the conventional water-filling algorithm is not applicable in such a scenario. The transmit power in each sub channel is comprised of the power allocated to the subcarriers inside the sub channel and the side lodes power of the subcarriers in other sub channels.

Thus, Wireless communication is the fastest growing sector of the communication industry because of the invention of smart phones and successful deployment of Wi-Fi and cellular networks. Everywhere in any parts of the earth, users are having connection to the internet through their devices. In the era of the Internet of Things (IoT) [11], wireless traffic is increasing exponentially as the number of subscriptions increases. If multiple devices are in connection with the internet, the spectrum scarcity issue which has been because of the static radio frequency (RF) allocation policy will probably worsen it. Thus, dynamic spectrum access using cognitive radio networks could solve the artificial spectrum scarcity issue which allows unlicensed users to access licensed bands opportunistically. Policy levels including the technical challenges are available so as to realize the full dynamic spectrum access in the cognitive radio networks. But also, allocating resources in cognitive radio networks for dynamic spectrum access for an unlicensed secondary users as well as protecting primary users from any possible harmful interference can be very challenging [12].

II. SYSTEM MODEL

Considering a case where a cognitive radio system coexists with one primary system, where K secondary cognitive radio users communicates with a cognitive base station in the uplink and primary users are receiving signals from a primary base station in the downlink [13]. Also considering that a downlink transmission for cognitive radio system where there is a single CR transmitter, transmitting information to K cognitive radio users using the spectrum of bandwidth W. We assume that, in a given geographical location, a contiguous portion of radio spectrum of total bandwidth W is divided into M bands with respective bandwidth, i.e., W_i ($i = 1, 2, \ldots, M$). These spectrum bands are assigned to different group of PUs, and a particular band may not be used in a given time in a given geographical region.

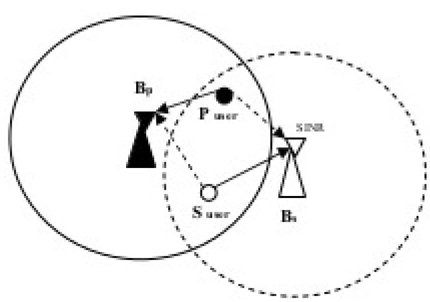

Fig. 3: PU and SU arrangement, base stations are indicated as Bp and Bs respectively.

In figure 3, the left circle with full line circle shows the area of service for the primary system and the dotted circle on the right represents that of the cognitive radio system. The intersection of the two circles constructs what we call the Overlay Region. The other region which is left of the CR service region is called the Hybrid Region. The problem formulation and analysis thereafter apply similarly to the secondary downlink scenario. Supposing that both primary system and CR system are OFDM-based systems, in which the licensed spectrum is divided into N sub-channels of similar bandwidth with each sub-channel involving flat fading. It is also assumed that there is no spectrum sensing error. According to the location of secondary users, resource allocation design should exhibit an adaptive structure, allowing diverse spectrum access methods when the secondary users fall into different service regions. In order to avoid mutual interference among secondary users, we assume that each sub-channel can be at most allocated to one SU and each SU may be allocated more than one sub-channel. In addition, it is assumed that $N \geq K$ and the number of unoccupied channels is larger than the number of SUs located in the Overlay Region. Thus, it is assumed that the CBS coordinates channel and power allocation and spectrum sensing in a centralized manner.

Secondary users are capable of accessing spectrum resources from primary users through opportunistic or negotiation-based methods while not causing harmful interference or channel collision. Flexible spectrum access is possible by allowing secondary users to gain access to multiple primary operators or having multiple secondary users compete for available spectrum. The network users are equipped with cognitive radio devices, which enable them to perform various dynamic spectrum access techniques including spectrum sensing, spectrum management, seamless handoff, and spectrum sharing. The importance of studying dynamic spectrum sharing in a game theoretical framework is multifold. First, by modelling dynamic spectrum sharing among network users (primary and secondary users) as games, the network users' behaviours and actions can be analyse in a formalized game structure, by which the theoretical achievements in game theory can be fully utilized. Second, game theory equips us with various optimality criteria for the spectrum sharing problem [14]. Specifically, the optimization of spectrum usage in DSANs is generally a multi-objective optimization problem, which is very difficult to analyse and solve. Game theory provides us well defined equilibrium criteria to measure game optimality under various game settings (network scenarios in our context). Third, non-cooperative game theory, one of the most important game theories, enables us to derive efficient distributed approaches for dynamic spectrum sharing using only local information. Such approaches become highly desirable when centralized control is not available or flexible self-organized approaches are necessary.

For a multiuser OFDM system, in the base station, all channel information is sent to the sub-channel and power allocation algorithm through feedback channels from all mobile users. The resource allocation scheme made by the algorithm is forwarded to the OFDM transmitter. The transmitter then selects different numbers of bits from different users to form an OFDM symbol. The resource allocation scheme is updated as fast as the channel information is collected. In a cognitive radio system, the transmitted power of secondary users may cause unexpected interference to primary users, whether or not primary users are starting communication on channels currently used by secondary users. Thus, an additional mechanism is needed to protect the communication links of primary users so that the received signal-to-interference-plus noise ratio (SINR) on each primary user is larger than a threshold [10]. In order to maximize the achievable rates of secondary users by satisfying the quality of service and other imposed constraints, the optimization problem focused can be explained as the maximum allowed transmission power is predefined interference power limit of the primary user. Another problem is that each channel can only be allocated to one secondary user. The optimization problem of resource allocation is to maximize the total capacity of CR users while keeping the total interference introduced to the PU band below a certain threshold and the total power allocated to the CR users under a constraint.

III. ALLOCATION OF CHANNEL AND POWER

The formulation of the channel allocation includes two secondary users compete for access in the band [F_1 F_2]. The interference plus noise power is observe by the first user:

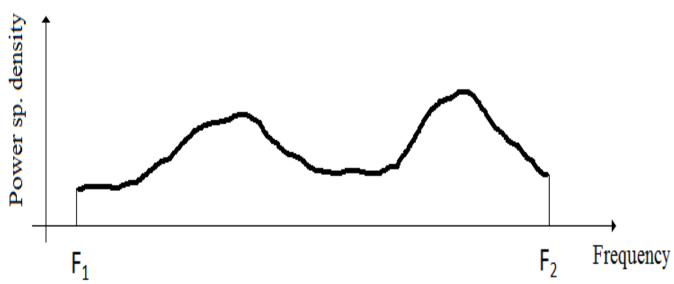

Fig.4: Users compete for access in the bands [F1 F2]

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Channel allocation problem includes the M users compete to access a band. Instead of using the selfish water filter strategy, they cooperate and divide the spectrum among them in the most efficient way. The initial band is divided into a number of non overlapping frequency bins. An algorithm maps the bins to users in such a way that a global utility function is maximized. There are various ways that channel allocation algorithm could be designed which includes distributed or centralized, proactive or on demand, predetermined channel allocation, allocation of contiguous or non-contiguous bins to devices.
There are two issues which are needed to decide when dealing with the subcarrier allocation and it is the core of the bit and power allocation. The first problem is the number of subcarriers that should be allocated to each of the user and the second problem is the procedure of allocation. There are three subcarrier allocation algorithms which can be suggested, those are: Max-Rate subcarrier allocation algorithm (MaxR-SAA), Min- Interference subcarrier allocation algorithm (MinI-SAA) and Fair-Rate subcarrier allocation algorithm (FairRSAA), individually. The power density spectrum will not lead to the debase of the system throughput until the subcarriers are allocated appropriately. Power allocation to all the subcarriers is assumed to be uniform. Thus, to fulfill all the interference thresholds and power constraint, equal power has been allocated.

A. MaxR-SAA

Cognitive radio users are capable of sensing and accessing the spectrum which are not being used in cognitive radio systems so as to progress the efficiency of the spectrum. Attaining the maximum transmit rate of the cognitive radio system is the main goal of the Max-Rate subcarrier allocation algorithm but also maintaining the total interference made known to the primary user band under a certain threshold including the total power allocated to the cognitive radio users within a limit.

B. MinI-SAA

It is a must to make sure that the primary user is able to continue its task with no interruption in a network of the cognitive radio in which the cognitive radio users and the primary users remain next to the other spectrum. Therefore, the interference made known to the primary user band should be as low as possible.

C. FairR-SAA

Unlike other algorithms, the goal for the FairR-SAA is to achieve the fairness among all the secondary users. It allocates subcarriers to the cognitive users by increasing the based step power allocation algorithm and modified equal power allocation algorithm, which have less complexity.

1) *Distance-based step power allocation:* Fixing the step size which is equal to the level of the power of the subcarrier and is also closest to that of the primary user band.
2) *Interference-based step power allocation:* In this scheme, the step size of the ladder is inversely proportional to the sum interference which is made known by the subcarrier allocated to the cognitive radio user to all the primary users.
3) *Modified equal power allocation:* It is possible to allocate equal power to each subcarrier considering the total interference introduced to the primary user. Then, each cognitive radio users are possible to occupy part of the subcarriers after the allocation of the subcarrier. Thus, the modification of the total interference is needed. Hence, the power is then equally allocated

IV. PROPOSED METHOD

A. Cognitive Radio scenario

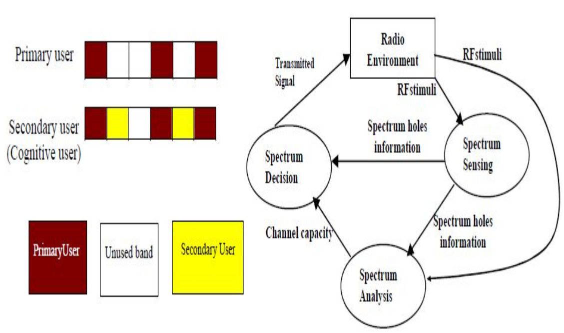

Fig.5 : Cognitive radio scenario and cycle

The block diagram of cognitive radio scenario and the cycle is shown in figure 5. In this section, an overview of the three main steps

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of the cognitive cycle is given: spectrum sensing, spectrum analysis, and spectrum decision. The steps of cognitive cycle as shown in figure:

1) *Spectrum sensing:* A cognitive radio monitors the available spectrum bands, captures the information, and then detects the spectrum holes.
2) *Spectrum analysis:* The characteristics of the spectrum holes that are detected through spectrum sensing are estimated.
3) *Spectrum decision:* A cognitive radio determines the data rate, the transmission mode, and the bandwidth of the transmission. Then, the appropriate spectrum band is chosen according to the spectrum characteristics and user requirements.

Once the operating spectrum band is determined, the communication can be performed over this spectrum band. However, since the radio environment changes over time and space, the cognitive radio should keep track of the changes of the radio environment. If the current spectrum band in use becomes unavailable, the spectrum mobility function is performed to provide a seamless transmission. Any environmental change during the transmission such as primary user appearance, user movement, or traffic variation can trigger this adjustment.

B. Water filling Algorithm

The optimal power allocation algorithm for conventional OFDM systems that maximizes the channel capacity is the well known water-filling.Water filling algorithm provides an optimal solution for the problem of maximizing the throughput of a time varying channel by adjusting the transmitted power based on channel gain.Water filling algorithm follows the simple strategy of pouring water into a vessel with its surface defined by the inverse channel gain (hj-1). When hj-1 is small, more power is transmitted in the corresponding sub carrier and when hj-1 increases, the transmitted power in the corresponding sub carrier is significantly reduced.

In other words more power is allocated to a better channel to maximize the throughput of the system.In OFDM-based cognitive radio systems, the band of the SU can be divided into several sub channels, each of which is corresponding to a licensed band of one PU system. The interference limit of each PU introduces the sub channel transmit power constraint for the SU.So, the power allocation in OFDM-based cognitive radio systems should not only satisfy the sum transmit power constraint but also the sub channel transmit power constraints. Therefore, the conventional water-filling algorithm is not applicable in such a scenario.The transmit power in each sub channel is comprised of the power allocated to the subcarriers inside the sub channel and the side lodes power of the subcarriers in other sub channels.

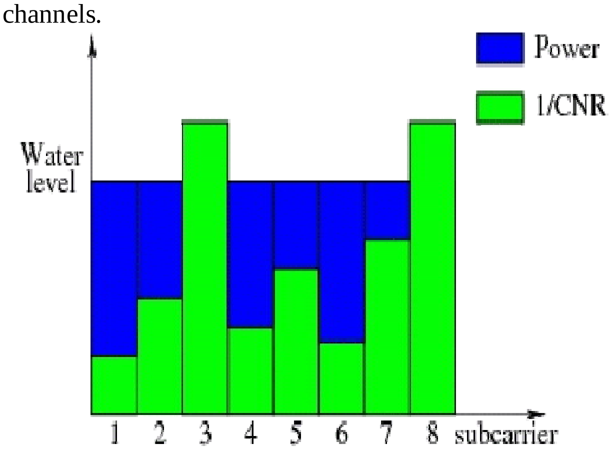

Fig.6: Water Filling Algorithm

V. RESULT

A. Channel Allocation

One scenario which we simulated in Matlab is given below. Interval between each symbol assigned the frequency value. Red boxes are secondary users with their protection ring and green ones are primary users with their reliable detection ring. The total number of the sub-channel is assigned to be 40 while the assigned sub-channel is 32 creating one random signal. The length of the coverage area is assigned to be 2. Secondary users (SUs) are allowed to sense the spectrum registered by a licensed system and use the idle band of spectrum in an opportunistic spectrum access manner; that is, if an SU detects the presence of a licensed user (LU) in a given channel, it releases the channel and switches to a vacant channel, or waits in a pool if no vacant channel is available.

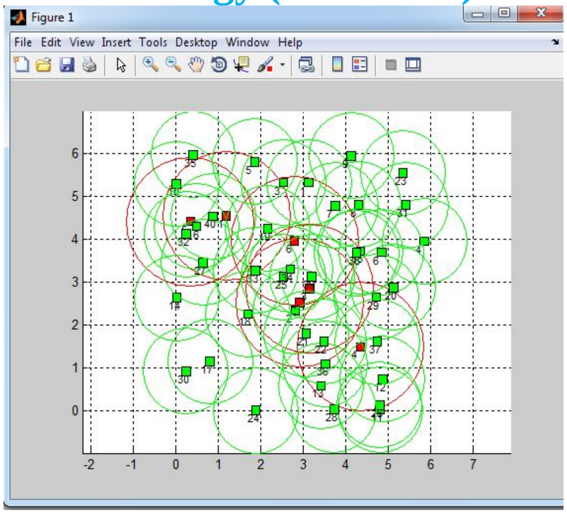

Fig.6: Result of the simulation for channel allocation

B. Power Allocation

The power allocation has been done using an algorithm called water filling algorithm and the result for power allocation is shown in figure 7 below.

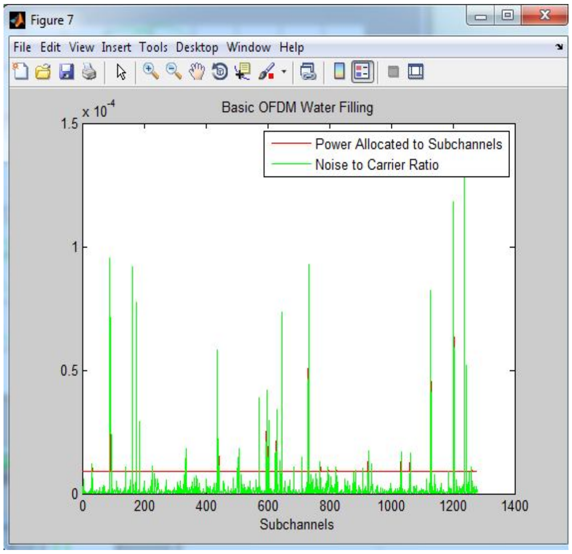

Fig .7: Graph showing allocation of power with respect to noise to carrier ratio.

VI. CONCLUSION AND FUTURE ENHANCEMENT

From the simulation results, it is found that the signal is being transferred from the one user to the other user in each path, this helps solve the serious problem of scarcity of resources to some extent. The water filling algorithm has been implemented successfully. It can be observed that water filling algorithm serves as a good technique for equalizing channel and power allocation and hence has an advantage of possibility for multiple users which in most cases possible only for a single user.

The power spectrum allocation has always been a serious problem due to scarcity of resources. For further development of this project, an attempt to equalize the power and channel allocation by means of modifying the Water filling Algorithm which is by implying a Sum Power Iterative Water-Filling Algorithm.

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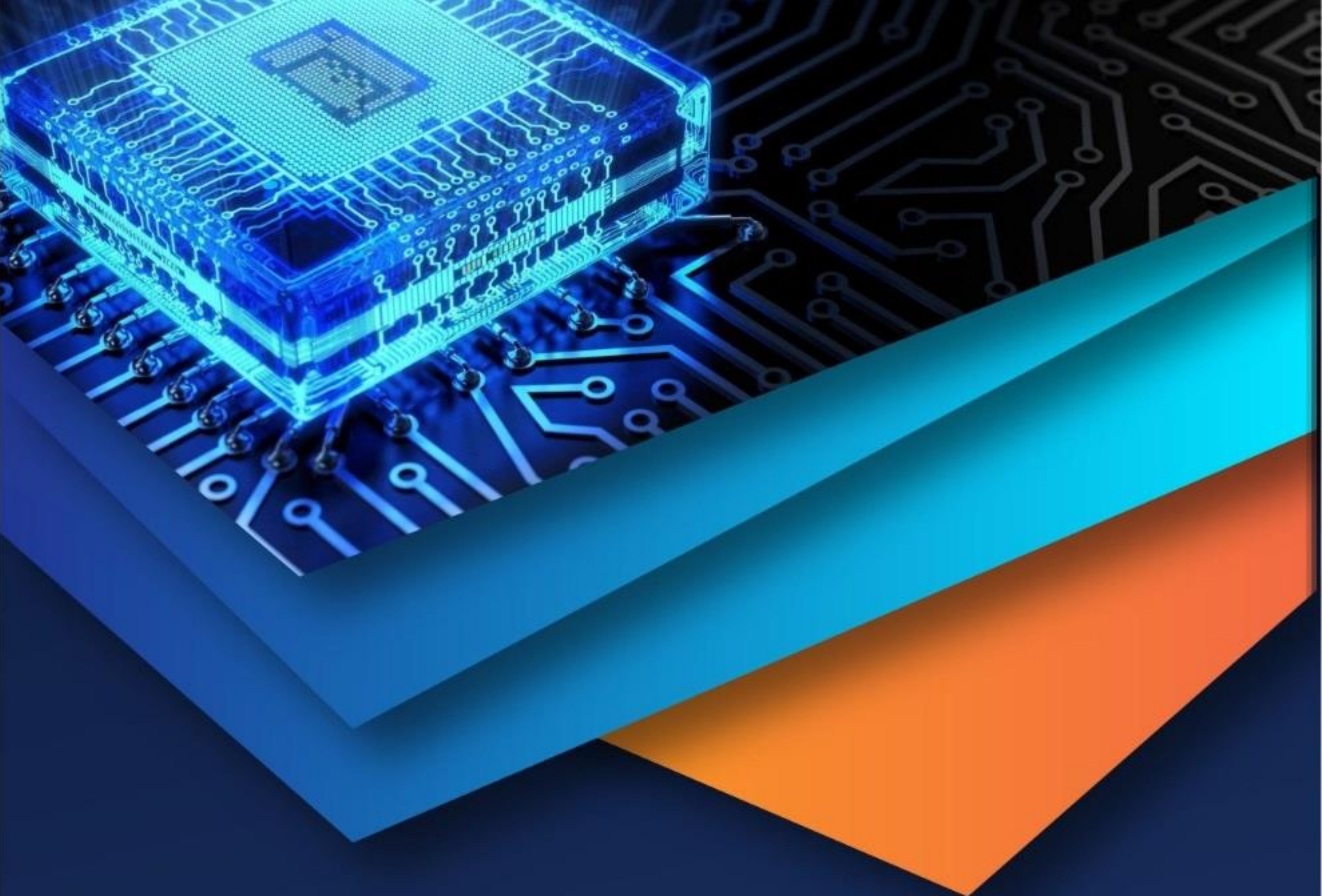

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