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Internet of things (IoT) fusion with cloud computing: current research and future direction

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Abstract

The internet of things (IoT) has been a major buzzword in recent years, with the potential to connect a huge number of devices to the internet and each other. The integration of all of these devices and data sources into a cohesive system is one of the key challenges involved in the development of the IoT. Cloud integration is one approach that can be used to achieve this, and there are several different cloud-based IoT platforms available. As consequences, IoT and cloud computing has drastically changed the environment of technological development. A synergistic strategy that combines the strengths of these two breakthrough technologies into one package is estimated to provide enormous benefits. Despite these advantages, the integration of such technologies poses numerous issues and challenges. An in-depth analysis of each of these technologies is discussed, along with the advantages, challenges, and limitations associated with convergent approach. The preferred reporting items for systematic reviews and meta-analyses (PRISMA) method has been used to identify all relevant articles from the literature, and the most relevant articles have been included for further analysis. The relevant articles have been analysed using the method of the Bibliometric network, such as co-authorship analysis, term co-occurrence. Furthermore, taxonomy of IoT-based cloud applications has been discussed and quality of service (QoS) factors-based analysis for each applications domain has been done. In this review, we take a look at some of the most popular IoT cloud integration platforms and compare their features and capabilities. In addition, we have investigated a variety of related technologies and anticipated future developments.

Keywords

Internet of things (IoT), Cloud computing, Edge computing, Bibliometric analysis, Preferred reporting items for systematic reviews and meta-analyses (PRISMA), Real-world applications.

1.Introduction

The internet of things (IoT) represents a revolutionary concept that has become a part of modern society and is generating tremendous enthusiasm among both the business and academic communities. IoT, as the next-generation technology, has enormous ramifications for many industries [1]. According to analyst predictions, the IoT could reach 64 billion devices by 2025, constituting one of the major sources of "Big Data," distinguished by volume, value, variety, velocity, and accuracy [2–4]. The IoT is primarily concerned with the development of an infrastructure that supports fully interoperable protocols and software for interconnection and integration.

A system that is embedded with a combination of software, electronic components, actuators, sensors, detectors, and wireless connectivity, which enables them to gather data from these objects can be defined as the "IoT" [5]. An IoT system has the following prominent characteristics [6, 7]:

- IoT is a technological advancement that enables objects to be connected to the internet via wired or wireless networks so that they can communicate with one another.
- A variety of wireless sensor networks are available for IoT devices, including near-field communication (NFC), Zigbee, radio frequency identification (RFID), Bluetooth, and Wi-Fi.
- The sensors can be connected to various technologies, including long-term evolution (LTE), general packet radio service (GPRS), third generation of mobile telephony (3G), and global system for mobile communication (GSM).

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- The efficiency of an IoT system is largely determined by three primary components, each of which is crucial to its operation.
  - Perception
  - Middle-ware (Edge, Fog, and Cloud)
  - Application

Nevertheless, cloud technology offers virtually unlimited storage and system capabilities to address a wide range of challenges related to IoT. In consequence, the phrase "cloud of things" (CoT) is used to allude the fusion of IoT and cloud computing. The "CoT" is a paradigm for increasing productivity and improving system performance that is widely used by most industries and manufacturers [8]. Several researchers discussed in their research [9] regarding the use of cloud as a platform to analyze Big Data when data storage and processing are required. A recent empirical study [10] identified many challenges for energy efficient technology that will need to be addressed in the future.

With the advent of the IoT, gigantic amounts of data are generated in real-time, and this poses a major concern for traditional cloud computing network topologies [11]. A traditional cloud infrastructure condenses all processing, storage, and networking into a limited set of data centers, and the distance between remote devices and remote data centers is relatively wide [12]. This challenge could be addressed by edge computing since it provides access to computing resources that are closer to IoT edge devices and may lead to a new ecosystem for IoT innovation [13].

1.1Background

A brief introduction to some of the most important aspects and terminology used throughout this study is provided in this section. This section is intended to help the reader understand and better comprehend the information that is presented in each section of the paper.

1.1.1Internet of things (IoT)

Kevin Ashton, a British technology pioneer, formed the phrase "IoT" in 1999 to represent a system in which physical artifacts are connected to the internet using sensors. A "thing" can refer to any physical entity on the surface of the earth, whether it is a communication device or not. Despite the widespread acceptance of the IoT concept, no standard definition has been adopted. There are several definitions in existence: "The IoT refers to the prospect of devices that can create, exchange, and utilize data without the use of a central computing device, where the connectivity of networks and computing capability can be applied to objects, sensors, and everyday objects, not to personal computers.

It is stated in the Oxford Dictionary [14]. “An Internet-based architecture provides connectivity between electronic devices embedded in real-world objects, enabling them to exchange information”. According to the RFID group, “It is a global network of interconnected objects with standardized communication protocols that allow them to be accessed by a single entity.”

Three-layered architecture of IoT

IoT architecture comprises mainly three layers [15, 16], namely “perception layer”, “middleware layer”, and “application layer”, as demonstrated in *Figure 1*. The middle layer of this architecture exists on the edge, fog, and cloud computing [17–20].

Perception layer

Perception layer senses data from the surrounding via actuators and sensors. It identifies, gathers, and processes data and sends it to the network layer. It detects other physical parameter in the physical environment or recognize intelligent objects. It also collaborates on local and small-scale networks with the IoT node.

Middleware

As the 'processing layer', the middleware is responsible for the analysis, processing, and storage of a large amount of data obtained from the perception layer. It can perform a variety of tasks and providing services to the lower layer. Various technologies are employed, including high-performance computing tools, cloud computing, and database management systems. Additionally, it introduces a level of abstraction for developers as well as users.

Application layer

It is the responsibility of this layer to provide specialized application services to the client. As a result, it includes a variety of applications, including air quality monitoring, smart buildings, precision farming, intelligent cities, and innovative health care, as well as data integrity, authenticity, and security. This layer is intended to enable designing an intelligent environment.

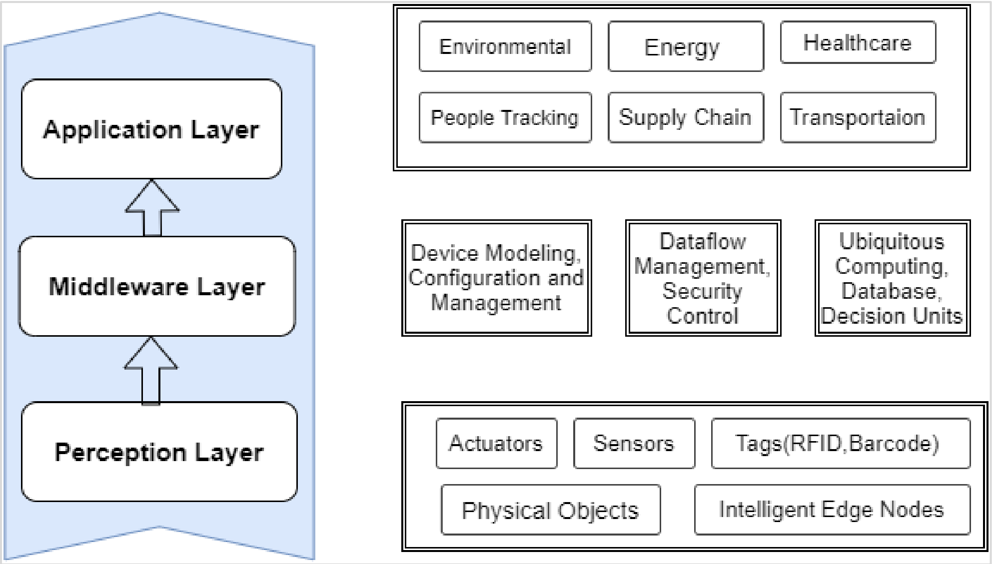


Figure 1 Three-layered architecture of IoT

1.1.2Cloud computing

During the last few decades, cloud computing has taken on several definitions. As per National Institute of Standards and Technology (NIST): "Cloud computing is a service delivery model that facilitates easy, on-demand access to a shared pool of flexible computing resources that can be accessed and delivered on time with a minimum of effort or management" [21]. As utility-based computing progresses, it is anticipated that it will move to cloud computing, which has the potential to be a more intelligent in-service provisioning process. Another key advantage of cloud computing is that it reduces information technology (IT's) dependence on fundamental infrastructure settings [22]. The implementation and execution of scientific workflows involving Big Data requires a synergistic model, according to recent studies [23]. Cloud computing has suggested the following functionality: measured services, rapid elasticity, scalability, multi-tenancy, resource pooling, extensive network access with on-demand service [24–26]. The cloud computing characteristics are shown in *Figure 2.*

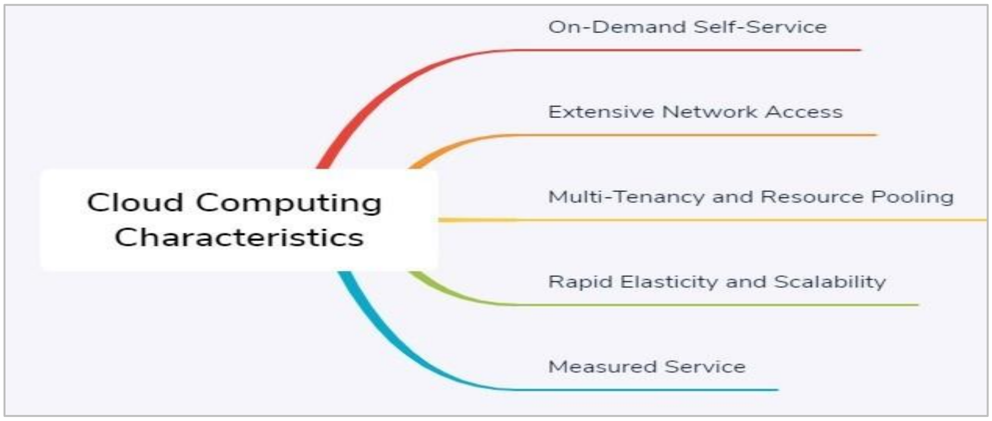


Figure 2 Cloud computing characteristics

On-demand self-service

Numerous cloud-based services may be delivered without involving human involvement on the part of the service provider. Most of these services comprise storage capacity, database instances, and virtual machine instances. Accessing cloud accounts and monitoring services can be done using a self-service web interface provided by production organisations. An end-user can provide computing resources independently, such as database setting and shared storage when required, without any interference from the IT manager of the provider.

Extensive network access

Cloud services may be accessed by a variety of user applications on the network. A local area network (LAN) or the internet in the setting of a private cloud are both viable choices, even though the enterprise prefers robust, wide-bandwidth networks. The quality of service (QoS) of cloud computing is heavily dependent on network capacity and latency. It has been conventional to use a variety of network-accessible technologies to make thin and dense heterogeneous business solutions more accessible (such as smartphones, laptops, workstations, and personal computers).

Multi-tenancy and resource pooling

Multi-tenant environments can be accommodated by cloud computing resources. With numerous tenancies, a single software or physical infrastructure can be used by a variety of clients, all while ensuring the privacy and confidentiality of their data. In multitenant systems, different services, for instance memory, processing capability, storage space, and network resources, are allocated to several users in accordance with their individual needs (virtual resources are assigned or moved dynamically in response to the requirements of each user). The word "resource pooling" refers to the sharing of physical assets among multiple clients.

The provider's resource pool should be sufficiently large and diverse to serve a variety of consumer needs while maintaining economic spectrum. As a result of resource pooling, the performance of mission-critical industrial applications should not be adversely affected. Scheduling resources is a critical part of cloud computing. According to the study [27], the present state of task scheduling methodologies is based on a host of different scheduling parameters.

Rapid elasticity and scalability

It is feasible to scale cloud computing services to meet the demands of a business. It is an essential aspect of cloud computing. There are no penalties associated with customizing costs, efficiency, or availability. It enables manufacturing companies to rapidly produce and deliver any cloud computing resource. This functionality can be utilised for storage, virtualization software, or marketing assistance. Scalability is more liberal and pragmatic. Scalability dynamically adds or removes resources to meet changing application requirements within the network's constraints.

Measured service

Cloud computing applications are quantified, and producing businesses pay for what they use. The authors of the study [28] emphasised the challenges encountered by researchers working in bioinformatics in terms of planning their research efficiently and effectively utilising cloud computing. In cloud technologies, resource consumption is effectively managed and optimized automatically by utilizing measurements at many levels of abstraction, such as network bandwidth, computing power, storage, and the number of active users. Both the supplier and the consumer's resource requirements may be monitored, quantified, and communicated openly.

1.1.3Edge computing technology

Edge computing is a data networking paradigm that stresses minimising latency and bandwidth consumption by processing as near to the data source as feasible [29]. According to [30], "Edge computing is a distributed computing paradigm that brings computation and data storage closer to the location where it is needed, to improve response times and save bandwidth."

Role of edge computing in IoT technology

In IoT technology, edge computing transforms the data that is managed, processed, and distributed by millions of IoT devices [31]. With the explosive growth of internet-enabled technologies, the IoT and emerging technologies requiring real-time cloud services tend to support sophisticated computing systems, the IoT and emerging technologies requiring real-time cloud services tend to support sophisticated computing systems [32]. With edge computing, data is evaluated on the edge of the local network before reaching the fog and the cloud for rapid, reliable, connectivity-independent, and scalable IoT Edge processing. *Figure 3* depicts the IoT, edge, fog, and cloud computing architecture.

1.1.4Fusion of IoT and cloud technology

The IoT consists of a network of physical objects that are connected to the internet and are equipped with the ability to collect, exchange, and use data. In cloud computing, resources are delivered over the internet as a service. With the integration of IoT and cloud computing, new applications have been developed that have the potential to revolutionize the way we live and work. In addition, the integration of the IoT into the cloud is a natural evolution of the technology. The cloud provides the perfect platform for storing and analyzing the vast amounts of data produced by IoT devices. In addition, it provides real-time data processing and analytics, which is essential for applications such as predictive maintenance and energy management. In the last decade, the IoT and cloud-based services have evolved and matured independently on both continents. Due to their unique characteristics, these technologies are attractive to researchers and have multiple applications. The integrated paradigm does not have a well-known term in the scientific community. In the literature, other general terms have been discovered, including fusion of internet of everything and cloud (Cloud of Everything), IoT Cloud, CoT and web of things (WoT) [33].

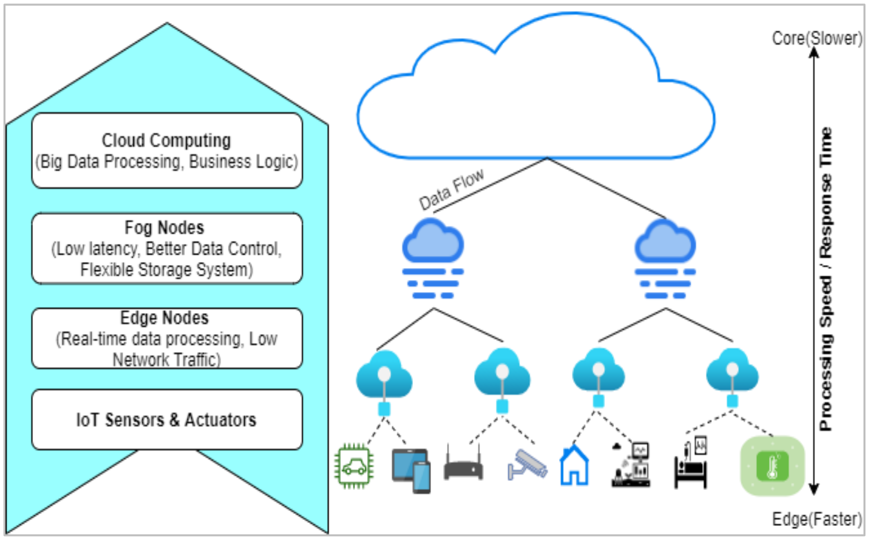


Figure 3 IoT, Edge, Fog, and cloud architecture

A key component of the IoT is its capacity to utilize virtually unlimited amounts of cloud computing resources and capacity (such as computation capabilities, storage capabilities, and energy efficiency) to help overcome technological limitations. A cloud-based computing strategy is an effective tool for preserving data as well as for use in a variety of applications As a contrast, cloud computing could influence the IoT by introducing new applications that address distributed real-world problems and by allowing new installations that can be applied to various real-world scenarios [34].

Due to its limited and vigorous capabilities, the IoT contains devices with minimal processing power and storage capacity in comparison with the numerous complex tasks that need to be completed. These devices may serve as data providers and transfer data for processing and storage directly to the cloud [35, 36].

In the cloud computing environment, applications and objects communicate over an intermediary layer that hides the functionality and complexity required to implement them. This strategy will dramatically impact applications that address current challenges with gathering data, integration, and distribution in a multi-cloud context.

Current research on the integration of IoT with cloud computing focuses on allowing real-world applications including sustainable buildings, smart cities, connected vehicles and industrial automation. The use of IoT devices and sensors in conjunction with cloud-based analytics and decision-making models offer the promise of significant improvements in efficiency, safety, and quality of life.

The future direction of research on IoT and cloud computing integration will be driven by the need to address challenges including data privacy, security, scalability, energy efficiency, and interoperability. In addition, there is a need for further research into how best to exploit the unique capabilities offered by this technology combination to create new applications that deliver real value to user.

Architecture for cloud-based IoT

A cloud-based IoT architecture must be accomplished of supporting a wide range of devices and sensors, as well as the data they acquire. It must be able to handle the data generated by the devices in real-time and provide the necessary processing and analysis. The architecture must also be able to support the security and privacy requirements of the IoT applications [37, 38]. An IoT-based cloud ecosystem is composed of three layers: the physical layer, the networking layer, and the application layer. The bottom layer (the physical layer) is responsible for collecting the data required by the next layer, that is, the network layer, from their surroundings. A variety of interesting services are accessed by the network layer from the physical layer. *Figure 4* demonstrates the cloud-based IoT infrastructure.

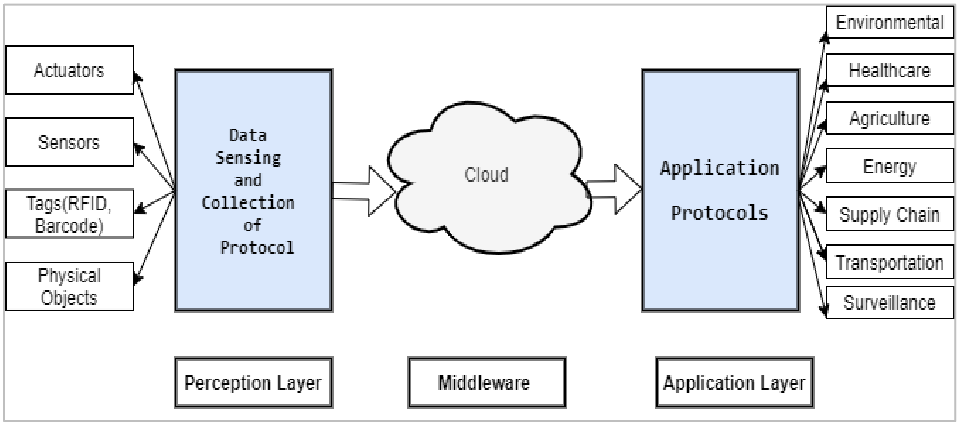


Figure 4 Cloud of things architecture

1.2 Challenges of the domain

After a comprehensive analysis of the included literature, we revealed a lot of emerging research challenges in the field of integration of IoT and cloud. However, here we are going to mention the most cited one. Since, the challenges of the IoT cloud domain are mainly related to data gathering, communication, and storage. The data collected by various IoT devices need to be transmitted to the cloud for analysis and decision-making. This requires efficient and reliable communication protocols between the devices and the cloud. The data collected by IoT devices also need to be stored securely in the cloud. Moreover, throughout this study, we cited some more such challenges in section 7.

1.3 Research motivation

Although this field is still in a developmental stage, researchers are working on integrating domain, security, and QoS to develop a more secure and efficient system. Meanwhile, we investigated a large number of relevant studies on this domain. However, we could not find extensive research in the domain of integration of IoT and cloud. Although a countable set of researchers working on this domain, they have revealed some unavoidable research gaps regarding this field. Therefore, more research on this field is the pressing need of the hour. This study explores the current state of the art in this domain.

The motivation for the review of the integration of IoT and cloud computing are as follows.

- With the vast amount of data produced by IoT devices, it is becoming increasingly difficult to manage and analyze this data effectively without the use of cloud computing. So, the need for better data management and analysis motivates me to explore in this direction.
- By storing data in the cloud, it is feasible to utilise the security features provided by cloud service providers. So, the need to improve security is another motivation for me to integrate these two technologies.
- Any IoT-device-reliant application must have the capacity to dynamically scale up or down as needed. In this regard, increasing scalability is one of the factors motivating me to pursue this pathbreaking technology.

1.4 Research objectives

The IoT and cloud computing are two new technologies that are gaining traction in a number of different industries. There is a growing need for effective integration (IoT and cloud) of these technologies for improved decision-making, increased efficiency, and decreased costs. Nonetheless, current research in this field is still in its infancy. In this article, first, we will discuss a summary of the current literature on IoT and cloud integration. We will then identify some key challenges, opportunities, and future directions for research in this area. Three broad categories of research are currently being conducted on IoT and cloud integration: (1) Development of frameworks and platforms for IoT and cloud integration; (2) Design and implementation of applications using IoT and cloud technologies; (3) Evaluation and comparative analysis based on various parameters of IoT and cloud systems. In terms of frameworks and platforms for IoT and cloud integration, there has been considerable work on developing middleware solutions that can enable seamless interaction between these two technologies. Some notable examples include the Eclipse Smart Home platform (https://www.eclipse.org/), IBM Watson IoT platform (https://www.ibm.com/), and Microsoft Azure IoT Suite (https://azure.microsoft.com/).

The objectives of this research article are follows:

- To present an overview of current research on the integration of IoT and cloud computing.
- To compare and analyze the existence literature associated with IoT cloud integration.
- To identify and discussed the challenges associated with IoT cloud integration.
- To identify and analyze the opportunities associated with IoT cloud integration in many real-world applications.
- To identify future research directions in this area.

1.5 Research questions

As this study aims to provide a survey on cloud and IoT integration, the following research questions are framed to cover the related concepts, applications, and tools/techniques.

RQ1. How many research publications have been done in the field of IoT and cloud integration spread over the years?
RQ2. What are the latest research trends with IoT and cloud computing integration?
RQ3. What are the potential uses of IoT-based cloud technology in real-world applications?
RQ4. Which are the most appropriate IoT-based cloud solutions, middleware technologies, and platforms?
RQ5. What are the current limitations and unresolved research problems with the integration of IoT and cloud services?
RQ6. What are the major suggestions for future research for IoT and cloud approaches that work together?

1.6 Systematic review process

To carry out a systematic review of the literature on IoT cloud integration, the following steps need to be followed:
Step 1. The first step in the systematic review process is to identify the research question. The question should be specific and answerable and should focus on the effects of a particular intervention or exposure.
Step 2. The next step is to identify relevant studies. Studies can be identified through a variety of sources, including databases, literature reviews, and conference proceedings.
Step 3. The third step is extracting data from high-quality and valid studies from the collection-related literature in step 2.
Step 4. The fourth step is to analyze the data that has been extracted. This analysis should be performed in a systematic and unbiased manner.
Step 5. The data extracted in step 4, we analyzed each category of data and outcome of this step came to the final step 6.
Step 6. The final step is to write a report of the findings. This report should be clear, concise, and should provide a synthesis of the evidence that was gathered during the systematic review process.

In general, the structure of this paper can be summarized as follows this article begins with an introductory section 1 which discusses some of the basics of the IoT, cloud computing, edge computing, and their architectures. In addition, the challenges, motivations, and objectives are described in this section.

Section 2 reviews the current state of IoT and cloud technologies. A comparative analysis of the existing literature is also provided in this section.

In section 3, we provide an overview of the research methodology, which includes the search query, selection criteria, and process flow. Moreover, literature trends, distribution of literature, and bibliometric analysis are described in this section. We analyze IoT and cloud technology employing several resources following preferred reporting items for systematic reviews and meta-analyses (PRISMA) standards. An overview of the systematic process flow adopted for this study is presented in *Figure 5*.

In section 4, the taxonomy of various real-world applications and QoS comparison are described.

Section 5 discusses existing middleware technologies and cloud platforms are discussed. A discussion of a variety of benefits and challenges related to CoT is provided in sections 6 and section 7.

Discussion of IoT cloud integration discusses in *Section 8*. Finally, section 9 summarizes the findings of this study and provides a roadmap for the future.

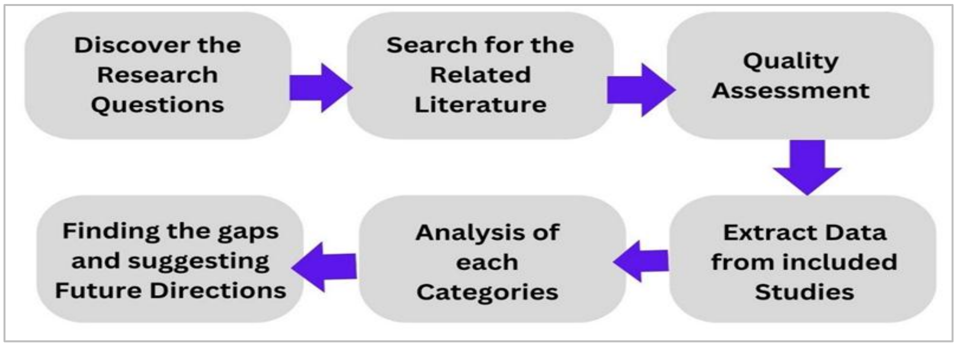


Figure 5 Systematic process flow

2.Related work

Over the past decade, a number of studies have been conducted to provide insight into the topic of IoT and cloud computing solutions. These studies helped to address the emerging concern. Our study has been enriched with comprehensive literature reviews covering a variety of disciplines in this area of research.

The articles [39–41] considered recent attempts to integrate cloud computing into a range of IoT scenarios and applications. An extensive review of the literature was conducted by Botta et al. [42] where they explored the complementary aspects of IoT and cloud, and the factors which drive their integration into various infrastructures. The recent acceptance of the cloud-based IoT paradigm has opened a wide variety of new applications, which are presented along with the major research challenges. Further analysis of these challenges led to the development of research directions. Additionally, by comparing its numerous features, platforms, and accessible operations, they highlighted problems and future research areas in this domain.

An analysis of cloud platforms, cloud infrastructures, and middleware technologies for the IoT has been conducted by Diaz et al. [43]. A wide array of data analysis techniques, approaches, and issues are also addressed, as well as various research challenges.

Dang et al. [44] aim to investigate the scope of IoT applications, implementations in the health sector, and evaluations of cloud-based IoT platforms that have been developed over the last year. The goal of this research is to explore how developing technologies including the cloud, wireless networks, Big Data, and wearable devices may be utilised to enhance the efficiency and effectiveness of healthcare by introducing health policies for the IoT and eHealth services around the world. Several security and privacy risks associated with the IoT are also discussed in depth, including issues, threats, and risk factors. A subsequent IoT-based healthcare development is discussed in terms of analytical frameworks that can be used to identify and evaluate security threats, mitigation strategies, and limitations.
As part of their discussion on the IoT, Malik and Om [45] examined the platforms, devices, and available solutions. The IoT layer architectures were compared to the internet protocol (IP) layer as well as its qualities. Additionally, a comparison of IoT and cloud technology has been conducted. Moreover, a framework for integrating IoT with cloud services has been developed utilizing 6LowPanel and architecture. Cloud computing has been discussed, as constrained application protocol (CoAP). However, for standardized cloud and IoT integration to reach its full potential, additional studies in other sectors are required.

Amairah et al. [46] examined the reference architectures and definitions of IoT and cloud computing, as well as the associated security concerns and solutions. Additionally, future directions were studied by evaluating the most often cited researchers. Additional study is recommended to examine and address integration system security vulnerabilities as new research areas in this domain.
During an extensive study conducted by Atlam et al. [47] on the integration of cloud technologies with IoT platforms and compare IoT and cloud technologies. Six main benefits have been discussed that are related to IoT cloud integration. Cloud-based IoT architecture has been proposed in this study. In addition, various IoT-cloud applications have been presented. Authors have studied the seven main challenges of cloud-based IoT integrations.

The study presented by Cavalcante et al. [48] discussed an overview of the current development and investigations of IoT cloud integration and discusses future directions. Moreover, four main types have suggested (i) IoT cloud architecture (ii) platforms (iii) framework, and (iv) middle-ware technologies. Also, different challenges have been discussed in this study. These challenges are (i) standardizing IoT products, data, and services delivered over the cloud; (ii) enabling IoT devices/applications to efficiently utilize cloud resources; (iii) Handling enormous amounts of data in real-time; (iv) Providing context-specific information; (v) Assuring the security and privacy of data by providing effective solutions (vi) removing the large degree of variability inherent in both IoT and cloud settings; (vii) Considering concerns about flexibility and dependability; (viii) assist for cloud-based IoT developing and maintaining software, and (ix) offering virtualization paradigms for devices. *Table 1* illustrates a study of the existing research on the convergence of IoT and cloud computing, including the contributions and limitations of the research publications.

Table 1 Comparative study of existing literature on IoT and cloud computing

Reference	Research article	Main contributions	Limitations
Botta et al. [42]	"Integration of Cloud Computing and Internet of Things: A Survey"	• IoT and cloud technology are discussed, as well as their complementary modes of operation, applications, challenges, platforms, and current projects.	• Inadequacy of open service platforms and multi-connectivity.
Díaz et al. [43]	"State-of-the-art, challenges, and open issues in the integration of Internet of things and cloud computing"	• Analyse the underlying platforms, infrastructure, middleware, integration approach, data analytics techniques, open issues, challenges, and future developments.	• Lack of awareness of other relevant technologies.
Dang et al. [44]	"An overview of Internet of Things (IoT) and Cloud Computing in the healthcare sector"	• Performs an analysis of IoT characteristics and applications in healthcare as well as market trends. • Discuss different threats, vulnerabilities, attacks, security models, government policies, as well as challenges affecting healthcare.	• Uncovering other standard applications.
Aazam et al. [8]	"Cloud of things: Integrating internet of things and cloud computing and the issues involved"	• CoT and future directions. • Also presenting Key challenges of CoT.	• A dearth of discussion on the many types of IoT and their associated services.
Malik and Om [45]	"Cloud computing and internet of things integration: Architecture, applications, issues, and challenges"	• To discuss applications, challenges, and future directions of integration components.	• Inadequate standardisation of the CoT.
Atlam et al. [47]	"Integration of cloud computing with Internet of things: challenges and open issues"	• IoT-based cloud-based architecture and applications. • Also demonstrating the need for IoT-enabled cloud services.	• Inadequate testing of cloud-based IoT applications.
Amairah et al. [46]	"Cloud computing and internet of things integration systems: A review"	• These technologies are reviewed in terms of reference architectures and definitions as well as security concerns and proposed solutions.	• A dearth of research into the security implications of these CoT.
Cavalcante et al. [48]	"On the interplay of Internet of Things and Cloud Computing: A systematic mapping study"	• Oversight of IoT and cloud integration research and development. • The integration challenges and future directions are also discussed.	• Lack of research on other significant issues.

3.Research methodology

3.1Search query

To identify IoT and cloud computing research publications, we analyzed scholarly databases including Google Scholar, database and logic programming (DBLP) computer science database, web of science (WOS), Science Direct, and IEEEXplore. The title field was searched in the databases using the search words (("IoT" OR "Internet of Things") and ("Cloud Computing")). The search string along with the database is shown in *Table 2*.

Table 2 A database-specific search string

Digital library	**Search string**
Google Scholar	*Title :(("IoT" OR "Internet of Things") AND ("Cloud Computing")).*
Science direct	*Title: (("IoT" OR "Internet of Things") AND ("Cloud Computing"))*
IEEEXplore	*("Document Title": IoT OR "Document Title": Internet of Things) AND "Document Title": Cloud Computing*
Scopus	*TITLE ("IoT" OR "Internet of Things" AND "Cloud Computing")*
Springer Link	*(("IoT" OR "Internet of Things") AND ("Cloud Computing"))*
ACM	*[[Title: "IoT"] OR [Title: "internet of things"]] AND [[Title: "cloud"] OR [Title: "cloud computing"]]*
DBLP Computer Science	*(("IoT" OR "Internet of Things") AND ("Cloud Computing"))*

3.2Selection criteria

From search results obtained from seven databases, relevant papers are selected and screened based on the eligibility criteria. Various inclusion and exclusion criteria are incorporated into these criteria. This systematic review emphases on the fusion of IoT and cloud technology as can be seen from the initial search query. Therefore, studies related to IoT-cloud-based real-world applications will be included. The inclusion and exclusion criteria for this systematic review are outlined in *Table 3*. After applying these inclusion and exclusion criteria to the initial search results from the seven databases, 63 studies were finally identified for further analysis.

3.3Process flow

As seen in *Figure 6*, the process of identifying and selecting appropriate studies is depicted. To identify papers regarding IoT and cloud convergence, several electronic databases (Google Scholar, Science Direct, IEEEXplore, DBLP Library of Computer Science, and WOS) are investigated. Then, the refining process was used to determine whether or not to include and exclude the following requirements, which are listed in *Figure 6.*

Without any further adjustment of the search parameters, the combined databases yielded 1239 articles. A total of 592 duplicate articles were found during the identification phase. Apart from duplicate articles, we are left with 647 articles for the screening phase. We have identified 348 articles that are irrelevant to our domain literature during the screening process. Apart from 348 articles, we have 299 articles based on real-world applications. We excluded 129 articles from the proposed taxonomy since these articles lack experimental evaluations or comparisons of their approaches. Except for 129 articles, 170 experimental evaluations based on the proposed taxonomy are explored. And finally, we included only the best articles for our study, which are the articles that are selected by the expert panel. With the exclusion of all irrelevant, duplicate, and un-evaluated articles from our study, we have a total of 63 included papers published between 2015 and articles. Following the refining process, 63 research publications were chosen for final evaluation. These articles 2022, and all research articles, reviews, conference proceedings and book chapters were written in English. These 63 articles cover IoT and cloud computing research, with some focusing on the convergence of IoT and cloud technology, while others focus on CoT platforms, CoT applications, the advantages and problems of CoT, architectures, and middleware technologies. The PRISMA standards guide this research, the most used reporting tools for systematic reviews and meta-analysis [49, 50].

3.4Literature trend

Over the years, IoT and cloud computing experienced accelerated and autonomous mushroom growth, with researchers striving toward seamless incorporation. Numerous academics have conducted comprehensive reviews of this field's affluent and eloquent literature. The popularity of both technologies, as determined by Google search patterns, is shown in *Figure 7. Figure 8* illustrates the growth trend of IoT and cloud computing in Google search from 2015 to 2022. *Figure 9* illustrates the analysis and classification of 63 research articles obtained from different databases in accordance with the publication year of the articles.

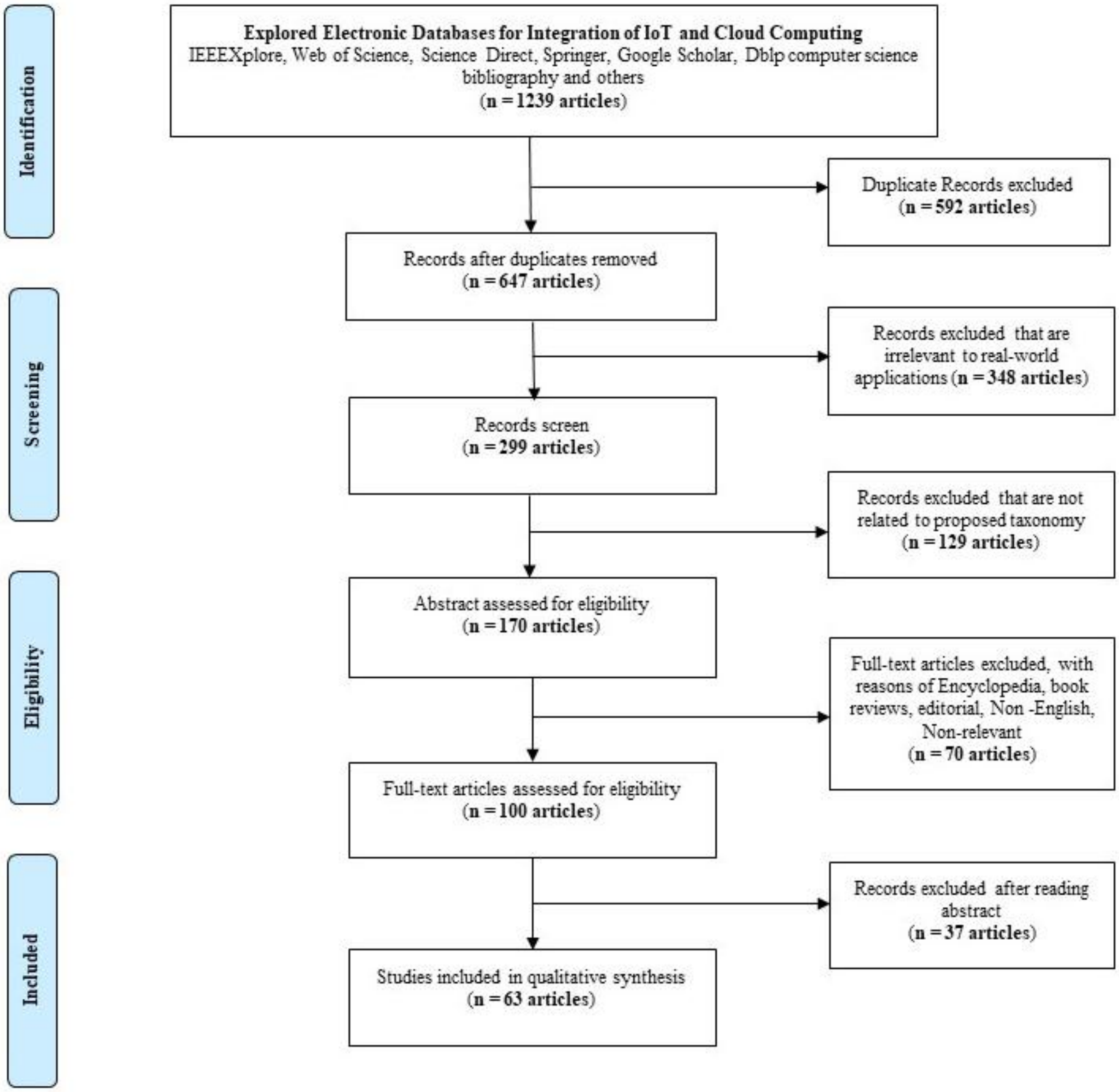


Figure 6 PRISMA data flow diagram

Table 3 Inclusion and exclusion criteria for systematic literature review

Inclusion criteria (IC)	**Exclusion criteria (EC)**
IC1 Papers that incorporate IoT and cloud integration.	**EC1** Papers that are duplicates.
IC2 Papers that focus on various real-world applications.	**EC2** Papers that are irrelevant to the applications domain.
IC3 Papers that provide information regarding QoS factors (such as availability, security, reliability, and latency).	**EC3** Papers that are not related to the proposed taxonomy.
IC4 Papers that provide clear details about middleware, tools, and platforms.	**EC4** Papers that are secondary studies (e.g., editorial, erratum, retracted, short survey, articles in press, tutorials, Note, Letter, Data paper and posters)
IC5 Papers published in the span of seven years from 2015 to 2022.	**EC5** Papers that are not written in the English language.

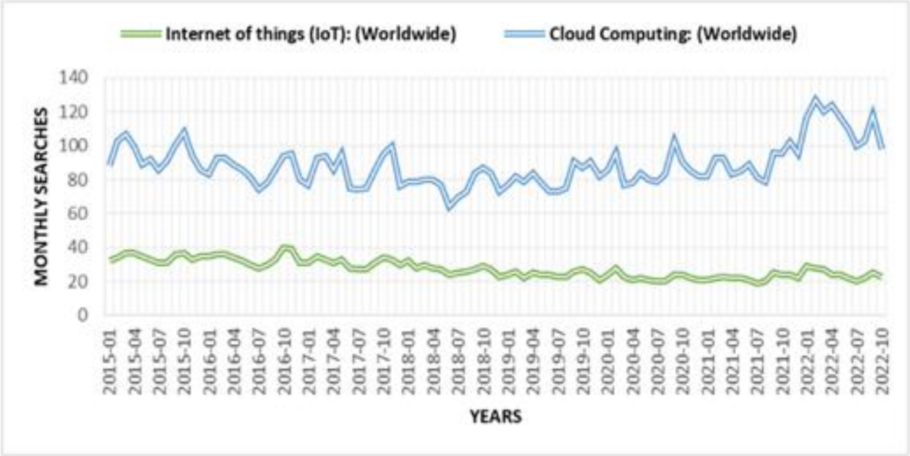


Figure 7 As per google research trends (a comparison of IoT and cloud services)

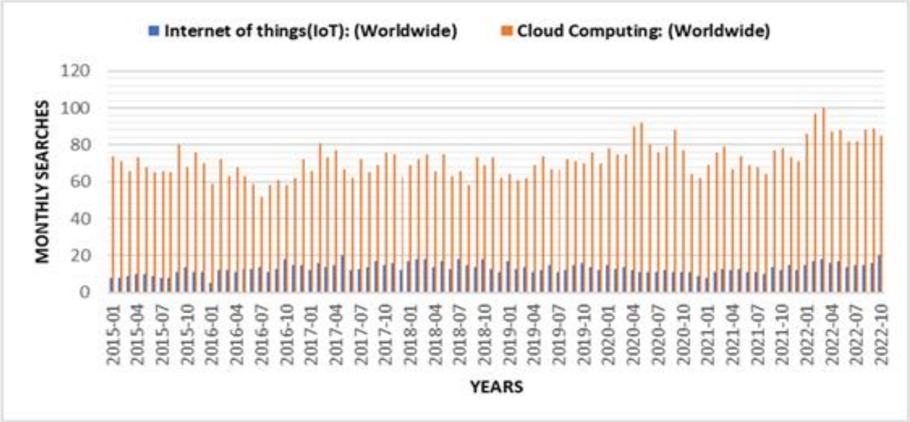


Figure 8 Google research trends (comparative analysis of academic conference publications worldwide on IoT and cloud technology)

Figure 9 CoT-related research papers published by year

3.5Distribution of research documents

A preliminary analysis indicated that after the removal of book reviews, encyclopedias, and editorial materials, 63 papers were left, of which 55% were research articles, 30% were conference papers, 7% were major reviews, and 8% were book chapters. The percentage distribution of research document types is shown in *Figure 10*. Furthermore, the dataset assesses the research publications quality. Articles that have been published in reputable journals are regarded to be high-quality research articles. *Figure 11* illustrates the distribution of articles by the reputable publications who published them. IEEE publishes 26% of articles, Springer publishes 17%, ACM, Elsevier and Hindawi publishes 7%, 12%, and 10% of articles, respectively and the remaining 28% of articles are published in different other publications. *Figure 12* shows a comparison of the year-by-year distribution of articles by publishers.

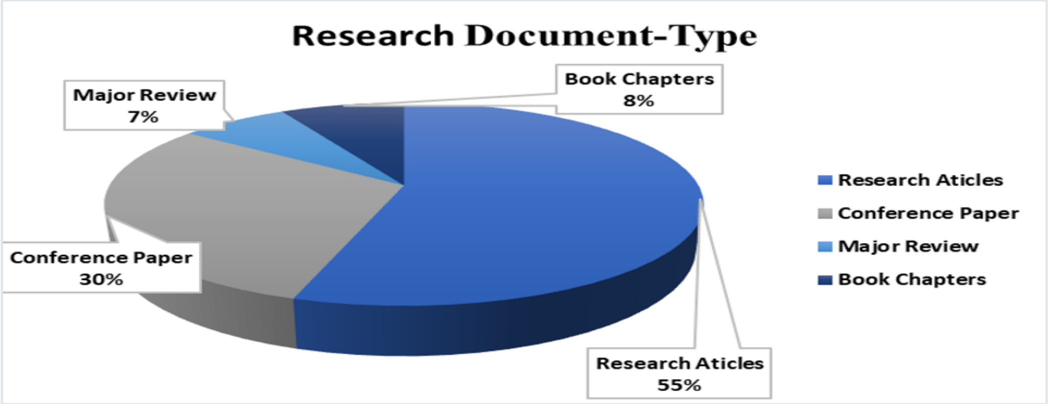


Figure 10 The distribution of research documents

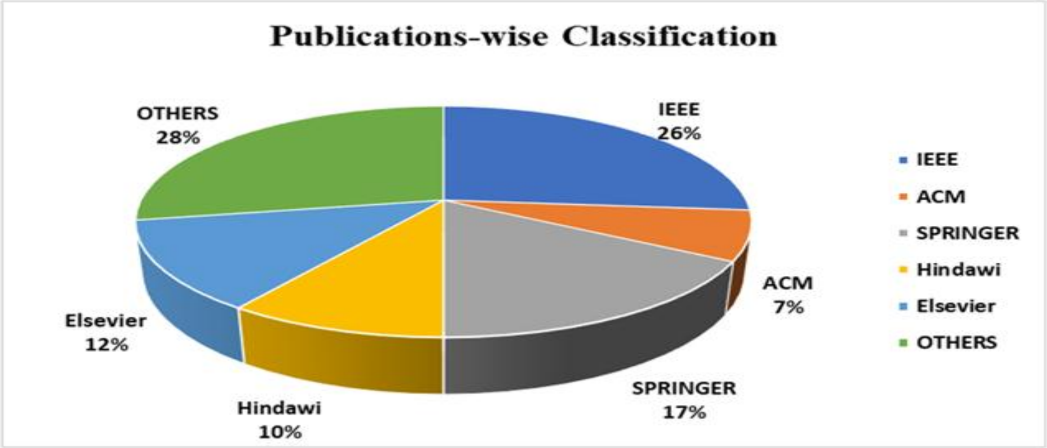


Figure 11 Distribution of papers according to publishers

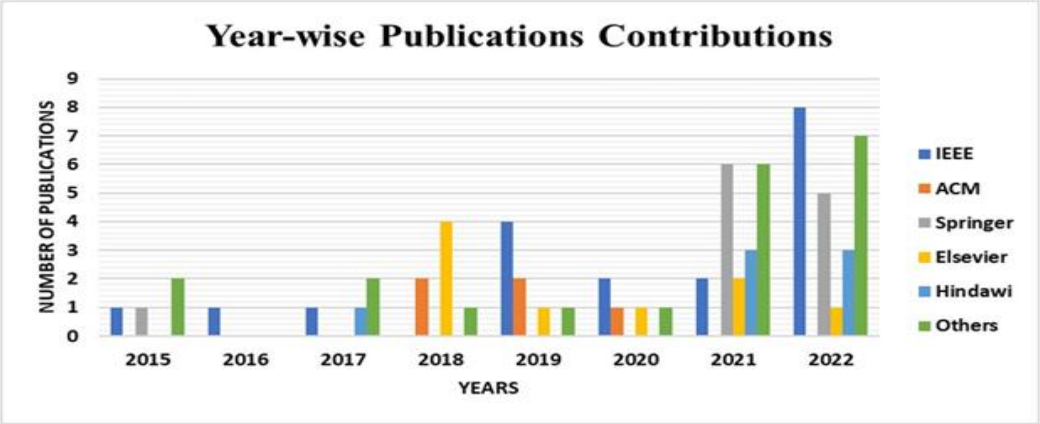


Figure 12 An analysis of the distribution of papers by publisher according to year

3.5.1Bibliometrics analysis

Based on the string ("IoT" OR "Internet of things") and ("Cloud" OR "Cloud Computing"), which is applied on the title field. In the analysis of the relevant articles, the Bibliometric network method was applied, such as citation analysis (or bibliographic coupling), co-authorship analysis, co-occurrence analysis [51–54]. This study built the network, overlay visualizations, and density visualization to visualize bibliometric networks using VOSviewer [55], an open-access tool.

3.5.1.1 Network, overlay, and density visualization analysis for author

A visual representation of the author's co-authorship network can be seen in *Figure 13*, which covers all of the articles compiled for this research concerning IoT and cloud services. A different author's name is represented by each circle in *Figure 13*.

The diameter of the circle indicates how many articles each author has authored on this subject. In general, the more prominently the authors appear next to one another in the visualisation, the more strongly they are associated bibliographically. Thirty-one clusters have appeared in the author's network visualization analysis, and each cluster has different authors. The red cluster, which is shown in *Figure 14*, presents highest co-authorship that contain twenty-six authors. Similarly, the second-highest co-authorship shows in the green cluster, which consists of twenty-two authors who have been working together shown in *Figure 15 (a).* Density visualization per year publication depicts in *Figure 15 (b).*

3.5.1.2 Network, overlay, and density visualization analysis for content

The visualization of content co-occurrence networks is presented in *Figure 16 (a).* The network shown in *Figure 16 (a)* symbolizes a keyword by each circle. The diameter of a circle represents the number of articles that have the phrase in their keywords. There are nine clusters created from the terms, four of which are particularly significant.

The keywords are then grouped into nine clusters based on the most frequent terms. A red cluster can be considered to encompass terms related to IoT technology, cloud, cloud environment, cloud platform, edge cloud, IoT application, IoT device, IoT service, and things application. The green cluster consists of cloud IoT, Internet, and thing terms. The blue cluster is more related to IoT cloud and innovative city, while the yellow and purple cluster focuses on cloud computing and industrial Internet. *Figure 16 (b)* and *Figure 16 (c)* show overlay and density visualization analysis.

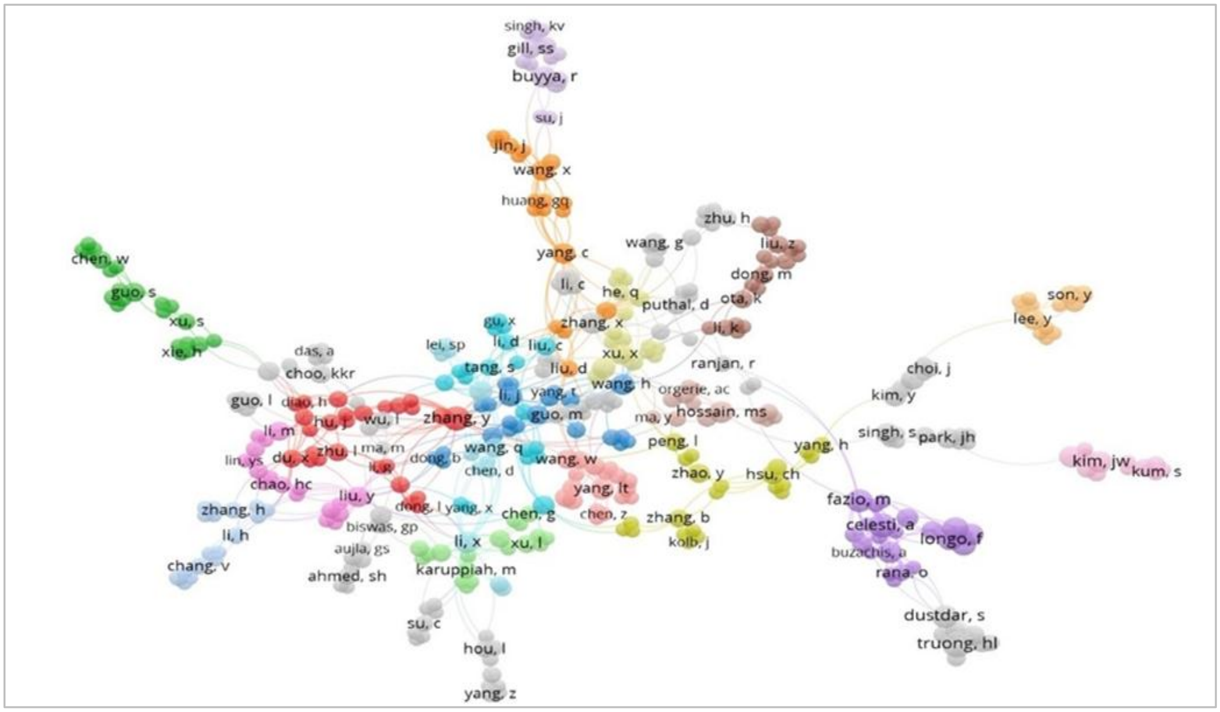


Figure 13 Network visualization analysis for author

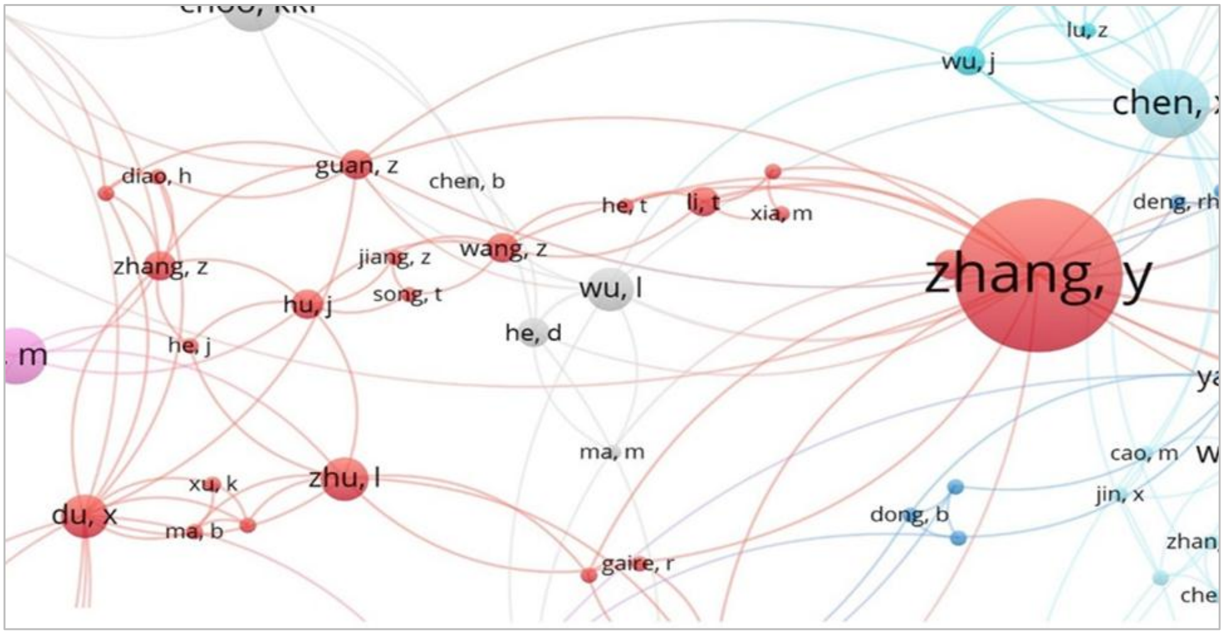
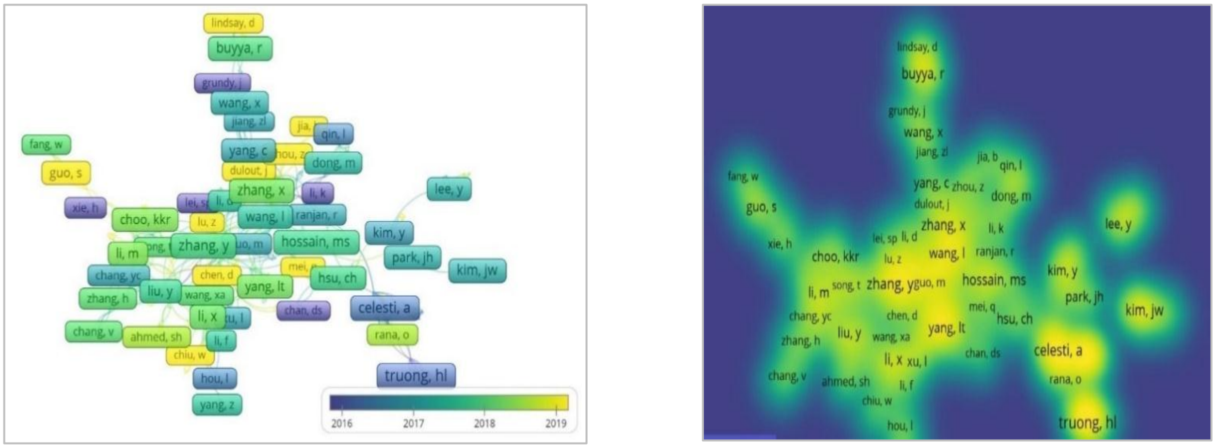
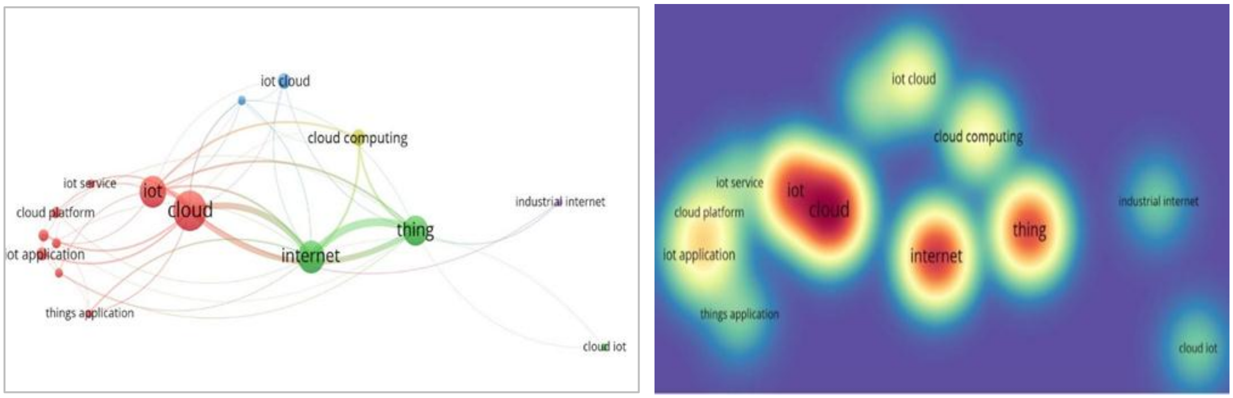


Figure 14 Network visualization analysis for highest co-authorship

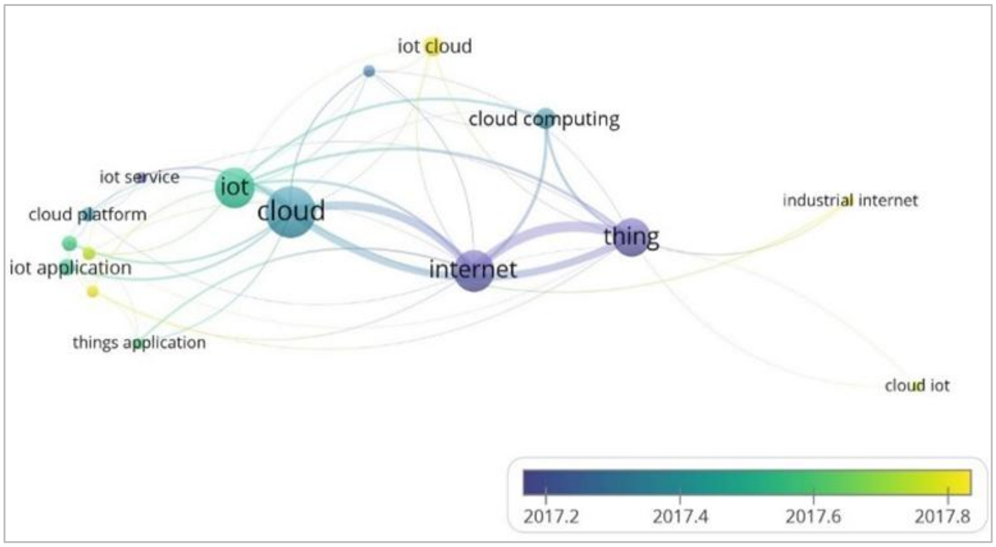


(a) (b)

Figure 15 (a) Overlay and (b) Density visualization analysis for author



(a) (b)



(c)

Figure 16 (a) Network, (b) Overlay and (c) Density visualization analysis for content

4.Taxonomy of IoT-cloud applications

A technical review of selected IoT-based cloud applications is presented in this section, in accordance with the systematic review process used in the existing studies. There are many types of IoT cloud applications, but some of the most common are those that allow for remote monitoring and control of devices; data collection and analysis, and platform for deploying IoT applications.

In *Figure 17* a taxonomy of IoT-cloud applications is depicted, which includes applications related to healthcare, environment, agriculture, smart cities, and industry [56]. To make the IoT-cloud applications more efficient and effective in real-life deployments, several constraints may need to be addressed.

In this review, we examine literature addressing some of the issues involved with supporting IoT-enabled cloud applications in a particular field. Accordingly, this study's taxonomy is determined by the specifics of the different IoT-cloud applications discussed in the subsequent section. Our study examines the type of IoT-cloud applications, and then examines the context within which the literature was presented, to assess the challenges and concerns associated with them. A brief overview of IoT-cloud applications is provided in the following subsections. Furthermore, the different studies will be compared from several perspectives, including their context, domain, mechanism, significance differences, and limitations that shown in the following *Table 4*. In addition, *Table 5* to *Table 9* provide an analysis of QoS factors associated with various domains of applications.

Healthcare

Healthcare IoT applications are cloud-based applications that enable healthcare providers to remotely monitor and manage the health of their patients. These applications use sensors and other devices to collect data from patients, and then use cloud computing to analyze and store the data. Healthcare providers can use these applications to track the health of their patients and to provide them with timely information and advice. A cloud-based IoT architecture may lead to more sophisticated healthcare applications. In hospitals, sensor networks are used to gather information about the health of patients [57, 58].

An evaluation of the studies is presented in *Table 5* by combining the evaluation elements within healthcare IoT applications. Availability, real-time, artificial intelligence (AI), latency, cost, reliability, security, energy consumption, and Big Data are some parameters considered. Furthermore, *Figure 18(a)* illustrates that most research papers in this field evaluate their proposed approach in terms of real-time, cost, and security concerns.

Environment monitoring

IoT devices may produce large amounts of data, which can be challenging to store and analyse. The data collected from the sensors can be stored in the cloud and analyzed for use in monitoring environmental conditions, such as air quality or water levels. By providing feedback on how IoT devices are utilised, such data can also be used to improve their efficiency. As a smartphone can do various activities, the smart home is based on an innovative mobile phone paradigm. A network system connects the devices to perform activities automatically according to the user's preferences through the IoT [59, 60].

Table 6 compares and evaluates studies based on the application of evaluating aspects to IoT applications. Several parameters are evaluated, including availability, real-time, AI, latency, cost, reliability, security, energy consumption, and Big Data. Further, *Figure 18 (b)* illustrates that most research studies evaluated the real-time, cost, and reliability characteristics of the health-care approach.

Agriculture

Agriculture is a rapidly increasing use of the IoT these days. Mobile phones are being used by farmers to monitor their fields and take necessary actions against unwanted insects, such as irrigation, insect screening and fungicide applications in the field. Additionally, smart objects powered by the IoT are extensively used in the various poultry and agriculture industries [61, 62].

As shown in *Table 7* an evaluation element comparison for IoT applications in agriculture is presented. In addition to availability, real-time, AI, latency, cost, reliability, security, energy consumption, and Big Data, several parameters are analyzed. As can be seen in *Figure 18 (c)*, most research studies evaluated the real-time, cost, availability, AI, latency, security, and reliability characteristics of agriculture solutions.

Smart city

A smart city IoT-cloud application can help to manage a city's infrastructure and resources more efficiently. Several IoT-driven smart city initiatives are proving to deliver tangible benefits to all citizens. Several ecosystems contribute to the development of smart cities. Many prominent innovations that help to the establishment of smart cities include energy management and transportation management [63, 64].

A summary of each of the literatures, based on the elements used in IoT applications for smart cities, is presented in *Table 8.* As part of this analysis, we consider the following parameters: availability, real-time, AI, latency, cost, reliability, security, and energy consumption. According to *Figure 18 (d),* most studies investigating smart city approaches evaluated their offerings in terms of availability, cost, reliability, and energy consumption.

Industrial

Industrial IoT (IIoT) is a novel intelligent industrial management technique that leverages intelligent devices, sensors, and computer systems. IIoT enables enterprises to get real-time data on their inventories and manufacturing units, as well as a sensor-enabled alarms system that alerts staff. Sensor data is recorded and evaluated to determine the sensors' future and direction [65, 66]. According to *Table 9*, the papers were evaluated by using evaluation elements for applications related to IIoT. As part of this assessment, we will consider the following parameters: availability, real-time, AI, latency, cost, reliability, security, and energy consumption. According to *Figure 18 (e)*, most research papers on IIoT applications evaluated what they suggested regarding availability, real-time, cost, reliability, and energy consumption.

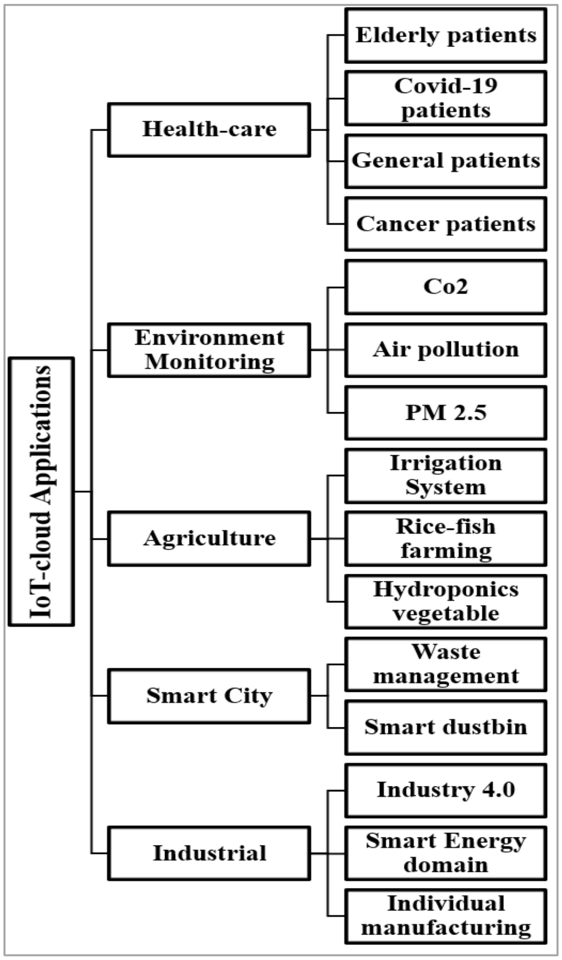


Figure 17 Taxonomy of IoT-cloud applications

Table 4 Comparative analysis for various aspects, and real-world applications domain for the research article

Citation references	**Year of publication**	**Real-world applications**	**Domain**	**Main context**	**Methodology/technology/algorithm involved**	**Significance differences of the current research articles**	**Limitations**
Hu et al. [67]	2017	**Healthcare Monitoring**	Elderly patients	Implement a cloud-based health monitoring system using IoT sensors.	Asymmetric/symmetric encryption mechanism.	Ensure the integrity, security, non-repudiation, and confidentiality of cloud-based data.	Lack of focus on the bioinformatics certification.
Nasser et al. [68]	2021		Covid-19 patients	COVID-19 can be detected and classified with the use of IoT-cloud technologies.	A DL based classification algorithm ResNet50 CNN.	The suggested system is verified utilising the Covid-ChestXray and Chex-Pert reference datasets.	There is no attempt to identify different COVID-19 categories or multiclasses.
Bao et al. [69]	2022		General patients	In cloud-assisted MIoT, ERPD-DS-KS enables fine-grained sharing of data.	KU Nodes algorithm.	For resource-constrained devices, the cloud can quickly determine if ciphertexts include the desired keyword.	Cloud assisted MIoT scenarios are not as realistic as other related methods.
Farid et al. [70]	2021		Individual patients	To perform authentication, the proposed framework uses multimodal encrypted biometric traits.	A Centralised and Federated Identity Management System (IDMS).	Ensure personal healthcare information is secure and private.	There is limited research on identity-based attacks.
Anuradha et al. [71]	2021		Cancer patients	To improve cancer prediction by integrating IoT and cloud computing.	Advanced Encryption Standard (AES) algorithm and Cloudsim.	Due to cloud storage, traditional medical treatment constraints can be overcome.	Several malignancies are not investigated in this study using deep learning.
Ming et al. [72]	2019	**Environment Monitoring**	CO_2	To design a methodology for CO_2 using IoT and cloud computing.	MQ-135 with NodeMCU ESP8266 WiFi module and Firebase cloud.	To improve accessibility and availability, mobile platforms and cloud data storage have replaced traditional local server solutions.	Insufficiency of the system's functionality can be expanded by including new parts.
Singh et al. [73]	2020	**Environment Monitoring**	Air pollution	Several variables related to climate are examined in the research, including air temperature, humidity, pressure, and carbon dioxide levels.	ThingSpeak IoT app, Raspberry pi 3, Arduino UNO, MQ-135 gas sensor.	In real-time, sensor interfaces can detect and collect many parameters simultaneously.	Due to the nature of the device, it cannot be operated from anywhere.
Mi et al. [74]	2022		PM 2.5	A residential environmental pollution monitoring system is developed using cloud computing and the IoT.	STM32, Wi-Fi module, a serial port, and a sensor.	A pollution monitoring system uses sensor networks, wireless communications, integrated development, image	The insufficient implementation of machine learning models.

Citation references	Year of publication	Real-world applications	Domain	Main context	Methodology/technology/algorithm involved	Significance differences of the current research articles	Limitations
						processing, and data fusion.	
Phasinam et al. [75]	2022	**Agriculture**	Irrigation System	Implementing a soil moisture and humidity data stored in the cloud are analyzed.	DHT11/DHT22 humidity sensors, YL-69 soil moisture sensor, AI technique (support vector machine, random forest, and Naïve Bayes).	With the aid of machine learning, Agriculturists receive accurate guidance on groundwater management.	For IoT and cloud computing to become a reality, significant research is still required.
Uddin et al. [76]	2022		Rice-fish farming	A cloud-based IoT-based automated farming system that employs WSN to remotely monitor factors.	DWIFS (Developed Website for Integrated Farming System).	For intelligent fish farm monitoring, farmer can access DWIFS and the IoT cloud server via SMS and email from anywhere in the world.	An Android app is not available to remotely monitor output data from mobile devices.
Namee et al. [77]	2020		Hydroponics vegetable	To help soilless vegetable by using IoT, Edge computing, and Cloud computing.	Node MCU ESP8266, Arduino UNO R3, and Raspberry Pi v3.	To significantly monitor various components within the cabinet, such as pH, humidity, EC in water, and temperature.	Insufficient security measures and procedures leveraging machine learning.
Hundera et al. [78]	2021	**Smart City**	Smart city	Proxy-based public-key encryption scheme for smart city IoT cloud data security.	EF-PB-PKC-IoT-CMA and IND-PB-PKC-IoT-CCA2	Highly suitable for cloud and IoT contexts, with reduced computational complexity than conventional techniques.	Insufficient effort has been expended to create and improve the PB-PKC-IoT scheme for various applications.
Hojjati et al. [79]	2022		Waste management	A system based on trash objects has been designed and constructed to monitor and score user sorting behavior.	YOLOv3, Light dependent resistor (LDR) module, Intel AC8265 WiFi Wireless adapter and C270 HD camera.	System uses solar panels to generate electricity and does not save user data.	During the autumn and winter, where sunlight is sparse, batteries and solar panels are not used to provide this power.
Hussain et al. [80]	2019	**Smart City**	Smart dustbin	A real-time trash monitoring platform based on IoT is used to transfer data to a cloud-based platform.	ThingsSpeak, ESP8266 module, DHT 11, GSM, GPS.	The module provides an alert when the trash level exceeds a certain point, while also preventing fires caused by cigarettes and other combustible materials.	Inadequate safety measures.
Garbugli et al. [81]	2022	**Industrial**	Individual manufacturing	IoT-based middleware for managing virtualized resources and monitoring QoS.	TEMPOS: a Time-Effective Middleware for Priority Oriented Serverless.	To control QoS end-to-end in terms of jitter, latency, and queueing time, TEMPOS may exploit and coordinate QoS mechanisms throughout the stack of virtualized FaaS services.	Lack of resources scalability.

Citation references	Year of publication	Real-world applications	Domain	Main context	Methodology/technology/algorithm involved	Significance differences of the current research articles	Limitations
Qader et al. [82]	2022		Industry 4.0	Using the Supply Chain Efficiency (SCP) model, the effects of Industry 4.0 on supply chain efficiency are examined.	Modeling structural equations with partial least squares (PLS-SEM).	Industry4.0 has been proved to have a considerable and substantial effect on the performance of SCs.	SCs face significant challenges due to lack of security in Industry 4.0.
Venticinque and Amato [83]	2019		Smart Energy domain	Content-based cross-layer scheduling approach to fog service placement.	CoSSMic European project.	Methodology describes how to optimize performance and resource consumption by application requirements.	A lack of dynamic optimization of deployment.

Table 5 Comparative analysis of the existing QoS parameter in the healthcare domain

Citation references	Availability	Real-Time	AI	Latency	Cost	Reliability	Security	Energy consumption	Big Data
Hu et al. [67]	✗	✗	✗	✗	✓	✗	✓	✗	✗
Nasser et al. [68]	✗	✓	✓	✗	✓	✗	✗	✓	✗
Bao et al. [69]	✗	✓	✗	✗	✓	✗	✓	✗	✗
Farid et al. [70]	✗	✓	✓	✗	✓	✗	✓	✗	✗
Anuradha et al. [71]	✗	✗	✓	✗	✗	✗	✓	✗	✗
Kim and Kim [84]	✗	✗	✗	✗	✓	✓	✗	✗	✗
Jimenez and Torres [85]	✓	✗	✓	✗	✓	✗	✗	✓	✗
Suciu et al. [86]	✗	✓	✗	✓	✗	✓	✓	✓	✓
Alshammari et al. [87]	✗	✗	✗	✓	✗	✓	✓	✗	✓
Firouzi et al. [88]	✗	✗	✓	✓	✗	✗	✓	✗	✓

Table 6 Comparative analysis of the existing QoS parameter in the environment monitoring domain

Citation references	Availability	Real-Time	AI	Latency	Cost	Reliability	Security	Energy consumption	Big Data
Ming et al. [72]	✓	✓	✗	✗	✓	✗	✗	✗	✗
Singh et al. [73]	✗	✓	✗	✗	✓	✗	✗	✗	✗
Mi et al. [74]	✗	✓	✗	✗	✗	✗	✓	✗	✗
Arvaree et al. [89]	✗	✓	✗	✗	✓	✓	✓	✗	✗
Li et al. [90]	✗	✗	✗	✗	✓	✓	✗	✗	✗
Kim et al. [91]	✗	✗	✗	✗	✗	✗	✗	✓	✗
Hojjati et al. [79]	✗	✓	✓	✗	✗	✓	✗	✗	✗
Asha et al. [92]	✗	✓	✓	✗	✓	✗	✗	✗	✓
Qian and Wang [93]	✗	✗	✗	✓	✓	✗	✗	✗	✗

Table 7 Comparative analysis of the existing QoS parameter in the agriculture domain

Citation references	Availability	Real-Time	AI	Latency	Cost	Reliability	Security	Energy consumption	Big Data
Phasinam et al. [75]	✓	✗	✓	✗	✗	✗	✗	✗	✗
Uddin et al. [76]	✗	✗	✗	✗	✓	✗	✗	✗	✗
Namee et al. [77]	✗	✓	✗	✗	✗	✗	✗	✗	✗
Misra et al. [94]	✗	✓	✓	✗	✓	✗	✓	✗	✓
Perumal et al. [95]	✗	✗	✗	✓	✓	✓	✗	✓	✗
Mekala and Viswanathan [96]	✓	✓	✗	✗	✓	✓	✓	✗	✗

Liu et al. [97]	✓	✓	✓	✓	✓	✓	✓	×	✓
Aiswarya et al. [98]	×	✓	×	✓	×	×	×	×	×
Rathor and Kumari [99]	×	✓	×	×	✓	×	×	×	×

Table 8 Comparative analysis of the existing QoS parameter in the smart city domain

Citation references	Availability	Real-Time	AI	Latency	Cost	Reliability	Security	Energy consumption
Hundera et al. [78]	×	×	×	×	✓	×	✓	×
Hojjati et al. [79]	×	✓	✓	✓	×	✓	×	×
Montori et al. [100]	✓	×	×	×	✓	×	×	✓
Zia et al. [101]	✓	×	×	×	×	✓	×	✓
Distefano et al. [102]	✓	×	×	×	×	✓	×	✓
Zeng et al. [103]	×	×	×	×	✓	×	×	×
Duttagupta et al. [104]	✓	×	×	×	×	×	×	✓
Chen et al. [105]	✓	×	×	×	✓	×	×	×
Lee et al. [106]	✓	×	×	×	×	×	×	×
Akbar et al. [107]	×	×	×	×	×	✓	×	×
Sun and Ansari [108]	×	×	×	×	×	×	×	✓

Table 9 Comparative analysis of the existing QoS parameter in the industrial domain

Citation references	Availability	Real-time	AI	Latency	Cost	Reliability	Security	Energy consumption
Pustišek and Kos [109]	×	×	×	×	✓	×	×	×
Alodib [110]	✓	✓	×	✓	✓	✓	×	✓
Han and Crespi [111]	✓	×	×	✓	✓	✓	×	✓
Huo et al. [112]	✓	✓	×	×	✓	✓	×	✓
Huo and Wang [113]	×	×	×	×	✓	×	×	×
Temglit et al. [114]	✓	✓	×	×	✓	✓	×	✓
De et al. [115]	✓	✓	×	×	×	×	✓	✓
Rath et al. [116]	×	×	✓	×	×	×	✓	×

5. Analysis based on the existing middleware and platforms tools

A software layer known as middleware is located between the application and perception layers. This layer is capable of addressing several issues, including reliability, scalability, homogeneity, and security. Middleware, as defined by Farahzadi et al. [117], is a "network-oriented" perspective. Middleware technology is primarily used to abstract and communicate with devices to facilitate the inevitable integration of IoT devices with other technologies, including cloud services [118]. The overall concept and primary characteristics or feature of IoT-based middleware are shown in *Figure 19.*

In addition, as part of an integrated framework, various existing platforms deliver IoT-enabled cloud services as a service [119]. A variety of IoT cloud providers are available in the market for leveraging appropriate and unique IoT services [120, 121]. This article analyses the present state of the industry in order to identify the leading IoT platforms. This research may aid in the creation of the best environment for IoT application development. This section discusses in depth developing IoT cloud service platforms, their characteristics, and the associated benefits and drawbacks. *Table 10* details the design and application of the IoT platform, while *Table 11* details the top 10 middleware.

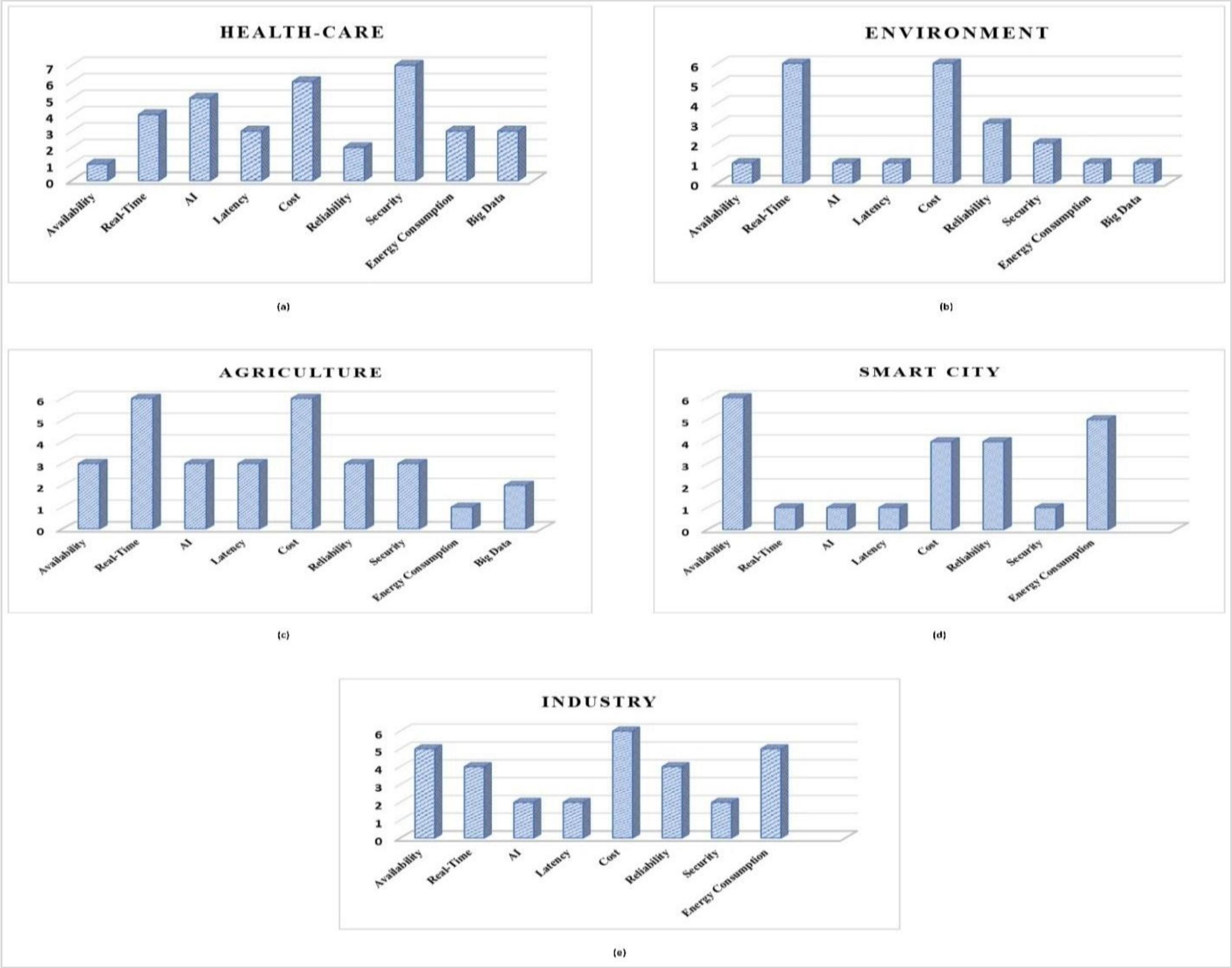


Figure 18 Analysis of QoS factors for (a) Health-care (b) Environment (c) Agriculture (d) Smart city (e) Industry

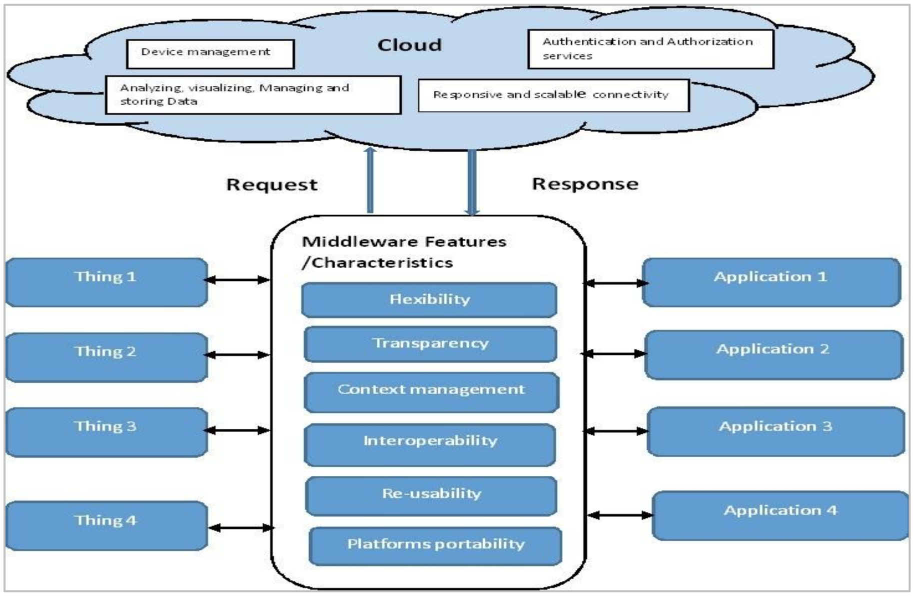


Figure 19 An overview of CoT-based middleware including its main characteristics and features

6.Benefits of integration IoT and cloud

IoT-enabled services comprise a wide variety of devices such as embedded devices, sensor devices, communication devices, and mobile devices. In the absence of adequate storage and processing resources, the IoT-based system cannot retain and process large volumes of sensor-driven data. As a result, the IoT system will need assistance in overcoming these constraints.

Cloud computing provides an unlimited storage capacity, enormous computational power, and network bandwidth, among other capabilities which may assist the IoT system in addressing the barriers described prior. Cloud computing resources are elastic, allowing them to grow and contract in response to the IoT environment's requirements. Sensor data analysis may also be aided by cloud-based Big Data analytics [122,123]. Cloud computing integration with IoT systems improves the efficiency and reliability of IoT-based applications. An array of benefits can be achieved by combining the IoT with cloud computing. Following are some of the advantages.

Data transmission

Cloud-based IoT paradigms allow efficient transmission. IoT applications provide low-cost data transmission between nodes. Cloud computing enables the cost-effective and efficient connection, control, and exchange of data via the use of integrated applications.

Storage

The IoT ecosystem is composed of several associated gadgets and sensors that cause enormous amounts of real-time data. Local storage on the IoT is insufficient to hold this volume of data. Additionally, a large number of IoT devices generate both structured and unstructured data. Conventional databases are incapable of holding such a diverse set of data. Cloud computing enables IoT devices to overcome this data storage challenge. Cloud computing is comprised of a group of commodity computers equipped with a significant quantity of inbuilt storage. Cloud-based IoT systems allow users to store data and access it from anywhere using the internet. Additionally, this vast data storage may be leveraged to address the heterogeneity of devices by enabling analytics and system enhancements.

Processing

IoT devices have rudimentary computing power. As a result, they are incapable of processing massive amounts of data generated by millions of linked, intelligent gadgets. Cloud computing offers computational capacity for IoT devices by dividing the real computer into several virtual ones. A virtual computer may be rented through Internet-enabled devices on a pay-per-use basis. Due to the integration of IoT technology into cloud services, end users can benefit from low-cost computing power while generating high income.

Modern capacities

Multiple operational devices are interconnected via IoT-enabled devices. These devices communicate using a variety of protocols and techniques. As a result, coordination between these disparate devices is difficult. Additionally, obtaining maximum dependability and efficiency might be difficult. Cloud computing is characterized by its elasticity and ease of usage. By integrating cloud computing with IoT, users can be assured that their applications are more reliable, scalable, secure, and efficient.

Models for the cloud of things

SaaS, IaaS, and PaaS are the three primary deployment methods for cloud computing. With the combination of cloud and IoT, new deployment methods have been developed, including the following:

- Sensing as a Service (SaaS) provides services for acquiring access to the information collected by IoT sensors.
- Integration Platform as a Servic **(**IPaaS) allows identifying devices connected to the network and setting up access control policies.
- The Database as a Service (DBaaS) is involved in both database administration and storage services.
- Ethernet as a Service (EaaS) enables IoT-enabled devices to connect to the internet.
- The Sensor and Actuation as a Service (SAaaS) ensures automatic control of sensors and devices.

Table 10 Existing IoT-cloud platforms

Platforms	Features	Merits	Limits	Web links
Arrayent Connect	Intelligent devices and web applications can effortlessly integrate heterogeneous IoT systems.	Maintains elasticity	Due to the configuration of the system, trigger-based services are delayed.	http://prodea.com/platform
Ethings.Io	An effective application	Device uncertainty support	Third-party development	https://blog.thethings.io/

Platforms	Features	Merits	Limits	Web links
	programming interface (API) is developed for IoT developers. due to hardware insecurity, it is limited to devices that implement the HTTP, MQTT, and COAP protocols.		becomes challenging.	
Open Remote	Using any available resources, the user may connect to any device, protocol, or system design. A user may utilize remotely cloud services to design any personalized software system.	Open cloud services are supported.	Insufficient data management	https://openremote.io/
Arkessa	It allows companies to connect and control their gadgets.	Enterprise based design model	Not enough visualization tools	https://www.arkessa.com/
Axeda	A cloud-based approach is used to develop IoT and M2M applications.	The M2M paradigm is used to manage data.	Dependence on a third-party service	https://support.axeda.com/help/ en/about_axeda_access.htm
Oracle IoT Cloud	There are four key benefits it offers: transparency, insight, security, and acceleration. End-to-end security allows it to connect any device and deliver business value with the least amount of risk.	It aids in the management of data.	An issue with open-source system connection caused by the size restriction.	https://www.toracle.com/ internet-of-things/,
Nimbits	IoT services are provided utilizing edge computing limitations in a hybrid cloud approach. Aside from that, it effectively filters and uploads cloud data.	Developers may utilize it effortlessly and without issues.	The processing of real-time data is unsatisfactory.	https://www.crunchbase.com/ organization/nimbits,
Thingsworx	It is a decision-making tool that is based on data. The squeal paradigm for m2m and IoT applications provides search-based insight.	Data-intensive applications may emerge fast.	Simultaneous device restrictions	https://www.ptc.com/en/ technologies/iIoT
Kaa	An Open-Source Platform for Deploying, Monitoring, And Administering Iot Applications on The Cloud. To identify devices and objects, digital twins offer a lightweight IoT connection protocol.	Several applications related to Big Data and NoSQL are implemented.	It supports less heterogeneous hardware devices.	https://kaaproject.github.io/kaa

Platforms	Features	Merits	Limits	Web links
	It delivers scalability, data analytics and visualisation, and system dependability.			
Carriots	It is a cloud platform that enables organisations to rapidly and cost-effectively develop IoT applications. It is built on a cloud-based platform paradigm, which allows users to remotely operate the device, set alarms, and export data.	It supports trigger-based application	They have a complicated user interface.	https://www.altair.com/smart-product-development
Temboo	Cloud-based IoT application development platform specialising on manufacturing industry inventory management. An alert message is sent out when a sensor detects a change in a physical asset's condition.	Choreos applications are employed easily	Applications that need a lot of resources are not supported.	https://temboo.com/IoT
SeeControlIoT	A cloud-based administration system and connectivity system for IoT devices. It also has a push/pull architecture to analyse and interpret sensor data.	Push/pull messaging mechanism between devices	Inefficient data visualisation	https://www.IoTglobalnetwork.com
SensorCloud	IoT data storage, visualization, monitoring, and analysis platform for smart IoT devices. The MathEngine and FastGraph tools allow users to analyze and visualize data.	It can handle several resources.	Connecting open-source devices	https://www.scc.com/insights/it-solutions
Etherios	Etherios combines with westmonroe partners. it offers several goods and services. It uses the cloud PaaS paradigm to connect and monitor items in real-time.	Cloud-based services for third-party and unique devices	The device selection is limited.	https://www.sensorcloud.com
Xively	In the current state of affairs, xively is an official member of the google cloud platform. It is comprised of a number of	Integration with devices is effortless	Poor management of the system	https://www.developerxively.com/docs/what-is-xively

Platforms	Features	Merits	Limits	Web links
	application-specific sub-parts, including lutron, freight farm, watts, tekmar, sato, and sureflap.			

Table 11 Middleware technologies

Middleware	Applications	Architecture	Cloud-Based
Aura	The Ubiquitous Computing Environment	Distributed	×
Abs & S	Automatic Vehicle Parking	Service-Related	✓
Carriots	An Energy-Efficient Smart City	Service-Related	✓
Carisma	Computing on Mobile Devices	Distributed	×
Droplock	Deployment of Smart Homes	Service-Related	✓
Openiot	Mobile Crowdsourcing and Smart Cities	Service-Related	✓
Rimware	The Installation of a Smart Lighting System and Heart Rate Monitor	Service-Related	✓
Thingworx	Agribusiness, Intelligent Cities, and Smart Infrastructure	Service-Related	✓
Virtus	Internet-Based Health Services	Distributed	×
Xively	Home Appliances Connectivity and Management	Service-Related	✓

7.The challenges and open research issues of the cloud of things (CoT)

The Integration of the IoT with cloud technology is problematic and a number of problems remain unresolved. A number of legitimate concerns have been identified:

Privacy and security

In developing IoT-based cloud services, privacy and security are the key concerns. The IoT-based Cloud enables the transfer of real-world data to the cloud. In order to ensure only authorized customers have access to data, it is important to determine how effectively authorization rules and regulations should be enforced. As a precaution, critical information should be shielded from unwanted access. Cloud-based IoT devices pose a number of challenges, such as the lack of transparency in service-level agreemen **(**SLAs), data privacy, and the remote-access of the system. Additionally, multi-tenancy may result in the restriction of sensitive data using public key cryptography. In comparison, serious problems, such as user takeover and virtual machine rescue, are also a source of concern. The researchers [124], make an assault on the system and provide a recommendation. Using neural networks (NN) and cloud trace back (CTB) technologies, they propose a method to identify the cause of attacks.

Ipv6 addressing strategies

It is widely recognized that the Internet is a key component of the IoT. IPv4 has a profound influence on the IoT. The CoAP technology allows devices and servers to communicate directly over the internet. As part of the future development of these technologies, network address translation (NAT) operations will be eliminated in order to provide a specific IP address to the expanding IoT platform or network. IPv6 is designed to overcome IPv4's limitations by employing a 128-bit Internet Protocol address. There are numerous benefits to RESTful interfaces, including the availability of an almost unlimited number of Internet-connected devices, cross-platform compatibility, and compliance with REST protocol agreements. The IP protocol 6LoWPAN and ZigBee can be applied to integrated IoT devices to implement IPv6, however, several platforms are yet to implement these protocols. IPv6 is used by the IoT network, which originates from human-initiated networks.

Interoperability

Due to the diverse and independent nature of IoT devices, interoperability is a critical challenge in cloud-based IoT systems. Several forms of work have been conducted in this area during the past several years to address this issue. Due to the heterogeneity of cloud platforms and applications, the presented methodologies give a variety of solutions. Additionally, lack of compatibility may result in the difficulty to construct cross-platform and cross-domain applications [125].

Intelligent analytics

Intelligent analytics can provide insights into large volumes of data collected from connected devices. This data can be used to identify patterns and trends, uncover anomalies, and provide predictive analytics to help inform decisions. Intelligent analytics can also be used to create automated control systems, allowing for more efficient operations, improved safety, and better energy management. Additionally, intelligent analytics can help improve customer experience by providing personalized services and targeted recommendations [126,127].

Integration methodology

By combining present and future intelligent cyber-physical systems into fully realised IoT, the demand for interoperability cannot be neglected. There are no existing IoT standards or approaches for integrating IoT systems due to their diverse nature and interoperability [128]. The heterogeneity issue might be exacerbated when end users utilize multi-Cloud solutions, since applications depend on a multitude of providers to support scalability and efficiency.

Heterogeneity

IoT and cloud computing are hindered by the complexity of legacy systems, platforms, operating systems, and services. As a result, the heterogeneity problem may worsen dramatically as end users adopt multi-cloud solutions, where applications become increasingly dependent on the capabilities provided by numerous providers.

Standardizations

A number of experts have acknowledged that the lack of standards is one of the major challenges facing CloudIoT models in recent years. IoT-based Cloud paradigms require standardized protocols, interfaces, and APIs to interconnect heterogeneous intelligent objects and provide unique services. Many IoT and cloud deployment approaches have been recommended by the technical community.

Edge/Fog computing

Computing can be applied at the edge of providing cloud-based services. To assist customers with their cloud computing needs, Fog provides application services. As a generalisation, fog is an expansion of the cloud system that connects the cloud to the network's edge. To achieve latency constraints, additional nodes are necessary for services that are latency-sensitive. Although Cloud and Fog are highly dependent on processing, networking, and computing.

Cloud capabilities

An IoT architecture based on the cloud poses a significant security risk to every networked system. There are additional attack vectors on both the IoT and cloud sides. An IoT setting can benefit from encryption for data privacy, confidentiality, and authentication. On the other hand, internal threats cannot be defeated, and operating IoT devices with limited functionality is equally problematic.

S.L.A. implementation

Cloud-based IoT applications enable the transmission and storage of data created within the confines of application-specific limits, which might be troublesome in certain cases.

A single provider may not always be sufficient to assure a specified level of QoS. As a result, it is likely to require the support of several cloud service providers for addressing SLA violations.

Big Data

The pervasiveness of mobile devices and sensors necessitates the use of modular systems. As a result, several Cloud service providers may be required to avoid breaches of S.L.A. files. However, the flexibility of the most regularly come up of cloud services is still an unresolved problem because of the time, cost, and maintenance of QoS complexity.

Power and energy efficiency

During the past decade, IoT-enabled applications have enabled frequent data flow between IoT devices and the cloud, which has resulted in rapid power consumption on the nodes. Consequently, the data processing and transmission industries continue to prioritize energy efficiency.

Performance

Several cloud computing and IoT technologies (such as networking, processing, and storage) are difficult to standardize due to their scale-dependent performance requirements.

Reliability

Cloud computing and IoT convergence typically introduce dependability concerns in mission-critical applications. For example, in the domain of intelligent mobility, vehicles are frequently in motion, and automotive networking and connection are frequently irregular and inefficient. In a resource-constrained setting, a range of issues relating to system breakdown or systems that are not always approachable are highlighted.

Monitoring

In cloud environments, monitoring is essential for batch processing, resource management, S.L.A.s, dependability and security, and troubleshooting. Consequently, the cloud-based IoT system adheres to all the same requirements as a traditional cloud monitoring system, despite the IoT's inherent challenges associated with speed, volume, and diversity.

8.Discussion

In an effort to maximize the yield of IoT and cloud integration, researchers from around the world have explored a variety of technological solutions. IoT and cloud computing are two buzzword-rich digital transformation topics that have been the focus of a lot of attention in recent years. This research reviews multiple aspects of IoT-based cloud applications (i.e., health-care, environment, agriculture, smart city, and industry). Furthermore, various QoS factors (such as availability, AI, reliability, security, real-time, and Big Data) have been analysed for each domain. For deeper insight, a comprehensive review of various existing platforms and enabling middleware technologies also have been synthesized. There are following potential impacts of methods and platforms for IoT cloud integration which include:

- Increased efficiency and productivity: By automating tasks and monitoring devices and systems remotely, businesses can improve operational efficiency and productivity.
- Improved decision making: With real-time data and analytics, IoT-enabled cloud applications can make better informed decisions about their operations.
- Enhanced customer experience: IoT-enabled businesses can provide better customer experiences by customizing products and services to meet customer needs.
- Reduced costs: Automation and remote monitoring can help businesses reduce costs associated with labour, energy, and other resources.
- Enhanced security: Cloud-based IoT platforms can offer enhanced security features such as data encryption and user authentication. This can help organizations to protect their data and prevent unauthorized access.
- Increased scalability: Cloud-based IoT platforms offer increased scalability, which allows organizations to easily add or remove devices and users as per their requirement.

Furthermore, this article uses PRISMA guidelines for quality assessment. Our primary objective is to identify the current state of the art of integrating IoT cloud technologies and map the key research areas and future development trends. To achieve this objective, a comprehensive literature review was conducted and a total of 63 papers were identified and analyzed. The results of the bibliometric analysis showed that the field of IoT cloud integration is a relatively new research area with a rapidly growing body of literature. However, there are some limitations of IoT and cloud integration as follows:

- Security issues: It is important to note that security is one of the primary concerns with the IoT. There is a potential for hackers to gain access to IoT devices which are constantly connected to the internet.
- Privacy concerns: Another concern is the privacy of data. IoT devices may capture a plethora of information about individuals and their actions. There is a possibility that this information could be used to follow individuals or compromise their privacy.
- Reliability: One of the most challenging aspects of IoT network is the reliability of data. IoT devices can malfunction or lose data. This data may not be backed up and could be lost forever.
- Lack of standardizations: The major limitation of IoT cloud integration is the lack of standardization. There is no such standard protocol that fits to all solution for integrating IoT devices and data into the cloud. Each cloud provider has their own proprietary solution, which makes it difficult to integrate multiple IoT devices and platforms. In addition, many IoT devices are not compatible with standard cloud technologies, which further complicates integration.
- Dependence on internet: IoT devices are dependent on the internet for data transmission. If there is no internet connection, the devices will not be able to function properly.
- Cost: The IoT and cloud computing integration can be costly, as organizations need to invest in hardware, software, and services.
- Complexity: The convergence of IoT with cloud computing might be complex since it requires for the deployment of a variety of different technologies.

A complete list of abbreviations is shown in *Appendix I.*

9.Conclusion and future directions

As the IoT continues to grow in popularity, so does the need for efficient and reliable cloud integration solutions. In light of systematic literature reviews (SLRs), the integration of IoT devices with cloud-based applications has emerged as an attractive approach. This article is intended to provide an assessment of the current status of IoT and cloud integration, including a review of available SLR tools, middlewares and platforms. Despite the potential of cloud integration for IoT, there are still several significant challenges to be overcome. First, the development of IoT cloud integration solutions is still in its early stages, and there is a lack of mature and robust tools and platforms. Second, the use of IoT cloud integration solutions often requires a significant amount of manual effort, which can be time-consuming and error-prone. As part of this study, we aim to investigate various aspects of cloud computing and the IoT, as well as advantages and limitations of a synergistic approach. The PRISMA method has been used for a systematic literature review. Literature identification and relevant articles inclusion and exclusion have been made using the PRISMA technique. The Bibliometric networks method, such as co-authorship analysis, and term co-occurrence, has been used to analyze the literature. The IoT powered by the cloud is paving the way for new business opportunities and research opportunities.

In the future, we believe that IoT cloud integration solutions will become more mature and robust and that they will be increasingly used to integrate IoT devices with cloud-based applications.

The future of IoT cloud integration is looking promising with the advent of new technologies, including edge computing, Big Data, blockchain, industrial 5.0, 5G, and AI, the possibilities for IoT applications are endless. In the near future, we can expect to see more IoT devices and applications being integrated into the cloud. This will enable more data to be gathered and processed, resulting in improved decision-making and more efficient operations. Our research has revealed that the combination of these technologies could lead to new opportunities for practitioners and researchers.

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Conflicts of interest

The authors have no conflicts of interest to declare.

Author's contribution statement

Manzoor Ansari : Conceptualization, investigation, data curation, writing-original draft, writing-review and editing. **Syed Arshad Ali :** Data collection, analysis and interpretation of results. **Mansaf Alam :** Study conception, design, supervision, investigation on challenges and draft manuscript preparation.

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Appendix I

S. No.	Abbreviations	Descriptions
1	3G	Third Generation of Mobile Telephony
2	AES	Advanced Encryption Standard
3	AI	Artificial Intelligence
4	API	Application Programming Interface
5	COAP	Constrained Application Protocol
6	CoT	Cloud of Things
7	CTB	Cloud Trace Back
8	DBaaS	Database as a Service
9	DBLP	Database and Logic Programming
10	EaaS	Ethernet as a Service
11	GPRS	General Packet Radio Service
12	GSM	Global System for Mobile Communication
13	IoT	Intenet of Things
14	IIoT	Industrial IoT
15	IP	Internet Protocol
16	IPaaS	Integration Platform as a Service
17	IT	Information Technology
18	LAN	Local Area Network
19	LTE	Long-Term Evolution
20	NAT	Network Address Translation
21	NFC	Near-field Communication
22	NN	Neural Networks
23	PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
24	QoS	Quality of Service
25	REST	Representational State Transfer
26	RFID	Radio Frequency Identification
27	SAaaS	Sensor and Actuation as a Service
28	SaaS	Sensing as a Service
29	SLA	Service-level Agreement
30	SLR	Systematic Literature Review
31	WoS	Web of Science
32	WoT	Web of Things