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Detailed Study on Low Complexity Detection Techniques for Large MIMO System: A Review

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Abstract: The MIMO technology playing the vital role in the deployment of 3G and 4G communication, and further its advancement like 5G communication is yet to working upon. The bigger the communication network the more number of antenna we need to send the data in an efficient way, so that we could achieve the high spectral efficiency. The major concern in this area is the detection complexity at the receiver section, it increases with the number of antenna increases. To nullify the effect of the detection complexity there are some detection algorithm by which we can diminish the effect of complexity. Three major section of detection algorithm are 1. optimal detection, 2. suboptimal detection, 3. Near optimal detection. It consists the ML detection in the optimal detection. There are two part of the suboptimal detection, which is linear and non – linear detection techniques containing ZF, MMSE RTS, the third one contains LAS, K-neighborhood.
Keywords: MIMO, low detection complexity, zero forcing, Las Algorithm, Reactive Tabu Search, Successive interference cancellation (SIC), V-Blast, MMSE.

I. INTRODUCTION

MIMO technology has many advantages over traditional system, by means of data transferring, Spectral Efficiency, Diversity, and Capacity. MIMO system improve diversity to combat Fading [1], [3], the Fading which generally occur in no line of sight propagation which creates some hurdle in the communication process, so it is necessary to improve the fading, if diversity improves then the gain of the MIMO system also increases and it improves the signal to noise ratio (SNR) as well, so that we could attain the high spectral efficiency [5], [6] in the MIMO system. In order to achieve high gain and efficiency we add multiple number of antennas at the transmission and as well as at the reception of signal. So there may arise some signal detection complexity at the receiver section at the time of signal detection. There are some techniques by which we can diminish the signal complexity at the receiver side with a great extent. For the upcoming 5G technology MIMO system will play a major role to deploy this technology efficiently. Substantial MIMO is as yet a developing field and it can be a potential innovation to meet the remote correspondence's massive request which is anticipated to develop quickly in upcoming era. A key test confronted in for all intents and purposes acknowledging huge MIMO framework is high computational difficulty raised in recognition of got flag on recipient side. The increment of antennas in MIMO framework not just increments spatial obstruction, moreover it expands the location multifaceted nature on collector side altogether. Most extreme Probability (ML) based discovery has ideal execution yet the ML based recognition [7] has got exponential time identification many-sided quality [4]. In view of nearby neighborhood look, low intricacy recognition techniques named receptive Tabu hunt (RTS) [10], [11], and probability ascension search (LAS) have [15] been accounted. Delicate heuristic based finders [18] performs consider-capably well for huge MIMO frameworks with higher computational unpredictability. Despite the fact that ML gives ideal arrangement, it can't be utilized as a part of huge MIMO frameworks in view of its exponential ascent in unraveling multifaceted nature with increment in number of receiving wires. The successive interference cancellation is the technique in which the signal is detected using one of the detection techniques like Zero forcing [16], [20] and MMSE detection then the estimate of the interference is calculated and further to obtain the interference cancelled output the estimated interference vector is subtracted from the acknowledged signal. According to the vertical Bell Lab the ZF-SIC [16], [20] is the detection techniques which generally called the V-Blast detector which performs far better than the linear detection. To process V-Blast detection scheme, it needs to make the solution of the input data stream with linear detector and then it calculates the estimate of the interference in the received signal, and further removes it out of the system. In this paper we have explained the detailed study of low complexity detection techniques, which plays an important role to combat complexity at the reception of the data stream in MIMO system.

This paper contains the further section as follows: Section 2 describes the system model. Section 3 describes the main part of the paper containing all the low complexity detection techniques. Section 4 describes the conclusion of the paper.

II. SYSTEM MODEL

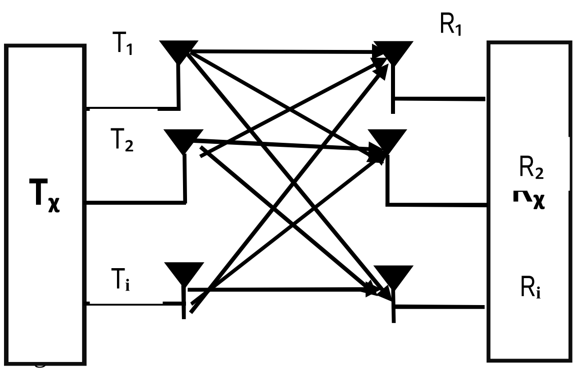
If we consider N_t X N_r MIMO System, where N_t is number of transmitting signal antennas and N_r is number of receiving signal antennas. Input signal vector is **X** and output signal vector is **Y** channel matrix is represented by H hence the system equation is symbolized by.

$$\mathbf{Y = Hx + n} \quad \ldots\ldots\ldots\ldots\ldots 1$$

Where H is,

$$\mathbf{H = [h_1, h_2, h_3, \ldots\ h_i]} \quad \ldots 2$$

Channel state data at receiver section is accessible and channel additions may differ between two sequential transmissions. Here **H** is the channel gain of the system. We consider Rayleigh fading channel as the imaginary and real portion of path gain are independent identically distributed. Here either we can use QAM or BPSK [5], [6] for modulation and demodulation. Modulated symbols are transmitted from transmitted section with the help of transmitter antennas. And at the receiver section we can easily receive the symbols and decode them. Fig. 1 shows the typical diagram of Multi transmit and multi receiving antennas, which is generally refers to MIMO system.



Typical diagram of N_t X N_r MIMO System.

III. MAIN PART

This section describes that how the detection techniques works. Before knowing how these techniques work, we have to know that why we need all these techniques In the era of 4G communication all we want high speed data rates. For 4G communications this rate marks up to 100 Mbps for 3GPP Long Term Evolution. To attain higher rates of data [1], [3], large MIMO system are the major benchmark to attain high spectral efficiency. One major problem raised in the MIMO system is system complexity. In this paper we will discuss about the detection complexity of the signal at the receiver section in MIMO system. This detection complexity minimized using low complexity detection techniques [2] or algorithm makes the system faster and efficient. Hence to minimize the detection complexity we use the low complexity detection techniques. Some of the linear detection techniques are as follows.

IV. LOW COMPLEXITY DETECTION TECHNIQUES

A. *Likelihood Ascent Search*

It is the simplest algorithm which is used in the search operation of the better cost function vector in solution space. This operation needs the solution vector. Which can be an array matrix, or data matrix which is transmitted by the sender to receiver. It is not only the data matrix which arrives at the signal reception side, so multiple data matrix arrives at the signal reception antennas. This algorithm helps to choose the best solution first among them. To compute the LAS algorithm [9], [13], [15], it needs to initialize the solution first with solution vector like ZF (Zero Forcing) or Minimum Mean Square Error (MMSE). After initialize the vector it helps to find the neighborhood solution vector of the solution, and after that it choose the best vector among them. It evaluates the cost function of the best vector, if the cost function is better, then it updates the current solution vector with this best solution vector, and if not we get the better cost function of the best solution vector this process ends. The flow diagram of the LAS algorithm [13] is as follows:

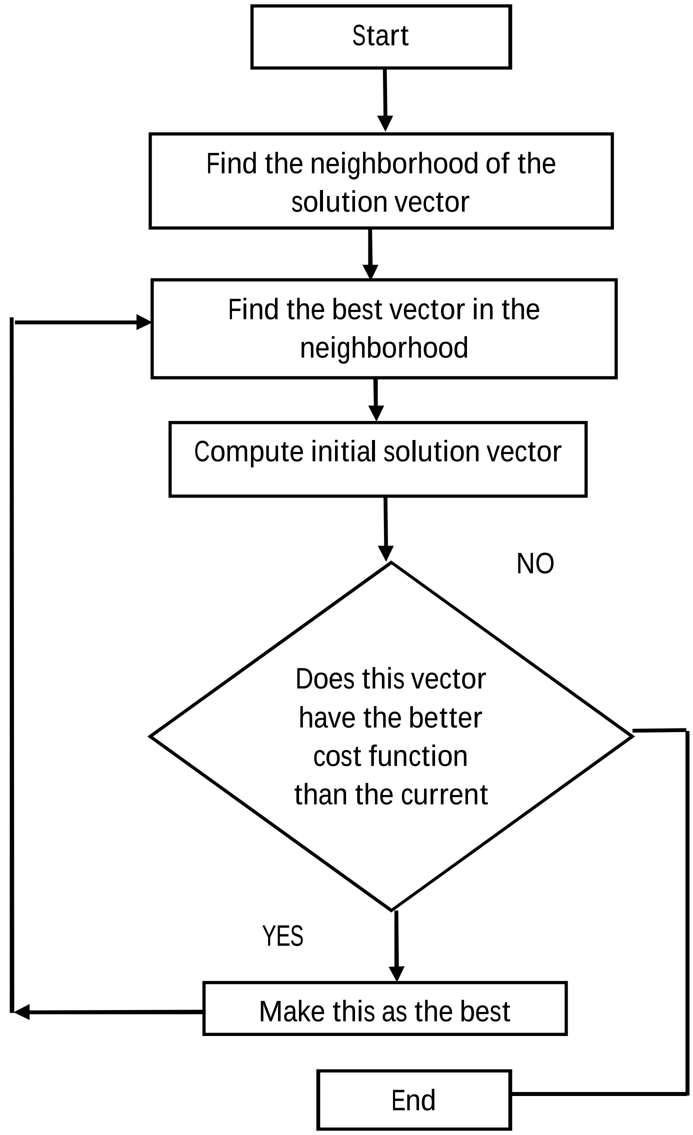


Fig.2. Flow diagram of LAS Algorithm.

B. Zero Forcing

It is known by interference nulling [16] algorithm. It is a part if linear detection algorithm which used in MIMO system to detect the signal at the receiver side which nulls the interference at the time domain or in frequency domain it inverts the frequency response of channel.

If channel response is ћ, this algorithm multiplies the reciprocal of h to the input signal which removes the outcome of channel from the yield signal. If zero forcing [16], [20] weight vector is w the relationship with the channel is:

$$W^H h = 0 \qquad \text{……….} 3$$

The interference nulling algorithm removes all interference and is perfect when channel is noiseless. However, when the channel is noisy, an additional stable linear processing in this case is the least mean square error processing which does not generally eliminate interference signal totally but in its place minimizes the total power of the noise and interference components in the output.

The**e** z_F estimator is given by

$$W_{ZF} = \quad H\,(H^H H)^{-1} \qquad \text{……. } 4$$

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C. Minimum Mean Square Error Detection

In this detection estimation of error is calculated by the algorithm. In insights and flag preparing, a base mean square mistake (MMSE) estimator is an estimation technique which limits the MSE (Mean Square Error), which measure the quality of estimator. The MMSE evaluator is given by the back mean of the parameter to be assessed in this case. Since the back mean is bulky to figure, the type of the MMSE estimator is generally obliged to be inside a specific class of capacities. Direct MMSE estimators are a prominent decision since they are anything but difficult to utilize, compute, and exceptionally adaptable. It has offered ascend to numerous mainstream estimators, for example, the Wiener–Kolmogorov channel and Kalman filters. In insights and flag preparing, a base MMSE (minimum mean square error) estimator is an estimation technique which limits the MSE (mean square error), which is a typical measure of evaluator quality, of the fitted estimations of a reliant variable. In such case, the MMSE evaluator is given by the back mean of the parameter to be evaluated. Since the back mean is bulky to figure, the type of the MMSE estimator is generally obliged to be inside a specific class of capacities. Direct MMSE estimators are a prominent decision since they are anything but difficult to utilize, compute, and exceptionally adaptable. It has offered ascend to numerous mainstream estimators, for example, the Wiener–Kolmogorov channel and Kalman filters. To lessen the effect from the channel noise, the linear filter can be employed by the MMSE detector that can minimizes the effect of noise. The MMSE filter minimizing the MSE (Mean Square Error) as:

$$\mathbf{W}_{mmse} = \arg\min E\,[\|\,N - \mathbf{W}^H y\,\|^2]$$
$$= (E\,[yy^H])^{-1} E[ys^H]$$
$$= H\,(\mathbf{H}^H\mathbf{H} + N_o/E_s) \ldots\ldots. 5$$

Where E_s = symbol energy.

Hence the aftereffect symbol vector (estimated) is given by:

$$\hat{\mathbf{S}}_{mmse} = \mathbf{W}^H{}_{mmse}\, y$$
$$= (\mathbf{H}^H\mathbf{H} + \boldsymbol{N_o/E_s}\ \mathbf{I})^{-1} \ldots. 6$$

D. Reactive Tabu Search Algorithm (RTS)

It is a heuristic based random search algorithm to find the best solution vector in the solution space. It is the fast processing technique which is proposed by the *Fred Glover* in 1986. To overcome local optima, it allows local search methods. The main objective of the reactive Tabu search criteria [10], [11], [13], [19] is to prevent the cycling back to the previously visited nodes. Search history is recorded by the Tabu list so that it could not go for search at the previously visited nodes. An important role of algorithm Tabu search is the methodical use of the memory.

To improve the throughput of the search process, it is necessary to keep the record of the local information and information related to the search process. The best solution vector *i* is chosen from the solution space or search space *f(i)* and it update the current solution vector with this best solution vector *i.*

The basic steps of the reactive Tabu search is:

Steps 1: Choose the primary solution *i* in solution space S.

Step 2: Create a subset V in *N(i)* of arrangement *i.*

Step 3: Find a best vector *j* in subset V.

Step 4: If the best vector *f(j)* is greater than the current vector *f(i), f(j)>f(i).*

Step5: Update the current vector with the best vector, else go to step 2 to repeat the process again till find the best cost function vector.

The flow diagram of the RTS algorithm is as follows:

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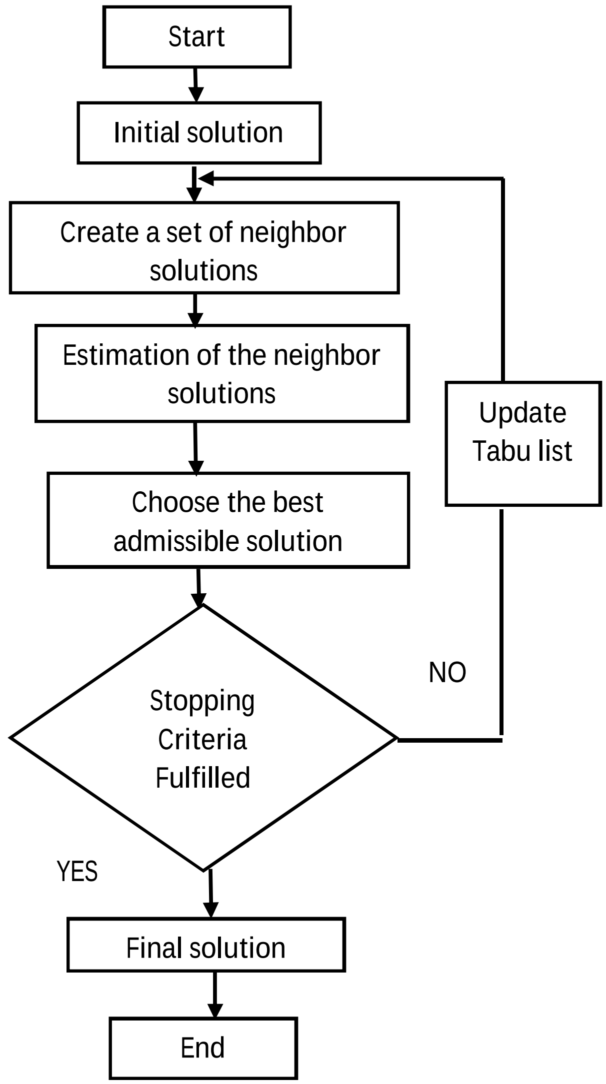

Fig.3. Flowchart of a standard RTS algorithm.

E. Optimal Detection

It is the detection technique which reduces the average probability of error. In this technique, at the receiver section an approximation of the transferred symbol vectors is generated, which is denoted by $\tilde{\mathbf{x}}$**.**

F. Maximum Likelihood

This is the part of non-linear MIMO detection in which the maximum likelihood, [4], [7], detection plays the important role to solve the non – linear optimization problem. This technique minimizes the Euclidean distance among the authentic received vector $\bar{y}$ and the assumed received vector Hx. The maximum likelihood solution is specified as:

$$\tilde{x} = \arg\min \|\bar{y} - Hx\|^2 \quad \ldots\ldots 7$$

where $x \in A^{N_t}$

To compute the optimization problem, the exponential complexity requires in optimal detection. So it is only admissible for small values of **N*t***. For large values of **N*t*** it is infeasible to compute the exact solution of maximum likelihood (ML) due to increase in the complexity exponent.

G. Interference Cancellation Detection

These type of detectors comes into the category of non-linear detector. The estimation of interference is performing by this technique and this detection also deals with the elimination of interference. The most widespread interference elimination techniques consist of Successive Interference Cancellation Detection (SIC). The basic steps of SIC detection are:

1) At first the stream of data is transmitted consisting the symbol vector. It is detected according to the rule of highest strength signal detected first, here we can use any of the detector like ZF, MF, MMSE, hence SIC denoted by means of ZF-SIC, MF-SIC, and MMSE-SIC.
2) Estimation of interference is calculated using the symbol data and the information of channel matrix.
3) To minimize the interference, it is need to subtracted the estimated interference from the received signal.
4) To detect the next symbol, the canceled interference output signal is used. It repeats the process until the weakest stream of data is not detected.

H. V- Blast Detector

It is the part of interference cancellation detection, which is used to nullify the effect of interference effectively. It (V-BLAST, [16], [20]) is associated with the ZF-SIC detector. In this detection the Zero Forcing detection is used to detect symbol vector at every stage. This algorithm (ZF-SIC) states that:

If the input data symbol is x and output data symbol is y. The channel coefficient matrix is $\mathbf{H}^{\text{ɱ}}$. Pseudo inverse of $\mathbf{H}^{\text{ɱ}}$ is denoted by $q^{\text{ɱ}}$, which lies to the *nth* row of $Q^{\text{ɱ}}$, k is the user index at stage index $^{\text{ɱ}} = ^{1}$.

1) ZF detector detects the symbol of *r*th data stream as:

$$\breve{x}_r = f\,(q_r^{\text{ɱ}}\, y^{\text{ɱ}}) \quad \ldots\ldots.\ 8$$

2) With the help of $\breve{x}_r$, the estimation of interference vector of *r*th data stream calculated as $\tilde{a}_r$:

$$\tilde{a}_r = h_r\, \breve{x}_r \quad \ldots\ldots\ldots\ 9$$

3) The estimate $\tilde{a}_r$ is subtracted from $y^{\text{ɱ}}$ to generate the output:

$$y^{\text{ɱ}}+1 = y^{\text{ɱ}} - h_r\, \breve{x}_r \ \ldots.10$$

4) The *r*th column of $H^{\text{ɱ}}$ set as zero to obtain $H^{\text{ɱ}}+1$.

$$H^{\text{ɱ}}+1 = H^{\text{ɱ}} \text{ (with column } k\text{th as zero) } \ldots 11$$

In every stage this algorithm does a matrix inversion. The subsequent complexity order is $O(n_i 4)$. Hence it is better when comparable to ZF detector.

V. CONCLUSION

We have contemplated about the detection techniques in this paper, which decides the detection complexity at the receiver side. In MIMO framework detection complexity is a major issue. To diminish the effect of detection complexity, the low intricacy detection algorithms are the important techniques used at the receiver section to detect the transmitted signal efficiently with low complexity. Hence in this paper we conclude that SIC detection techniques performs superior than linear detection techniques.

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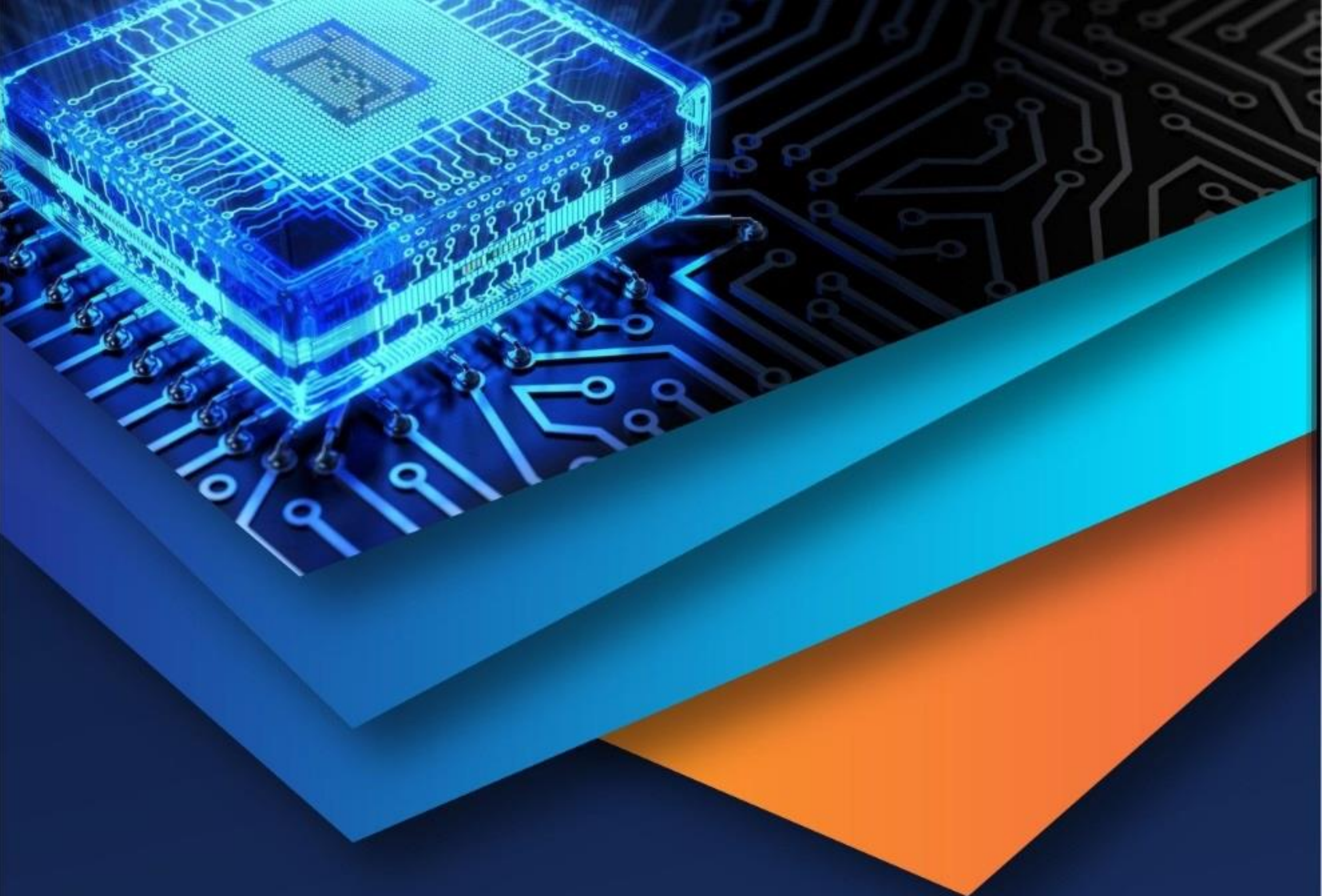

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