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REVIEWARTICLE

A Survey of Distributed Computing Approaches in IoT (Internet of Things)-Based Smart Applications

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Abstract The exponential growth of the Internet of Things (IoT) has created a pressing demand for computing solutions that are both efficient and scalable. When it comes to processing huge amounts of data created by the Internet of Things (IoT) in real-time with minimal latency, distributed computing techniques like as cloud, fog, edge, and dew computing are indispensable.This paper surveys the existing distributed computing paradigms in IoT-based smart applications, highlighting their strengths, limitations, and applicability in various domains such as smart cities, healthcare, industrial IoT, and smart agriculture. Furthermore, the paper discusses the key enabling technologies, including artificial intelligence (AI), blockchain, 5G connectivity, and virtualization, that enhance the performance and security of distributed IoT systems. Challenges such as interoperability, data security, and infrastructure costs are explored, along with potential solutions to improve the effectiveness of these computing approaches.

Keywords IoT, Distributed Computing, Cloud Computing, Fog Computing, Edge Computing, Dew Computing, Smart Applications, AI, Blockchain, 5G, Virtualization, Interoperability, Security, Scalability.

I. Introduction

The IoT is revolutionizing computing by embedding smart, networked devices into everyday objects, enabling real-time communication, automation, and decision-making. This transformation enhances industries like healthcare, manufacturing, and smart cities by integrating distributed computing principles to manage massive data flows efficiently. Unlike traditional centralized systems, IoT relies on distributed architectures for improved scalability, interoperability, and real-time processing.The increasing adoption of cloud[1], edge, and fog computing further supports IoT's ability to handle complex tasks across diverse environments. With billions of connected devices worldwide, IoT continues to reshape industries, driving innovations in artificial intelligence, security, and automation, making it a critical field of research and development.

Smart applications built on the IoT depend on many distributed computing paradigms to manage scalability, real-time decision-making, and massive amounts of data. Cloud computing provides centralized storage and computational power, enabling IoT devices to offload processing tasks to remote servers[2]. However, cloud-based IoT faces latency issues, leading to the implementation of fog computing, which minimizes latency by processing data at the network's periphery, closer to its point of origin. Edge computing further decentralizes computation by processing data directly on IoT devices, enhancing real-time responsiveness. Grid and cluster computing also support IoT by aggregating distributed resources for parallel processing[3]. Future advancements will focus on hybrid architectures, optimizing performance, security, and efficiency in IoT ecosystems.

IoT-based distributed computing faces several challenges, including security and privacy risks, interoperability issues, scalability concerns, and energy efficiency constraints. Ensuring secure data transmission[4], authentication, and encryption is crucial to prevent cyber threats. Interoperability remains a challenge due to heterogeneous devices and communication protocols, requiring standardized frameworks. Scalability demands efficient cloud-edge-fog integration to handle massive IoT data while maintaining low latency and high availability[5].Additionally, energy-efficient solutions are needed to prolong IoT device lifespan. Future research should focus on AI-driven optimizations, green computing, and ethical regulatory frameworks to enhance security, reliability, and sustainability in distributed IoT environments.

A. Structure of the paper:

Section 1 introduces the significance of IoT and distributed computing in smart applications, outlining their role in enhancing efficiency and scalability. Section 2 discusses the fundamental concepts of IoT and distributed computing, providing a foundation for understanding their integration. Section 3 explores key enabling technologies, including cloud, fog, edge computing, and distributed intelligence, essential for efficient IoT-based data processing. Section 4 examines various distributed computing applications in IoT smart systems, highlighting their impact on industries, healthcare, and smart cities. Section 5 presents a comparative analysis of different distributed computing approaches, evaluating their advantages, limitations, and performance metrics. Section 6 reviews existing literature, identifying research gaps and advancements in distributed IoT computing. Finally, Section 7 concludes the paper by summarizing key findings and proposing future research directions to address current challenges in security, scalability, and interoperability.

II. Fundamentals Of IoT And Distributed Computing

A. *Definition and principles of distributed computing:*

In distributed computing, many computers work together across a network to complete a single computation. The idea behind distributed computing is to use several computers to do a single task. The processing nodes, network architecture, and other components of a distributed network are often diverse from one another[6], The communication channel, operating system, and other components of various networks spread out over the world could vary.

B. *Concept of distributed computing in IoT environments:*

1) *Internet of Things:*

The idea behind the IoT is to link gadgets that can talk to one other, mostly over the internet.This innovation has a history that begins in 1999 and is attributed to Kevin Ashton. "Uniquely identifiable interoperable connected objects" is how he described RFID technology. However, as scientists and researchers work to comprehend the idea and the advances involved, this categorization has been evolving.

The emergence of distributed computing systems and the IoT has revolutionized business structures in a number of sectors. These developments have completely changed how companies function, compete, and provide value to customers while also redefining the technology landscape[7]. A change from conventional, centralized corporate frameworks to more flexible, decentralized, and data-driven models is sparked by the confluence of IoT and distributed computing systems.

The IoT and distributed computing platforms have significantly impacted corporate architectures.These days, classic companies—which often employed hierarchical and sequential processes—are evolving into more dynamic, networked entities[8]. Businesses may continually monitor operations and make modifications to optimize efficiency by utilizing real-time data from IoT devices. Businesses may reduce downtime and increase efficiency by using predictive analytics, which is fueled by data from IoT devices, to foresee problems before they arise[9].

C. *Distributed Computing Paradigms in IoT*

1) *Cloud Computing:*

The computing cloud serves as a glue that holds people, processes, and technology together as they develop and evolve to provide clients with digital experiences.Cloud computing is a technological improvement that allows people and various small and big organizations to use IT resources on demand for computations, networking, storage, and application development, the cloud architecture is schematically explained as Figure 1.Similar to electrical power grids, cloud computing allows users to access services based on their needs rather than being the custodian of the entire computer network. The three main services provided by cloud computing are IaaS, SaaS, and PaaS. Since its introduction in 2007, cloud computing has transformed the way the IT sector operates. The IT service girding paradigm, which was formerly product-centric, has evolved into a dispersed and service-centric one internationally, thanks to cloud computing. Even businesses that lack the funds and operational know-how to pay for computer and storage infrastructure are using the powerful capabilities that cloud computing offers.

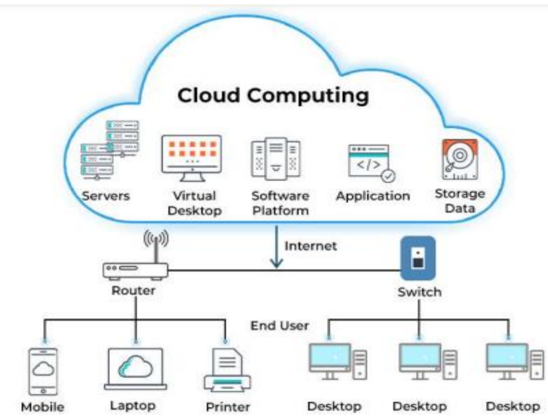

Fig. 1. Cloud Computing Architecture

2) *Fog Computing:*

To get over the problems with cloud computing, CISCO launched fog computing in 2012 as a new distributed computing paradigm as illustrated in Figure 2.The seamless integration of cloud computing allows Fog to move processing closer to the network edge[10]. It takes advantage of computational resources for IoT settings and real-time applications.Two big problems arise from the need to transmit data from all the linked devices to the cloud for processing: storage and bandwidth.A new technology called fog computing has emerged to address these issues[11]. The computing demands of the modern world cannot be satisfied by cloud or fog alone. Fog can only enhance cloud services by working in tandem with them.The fog-assisted cloud architecture relies on cloud computing. Fog computing has been defined in a variety of ways by various scholars.

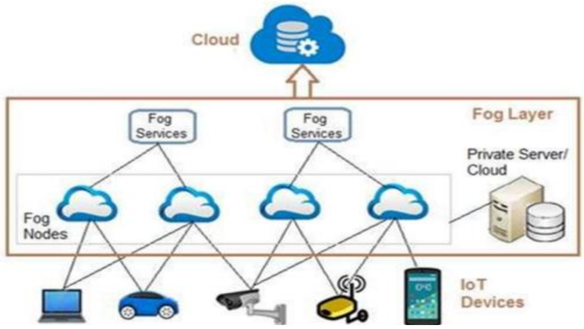

Fig. 2. Architecture of Fog Computing

Cloud computing will continue to handle complicated computing tasks, but fog computing is used for smaller, time-sensitive applications[12]. While fog won't be able to fully replace cloud, it may greatly enhance cloud computing services when combined with cloud. Cloud and fog operations may be compared using many factors[13].

Cloud computing is inefficient when there are a large number of connected devices. Cloud computing models will experience problems with bandwidth and latency in certain situations. By moving the processing of these requests closer to the network's edge, Fog is able to achieve additional benefits, such as lower bandwidth consumption and low latency[14].

3) Edge Computing:

There has been a change in architectural and implementational emphasis toward achieving real-time answers, supporting context awareness, and enabling mobility in the IoT through edge computing.

Edge computing has the potential to conceal temporary cloud disruptions, provide scalable and privacy-policy-enforcing services for the IoT, and provide lightning-fast cloud services for mobile computing. In order to speed up access to cloud services, Satyanarayana explains, edge computing makes use of caching.

In addition to retrieving IoT micro-services from IoT devices, edge computing brings cloud services closer to the consumer. It shifts the focus from an IoT device's data consumer to data producer.

There are primarily two methods for organizing architectural components of edge computing[15].The difference between fog computing and cloudlet solutions is in the implementation provider. Fog computing is based on mobile operators supplying infrastructure, whereas cloudlet refers to Internet providers using LAN networking for edge devices. These words are considered by some writers to mean the same thing as "edge computing."

4) Dew Computing:

The ideas behind edge computing and Dew computing are complimentary.A dew computing idea is defined for streaming Internet of Things devices as end-user devices that cannot transfer data or offload computations to an edge or cloud server because they do not have Internet connection via a LAN.The two most important aspects of the dew computing idea are defined in its most basic form:

- Complete autonomy, by removing the necessity for a constant Internet connection and creating a setting in which the IoT device may operate locally and communicate with the user.
- Collaboration, by making it possible for IoT devices to work together in a networked setting[16].

A specification of Wang presented a dew computing architecture, along by a detailed exposition of functional needs. It is an adaptation of a cloud-based client-server architecture idea to a novel setting.

A dew server, according to Wang's definition, is a small, lightweight server that offers microservices. It is improved by Ray by adding a more precise specification. There are three separate novel-related services that he addresses, infrastructure-as-a-service, SaaS, and SaaS solutions[17]. Moreover, he specifies that the dew computing paradigm has six key features, Collection of data based on rules, synchronization, scalability, re-origination, transparency, and accessibility via any means at any time.

III. Key Technologies Enabling Distributed IoT Computing:

The unique properties of IoT devices necessitate a more nuanced balance between communication and processing. In instance, new distributed solutions are required because to the high number of sensors and the stringent quality of service requirements. IoT distributed computing architectures need edge nodes to provide data processing for sensor clusters as the number of sensors increases. In addition, they need to do analytics at the edge to lessen the amount of data transmitted to the core from measurements taken at high frequencies and therefore the bandwidth requirements.

A. Machine Learning & AI:

ML is “a subset of AI,” according to Melo Lima and Dursun Delen. It is used when computers try to solve problems and learn like humans to get the best possible outcomes. "ML" is defined by Harleen Kaur and Vinita Kumari as "the development of algorithms and techniques that enable computers to learn and acquire intelligence based on past experience." A subfield in AI, this has strong ties to the statistical field[18][19]. In order for the system to learn, it must be able to recognize and comprehend the input data before it can use it to generate predictions and judgements. We employ the following brief definition[20] for the sake of this research: In ML, training systems are able to comprehend input data and utilize it to either anticipate replies or extract valuable information. The field is strongly associated with statistics and is a subset of AI.

In this study, examine the following four learning approaches: supervised, unsupervised, semi-supervised, and reinforcement learning.

Supervised learning: Its employed when relevant past data is accessible for an issue at hand. In order to train the system to anticipate the responses to fresh inputs, it is fed examples of both the inputs and the replies. Two subsets of supervised learning exist: regression and classification.

To classify something, one must first establish a connection between its individual inputs and outputs [13]. Various names for output variables include categories and labels. Predicting categorical class labels in the classification stage requires a mapping function (classifier) that was built in the learning step by evaluating training data. Calculating or forecasting continuous variables is the domain of regression. The link between several independent variables may be established by regression analysis, which uses statistical features as inputs.

Unsupervised learning: Dissimilar to supervised learning, it lacks labels and so does not provide output vectors. Determining actionable insights from data structures without prior knowledge of the desired outcome is the goal of unsupervised learning.Clustering and dimensionality reduction are the two main categories of unsupervised learning. Clustering involves organizing a collection of things into distinct groups with the goal of making each group as similar to the others as feasible while simultaneously making each group as distinct as possible from all others. Whereas, the goal of dimensionality reduction is to condense a huge data space without sacrificing any of the original data's relevant information.

Semi-supervised learning: It combines elements from both of the aforementioned methods, as its name implies[21]. For issues where the majority of instances only contain values for the variables and no data on the predicted outcome, semi-supervised learning is a frequent solution. In these circumstances, the inputs and outputs are both measured.

B. Blockchain

The term "blockchain" refers to a distributed ledger that allows for the storing and transfer of data between peers using timestamps[22]. It is tamper-resistant, immutable, auditable, permanent, and block-based. Information stored in the BC might range from a person's private details to their financial history or even a contract.The original motivation for developing BC technology was to address the problem of duplicate spending in cryptocurrencies. The distinctive and appealing qualities of BC, such as security[23] and potential applications outside of the Bitcoin industry are piqued by its features such as integrity, auditability, data immutability, authorization, resistance to censorship, fault tolerances, and transactional privacy.Mobile crowd sensing, identity management, intelligent transportation, healthcare, supply chain management, smart grids, food production, and mission-critical system security are just a few examples. The security, audibility, and anonymity of BC technology have made it a hot topic during the past decade.Figure 3 illustrates the evolution of blockchain technology from its inception in 2009 with Bitcoin (Blockchain 1.0) to its advancements in smart contracts (Blockchain 2.0), decentralized applications (Blockchain 3.0), and real-time distributed databases supporting Industry 4.0 and Healthcare 4.0 (Blockchain 4.0) by 2018.

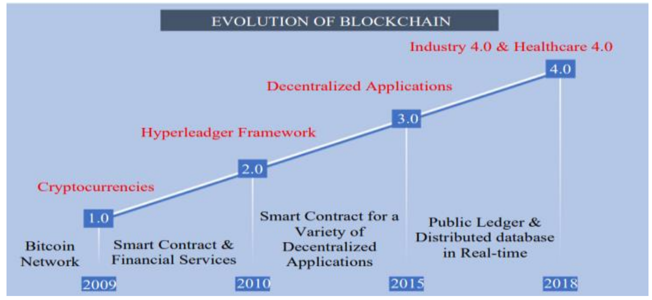

Fig. 3. Blockchain Evolution

Blockchain Uses in Security Applications:

- **Security of IoT:**Data and system security has always been a major concern, especially with the proliferation of AI and the IoT [24]. A use of blockchain technology that might help ensure the safety of the IoT would be to encrypt data exchanged between devices, implement key management techniques, and verify user identities. Implementing blockchain technology in this way has the potential to fortify IoTsecurity measures.
- **Software download authenticity:**To lessen the likelihood of malicious software exploiting compromised systems, BC technology might be used to verify software updates and installers. Here, hashes are appended to the BC, and any newly downloaded program may have its authenticity checked by comparing it to the hashes.
- **Protection during data transmission:**Data encryption is one way to provide this protection, preventing unauthorized parties from reading the data while it is in transit.
- **The decentralized storage of essential data:**The volume amount of data created daily is growing at an exponential pace; hence, decentralised storage solutions based on the blockchain can aid in protecting digital data[25].
- **Protecting Against DDoS Attacks:**This is among the most common cyberattacks that are now facing [26]. The purpose of these assaults is to increase Internet traffic so that hackers may interrupt service delivery.Blockchain has the potential to be an effective defensive mechanism against these dangers because of its immutability and cryptographic capabilities.
- **Security of the DNS:**The DNS connects IP addresses to domain names, much like a public directory[27]. Over time, hackers have tried to take down websites by using these linkages and the DNS. The decentralized and immutable nature of BC technology allows for the DNS to be kept with greater security.

C. 5G & IoT Connectivity:

5G allows wireless communication to advance exponentially in the next generation of mobile networks. The needs of numerous applications are rising daily. In an effort to stay up with this progress, wireless technology is evolving at a rapid pace [28]. Applications that rely on big data and other networks for a variety of purposes, such as inventory management, rapid money transfers, and the detection of serious illnesses, employ 5G's features to improve system performance[29]. The latest applications require a lot of data processing power, high quality of service, and quality of experience, which 4G and older generations just can't provide. The average transmission rate is 100+ Mbps, and the rates are also expressed in Gbps. The results show that 5G has the potential to deliver a transmission rate of 20 Gbps, which is one hundred times quicker than 4G. Therefore, adding 5G to the network architecture has the potential to completely alter how people communicate. The fifth generation of mobile networks is called 5G. Three general 5G kinds will be covered here:

1) Low Band 5G

Frequencies lower than 2 GHz are used in low-band 5G. The longest-running television and radio frequencies are these ones. There aren't any very big channels, although they can go great distances. The lowest potential data rate is shown by the Low Band 5G. As a result, 5G with limited bandwidth is sluggish.T-Mobile, AT&T, Verizon, and other cellular networks use these frequencies, which range from 5 to 15 MHz. Although 5G is a little faster than 4G, it is thought to be the worst scenario.

2) Medium Band 5G

The frequencies used by mid-band 5G in most countries are 2.5 GHz and 3.5–3.7 GHz. It uses a frequency lower than 6 GHz, making it quicker than Low-band 5G. It can cover most of the frequencies used by Wi-Fi and mobile networks, as well as a few frequencies that are a little higher. In most countries, these networks are the ones with the most 5G traffic since they can cover a distance of several miles from towers that are positioned within a half-mile radius.

3) High Band:

5G High-band 5G is brought about by the millimeter wave spectrum enabled by short-distance towers, as opposed to the previously described 5G. Most of the airwaves have so far been in the 20–100 GHz spectrum[30]. There has never been any prior consumer usage of these frequencies. They are limited to short-distance usage.As a result, doing the experiments on many platforms indicates that the towers should be about 800 feet away in a crowded metropolitan setting [31]. But since there are so many unused channels, very high speeds—ideally up to 800 MHz at a time—are possible.

D. Virtualization & Microservices:

The process of Virtualisation is the process of creating a virtual version of anything, including an operating system, storage device, computer hardware platform, or computer network resources. The terms server, network, storage, application, and desktop virtualization are all included in the category of virtualization. In recent years, virtualization techniques have demonstrated a number of advantages, such as reduced expenses and power usage, simpler deployment and management, improved mobile applications, cross-platform compatibility, etc[32]. A type of computing known as "cloud computing" uses the Internet to deliver virtualized and dynamically scaled resources as a service. Distributed computing, utility computing, parallel computing, virtualization, and other technologies are all integrated into this process. It falls into one of three categories: public, private, or hybrid. Three-tiered services, including SAAS, PAAS, and IAAS, are common in cloud computing settings. Virtualization is now one of the most important core technologies in cloud computing. If virtualization technology is used in cloud computing, more and more companies can benefit from reduced administrative, hardware, and power usage costs. Data centres, education, banking, and government are just a few of the industries that have recently made extensive use of cloud computing services based on virtualization.

Cloud computing is the delivery of computing as a service rather than a product, whereby computers and other devices are granted network utility access to shared resources, software, and data[33]. High availability, high performance, load balancing, on-demand resource allocation, and Important characteristics of a well-designed cloud computing infrastructure include dynamic scalability[34][35]. Research topics related to cloud computing are many and include virtualization, scalability, power management, and stability. The technique of virtualization is only one of several crucial cloud computing technologies. Cloud computing uses virtualization[36]to manage a distributed shared resource pool's hardware. Virtualization allows all IT resources to be more efficiently used and distributed in a dynamic manner.

Microservices are a collection of tiny services that focus on business functions. They can be built in different programming languages and are autonomous and decentralized. Because it was constructed as a single unit, the conventional monolithic design was not appropriate for the creation of complex processes and was challenging to scale. Microservices grew and gained popularity as a result of the requirement for a strong, adaptable, and dependable pattern[37].

These days, the majority of businesses are using microservices to meet the needs of their particular applications. The following are a few large companies that have embraced this architectural style:

- **Netflix:**One of the forerunners of this architectural style, if you will. When it first launched its video streaming service, Netflix employed a monolithic architectural design. However, the data centres and the monolithic application could not handle the increasing number of users and the continuously increasing volume of data and services. They thus embraced the micro-services design and moved to the cloud. Scalability, adaptability, and even quicker application development and deployment were among its many advantages. Additionally, the move to the cloud-assisted them in cost optimization and reduction while simultaneously improving service availability for its consumers.
- **Uber:**The microservices architecture was also used by this transport corporation when its fast expansion

demands could not be met by the monolithic design. However, some of the difficulties also resulted from the switch to micro services. The majority of these issues were addressed, and they are now employing microservices to make their application scalable and fault-resistant.

- **Amazon:**Amazon also implemented microservices, which altered its development process. Additionally, they assigned small, autonomous teams, which altered their organisational structure[38]. They were able to organise more efficiently, launch their apps more quickly, and even incorporate new and enhanced features as a result.

IV. Distributed Computing Applications In IoT-Based Smart Systems:

A. Smart Cities:

In order to effectively monitor the state of the city and administer its services, smart city initiatives are being implemented throughout all smart city domains through the deployment of IoT devices. IoT-based management is crucial for smart cities as it enhances sustainability, effectiveness, and quality of life[8]. IoT-enabled real-time data collection and analysis improves decision-making and resource allocation. This maximizes resources, reduces costs, and improves services including energy consumption, traffic control, and public safety.When combined with existing ICT infrastructure, IoT devices open up a wide range of previously unattainable or challenging opportunities. City managers may now have a more comprehensive and up-to-date picture of the state of the city by utilizing the vast quantity of data made accessible by dispersed sensor installations [39]. The use of data processing and analysis tools across edge computing resources in the city and cloud enables this newfound situational awareness. In order to meet the ever-increasing urbanization difficulties encountered globally, cities are now becoming more efficient and controllable with the aid of the IoT[40].

B. Healthcare:

The IoT is being used in many different fields, such as healthcare systems, home, and unmatched advantages and extensive prospective applications of home automation, industrial automation, smart enterprise, smart cities, smart agriculture, and warning and recovery systems for natural and man-made disasters[41]. Through embedded technology, networks of physical objects may sense their internal and external environments in the IoT [42].

The proliferation of advanced components, such as sensors, actuators, and complex communication networks, as well as their declining cost, have contributed to the quick development of embedded systems. The healthcare industry is growing quickly, broadening its scope and services.The healthcare system enabled the time and space constraints that occur in health promotion medical services, which need a physician to examine a patient's bio signal-related data while facing the patient[43]. Additionally, it saves the lives of several people in the event of an emergency or accident. Using the IoT, distributed databases, and distributed database management systems, IoT-based distributed healthcare systems link a range of medical resources embedded with sensors, such as blood pressure, glucose, ECG, EMG, and so on, to provide reliable, effective, and intelligent healthcare services to the elderly and patients with chronic illnesses. The IoT-DHS helps collect a range of patient parameters using a variety of health monitoring devices. It then instantly alerts the physician, nurse, hospital, or other relevant parties so that proper prescription measures may be prescribed by a physician and first aid measures can be administered.

C. Industrial IoT (IIoT):

The IIoT in recent years has brought a disruptive change over traditional maintenance practices specifically within the operational aspects[44]. CategoriesPdM is one such approach, which predicts equipment failures and recommends a preventive schedule through real-time data analytics. Thanks to Master A I, the way we have changed from a reactive type of maintenance and operations planning into predictive has become much simpler for us[45], rather than maintaining it ourselves because this would require very high demands on human calculation as well as using statistical conductivity. Predictive maintenance These systems continuously monitor the status of equipment using sensors installed in various industrial/public assets, for example.These sensors can provide a wealth of operational data, including feedback on temperature, vibration, pressure,and acoustic emissions. The old maintenance strategies, like preventive and corrective maintenance, will lead to either too much unnecessary work or unplanned downtimes that decrease efficiency & operational costs.

D. Smart Agriculture:

One of the most crucial foundations of the economy is agriculture, and the security of food commodity supply is essential to the stability of society. By producing the food commodities that society needs locally, all societies hope to achieve this stability. To do this, they try to recover land, supply water, invest in the agricultural sector, and develop it to maximize the yield from the labor, water, and land resources at their disposal.

Improving the current irrigation infrastructure is one strategy to grow the agricultural industry [46]. The farmer manually initiates the watering process on a regular basis in conventional irrigation systems[47].Because the soil's surface varies in saturation from within, the worker's visual observation of the time intervals for the irrigation process and between them may not be accurate, which could result in inefficient crop irrigation and waste of scarce water supplies.

E. Smart Homes & Buildings:

One example is an Internet of Things-based smart home. IoT-enabled Smart Home conditions include a variety of items, including as lights, household appliances, computers, surveillance cameras, etc., all of which are connected to the Internet and provide users the ability to monitor and manage things with minimal regard for time and location requirements[48].

IoT devices are a subset of the broader concept of home automation, which may integrate media, security, heating and cooling, and lighting [49]. By assuring that lights and equipment are killed, long-distance preferences might join essentialness venture reserves. A significant percentage of IoT-related applications are being considered and identified by endeavours, and they can be divided into two categories. The gadgets in the first grouping are connected, creating a mechanized setup with M2M communication and importance to enhance people's lives [50].IoT can be observed anticipating TCC&R (track, request, and control) action in this category. For instance, in nuclear households, the room temperature, windows, lighting, electrical devices, etc., might all be remotely controlled from a PC and automated to eliminate the manual methods that individuals encounter on a daily basis.

V. Comparative Analysis Of Distributed Computing Approaches

Distributed computing achieves a computational result significantly faster than a single computer by using a network of several computers, each of which completes a component of a larger assignment [51][52]. Distributed computing not only offers more processing power but also enables open communication and interaction between several users. The process of running a single computer program on several computers simultaneously is known as distributed computing. Specifically, various computer processors are used to operate or process the various components and objects of a program [53]. By enabling computational components to be dispersed over a heterogeneous network and smoothly collaborate to complete a job, distributed computing goes beyond traditional computing [54]. One way to think of distributed computing is as an effort to create a virtual supercomputer from hundreds or thousands of separate machines.

A. Grid Computing:

One of the most recent buzzwords in the IT sector is "grid computing." Grid computing, also known as distributed and large-scale cluster computing, is a form of network-distributed parallel processing[55].This cutting-edge method of computing makes use of the current IT infrastructure to manage data and processing workloads and optimize computing resources. Heterogeneous processing and storage resources dispersed over several network domains make up grids [56]. Grids provide consumers the tools they need to discover, distribute, and use resources. In a heterogeneous grid system, grid middleware gives users consistent access to resources and smooth processing capabilities. Figure 4 shows the grid's structure.

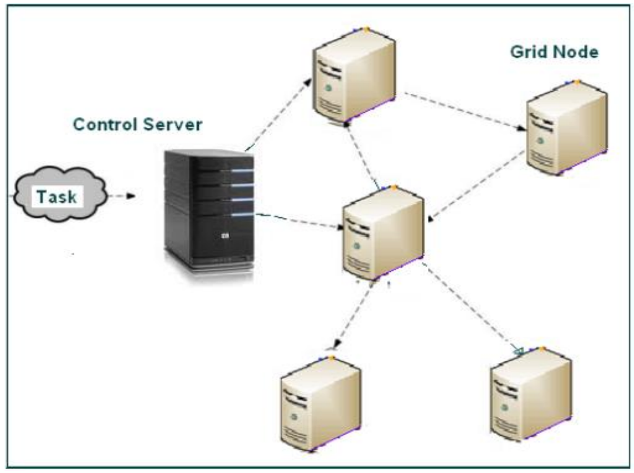

Fig. 4. Grid Computing

B. Cloud Computing:

In order to provide a more flexible method of delivering and the combination and advancement of several concepts from virtualization, distributed application design, grid, and enterprise IT management results in cloud computing, which scales applications[57]. A brief illustration is described in the figure 5.

Architects must comprehend the main advantages of cloud computing in order to create a future state architecture that fully realizes its potential:

- Decoupling and separating the business service during operation from the required infrastructure (virtualization)[58].
- Flexibility to select several suppliers offering development environments, infrastructure, and dependable and scalable business services with metered prices that are available for instant usage and don't require long-term commitments.
- The infrastructure's ability to quickly assign and de-allocate enormously scalable resources to business services in response to demand[59].
- Flexibility in cost allocation for clients wishing to convert capital expenditures into operational expenditures.
- Cost savings via improved operations and quicker rollout of new business offerings.

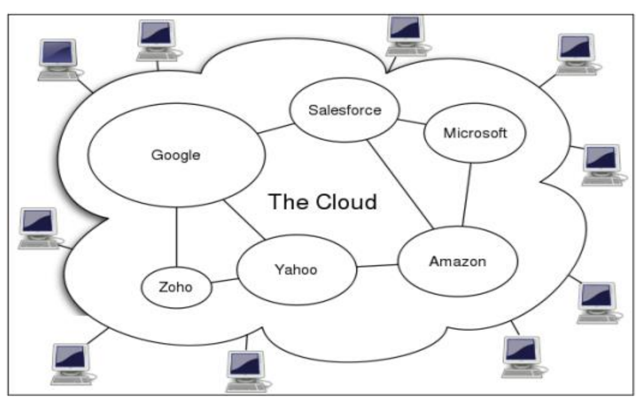

Fig. 5. Cloud Computing

VI. LITERATURE OF REVIEW

The literature study in this area covers all the bases when it comes to distributed computing methods for smart applications built on the IoT. The article discusses recent developments in the IoT, such as distributed intelligence, fog computing, and edge computing, and it tackles problems like security, scalability, interoperability, and the efficiency of processing data in real-time.

Sathish & Smys (2020) This paper takes a look at the many uses and applications of IoT smart technologies. Through a wireless connection, the IoT gathers and processes data from a wide variety of actuators and sensors. Various applications use the IoT. In all of these uses, the Internet of Things is essential to raising living standards. This covers, among other things, industry, the environment, smart energy, and household appliances. Additionally, the IoT creates a more pleasant atmosphere[60].

Prieto et al. (2018) This paper explores how distributed computing and the IoT might work together to improve data processing and analysis methods and control the vast amounts of resources needed by linked devices. When it comes to the specific difficulties of sensor networks, such as satisfying stringent latency and quality of service criteria, fog computing appears to be an appropriate paradigm. Various applications, including mobile cloud computing and multimedia sensor networks, rely on efficient and energy-conserving task distribution between edge devices and the cloud. This special issue gathers creative approaches to these problems, with an emphasis on these three areas[61].

Alsboui et al. (2021)This paper examines DI methods in the IoT, begins with a brief explanation of DI's need, and then proposes a thorough taxonomy of DI in the IoT. After that, we utilize this taxonomy to look at present problems that need serious thought and to evaluate current methods. According to the taxonomy, there are five distinct types of IoT DI approaches, each characterized by one or more characteristics that facilitate distributed functionality and data acquisition: hybrid, distributed ledger technology, cloud computing, mist computing, and service-oriented computing[62].

Fredj et al. (2021)This paper the current literature on designing dynamic distributed systems, with a focus on IoT applications, using AI and MDE, and organizes it into categories. We zeroed down on a set of standards that draw attention to the gaps in current methods for designing dispersed devices' interactions, adaptations, and system restrictions. Lastly, we provide our plans for the future to address the limitations of current solutions, considering the criteria that have been noticed[63].

Ahmed et al. (2020) In this paper, distributed fog computing allows us to effectively monitor air quality, and we've suggested a tiered architecture to handle and analyze data. We suggest both mobile platforms and fixed nodes for data collecting to ensure coverage everywhere. While data analytics benefit from cloud computing, the system becomes slower while using it; in contrast, a fog layer improves performance and efficiency. To avoid compromising the privacy and security of sensitive data transmitted to the cloud, fog nodes make it easier to conduct analyses locally rather than in the cloud itself. To keep IoT devices safe, it's necessary to analyze data in real-time, and doing so locally is considerably more convenient and accessible than doing it on the cloud[64].

GabAllah et al. (2023)In this paper, to create an innovative IoT system with intelligence dispersed across several levels, including the network edge, we suggest an architecture, plan the design, and construct a prototype. The three levels of our suggested architecture—the edge, the gateway (fog), and the cloud—make up a modular Internet of Things system. A distributed ML model is realized by the proposed system utilizing data received by edge devices. A lightweight ML model is used to ensure a timely response at the edge[65].

TableIhighlights IoT advancements, challenges in security, scalability, and efficiency, and contributions in fog, edge computing, and distributed intelligence.

TABLE I. COMPARATIVE ANALYSIS OF KEY STUDIES ON DISTRIBUTED COMPUTING APPROACHES IN IOT

Reference	Focus Area	Key Findings	Challenges	Key Contribution
Sathish & Smys, (2020)	IoT Applications in Smart Systems	IoT enhances smart living through automation in various domains.	Security, scalability, and interoperability issues.	Highlights IoT's role in improving living standards.
Prieto et al., (2018)	IoT and Distributed Computing Integration	Fog computing addresses latency and QoS challenges in sensor networks.	Efficient resource management and energy conservation.	Emphasizes task distribution in mobile and multimedia sensor networks.
Alsboui et al., (2021)	Distributed Intelligence (DI) in IoT	Proposes a taxonomy of DI in IoT covering cloud, mist, and hybrid computing.	Lack of standardization and interoperability among DI techniques.	Classifies IoT DI approaches based on distributed functionality.
Fredj et al., (2021)	AI & Model-Driven Engineering (MDE) in IoT	Reviews AI and MDE approaches for dynamic distributed systems.	Design limitations in adaptation and system constraints.	Identifies gaps in distributed system interaction and proposes future research directions.
Ahmed et al., (2020)	Monitoring Air Quality using Fog Computing	Proposes a layered architecture using fog computing for efficient air quality monitoring.	Security and privacy concerns in cloud-based analytics.	Advocates for local data analysis at fog nodes to enhance security and efficiency.
GabAllah et al., (2023)	Edge Computing & Distributed Machine Learning	Introduces a three-tier IoT architecture integrating edge, fog, and cloud computing.	Challenges in lightweight ML models and real-time response.	Develops a distributed ML framework for efficient edge processing.

VII. CONCLUSION AND FUTURE WORK

Cloud computing provides massive computational resources that can be complemented using fog, edge, and dew computing for other functionalities. Compatibility, security vulnerabilities, and actual costs are among the barriers that discourage mass adoption.Distributed computing paradigms, including cloud, fog, edge, and dew computing, enhance IoT scalability, efficiency, and real-time processing. However, challenges like security, interoperability, and infrastructure costs hinder adoption. Future research should focus on AI-driven optimization, blockchain-based security, and hybrid computing models. Advancements in 5G, edge intelligence, and energy-efficient architectures will further enhance IoT applications.Addressing these challenges will drive innovation, ensuring seamless integration and improved performance in diverse smart applications.

Future work must thus seek to create standardized frameworks, for example, cases of successful integration of distributed computing paradigms. Advancing data privacy through blockchain-based security, resource allocation, with the aforementioned algorithms present, and ultra-reliable low-latency communication via 5G networks are plausible research directions. On top of that, hybrid computing models that integrate several of the distributed computing paradigms can enhance cooperation in the face of multiple potential use cases for IoT applications.By embracing emerging technologies, distributed computing is set to open up further these new opportunities in smart applications, leading to the next wave of innovation in the IoT.

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