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"A systematic literature review on IoT gateways"

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A B S T R A C T

Gateways in the Internet of Things (IoT) play a decisive role in routing the preprocessed filtered data to cloud platforms. While investigating gateways, the need for a comprehensive systematic literature review that can elaborate the working and functionalities of IoT gateways was felt. This paper presents a systematic literature review of IoT gateways in general and smart gateways in particular. It considered papers published over the last 10 years, i.e., from 2011 till July 2021. A methodical literature analysis technique is used in this review; out of 2347 papers, 67 articles are selected for complete analysis based on well-defined criteria. The survey starts with the broad categorization of gateways in IoT as basic and smart gateways. Further, smart gateways are sub-divided into three categories as passive gateways, semi-automated and fully-automated gateways. The survey is performed based on well-defined criteria, which include: the type of gateways, their requirements, tools/platforms, the approach adopted, evaluation and their application domain. This paper demonstrates further bifurcation of functional requirements of IoT gateways. Research gaps and open issues have been identified in the area. Future prospects have accordingly being suggested to help academicians embark on advanced research.

Contents

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1. Introduction and motivation

Significant advancements in technology and emerging techniques in wireless communication, sensor networks and embedded systems have resulted in the hike in low power, resource-constrained, compact, affordable IoT devices. These tiny smart devices are interconnected and communicate via Internet to fulfill the required services. This evolving field of smart connected things is known as the Internet of Things (IoT). It has various applications, including home automation, smart cities, smart agriculture, e-healthcare system, smart power grids, smart vehicles, smart aquaculture, smart gardening and many more. In 1999, market researcher Kevin Ashton coined the word "Internet of Things" in the sense of supply chain management (Ashton, 2009). While the concept of "Things" has expanded as technology has progressed, the primary purpose of designing a machine sensing information without the assistance of a human remains the same. The Internet of Things (IoT) envisions the overall integration of multiple "things" while establishing a smart interface between people and nearby objects using the Internet as the backbone of the communication system. The capacity of intelligent devices to sense and assemble data from the surroundings is referred to as IoT. The evolution in IoT and its continued expansion created a broad link between "things," i.e., sensors, actuators and devices.

Cloud computing (Wang et al., 2010; Botta et al., 2016; Dang, 2019) is used to store and analyze big data. It provides a suitable utility model that offers on-request access to the application users. However, IoT devices exponentially scaled up with the growing demands, leading to a tremendous amount of data volume and processing needs, creating specific latency and bandwidth issues in solving real-time problems.

Cisco introduced Fog computing in 2012 to address the massive issues IoT applications face in a conventional cloud computing framework (Bonomi et al., 2012). Because of the centralized nature of cloud platforms, problems like network congestion, high latency, bandwidth issues, storage, and processing of every bit of data become a significant challenge. Fog computing is not a substitute for cloud computing but an expansion. It acts as a distributed computing model that extends cloud services to the network's edge, allowing billions of devices to be served (Bala and Chishti, 2019; Mouradian et al., 2018).

The smart things, including sensors and actuators, gathers data from the surroundings and send the data to gateways. The gateway aggregates the data transmitted by heterogeneous devices using various communication protocols and further sends it to fog or cloud data centers for high-end processing (Sethi and Sarangi, 2017, 2017.). Thus, a gateway is a decisive part of the Internet of things. It can act as a protocol converter and build a network domain with high performance, reliability energy consumption, and low response time. The placement of the gateway in the IoT architecture is depicted in Fig. 1.

As per IoT architecture, a gateway is a device that acts as a connection point between smart IoT devices and their applications. It's an essential aspect of an IoT system because most IoT devices can't connect with the cloud directly as they rely on near-range technology (MATSUO, 1971).

1.1. Motivation

An ample amount of research has been done in the field of IoT (Gubbi et al., 2013; Ray, 2018; Al-Fuqaha et al., 2015), cloud computing (Ray, 2016; Nazari Jahantigh et al., 2020; Cavalcante et al., 2016), fog computing (Yousefpour et al., 2019; Singh et al., 2019), edge computing (Ai et al., 2018)and is still in the emerging phase. But while investigating gateway, it has been observed that there is no systematic literature review that can elaborate the working and functionalities of IoT gateway in general. However, an effort is made by (Yan et al., 2020)in the field of smart gateway for smart homes. The motive of this systematic study is to provide a complete analysis and comprehensive abridgment of the already implemented work related to this field of study. This paper supplies a method based on the SLR approach and provides a well-defined process to extract and analyze the results to build a lucid background about the IoT gateways. The scope of this work is to consider research publications from the year 2011 till July 2021 related to IoT gateway. With this goal, all the tools, platforms, validation techniques applied on gateway for improving Quality of Service (QoS) are highlighted in this systematic review, along with numerous application fields in which they have been applied.

1.2. Contribution

The contribution of this work includes:

- A systematic literature review on IoT gateway.
- State-of-art tools/platforms and their contribution to IoT gateway.
- State-of-art evaluation techniques used for IoT gateway.
- Classification of the functional requirement of IoT gateway.
- Analysis of several parameters used to provide QoS in IoT gateway.
- Identification of existing issues and research gaps in the field of IoT gateway.

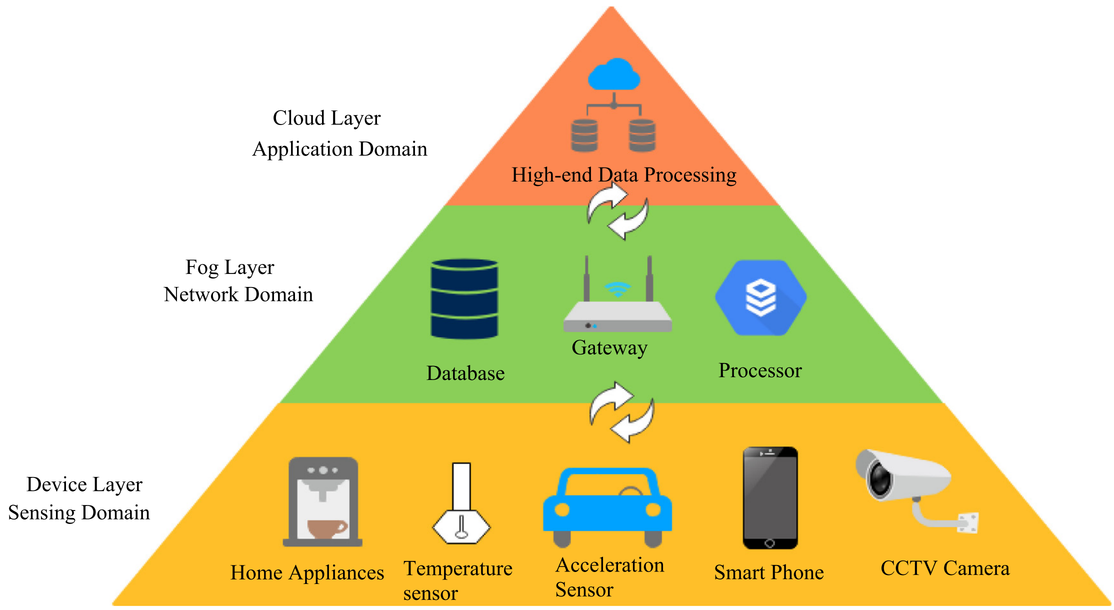

Fig. 1. Placement of Gateway in IoT architecture.

- The future research avenues in the field of IoT gateway to focus on autonomous IoT systems.

After the introduction section, the paper's complete flow is as follows: Background information and the main concept of IoT gateway are discussed in section 2. Review Technique is provided in section 3, describing the selection criteria and exclusion procedure of related work along with the formation of research questions. The selected research work accompanied by approaches and tools/platforms is presented in section 4, followed by discussions on the research questions and their analysis in section 5. Finally, the conclusion is presented in section 6.

2. Background information and concept of IOT gateways

Gateway in the Internet of Things arena acts as an intermediary between numerous sensing networks and cloud platforms or data centers connected through the Internet. Its goal is to control heterogeneity created by different devices which collect vast amounts of data in other formats and forward this collected data to a higher platform. For proper functioning and management of IoT systems, the gathered data should be cleaned, preprocessed, and filtered before sending to data centers based on required applications.

Gateway is of two types, i.e., Basic Gateway and Smart Gateway. Basic Gateway acts as a proxy between low-end IoT devices and data centers by forwarding the incoming data. In contrast, a smart gateway handles data efficiently by preprocessing, filtering, analyzing the data, and delivering only the related or necessary data to the cloud platform. These intermediate devices are designed to handle harsh environmental conditions and recover from failure while solving the communication gap in minimal time. Gateway is hardware and software-related device, and this study mainly focuses on the software part. It consists of a small operating system that helps manage the nodes, preprocessing and storing them (Bansal and Kumar, 2020). Furthermore, the gateway should allow a small backup to resolve the network failure problem, save the current system status, run it in nesting mode to recover, and run from the same failure point without losing data (Zhu et al., 2010; Kang, 2018). Gateways can communicate via multiple communication technologies like Wi-Fi, Bluetooth, Zigbee, Ethernet, etc., to gather information and transmits data to the cloud via protocols like Message Queuing Telemetry Transport (MQTT), Constrained Application Protocol (CoAP), Advanced Message Queuing Protocol (AMQP), Extensible Messaging and Presence Protocol (XMPP), Representational State Transfer (REST), etc.

A smart gateway can be divided into three categories based on functionalities (Bansal and Kumar, 2020), as shown in Fig. 2.

- Passive Gateway
- Semi-automated Gateway
- Fully automated Gateway

In some applications, gateways are designed to act smart by discovering the IoT device, registering them to the network, or removing the device for better performance. When these functionalities are performed manually, it is known as a passive gateway. The users provide permissions to add a new device or remove the existing ones. However, these gateways are not customizable and flexible (Zhu et al., 2010; Mueller et al., 2007; Emara et al., 2009; Yoon et al., 2009; Bimschas et al., 2010).

A semi-automated gateway maintains a link between the newly added devices and creates a connection through an interface. These types of gateway support pluggable configuration architecture, which means they can be plugged in based on the requirement of the network device. These gateways are more flexible than a passive gateway and perform better in real-time applications (Min et al., 2012; Guoqiang et al., 2013; Wu et al., 2013; Xu et al., 2015; Chang et al., 2015).

Self- configurable and self-manageable devices are known as fully- automated smart gateway (Kang et al., 2017; Ramirez et al., 2020; González Ramírez et al., 2021). There is no human intervention, and the device can be added or deleted from the network automatically. These gateways can efficiently operate in a heterogeneous network. They can communicate with different protocols like Bluetooth, ZigBee, Ethernet, etc., and interface like Wi-Fi, MQTT, CoAP (Carpio et al., 2019), etc., with the advancement in technology. Every application related to IoT needs a fully automated gateway to provide a quality experience and better

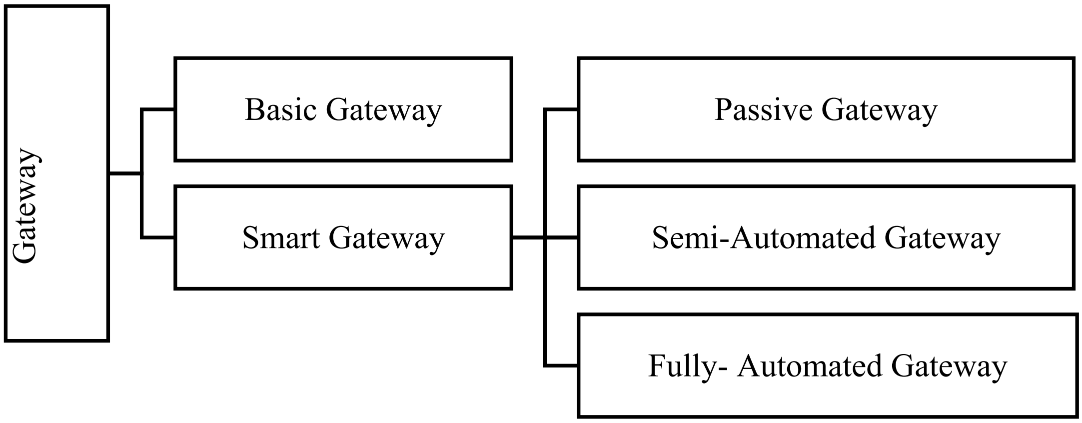

Fig. 2. Types of the gateway in IoT.

performance. Work has been done in this field but is still in the growing phase, and researchers can focus on making gateways smart enough to give users better performance and Quality of Service (QoS).

Different quality parameters for gateway includes (White and Nallur, 2017; Singh et al., 2020; Filho et al., 2019):

- Reliability: Capability of a gateway to complete the required task in a defined amount of time in a specified condition.
- Latency: Time taken to transfer the data from one point to another across the network.
- Throughput: The amount of data transfer per unit time.
- Network bandwidth: It defines the max signal rate required to send the data.
- Execution Time: Time taken for the entire execution of a program.
- Cost: It encompasses computation cost, storage cost and communication cost in a defined interval of time.
- Energy consumption: Energy consumed to execute the specified task.
- Response time: The amount of time taken in between the user's request and its response, it depends on the gateway's operating speed.
- Security: Protection of system by unauthorized access and users.
- Scalability: Capability of gateway to perform well with the increasing number of connected devices or applications of the resources.

3. Review technique

This section provides a systematic study of characteristics, functionality, and classification of IoT gateway. The SLR methodology (Sitender et al., 2021) is presented in Fig. 3.

4. Research questions

As this study aims to provide a survey on the gateway in the Internet of Things (IoT), five research questions are framed to cover the related concepts and challenges. The purpose is to find the answer to these questions through this study:

RQ1: What are the research trends related to gateways in IoT?

RQ1.1. How are publications related to gateways in IoT spread over the years?

RQ1.2. How are publications in journals on gateways in IoT distributed over the years?

RQ1.3. Who are the prominent contributing authors in the field of IoT gateways?

RQ1.4. What tools/platforms are used for the evaluation of IoT gateways?

RQ1.5. Which type of evaluation technique is applied in IoT gateways?

RQ2: Which type of gateway has attracted more attention in the field of IoT?

RQ3: How can gateways be classified based on functional requirements?

RQ4: Which evaluation parameters are considered for QoS provisioning in IoT gateways?

RQ5: What are the existing challenges and open issues of research in IoT gateways?

RQ6: What are the prospective future directions for research in IoT gateways?

4.1. Search for relevant studies

The searching procedure involves finding the related papers from well-known databases and selecting the appropriate ones. First, a search string based on keywords is made and then the articles are downloaded from IEEE, ACM, Springer, Science Direct, Scopus, Sage, Taylor & Frances and Wiley databases.

The selection procedure consists of three phases: automated search of papers from online scientific databases based on keywords, selecting the relevant papers according to the article's title, abstract, conclusion and finally shortlisting the papers based on full-text.

4.1.1. First phase

The process of selecting the paper is done by forming a search string: "IoT" AND ("Smart" OR "Intelligent" OR "Adaptable" Or

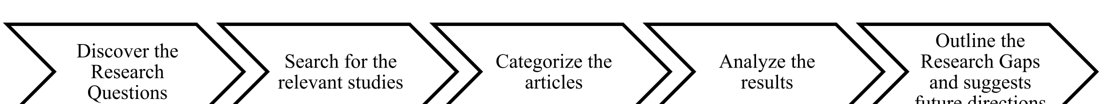

Fig. 3. SLR methodology.

"Autonomous") AND "Gateway"; automated searching was done among the genuine databases based on the search string. Online scientific databases are mentioned in Table 1.

4.1.2. Second phase

Out of 2347 papers downloaded in the first phase, 280 research articles were selected in the second phase based on the title, abstract and conclusion. Inclusion and exclusion criteria are mentioned in Table 2.

After removing the redundant papers and papers that satisfied the exclusion criteria, 67 papers were selected. IEEE has a major share of 55%, followed by Science Direct, having an 18% share. The details of the percentage share of each database are shown in Fig. 4.

4.1.3. Third phase

After investigating and probing the papers selected in the second phase, this phase considers only the most relevant studies in the related field based on full-text selection criteria. Out of 280 papers, only 67 papers were finally selected for the comprehensive study. The complete workflow of the selection process of all the relevant papers used for the study of IoT gateways is depicted in Fig. 5.

4.1.4. Primary and secondary studies

Research in the IoT field is primarily application-based. Work in this area is related to the specific application. The selected articles were segregate between primary and secondary categories. Most of the studies fell under primary ones. Out of 67 studies, 61 were application-specific and their contribution was significant. In contrast, only 6 studies were found to be an extension of the author's previous works. Therefore, the studies (Ramirez et al., 2020; Rahmani, 2015; Aloi, et al., 2016; Al-Osta et al., 2017; De et al., 2017)were the primary studies whose work was extended in the studies (González Ramírez et al., 2021; Filho et al., 2019; De et al., 2017; Moosavi et al., 2015; Aloi et al., 2017; Rahmani et al., 2018). Hence, considered as secondary studies for this SLR.

5. Literature analysis

According to the selection criteria of inclusion and exclusion, 67 papers were selected for analysis. Proposed algorithm or architecture with applied tools and techniques, their evaluation type and the application domain are mentioned here and described in brief in Table V of the appendix for reference. Even though the research work in IoT gateway is exceptionally diverse, all major research focused on gateways' working and functionality in different applications has been covered.

Based on the available literature (Razzaque et al., 2016), gateways have mainly been categorized depending on their requirements, as Functional, Non-Functional, and Architectural requirements. The complete taxonomy is presented in Fig. 6. Functional requirements are further divided into data management, resource management, QoS management, device management, security management, and protocol translation. It deals with requirements like how to handle and store and analyze data, which resource should be allocated to which node based on scheduling or prioritization techniques, on what basis, or how a device should be registered or configured and connected to the network, or how to manage the security and privacy of data being transferred into the network and many more. Non-functional requirements include the basic necessity of the gateway to handle difficulties faced while working with a vast number of IoT devices. These need to address issues like how a gateway can be scalable, reliable and mobile or deal heterogeneous data received through various communication protocols or how it can be energy efficient and can be used in latency-driven applications. Architectural requirements are specific to end-user applications where gateways can be used for autonomous applications, adaptable environments, or as a semantic gateway, interoperable, smart gateway, or intelligent gateway. Based on the types of smart gateway, the literature review work is divided into passive, semi-automated and fully automated gateways in the following subsections.

Table 1
Online digital library databases referred for the study.

S. No	Database	URL
1	ACM	https://dl.acm.org/
2	IEEE	https://ieeexplore.ieee.org/
3	Science Direct	https://www.sciencedirect.com/
4	Taylor & Francis	https://www.tandfonline.com/
5	Sage	https://journals.sagepub.com
6	Wiley	https://onlinelibrary.wiley.com/
7	Springer	https://www.springer.com/

Table 2
Criteria for inclusion and exclusion of research papers.

Criteria	Details
Inclusion	• Articles that proposed or implemented any technique using IoT gateway. • Articles focusing on the software implementation of smart gateways in IoT. • Articles related to IoT gateways, which are available online in the time range starting from 2011 till July 2021.
Exclusion	• Articles not focusing explicitly on the implementation of IoT gateway. • Articles proposing any technique related to the hardware of IoT gateways. • Articles not in the context of smart gateways in IoT. • Articles discussing only on the deployment of IoT gateways. • Editorials or short papers, Book Chapters or Books, Non– English papers, Non-peer-reviewed papers

5.1. Passive Gateway

An Android-based smartphone was used to propose a dynamic and intelligent gateway (Bian et al., 2011). It could predict the end-user behavior and act accordingly by switching the device ON and OFF subsequently, reducing the IoT system's energy consumption and total cost. A heterogeneous IoT gateway was introduced in (Min et al., 2014), with dynamic priority scheduling to improve the performance and overcome the data concurrency problem. The proposed gateway was responsible for data transmission and protocol conversion among GSM, Bluetooth, Zigbee, RS485 and CAN protocols. An IoT architecture was presented in the healthcare domain in (Chang et al., 2015). It consisted of a resilient and energy-efficient gateway designed to gather data from wired and wireless IoT sensors to monitor the patients remotely. Smart gateway was implemented in (Rahmani, 2015), UT-GATE middleware was used to provide features like embedded mining, protocol translation, local data repository and standardization, along with tunneling and firewall services.

A semantic IoT architecture was proposed in (Tilkov, 2015), named Semantic Gateway as a Service (SGS). Gateway was placed between sensor and cloud layer for protocol translation among MQTT, CoAP, and XMPP through multi-protocol proxy architecture. An architecture for security management in IoT was proposed in (Moosavi et al., 2015), using smart e-health gateway in the healthcare domain and privacy of a patient's medical history was the primary concern. Protocol fragmentation was focused in (Al-Fuqaha et al., 2015), aiming to provide a specific protocol for a particular application. A rule-based intelligent gateway was proposed to

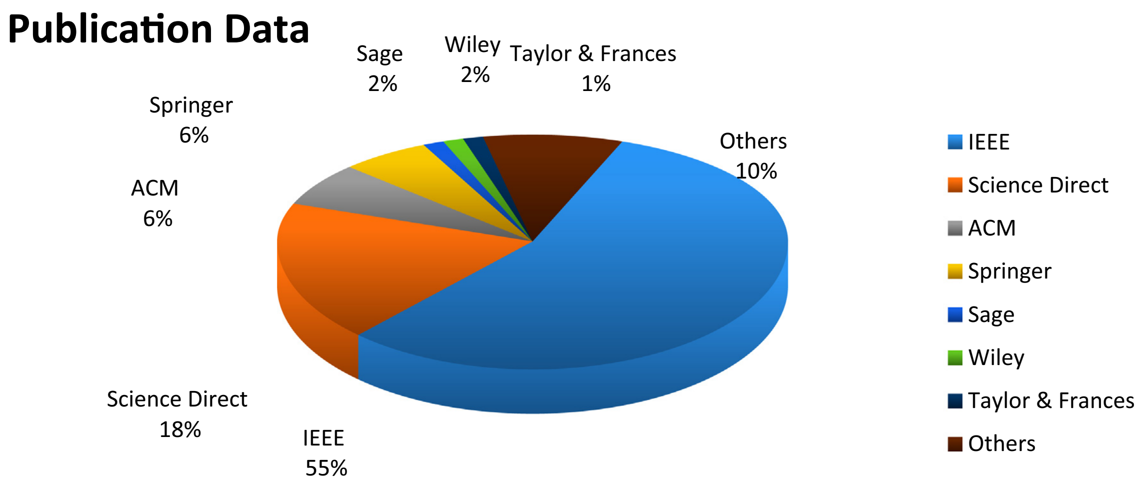

Fig. 4. Publication data gathered from different online databases.

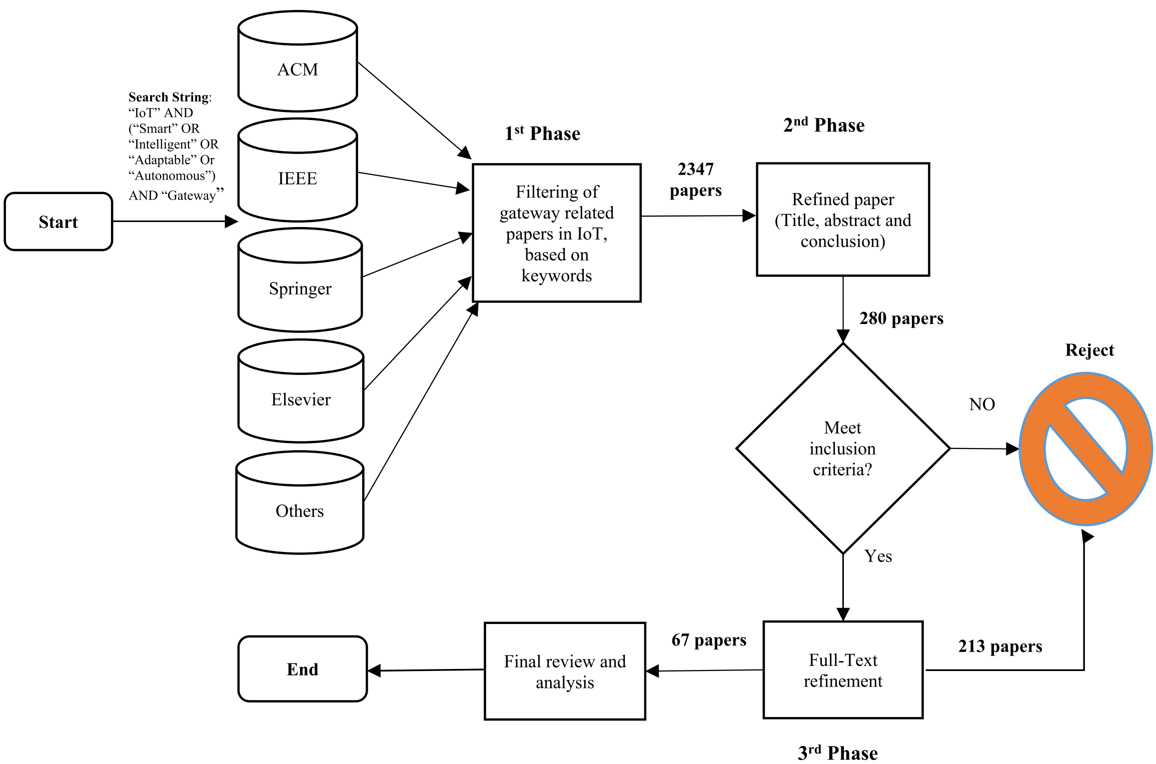

Fig. 5. Selection Process workflow.

support a proposed generic protocol. Modified MQTT protocol was developed with the combined benefits of IP multicast, intelligent broker queue management, and traffic analysis techniques. IoT Gateway Problem: "Every new device to connect needs a new application" was considered in (Zachariah et al., 2015). A general-purpose gateway was proposed using a smartphone so that every device which communicated through Bluetooth Low Energy (BLE) would be connected through the Internet. An interconnection model named WiSEGATE was proposed in (Serdaroglu and Baydere, 2016)for seamless communication between IP and WSN. Integrated Access Gateway Architecture (IAGW) was proposed in (Ding et al., 2016)to provide a standard interface for various smart home applications. Design and implementation of the heterogeneous multi-interface gateway were presented in (Bai et al., 2016)through information exchange between a Christmas tree and a Facebook account user. The Christmas tree transmitted the data to the gateway, which accessed the Facebook account and demonstrated the activity on the Christmas tree. An adaptable data model was used to design a gateway for smart digital emergency evacuation systems (Karagiannidis et al., 2016). Data-centric Publish-Subscribe (DDS) model at the gateway was used to notify people with updated and accessible information. Adaptive gateway was proposed in (Abdelaal et al., 2019)to retrieve sensor data from power-constrained devices. Bluetooth Low-Energy (BLE) radios were used for connecting nearby IoT devices and priority-based scheduling was used for efficient data retrieval. The architecture of the gateway was proposed for the cloud in (Petrolo et al., 2017). The virtualization technique combined with

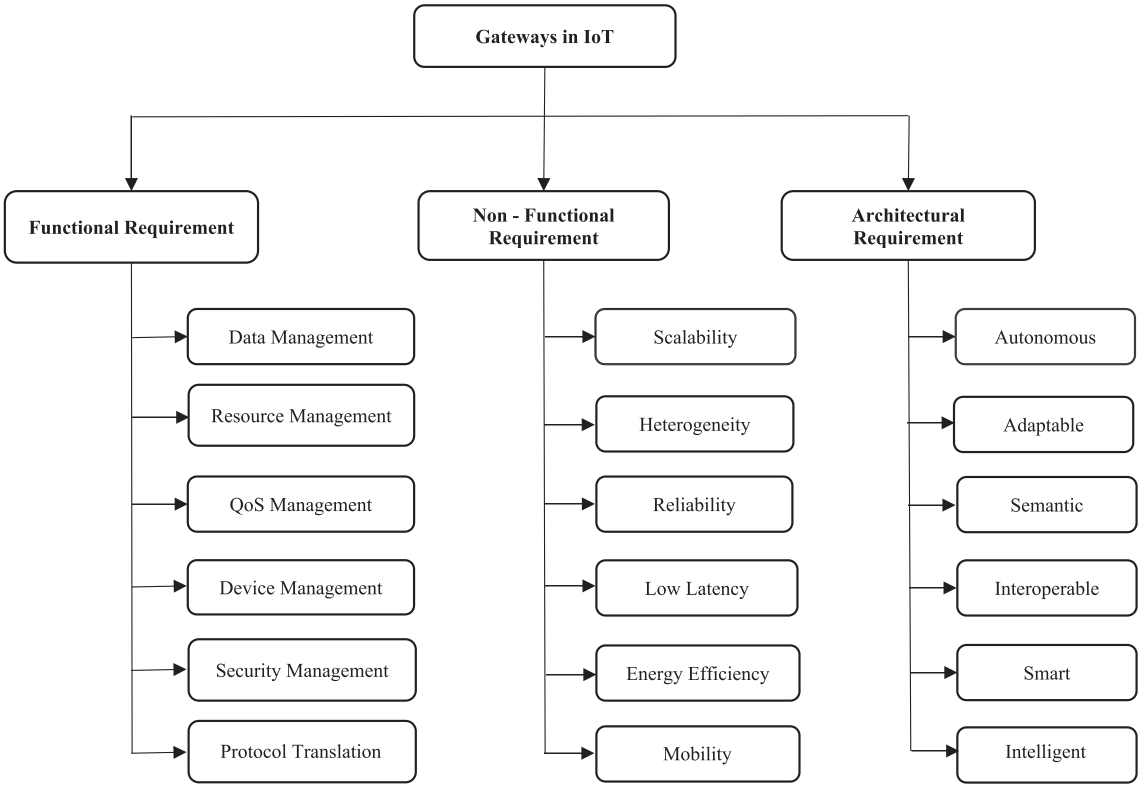

Fig. 6. Classification based on requirements of gateways in IoT.

gateway resulted in the lightweight and dense deployment of services at the cloud platform. Docker containers were used for virtualization.

Gateway for Technical and Syntactical Interoperability (GW-TSI) was designed and implemented in (Yacchirema et al., 2017)for storing, transforming, preprocessing and delivering the data in IoT systems. The problem of underutilization of resources at the gateway while offloading the data was focused on (Samie et al., 2017). The method of computation offloading was explained at three levels: raw data transmission, partial processing of data, and full processing of data. Enhanced MQTT protocol for smart gateway was proposed in (Ameer and Hasan, 2020). The gateway for data aggregation, DA-GW, was proposed in (Cha et al., 2016)for group communication using the CoAP protocol. It used four functional blocks and three databases to store the related information. A reliable oneM2M IoT-based architecture was proposed in (Woo et al., 2018)for the healthcare domain. The Daisy Chain algorithm was used in layered architecture to support more than one gateway failure at a time. An edge-centric distributed architecture was proposed in (Tanganelli et al., 2018), where Distributed Hash Tables (DHT) were maintained at each gateway for efficient resource allocation and access to the services in multiple IoT applications. A practical implementation of the smart gateway in (Glória et al., 2017)was used for remote monitoring and access to the swimming pool. Data annotation of raw data was proposed in (Al-Osta et al., 2017)by using a lightweight semantic web approach. A smart home gateway-based architecture was proposed in (Guan et al., 2017)to monitor older people remotely. The proposed architecture has three primary submodules: smart clothes for data collection, the smart gateway for efficient data transmission and a healthcare server to process and store the elderly data. Semantic gateway architecture was proposed in (De et al., 2017), an intermediate between heterogeneous IoT devices and communication protocol. The proposed gateway could devise and register services using token management, authentication and seamless data transmission.

The bayesian inference approach was adopted in (Razafimandimby et al., 2017)to avoid unnecessary data in IoT systems. The belief propagation model was used to reconstruct the missing values of data gathered by IoT sensors while smart gateways were deployed to minimize the estimation error in the cloud. CoAP enabled a multithreaded hybrid IoT gateway proposed in (Ding et al., 2016)to provide quick remote access to the user. The authors extended the previous work (Al-Osta et al., 2017)and proposed a decentralized approach in (Al-Osta et al., 2019)for preprocessing the data using a smart gateway. A two-layered approach was followed for forwarding the necessary and valuable data to the cloud. The architecture of the smart gateway, along with communication protocol, was proposed in (Mastilak et al., 2018)for low-cost devices to communicate securely. The authors developed a distributed machine learning framework for the smart gateway in (Yu, 2018)for the smart grid domain. The short-term load was forecasted to allocate renewable energy at peak hours based on the occupant's smart building behavior. Micro-service-based Light Weight Edge Gateway (LEGIoT) in IoT systems was designed and implemented (Morabito et al., 2018). Optimal resource allocation along with energy efficiency, multi-tenancy and interoperability were resolved by the proposed architecture. IoT@HoMe's prototype was implemented in (Jabbar et al., 2019)with an algorithm for automation and monitoring the Smart Home environment. A distributed framework for optimized data retrieval and storage at the gateway was designed in (Javed et al., 2019). A consistent hashing mechanism was used along with micro-services provided by Docker containers for a scalable and flexible solution for accessing data efficiently. A novel packet structure was proposed in (Ray et al., 2019), along with the packet generation flow of data at the gateway. The DISMISS approach was used in the smart gateway to preprocess data, which involved noise reduction, imputed missing data, and filtered out irrelevant data (Balasubramanian and Meyyappan, 2019). A collaborative IoT gateway was introduced in (Ooi et al., 2019), which maintained a transparent connection between sensors and the cloud.

The Modified Hierarchical Token Bucket (HTB) algorithm was proposed in (De Caldas Filho et al., 2019)to prioritize messages in queues to reduce latency. The author proposed a smart gateway with fog capabilities in (Maiti et al., 2019). For processing the IoT traffic, virtual machines were used. Five different techniques were compared for an optimized selection of fog nodes, out of which simulated annealing performed best. A heuristic algorithm was proposed to schedule and allocate resources among gateways in (Sangaiah et al., 2020). Whale Optimization Algorithm (WOA) was modified in the cloud computing domain to estimate the minimum total cost and balance the load at gateway. A generic IoT monitoring and control gateway was presented in (Aloul et al., 2020)to provide edge security and control the IoT devices and appliances in the smart home. An architecture based on residents' context analytics and behavior pattern was proposed in (Chenaru and Popescu, 2020), along with a two-staged algorithm for comfort models in smart home applications. An IoT Gateway-as-a-Service (IGAAS) algorithm was proposed in (Aminul Hoque et al., 2020)for the on-demand provisioning of gateways in IoT systems. The incentive for device providers, including smartphones and drones, were calculated for both stationary and mobile gateways. Gateway system was designed in (Du et al., 2021)to monitor breeding environment using Bluetooth Low Energy (BLE). Priority queue, cache queue and feedback mechanism was adopted for efficient processing of task. Edge computing architecture was proposed in (Wu et al., 2021)consisted of hybrid routers and IoT gateways. The software architecture of the gateway was designed to support advanced tasks in edge computing with multiple protocols.

Relinquish probability was proposed for resource estimation in (Aazam and Huh, 2015). The proposed technique was implemented with the help of a fog smart gateway. It was used to determine the percentage of resource utilization efficiency and avoid resource wastage. A low-cost health monitoring system was proposed in (Nguyen Gia, et al., 2017)to provide continuous monitoring of electrocardiogram (ECG) reading with automatic analysis and notification alert system. Security middleware acting as the smart gateway was proposed in (Razouk et al., 2017)with CoAP and REST for a lightweight framework. A combined framework to provide an automatic selection of suitable execution locations for tasks processing in fog or cloud was addressed in (Happ and Wolisz, 2017). Multi-technology service architecture based on fog computing integrated with Smart Gateway Service (SGS) was proposed in (Le et al., 2019). Load balancing scheme based on smart gateways was described in (Sarma et al., 2019). Four different situations were considered and compared for evaluation of the proposed technique.

5.2. Semi-Automated Gateway

The smart gateway framework was proposed in (Wang et al., 2018)with Multi-dimensional Awareness (MDA) lightweight plug-in for data collection and awareness in smart homes. The framework had three layers. The data trimming problem was solved in (Aazam and Huh, 2014)by using the concept of a smart gateway at the fog layer for smart communication. The proposed concept was validated using testbeds and tested on various QoS parameters by considering two types of data: the multimedia data included the audio and video format files, and the bulk- data considered all the heterogeneous files of different formats, sizes, and types. The smart home IoT gateway architecture was proposed in (Kim et al., 2015)to satisfy the needs and requirements of the end-user. The proposed gateway discovered the device on the network and gathered the data from IoT devices after its registration and configuration. Collected data was then transmitted to the cloud via lightweight MQTT protocol for appropriate service. IoT-based mobile gateway was proposed in (Santos et al., 2016)to work with AMBRO, an Intelligent Personal Assistant (IPA), to provide autonomous, interoperable, and heterogeneous connectivity to various IoT devices during remote monitoring of a patient. A smartphone-based IoT gateway was proposed to provide a universal interface to the devices in (Aloi, et al., 2016). Gateway's multi-interface and multi-technology framework could dynamically discover the device and manage it along with data collection and processing before forwarding it to the cloud. The authors extended the work of (Aloi, et al., 2016)in (Aloi et al., 2017), which includes opportunistic mobile gateway as a universal interface with enhanced architecture, detailed working and efficient results. A smart e-Health gateway was presented in (Rahmani et al., 2018)for healthcare applications. The geo-distributed intermediary layer was proposed to provide intelligence at the gateway for local preprocessing, data storage, standardization, security, and real-time alert notification service to the user. A layered framework was proposed for monitoring the health of remote patients using the concept of fog computing in the smart home domain (Verma and Sood, 2018). Based on collected data, mining and analysis were performed at the smart gateway. Bayesian Belief Network (BBN) classifier was proposed to classify the state of patients as safe or unsafe. Temporal Health Index (THI) was used to calculate the urgency of the situation. The framework for scalable, comprehensive, plug-and-play gateway was proposed in (Kesavan and Kalambettu, 2018)for seamless communication.

A variety of health sensors were connected to the proposed gateway and transmitted data to the cloud efficiently for storage, analysis and prediction of data for the future. Multi-tasking IoT gateway (IoTGW) was proposed in (Diyan et al., 2020)to preprocess and classify heterogeneous data gathered from IoT devices and smart appliances. A hybrid AdaBoost multi-layer perceptron (AMPL) mechanism was adopted for classification. In addition, a data loading and storing module (DLSM) was introduced to efficiently store and preprocess the data and further share the data with end-user through IoTGW application services. A multi-protocol home automation system was presented in (Chaudhary et al., 2021)for remote health monitoring of elderly people. Fall detection algorithms based on two methods: threshold-based and neural network-based, were compared and prosed a Beehealth model for monitoring the health of remote patients. 5GEE architectural model, based on use-case for quality constrained container-based virtualization integrated with IoT gateways, was proposed in (Bellavista et al., 2017).

5.3. Fully automated Gateway

A Fully automatic Gateway was proposed in (Kang et al., 2017)for dynamic device discovery, automatic updates, and managing the connections with smart IoT devices. Alljoyn platform was used to connect non-IP devices and validate the architecture along with the CoAP protocol for message transmission. A self-configurable and reliable IoT gateway was implemented in (Kang, 2018)to provide dynamic device registration and configuration in the home automation domain. Furthermore, a fully - automated IoT gateway was proposed by using IoTivity testbeds. The author presented an adaptive algorithm for dynamic resource allocation to the "things" in (Ramirez et al., 2020), which are automatically discovered by the gateway in a network. Protocol named Function and Service Discovery Protocol (DFSP) was used to announce all the new devices connected to the network, and the MQTT protocol was used over TCP/IP for messages exchange. With machine learning techniques, artificial intelligence was used to collect information and learn according to the device's habit and services to make gateway self-manageable and configurable, which was used for discovering and allocating resources dynamically in the real world. In addition, the MQTT protocol was modified to send messages which consumed less bandwidth and improved QoS. The extended version of (Ramirez et al., 2020)was presented in (González Ramírez et al., 2021). The network group model was proposed to create a group of IoT devices to provide services to the user based on data analytics using AI and Machine learning. AGILE multi-container using microservices architecture was proposed in (Dolui and Kiraly, 2018)for optimization of IoT gateway.

6. Discussion and analysis

This section depicts statistical information pictorially for detailed analysis and discussion on different parameters to answer the research questions.

6.1. RQ1: What are the research trends related to gateways in IoT?

The answer to this research question provides research trends related to IoT gateways. Publication trends of the articles highlight the growth of research in the field of IoT gateways. Popular journals have been identified which have published significant studies in this area. The top 10 contributing authors are listed. A comprehensive list of the tools and platforms required to implement and evaluate the work in IoT gateways is presented. The type of evolution technique is also discussed to identify the most adopted evaluation method, including simulation tool, prototype, or real-testbeds.

6.1.1. RQ1.1. How are publications related to gateways in IoT spread over the years?

The yearly rate of publication growth in the IoT field related to smart gateways is shown in Fig. 7. As apparently visible, research on smart gateways picked up pace from 2015 onwards, and still, there is a space for more smart/intelligent gateway in the field of IoT for autonomous systems. The concept of using gateways for communication is not new, but the gateways in IoT were introduced and explored more after 2011. The selected papers focused more on the gateway present in the Fog computing layer to analyze and get a clear picture of the domain to work on to support real-time latency-driven applications. Earlier only one or two functionalities of the gateway were considered to make it smart, but now combined functionalities are believed to work on. The publication growth rate in IoT gateways can be helpful to future academicians to analyze the research trend and can accordingly focus on their research in the future.

6.1.2. RQ1.2. How are publications in journals on gateways in IoT distributed over the years?

According to the reviewed literature, most of the work is published in reputed journals from IEEE, ACM, Elsevier, Sage, Springer, Hindawi and MDPI. Around 52% of the published work came from conferences, workshops, and magazines, whereas 48% came from reputed journals. The popular journals identified in the field of IoT gateways are listed in Table 3, according to which Internet of Things Journal and Future Generation Computer Systems are among the top journals from renowned publishers. The researcher can identify popular journals for the latest research updates, form a research group and can communicate submissions accordingly. An efficient search can be done by searching pertinent topics from the reputed journal other than searching in renowned databases.

6.1.3. RQ1.3. Who are the prominent contributing authors in the field of IoT gateways?

Amir Masoud Rahmani published six research articles from the selected ones, followed by his team Tuang Nguyen Gia, Pasi Liljeberg, Hannu Tenhunen, and Jose Granados, who published five papers, respectively. Byungseok Kang, Hyunseung Choo, Francisco L. de Caldas Filho, Pedro Luis González Ramírez, Roberto Morabito are among top 10 contributing authors with most of the citations. Academicians can subscribe and follow these most-cited authors to get detailed studies and the latest update related to the smart gateway in IoT. Many other authors contributed to the relevant studies, which can be referred to from Table V in the appendix. Book chapters, short papers and other language papers were excluded from the selected papers; else, more counts could have been seen.

6.1.4. RQ1.4. What tools/platforms are used for the evaluation of IoT gateways?

The tools and platforms used for research in IoT gateways are shown in Fig. 8 to give an idea to the researchers for future work. MATLAB, Cisco Packet Tracer, OMNET++, Cooja are some of the simulation tools used to implement IoT gateways.

Raspberry Pi and Arduino are the most extensively used real testbeds along with other microcontrollers and platforms. Around 20% of work was implemented and evaluated using Raspberry Pi.

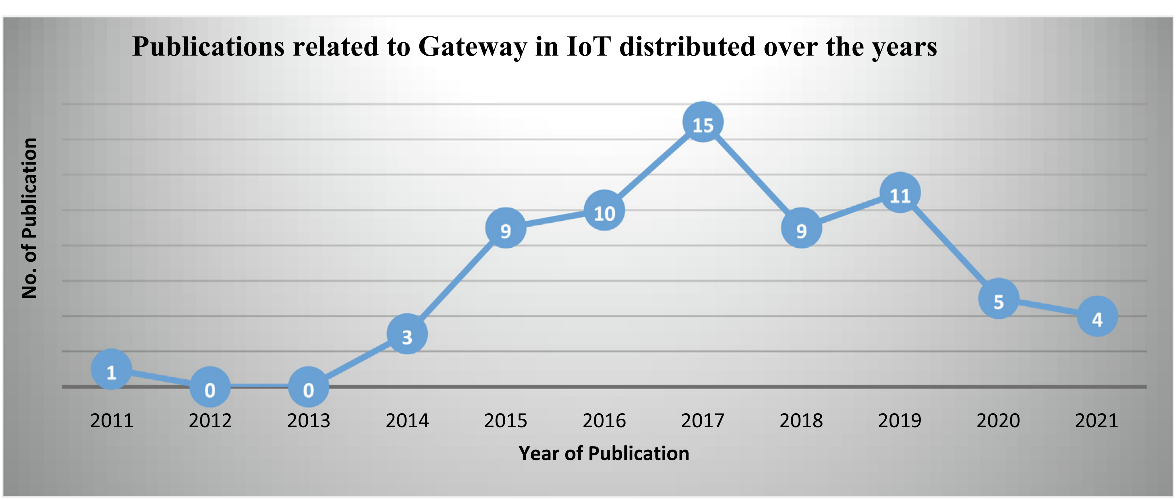

Fig. 7. Rate of publication over the years.

Table 3
List of popular journals.

Publisher	Name of the Journal	Count of Publication Per Journal
IEEE	Internet of Things Journal	5
Elsevier	Future Generation Computer Systems	4
Elsevier	Journal of Network and Computer Applications	3
Elsevier	Procedia Computer Science	2
IEEE	IEEE Access	2
Sage	Transaction of Institute of Management and Control	1
IEEE	Transactions on Consumer Electronics, IEEE transaction of Multi-Scale Computing Systems	1
MDPI	Sensor, Wireless Networks, Symmetry, Information	1
Springer	Journal of Ambient Intelligence and Humanized Computing, Annals of Telecommunication, Wireless Personal Communication	1
Hindawi	Journal of Sensors, Journal of Healthcare Engineering	1
Elsevier	ICT Express	1
Inderscience	International Journal of Ad Hoc and Ubiquitous Computing	1
ACM	ACM Transaction on Design Automation of Electrical Systems	1
University of Technology	Iraqi Journal of Computers, Communication, Control & Systems Engineering	1

Approximately 19% of work was implemented and evaluated using combinations of different microcontrollers like XBee daughterboard, Pandaboard, Zigduino, Smart RF06 board, DPWSim, Octopus X, MCU Node, Docker Containers, Weka tool, Jena, Orange Pi and Beagle boards. Around 17% using Arduino board, 17% other platforms including personalized platforms like IoTivity and case studies, 7% using smartphones, 5% using MATLAB simulator, 5% using self-made UT-GATE, 3% OMNET++ simulator, 3% Cisco Packet Tracer, 2% Cooja simulator and 2% AllJoyn platform. All the details are mentioned in Table V in the appendix for reference.

6.1.5. RQ1.5. Which type of evaluation technique is applied in IoT gateways?

According to the type of evaluation technique used in the reviewed work, 60% are implemented in real testbeds, 24% are prototyped, and only 16% are simulated. Since IoT is an application-based technology, various microcontrollers and circuit boards are used for real-time implementation. Further, researchers can weigh the pros and cons of each evaluation technique and identify the most appropriate one within specified constraints.

6.2. RQ2. Which type of gateway has attracted more attention in the field of IoT?

Passive gateways have a 75% contribution in research work compared to 18% semi-automated and only 7% Fully-automated gateways, as analyzed by Table V of the appendix. Since gateways are primarily based on IoT applications, specific functions were targeted, leading to the popularity and adoption of the passive gateway, which needs to be handled manually for configuring and registering any new device to the network. As the technology becomes more advanced, the current focus has shifted to fully automated gateways, which work without any human intervention. Therefore, the identified applications currently using passive or semi-automated gateways could be upgraded to use fully automated gateways.

6.3. RQ3: How can gateways be classified based on functional requirements?

Functional requirements provide the basic necessity of smart gateway in every field of application of IoT. The details of functional requirements are shown in Fig. 9. Functional requirements are categorized into data management, resource management, Quality of Service (QoS) management, device management, secu-

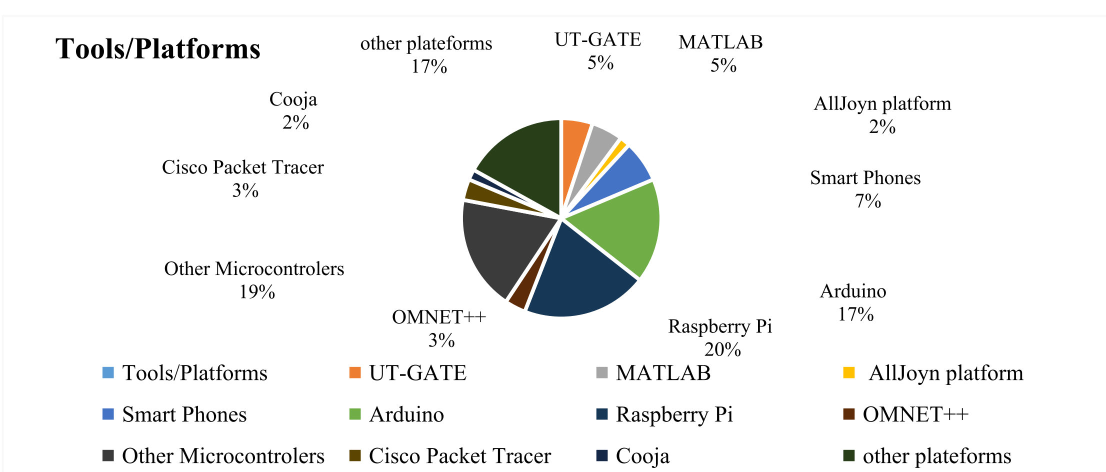

Fig. 8. Types of tools and platforms adopted for implementation and evaluation of proposed work.

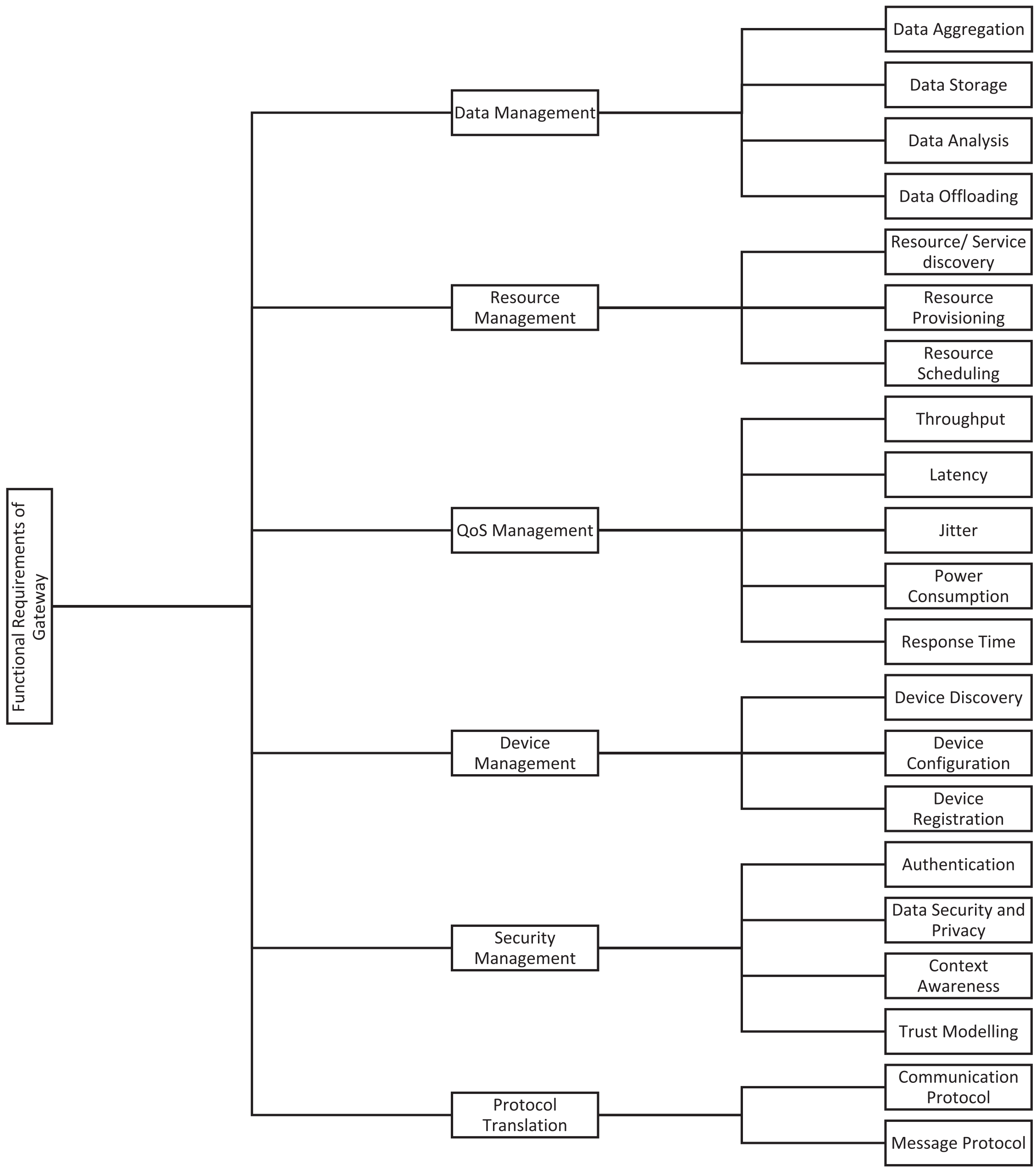

Fig. 9. Classification of functional requirements of IoT gateway.

rity management and protocol translation. These can be further bifurcated into categories that depict some of the major detailed functions performed by a smart gateway. Data Management (Sadri et al., 2021; Cha et al., 2016; Diyan et al., 2020; Fitzgerald et al., 2018; Lu et al., 2017; bin Baharudin et al., 2018; Alencar et al., 2020; Silva, 2021; Taneja et al., 2019)is further categorized into data aggregation, data storage, data analysis and data offloading. It deals with the management of collected data from various sensors and IoT devices. Databases are maintained for storing the pre-processed data. Gateways are also responsible for offloading the data after analyzing the complexity of the data. Data can be offloaded, fully or partially, for higher computation. Resource management (Ghobaei-Arani et al., 2020; Matrouk and Alatoun, 2021; Zahoor and Mir, 2021; Le Duc and Östberg, 2019; Chowdhury and Raut, 2018; Yang and Rahmani, 2021; Pourghebleh et al., 2020)is subdivided into resource discovery, resource provisioning, and resource scheduling. The prime responsibility of a gateway is to allocate the needed resources to the IoT nodes for processing. Resources are discovered and then allotted based on well-defined criteria or algorithms. Resource scheduling is a research domain that deals with scheduling tasks and assigning priorities to tackle latency-driven or important tasks. Quality of Service (QoS) management (White and Nallur, 2017; Ardagna et al., 2014; Simiscuka et al., 2017; Tanganelli and Vallati, 2018) is categorized into related parameters like throughput, latency, jitter, power consumption and response time. Managing the data, scheduling and allocating the resources wisely to the IoT nodes improve the QoS of the overall IoT system.

Similarly, Device Management (Henkel, 2018; Sahni et al., 2017; Kim et al., 2015)can be classified into device discovery, device configuration, and device registration. For any processing, devices need to be discovered on the same network before configuration and registration to manage the devices at the gateway. Smart gateways deal with passive, semi-automated and fully automated pro-

Table 4
Parameters considered to provide Quality of Service (QoS) at the gateway.

		QoS Parameters								
S. No	Ref.	Response time	Latency	Energy efficiency	Network Bandwidth	Security	Reliability	Cost	Execution Time	Scalability
1	(Bian et al., 2011)			✓						
2	(Aazam and Huh, 2014)		✓							
3	(Min et al., 2014)					✓	✓			
4	(Granados et al., 2014)			✓						✓
5	(Gia et al., 2015)	✓	✓		✓				✓	
6	(Rahmani, 2015)						✓		✓	✓
7	(Tilkov, 2015)							✓		
8	(Moosavi et al., 2015)		✓			✓	✓			
9	(Al-Fuqaha et al., 2015)		✓				✓		✓	
10	(Zachariah et al., 2015)									✓
11	(Kim et al., 2015)	✓		✓				✓		
12	(Serdaroglu and Baydere, 2016)					✓				✓
13	(Aazam and Huh, 2015)					✓			✓	✓
14	(Santos et al., 2016)			✓			✓			
15	(Ding et al., 2016)									✓
16	(Aloi, et al., 2016)			✓						
17	(Aloi et al., 2017)			✓			✓			
18	(Bai et al., 2016)			✓	✓					
19	(Karagiannidis et al., 2016)	✓	✓		✓		✓		✓	✓
20	(Abdelaal et al., 2019)		✓		✓			✓		
21	(Petrolo et al., 2017)			✓			✓			
22	(Yacchirema et al., 2017)			✓						
23	(Samie et al., 2017)			✓	✓					
24	(Ameer and Hasan, 2020)	✓	✓	✓					✓	
25	(Cha et al., 2016)	✓		✓					✓	✓
26	(Rahmani et al., 2018)			✓		✓	✓			
27	(Woo et al., 2018)						✓			
28	(Kang et al., 2017)		✓	✓						✓
29	(Tanganelli et al., 2018)		✓							✓
30	(Glória et al., 2017)			✓						
31	(Al-Osta et al., 2017)		✓		✓					✓
32	(Guan et al., 2017)				✓			✓		✓
33	(Kang, 2018)						✓			✓
34	(De et al., 2017)			✓						
35	(Razafimandimby et al., 2017)			✓			✓	✓		
36	(Nguyen Gia, et al., 2017)	✓		✓						
37	(Razouk et al., 2017)					✓				
38	(Bellavista et al., 2017)		✓					✓		
39	(Happ and Wolisz, 2017)		✓						✓	
40	(Verma and Sood, 2018)	✓	✓				✓		✓	
41	(Banaie et al., 2019)		✓	✓			✓			
42	(Al-Osta et al., 2019)		✓					✓		
43	(Wang et al., 2018)						✓			✓
44	(Mastilak et al., 2018)			✓			✓			
45	(Kesavan and Kalambettu, 2018)						✓			✓
46	(Dolui and Kiraly, 2018)		✓			✓				
47	(Yu, 2018)			✓						
48	(Morabito et al., 2018)			✓	✓		✓			
49	(Jabbar et al., 2019)			✓			✓			
50	(Javed et al., 2019)	✓					✓			✓
51	(Ray et al., 2019)			✓	✓					
52	(Ramirez et al., 2020)		✓	✓	✓		✓			✓
53	(Balasubramanian and Meyyappan, 2019)		✓	✓	✓		✓		✓	✓
54	(Ooi et al., 2019)		✓	✓						
55	(De Caldas Filho et al., 2019)	✓					✓			
56	(Maiti et al., 2019)		✓						✓	
57	(Le et al., 2019)	✓						✓		
58	(Sarma et al., 2019)	✓	✓						✓	
59	(Diyan et al., 2020)		✓	✓						
60	(Sangaiah et al., 2020)			✓				✓		
61	(Aloul et al., 2020)			✓		✓				
62	(González Ramírez et al., 2021)		✓	✓	✓	✓	✓		✓	✓
63	(Chenaru and Popescu, 2020)			✓			✓			
64	(Aminul Hoque et al., 2020)		✓	✓				✓		
65	(Du et al., 2021)			✓			✓			
66	(Wu et al., 2021)		✓							
67	(Chaudhary et al., 2021)			✓				✓		

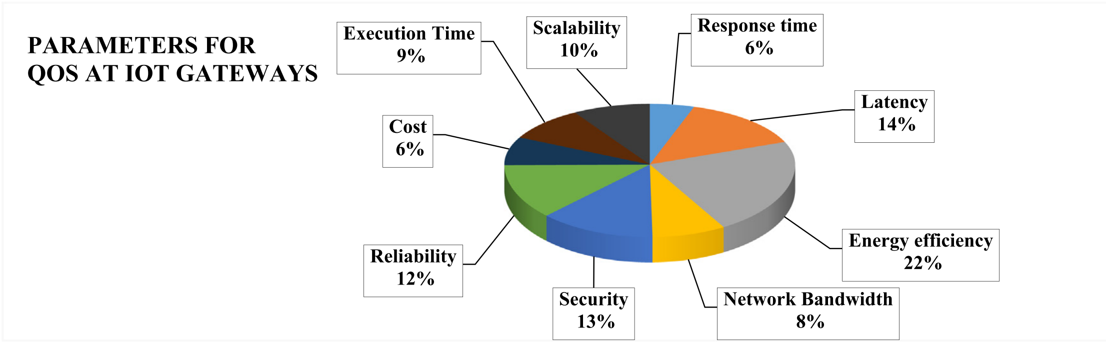

Fig. 10. Parameters for QoS at IoT gateways.

cesses of device management. Security Management (Jabbar et al., 2019; Seliem et al., 2016; Lin et al., 2017; Alwarafy et al., 2021; Hassija et al., 2019; El-Hajj et al., 2019; Gharaibeh et al., 2017; Ding et al., 2019)is bifurcated into authentication, data security and privacy, context awareness, and trust modelling from security aspects. Gateways act as an entry point to the network, most vulnerable to threats or attacks through malicious activities. Different traditional algorithms combined with machine learning and deep learning techniques can be used to provide security to the data and the gateway. Protocol Translation (Sethi and Sarangi, 2017, 2017.; Al-Fuqaha et al., 2015; Carpio et al., 2019; Souri et al., 2019; Masek et al., 2016; Glaroudis et al., 2020) can also be further sub-divided into two major categories, including communication protocol and message protocols. Wi-Fi, Bluetooth, Ethernet, ZigBee, Low-Power Wireless Personal Area Networks (LoWPAN), etc., are some of the communication protocols used in IoT to communicate with other IoT devices. Protocols including MQTT, CoAP, XMPP, AMQP, REST, etc., are well-known protocols adopted for message transmission in IoT systems.

6.4. RQ4. Which evaluation parameters are considered for QoS provisioning in IoT gateways?

The Quality of Service parameters considered during the evaluation of IoT gateways are shown in Table 4 and detailed analysis is shown in Fig. 10. Most of the reviewed literature had focused on improving the energy efficiency of the system. In contrast, others improved the gateway's architecture to perform better with low latency, high reliability, and scalability.

6.5. RQ5. What are the existing challenges and open issues of research in IoT gateways?

With significant development in the Internet of Things, a tremendous amount of data is generated from smart devices, gathered and forwarded for further processing. For managing the disparate applications, much work has already been done. It will still make gateways present in the fog layer smart/intelligent enough to handle the data in real-time in latency-driven applications. There is still much bigger room for research and improvement to fully automated gateways work, which involves no human intervention. In this section, RQ5 will be discussed, answering some of the existing issues and research challenges in the field of IoT gateways.

- Heterogeneity: IoT applications deal with many heterogeneous smart devices to gather data in different formats and sizes. These are connected to disparate communication techniques like ZigBee, Ethernet, LoWPAN, etc., and data is transferred through message protocols such as MQTT, CoAP, XMPP, AMQP, REST, etc. The gateway is a bridge between all the connecting devices and should handle heterogeneous data among different protocols. Architectures and models are proposed in (Aazam and Huh, 2014; Bai et al., 2016; Yacchirema et al., 2017; Al-Osta et al., 2017; Al-Osta et al., 2019)for dealing with data and protocol heterogeneity problems. But there is no standardized solution proposed to overcome this problem.
- Scalability: Gateway should handle the increasing IoT devices without deteriorating the services applied to them. With growing technology, smart IoT devices are also exponentially increasing, leading to issues regarding scalability. How many sensors can be handled from one gateway is problematic, as it depends on factors like resources, the gateway processing capability and the IoT application. Working on the scalability aspect will be a fascinating challenge for exponentially growing IoT devices.
- Quality of Service (QoS): While dealing with a colossal amount of data and services applied in different domains, the gateway should also provide quality of service while dealing with real-time data. Many parameters were considered in (Rahmani, 2015; Samie et al., 2017; Tanganelli et al., 2018; Aminul Hoque et al., 2020)like reliability, latency, energy efficiency, scalability, etc., individually, but parameters like throughput, roundtrip delay and jitter were overlooked. Simultaneous parameters should also be considered for improving QoS at gateways in IoT.
- Security and Privacy: Since the gateway is one of the significant data entry points to the network, it is more vulnerable to threats and malicious activities. Securing and preserving user data is a prime necessity. Work in (Moosavi et al., 2015; Min et al., 2014; Jabbar et al., 2019)have focused on network security, but algorithms and architectures can also opt for more secure gateways and IoT architecture.
- Intelligence: Gateways should be smart enough to deal with intelligent data offloading. It should be capable of making efficient decisions to perform better when dealing with complex situations. How much data should be offloaded, in which case, for how much processing, is still an issue. Automatic Gateways can make predictions based on end-user behavior and operating patterns.
- Robustness: By reviewing the existing work, it has been observed that the concepts like a recovery of the gateway, fault tolerance, self-healing concept have not been considered and not much work has been done in this direction.

6.6. RQ6: What are the prospective future directions for research in IoT gateway?

After analyzing the existing issues and research gaps, future directions are presented in this section.

- Based on the problems of heterogeneity, scalability and interoperability, a standardized solution may be developed to deal with the preexisting issues. Much work has already been done to deal with these aforementioned issues individually, but those gaps still need to be filled simultaneously from a standardized solution.
- Quality of Service (QoS) parameters can also be simultaneously measured in IoT gateways in the future for the better overall performance of IoT systems.
- Machine learning and deep learning techniques can be used with traditional security algorithms to deal with privacy and security concerns in IoT gateways.
- Fully automated gateways need to be worked on in the future for more autonomous systems. Based on user behavioral patterns and complex situations, gateways need to make spontaneous decisions to deal with existing issues related to the vast data. Working more with intelligent and smart gateway can prove to be an exciting challenge.
- Self-healing and fault-tolerant gateways are the need of the future to deal with the colossal amount of data. It will be of no use once the data is lost due to system failure or power breakout. Dealing with Big Data, gateways should be reliable, fault-tolerant, self-manageable and self-healed. These mentioned parameters and present techniques can prove to be an appealing issue in the future.

7. Conclusion

Smart gateways in IoT are the core component for autonomous IoT systems. In this SLR, IoT gateways were categorized as Basic and Smart Gateways. Smart gateways were further classified as passive, semi-automated and fully automated. The literature review of the studies selected from the methodological review process was bifurcated according to these classifications of smart gateways. Presented work has determined the type of smart gateways being extensively worked on along with their functional, non-functional, and architectural-based requirements. The survey was performed based on the criteria, which include: the type of gateways, their requirements, tools/platforms, approach adopted, including proposed architecture or algorithm, evaluation techniques like simulation tools, prototype or real test-beds used and their application domain. Pursuant to the statistics depicted while answering the research questions, the publication took a pace from 2015, among which 48% of the reviewed work is published in reputed journals. Internet of Things Journal and Future Generation Computer Systems are among the top journals from prominent publishers. Researchers who are actively working in the field of IoT gateways have also been identified in this work. It was found that 20% of Raspberry Pi-based implementation and 17% using Arduino-based evaluation was done. Comparison studies showed that 60% of Real testbeds were used to validate and evaluate the proposed work. Among three types of smart gateways, passive smart gateways were extensively being worked upon. Functional requirements of IoT gateways were bifurcated for future research perspectives. Also, most of the available literature focuses on improving the energy efficiency, reliability and latency of IoT gateways. Future prospects in the area include developing more autonomous applications in the IoT domain, and more fully automated gateways are needed to be developed and worked on. A standardized solution should be provided to deal with the existing issues in IoT gateways.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix

The details of the reviewed work are presented in tabular form in Table V. The abbreviations used are:

Functional Req.: DM (Data Management), **DV** (Device Management), **RM** (Resource Management), **QoS** (QoS Management), **SM** (Security Management), **PR** (Protocol Translation);

Non-Functional **Req**.: **SC** (Scalability), **HT** (Heterogeneity)**, RL** (Reliability), **LL** (Low latency), **EE** (Energy Efficiency), **MB** (Mobility);

Architectural Based Req.: **AD** (Adaptable), **AM** (Autonomous), **SG** (Smart Gateway), **InT** (Interoperability), **IG** (Intelligent Gateway), **SMG** (Semantic Gateway);

Table V
Literature review table.

S. No	Author name, Year, Reference citation	Title of paper	Journal / Conference, Publisher	Type of Gateway	Description	Functional Req.	Non–Functional Req.	Architectural Based Req.	Approach	Validation Type	Tool/ Platform	Application in IoT
1	J. Bian et al., 2011, (Bian et al., 2011; Bian et al., 2011)	The new intelligent home control system based on the dynamic and intelligent Gateway	2011 4th IEEE International Conference on Broadband Network and Multimedia Technology, IEEE	Passive Gateway	•Proposed Intelligent and dynamic Gateway for Home Automation. •Gateway can predict end-user behavior and act dynamically by switching the device On/Off.	DV	EE	IG	AT	PT	Android Smartphone	Smart Home
2	M. Aazam et al., 2014, (Aazam and Huh, 2014)	Fog Computing and Smart Gateway Based Communication for Cloud of Things	Future Generation Computer Systems, Elsevier	Semi-Automated Gateway	•Data trimming and preprocessing at smart Gateway for smart communication. •Evaluated various QoS parameters. •Two types of Data sets were considered	DM, QoS	HT, LL	SG	AT	RT/ST	Not Mentioned	Not Mentioned
3	D. Min et.al, 2014, (Min et al., 2014)	Design and implementation of heterogeneous IoT gateway based on dynamic priority scheduling algorithm.	Transaction of Institute of Management and Control, SAGE	Passive Gateway	•Dynamic Priority Scheduling adopted at proposed Heterogeneous IoT Gateway •Conversion and transformation of data realized between sensor nodes, the Internet, and various communication protocols. •High-level protocol designed and implemented on proposed Gateway to ensure data security and reliability.	DM, RM, QoS	HT, RL	Not Mentioned	AG/AT	ST	MATLAB	Not Mentioned
4	J. Grandos et.al, 2014, (Granados et al., 2014)	Towards energy-efficient HealthCare: An Internet-of-Things architecture using intelligent gateways	4th international conference on (MOBIHEALTH), IEEE	Passive Gateway	•Power over Ethernet enabled Gateway in the healthcare domain. •Delivers both connectivity to the cloud and power to IoT sensors and appliances. •Ell-i platform both hardware and software, proposed as the Gateway for data collection and forwarding to cloud for other services,	DV, DM	SC, EE	IG	AT	RT	Arduino UNO, Xbee daughterboard	Healthcare
5	T. N. Gia et.at, 2015, (Gia et al., 2015)	Fog Computing in Healthcare Internet of Things: A Case study on ECG Feature Extraction.	Conference, IEEE	Passive Gateway	•Smart Gateway with low bandwidth and low latency for remote Health-monitoring. •Services: embedded Data Mining, Alert notifications in an emergency, distributed database, interactive GUI with Access management, implemented on Smart Gateway.	DM, QOS	HT, LL	InT, SG	AT	RT	Pandaboard, Arduino, Bluetooth/Wi-Fi, zigduino, Smart RF06 board.	Healthcare
6	A.M. Rahmani et. al, 2015, (Rahmani, 2015)	Smart e-Health Gateway: Bringing Intelligence to Internet-of-Things Based Ubiquitous Healthcare Systems.	2015 12th Annual IEEE Consumer Communications and Networking Conference (CCNC), IEEE	Passive Gateway	•Smart e-Health Gateway for implementing automation with appliances and IoT devices. •Proposed Strategic positioning of smart Gateway •UT-GATE implemented to provide services: local repository, data standardization, compression, protocol translation, tunneling, firewall, notification, and data mining.	DM, QoS, PR, SM	SC, RL	InT, SG	AT	PT	UT-GATE	Healthcare
7	P. K. Desai et.al, 2015, (Tilkov, 2015)	Semantic Gateway as a service architecture for IoT Interoperability	International Conference on Mobile services, IEEE	Passive Gateway	•SGS proposed to provide interoperability. •Provide protocol translation through multi-protocol proxy at Gateway. •SSN ontology used for messages interpretation	DM, PR	Not Mentioned	InT, SMG	AT	Not Mentioned	Not Mentioned	Not Mentioned
8	S. R. Moosavi et.al, 2015, (Moosavi et al., 2015)	SEA: A Secure and Efficient Authentication and Authorization Architecture for IoT-Based Healthcare Using Smart Gateways	6th International Conference on Ambient Systems, Networks and Technologies (ANT 2015)	Passive Gateway	•Secure Authorization and Authentication using distributed Smart e-health Gateway •DTLS handshaking IP protocol for security •Proposed architecture resilient to DoS attack and more secure than centralized ones.	SM	SC, RL, LL	SG	AT	PT	UT-GATE	Healthcare
9	A.Al-Fuqaha et.al, 2015, (Al-Fuqaha et al., 2015)	Towards Better Horizontal Integration Among IoT Services	Communication magazine-Communication Standard Supplement, IEEE	Passive Gateway	•Rule based Intelligent Gateway for Protocol translation •Generic IoT protocol is proposed, i.e., enhanced MQTT protocol with combined benefits of IP multicast, intelligent broker Queue management, and Traffic Analytics technique.	QoS, PR	RL, LL	IG	AT	ST	Not Mentioned	Not Mentioned

(continued on next page)

Table V (*continued*)

S. No	Author name, Year, Reference citation	Title of paper	Journal / Conference, Publisher	Type of Gateway	Description	Functional Req.	Non–Functional Req.	Architectural Based Req.	Approach	Validation Type	Tool/ Platform	Application in IoT
10	T. Zachariah et.al, 2015, (Zachariah et al., 2015)	The internet of things has a gateway problem	Proceedings of the 16th international workshop on mobile computing systems and applications, ACM	Passive Gateway	•Gateway Problem: New Device, a new application •Proposed General purpose IoT Gateway as a smartphone to provide Internet through BLE-connected devices. •Proposed approach use smartphone as a gateway in 2 ways: IPv6 router as well as BLE proxy	DV	SC, MB	AD	AT	RT	Smartphone	Not Mentioned
11	S. M. Kim et.al, 2015, (Kim et al., 2015)	IoT Home Gateway for Auto-Configuration and Management of MQTT Devices	Conference on Wireless Sensor, IEEE	Semi-Automated Gateway	•Gateway for smart home proposed to support dynamic device discovery, registration, and configuration. •MQTT for lightweight message transmission. •DPWS is used for device discovery of IP-based devices, whereas Auto-configuration module for non-IP-based devices.	DM, DV	HT, EE	InT	AT	RT	Arduino, Java EE, Apache tomcat, Mosquitto, DPWSim	Smart Home
12	K. C. Serdaroglu et al., 2015, (Serdaroglu and Baydere, 2016)	WiSEGATE: Wireless Sensor Network Gateway framework for Internet of Things	Journal of Wireless Networks, Springer	Passive Gateway	•Interconnection model - WiSEGATE proposed for seamless communication.	QoS, DV	RL, SC	InT	AT	RT/ST	OMNET++	Not Mentioned
13	M.Aazam et.al, 2015, (Aazam and Huh, 2015)	Dynamic Resource Provisioning Through Fog Micro Datacenter	The 12th IEEE International Workshop on Managing Ubiquitous Communications and Services, 2015	Passive Gateway	•Relinquish Probability proposed for resource estimation through Fog Smart Gateways(FSG)	RM, DM, SM	SC	SG	AT	ST	CloudSim Toolkit	Not Mentioned
14	J. Santos et.al, 2016, (Santos et al., 2016)	An IoT-based Mobile Gateway for Intelligent Personal Assistant on Mobile Health Environment	Journal of Network and Computer Applications, Elsevier	Semi-Automated Gateway	•Mobile IoT Gateway integrated with IPA platform • Remote monitoring system with AMBRO and IPA to manage actions and alarms as per the patient's condition.	DV	HT, RL, EE, MB	AM, InT	AT/AG	RT	Samsung Galaxy Smartphone, Android OS	Smart Home, Healthcare
15	F. Ding et al., 2016, (Ding et al., 2016; Ding et al., 2016)	A smart Gateway Architecture for Improving Efficiency of Home Network Application	Journal of Sensors, Hindawi	Passive Gateway	•IAGW architecture proposed for Home automation •Provides network support to new applications, access to service, and a standard interface for various applications	DV	SC, HT	InT, SG	AT	PT	MCU node, SDRAM, NAND Flash	Smart Home
16	G. Aloi et.al, 2016, (Aloi, et al., 2016)	A Mobile Multi-Technology Gateway to enable IoT Interoperability	IEEE First International Conference on IoT Design and Implementation, IEEE	Semi-Automated Gateway	•Smartphone-based IoT gateway proposed for multi-interface and multi-technology framework.	DV, RM, PR	EE, MB	InT	AT	RT	Samsung Galaxy Smartphone	Not Mentioned
17	G. Aloi et.al, 2016, (Aloi et al., 2017)	Enabling IoT Interoperability through opportunistic smartphone based mobile Gateway	Journal of Network and Computer Applications, Elsevier	Semi-Automated Gateway	•Opportunistic mobile Gateway proposed as a universal interface between IoT devices and the Internet. •Capable to dynamically discover/manage the devices, collect and process data and forward it to the cloud.	DM, DV, RM, PR, QoS	EE, MB	InT	AT	RT	Samsung Galaxy Smartphone	Smart Health, Smart Street
18	Z. Y. Bai et.al,2016, (Bai et al., 2016)	Design and implementation of an IoT multi-interface gateway for establishing a digital art interactive system	International Journal of Ad Hoc and Ubiquitous Computing, Inderscience	Passive Gateway	•Heterogeneous multi-interface gateway designed to connect objects to social network to demonstrate interoperability through exchange of information	DV, PR	HT, EE	InT	AT	RT	Arduino, Octopus X, Wi-Fi module	Social network Connectivity
19	L. Karagiannidis et. al, 2016, (Karagiannidis et al., 2016)	A novel and interoperable communication gateway implementation for evacuation systems	2016 International Wireless Communications and Mobile Computing Conference (IWCMC), IEEE	Passive Gateway	•DDS, Adaptable model used to design Gateway to work in an emergency for Evacuation and notify people with updated and accessible information.	PR, QoS	SC, RL, HT, LL	InT, SG, AD	AT	ST	Not Mentioned	Evacuation System
20	M. Abdelaal et.al, 2019, (Abdelaal et al., 2019)	GaaS: Adaptive Cross-Platform Gateway for IoT Applications	2019 IEEE 16th International Conference on Mobile Ad Hoc and Sensor Systems (MASS), IEEE	Passive Gateway	•Architecture of Gateway-as-a-Service proposed to retrieve data from power-constrained devices. •BLE radio used for the connection. •Priority-based scheduling opted for energy-efficient retrieval of data.	DM, RM, QoS	LL, EE	AD	AT	RT	Arduino kit	Not Mentioned
21	R. Petrolo et.al, 2017, (Petrolo et al., 2017)	The design of gateway for Cloud of Things	Annals of Telecommunication, Springer	Passive Gateway	•Gateway combined with virtualization technique guarantees lightweight and dense deployed services at cloud	RM, DM	EE	SMG, InT	AT	PT	Raspberry Pi 2, Docker Containers	Not Mentioned

Table V (*continued*)

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22	D. C. Yacchirema et al., 2016, (Yacchirema et al., 2017)	Design and Implementation of a Gateway for Pervasive Smart Environments	IEEE International Conference (SMC), IEEE	Passive Gateway	•GW-TSI designed and Implemented for storing, transforming, preprocessing, and transmitting data. •CoAP and MQTT protocols were used to deal with technical interoperability, and standard message format deals with syntactic interoperability.	DM, QoS	HT, EE	InT, SG	AT	RT	Not Mentioned	Transportation and Logistics
23	F. Samie et al., 2016, (Samie et al., 2017)	Computation Offloading and Resource Allocation for Low-power IoT Edge Devices	3rd World Forum on Internet of Things (WF-IoT), IEEE	Passive Gateway	•Technique proposed to manage computational offloading at Gateway under bandwidth constraints to utilize the gateway resources fully.	RM, DM, QoS	EE	AD	AT	RT	Intel Quark SoC	Healthcare
24	A. Hawraa R et al., 2016, (Ameer and Hasan, 2020)	Enhanced MQTT Protocol by Smart Gateway	Iraqi Journal of computers, communication, control & systems engineering , University of Technology	Passive Gateway	•Smart Gateway designed to provide priority to emergency data using enhanced MQTT protocol in healthcare application	DM, RL, QoS	LL, EE	SG	AT/AG	ST/PT	INET, OMNET++	Healthcare
25	M. Cha et.al, 2016, (Cha et al., 2016)	Data Aggregation Gateway Framework for Group Communication	Symmetry. MDPI	Passive Gateway	•DA-GW proposed for group communication using CoAP to simultaneously communicate with groups, resulting in improved throughput and energy consumption.	QoS, RL, DM	LL, HT	InT	AT	RT	jCoAP library, Raspberry Pi 2	Not Mentioned
26	A.M. Rahmani et. al , 2017, (Rahmani et al., 2018)	Exploiting smart e-Health gateways at the edge of healthcare Internet-of-Things: A fog computing approach	Future Generation Computer Systems, Elsevier	Semi-Automated Gateway	•Strategic positioning of smart Gateway •Geo-Distributed Intermediate layer proposed for intelligence •Local data processing at the Gateway for real-time notifications with security •Medical case study-(EWS) for validation.	DM, DV, SM	SC, RL, MB, EE	AD, SM, InT	AT	PT	UT-GATE	Healthcare
27	M. W. Woo et al., 2017, (Woo et al., 2018)	A reliable IoT system for Personal Healthcare Devices	Future Generation Computer Systems, Elsevier	Passive Gateway	•Reliable OneM2M system proposed in healthcare • Gateway used for protocol conversion and provide fault-tolerance through Daisy Chain Algorithm	DM, DV, RM, PR, SM	RL	AD	AT/AG	PT	PC, Notebook, 500 pulse oximeters	Healthcare
28	B. Kang et al., 2017, (Kang et al., 2017; Kang et al., 2017)	Internet of Everything: A large-scale automatic IoT gateway	IEEE transaction of Multi-Scale Computing Systems, IEEE	Fully-Automated Gateway	•Self- configurable Gateway •Automatic detection of the device •Updates for Hardware changes •Manages connections with smart IoT devices	DV, QoS, PR	SC, HT, LL, EE	SM, InT, AM	AT	RT	AllJoyn platform	Not Mentioned
29	G. Tanganelli et.al, 2017, (Tanganelli et al., 2018)	Edge-Centric Distributed Discovery and Access in Internet of Things	Internet of Things Journal, IEEE	Passive Gateway	• Edge-centric distributed architecture proposed •DHT is maintained at Gateway • Resource allocation and access to service is the main focus • CoRE RD and CoAP protocol used along with XMHT to provide lower latency and scalability	DM, RL, QoS, SM	SC, HT, LL	AD	AT	RT/PT	OpenStack	Not Mentioned
30	A. Gloria et al., 2017, (Glória et al., 2017)	Design and implementation of an IoT gateway to create smart environment.	Procedia Computer Science, Elsevier	Passive Gateway	•Practically implemented IoT gateway monitoring and controlling swimming pools in real-time. • Bi-directional communication along with the exchange of data among sensors and users are implemented	DM, SM	HT	Not Mentioned	AT	PT	Raspberry Pi, Arduino	Smart Home
31	M. Al-Osta et.al, 2017, (Al-Osta et al., 2017)	A lightweight semantic web-based approach for data annotation on IoT gateways	Procedia Computer Science, Elsevier	Passive Gateway	•Data Aggregation and filtering at Gateway for minimum resources • Limited and meaningful data forwarded to the cloud •Lightweight annotation by listing the most queried data after applying the rule engine.	DM	HT, SC	SMG, InT	AT	PT	Not Mentioned	Smart City
32	K. Guan et.al, 2017, (Guan et al., 2017)	A Remote Health Monitoring System for the Elderly based on Smart Home Gateway	Journal of Healthcare Engineering, Hindawi	Passive Gateway	• Architecture proposed for remote health monitoring of older people. • Smart Home Gateway architecture consists of 3 main parts: Smart Cloths, Smart Gateway, and a server for healthcare. •For continuous data streaming, ECG compression Algorithm was proposed to resolve network congestion and data overloading issues.	DV	SC	SG	AT	PT	Exynos4412, MT6620, DM9621,MPS450	Smart Home, Healthcare

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33	B. Kang et al., 2017, (Kang et al., 2017; Kang, 2018)	An Experimental study of a reliable IoT gateway	ICT Express, Elsevier	Fully-Automated Gateway	• Self-Configurable and reliable IoT gateway designed for home automation • Operation in IoTivity modified by using INIT operation for automatic registration.	DV	RL	SG ,IG, AM, InT	AT/AG	RT	IoTivity	Smart home
34	F. L. C. Filho et al., 2017, (De et al., 2017)	Design and evaluation of a semantic gateway prototype for IoT networks	Companion Proceedings of the10th International Conference on UCIoT, ACM	Passive Gateway	•Semantic Gateway was proposed to provide seamless communication with heterogeneous devices and communication protocol also has various choices to choose the platform and data visualization techniques.	DM, SM	HT, EE	InT, SMG	AT	RT	UIoT middleware	Not Mentioned
35	C. Razafimandimby, 2017, (Razafimandimby et al., 2017)	A Bayesian and Smart Gateway Based Communication for Noisy IoT scenario	2017 International Conference on Computing, Networking and Communications (ICNC), IEEE	Passive Gateway	•Bayesian Inference based approach adopted to avoid transmitting useless data in IoT network. •BP algorithm used to reconstruct missing values.	DM, QoS	HT, EE	AD	AT	ST/RT	Not Mentioned	Not Mentioned
36	T.N.Gia et.al, 2017, (Nguyen Gia, et al., 2017)	Low-Cost Fog-assisted Health-care IoT system with Energy-efficient Sensor Nodes	13th international wireless communications and mobile computing conference (IWCMC). IEEE	Passive Gateway	• Low-cost health monitoring system with automatic analysis with a notification alert.	DM, DV, SM	EE	AD	AT	PT	Orange Pi	Healthcare
37	W.Razouk et.al, 2017, (Razouk et al., 2017)	A New Security Middleware Architecture Based on Fog Computing and Cloud To Support IoT Constrained Devices	Proceedings of the 1st international conference on internet of things and machine learning, ACM	Passive Gateway	•Security middleware acting as smart gateway to preprocess data at the edge of the network using CoAP and REST techniques	DM, SM	EE	SG	AT	Not Mentioned	Not Mentioned	Not Mentioned
38	P.Bellavista et.al, 2017, (Bellavista et al., 2017)	Converging Mobile Edge Computing Fog Computing and IoT Quality Requirements	5th International Conference on Future Internet of Things and Cloud, IEEE	Semi-Automated Gateway	• Quality constrained exploitation of container-based virtualized resources integrated with IoT gateways	DM, DV, RM, QoS	LL	SG	AT	Not Mentioned	Not Mentioned	Not Mentioned
39	D.Happ et.al, 2017, (Happ and Wolisz, 2017)	Towards Gateway to Cloud Offloading in IoT Publisher/Subscribe Systems.	Second International Conference on Fog and Mobile Edge Computing (FMEC), IEEE	Passive Gateway	• Processing task migrated from one system to another without interruption on the suitable location	DM	LL	SG	AT	PT	Beaglebone	Not Mentioned
40	P. Verma et.al, 2018, (Verma and Sood, 2018)	Fog-Assisted-IoT-Enabled Patient Health Monitoring in Smart Homes.	Internet of Things Journal, IEEE	Semi-Automated Gateway	• Layered architecture at Gateway, successfully providing embedded mining, distributed storage, and alert notification service to the caregivers. • BBN classifier to classify safe or • THI is calculated at the cloud layer to decide the urgency of the situation	DM, QoS, PR, SM	RL, LL	SG	AT/AG	PT/ST	R Studio, WEKA, Amazon E2C	Healthcare in Smart Home
41	F. Banaie et al., 2018, (Banaie et al., 2019)	Performance Analysis of Multithreaded IoT Gateway	Internet of Things Journal, IEEE	Passive Gateway	•CoAP enabled multithreaded hybrid IoT gateway proposed for quick remote access. • Selective caching policy used for updating and validation of user requests to access data.	DM, RL, QoS	RL, LL, EE	Not Mentioned	AT	PT	Maple 16 from Maplesoft	Not Mentioned
42	M. Al-Osta et.al, 2018, (Al-Osta et al., 2019)	Event driven and semantic based approach for data processing on IoT gateway devices	Journal of Ambient Intelligence and Humanized Computing, Springer	Passive Gateway	•Proposed decentralized approach for data preprocessing using Smart Gateway • Data Collection module for data aggregation and preprocessing, whereas Data processing module for Semantic annotation and tagging the raw data.	DM	HT, LL	SMG, InT	AT	PT	Raspberry Pi 3, Jena	Smart City
43	P. Wang et al., 2018, (Wang et al., 2018; Wang et al., 2018)	A Smart Home Gateway Platform for Data Collection and Awareness	IEEE Communications magazine, IEEE	Semi-Automated Gateway	• Smart Gateway data collection and awareness framework proposed along with MDA lightweight plug-in for Smart Home domain.	DM, DV, SM, QoS	RL, SC	InT, SG	AT	RT	Microcontrollers	Smart Home
44	L. Mastilak et.al, 2018, (Mastilak et al., 2018)	Improved smart gateway in IoT	2018 16th International Conference on Emerging eLearning Technologies and Applications (ICETA), IEEE	Passive Gateway	•Smart Gateway along with communication protocol proposed for secure data transmission.	SM, PR	RL,EE	InT	AT/AG	RT	Raspberry Pi 3, Arduino	Not Mentioned

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45	S. Kesanav et.al, 2018, (Kesavan and Kalambettu, 2018)	IoT enabled comprehensive, plug and play gateway framework for smart health	2018 Second International Conference on Advances in Electronics, Computers and Communications (ICAECC), IEEE	Semi-Automated Gateway	•Framework for scalable plug and play gateway proposed for seamless connection and efficient communication	DM, SM	SC, RL	InT	AT	RT	BLE Devices and health sensors	Healthcare
46	K.Dolui et.al, 2018, (Dolui and Kiraly, 2018)	Towards Multi- Container Deployement on IoT Gateway	Global communications conference (globecom), IEEE	Fully Automated	• AGILE- multi-container and microservice-based open-source framework	DV, DM, PM, SM	LL	SG	AT	PT	Docker Containers	Not Mentioned
47	H. Huang et al., 2018, (Yu, 2018; Yu, 2018)	Distributed Machine learning on smart Gateway Network toward Real-time Smart Grid Energy Management with Behaviour Cognition.	ACM Transaction on Design Automation of Electrical Systems, ACM	Passive Gateway	•Based on occupants behavior, short term load predicted using machine learning analytics to allocate renewable energy at peak hours with the help of distributed Smart Gateway	DM	EE	AD	AT/AG	RT	Beagle-board	Smart Grid
48	R. Morabito et al., 2018, (Morabito et al., 2018; Morabito et al., 2018)	LEGIoT: A Lightweight Edge Gateway for the Internet of Things	Future Generation Computer Systems, Elsevier	Passive Gateway	•LEGIoT proposed using a container visualization technique •Optimized resource allocation along with energy efficiency, multi-tenancy, and interoperability issues are resolved	DM, DV, RM, QoS	HT, EE, RL	InT, SG	AT	RT	Microcontrollers and various sensors	Smart Building
49	W. A. Jabbar et.al, 2019, (Jabbar et al., 2019)	Design and fabrication of smart home with Internet of Things enabled automation system	IEEE Access, IEEE	Passive Gateway	• IoT@HoMe named prototype is implemented with an algorithm for home automation and monitoring the smart home environment.	DV, SM	RL, EE	AM, InT	AT/AG	RT/PT	Node MCU, Adafruit, MQTT Dash, FTTT	Smart home
50	A. Javed et al., 2019, (Javed et al., 2019; Javed et al., 2019)	Access time improvement framework for standardized IoT gateways	International Conference on Pervasive Computing and Communications Workshops, IEEE	Passive Gateway	•Distributed framework to optimize data retrieval and storage at Gateway was designed by using a consistent hashing mechanism with microservices to provide a scalable and flexible solution.	DM, RM, QoS	SC, RL	InT	AT	RT	Docker containers	Smart Mobility
51	P. P. Ray et.al, 2019, (Ray et al., 2019)	Implementation and performance Analysis of Interoperable and Heterogeneous IoT-Edge Gateway for Pervasive Wellness Care.	Transactions on Consumer Electronics, IEEE	Passive Gateway	•Gateway was developed to deal with heterogeneity and Interoperability problems. •Packet structure and generation flow mechanism proposed. •Victual motes implemented to be used as plug and play option.	QoS, DV	HT, EE	InT	AT	RT	IoT Motes	Healthcare
52	P. L. G. Ramirez et. al, 2019, (Ramirez et al., 2020)	An Intelligent Algorithm for Resource Sharing and Self-Management of Wireless-IoT-Gateway	IEEE Access, IEEE	Fully-Automated Gateway	•Adaptive algorithm for dynamic resource allocation •DFSP to announce all the new devices on the network •AI with ML techniques makes Gateway self-manageable and configurable •MQTT protocol is modified to send messages which consume less bandwidth to improve QoS.	DM, DV, RM, QoS	HT, EE	InT, AD	AG	ST	Cisco Packet Tracer	Smart Home
53	S. Balasubramaniam et.al, 2019, (Balasubramanian and Meyyappan, 2019)	Enhancing the Computational Intelligence of Smart Fog Gateway with Boundary-Constrained Dynamic Time wrapping Based Imputation and Data Reduction.	3rd International Conference on Imaging, Signal Processing and Communication, IEEE	Passive Gateway	•DISMISS approach used in smart Gateway for preprocessing data involves noise reduction, imputing missing values, and filtering out irrelevant data. •Binning Technique for Noise reduction, Boundary constrained DTW method for missing value prediction, and PIP method with PSO technique for relevant data extraction was used from the stream of data at Gateway.	DM	LL, EE	AD	AT	PT	Weather Dataset	Not Mentioned
54	B. Y. Ooi et. al,2019, (Ooi et al., 2019)	A Collaborative IoT-Gateway Architecture for Reliable and Cost Effective Management	Instrumentation and Measurement Magazine, IEEE	Passive Gateway	•Transparent connection between sensor and cloud was made through Collaborative IoT-Gateway, which provides reliable connection. •GA was adopted for optimal deployment of Gateway to provide a reliable connection.	DM, SM	HT, RL	InT	AT	RT	Raspberry Pi	Not Mentioned

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55	FLD.C. Filho et.al, 2019, (De Caldas Filho et al., 2019)	QoS Scheduling Algorithm for a Fog IoT Gateway	2019 Workshop on Communication Networks and Power Systems , IEEE	Passive Gateway	•Proposed HTB algorithm for prioritization of message in queues organized by classifier at Gateway to reduce latency	QoS, RM, PR	LL, HT	SMG, InT	AT/AG	RT	UIoT middleware	Not Mentioned
56	P. Maiti et.al, 2019, (Maiti et al., 2019)	An effective approach of latency-aware fog smart gateways deployment for IoT services	Internet of Things, Elsevier	Passive Gateway	•4-Tier architecture for device-gateway communication •Among five different algorithms, simulated annealing proves to provide low latency and efficient results.	QoS	LL, EE	SG	AG/AT	ST	MATLAB	Not Mentioned
57	H.Le et.al, 2019, (Le et al., 2019)	Fog Computing architecture with hetrogeneous Internet of Things technologies.	10th International Conference on the Network of the Future (NoF), IEEE	Passive Gateway	• Multi-technology service architecture proposed for smart gateways to choose the best node	DM, DV	HT, MB	SG	AG	Not Mentioned	Not Mentioned	Not-Mentioned
58	B.Sarma et.al, 2019, (Sarma et al., 2019)	Fog Computing: An Enhanced Performance Analysis Emulation Framework for IoT with Load Balancing Smart Gateway Architecture.	Proceedings of the Fourth International Conference on Communication and Electronics Systems (ICCES 2019), IEEE	Passive Gateway	• Four different scenarios considered and compared for load balancing	DM, DV, RM	LL	SG	AT	PT	Virtual Machines, Raspberry-Pi	Not Mentioned
59	M. Diyan et.al, 2020, (Diyan et al., 2020)	Intelligent Internet of Things gateway supporting heterogeneous energy data management and processing.	Special Issue Article, Wiley	Semi-Automated Gateway	•Multitasking IoTGW proposed for data preprocess and analysis it for quick decisions. •Hybrid AMLP classifier used to classify the heterogeneous data.	DM, DV	SC, HT, EE	InT, AD	AT/AG	PT	Spark, GraphX	Not Mentioned
60	A. K. Sangaiah et al., 2020, (Sangaiah et al., 2020)	IoT Resource allocation and Optimization Based on Heuristics Algorithm	Sensor, MDPI	Passive Gateway	• Algorithm based on Whale Optimization proposed for Resource Allocation and scheduling in Gateways.	RM, QoS	EE	Not Mentioned	AG/AT	ST	MATLAB	Not Mentioned
61	F. Aloul et al., 2020, (Aloul et al., 2020; Aloul et al., 2020)	A monitoring and Control Gateway for IoT Edge Devices in Smart Home	2020 International Conference on Information Networking (ICOIN)	Passive Gateway	•Generic IoT MCG presented to provide edge security and control the IoT devices and appliances in smart home	SM	EE	AD	AT	RT	Not Mentioned	Not Mentioned
62	P. L. G. Ramirez et al., 2021, (González Ramírez et al., 2021)	IoT-networks group-based model that uses AI for workgroup allocation	Journal of Computer Networks, Elsevier	Fully-Automated Gateway	•Group of network model proposed to work with the different appliances in a smart home. •Group of objects can provide service to the user based on AI model using ML data analytics	DM, DV, RM, QoS	HT, EE	InT, AD	AT	ST/RT	Cisco Packet Tracer, Jupyter, iFogSim	Smart Home
63	O. Chenaru et.al, 2020, (Chenaru and Popescu, 2020)	IoT Gateway for Personalized User Comfort Management in Smart Home Application	28th Mediterranean Conference on Control and Automation, IEEE	Passive Gateway	•Through context analysis and behavior pattern, architecture proposed along with a two-staged algorithm for comfort model implementation at Gateway	DM, DV	RL, EE	AM	AT/AG	RT	Not Mentioned	Smart Home
64	M. A. Hoque et al.,2020, (Aminul Hoque et al., 2020)	IGaaS: An IoT Gateway-as-a-Service for On-demand Provisioning of IoT Gateway	IEEE 6th World Forum on Internet of Things (WF-IoT), IEEE	Passive Gateway	•Incentive Model algorithm proposed for IoT devices which serves as Gateway on demand •IGaaS provides QoS by providing appropriate Gateway anywhere anytime to decrease latency and power consumption.	QoS, RM, DV	LL, EE	AD	AG	ST	Cooja Simulator	Not Mentioned
65	Y. Du et.al, 2021, (Du et al., 2021)	Design and implementation of intelligent Gateway System for Monitoring Livestock and Poultry feeding environment based on Bluetooth Low Energy	Journal – Information, MDPI	Passive Gateway	•Priority Queue mechanism • Cache Queue mechanism •Feedback Mechanism implemented for efficient task processing	DM, QoS	RL, EE	AD	AT	PT	Microcontrollers, Bluetooth module	Poultry Farming
66	F. Wu et al., 2021, (Wu et al., 2021; Wu et al., 2021)	Edge-based Hybrid Implementation for Long Range Safety and Healthcare IoT Application.	Internet of Things Journal, IEEE	Passive Gateway	•Edge computing-based architecture consists of hybrid routers and IoT Gateways was designed •Software architecture of Gateway designed for data preprocessing, data storage and gateway, cloud connection	PR, DT	LL	AD	AT	PT	XBee module, Raspberry Pi	Not Mentioned
67	S. K. Chaudhary et al., 2021, (Chaudhary et al., 2021; Chaudhary et al., 2021)	A Multi-Protocol Home Automation System Using Smart Gateway	Journal of Wireless Personal Communication, Springer Nature	Semi-Automated Gateway	•Fall Detection algorithms were compared based on two methods: threshold-based and neural network-based. •Beehealth model was proposed for remote health monitoring of elder patients. •Model can work with multiple protocols like Wi-Fi, Bluetooth and Zigbee	DM, PR	EE, SC	SG	AT	PT	OpenHAB, Xbee s2 module, Raspberry Pi	Healthcare

Approach - AT (Architecture) **& AG** (Algorithm);
Validation type: ST (Simulation)**, PT** (Prototype)**, RT** (Real Testbed);

References

Ashton, K. et al., 2009. That 'internet of things' thing. RFID J. 22 (7), 97–114.

Wang, L., Von Laszewski, G., Younge, A., He, X., Wang, L., 2010. Cloud Computing: A Perspective Study 28, 137–146.

Botta, A., De Donato, W., Persico, V., Pescapé, A., 2016. Integration of cloud computing and internet of things : a survey. Futur. Gener. Comput. Syst. 56, 684–700. https://doi.org/10.1016/j.future.2015.09.021.

L. M. Dang, J. Piran, D. Han, K. Min, and H. Moon, "A Survey on Internet of Things and Cloud Computing for Healthcare," pp. 1–49, 2019, doi: 10.3390/electronics8070768.

Bonomi, F., Milito, R., Zhu, J., Addepalli, S., 2012. Fog computing and its role in the internet of things. In: in Proceedings of the first edition of the MCC workshop on Mobile cloud computing, pp. 13–16.

Bala, M.I., Chishti, M.A., 2019. Survey of applications, challenges and opportunities in fog computing. Int. J. Pervasive Comput. Commun. 15 (2), 80–96. https://doi.org/10.1108/IJPCC-06-2019-059.

Mouradian, C., Naboulsi, D., Yangui, S., Glitho, R.H., Morrow, M.J., Polakos, P.A., 2018. A Comprehensive survey on fog computing: state-of-the-art and research challenges. IEEE Commun. Surv. Tutorials 20 (1), 416–464. https://doi.org/10.1109/COMST.2017.2771153.

Sethi, P., Sarangi, S.R., 2017. "Internet of things : architectures. Protocols, and Applications".

MATSUO, M., 1971. A study on the development of radula. J. Kyushu Dent. Soc. 25 (3), 250–261. https://doi.org/10.2504/kds.25.250.

Gubbi, J., Buyya, R., Marusic, S., Palaniswami, M., 2013. Internet of Things (IoT): A vision, architectural elements, and future directions. Futur. Gener. Comput. Syst. 29 (7), 1645–1660. https://doi.org/10.1016/j.future.2013.01.010.

Ray, P.P., 2018. A survey on internet of things architectures. J. King Saud Univ. - Comput Inf. Sci. 30 (3), 291–319. https://doi.org/10.1016/j.jksuci.2016.10.003.

Al-Fuqaha, A., Guizani, M., Mohammadi, M., Aledhari, M., Ayyash, M., 2015. Internet of Things: a survey on enabling technologies, protocols, and applications. IEEE Commun. Surv. Tutorials 17 (4), 2347–2376. https://doi.org/10.1109/COMST.2015.2444095.

Ray, P.P., 2016. A survey of IoT cloud platforms. Futur. Comput. Informatics J. 1 (1–2), 35–46. https://doi.org/10.1016/j.fcij.2017.02.001.

Nazari Jahantigh, M., Masoud Rahmani, A., Jafari Navimirour, N., Rezaee, A., 2020. Integration of Internet of Things and cloud computing: a systematic survey. IET Commun. 14 (2), 165–176. https://doi.org/10.1049/cmu2.v14.210.1049/iet-com.2019.0537.

Cavalcante, E., Pereira, J., Alves, M.P., Maia, P., Moura, R., Batista, T., Delicato, F.C., Pires, P.F., 2016. On the interplay of internet of things and cloud computing: a systematic mapping study. Comput. Commun. 89-90, 17–33. https://doi.org/10.1016/j.comcom.2016.03.012.

Yousefpour, A., Fung, C., Nguyen, T., Kadiyala, K., Jalali, F., Niakanlahiji, A., Kong, J., Jue, J.P., 2019. All one needs to know about fog computing and related edge computing paradigms: A complete survey. J. Syst. Archit. 98, 289–330. https://doi.org/10.1016/j.sysarc.2019.02.009.

Singh, S.P., Nayyar, A., Kumar, R., Sharma, A., 2019. Fog computing: from architecture to edge computing and big data processing. J. Supercomput. 75 (4), 2070–2105. https://doi.org/10.1007/s11227-018-2701-2.

Ai, Y., Peng, M., Zhang, K., 2018. Edge computing technologies for Internet of Things: a primer. Digit. Commun. Networks 4 (2), 77–86. https://doi.org/10.1016/j.dcan.2017.07.001.

Yan, W., Wang, Z., Wang, H., Wang, W., Li, J., Gui, X., 2020. Survey on recent smart gateways for smart home: Systems, technologies, and challenges. Trans. Emerg. Telecommun. Technol. no. June, 1–20. https://doi.org/10.1002/ett.4067.

Bansal, S., Kumar, D., 2020. IoT ecosystem: A survey on devices, gateways, operating systems, middleware and communication. Int. J. Wirel. Inf. Networks 27 (3), 340–364.

Zhu, Q., Wang, R., Chen, Q., Liu, Y., Qin, W., 2010. Iot gateway: Bridgingwireless sensor networks into internet of things, in. IEEE/IFIP International Conference on Embedded and Ubiquitous Computing 2010, 347–352.

B. Kang and H. Choo, An experimental study of a reliable IoT gateway, *ICT Express*, vol. 4, no. 3, 2018, doi: 10.1016/j.icte.2017.04.002.

Mueller, R., Rellermeyer, J.S., Duller, M., Alonso, G., 2007. A generic platform for sensor network applications, in. IEEE International Conference on Mobile Adhoc and Sensor Systems 2007, 1–3.

Emara, K.A., Abdeen, M., Hashem, M., 2009. A gateway-based framework for transparent interconnection between WSN and IP network. IEEE EUROCON 2009, 1775–1780.

J.-W. Yoon, Y. Ku, C.-S. Nam, and D.-R. Shin, "Sensor network middleware for distributed and heterogeneous environments," in 2009 International Conference on New Trends in Information and Service Science (NISS 2009), 2009, pp. 979–982.

Bimschas, D., Hellbrück, H., Mietz, R., Pfisterer, D., Römer, K., Teubler, T., 2010. Middleware for smart gateways connecting sensornets to the internet. In: in Proceedings of the 5th International Workshop on Middleware Tools, Services and Run-Time Support for Sensor Networks, pp. 8–14.

Min, D., Xiao, Z., Sheng, B., Shiya, G., 2012. Design and implementation of the multi-channel RS485 IOT gateway. In: in 2012 IEEE International Conference on Cyber Technology in Automation, Control, and Intelligent Systems (CYBER), pp. 366–370.

Guoqiang, S., Yanming, C., Chao, Z., Yanxu, Z., 2013. Design and implementation of a smart IoT gateway. In: in 2013 IEEE International Conference on Green Computing and Communications and IEEE Internet of Things and IEEE Cyber, Physical and Social Computing, pp. 720–723.

Wu, L., Xu, Y., Xu, C., Wang, F., 2013. Plug-configure-play service-oriented gateway-for fast and easy sensor network application development. International Conference on Sensor Networks 2, 53–58.

Xu, D., Yang, L., Jiang, L., 2015. Research and design of IoT gateway, in. International Industrial Informatics and Computer Engineering Conference 2015, 837–840.

Chang, C.-T., Chang, C.-Y., Shih, K.-P., Martinez, R.D.B., Chen, P.-T., Chen, Y.-D., 2015. An IoT multi-interface gateway for building a smart space. Open J. Soc. Sci. 03 (07), 56–60.

B. Kang, D. Kim, and H. Choo, Internet of Everything : A large-scale autonomic IoT gateway, vol. 6, no. 1, 2017, doi: 10.1109/TMSCS.2017.2705683.

Ramirez, P.L.G., Taha, M., Lloret, J., Tomas, J., 2020. An intelligent algorithm for resource sharing and self-management of wireless-IoT-gateway. IEEE Access 8, 3159–3170. https://doi.org/10.1109/Access.628763910.1109/ACCESS.2019.2960508.

González Ramírez, P.L., Lloret, J., Tomás, J., Hurtado, M., 2021. IoT-networks group-based model that uses AI for workgroup allocation. Comput. Networks 186 (October), 2020. https://doi.org/10.1016/j.comnet.2020.107745.

Carpio, F., Jukan, A., Masip-bruin, X., 2019. "and Related Challenges of Fog and Cloud Computing" 1 (1), 1–30.

G. White and V. Nallur, PT US CR, 2017, doi: 10.1016/j.jss.2017.05.125.

Singh, M., Baranwal, G., Tripathi, A.K., 2020. QoS-aware selection of IoT-based service. Arab. J. Sci. Eng. 45 (12), 10033–10050.

F. L. D. C. Filho, R. L. Rocha, and C. J. B. Abbas, QoS Scheduling Algorithm for a Fog IoT Gateway, no. October, 2019, doi: 10.1109/WCNPS.2019.8896311.

Sitender, S. Bawa, M. Kumar, and Sangeeta, A comprehensive survey on machine translation for English, Hindi and Sanskrit languages, no. 2013. Springer Berlin Heidelberg, 2021.

Rahmani, A.M. et al., 2015. Smart e-health gateway: bringing intelligence to internet-of-things based ubiquitous healthcare systems. 2015 12th Annu IEEE Consum. Commun. Netw. Conf. CCNC 2015 (July), 826–834. https://doi.org/10.1109/CCNC.2015.7158084.

G. Aloi *et al.*, A mobile multi-technology gateway to enable IoT interoperability, Proc. - 2016 IEEE 1st Int. Conf. Internet-of-Things Des. Implementation, IoTDI 2016, pp. 259–264, 2016, doi: 10.1109/IoTDI.2015.29.

Al-Osta, M., Ahmed, B., Abdelouahed, G., 2017. A Lightweight Semantic Web-based Approach for Data Annotation on IoT Gateways. Procedia Comput. Sci. 113, 186–193. https://doi.org/10.1016/j.procs.2017.08.339.

F. L. De Caldas Filho, F. L. L. De Mendonça, L. M. C. E Martins, J. P. C. L. Da Costa, I. P. Araújo, and R. T. De Sousa Júnior, "Design and evaluation of a semantic gateway prototype for IoT networks," UCC 2017 Companion - Companion Proc. 10th Int. Conf. Util. Cloud Comput., pp. 195–201, 2017, doi: 10.1145/3147234.3148091.

Moosavi, S.R., Gia, T.N., Rahmani, A.-M., Nigussie, E., Virtanen, S., Isoaho, J., Tenhunen, H., 2015. SEA: A secure and efficient authentication and authorization architecture for IoT-based healthcare using smart gateways. Procedia Comput. Sci. 52, 452–459. https://doi.org/10.1016/j.procs.2015.05.013.

Aloi, G., Caliciuri, G., Fortino, G., Gravina, R., Pace, P., Russo, W., Savaglio, C., 2017. Enabling IoT interoperability through opportunistic smartphone-based mobile gateways. J. Netw. Comput. Appl. 81, 74–84. https://doi.org/10.1016/j.jnca.2016.10.013.

Rahmani, A.M., Gia, T.N., Negash, B., Anzanpour, A., Azimi, I., Jiang, M., Liljeberg, P., 2018. Exploiting smart e-Health gateways at the edge of healthcare Internet-of-Things: A fog computing approach. Futur. Gener. Comput. Syst. 78, 641–658. https://doi.org/10.1016/j.future.2017.02.014.

Al-Osta, M., Bali, A., Gherbi, A., 2019. Event driven and semantic based approach for data processing on IoT gateway devices. J. Ambient Intell. Humaniz. Comput. 10 (12), 4663–4678. https://doi.org/10.1007/s12652-018-0843-y.

M. A. Razzaque, M. Milojevic-jevric, A. Palade, and S. Clarke, "Middleware for Internet of Things : A Survey," vol. 3, no. 1, pp. 70–95, 2016.

J. Bian, D. Fan, and J. Zhang, "The new intelligent home control system based on the dynamic and intelligent gateway," Proc. - 2011 4th IEEE Int. Conf. Broadband Netw. Multimed. Technol. IC-BNMT 2011, pp. 526–530, 2011, doi: 10.1109/ICBNMT.2011.6155990.

Min, D., Xiao, Z., Sheng, B., Quanyong, H., Xuwei, P., 2014. Design and implementation of heterogeneous IOT gateway based on dynamic priority scheduling algorithm. Trans. Inst. Meas. Control 36 (7), 924–931. https://doi.org/10.1177/0142331214527600.

S. Tilkov, The modern cloud-based platform, IEEE Softw., vol. 32, no. 2, 2015, doi: 10.1109/MS.2015.51.

Al-Fuqaha, A., Khreishah, A., Guizani, M., Rayes, A., Mohammadi, M., 2015. Toward better horizontal integration among IoT services. IEEE Commun. Mag. 53 (9), 72–79. https://doi.org/10.1109/MCOM.2015.7263375.

Zachariah, T., Klugman, N., Campbell, B., Adkins, J., Jackson, N., Dutta, P., 2015. The internet of things has a gateway problem. HotMobile 2015–16th Int. Work. Mob. Comput. Syst. Appl., 27–32 https://doi.org/10.1145/2699343.2699344.

Serdaroglu, K.C., Baydere, S., 2016. WiSEGATE: wireless sensor network gateway framework for internet of things. Wirel. Networks 22 (5), 1475–1491. https://doi.org/10.1007/s11276-015-1046-5.

Ding, F., Song, A., Tong, E., Li, J., 2016. A smart gateway architecture for improving efficiency of home network applications. J. Sensors 2016, 1–10. https://doi.org/10.1155/2016/2197237.

Bai, Z.Y., Kuo, C.H., Wang, T.C., 2016. Design and implementation of an IoT multi-interface gateway for establishing a digital art interactive system. Int. J. Ad Hoc Ubiquitous Comput. 21 (3), 157–170. https://doi.org/10.1504/IJAHUC.2016.075376.

Karagiannidis, L., Misichroni, F., Damigos, Y., Tsertou, A., Amditis, A., 2016. A novel and interoperable communication gateway implementation for evacuation systems. 2016 Int Wirel. Commun. Mob. Comput. Conf. IWCMC 2016, 1045–1050. https://doi.org/10.1109/IWCMC.2016.7577203.

M. Abdelaal, M. Dandy, F. Dürr, K. Rothermel, and M. Abdelgawad, "GaaS: Adaptive cross-platform gateway for IoT applications, Proc. - 2019 IEEE 16th Int. Conf. Mob. Ad Hoc Smart Syst. MASS 2019, pp. 217–226, 2019, doi: 10.1109/MASS.2019.00034.

Petrolo, R., Morabito, R., Loscrì, V., Mitton, N., 2017. The design of the gateway for the Cloud of Things. Ann. des Telecommun. Telecommun. 72 (1–2), 31–40. https://doi.org/10.1007/s12243-016-0521-z.

Yacchirema, D.C., Esteve, M., Palau, C.E., 2017. Design and implementation of a Gateway for Pervasive Smart Environments. 2016 IEEE Int Conf. Syst. Man, Cybern. SMC 2016 - Conf. Proc., 4454–4459 https://doi.org/10.1109/SMC.2016.7844933.

Samie, F., Tsoutsouras, V., Bauer, L., Xydis, S., Soudris, D., Henkel, J., 2017. Computation offloading and resource allocation for low-power IoT edge devices. 2016 IEEE 3rd World Forum Internet Things WF-IoT 2016 (December), 7–12. https://doi.org/10.1109/WF-IoT.2016.7845499.

Ameer, H.R.A., Hasan, H.M., 2020. Enhanced MQTT Protocol by Smart Gateway. Iraqi J. Comput. Commun. Control Syst. Eng., 53–67 https://doi.org/10.33103/uot.ijccce.20.1.6.

Cha, M., Kwon, J.H., Kim, S.J., Shon, T., Kim, E.J., 2016. Data aggregation gateway framework for CoAP group communications. Symmetry (Basel) 8 (12), 1–18. https://doi.org/10.3390/sym8120138.

Woo, M.W., Lee, J.W., Park, K.H., 2018. A reliable IoT system for Personal Healthcare Devices. Futur. Gener. Comput. Syst. 78, 626–640. https://doi.org/10.1016/j.future.2017.04.004.

Tanganelli, G., Vallati, C., Mingozzi, E., 2018. Edge-centric distributed discovery and access in the internet of things. IEEE Internet Things J. 5 (1), 425–438. https://doi.org/10.1109/JIOT.2017.2767381.

Glória, A., Cercas, F., Souto, N., 2017. Design and implementation of an IoT gateway to create smart environments. Procedia Comput. Sci. 109, 568–575. https://doi.org/10.1016/j.procs.2017.05.343.

Guan, K., Shao, M., Wu, S., 2017. A remote health monitoring system for the elderly based on smart home gateway. J. Healthc. Eng. 2017, 1–9. https://doi.org/10.1155/2017/5843504.

Razafimandimby, C., Loscri, V., Vegni, A.M., Neri, A., 2017. "A Bayesian and smart gateway based communication for noisy IoT scenario. 2017 Int Conf. Comput. Netw. Commun. ICNC 2017, 481–485. https://doi.org/10.1109/ICCNC.2017.7876176.

Mastilak, L., Galinski, M., Kotuliak, I., Ries, M., 2018. Improved smart gateway in IoT. ICETA 2018–16th IEEE Int Conf. Emerg. eLearning Technol. Appl. Proc., 349–354 https://doi.org/10.1109/ICETA.2018.8572057.

H. Huang, H. Xu, Y. Cai, R. S. Khalid, and H. Yu, Distributed machine learning on smart-gateway network toward real-time smart-grid energy management with behavior cognition, ACM Trans. Des. Autom. Electron. Syst., vol. 23, no. 5, 2018, doi: 10.1145/3209888.

Morabito, R., Petrolo, R., Loscrì, V., Mitton, N., 2018. LEGIoT: a Lightweight edge gateway for the internet of things. Futur. Gener. Comput. Syst. 81, 1–15. https://doi.org/10.1016/j.future.2017.10.011.

Jabbar, W.A., Kian, T.K., Ramli, R.M., Zubir, S.N., Zamrizaman, N.S.M., Balfaqih, M., Shepelev, V., Alharbi, S., 2019. Design and Fabrication of Smart Home with Internet of Things Enabled Automation System. IEEE Access 7, 144059–144074. https://doi.org/10.1109/Access.628763910.1109/ACCESS.2019.2942846.

A. Javed, N. Yousefnezhad, J. Robert, K. Heljanko, and K. Framling, Access Time Improvement Framework for Standardized IoT Gateways, 2019 IEEE Int. Conf. Pervasive Comput. Commun. Work. PerCom Work. 2019, no. December 2018, pp. 220–226, 2019, doi: 10.1109/PERCOMW.2019.8730867.

Ray, P.P., Thapa, N., Dash, D., 2019. Implementation and performance analysis of interoperable and heterogeneous iot-edge gateway for pervasive wellness care. IEEE Trans. Consum. Electron. 65 (4), 464–473. https://doi.org/10.1109/TCE.3010.1109/TCE.2019.2939494.

S. Balasubramanian and T. Meyyappan, Enhancing the Computational Intelligence of Smart Fog Gateway with Boundary-Constrained Dynamic Time Warping Based Imputation and Data Reduction, 2019 3rd Int. Conf. Imaging, Signal Process. Commun. ICISPC 2019, pp. 15–23, 2019, doi: 10.1109/ICISPC.2019.8935698.

Ooi, B.-Y., Kong, Z.-W., Lee, W.-K., Liew, S.-Y., Shirmohammadi, S., 2019. A collaborative IoT-gateway architecture for reliable and cost effective measurements. IEEE Instrum. Meas. Mag. 22 (6), 11–17. https://doi.org/10.1109/MIM.528910.1109/MIM.2019.8917898.

F. L. De Caldas Filho, R. L. Rocha, C. J. B. Abbas, L. M. C. E. Martins, E. D. Canedo, and R. T. De Sousa, QoS scheduling algorithm for a fog IoT gateway, WCNPS 2019 - Work. Commun. Networks Power Syst., no. January 2020, 2019, doi: 10.1109/WCNPS.2019.8896311.

Maiti, P., Apat, H.K., Sahoo, B., Turuk, A.K., 2019. An effective approach of latency-aware fog smart gateways deployment for IoT services. Internet of Things 8, 100091. https://doi.org/10.1016/j.iot.2019.100091.

A. K. Sangaiah, A. A. R. Hosseinabadi, M. B. Shareh, S. Y. B. Rad, A. Zolfagharian, and N. Chilamkurti, "IoT resource allocation and optimization based on heuristic algorithm," *Sensors (Switzerland)*, vol. 20, no. 2, 2020, doi: 10.3390/s20020539.

Aloul, F., Zualkernan, I., Shapsough, S., Towheed, M., 2020. A Monitoring and Control Gateway for IoT Edge Devices in Smart Home. Int. Conf. Inf. Netw. vol. 2020-Janua, 696–701. https://doi.org/10.1109/ICOIN48656.2020.9016465.

Chenaru, O., Popescu, D., 2020. IoT gateway for personalized user comfort management in smart home applications. 2020 28th Mediterr Conf. Control Autom. MED 2020 (978), 921–926. https://doi.org/10.1109/MED48518.2020.9182926.

M. Aminul Hoque, M. Hossain, and R. Hasan, IGaaS: An IoT Gateway-as-a-Service for On-demand Provisioning of IoT Gateways, IEEE World Forum Internet Things, WF-IoT 2020 - Symp. Proc., no. April, 2020, doi: 10.1109/WF-IoT48130.2020.9221225.

Y. Du, G. Sun, B. Zheng, and Y. Qu, Design and implementation of intelligent gateway system for monitoring livestock and poultry feeding environment based on bluetooth low energy, Inf., vol. 12, no. 6, 2021, doi: 10.3390/info12060218.

Wu, F., Qiu, C., Wu, T., Yuce, M.R., 2021. Edge-based hybrid system implementation for long-range safety and healthcare IoT applications. IEEE Internet Things J. 8 (12), 9970–9980. https://doi.org/10.1109/JIOT.2021.3050445.

M. Aazam and E. N. Huh, Dynamic resource provisioning through Fog micro datacenter, 2015 IEEE Int. Conf. Pervasive Comput. Commun. Work. PerCom Work. 2015, pp. 105–110, 2015, doi: 10.1109/PERCOMW.2015.7134002.

T. Nguyen Gia *et al.*, Low-cost fog-assisted health-care IoT system with energy-efficient sensor nodes, 2017 13th Int. Wirel. Commun. Mob. Comput. Conf. IWCMC 2017, pp. 1765–1770, 2017, doi: 10.1109/IWCMC.2017.7986551.

Razouk, W., Sgandurra, D., Sakurai, K., 2017. A new security middleware architecture based on fog computing and cloud to support IoT constrained devices. ACM Int. Conf. Proceeding Ser. https://doi.org/10.1145/3109761.3158413.

Happ, D., Wolisz, A., 2017. "Towards gateway to Cloud offloading in IoT publish/subscribe systems", *2017 2nd Int*. Conf. Fog Mob. Edge Comput. FMEC 2017, 101–106. https://doi.org/10.1109/FMEC.2017.7946415.

H. Le, N. Achir, and K. Boussetta, Fog computing architecture with heterogeneous Internet of Things technologies, Proc. 2019 10th Int. Conf. Networks Futur. NoF 2019, pp. 130–133, 2019, doi: 10.1109/NoF47743.2019.9014960.

B. Sarma, G. Kumar, R. Kumar, and T. Tuithung, Fog Computing: An Enhanced Performance Analysis Emulation Framework for IoT with Load Balancing Smart Gateway Architecture, Proc. 4th Int. Conf. Commun. Electron. Syst. ICCES 2019, no. Icces, pp. 1–5, 2019, doi: 10.1109/ICCES45898.2019.9002172.

Wang, P., Ye, F., Chen, X., 2018. A Smart Home Gateway Platform for Data Collection and Awareness. IEEE Commun. Mag. 56 (9), 87–93. https://doi.org/10.1109/MCOM.2018.1701217.

M. Aazam and E. N. Huh, Fog computing and smart gateway based communication for cloud of things, Proc. - 2014 Int. Conf. Futur. Internet Things Cloud, FiCloud 2014, pp. 464–470, 2014, doi: 10.1109/FiCloud.2014.83.

S. M. Kim, H. S. Choi, and W. S. Rhee, IoT home gateway for auto-configuration and management of MQTT devices, 2015 IEEE Conf. Wirel. Sensors, ICWiSE 2015, pp. 12–17, 2016, doi: 10.1109/ICWISE.2015.7380346.

Santos, J., Rodrigues, J.J.P.C., Silva, B.M.C., Casal, J., Saleem, K., Denisov, V., 2016. An IoT-based mobile gateway for intelligent personal assistants on mobile health environments. J. Netw. Comput. Appl. 71, 194–204. https://doi.org/10.1016/j.jnca.2016.03.014.

Verma, P., Sood, S.K., 2018. Fog assisted-IoT enabled patient health monitoring in smart homes. IEEE Internet Things J. 5 (3), 1789–1796. https://doi.org/10.1109/JIOT.2018.2803201.

S. Kesavan and G. K. Kalambettu, IOT enabled comprehensive, plug and play gateway framework for smart health, Proc. 2018 2nd Int. Conf. Adv. Electron. Comput. Commun. ICAECC 2018, pp. 1–5, 2018, doi: 10.1109/ICAECC.2018.8479431.

Diyan, M., Nathali Silva, B., Han, J., Cao, Z.B., Han, K., 2020. Intelligent Internet of Things gateway supporting heterogeneous energy data management and processing. Trans. Emerg. Telecommun. Technol. no. January, 1–15. https://doi.org/10.1002/ett.3919.

Chaudhary, S.K., Yousuff, S., Meghana, N.P., Ashwin, T.S., Guddeti, R.M.R., 2021. A Multi-Protocol Home Automation System Using Smart Gateway. Wirel. Pers. Commun. 116 (3), 2367–2390. https://doi.org/10.1007/s11277-020-07795-0.

P. Bellavista, L. Foschini, and D. Scotece, Converging Mobile Edge Computing, Fog Computing, and IoT Quality Requirements, Proc. - 2017 IEEE 5th Int. Conf. Futur.

Internet Things Cloud, FiCloud 2017, vol. 2017-Janua, pp. 313–320, 2017, doi: 10.1109/FiCloud.2017.55.

Dolui, K., Kiraly, C., 2018. "Towards Multi-Container Deployment on IoT Gateways", *2018 IEEE Glob*. Commun. Conf. GLOBECOM 2018 - Proc. https://doi.org/10.1109/GLOCOM.2018.8647688.

A. A. Sadri, A. M. Rahmani, M. Saberikamarposhti, and M. Hosseinzadeh, Fog data management: A vision, challenges, and future directions, J. Netw. Comput. Appl., vol. 174, no. July 2020, p. 102882, 2021, doi: 10.1016/j.jnca.2020.102882.

Fitzgerald, E., Pioro, M., Tomaszwski, A., 2018. Energy-optimal data aggregation and dissemination for the internet of things. IEEE Internet Things J. 5 (2), 955–969. https://doi.org/10.1109/JIoT.648890710.1109/JIOT.2018.2803792.

Lu, R., Heung, K., Lashkari, A.H., Ghorbani, A.A., 2017. A lightweight privacy-preserving data aggregation scheme for fog computing-enhanced IoT. IEEE Access 5 (March), 3302–3312. https://doi.org/10.1109/ACCESS.2017.2677520.

bin Baharudin, A.M., Saari, M., Sillberg, P., Rantanen, P., Soini, J., Jaakkola, H., Yan, W., 2018. Portable fog gateways for resilient sensors data aggregation in internet-less environment. Eng. J. 22 (3), 221–232. https://doi.org/10.4186/ej10.4186/ej.2018.22.310.4186/ej.2018.22.3.221.

Alencar, B.M., Rios, R.A., Santana, C., Prazeres, C., 2020. FoT-Stream: A Fog platform for data stream analytics in IoT. Comput. Commun. 164 (August), 77–87. https://doi.org/10.1016/j.comcom.2020.10.001.

L. Santos, B. Cunha, I. Fé, M. Vieira, and F. A. Silva, Data Processing on Edge and Cloud: A Performability Evaluation and Sensitivity Analysis, J. Netw. Syst. Manag., vol. 29, no. 3, 2021, doi: 10.1007/s10922-021-09592-x.

Taneja, M., Jalodia, N., Davy, A., 2019. Distributed decomposed data analytics in fog enabled IoT deployments. IEEE Access 7, 40969–40981. https://doi.org/10.1109/Access.628763910.1109/ACCESS.2019.2907808.

Ghobaei-Arani, M., Souri, A., Rahmanian, A.A., 2020. Resource management approaches in fog computing: a comprehensive review. J. Grid Comput. 18 (1), 1–42. https://doi.org/10.1007/s10723-019-09491-1.

Matrouk, K., Alatoun, K., 2021. Scheduling algorithms in fog computing: a survey. Int. J. Networked Distrib. Comput. 9 (1), 59–74. https://doi.org/10.2991/IJNDC.K.210111.001.

Zahoor, S., Mir, R.N., 2021. "Resource management in pervasive internet of things: a survey. J. King Saud Univ. - Comput Inf. Sci. 33 (8), 921–935. https://doi.org/10.1016/j.jksuci.2018.08.014.

T. Le Duc, R. G. Leiva, P. Casari, and P. O. Östberg, Machine learning methods for reliable resource provisioning in edge-cloud computing: A survey, ACM Comput. Surv., vol. 52, no. 5, 2019, doi: 10.1145/3341145.

Chowdhury, A., Raut, S.A., 2018. A survey study on Internet of Things resource management. J. Netw. Comput. Appl. 120 (July), 42–60. https://doi.org/10.1016/j.jnca.2018.07.007.

Yang, X., Rahmani, N., 2021. Task scheduling mechanisms in fog computing: review, trends, and perspectives. Kybernetes 50 (1), 22–38. https://doi.org/10.1108/K-10-2019-0666.

Pourghebleh, B., Hayyolalam, V., Aghaei Anvigh, A., 2020. Service discovery in the Internet of Things: review of current trends and research challenges. Wirel. Networks 26 (7), 5371–5391. https://doi.org/10.1007/s11276-020-02405-0.

Ardagna, D., Casale, G., Ciavotta, M., Pérez, J.F., Wang, W., 2014. Quality-of-service in cloud computing: modeling techniques and their applications. J. Internet Serv. Appl. 5 (1), 1–17. https://doi.org/10.1186/s13174-014-0011-3.

Simiscuka, A.A., Bezbradica, M., Muntean, G.M., 2017. "Performance analysis of the Quality of Service-aware NETworking Scheme for sMart Internet of Things gatewayS", *2017 13th Int*. Wirel. Commun. Mob. Comput. Conf. IWCMC 2017, 1370–1374. https://doi.org/10.1109/IWCMC.2017.7986484.

G. Tanganelli, C. Vallati, and E. Mingozzi, Ensuring quality of service in the internet of things, Stud. Comput. Intell., vol. 715, no. October 2017, pp. 139–163, 2018, doi: 10.1007/978-3-319-58190-3_9.

F. Samie, V. Tsoutsouras, L. Bauer, S. Xydis, D. Soudris, and J. Henkel, Distributed Trade-Based Edge Device Management in Multi-Gateway IoT, ACM Trans. Cyber-Physical Syst., vol. 2, no. 3, 2018, doi: 10.1145/3134842.

Sahni, Y., Cao, J., Zhang, S., Yang, L., 2017. Edge mesh: a new paradigm to enable distributed intelligence in internet of things. IEEE Access vol. 5, no. c, 16441–16458. https://doi.org/10.1109/ACCESS.2017.2739804.

Seliem, M., Elgazzar, K., Khalil, K., 2016. Towards privacy preserving IoT environments: a survey. Wirel. Commun. Mob. Comput. 2018 (October), 2018. https://doi.org/10.1155/2018/1032761.

Lin, J., Yu, W., Zhang, N., Yang, X., Zhang, H., Zhao, W., 2017. A Survey on internet of things: architecture, enabling technologies, security and privacy, and applications. IEEE Internet Things J. 4 (5), 1125–1142. https://doi.org/10.1109/JIoT.648890710.1109/JIOT.2017.2683200.

Alwarafy, A., Al-Thelaya, K.A., Abdallah, M., Schneider, J., Hamdi, M., 2021. A survey on security and privacy issues in edge-computing-assisted internet of things. IEEE Internet Things J. 8 (6), 4004–4022. https://doi.org/10.1109/JIoT.648890710.1109/JIOT.2020.3015432.

Hassija, V., Chamola, V., Saxena, V., Jain, D., Goyal, P., Sikdar, B., 2019. A survey on IoT security: application areas, security threats, and solution architectures. IEEE Access 7, 82721–82743. https://doi.org/10.1109/Access.628763910.1109/ACCESS.2019.2924045.

El-Hajj, M., Fadlallah, A., Chamoun, M., Serhrouchni, A., 2019. A survey of internet of things (IoT) authentication schemes. Sensors (Switzerland) 19 (5), 1–43. https://doi.org/10.3390/s19051141.

Gharaibeh, A., Salahuddin, M.A., Hussini, S.J., Khreishah, A., Khalil, I., Guizani, M., Al-Fuqaha, A., 2017. Smart cities: a survey on data management, security, and enabling technologies. IEEE Commun. Surv. Tutorials 19 (4), 2456–2501. https://doi.org/10.1109/COMST.2017.2736886.

Ding, W., Jing, X., Yan, Z., Yang, L.T., 2019. A survey on data fusion in internet of things: Towards secure and privacy-preserving fusion. Inf. Fusion 51 (2), 129–144. https://doi.org/10.1016/j.inffus.2018.12.001.

Souri, A., Hussien, A., Hoseyninezhad, M., Norouzi, M., 2019. A systematic review of IoT communication strategies for an efficient smart environment. Trans. Emerg. Telecommun. Technol. https://doi.org/10.1002/ett.3736.

Masek, P., Hosek, J., Zeman, K., Stusek, M., Kovac, D., Cika, P., Masek, J., Andreev, S., Kröpfl, F., 2016. Implementation of true IoT vision: survey on enabling protocols and hands-on experience. Int. J. Distrib. Sens. Networks 12 (4), 8160282. https://doi.org/10.1155/2016/8160282.

Glaroudis, D., Iossifides, A., Chatzimisios, P., 2020. Survey, comparison and research challenges of IoT application protocols for smart farming. Comput. Networks 168, 107037. https://doi.org/10.1016/j.comnet.2019.107037.

J. Granados, A.-M. Rahmani, P. Nikander, P. Liljeberg, and H. Tenhunen, Towards Energy-Efficient HealthCare: an Internet-of-Things Architecture Using Intelligent Gateways, pp. 279–282, 2014, doi: 10.4108/icst.mobihealth.2014.257394.

T. N. Gia, M. Jiang, A. M. Rahmani, T. Westerlund, P. Liljeberg, and H. Tenhunen, Fog computing in healthcare Internet of Things: A case study on ECG feature extraction, Proc. - 15th IEEE Int. Conf. Comput. Inf. Technol. CIT 2015, 14th IEEE Int. Conf. Ubiquitous Comput. Commun. IUCC 2015, 13th IEEE Int. Conf. Dependable, Auton. Se, pp. 356–363, 2015, doi: 10.1109/CIT/IUCC/DASC/PICOM.2015.51.

Banaie, F., Misic, J., Misic, V.B., Yaghmaee Moghaddam, M.H., Hosseini Seno, S.A., 2019. Performance analysis of multithreaded IoT gateway. IEEE Internet Things J. 6 (2), 3143–3155. https://doi.org/10.1109/JIoT.648890710.1109/JIOT.2018.2879467.