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Challenges of IoT Environments: A Taxonomy

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The IoT environment is a paradigm that leverages the benefits of the Internet and peripheral devices to provide information systems with mobility support and deliver superior services. In an IoT environment, the administration of computational duties is contingent upon the effective distribution and management of distributed and mostly heterogeneous resources. This paper reviews notable proposed resource management models and methods in IoT environments to present a new taxonomy of IoT environments concerning challenges created by different resource management models and methods on the efficiency, scalability, and sustainability of these environments. The main challenges include device heterogeneity, real-time data processing, cost management, defect tolerance, and reliability. The analysis of these researches demonstrates the importance of effective methods for surmounting the challenges associated with IoT applications. Since IoT systems produce vast amounts of data from various resource-constrained devices, managing and storing this voluminous data efficiently is crucial to ensure high performance, scalability, and reliability. Achieving scalability in IoT environments requires designing resource management strategies that can grow and adapt to large workloads and device densities while maintaining operational efficiency. Our presented taxonomy of different models and methods can guide researchers and developers in designing efficient means of resource allocation to raise QoS standards to encounter the challenges of the IoT environments.
Keywords: IoT Environment, Resource Management, Technologies, IoT Applications.

1. Introduction

Recently, the Internet of Things (IoT) environment leverages both the Internet and Edge devices to deliver superior services. The integration of Internet and Edge devices in IoT shows the advantages of the Internet by global connectivity that enables seamless communication and data exchange across the world. In addition, it facilitates remote access and control of IoT devices. In contrast, Cloud computing provides scalable resources for data storage and processing and supports large-scale analytics and complex computations. Hence, data accessibility of Cloud computing could be realized via IoT devices that could be accessed and managed from anywhere.

On the other hand, Edge devices provide local processing capability, which reduces latency by processing data in close proximity to the source and reducing the necessity of transmitting large volumes of data to centralized servers. Additionally, real-time analytics facilitates immediate data analysis and decision-making, which is crucial for time-sensitive applications such as industrial automation and autonomous vehicles. Reduced latency enhances the responsiveness and efficacy of IoT applications, as well as the operational performance and user experience (Yunana et al., 2021).

However, the growing demand for IoT applications and devices will likely result in the inefficiency of some fundamental computing and task management functions. These functions include low latency, mobility support, and location perception (Yunana et al., 2021)(Izhar et al., 2023). For example, processing energy, battery endurance, storage capacity, and bandwidth are some of the main issues preventing IoT devices from providing high-quality service. Employing robust IoT services based on integrated resources became the answer to the problem of compensating for the weight of restricted resources that IoT devices have.

On the other hand, there is a widespread belief that Cloud computing is the solution to the problem of providing services with flexible resources at a low cost (Mowla et al., 2023). However, according to the open Internet of Things Environment Consortium (N. Alqahtani et al., 2023), latency, location awareness, geo-distribution, and security are some of the disturbances that has led to the establishment of the IoT environment. Edge devices confront two significant problems from all Cloud services. There are many tasks for which a Cloud-only solution is insufficient due to security, bandwidth, reliability, and many other concerns of performance in an IoT environment. These include data that the IoT devices are creating exponentially, which causes network congestion and drive performance problems at the edge of infrastructure. Thus, effective distribution and task management are fundamental for managing computational costs and optimizing performance in IoT environments.

IoT systems can achieve cost efficiency, enhanced performance, and scalability by leveraging techniques like load balancing, distributed computing, Edge and Fog computing, and various scheduling strategies. These guarantee that IoT applications function effortlessly and efficiently, satisfying the needs of both consumers and industries.

This paper, based on conducting an extensive literature review, we present an analysis of the primary challenges of the IoT environment, alongside the most notable recent solutions that have been presented so far to address relevant issues. The research study presents a practical methodology for future research and to researchers interested in the IoT environment.

The remaining of the paper is structured as follows. Section 2 provides background on the IoT environment. Section 3 presents the technologies of the IoT environment. Section 4 presents the challenges of the IoT environment. Resource management of the IoT environment, specifically considered as the main challenge, is discussed in Section 5. Section 6 presents a discussion followed by a definitive conclusion in Section 7.

2. Background on IoT Environment

Nowadays, the Internet has reached each side of the world and is impacting human life in incomprehensible manners. The IoT is a paradigm shift that involves connecting a variety of devices, also known as "things," to the Internet. This allows these devices to gather, share, and act upon data. The IoT comprises of a variety of devices, ranging from commonplace domestic objects to technically advanced industrial machinery. A number of essential components and technologies are included in the computing infrastructure that underpins the IoT. These components and technologies collaborate to manage, process, and analyze the enormous volumes of data that IoT devices produce.

Through the integration of sensors, microcontrollers, Edge and Fog computing, Cloud services, and communication networks, the IoT ecosystem is a fast-developing sector that makes it possible to construct intelligent and linked systems. Several applications, such as smart homes, industrial automation, healthcare, agriculture, and smart cities, can benefit from this paradigm shift because it provides real-time data processing, improved decision-making, and increased efficiency. As the IoT technology advances, it will drive further innovation and transformation in numerous industries, creating more interconnected and intelligent devices (Krishnan et al., 2023).

IoT devices create a massive quantity of data, which raises the need for processing and voluminous storage resources. This necessitates implementing traditional resource management strategies to accommodate the limits of IoT nodes. Therefore, it is essential to incorporate high-end nodes into the IoT ecosystem to achieve adequate performance.

An example of the architecture of an IoT environment is shown in Fig. 1, which depicts appliances and services that may require significant resources to collect, transport, analyze, process, and store data. There is also the possibility that it will make use of resources and services to gather, transmit, search, analyze, and store data that is produced by complicated processes.

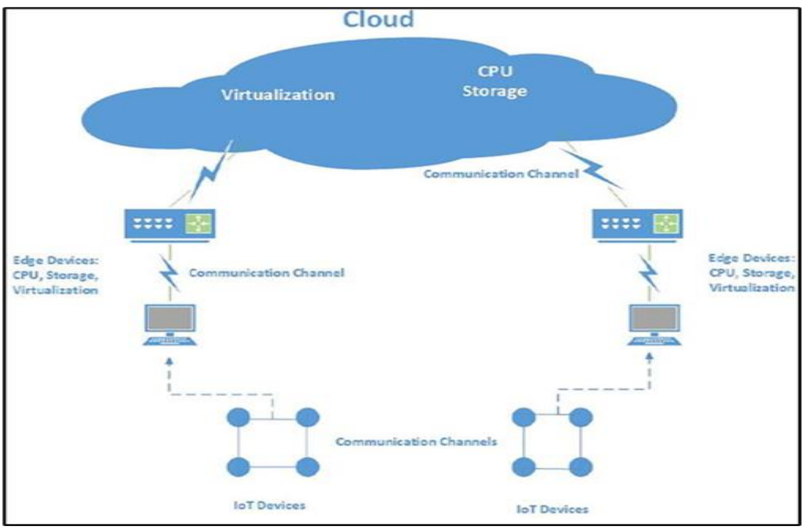

Figure 1. Architecture of the IoT Environment (Zahoor & Mir, 2021)

3. Technologies of IoT Environment

One exciting paradigm that offers computational services at the network edge is the enabling technologies for the IoT environment (Krishnan et al., 2023). This paradigm creates new services and applications to be developed for the Internet in the future. In contrast to other paradigms, such as Cloudlets, Mobile Cloud Computing (MCC), and Mobile Edge Computing (MEC), the IoT environment computing has a more advantageous placement position since it is closer to the IoT nodes. Additionally, it allows for the extension of services that are hosted in the Cloud. As a result, it contributes to the provision of effectively efficient services, including the large reduction in latency (Yunana et al., 2021). However, the existence of the IoT environment does not replace the Cloud service; rather, it enhances it to some degree (Krishnan et al., 2023)(Ahsan et al., 2021).

Many different computing paradigms have already begun to be implemented in the computing technology field, considering the idea of Edge computing and Cloud computing. The notions of Edge computing and Cloud computing have been considered in the development of a number of computing paradigms that have been developed in the field of computation technology. Possible advancements in Cloud and Edge computing include Mobile Edge Computing (MEC) and Mobile Cloud Computing (MCC), both of which are instances of mobile computing. It is generally agreed that MEC is an essential facilitator of the growth of cellular base stations that is now taking place. At the same time, MCC provides the processing resources necessary to support the distant execution of offloaded mobile apps located closer to the recipients of the applications.

Edge computation can also be enabled via IoT environments such as MEC and MCC. Moreover, the IoT ecosystem could expand to the core network in addition to the edge network. To be more explicit, components of edge and core networking may be utilized as processing infrastructure in an IoT context (Yunana et al., 2021). The purpose of the comparison figure, which is shown in Fig. 2, is to provide a clear picture of the distinctions between the paradigms that have been described, as well as the responsibilities of each paradigm (N. Alqahtani et al., 2023)(Ahsan et al., 2021). In this paper, we delineate the procedures and tasks that must be implemented to establish and oversee the integrity of the data that is collected. These activities and processes are classified as "processes."

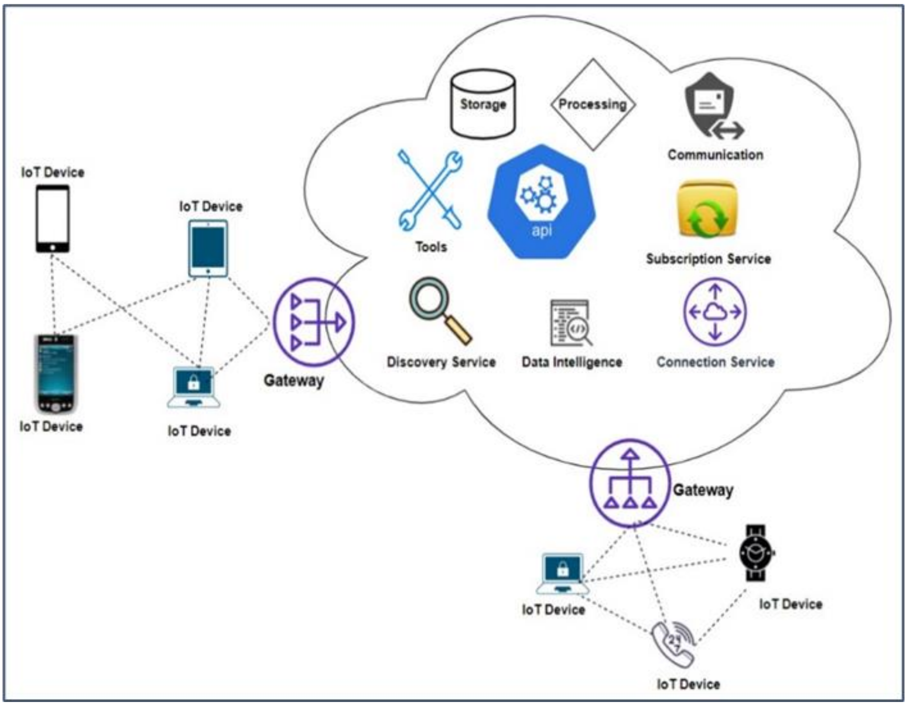

Figure 2. Gadgets utilized in IoT environments (N. Alqahtani et al., 2023).

In addition, most IoT systems comprising sensors, microcontrollers, and other appliances, enable real-time data processing close to the data source. Therefore, IoT appliances are primarily concerned with the issues that occur in an environment that is dynamic and shared.

4. Challenges of the IoT Environments

Following the examination of recent works and contributions in the IoT environment, a number of academics have proposed a taxonomy of the IoT environment that includes a variety of classifications and points of view. As an illustration, the academic contributions were categorized according to the system-level designs and frameworks of the IoT environment, satisfaction of the requirements of the end users' requirements, technological aspects, security and privacy, quality of service, and application. Another reported taxonomy (Yunana et al., 2021) is based on the issues such as the establishment of nodes in an IoT environment, the collaboration of nodes, resource and service provisioning networks, service level objectives, appropriate networking technologies, and security concerns.

Based on research conducted in the modern IoT environment, we present our Taxonomy in this paper. We have focused on connectivity obstacles, service concerns, operational issues, and data management. These are the fundamental and critical concerns in the IoT environments. The primary challenges associated with IoT ecosystems are tabulated in Table 1.

Table 1 Major challenges of the IoT environments

No.	Challenges	Description	Requirements	Ref.
1	Connectivity	Connecting big, dense populations of stationary and mobile devices with efficient energy is a challenge in machine-to-machine networks. Since the current wireless standards are unable to accommodate a large number of devices in a limited spectrum, this turns out to be an opportunity.	A group of devices that provide communication between machines and base stations, enabling communication via adjacent cluster heads that relay data to the base station.	(López et al., 2023)
2	Precision	One of the most significant issues that has to be resolved is precision. The health and safety of machine operators, other equipment, and associated businesses are at risk while working with precision machinery, which can malfunction if timing is incorrect by just one millisecond.	The development of high-precision systems is necessary to ensure the success of IoT deployment in intelligent settings.	(Balakrishnan et al., 2023)
3	Big IoT Data	IoT is one of the largest sources of collecting large amounts of data (i.e., big data). Special attention should be given to the storage, access, and processing of such big data generated by devices forming an IoT environment. The performance of most of the IoT applications depends on the data management services.	IoT data require highly scalable computing platforms that can manage big IoT data in terms of processing, access, and storage without affecting the performance of the application.	(Saeed et al., 2024)
4	Compatibility	One of the biggest problems in an IoT smart environment, where various goods are interconnected, is compatibility. Compatibility problems arise from most goods' inability to communicate with one another due to the lack of a universal language.	To connect gadgets with each other, businesses must work together.	(Sodiya et al., 2024)
5	Investment	Deploying an industrial IoT environment requires massive investment. The investment decision in such a scenario where things are not open and interoperable in terms of hardware and software makes it difficult for industries to adopt this technology	Deployment solutions should be flexible enough to enable industries to evolve and adapt to changes instead of replacing them with new systems. In addition, there is a need for stringent control over adopted technologies.	(Allioui & Mourdi, 2023)
6	Security and Privacy	Primarily focused on authentication and key management protocols to secure Industrial IoT environments	IoT applications should highlight privacy risks and regulatory issues to signify the use of confidentiality and data integrity between the interconnected devices.	(Rao & Deebak, 2023)
7	Sustainability	Require a network infrastructure to collect, store, and analyze real-time data to provide an efficient decision-making process.	The integration of sustainability considerations into architectural design through requirements engineering methodologies.	(Shirvani & Ghasemshirazi, 2024)

8	Management Tasks	System administration and rapid data processing are rendered challenging by the significant volume of data that must be transferred to remote nodes, which results in severe network congestion and significant time consumption.	The organization of tasks has the potential to improve the computational capabilities of nodes by transferring excess data to other nodes for processing, which is necessary due to the limited resources in the IoT environment.	(Rezaee et al., 2024)
9	Standardization	Is the establishment of common protocols and interfaces that facilitate interoperability and scalability among various devices and applications. It addresses the need for optimized standard interfaces for Machine-to-Machine (M2M) communication, which is crucial for enabling pervasive IoT applications. The lack of standardization can lead to challenges in data collection, data aggregation, and efficient data management, particularly in smart grid networks. across different devices and applications.	Creating a robust framework that can efficiently manage resources, ensure secure communication, and facilitate interoperability among a vast number of IoT devices.	(Sen, 2018)

From Table1, it can be clearly concluded that the heterogeneous and complex nature of the IoT environment has brought various challenges, such as connectivity, security and privacy, scalability, compatibility, and sustainability, that must be studied and focused on, in addition to scalability, cost management, interoperability, and energy constraints of IoT applications.

5. Resource Management of the IoT Environment

Devices, including mobile devices, sensors, controllers, and detectors. By offering processing capabilities, storage, bandwidth, virtualized systems, and a variety of software for a unified environment, the IoT influences the growth of these networks. Capacity management ensures the efficient utilization of resources and load balancing, prevents Service Level Agreement (SLA) violations, and improves machine efficiency by reducing operational expenses. A network that is cost-effective, well-maintained, and highly effective ensures that Quality of Service (QoS) standards are met. The network is connected to a diverse array of assets through the IoT architecture. Since an IoT network is employed to allocate resources prudently and effectively, it is a critical component of QoS requirements.

Consequently, the data in the IoT architecture is divided into multiple data streams that are sourced from a variety of sensors, and networked devices offer a variety of services. Additionally, resource allocation is accountable for the preservation of robust security standards. Computational components, storage, and energy comprise the networked resources employed by the IoT. By efficiently allocating Cloud resources to IoT networked devices, they can enhance system efficiency and productivity. The allocation of resources and management are essential components of the IoT ecosystem due to the heterogeneity and widespread dispersion of IoT resources and devices. The system and the IoT network app user establish a connection through an entity, an object, a person, or a location. These resources are allocated and can be categorized based on the data they exchange within a network. Table 2 tabulates the most notable models and resource management methods that have been proposed in recent studies of IoT environments.

Table 2 Proposed models and methods for resource management in IoT environments

No.	IoT Model	Methods	Ref.
1	SLA based resource management model	SLAs provide metrics for response time and resolve time and are designed to confirm that the service provider meets the customer's expectations.	(A. Alqahtani et al., 2024)
2	QoS-aware based resource management	A greedy-delay minimizing application module selection stage and a greedy-delay minimizing application module deployment stage is used. By choosing the order in which the application modules are distributed to Fog devices, the first step seeks to lower the end-to-end latency and preserve the high QoS of real-time applications. The Fog node that satisfies the processing, storage, and bandwidth needs of the application modules is chosen in the second stage using the depth-first search algorithm.	(Abu-Amssimir & Al-Haj, 2023)
3	Energy-efficient dynamic framework for resource management	System outage performance is enhanced by a resource optimization framework, which makes it possible to choose the best relay node and the ideal number of antennas at the mobile node.	(Taneja et al., 2024)
4	Cluster resource management for AI workloads	Creates a cluster resource management technique that respects the latency restrictions of several applications while managing them properly.	(Q. Liang et al., 2023)
5	Queues network model	Utilizes the minimum service queue length to handle the service requests. With the help of a Revised Fitness-based Political Optimizer (RF-PO), the network's performance is increased by optimizing the Queue model's parameters.	(Ahmad et al., 2024)
6	Reliable resource allocation and management	After being put in a queue, the IoT data is listed according to the nodes' processing times, which are ranked in decreasing order. The sorted list assigns the data to the nodes.	(Atiq et al., 2023)
7	Optimized task scheduling and preemption	In order to reduce the computational complexity and bandwidth overhead, expectation-maximization (EM) clustering is used to group the jobs from the IoT devices according to their priority and deadline. A modified heap-based optimizer is then used to schedule the clustered jobs according to SLA and QoS restrictions	(Wadhwa & Aron, 2023)

The effective utilization of resources can lead to significant cost savings and enhanced the performance for IoT applications. Therefore, it is important to consider all these factors while designing and deploying IoT solutions. However, IoT systems run in complicated environments that include numerous heterogeneous components. In an IoT ecosystem, the large volume of data created by real-world sensor-equipped items will greatly demand processing and storage resources to turn them into meaningful information or services. Some applications will be latency-sensitive, while others will need complicated processing, such as historical data and time series analysis. So, due to the resource limitations of IoT nodes, it is difficult to imagine a large real-world IoT system without using a Cloud platform or some strong hardware like Smart Gateways or Edge Fog nodes. The resource definition in this complicated IoT Edge Cloud scenario might range from physical resources like memory (storage), network bandwidth, CPU, energy, to software resources.

The resource management process is formally defined using a model based on the definition of the resource itself. Many researchers have provided numerous solutions to the problem of placing the services received from the applications in these networks. Reviews and research papers published in recent years on the challenges of IoT environments are presented under separate headings with different methods. We investigate resource provisioning methods and identify the factors that must be considered for better utilization of resources in distributed systems. We highlight the challenges and complexities of hybrid optimization for efficient allocation in the IoT environment as shown in Table 3.

These challenges create a hurdle and hindrance to the advancement of IoT systems, encompassing intricate matters like efficiency, availability, interoperability, and full operation. The most promising techniques for overcoming these restrictions in an IoT environment are resource sharing and effective resource management strategies that may be applied to inexpensive, widely-used devices. Therefore, researchers and developers can use an effective resource management technique as a case study to better understand the challenges of the many applications—such as Smart Homes, Industrial Automation, and Healthcare—that are designed by IoT gadgets.

Table 3 Resource management approaches and challenges of the IoT environments

No.	Challenges of Resources Management in IoT	Description	Resources Management Methodology	Ref.
1	Real-Time Data Processing	Refers to the immediate or near-immediate handling of data as it is generated or received. This type of processing is essential in applications where timely decisions and actions are critical.	They have surveyed emerging technologies toward the real-time utilization of IoT data streams in terms of networking, processing, and content curation and clarify the open issues, and proposed a new framework for IoT data streams called the Information Flow of Things (IFoT) that processes, analyzes, and curates massive IoT streams in real-time based on distributed processing among IoT devices.	(Yasumoto et al., 2016)
			A series of IoT sensors is used for real-time data collection. Their system incorporates feedback mechanisms and is constantly adapted to optimize the accuracy and efficiency of data transmission.	(Villegas-Ch et al., 2024)
			They have used Cloud-based services to overcome the limitations of on-premises data processing and storage. A fusion technique is applied on the Cloud platform combines and analyzes data from various sensors after receiving transmissions from Raspberry Pi.	(Haile et al., 2023)
2	Device Heterogeneity	Refers to the diversity of devices within an IoT environment, where various types of devices, each with different capabilities, characteristics, and requirements, are connected and work together.	They have proposed an Intelligent technique based on a new emergent technology of Machine Learning (ML), Deep Learning (DL), and Deep Reinforcement Learning (DRL) that could produce efficient with Heterogeneity IoT devices to offer QoS to applications emits massive amounts of data.	(Mahadik et al., 2024)

			They have proposed a Heterogeneity-aware Dual-interface Scheduling (HDS) scheme to fully exploit the heterogeneity between ZigBee and WiFi to realize energy-efficient and delay-constrained data collection in a tree-based IoT network, where each device is equipped with a ZigBee and a WiFi interface.	(Chen et al., 2024)
			They present two algorithms for energy-efficient communication in a constrained IoT environment. One variant considers the node degree, while the other doesn't consider it to improve the round speed by eliminating mandatory re-election processes. Both variants also eliminate the selection of zero cluster heads problem, specifically at the beginning or towards the end of the network.	(Hudda et al., 2024)
			They have proposed a cooperative energy-aware resource allocation and scheduling strategy based on a Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) multi-criteria decision-making method.	
3	Energy Constraints	Refers to the limited power availability of many IoT devices, particularly those that rely on batteries or other low-energy sources. These constraints are a significant challenge because many IoT devices are designed to be small, portable, and often deployed in remote or inaccessible locations, making frequent recharging or replacing batteries impractical.	This work investigates machine learning (ML) and deep learning (DL) methodologies for IoT device security and examines their benefits, drawbacks, and potential.	(Al-Masri et al., 2023)
				(Kornaros, 2022)

4	Fault Tolerance and Reliability	Refers to the system's ability to continue operating correctly even when some of its components fail or face disruptions. Given the distributed and often critical nature of IoT applications, ensuring that systems remain functional and reliable despite failures is a major challenge. Fault tolerance is essential to maintain continuous service, avoid data loss, and ensure that IoT devices can recover from issues without human intervention.	They have proposed a framework that is based on modified particle swarm optimization.	(Khan et al., 2024)
			They have proposed a novel Fault Tolerance (FT) mechanism. First, the proposed Priority - based Task offloading with Fault Tolerance (PToFT) scheme is used to identify the faulty-FNs using Fault nodes (FN's) remaining residual energy.	(Premalatha & Prakasam, 2024b)
5	Cost Management	Cost is a significant factor in the resource management of IoT environments due to the various expenses associated with deploying, operating, and maintaining IoT systems. Managing these costs effectively is crucial for organizations and individuals seeking to maximize the value of their IoT solutions while minimizing expenses.	They have used Total Cost of Ownership (TCO), Economic Order Quantity (EOQ), Activity-Based Costing (ABC), and Just-In-Time (JIT), for cost management in the e-supply chain.	(Mounia et al., 2024)
			They have presented a framework based on blockchain and encryption to preserve both data accountability and confidentiality in construction cost management. The proposed new framework involves the development of a cost data model containing the required confidential cost information to facilitate partially transparent recordings on the blockchain.	(Cheng et al., 2023)
6	High Efficiency and Scalability	Refers to the ability of an IoT system to handle an increasing number of devices, data volumes, and tasks efficiently without degrading performance. Achieving scalability in IoT environments means designing resource management strategies that can grow and adapt to larger workloads and device densities while maintaining operational efficiency.	They have proposed a mechanism that includes a dual-hierarchy access control structure and associated information retrieval algorithms, to develop a large-scale IoT device access control system. It can overcome the efficiency issues of granting and inquiring access control status over millions of devices in pervasive environments.	
			They have proposed a Lightweight, Secure and Scalable Scheme (LS3) for data transmission in IoT environments. LS3 is comprised of three phases and utilizes an efficient combination of symmetric keys and the Elliptic Curve Menezes–Qu–Vanstone asymmetric key agreement protocol.	(Yu et al., 2024)
			They have presented a simulated annealing-based horizontal scaling to achieve faster and more efficient scaling to accommodate IoT devices. They have explored different horizontal scaling methods and proposed a Markov chain process to model the scaling. They have used simulated annealing to optimize	

			the scaling visualized by the Markov chain process.	(Al-Hejri et al., 2024)
				(Subrahmanyam et al., 2023)
7	Task Offloading	Offloading of tasks is a critical issue in resource management within the IoT environment, where computational tasks are transferred from resource-constrained IoT devices to more powerful Edge, Fog, or Cloud computing nodes. The primary goal is to optimize performance, reduce energy consumption, and meet latency requirements.	An Improved Multi-Objective Aquila Optimizer (IMOAO) equipped with a Pareto front is proposed for task offloading from IoT devices to Fog nodes with the aim of reducing the response time.	
			They have proposed a method based on deep reinforcement learning that divides the offloading and resource allocation problem into two minor problems. This algorithm updates the offloading policy based on information from the environment, and with the help of the Salp Swarm Algorithm (SSA), optimizes resource allocation.	(Nematollahi et al., 2024)
			The Minimal Cost Resource Allocation (MCRA) algorithm is proposed to assign at least one Fog Node (FN) and Resource Block (RB) for each device, and ensure that each FN is connected with one or more RBs and devices.	(Aghapour et al., 2023)
8	Quality of Services (QoS)	Refers to ensuring that the system meets performance metrics such as availability, latency, throughput, and reliability while managing the limited resources of the devices involved. Given the diversity of devices and the need for real-time operations, maintaining a high QoS is essential in IoT systems.	They have proposed an algorithm that combines Ant Colony Optimization (ACO) and Artificial Bee Colony (ABC) optimization algorithms, taking into account energy consumption and QoS factors during the service selection process.	(Premalatha & Prakasam, 2024a)
			They have proposed an efficient means of allocating resources to raise QoS standards for challenges involving the IoT and its associated infrastructure. Their approach is to categorizes IoT traffic into two groups: Critical IoT traffic (CIoT) and Massive IoT traffic (MIoT).	(Hamzei et al., 2023)

				(AlQahtani, 2023)
			They have proposed a secure access method for the power system based on the zero-trust architecture, that carries out security authentication and dynamic access control.	(Wang et al., 2023)
9	Secure Access	Access security is vital to ensure that only authorized users and devices can access, manage, and utilize the system's resources. With the vast number of interconnected devices and the sensitive data often processed, security must be tightly integrated into every aspect of resource management.	Their proposed protocol applies mutual authentication with user authorization using smart card registration on a private blockchain without the need for a trustable server.	
				(Mirsaraei et al., 2022)
			They have qualitatively compared the WoT approach with the well-known FIWARE-based interoperability solution. Second, based on the previous analysis, they have designed and implemented a connector to bridge the WoT architecture to the FIWARE ecosystem. Third, they have conducted a performance analysis emulating a real IoT-based environment to understand the scalability, response time, and computer resource usage of the two interoperability solutions.	(Sciullo et al., 2022)
10	Interoperability	Refers to the ability of different IoT devices, systems, and platforms—often developed by various manufacturers and utilizing diverse protocols—to seamlessly communicate, share resources, and work together within a network. Achieving interoperability is crucial for ensuring efficient resource management, task execution, and overall system functionality in IoT environments.	Semantic and syntactic interoperability are the two fundamental pillars around which their methodology for addressing interoperability in IoT settings is based. They have determined the key components that must exist in the interoperable-to-be trust models and have shown how each one's definition of trust can be matched to a shared one.	
				(Fernandez-Gago et al., 2024)

			Fog nodes are planted to disperse the load on cloud servers using fog computing, which helps reduce delay time and network traffic.	(Vijarania et al., 2023)
			They have suggested a unique objective function (OF) that is suited only for the RPL algorithm. Using an adaptive fuzzy multi-criteria decision-making strategy, this OF combines techniques for order of priority by similarity to ideal solution (TOPSIS) and fuzzy analytical hierarchy method to integrate load on networks and congestion situations.	
11	Load Balancing	Refers to the process of distributing tasks, processing, or data across multiple devices or servers in an IoT network to optimize performance, reduce latency, and prevent overload. In IoT environments, where a vast number of heterogeneous devices generate large volumes of data, load balancing is essential for efficient resource utilization and ensuring that no single device or server is overwhelmed by too much data or computation.	They have used simulations on the Cooja/Contiki simulation–emulation platform, to compare their proposed algorithm with leading state-of-the-art clustering approaches to demonstrate how their algorithm improves both times until the first cluster head failure as well as network coverage by keeping more sensor nodes alive for a longer period of time.	(Maheshwari & Panneerselvam, 2024)
				(Sreenivasamurthy & Obraczka, 2024)
			They have studied popular architectures, typical IoT implementations, and reoccurring issues, as well as 5G and IoT technologies. They have presented an overview of the interference specific to 5G and IoT, as well as interference in general wireless applications and potential optimization strategies to address these issues.	(Pons et al., 2023)
12	Network Bandwidth Limitations	Refers to the constraints on the amount of data that can be transmitted between IoT devices and other systems (such as Edge or Cloud servers) within a given time frame. In IoT environments, sensors and devices continuously generate vast amounts of data bandwidth limitations can become a significant bottleneck.	They have proposed an Optimal Energy and bandwidth-based Link Stability Routing (OEBLS) algorithm, to improve the link stable route with minimized error rate and throughput.	(Kothandaraman et al., 2022)
			Constrained Applications Protocol (CoAP), Message Queuing Telemetry (MQTT), and WebSocket protocols that are more practical for small IoT devices are compared experimentally.	(Bayılmış et al., 2022)

13	Data management and storage	Refers to the processes and technologies used to collect, process, store, and retrieve data generated by IoT devices. Since IoT systems produce vast amounts of data from sensors, cameras, actuators, and other devices, managing and storing this data efficiently is crucial to ensure performance, scalability, and reliability.	Thy have proposed an AI-based architecture for smart farming. This architecture called, Smart Farming Oriented Big-Data Architecture (SFOBA), is designed to guarantee the system's durability and the data modeling in order to transform the business needs for smart farming into analytics.	(Ouafiq et al., 2022)
			They have presented a BI-TSFID framework, which leverages the benefits of Ethereum and IPFS and optimizes the Merkle Tree structure and verification mechanisms. The BI-TSFID framework adopts a strategy of on-chain data summary storage and off-chain computation.	(C. Liang et al., 2024)

6. Discussion

We presented an analytical survey to estimate the latency behavior and different perspectives of the IoT environment. The validity of every perspective is contingent on the requirements for the development of an effective IoT system. There have been numerous publications within the IoT systems that have contributed to the enhancement of a variety of services, including security, privacy, application, and communication.

Our study has explored the paradigms of IoT environments to assist other researchers in the process of proposing a taxonomy based on the recent works that are being conducted in the IoT environment regarding connection, sustainability, precision, and compatibility. Moreover, challenges and applications with future potential are identified based on resource management, such as task offloading, QoS, device heterogeneity, high efficiency, and scalability. We presented a comparative study of notable published researches on notable models and challenges of IoT environments showing that resource management needs effective resource allocation and workload scheduling in large-scale distributed deep learning, indicating that traditional methods may not suffice due to new challenges posed by distributed systems. Furthermore, we showed that the IoT environments need efficient task scheduling methods to decrease the inherent computational complexities and bandwidth overhead, and ensure quality of service.

7. Conclusion

We examined notable recent models and methods to identify the main open research obstacles in deploying an IoT environment. We understood that the success of the IoT environments is hindered by the challenges highlighted in this paper. Device heterogeneity, real-time data processing, cost management, failure tolerance, and dependability are issues. Thus, IoT environments must prioritize data management and diverse system relationships. Presenting acceptable solutions can answer these problems and improve resource management, resulting in cost savings and improved IoT application performance. Furthermore, the heterogeneity of different IoT devices, systems, and platforms that are often developed by various manufacturers and utilize different protocols are considered the major issues for researchers and developers. Thus, achieving interoperability is crucial for ensuring efficient resource management, task execution, and overall system functionality in IoT environments. Thus, when building and deploying an IoT environment, these issues must be considered. They may also provide a foundation for overcoming IoT challenges. Future research should build lightweight protocols for heterogeneity and distributed applications, and apply efficient resource management methods to overcome IoT device restrictions in accordance with the existing trends.

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