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A Comprehensive Review of the Internet of Things (IoT): Architecture, Application, Challenges and Future Directions

Vineet Rana[1], Ravinder Singh[2], Yogesh Mohan[3]
Department of Computer Science, Himachal Pradesh University, Shimla, HP, India

Abstract: ***The Internet of Things (IoT) has emerged as a transformative paradigm in modern technology, connecting billions of devices and enabling seamless communication between the physical and digital world. This review paper provides a comprehensive analysis of the IoT ecosystem, including its fundamental concepts, current state of development, challenges and future directions. The paper begins by clarifying the core components of the IoT, including introduction, history, sensor networks, cloud computing. It explores the architecture and design principles underpinning IoT systems, highlighting the importance of interoperability, scalability, security, and privacy in the successful implementation of IoT projects. Ultimately, this review paper aims to provide a holistic understanding of the IoT domain, guiding researchers, policy makers and industry persons to a clearer appreciation of the importance of IoT, while addressing the challenges and unlocking the full potential of this transformative technology.***

Keywords: IoT ecosystem, Sensor Network, IoT Architecture, IoT Application.

I. INTRODUCTION

Internet of things(IoT)[1], [2], [3], [4], [5], [6], [7], [8], [9], [10], [11], [12], [13], [14], [15], [16], [17], [18], [19], [20] means interconnection of different physical devices, which are embedded with sensors and software. Here the devices share data and information with the help of internet. Or we say that, Internet of Things (IoT) term represents a general concept for the ability of network devices to sense and collect data from around the world[21]. The numbers of Internet connected devices are increasing at the rapid rate. These devices include personal computers, laptops, tablets, smart phones, PDAs and other hand-held embedded devices[22]. The interconnected devices are also known as smart devices over the internet. All the devices have their own IP address and they are capable to collect/gather and transmit data over the established network in which they are working. The devices can also be interact/communicate with the outside environment with the help of implanted technology, which also helps the devices to take decisions. IOT allows control the physical devices remotely through existing internet connection. This means that IOT devices can be connected to the internet and controlled from anywhere in the world, as long as there is an internet connection.

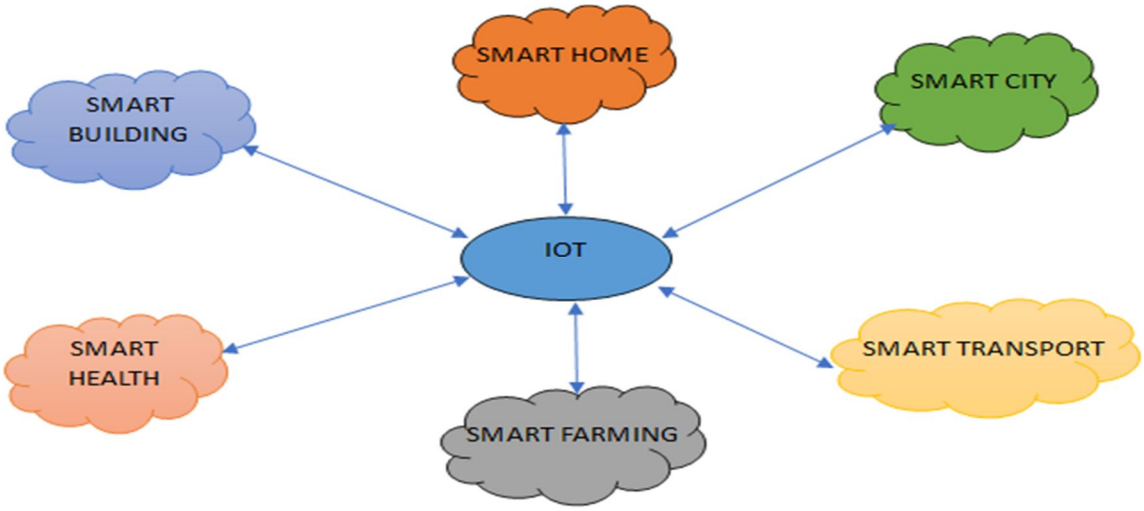


Figure 1: The IoT generic scenario.[22]

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These devices are different from those remote-control devices, which require dedicated connection between the controller and the device being controlled. The IOT devices are mostly controlled by the software. Because of the IOT devices are connected to the internet, this means they can be monitored and controlled in real time, regardless of their location. Or we can say that the number of devices availing internet services is increasing every day and having all of them connected by wire or wireless will put a powerful source of information at our finger tips [23]. IOT also provides the way to connect physical devices to the digital world. This means IOT opening up new possibilities for automation and control, as devices can be programmed to perform actions based on data collected from the environment. As we know that IOT is an embedded system which works with sensors and software, so name some of the sensors which work with IOT are: Temperature Sensors, Image Sensors, Gyro Sensors, Obstacle sensors, RF Sensor, IR Sensor, MQ-02/05 Gas Sensor, LDR Sensor and Ultrasonic Distance Sensor. Sometime IoT can be viewed as a Network of Networks

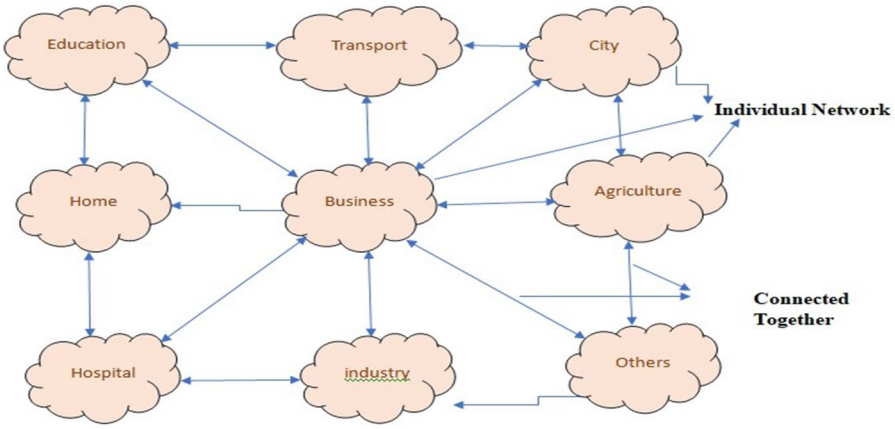


Figure 2: IoT can be viewed as a Network of Networks [24], [25]

A. History of IoT

The term IoT was first coined/proposed in 1999[26] by the computer scientist Kevin Ashton [27]. When he was working at Procter & Gamble, he proposed to putting Radio Frequency Identification (RFID) chips on products to track the products through the supply chain[27][28]. But the point of adding sensors and artificial intelligence to physical devices was initially discussed in the 1980s when some students of university decided to make a Coca-Cola vending machine to monitor and track its component remotely [27]. But the drawback was its bulky technology and limited progress [27]. Even the history of IoT does not start from here only. To get the complete history of IOT we need to study its timeline from beginning to end.

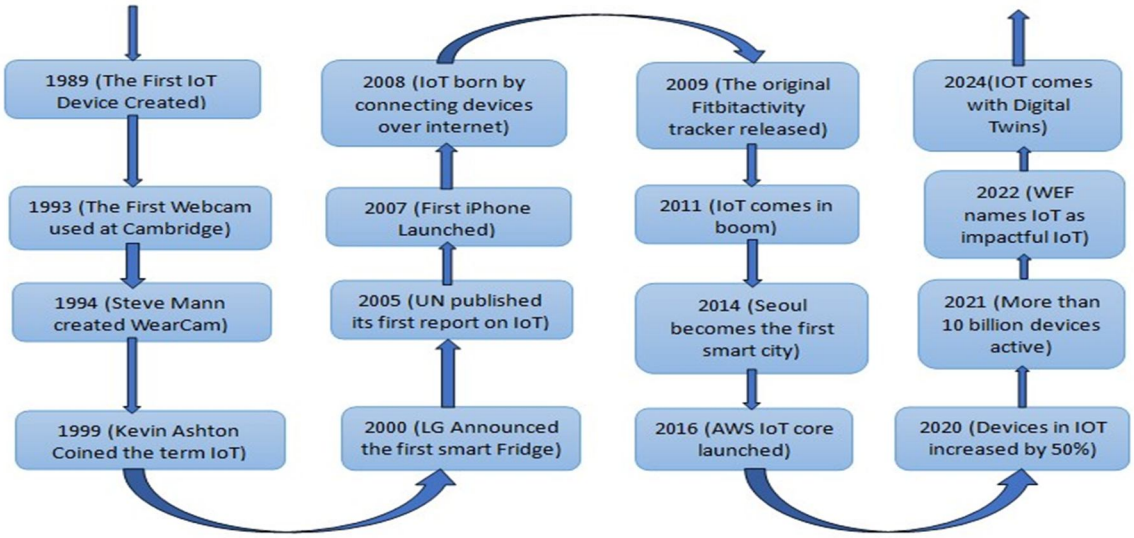


Figure 3: The IoT Timeline [27]

From the above timeline of IoT we find that the first IoT device was created in the year 1989, but that time the researcher and the scientists had not an idea about IoT. After this in the year 1993 the first online (with the help of Internet or through Internet) webcam used at Cambridge. Thereafter the IoT timeline increased gradually with advancement of technology and internet. With the advancement of technology, the people also start to show their interest in IoT devices, such as smart home appliances, smart phones, smart farming etc. In the year 2000 LG announces the first smart refrigerator and in the year 2008 the number of connected devices overtake the number of people in the world and IoT is "born" [27].

II. LITERATURE REVIEW

In literature review we have gone through different papers related to the field of IoT, its applications and many more. We found that there is huge advancement in the field of IoT from the past till now. A Review on Internet of Things[1] in this paper the authors have discussed about the M2M(Machine-to-Machine) communication, technologies and sensor network. In technologies authors have touched RFID, WSN, Networking technologies, Nano Technologies, Cloud Computing and optical technologies as well.IoT Based Intelligent Control System for Smart Building[4] this paper is covering the concept of building with technology (IoT). A smart building is one that makes use of cutting-edge technologies, like automation, sensors, and data analytics, to improve the building's operational efficiency, sustainability, and comfort. In this paper author discussing about the door sensor, AC control, light sensor and some other applications which are essential for the smart home/building Internet of Things (IoT) and its applications: A Survey[7] this paper has covered the IoT platform, IoT applications and IoT challenges. Smart Farming[29] IOT works with many applications in which smart farming/agriculture is one. In this paper the authors have discussed about the Mushroom farming using IOT. This paper is covering the IoT's technologies used in agriculture such as soil sensor, water sensor, moisture sensor, wireless sensor network etc. A Review of IoT Security Challenges and Solutions [30]in this paper author is discussing about the security challenges and solution of these. The main focus of this paper is on privacy, security, and block chain, Fog / Edge Computing. This paper is also covering the IoT attacks such as Man-In-The-Middle, Distributed DoS, and Eavesdropping etc.

A. IoT Architecture

IoT architecture refers to the intricate system of components that constitute IoT networks. These components include sensors, actuators, cloud services, protocols, and various layers. Since IoT involves numerous smart devices connected to the internet through different networking technologies, most of these devices are wirelessly connected, and the technologies used for controlling them are also wireless. This reliance on wireless technologies adds complexity to managing the system. Therefore, an architecture is essential in IoT. It serves as a blueprint for designing, organizing, and operating a network. The architecture also defines the data formats used within the network, as well as the operational principles and procedures that guide its functioning. In short, an architecture provides a detailed overview of how a network operates. Various researchers and authors have proposed different IoT architectures based on their needs, and among them, we will focus on the four-layer architecture.

APPLICATION LAYER This Layer includes applications supported by IoT		
Smart Home	**Smart City**	**Smart Health**
Smart Agriculture	**Smart Building**	**Smart Transportation**
SERVICE SUPPORT AND APPLICATION SUPPORT LAYER This Layer offers the different services		
Security	**Authentication**	**Identity Management**
Access Control	**Encryption**	**Data Mining**
NETWORK LAYER This layer deals with connectivity and routing		
WiFi	**GSM/GPRS**	**Ethernet**
SENSOR LAYER This layer includes the wide range of smart devices and sensors		
Zigbee	**Bluetooth**	**Ethernet**
WiFi	**UWB**	**Infra-Red**

Figure 4: layered IoT Architecture [24]

1) *Application Layer:* As its name suggesting, application layer manages all application processes based on information obtained from different connected devices over the internet. The main goal of the application layer is to process, analyse, and present data collected from IoT devices to end-users, other systems, or cloud platforms. This layer includes different applications such as Smart livings, Smart cities, Smart homes, Smart health, Smart farming etc. It includes software that acts as an interface between different IoT devices and end user/system to interact with each other without having to understand the specific details of each other protocols.
2) *Service Support and Application Support Layer:* The layer which supports all the applications and services of Application layer of IoT architecture is termed as Application support layer and Service support layer. This is second layer of IoT from upside. Service Support Layer and Application Support Layer are two important components that work together to ensure the smooth functioning and management of IoT services and applications. This layer is designed to provide support functions that aid in the efficient operation, maintenance, and troubleshooting of IoT systems. This layer supports all the services offered by the application layer such as security, authentication, identity management, access control, data management, encryption, data mining etc. This layer provides data processing and storage capabilities for IoT applications. This layer performs the variety of task on data, such as collecting the data, cleaning the data and analysing the data in order to provide users with insights that they can use it. We can call it as the brain of IoT system.
3) *Network/Communication Layer:* This layer deals with connectivity, routing of message between remote devices(the devices located in the different location or physically far from one another) and allow the devices to share data between them. The network/communications layer is a fundamental component of the Internet of Things (IoT) architecture. It is also responsible for facilitating seamless communication and connectivity between various IoT devices, sensors, gateways and central IoT platforms. The network/communication layer plays a vital role in transmitting data reliably, efficiently and securely. As we know that, the sensor technology works in IoT, so massive volume of data will be produced by these sensors and this requires a robust and high performance wired or wireless network infrastructure as a transport medium [24]. So, network layer provides the different protocols to deal with this situation. The protocols used by network/Communication layer of IoT structure are cellular, Wi-Fi (Wireless Fidelity), Sigfox, Bluetooth, Zigbee[24] etc for wireless short- and long-range communication.
4) *Smart Device/ Sensor Layer:* This is the last and the fourth layer of IoT architecture. The smart device/sensor layer is a fundamental component of the Internet of Things (IoT) architecture. It includes a wide range of smart devices and sensors that are equipped with embedded technologies together data from the physical world. These devices act as "things" in the IoT, capturing real-time information and passing it to higher layers of the architecture for processing and analysis. This layer works as an interface between the real world and digital world. This layer is the first point of contact between physical world and the IoT. It is responsible for collecting data from sensors and actuators, and transmitting it to the layers of the architecture. Here are some specific examples of devices, sensors, and actuator that might be found in the sensor layer of an IoT architecture:

a) Devices: Smartphones, laptops, tablets, Wearable devices, industrial control system, smart home devices and medical devices.
b) Sensors: Temperature sensor, pressure sensor, humidity sensor, accelerometers, gyroscopes, magnetometers and cameras.
c) Actuators: motors, switches and lights.

In short, the sensor layer is a critical part of an IoT architecture. It is responsible for collecting the data that is used to make decisions, control devices, and provide insight into the physical world.

B. IoT Applications

IoT applications are not only count but they are numerous and also quite diverse as they permeate into virtually all aspects of daily life of individuals, institutions, and society [25]. We have already mentioned the applications of IoT in IoT generic scenario in figure 1. So, the applications of IoT are [24]:

1) *Smart homes:* Smart home means, the home with smart devices inside. Smart home is the most effective application of an IoT. It can help us to ease our household activities, it can sense our mood accordingly plays the music and it can sense our activity to maintain the visibility of light [31]. Smart home devices are becoming increasingly popular, with 127 new ones connecting to the internet every second [32]**.** Popular smart home devices include Google home, Philips hue Lighting System and Amazon Echo Plus [32]. Smart home devices can be used to control a wide range of functions in the home, such as security system, thermostats, lighting, and entertainment system. The growth of smart home devices is also being driven by the increasing popularity of voice assistants, such as Amazon Alexa and Google Assistant [33].Smart home devices make our life very easy with their assistance and secure with their security systems. For example, Online Cameras, the accessibility of these cameras is worldwide with their IP addresses.

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2) *Smart Cities:* Smart cities are one of the leading domain of IoT [34]. After the smart home, our city should be smart. When we talk about the smart city, means we are talking about the city which has no problem at all, the problem faces by the people in their daily life such as, traffic problem, noise and pollution problem [31] waste management system[31]Smart cities use technology and data to make our life or the life of citizens better, protect the environment, and deliver services more efficiently. The goal of smart city is to use technology to make the city more liveable, sustainable and efficient. To deal with the traffic congestion problem, the automatic traffic management system is there, which activate itself after the fix period of time. Then the smart street lights, which on itself automatically when detects the movement of pedestrians, cyclist and vehicles. Smart energy harvesting devices, which are enabling to convert ambient energy into electrical energy [31].Installation of smart cameras in the public places and in the streets to protect the peoples from any kind of misshaping.
3) *Smart Transportation:* Smart transportation system also known as Smart Traffic Management System (STMS). STMS uses a variety of technologies to collect data on traffic conditions and then use that data to control traffic signals, provide real-time traffic information to drivers, and warn drivers in any emergency. Smart transportation can help to improve traffic flow, reduce congestion and increase safety. IoT is playing an increasingly important role in all modes of transportation such as land, water and air transportation as well. For example, in land transportation, IoT is being used to track the location of vehicles, monitor their speed, and provide real-time traffic information to drivers. This data can be used to improve traffic flow, reduce congestion and make transportation more efficient. In water transportation, IoT is being used to monitor the condition of ship, track their location and manage their cargo. This data can be used to improve safety, and optimize shipping routes. In air transportation, IoT is being used to track the location of aircraft, monitor engine performance, and predicts maintenance need. This data can be used to optimize flight routes, reduce fuel consumption, and prevent accidents. Smart street light and smart parking[35] are the common applications of IoT for smart cities and smart transportation[36][37].
4) *Smart Health:* Before the IoT, patient's interaction with doctors were limited to in-person visits, phone calls, and text messages. This meant that doctors had to rely on patients to report their symptoms and health status, which could lead to delays in diagnosis and treatment. But now with the advancement of the IoT devices in health sector doctors can easily monitor the health condition of their patients. Now doctor simply attaches the IoT devices with patient and start to monitor the patient's health condition with heart rate, blood pressure, oxygen level etc. the IoT is also being used to develop new types of medical devices that can provide real-time feedback to patients. For example, there are now smart pills that can track how much medication a patient has taken and send this information to their doctor. When we talk about smart health devices, few devices come in our mind such smart watches, smart thermometers, fitness trackers ECG monitor, connected inhalers, biosensors, blood pressure monitor and many more. With help of IoT in health care, report patient monitoring is possible. This has allowed doctor to keep patients safe and healthy from afar, while also empowering them to deliver better care.in short we can say that, the IoT revolutionizing the way that doctors and patients interact. With the ability to monitor patient's health continuously, doctors can now provide better care and make more inform decisions about treatment.
5) *Smart Farming/ Smart Agriculture:* Now-a-days, IoT applications are being used everywhere: In Agriculture as in Smart Farming[38].The population of the world is increasing day by day and expected to reach 10 billion by 2050[36]. Agriculture is very essential to our survival, and we need to find the way to produce more food in a sustainable way. One way to do this is to combine agriculture with technology.

IoT uses sensors in smart farming such as: soil moisture sensor [39], humidity sensor, stem sensor etc. Technology can help farmers in number of ways. For example, it can be used to:

- ✓ Improve crop yields by using precision agriculture techniques
- ✓ Reduce the use of water and other resources
- ✓ Protect crops from pests and diseases
- ✓ Monitor the health of soil[40]

By combining agriculture with technology, we can help to ensure that every one will have enough food to eat in future. Here are some examples of how technology is being used in agriculture today:

- ➢ Precision Agriculture: This uses sensor and GPS (Global Positioning System)[41] technology to collect data on soil conditions, crop health and weather patterns. This data can then be used to target fertilizer and pesticide application more precisely, which can help to reduce costs and improve crops.
- ➢ Drones [42]: Drones can be used to survey the crops, monitor pests and diseases, and apply pesticides and fertilizers. They can also be used to map fields and collect data on soil moisture and crop growth.

- Robotics: Robots are being used to automate a variety of task in agriculture, such as planting, weeding, and harvesting. This can help to reduce labour costs and improve efficiency
- Artificial Intelligence: AI is being used to develop new crop varieties, improve pest management, and optimize crop production.

III. CHALLENGES OF IOT

The Internet of Things (IoT) is a rapidly growing technology that has the potential to revolutionize many industries. IoT is providing number of benefits to the society, but apart of these there are also some challenges of IoT, that need to be addressed here.

1) Privacy: Privacy is one of the major challenges with IoT. Privacy concerns are issues related to the collection, storage, use and sharing of personal information. This can include concerns about who has access to personal information, how it is being used and whether it is being protected from unauthorized access misuse. In the digital age, privacy concerns have become increasingly important as personal information is being collected and stored on an unparalleled scale. This is especially true in the context of IoT, where devices are constantly collecting and transmitting data about our activities.

2) Authentication: Authentication in IoT (Internet of Things) is the process of verifying the identity of devices and users before allowing access to the IoT ecosystem or its resources. As the number of interconnected devices grows, it becomes increasingly important to ensure secure authentication to prevent unauthorized access and protect sensitive data. Generally, authentication can be of device, user, secure communication etc.

3) False Positives: False positives in IoT refer to situations where an IoT system mistakenly identifies a condition or event as true, when in fact it is not. This can lead to unnecessary actions or erroneous conclusions, which can have important consequences in various IoT applications. Some of the challenges posed by false positive in IoT are, Resource Wastage, Reduced System Trustworthiness, Increased Maintenance Overhead, Security Implication etc.

4) Scalability: Scalability is an important aspect in IoT (Internet of Things) that addresses the ability of IoT systems to handle increasing numbers of connected devices, data streams, and users without compromising performance, reliability, or security. As IoT applications continue to proliferate across various industries, the need for scalable IoT architectures becomes paramount. The key elements of scalability in IoT are: Device Management, Data Handling and Storage, Networking and communication, Edge Computing, Resource Management, Automatic Provisioning and Scaling etc.

5) Trust: Trust in IoT is a fundamental concern that revolves around the reliability, security, and privacy of interconnected devices and systems within the Internet of Things. Building trust is critical to the widespread adoption and successful integration of IoT technologies across various industries. However, some of the challenges need to be addressed to establish and maintain trust in IoT: Security Vulnerabilities, Privacy Concerns, Data Accuracy and Reliability, Identity and Authentication etc.

6) Access Control: Access control in IoT refers to the mechanisms and policies that determine which devices, users, or entities are allowed to access specific resources or functionalities within the IoT ecosystem. Effective access control is essential to ensure the security and privacy of IoT systems. However, there are several challenges in implementing access control in IoT, such as, diversity of devices and protocol, real-time requirements, dynamic nature of IoT etc.

Table 1 Comparison Table of IoT Applications with their Technologies and Limitations

Sr. No	Reference	Specific Topic Covered	Technologies/Methods/Protocol used	Limitations
1.	[1]	This paper focuses on comprehensive overview of the IoT scenario and reviews its enabling technologies and the sensor networks. This paper also covers the 6-layer architecture of IoT.	Radio Frequency Identification (RFID), Wireless Sensor Network (WSN),Micro-Electro-Mechanical Systems (MEMS)	Unauthorised access to RFID and WSNs are vulnerable because of sensor nodes.
2.	[2]	Internet of Things (IoT), IoT architecture,IoT applications, IoT challenges.	RFID, 3G/4G, WiFi, Bluetooth	Data Security and privacy is the major concern or challenges for IoT

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3.	[4]	This paper is covering the concept of Smart Building with door sensor, light sensor and CCTV technology.	Sensors, IR, Webcam	House security is the major concern as motion sensor and CCTV (webcam) have used
4.	[7]	This paper is covering IoT platform, IoT applications, sensors, personal health and IoT challenges.	Radio Frequency Identification (RFID), Representational State Transfer Configuration Protocol (RESTCONF), Constrained Application Protocol (CoAP)	Security is the main challenge or limitation because of the devices are interconnected with each other on internet
5.	[29]	In this paper authors are discussing the Mushroom farming using IoT. This paper is also covering the agriculture application such as Crop water management, Precision agriculture, IPM/C and Food production and safety etc.	Temperature and Humidity Sensor DHT-11	----------
6.	[30]	This paper showers light on the Blockchain, Fog and Edge Computing of IoT. It is also discussing about IoT attack models.	Bluetooth, WiFi, Zigbee, Z-Wave, Low Power Wide Area Network (LPWAN)	Security can be easily breach by Man-in-the-Middle, Distributed DOS, sybil attack and sinkhole attack.

IV. FUTURE SCOPE

The future scope of IoT is vast and promising, with many opportunities for innovation and change in various sectors. Some of the key areas where IoT is expected to have a significant impact are: Smart Homes, Smart Cities, Healthcare, Smart Farming, Smart Transportation, E-waste management system etc. As IoT technology continues to develop, it will undoubtedly open up new avenues and applications beyond the scope mentioned above. To fully realize the potential of the IoT, ongoing research, investment in infrastructure, and addressing privacy and security concerns will be necessary. The future of IoT promises a more connected, efficient and sustainable world.

V. CONCLUSION

In conclusion, this review paper has explored the vast landscape of Internet of Things (IoT) and its transformative impact on various industries and everyday life. Throughout the paper, we have discussed in detail the key components, applications, architecture, challenges and potential solutions shaping the development of IoT technologies. The emergence of IoT has ushered in a new era of connected devices, which enables seamless data exchange, intelligent decision making, and automation in various fields. From smart homes to industrial automation, healthcare, agriculture and beyond, IoT applications are revolutionizing the way we interact with technology and the world around us.

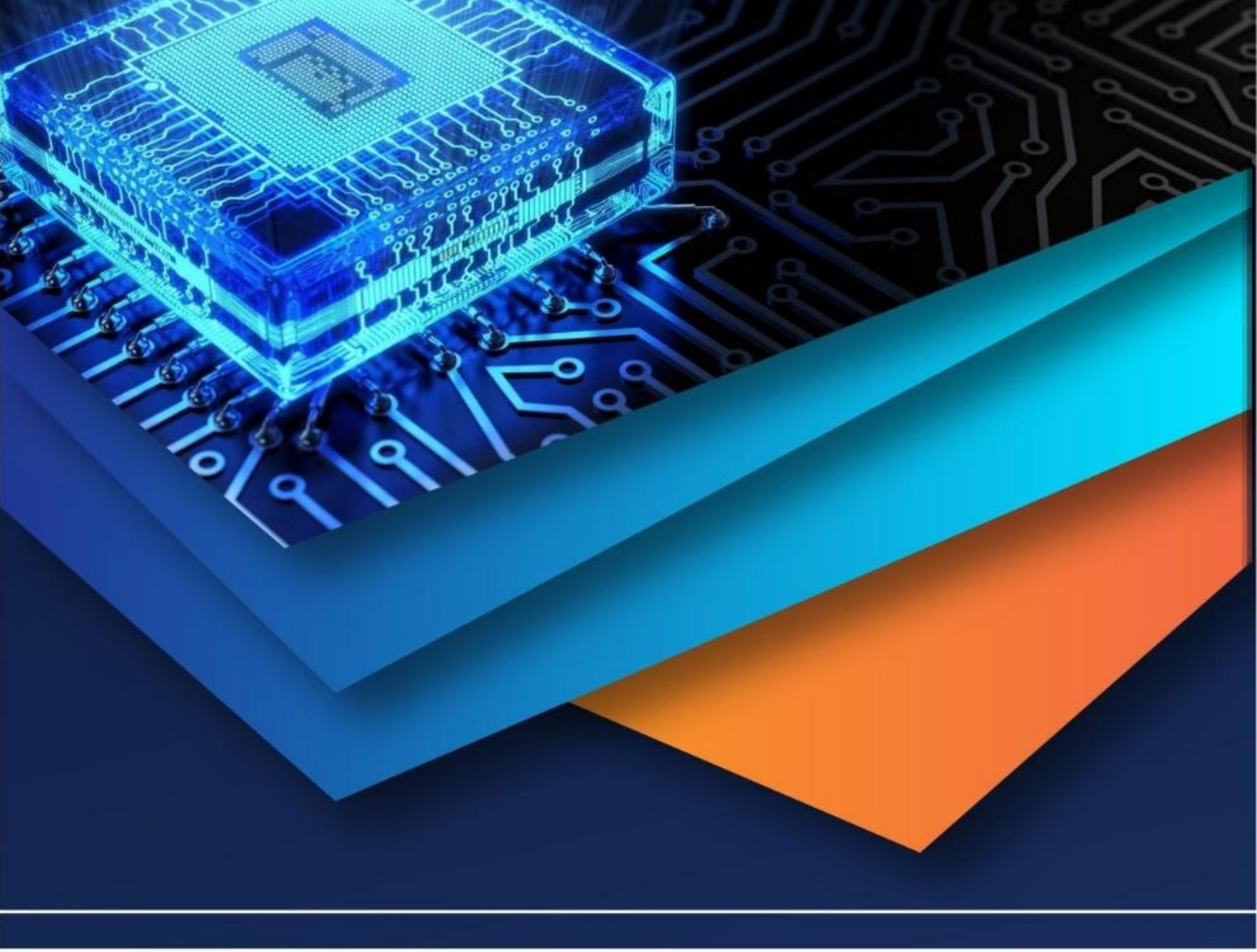
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