iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 10 Issue: IX Month of publication: September 2022

DOI: https://doi.org/10.22214/ijraset.2022.46748

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 10 Issue IX Sep 2022- Available at www.ijraset.com

Issues and Research Paths in Fog Computing

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Abstract: Cloud computing is a framework that provides data storage and data processing to edge network users. Until recently, cloud has been a great solution to access our data and process them any time and everywhere. But the price decrease of connected devices with internet network increases the end users' number in the edge network. Consequently, the data coming from edge network will be concentrated around the cloud. This causes congestion and significant response latency of data. Fog computing is installed as a solution for the congestion problem; it is an extension of cloud placed closer to each area of end users. This solution provides low response latency for devices that request data from cloud. It also provides processing and storage features to IoT/sensors witch do not adopt them. In this work, we present Fog computing by defining the limits of cloud computing which led to creating the Fog. Afterwards, we set the Fog computing architecture by underscoring its difference from the cloud. We also specify some issues to improve paths of this new technology. Finally, we present some related works.
Keywords: Fog computing, Internet of Things, Cloud, Survey, Issues.

I. INTRODUCTION

The Internet of Things (IoT) technology has started as a tool to collect data from the environment and forward them through Internet. Gartner predicts that about 21 billion "things" across industry sections will be connected to the network by 2020 [1]. This technology reduces the human data entry efforts. The capacity to store and process is not among the features of IoT devices. Because of this, the cloud has been integrated with the IoT technology for many reasons such as low-cost, leasing, and complex data processing. The spread of the IoT devices increases the quantity of data processing in the cloud and the collusion around it as well as a high consumption of bandwidth and high latency. To overcome these issues, Fog computing comes into play.

The Cisco Company has provided the Fog term as a new technology to give more benefits to IoT devices. The Fog is an extension of cloud computing that is installed close to the edge network with the features of storage capability and processing. In other words, Fog computing provides some features to IoT devices that these later lacks.

The presence of Fog computing in the edge network improves the quality of services. According to IDC [2], the estimation of the amount of data analyzed on the IoT, that are physically at or near the devices, is approaching 40 percent. Accordingly, this presence reduces the traffic concentration around the cloud, the quantity of traffic processed in the cloud, and the latency of the applications that are sensitive to these issues.

Cloud computing is operated by big and famous companies (Google, Amazon…) through huge data centers. Furthermore, the integration of Fog computing creates more services that are called fog as a service (FaaS). This allows big and small companies to provide computing, storage, and control services for IoT devices, and to meet the needs of a wide variety of customers.

The similarity evoked between Fog operating system (FogOS) and the operating system for network resource management (OSNRM) in several works should be discussed. There are two main differences between them [3]: the first one is that OSNRM controls all network devices that are fixed with relatively stable operating conditions, while FogOS highly controls dynamic's edge devices. The second one is that OSNRM participates in standardizing device interfacing. However, the FogOS is placed in an environment characterized by diversity in devices, services, and protocols, resulting in a more challenging environment.

II. CLOUD COMPUTING LIMITS

The cloud computing has been the best solution to provide features of computing and storage to the IoT device. The increase of the IoT provider number and the lowering of their price increase their usage. As predicted by Cisco, the average of connected devices per person will reach 6.58 in 2020. Therefore, the traffic kind of IoT will be increasing in the network, consequently, this increase will produce many issues and limits to the cloud computing:

1) *Flexible Service:* the spread of different kinds of IoT devices and IoT applications on large scale renders the services provided by cloud computing different. To this effect, the centralized architecture of cloud computing concentrates the traffic around it, and therefore the congestion appears. This prevents the cloud from providing an optimal QoS for different IoT applications.

2) *Short latency:* many IoT applications that work by a real-time response (e.g. Google glasses and Microsoft Hololens) are limited in resources by nature. These applications need to use the cloud to benefit from computing and storage. Therefore, the cloud must support short real-time response and data processing. These performance variables will be unreachable with the increase of IoT devices.
3) *High-Rate Connection:* the IoT devices are either fixed or mobile. It is preferable to connect them with WIFI technology which is used by many IoT applications. This increases the concurrence between them to use the bandwidth. Also, IoT traffics arriving at the cloud must cross many network technologies and far distances. The performances of each technology are different from each other. Consequently. The connection rate between IoT and the cloud will be weak in a situation where we have resource hungry IoT applications.

III. FOG ADVANTAGE COMPARED TO THE CLOUD

Technically, Fog computing is almost like cloud computing considering that both are providers of storage and computing data coming from the end-users. The difference between them is their locations. The Cloud is far from end-users whereas the Fog is closer to them. In table 1 we present the similarities and differences between these two technologies.

Table 1: Cloud computing vs Fog computing [15][16]

Parameters	Cloud computing	Fog Computing
Latency	High	Low
Delay Jitter	High	Very low
Location of server nodes	Within the Internet	At the edge of the local network
Distance between the client and server	Multiple hops	One hop
Security	Undefined	Can be defined
Attack on data enroute	High probability	Very low probability
Location awareness	No	Yes
Geographical distribution	Centralized	Distributed
Number of server nodes	Few	Very large
Support for Mobility	Limited	Supported
Real time interactions	Supported	Supported
Type of last mile connectivity	Leased line	Wireless

Table 1 indicates that the cloud computing technology has many limitations which will be visible when the data to be processed increases. Fog computing, however, is a concept placed as complementary to the cloud to surpass these limitations.

IV. FOG COMPUTING TECHNOLOGY

A. *Fog computing architecture*

Fog computing is a framework presented as a layer between IoT devices and sensors on the one hand and cloud computing on the other hand. Its role is to collect data from end-users to process and store them; those are the features that the end-users lack. Fog computing cans also forward some data to the cloud. Figure 1 shows the outdoor model.

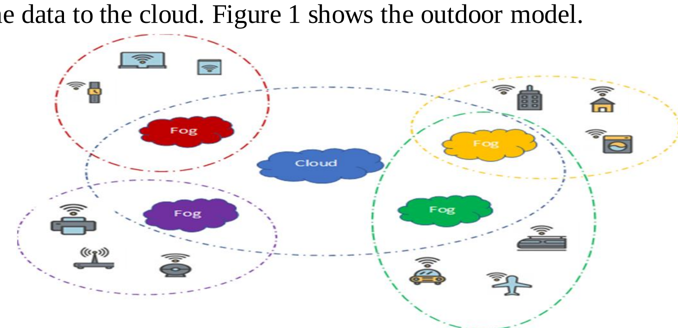

Fig.1. Fog computing topology

Fog computing, as shown in figure1, associates several traditional components, e.g. routers, switches, set-top boxes, proxy servers, base stations (BS), etc., to create a network coverage for fog computing. Those components are placed closer to end-users and far from cloud computing and are also placed in a distributed manner between them. Consequently, Fog creates a large geographical distribution of cloud-based services near IoT devices and sensors. The communication between Fog nodes is done with WIFI technology in most cases. This last provision provides mobility and interoperability features to the Fog nodes [17].

B. Fog Computing Nodes

1) *Servers:* are stations that adopt storage, compute, and facilitate networking. They are deployed in public areas like parks, supermarkets, train stations, football stadiums, universities, etc. These servers are virtualized and are considered the main functional components of fog computing. Several works [18] [19] describe Fog node servers as micro servers, micro data centers, and nano servers. Other works present node servers according to their functionality; computation servers [20], storage servers [21].
2) *Networking Devices:* Fog computing is a set of components connected to each other. For that, it is designed by traditional networking nodes such as (routers, switches, set-top boxes, etc. Those components help Fog to perform networking activities like routing, packet forwarding, analog to digital signal conversions, etc. Normally, those components adopt systems capable of data processing and temporary data storage in addition to data forwarding [22] [23].
3) *Cloudlet:* According to the works [24] [25], cloudlet is a fog node. They are closer to the end use as a micro-cloud. In other words, a cloudlet is an extension of a cloud server. The cloudlet extends the cloud in serving mobile devices and minimizing the limitations of centralized computation by using the cloud.
4) *Base Stations:* It is very important to process and regenerate wireless signal communication between far mobile and vehicular devices. The base stations play this role and are also equipped with certain storage and computing capabilities. These lasts are the principal concepts of Fog computing [26] [27]. It is recommended to use base stations as an extension of the Cloud Radio Access Network (CRAN), Vehicular Adhoc Network (VANET), etc.
5) *Vehicles:* Vehicle nodes with storage and processing capabilities can be used as Fog nodes. Their capability of guaranteeing fault tolerance, privacy, and QoS for real-time applications is one of the issues. Furthermore, the distributed application feature in Fog concept will be a complex construction in the presence of a vehicle network.

C. Fog Distributed Processing

The data processing in fog computing is made with a nodal collaboration paradigm by sharing data computing and storage between nodes. The nodal collaboration is made in different ways. Table 1 summarizes them:

1) Cluster

a) The fog nodes can regroup themselves according to their homogeneity or their existence in the same area to form one cluster [25] [28]. His objective is to process/save data coming from sensors/devices in the edge network.
b) This way can provide higher reliability [29] in terms of process and storage in an optimal data flow case.
c) Nodes collaboration with the cluster method centralizes the network architecture while the concept of Fog distributes the data processing. Also, the centralized network increases congestion and delay.

2) Peer to Peer

a) P2P collaboration in Fog is not only a link between one node exit and the entry of another node but also between virtual processing instances in different nodes [30].
b) The data transfer time from one node to another is very high due to their reservation of all bandwidth.
c) The response time in P2P collaboration will be important due to support access concurrence when we have a higher number of nodes.

3) Master-Slave:

a) The Master-Slave way is giving control to one node (master), which controls processing, resource management, and data flow of underlying nodes (slaves) [18].
b) This manner is a hybrid collaboration combining cluster and P2P to improve real time response [31].
c) Fog nodes require high bandwidth to communicate with each other.

D. Fog Routing protocol

Fog computing is a new concept to store and process data in the edge network. To make this with optimal performance, we need to set up a routing protocol according to the requirements of the hierarchical structure of fog computing and the services offered by fog.

The Fog computing structure is composed of three-tiered, which means that the data is transmitted over four types of communication channels between tiers: device-to-device, device to Fog node, Fog node to Fog node, and Fog node to cloud. In this situation, we need more than one routing protocol whereby each of them will have to adapt to the requirements of different technologies in the structure three-tiered. Also, these routing protocols must respect bi-directional communication channels and upgrade the performance parameters (throughput, latency...).

The Fog traditional services such as computing, and storage need an efficient routing protocol to provide these services with confidentiality and rapidity Furthermore, there are other services provided by Fog that the routing protocols will implement and must respect. We can categorize those services through a survey of several works:

1) *Devices Mobility:* the edge network relies more and more on wireless communication. Consequently, the devices at the edge are static or mobile. In mobility, the device may dynamically change its route to other devices or to the Fog server which dominates it in its coverage area. Thus, the device can go out from the coverage area of one Fog server, and it could enter another coverage area. In this case, the device must create a route to this new Fog server which is connected to the old Fog server. Generally, the mobility service must be taken in consideration by the routing protocol.
2) *Server Content Delivery:* The users in the edge network can obtain their desired information from Fog servers using two ways: reactive and proactive. We are going to concentrate on the proactive way. The latter allows servers to deliver some information to users before they request it. These results in, reducing communication bandwidth and latency. In the case of a network with a non-optimal performance, the proactive delivery needs an effective routing protocol that respects the requirements of this service.
3) *Assign Computing:* the limitation of computing capacity for the end devices pushed the fog concept to allow these devices offload its computations to the Fog Servers. The assignment of the computing service will have to be done by the network that has reliability, meaning that the computation may be offloaded in different servers, to avoid overloading a single server. In other words, the reliability is one of the goals of the routing protocol in Fog network.
4) *Planning And Assigning Tasks:* Fog computing can consist of nodes such as routers, switches, base stations, gateways, and access points. These nodes are characterized by their limitations of memory and computing. Therefore, the Fog shares its tasks on different nodes. Also, these tasks must be done by planning. The data should be routed to the concerned node.

What we have detailed above are some services and technologies in the Fog, which require specific routing protocols. We recommend the work [32] which details the different services provided by Fog, and it presents a study carried out on different routing protocols in different cases of Fog services.

V. FOG COMPUTING ISSUES

Even if Fog computing technology provides some advantages compared to the cloud, there are many issues that we must resolve to develop it like any new technology. Among them, we quote:

1) *Cost:* unlike the cloud, in which the deployment is done at a low cost through the rental of resources by the cloud providers, the Fog computing components must be installed closer to many kinds of edge networks, to provide the computing and storage features to the end-users. Consequently, the dispersion of several fog layers between the cloud and edge network increases not only the deployment cost but also the energy consumption [11].
2) *Confidentiality:* The fog layer is a collection of many components that provide cloud services to sensors and some devices with limited storage and computing power. These sensors/devices are connected to fog components with WIFI technology (the wired network is useless in this context.), and they forward data to the fog layer before forwarding it to the cloud. Consequently, the data flows between IoT devices and Fog will have physical security problems [11].
3) *Access Control:* the main security issue, which the proposed solutions must strengthen, is node control access to the Fog platform [12]. Each node has its own IP address, yet it may use a fake IP address to have access to a fog platform where it is not a member.
4) *Heterogeneous Devices:* In the fog layer, many network technologies are made up of heterogeneous devices. Consequently, the connection and network management between devices will be complex [13].

5) *Nodes Placement Management:* Services in Fog layer are placed in a distributed manner. The goal was to serve almost all the total end users. Therefore, an optimal distribution of nodes Fog and services will reduce setup and maintenance costs [14].
6) *Communication Delay:* The storage and computing features are the main operations in Fog. Thus, they must be made with minimum delay. To achieve this objective, we must take into consideration resource over-usage, priority computing, and node mobility [15].
7) *Energy Consumption:* The addition of several fog layers closer to various types of end-users will bring several smaller service provider companies, such as cloud extension. To this effect, the need for energy will arise, and the reduction of its consumption in fog computing will be essential.

VI. RELATED WORKS

The article [4] explains in the first place how Fog computing was born from cloud data centers and the relationship between the performance parameters (Delivery latency, QoS, energy consumption ...) and the added value of the fog computing paradigm. This paper also provides the location of Fog computing in the cloud network. Afterward, they describe the similarities and differences between Fog Computing and other edge networking. It also discusses some issues, starting from structural issues in which there is a challenge to provisioning the components for fog computing purposes. Thus, the selection of suitable nodes, corresponding resource configuration, and places of deployment. The research of techniques to provision resources using inter-nodal collaboration and vehicular Fog computing has also been discussed as a structural issue. Another issue has been mentioned concerning the oriented service: not all Fog nodes are resource enriched. Thus, we must find a potential programming platform for distributed application development in Fog. Moreover, the organization of services between IoT devices/sensors, Fog, and cloud infrastructures must be specified. Another oriented service issue is the difficulty in specifying the service provisioning metrics that affect the Service Level Agreement (SLA). Another important issue has been security: the Fog paradigm must implement a security system that can't affect the QoS. In another context, the work gives a taxonomy to classify some works and highlight some aspects. It also describes the components' configuration of Fog computing.

The article [5] describes the recent related works that investigate the setting up of the fog computing layer between the IoT devices and the cloud. The authors give the reasons why the technology of IoT devices/Cloud needs Fog computing, and how this last resolves some IoT challenges. They explain also how Fog computing provides more IoT applications by citing some examples. Each new technology includes many problems and challenges, which is why this work is discussing the challenges resulting from integrating the IoT with fog computing. Finally, the challenges that have been described, provide to authors future research regarding fog computing and the IoT.

Nakjung Choi and his colleagues in [6] describe in a general manner the issues in Fog computing technology. Afterward, to understand more about the Fog operating system, they suggest their conception model describes the Fog architectural network. This conception is composed of four major components: service/resource abstraction; resource manager; application manager; and edge resource identification and registration. They also propose these components as the starting points for searching for solutions to the challenges that face Fog computing. To show the utility of their model, they suggest a real-world use case of a drone-based surveillance service.

The existing difference in the work [7] compared to the papers above resides in their description of smart mobile phones and their interactions with fog computing architecture. They started presenting some limitations of cloud computing performance. Thereafter, they defined the Fog computing concept used in the smart mobile area. This work also demonstrates the benefit of using Fog as a layer between the cloud and the edge network, and it continues some comparisons in the table. This article gives a view of Fog design from storage, computing, and communication. Finally, like most of the papers mentioned above, the authors indicate the research paths in: communications between Mobile and Fog, communications between Fog and Cloud, communications between Fogs and challenges of Fog computing deployment.

Contrary to previous articles, the paper [8] makes a study of two routing protocols to aim to conclude the performance difference between them. They import the OLSR and MP-OLSR routing protocols in an edge network context using two scenarios. The environment proposed in this study is a framework to improve public safety services in disaster cases, especially fire spread. This framework called FANET Emergency Application FEA is a combination of some technologies: firstly, it exists on Mobile Ad-hoc Network MANET to connect mobile user phones to Unmanned Aerial Vehicles (UAVs, commonly known as drones). Secondly, the Flying Ad Hoc Networks FANET connects the drones between them, equipped with video and GPS. Finally, Fog infrastructure provides data storage, computing, and interconnection with another edge system. The result of this study shows that MP-OLSR is more performant than OLSR in FEA.

As the previous papers mentioned, the Fog is a new concept that provides computing and storage power to IoT devices in the edge network. For this reason, work [9] focuses on the Object Store Systems in a Fog and Edge Computing Infrastructure.

The goal is to build a similar storage system to the one used in cloud computing closer to the edge network. The work was firstly specifying the features of this system to make it compatible with the Fog context. Secondly, they have evaluated through performance analysis three object-store solutions, namely Rados, Cassandra, and InterPlanetary File System (IPFS). They have focused on some parameters like times to push and get objects under different scenarios and the amount of network traffic that is exchanged between the different geographical sites. The result of this experiment shows that IPFS is best for Fog computing.

Many articles have proposed several recommendations to improve the work techniques of the Fog computing framework. To evaluate these recommendations, many works have made some simulations in testbeds or with some simulators. Many simulators have been proposed (NS-3, TOSSIM, EmStar, OMNeT++, J-Sim, ATEMU, Avrora, Qualnet 5, ifogSim …). IfogSim is one of the recommended simulators. The article [10] presents the architectural design and implementation of this simulator. Afterward, they propose simulations with it and show how to extract some performance parameters.

VII. CONCLUSION

This article was an opportunity to discover Fog computing as new technology. Our objective was on different levels: to know why fog computing has appeared, what are the advantages that exist in Fog and don't in the Cloud, the architecture of this new technology, to especially search some paths through issues that we have defined, and finally to start our first steps about fog computing improvement. In future work, we will be trying to show the added value of this future implementation through a simulation on IfogSim.

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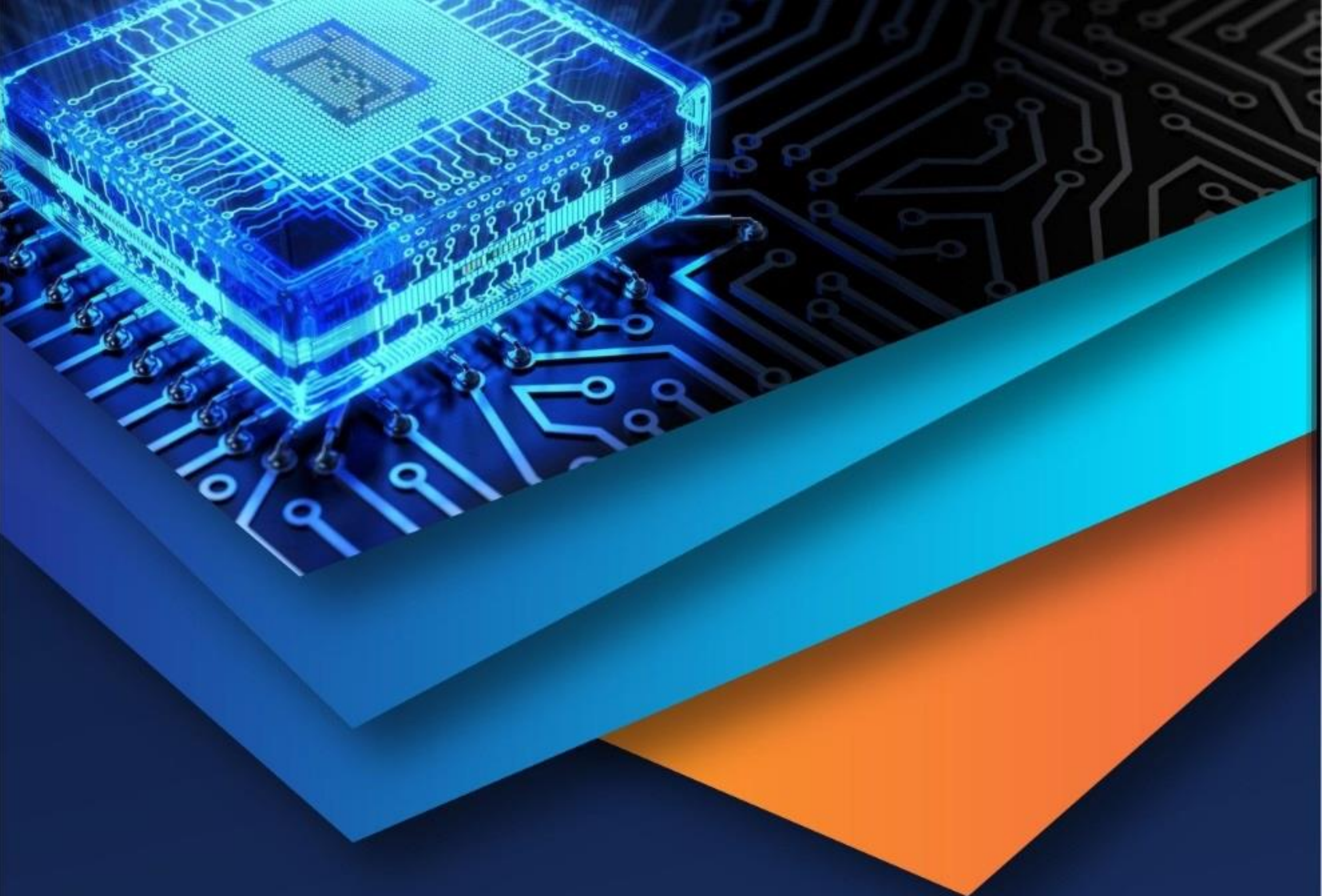

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