Computer Networks 148 (2019) 241–261

Contents lists available at ScienceDirect

Computer Networks

journal homepage: www.elsevier.com/locate/comnet

Internet of Things applications: A systematic review

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ARTICLE INFO

Article history:
Received 7 July 2018
Revised 23 November 2018
Accepted 7 December 2018
Available online 10 December 2018

Keywords:
Application-based services
Internet of things
Systematic literature review
Smart objects
Quality of service

ABSTRACT

Internet of Things (IoT) is considered as an ecosystem that contains smart objects equipped with sensors, networking and processing technologies integrating and working together to provide an environment in which smart services are taken to the end users. The IoT is leading numerous benefits into the human life through the environment wherein smart services are provided to utilize every activity anywhere and anytime. All these facilities and services are conveyed through the diverse applications which are performed in the IoT environment. The most important utilities that are achieved by the IoT applications are monitoring and consequently immediate decision making for efficient management. In this paper, we intend to survey in divers IoT application domains to comprehend the different approaches in IoT applications which have been recently presented based on the Systematic Literature Review (SLR) method. The aim of this paper is to categorize analytically and statistically, and analyze the current research techniques on IoT applications approaches published from 2011 to 2018. A technical taxonomy is presented for the IoT applications approaches according to the content of current studies that are selected with SLR process in this study including health care, environmental monitoring, smart city, commercial, industrial and general aspects in IoT applications. IoT applications are compared with each other according to some technical features such as Quality of Service (QoS), proposed case study and evaluation environments. The achievements and disadvantages of each study is discussed as well as presenting some hints for addressing their weaknesses and highlighting the future research challenges and open issues in IoT applications.

1. Introduction

In recent years, the Internet of Things (IoT) has penetrated pervasively into the most aspects of human life everywhere such as cities, homes, universities, industrial factories, organizations, agriculture environments, hospitals and health-care centers [1–4]. Numerous capabilities such as produce/consume data and online services, improve daily life and activities around the world through the IoT context [5]. The facilities and smart services are carried through the various applications which are performed in the IoT environment [6]. As users' desires grow, innovative applications are being provided for monitoring, managing and automating human activities [7,8]. Also, IoT applications apply cloud service computing for achieving proper composite services via composition of existing atomic services for service-based applications in the IoT context [9,10]. IoT scenarios are applied to applications with smart devices which users apply them in their daily activities in various fields. Also, IoT applications have some benefits for users to choose the best opportunity in any case, decision making, managing, and monitoring environmental cloud resources [11].

Despite the different application domains' motivations, all of them have a shared and common goal: provisioning smart services to increase the quality of human life [12,13]. The main concern of IoT applications is satisfying Quality of Service (QoS) metrics. User's requirements should be supported by smart services in IoT applications that cover the QoS metrics such as security, cost, service time, energy consumption, reliability and availability.

There are some technical surveys and review papers that do not concentrate on the IoT applications systematically [14,15]. The main aim of this research is to survey in different IoT applications to comprehend the diversity of approaches in IoT applications which have been recently presented. The key approaches of IoT applications that have been focused in selected studies consist of health-care, environmental monitoring, smart city, commercial, industrial and general approaches. We present a Systematic Literature Review (SLR) method and overview opportunities of the IoT applications. The main commitments of this study are highlighted as follows:

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https://doi.org/10.1016/j.comnet.2018.12.008
1389-1286/

Table 1
Related studies in IoT applications.

Reference	Main topic	Publication year	Covered years
Li et al. [15]	IoT technology	2015	–
Han et al. [16]	IoT smart objects	2015	–
Ray [17]	IoT architectures	2016	–
Bello and Zeadally [12]	IoT services	2017	2004–2017
Talavera et al. [5]	IoT in environmental and agro-industrial fields	2017	2006–2016

- Designing a technical taxonomy to classify the various IoT applications.
- Presenting a discussion of the key challenges for the applications approaches in IoT environment.
- Highlighting the future research challenges and open issues in IoT applications.

The organization of this review is considered as follows: The related works are presented in Section 2. Section 3 provides a research selection technique and motivation regarding the SLR process. Section 4, outlines the applications approaches in IoT systematically and categorizes them. Also, in this section a technical taxonomy and comparison of the approaches for selected papers is presented. In Section 5, a discussion is provided on the IoT applications that have not been analyzed comprehensively up to now. Finally, Section 6 demonstrates the conclusion along with the paper restrictions.

2. Related work

This section presents a momentary explanation of the related work studies in IoT applications.

Bello and Zeadally [12] discussed the existing networking standards in the IoT environment to clarify how they can afford to satisfy the QoS necessities of objects to make the smarter IoT ecosystem. Furthermore, an analysis on diverse applications and the risk of lack of cross-domain integration in the IoT environment was presented to realize to fulfill the interoperability and QoS requirements such as availability, reliability, scalability and security for providing the IoT services. The strong point of this study is to present a classification of various recent standards in the network layer and application layer in diverse areas including building, transportation, smart city, business and grid systems. The main deficiencies of this study are the absence of presenting any statistical information about discussed standards applied in different stated domains and similarly not giving any statistic chart for the risk analysis of the lack of interoperability between IoT objects and transport protocols to illustrate briefly the judgments.

Talavera et al. [5] surveyed on IoT applications in environmental and industrial agriculture. In this review paper four area including prediction, monitoring, control and logistics, are considered. Two important subjects are mentioned and answered in this study. The first one is about the fundamental technological efforts in IoT-based applications for agro industrial and environmental issues, and the second one is about the infrastructures and technologies used in the mentioned solutions. It is derived that the maximum of the papers were concentrated on monitoring (62%), and then control (25%), logistics (7%), and prediction (6%). Furthermore, according to the second question mentioned in this survey, it is realized that the most technologies and Infrastructures applied in the IoT agro industrial and environmental applications, categorized in seven sets including visualization approaches, storage approaches, edge computing technologies, communication techniques, power sources, actuators and sensing variables. The mentioned open issues in this review contain these topics: robust standardization, improved power consumption, security, reusability of software and hardware components, decrease cost, appropriate compatibility with existing infrastructures and scalability issues. The authors presented an architecture for the IoT agro industrial and environmental applications. The offered model consists of four layer including application, service, communication and physical layer. The advantage of this study is presenting beneficial and comprehensive statistics about the studies and efforts in the agro industrial and environmental applications in the IoT context. The weakness of this paper is that the explanation of the related works is not sufficient.

Han et al. [16] presented a review on problem of service composition of Internet Protocol (IP) smart IoT objects. The authors provided a full investigation based on some issues such as smart IoT objects systems, service modeling, target applications, target platforms and service composition approaches for the IPs in IoT The main weakness of this survey is that the evaluation factors including availability, response time, cost, and scalability as important quality factors were not analyzed.

Li et al. [15] provided a survey in IoT major techniques. This review discussed architecture layers including perception layer, network layer, service layer and the interface layer. The advantage of this review is presenting comprehensive open issues and challenges in the IoT, however, the compatibility of each approach in the IoT applications was not considered.

A survey on IoT was presented by Ray [17]. This study discusses about the topics such as Service Oriented Architecture (SOA), WSN, health-care systems and social computing. The main defect of this study is not providing any analysis on evaluation parameters such as availability, energy consumption, cost, response time and reliability as quality factors in this area.

Table 1 represents a summary of the related review studies on the IoT applications issues with respect to the systematic literature review and survey studies. The core subject, publication year and covered years are listed for each study in this table.

According to the existing review papers, the existing deficiencies propose that we provide a comprehensive literature review to address these weaknesses as follows:

- The present studies do not provide any analytical assessment and taxonomy for application approaches in IoT.
- Some studies do not evaluate the important assessment factors on applications in IoT.
- The structure of the presented studies does not have the systematic arrangement and the paper selection method is not clear.

3. Research selection method

This section provides a review based on SLR method as a research study assessment for classifying the IoT applications [18–20].

Considering the alternatives and other synonyms of the key essential components, the subsequent exploration string was defined [21–26]:

- (“Application” OR “Software” OR “Application-based” OR “Application layer” OR “App”) AND (“IoT”) OR (“Internet of Things”)

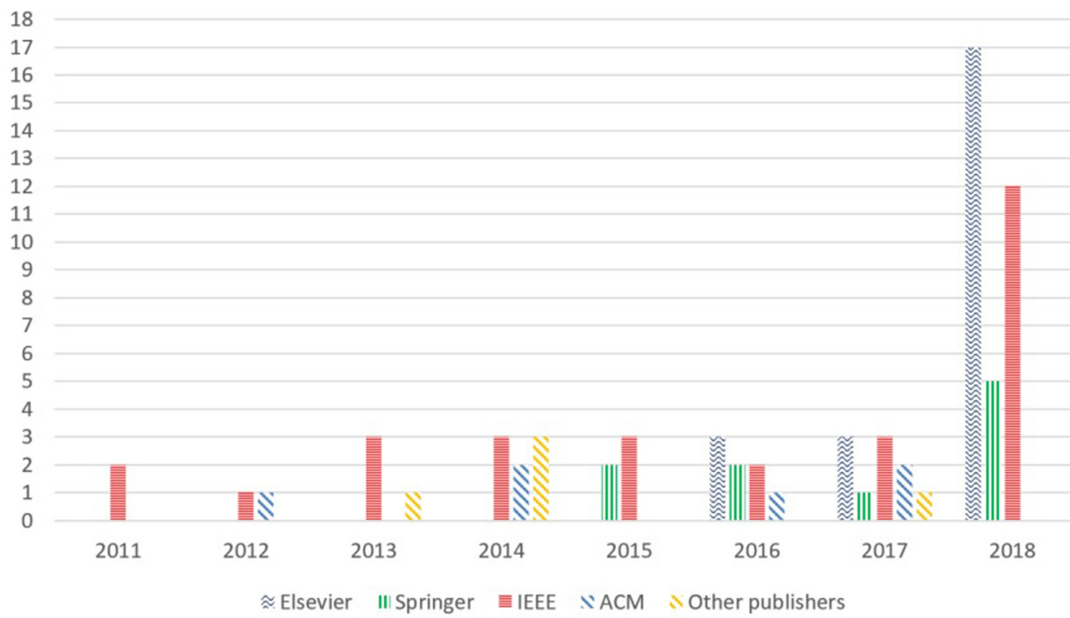

Fig. 1. Distribution of research papers by publisher.

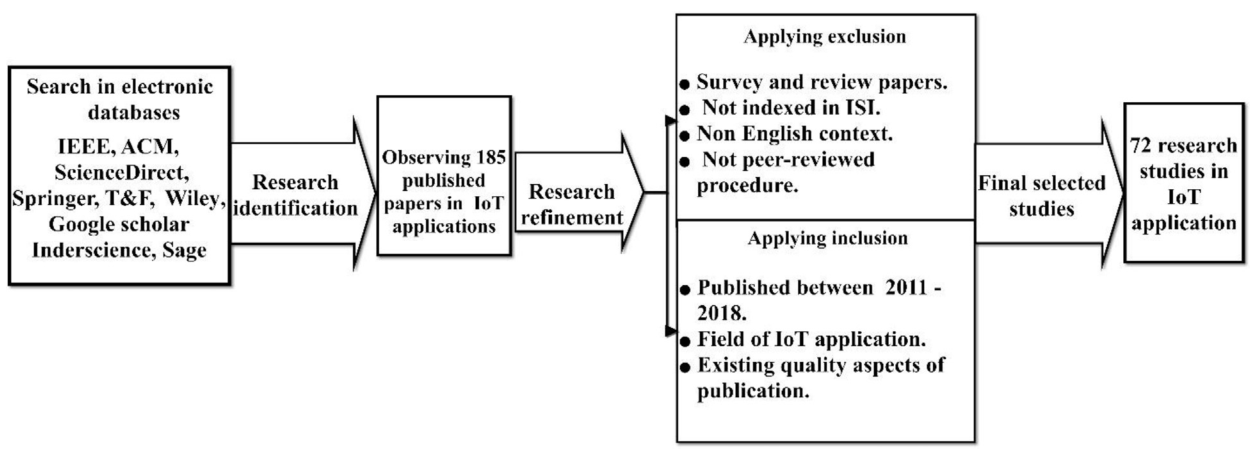

Fig. 2. The selection criteria and evaluation chart of research studies.

This SLR paper presents inclusive answers to the following Analytical Questions (AQ) regarding the aims of this research [27]:

- AQ1: Which domains are categorized in IoT applications?
- AQ2: Which main contexts are considered for IoT applications?
- AQ3: What measurement environments are used for evaluating the IoT applications?
- AQ4: What are the evaluation factors usually applied in IoT applications?
- AQ5: What are the future researches directions and open perspectives of IoT applications?

Fig. 1 shows the distribution of the research studies completed by the leading scientific publishers regarding the article citations and review method, including Elsevier, IEEE, Springer, ACM, Wiley and Taylor & Francis. In this organization, scientific electronic databases including IEEE Xplorer and Science Direct are applied in the SLR method.

After providing the analytical questions, the inclusion/exclusion criteria for the ultimate research selection was applied. Regarding the number of published papers, we just analyze the journal articles and conference papers indexed in WoS and ISI proceedings as the peer-reviewed papers for the applications approaches in IoT. Finally, 72 peer-reviewed papers were selected for analyzing and answering the mentioned analytical questions which are presented in detail in Section 4.

Fig. 2 shows the selection principles and evaluation flowchart designed for the studies. The exclusion phase consist of ignoring non-peer-reviewed researches, short papers, white papers, book chapters, and low-quality studies (published in predatory journals) that did not present any scientific discussion and technical information. For mapping the final selected studies, the inclusion principles are considered as follows:

- The studies available online between 2011 and 2018.
- The studies in IoT applications topics.
- The studies with a technical quality method in IoT applications.
- Studies using existing quality aspects.

For mapping the final selected studies, the exclusion principles are considered as follows:

- The studies presenting review and survey papers.
- The studies not indexed in WoS and ISI.
- The studies not written in English language.
- The studies not peer-reviewed process.

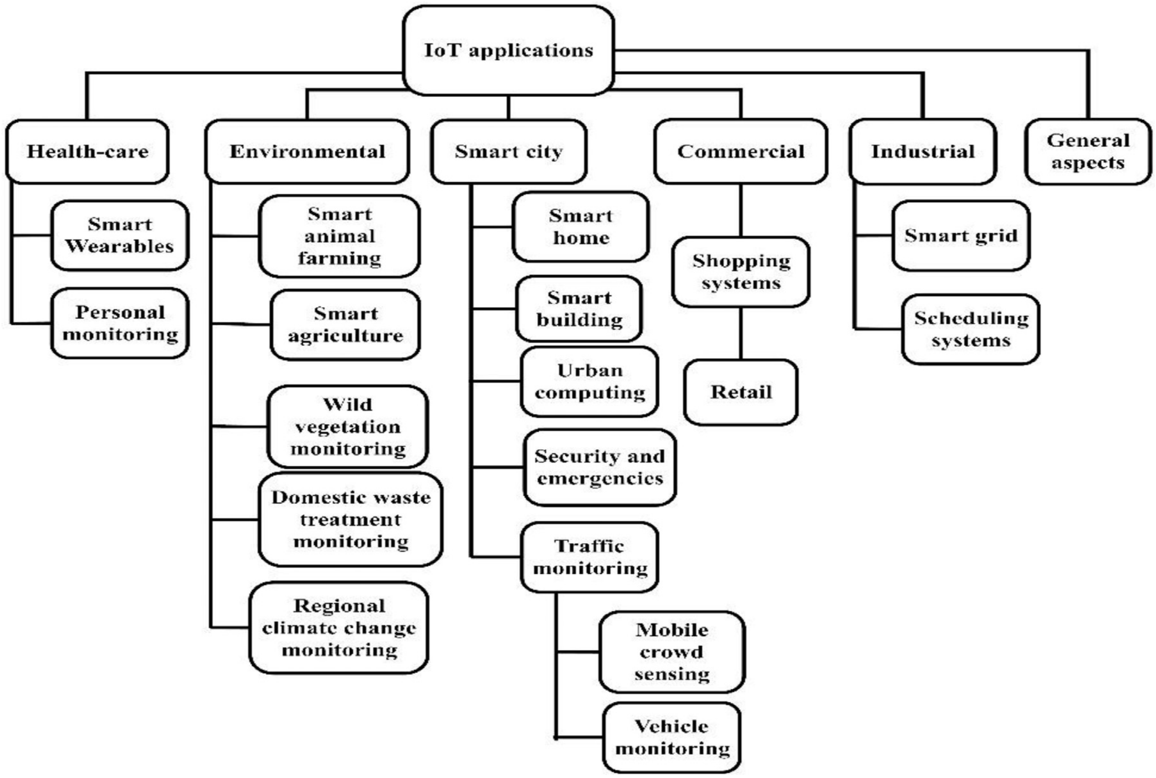

Fig. 3. The taxonomy of IoT applications.

4. Organization of the IoT applications

This section presents a technical review of the selected IoT applications for the existing studies according to the applied SLR process. Fig. 3 shows a comprehensive taxonomy on the IoT applications that include health-care, environmental, smart city, commercial, industrial and general aspects [28,29]. Since, in each type of IoT applications, some problems can potentially emerge that should be focused to find effective solutions to make the IoT applications more efficient and applicable in the real IoT environments, we review the papers that try to address some issues to support the IoT applications in a particular domain. For example, in smart city applications, the key subjects such as semantic-aware mobile crowd-sensing, vehicular monitoring, location finding, context-aware or QoS-aware service composition, scalable IoT platforms, managing scalable heterogeneous data streams and many other issues arise in various aspects of smart city IoT applications. Therefore, the presented taxonomy in this paper is based on different types of IoT applications in which particular subjunctives were discussed and addressed in the selected research papers. Regarding the challenges and concerns in different categories of IoT applications, firstly, we concentrate on type of the IoT applications, and then we try to study the main context focused in the selected papers. Since, some concerns are general in the IoT applications, we introduce a category in our taxonomy named *"general aspects"*, to classify the papers which presented an approach to cope with a specific challenge for supporting any type of IoT application. Of course, the general aspects in the proposed taxonomy are applied in all IoT application domains such as applied and systematical software, evaluation procedure or performance prediction of IoT applications [30]. In other words, the illustrated studies of the general aspects presented a novel conceptual approach for using in development any type of IoT application.

The following subsections illustrate the different approaches in IoT applications. Also, the different studies will be compared in several sides such as the specified main context, case studies, advantages, weaknesses and finally the particular outputs.

4.1. Health-care applications

Kim and Kim [31] provided a guide for IoT health-care service providers based on the users' view point. In this study some important offered attributes, have further impacts on users' confirmation of such services. An analysis was performed to evaluate the suggested factors such as trust and risk sensitivity to qualify the services. In this study by focusing on lifestyle disease, the results exposes that in South Korea people prefer trustworthy and safe health-care services. The advantage of this work is to give a simple and new guide for IoT health-care service producers and improve the reliability. The weakness of this study is that the extracted results are based on the hypothetical service description instead of commercial service applied by the health-care user. Also the other deficiency is that the response time is not evaluated.

Fafoutis et al. [32] proposed a platform to develop a monitoring system to detect and prevent chronic medical conditions including diabetes, obesity or depression in today life in a residential environment. In this work, as a result of the related costs of recharging or replacing the batteries of the wearable devices, the issue of energy limitations is considered. In this paper, only the solutions which focus on battery-powered are taken into account. By deploying the asymmetry of the network resources, the energy efficiency of the wearable hardware is correspondingly improved. The proposed system is relied on Bluetooth low power and also is a portion of a residential platform which is equipped with video cameras on body and ecological sensors for distinguishing to realize immediate perceptive and making decision by means of machine learning techniques. To evaluate the proposed framework, a prototyped wearable hardware and three prototyped receiver units were applied. The advantages of this paper are improving the energy feeding of the wearable devices and also enhancing the reliability of the proposed system. Furthermore, the precision of the RSSI and the transmission power is evaluated. The weakness of this work is that the response time is not assessed.

Jimenez and Torres [33] developed a prototype as an IoT healthcare monitoring system which could be extended in duration of use. In this work, the system was developed by means of low cost sensors and existing IoT platform which exist commonly in homes. The presented ad-hoc monitoring system checks the patient's biological factors and the environmental data such as humidity and temperature that sensed by either present sensors or the new sensors, are added during the system execution time. In this paper, smart phones are considered as gateways for collecting the mentioned information from sensors at patient's environment. The offered health-care monitoring system is used for collecting business necessities in actual circumstances to evaluate the performance and scalability of the presented prototype. The advantage of this work is using low cost sensors and low energy consumption devices that exist typically in homes. The weakness of this system is to satisfy just minimum service level according the collected business requirements.

Ding et al. [34] proposed an IoT system for remote mobile medical monitoring. The authors suggested a model of the human interaction and physiological parameters by using intelligent nodes. The offered system is implemented for developing the efficient emergency alarm systems by saving the critical emergency information in hospital database. The advantages of this work are improving the rapidity and precision of the physiological factors measurement and also using low power consumption devices. The weakness of this work is that the cost was not considered.

Savola et al. [35] offered a high-level adaptive mechanism for security management with respect to security metrics. For presenting this idea the security intentions of E-health IoT applications particularly for health of aged people and the treatment of lasting diseases, are analyzed. Furthermore, in this paper, the requirements of adaptive security management and decision-making, which are necessary to set the security needs, and also applying the sufficient security controls in condition of changing security threats in such applications, are discussed. The presented mechanism for adaptive security management considers several security factors such as security accuracy, effectiveness, efficiency, privacy level and confidentiality. The main advantage of this study is improving the security intentions of E-health IoT applications. The weakness of this work is the absence of any detailed analysis of security metrics and adaptive decision-making algorithm in such E-health IoT applications.

Baloch et al. [36] proposed a layered context-aware data combination approach for IoT health-care applications. The proposed approach consists of context attainment, condition structure and implication. In this paper, it is explained that Body Sensor Networks (BSN) or Wireless Body Area Networks (WBAN) that are ordinarily positioned to the patient's body to accumulate physiological data for IoT health-care applications. As the data are collected from multiple heterogeneous sources, a technique for combining these datasets is necessary which is known as “data fusion”. In this paper, a novel approach presented for demonstrating the collected data in a way that assistances taking on time precise decision. The advantage of this study is addressing some challenges such as sensor deficiency, limited coverage, irregularity and ambiguity. The weakness of this paper is that not presenting any specific algorithm to evaluate the suggested approach.

Subrahmanyam et al. [37] proposed a least error adjusted IEEE 802.15.4 transceiver for health-care applications in IoT environment. In this paper, an improved frequency offset evaluator suggested with better performance of error modification than the current assessors for IEEE 802.15.4. The advantage of this study is a considerable improving in bit error amount and packet error frequency of the offered transceiver in contrast to the standard architecture. Also, another achievement of this paper is decreasing power consumption as a result of fewer number of retransmission in each packet for successful broadcast of the packet.

Lin et al. [38] developed a novel paradigm for sensor tasking such as choosing to detect sensors in Cognitive Radio Sensor Networks (CRSNs). Also, in this study, a conceptual attitude of the suggested model in contradiction of the Primary User Emulation Attack (PUEA) is proposed. The advantage of offered approach is improving the effectivity of attack detection. The main weakness of this paper is that not considering the reliability and operability of the scheme according to the influence of node movement on detection performance.

Damis et al. [39] presented an analysis for three epidermal loop antennas in theoretical and experimental aspects for measuring biological factors in order to apply in health-care IoT applications. In this study, Error-Vector Magnitude (EVM) examinations and BER factors are showed and evaluated, correspondingly, to validate the truth of GSM and BLE communications for the QL antennas. Experimental results show proper dependability between radiation forms and refection factor. Data communication assessments represented that the attained BER could be suitable for this antenna technology to operate in a 4- QAM wireless connection.

Elappila et al. [40] presented a routing algorithm for WSN based on congestion and interference awareness of energy efficiency. The proposed technique was developed to operate in the networks with heavy traffic and interference on the connection among the nodes for the reason that several IoT objects deliver their data to a same target, which is a usual situation in the IoT monitoring applications. The proposed algorithm applies a function for choosing the next party node which works with three parameters: (1) signal to interference and noise ratio of the connection (SNIR), (2) the survivability parameter of the route from the next party node to the endpoint, and (3) the congestion degree at the next party node. The acquired results from simulation show improvement in network throughput, packet broadcasting ratio, energy consumption of the nodes and also decreasing the amount of the lost packets.

Jebadurai and Dinesh Peter [41] proposed an architecture for IoT healthcare applications in order to process retinal images which captured by smartphone funduscopy. An algorithm based on super-resolution (SR) using kernel Support Vector Regression (SVR) method, was offered to increase the quality of the images. The outcomes display that the suggested algorithm executes more efficient in comparison to other present super resolution algorithms.

Malik et al. [42] presented an analysis on performance of narrow band IoT (NB-IoT) which provides heavy communications with low data rate for long lifetime batteries and simple sensors, in IoT health-care applications. The main aim of this paper is to analyze the latency and throughput of NBIoT in health-care monitoring applications.

4.1.1. Analysis of the reviewed health-care applications

Table 2 shows the classification of the above papers and the important aspects to evaluate the health-care approach in IoT applications. The most important main contexts in the health-care approach are based on the user preferences for lifestyle disease management, residential maintenance-free long-term activity monitoring, home monitoring by remote mobile medical and metrics-driven adaptive security management.

Table 3 presents a side by side evaluation for the above studies applying the evaluation elements in health-care IoT applications. The parameters consist of availability, response time, energy consumption, cost, reliability, security and throughput. In the health-care approach, most research studies assessed their offered approach in the response time, cost and energy consumption properties.

Table 2
Classification of recent studies and other information in health-care applications.

Research	Main context	Advantage	Weakness	New finding
Kim and Kim [31]	User preference for lifestyle Disease management	–Easy to use –Improving reliability	–The extracted results were based on the hypothetical service description –Not considering response time	–Guide for IoT health-care service providers
Fafoutis et al. [32]	Residential maintenance-free long-term Activity monitoring	–Low energy consumption –High reliability –Considering the accuracy of the RSSI and the transmission power	–Not considering response time	–Platform
Jimenez and Torres [33]	IoT-aware health-care monitoring system	–Using low cost sensors Low energy consumption	–Satisfying just minimum service level	–Architecture –Prototype
Ding et al. [34]	home monitoring system by remote Mobile medical	–Improving the rapidity and precision of the physiological factors measurement –Low energy consumption	–Not considering cost	–Platform –Architecture –Prototype
Savola et al. [35]	Metrics-driven adaptive security management	–Improving security	–Not presenting any detailed analysis	–Adaptive security management model
Baloch et al. [36]	Context-aware data synthesis method for e-Health	–High availability	–Not any simulation or implementation	–Framework
Subrahmanyam et al. [37]	Minimal fault IEEE 802.15.4 transceiver	–High probability –Minimum error rate	–Static environment –High complexity	–Architecture
Lin et al. [38]	Two-tier authentication protocol	–Low delay rate –Low response time	–Low scalability –Low reliability	–Framework –Algorithm
Damis et al. [39]	A biotelemetry application	–Low cost –Low energy consumption	–Low scalability	–Implementation –Algorithm
Elappila et al. [40]	Survivable energy efficient routing algorithm	–Low energy consumption	–High time complexity –High cost	–Implementation –Algorithm
Jebadurai and Dinesh Peter [41]	Super resolution algorithm for image health-care	–Low cost –Low response time	–Low scalability	–Framework –Algorithm
Malik et al. [42]	Health-care monitoring application	–Low response time –Low delay rate	–High cost	–Algorithm

Table 3
Comparison of the existing evaluation factors in the health-care applications.

Research	Availability	Response time	Energy Consumption	Cost	Reliability	Security	Throughput
Kim and Kim [31]	✗	✗	✗	√	√	✗	✗
Fafoutis et al. [32]	✗	✗	√	√	√	✗	✗
Jimenez and Torres [33]	√	✗	√	√	✗	✗	✗
Ding et al. [34]	✗	√	√	✗	✗	✗	✗
Savola et al. [35]	√	√	√	✗	√	✗	✗
Baloch et al. [36]	√	✗	✗	✗	✗	✗	✗
Subrahmanyam et al. [37]	✗	√	✗	√	✗	✗	✗
Lin et al. [38]	✗	√	✗	✗	✗	√	✗
Damis et al. [39]	✗	√	√	✗	✗	✗	✗
Elappila et al. [40]	✗	√	√	√	✗	✗	√
Jebadurai and Dinesh Peter [41]	✗	√	✗	√	✗	✗	✗
Malik et al. [42]	✗	√	✗	√	✗	✗	√

4.2. Environmental applications

This subsection illustrates the environmental approach in IoT applications. In addition, the different studies will be compared in several sides such as the main context, case studies, advantages, weaknesses and finally the particular outputs.

Li et al. [43] proposed an online IoT monitoring system based on wireless sensor network for henhouses to control the environmental factors such as temperature, humidity, CO2 and NH3. In this paper, it is claimed that in earlier researches, most of the concentrations are on developing the systems in which the reliability of wireless data transmission is not considered. In this paper, to solve this issue, a wireless transport protocol is offered according to the loss recovery approach. Correspondingly, online lost data filling and duplicated data auto filtering for estimating node data and increasing the integrity of the proposed system, are performed. Furthermore, a web based remote monitoring system, according to the remote monitoring requirement, was designed in order to allow users to access the obtained information by means of smart mobile phones or personal computers for controlling the henhouse environment through an efficient interactive user interface. The main advantage of this work is the innovation in presenting an IoT-henhouse monitoring system focusing on improving the reliability wireless data transmission. Also, other improvements of this work are increasing the data gathering accuracy and the integrity of the system besides decreasing maintenance cost and low updating. The main weakness of this work is that the energy consumption is not evaluated.

Ye et al. [44] designed and developed an IoT Precision Agriculture Management System (PAMS) using WebGIS. In this study, four architectures are presented including the mobile objects and three platforms for the agriculture managing and the infrastructures for IoT and environmental information. The presented system is based on four main techniques including: (1) IoT, (2) WebGIS technique which provides three distinct platforms for geographic data, positioning and mobile control for the IoT, (3) communication and network technique and (4) Location Based Service (LBS) which is using GIS for geographic positioning of mobile objects as an information service. The presented system performs several activities such as gathering and processing the environment data during the process of agricultural production, monitoring and demonstrating the farmland videos, managing agricultural production, remote operating on farm devices and finally information broadcasting and feedback which all these activities are done over IoT. The main advantage of this work is to simplify the development such systems in low cost and high productivity through the open source characteristic and integration technique of software components in the presented system.

Zhang [45] presented an IoT environmental monitoring and protecting system according to the heterogeneity of communication networks which supports diverse protocols. Due to the different communication cost of transmission devices in the various communication networks, it is essential to propose applicable and operative transmission policies. Furthermore, the energy consumption is a significant issue in heterogeneous networks. In this paper, a power controlling pattern is presented which is able to decrease the energy consumption of the presented system. According to the claimed issue, three categories of nodes including high performance, medium performance and low power nodes that apply orderly 3G, WiFi and Zigbee, are used. The advantages of this work are reducing the communication workload through achieving high reliability and reducing the energy consumption by using the suggested system. The weakness of this work is that the scalability is not supported, yet it seems to be an essential issue for environmental monitoring and protecting system.

Kim et al. [46] presented a platform for ecological monitoring system based on IoT, for wild vegetation community, regarding the climate changes. In this work, low power consumption WSN is used for the proposed system architecture. For monitoring the wild vegetation environment, several important factors such (a) soil conditions including soil moisture and temperature, (b) habitat environment including temperature, humidity, illumination, CO2 and tilt, and finally (c) growth conditions such as tree diameter and sap flow, are considered. The suggested conceptual model for the monitoring system includes several layers such as ecological monitoring sensor networks, wire and wireless communication infrastructure, ecological data server, service platform, application services and finally, user layer. To evaluate the proposed platform, a prototype was developed and examined on a test-bed employed to wild trees. The weakness of this paper is that there is not any statistics to prove the efficiency and performance of the proposed model.

Qiu et al. [47] proposed an IoT intelligent monitoring platform in agriculture environment. The presented solution consists of four layer which are (1) the sensor layer including geometric sensors to gather environmental data in agricultural production, (2) the transmission layer for delivering the gathered data from sensor layer through internet technology, (3) the control layer for analyzing the data and monitoring the agricultural production task by means of adapting control method and (4) the application layer for providing an interactive interface which shows the business logic of agriculture. The advantage of the proposed framework is the proper level of flexibility and reliability. It seems that the proposed solution needs to become more mature in order to use in scalable operational environments.

Jing-yang et al. [48] suggested an application-based IoT platform on the local discarded action and dumping for online restriction monitoring and traceability. This platform is performed to real-time management and monitoring according to smart devices of the IoT that includes three main layers: smart application layer, transportation layer and perception layer. The smart application layer covers some intelligent sub-applications for navigating the statistical data analysis and environmental monitoring. The transportation layer communicates between information and existing networks of IoT, that are classified as network access platforms. The perception layer realizes and captures the existing information collection using smart sensors, GPS and RFID technologies. The advantage of the presented work is high efficiency and accuracy. The weakness of this paper is that some important factors such as low cost, low power feeding, decreasing the number of wireless sensors and management of technical standards are not considered.

Fang et al. [49] presented an Integrated Information System (IIS) architecture with respect to some main IoT technologies to refine the environmental monitoring efficiency and navigation of tasks using smart devices, RFID technology and wireless sensor network. The proposed architecture has four main layers including the perception layer for data gathering of physical aspects of environment, the network layer for transmitting the information and the association of things, the middleware layer to interact with application layer and network layer using real-time active database, and finally, the application layer for performing the environmental management by observation aspects using IoT devices. To evaluate the proposed architecture, the statistical analysis was considered to illustrate the comparison of the regional and environmental factors such as temperature and ecological responses. The main advantages of this work are as follows: improving data gathering of the environmental monitoring using IoT devices, increasing the interaction of the web services and applications to manage the decision making and efficiency of the monitoring environmental processes. The main defect of this research is omitting the type and number of the IoT devices to collect the environmental information.

Cheng et al. [50] addressed the challenging issue of precise and reasonable $PM_{2.5}$ real-time checking through a new cloud-based data analytics viewpoint at low cost. In this work, in order to support providing a model for regulating the proposed system called AQMs & miniAQMs and inferring $PM_{2.5}$ concentrations, environmental data and other types of cloud data should be collected. The experimental results show the improvement of 53.6% in a physical deployment applying the proposed cloud-based Air-Quality Analytics Engine. The advantage of this work is the scalability of the proposed system that makes it applicable for using in a large number of AQMs all over a city with dense handling spatially.

Mao et al. [51] presented a real-time CO_2 measuring system by sensor networks in an urban area. The proposed system named CitySee, addresses the issues including sensor distribution, data gathering, data processing, and network handling. In this work, the main problem which emphasized was the sensor deployment issue with some key problems including satisfying data representability, coverage and connectivity. Evaluation results show the performance of the proposed approach which implemented in a real environment.

4.2.1. Analysis of the reviewed environmental monitoring applications

Table 4 shows the classification of the above papers and the important aspects to evaluate the environmental monitoring approach in IoT applications. The case studies in this approach include henhouse, agriculture environment monitoring, wild vegetation environment monitoring, domestic waste treatment and disposal management, and regional climate change monitoring systems.

Table 5 describes an evaluation for the above studies applying the evaluation elements in environmental IoT applications. The following parameters include availability, response time, energy consumption, cost and reliability. In the environmental approach, most research papers assessed their suggested approach in response time, cost and reliability factors.

4.3. Smart city applications

Montori et al. [52] suggested a service composition architecture in IoT smart cities which is named SenSquare.[1] The proposed

[1] https://github.com/alainrk.

Table 4
Classification of recent studies and other information in the environmental monitoring applications.

Research	Main context	Case study	Advantage	Weakness	New finding
Li et al. [43]	Monitor multiple environmental factors of henhouses in modern chicken farms	Henhouse system	–Improving the reliability wireless data transmission –Increasing the data gathering accuracy –Increasing the integrity of the system –Decreasing maintenance cost –Low updating	–Not evaluating the energy consumption	–Prototype
Ye et al. [44]	IoT precision agriculture management system using WebGIS	Agriculture environment	–Simplify development –Low cost –High productivity	–Not evaluating the energy consumption	–Architecture –Platform
Zhang [45]	Heterogeneity of communication network with various protocols	Environmental monitoring	–Reducing communication workload –High reliability –Reducing energy consumption	–Not supporting the scalability	–Prototype –A power controlling pattern
Kim et al. [46]	Ecological monitoring system based on IoT	Wild vegetation environment monitoring	–Low power consumption	–Not presenting statistics to prove the model	–Platform –Prototype
Qiu et al. [47]	IoT intelligent monitoring platform in agriculture environment	Agriculture environment	–Proper flexibility –Improving reliability	–Not supporting scalability	–Platform –Architecture
Jing-yang et al. [48]	Domestic waste treatment and disposal management	Domestic waste treatment and disposal management	–High efficiency –High accuracy	–Not considering low cost, low power consumption	–Platform
Fang et al. [49]	Refining the environmental monitoring efficiency and navigation of tasks	Regional climate change monitoring	–Improving data gathering –Improving to manage decision making –Improving efficiency	–Omitting the type and number of the IoT devices to collect the environmental data	–Architecture –Prototype
Cheng et al. [50]	Cloud-based Air-Quality Monitoring System	$PM_{2.}$ monitoring	–High scalability	–Not considering reliability	–Prototype –Implementation
Mao et al. [51]	Urban CO2 monitoring with sensors	CO_2 monitoring	–High performance in the real urban area	–Not considering power-lasting requirement	–Prototype –Implementation

Table 5
Comparison of the existing evaluation factors in the environmental applications.

Research	Availability	Response time	Energy Consumption	Cost	Reliability
Li et al. [43]	✗	√	✗	√	√
Ye et al. [44]	✗	√	✗	√	√
Zhang [45]	√	√	√	√	√
Kim et al. [46]	✗	√	√	✗	✗
Qiu et al. [47]	✗	✗	√	√	√
Jing-yang et al. [48]	✗	√	✗	✗	✗
Fang et al. [49]	✗	√	✗	√	✗
Cheng et al. [50]	√	✗	✗	√	✗
Mao et al. [51]	✗	√	√	√	✗

architecture is based on monitoring that predicts the user experiments regarding existing data streams for smart city via semantic-aware mobile crowd-sensing. The offered service composition architecture uses data mining classification process for assessing the possibility of the suggested approach. In this study, the quality of data and users' privacy were not considered especially when the volume of data raises, therefore, the scalability is not supported.

Zia et al. [53] presented an application-specific digital forensics exploratory model in IoT. In this paper, digital forensics in IoT is considered to test the traditional guidelines and practices of industry to offer the mentioned model. It is claimed that the suggested model can be beneficial in any forensics analysis to support gathering, investigation, analysis and reporting of forensically sound evidence in an IoT digital forensics exploration application. To evaluate the presented model, three top IoT applications scenarios including smart city, smart home and wearables are considered as examples. The advantage of this the presented model is that it can be applied in analyzing the variety of evidence of forensics in variable IoT systems. The weakness of the offered model is that the IoT security protocols are not considered, yet it seems to be beneficial to make it more operational and protected.

Lingling et al. [54] developed a monitoring system for vehicle, based on the IoT. The architecture of the presented system consists of five layers including the application layer, the data layer, the network layer, the sensing layer and the object layer. To evaluate the presented system, it was installed in Nanjing (the second largest city in the East China region), based on the technology of the IoT which composes video recognition, GPS and RFID to provide information from driver's identity and vehicle information on traffic. The advantages of the presented system are increasing the dynamic resources management of the road network and improving the management control of emergency conditions. The main defect of this paper is that the cost is not considered.

Distefano et al. [55] presented an analytical modeling framework based on stochastic Petri nets to asses quantitative QoS factors of a group of mobile crowd sensing services. This modeling needs to encompass the Petri net formalism by identifying the semantics of pattern dependency for non-exponentially distributed transitions. In this work, the offered method is used in a mobile crowd sensing application sample to acquire some specified QoS degrees in order to obtain the quantitative assessment and description of the crowd comportment. The offered mobile crowd sensing system stack contains three levels including node level consists of battery discharge processes or usage profiles, the distinguishing environment level includes node churning, interactions and resource constraints and the application level which contains preprocessing, collection and number of contributing devices. The suggested solution method is not based on simulation. Thus, simulation is just applied for validation of the achieved outcomes. In this modeling, a real case study was implemented which contained some parts including implementation of a traffic checking service, gathering, collecting and processing traffic data delivered by mobile contributors to provide real-time data and finally sending them on the traffic in a specific zone. The advantage of this work is improving the response time and energy consumption. The main weakness of this paper is that the cost is not considered.

Lin et al. [56] described that a number of location based IoT applications were developed in the National Chiao Tung University (NCTU) in Taiwan. These applications were designed and implemented based on a platform named IoTtalk which is a platform for the IoT device handling. These location based applications consist of four applications. The first one is the dog tracking application for managing the dog movements in the campus environment. The second application is the emergency application for informing the police in an emergency state by pressing a button. The next one checks the PM2.5 by means of several PM2.5 sensors, and the last application is a robot containing a number of sensors to gather the inside information of the building such as temperature and other indoor conditions. Due to the nature of these applications, the problem of location finding is the main point that is noticed. In this paper, a mechanism was presented for finding the location trough including updating location configuration features to the IoTtalk GUI without positioning sensors. The advantage of this work is developing a mechanism for location finding according to improving the balance between tracing precision and use of energy for the IoT devices without positioning sensors. The weakness of this work is that the sensor-based solution is not presented.

Zhou et al. [57] offered an integrated message-oriented architecture for IoT applications applying MQTT protocol which was examined in some real-world systems. Due to the limited network bandwidth, storage, computing, and energy resources, message-centric models were considered for smart objects in this paper. According to unreliability of networks and restricted devices, MQTT was applied to adjust IoT scenario in this work. MQTT is the most popular lightweight M2M protocol which includes one-to-many message delivery, a header with 2 bytes length and three levels of QoS to make certain message distribution without considering the order of them. To evaluate the presented publish/subscribe message-centric architecture, some smart object models containing a fan, a smart bulb, a television and an Internet music player were developed based on Raspberry Pi and the related apps were implemented in python. The advantage of this work is improving the reliability and properness of the presented solution for limited network bandwidth, storage, computing, and energy resources.

Zeng et al. [58] developed a simulator called IoT-Sim based on Cloudsim to provide and empower simulation of IoT Big Data processing, applying MapReduce in cloud computing background. In this work, it is expressed that examining and assessing the IoT applications in an actual cloud computing environment, is a challenging task according to the cost of handling large scale datacenters with Big Data processing framework and dynamic resources configuration. The advantage of the presented simulator is to provide a proper environment to study and analyze the IoT applications on top of Cloudsim. The main defect of the developed simulator is that the stream processing regarding the constraints of dealing with low latency and real time necessities of such applications in MapReduce is not supported.

Duttagupta et al. [59] presented an experimental analysis for predicting the performance of applications installed on a scalable IoT platform. The main objective of this work is to achieve a complete attitude for enterprise level data management in IoT environments along with development of IoT applications. In this paper, it is noted that several factors including various on line transactions, different usage forms of smart devices, collaboration of diverse technologies and absence of appropriate testing platforms should be focused and measured in performance analysis of IoT applications. The method of prediction is based on simple queuing network modeling attitude which predicts the performance of APIs accessible by the specific platform and then confirms them over experimental examination on two distinct platforms to show the different results. Two important issues are considered in this study including the raise in number of sensors sending information to an IoT system over time which can affect the growth in data arrival rate and consequently size of arrivals and the other one is the growth in number of online users who demands information from IoT system. The measured factors that were checked included throughput, response time and system resource utilization at main servers. These factors were compared through predicting by a simulator model and the real values measured over performance testing or acquired from log analysis of the production environment. Clarifying essential hurdles in modeling IoT applications by means of standard modeling methods and presents the proper solutions are the advantages of this paper. Not presenting a novel modeling method in the IoT applications is the weaknesses of this study. Also, in this study, the analysis is generally based on data mining from production environment and involves only restricted performance assessments.

Chen et al. [60] presented an open framework for IoT applications for adaptive computation offloading. This paper offers a design pattern to support an IoT application to offload calculation on the fly by implementing the adjusting on offloading. Also, the authors present a model as a decision module for estimation which evaluates the entire execution time of IoT application and chooses the proper strategy to organize calculation tasks on the IoT environment. An environment for the design pattern, and the valuation model were presented by implementing an adaptive framework in this paper,. The advantage of this work is successful applying the presented computation offloading framework on an actual IoT application in which evaluations show the decreasing 45−50% of execution time for computation-intensive applications. It seems that in order to support superior deployment choice, more algorithms should be added to the decision module.

Urbieta et al. [61] offered a novel framework for adaptive service composition. This framework is based on a nonconcrete service model for ubiquitous software systems which signifies services regarding their capabilities and context-aware necessities such as pre-condition, post-condition and effects. Also, the conversation including the behavioral condition that associated dataflow and context-flow restrictions was mentioned. In this paper, a three level implementation of flexibility for service composition including, flexible integration, interleaving and adaptive reordering of task conversations, was presented. In order to assess the performance and correctness of composite services, a new testbed was established by merging simple services. Improving the performance, enhancing the quality of the outcomes and increasing the correctness of service composition engine are the advantages of this paper. The main weakness of this study is that the user tasks are not supported when the number of capabilities is increased.

Ara et al. [62] proposed a novel architecture and a new algorithm for semantic ontology-based service composition in the context of Web of Objects infrastructure. In this work, the relation between services, physical objects and rules is defined by ontologies in a dynamic manner. The authors state that in order to orchestrate and dynamic composing the services by reusing the virtual object's attributes, the virtual representation of existent physical objects which characterized by semantically related virtual objects, is necessary. The suggested architecture consists of several layers from analogous to semantic web stack with focusing on ontology and logic layers which is in the knowledge base of the ontology layer. Services are defined to execute reasoning tasks for service discovering automatically and handling them by several rules. To evaluate the proposed architecture and algorithm, a scenario as a use case for service composition in shopping mall is considered in Web of Objects context. The advantage of this work is the ability of processing natural language to assist the users to define the requests for assessment. The main deficiency of this work is that there is not any comparison between the suggested architecture and algorithm with the same existing models to evaluate the performance of the offered method.

Seo et al. [63] presented a novel architecture based on cloud computing platforms for ubiquitous computing environments. In this work, it is defined that the ubiquitous computing refers to a model of collaboration of computers in which dealing with information which is systematically integrated into daily events and objects. Therefore, Ubiquitous computing is an elementary necessity in ubiquitous M2M or IoT technology which offers numerous composite services for the cloud computing. According to the considerable dynamicity of the context in ubiquitous environments, context awareness is conducted in the suggested solution as an important issue. In the presented architecture, adapting the behavior of distributed applications with the context deviations is considered. This architecture contains three layers including cloud service layer, M2M service layer and ubiquitous service layer. In this work, provisioning the interoperability is implemented between objects through the semantic description models regarding a cross-layer methodology, where the application management layer correlate with the lower layers to gather related information for context specification. The related simulations show that the advantage of this paper can be provisioning an efficient framework for mobile applications which needs high performance in ubiquitous environments. The defect of this work is that the reliability is not considered.

Li et al. [64] implemented an algorithm for web service composition to solve the web service composition problem when existing numerous services have the same functionality. According to the several QoS factors as a multi objective problem, a multi-population genetic algorithm (MGA) was suggested in this paper. The presented solution can offer the best composite service with low failure rate regarding the defined QoS measures by users, in large scale problems. The main advantage of this work is offering possible answers by reducing the QoS limitations when the service composition results do not achieve the desired QoS factors degree. Improving the properties such as cost and response time in comparison with other existing solutions is another advantage of this paper is. The deficiency of this study is that the important QoS factors such as reliability are not considered.

Lee et al. [65] presented an application-based service composition approach to cover the directed-acyclic-graph style composition of constituent services. The Software as a Service (SaaS) layer is considered to carry out the offered service composition approach. Also, a workflow mechanism naming blueprint flow description is presented for satisfying the available service in the smart home scenario. The experimental results show that the proposed blueprint flow has lower memory consumption, minimum response time and high speed up CPU ratio. The main defect of this work is that just a small-level environment for showing the efficiency of the proposed service composition approach is considered.

Akbar et al. [66] offered and developed an approach for evaluating and comparing diverse data streams with the aim of providing a reliable, effectual and scalable solution for IoT applications. In this paper, a two layered architecture was suggested that includes a layer to provide an interface for investigating data from heterogeneous IoT structures in a scalable scheme, and the another layer for providing a probabilistic solution based on Bayesian network and CEP to associate high-level events.

Sun and Ansari [67,68] offered a method for dynamic IoT resources caching by utilizing CoAP Publish/Subscribe in the application layer for smart parking applications in smart cities. The main aim of this paper is that the NP-hard problem of dynamic popular resource caching in the broker that is formulated in order to make the most of the energy saving rate from servers and reduce typical delay for broadcasting data from the broker to the clients. The performance of the proposed solution is illustrated by simulation.

Chai et al. [69] developed a novel Cryptographically Generated Address (CGA) pattern for building IoT applications, according to an Authentication, Authorization, and Accounting (AAA) protocol and public key to guard PMIPv6/FPMIPv6 established indicating messages by means of security examination of patterns for mobile network. Also, a novel inter-domain handover is suggested which its performance is assessed via examining handover latency. The proposed management schema improves the stability and mobility by modeling via a Markov chain model.

Chien et al. [70] proposed a service-oriented load balancing architecture of Software Defined Networking (SDN) for the IoT applications. This architecture isolates data from control and manages the routing path of packet by Service Function Chain (SFC). Also, a Greedy-based Service Orientation Algorithm (GSOA) and SA-based Service-orientation Algorithm (SASOA) was proposed to decrease the data broadcast time of IoT devices and balance the load of service functions (SFs). The simulation outcomes show that the proposed service-oriented solution improves the load balancing influence in contrast with other SFs via sending fixed packets to the SF with a smaller amount of loads.

Krishna et al. [71] presented an overview and investigation of Routing Protocol for Low power (RPL) sensors and networks in IoT real-time applications. In order to examine the performance of IPv6 based on RPL, Contiki test-bed was used to evaluate the latency, received packets for each node, routing factor in a low-power WSN module (Zolertia Z1 mote) and a wireless sensor module (WiSMote).

In [72], a novel Fog-supported smart city network architecture named Fog Computing Architecture Network (FOCAN) was presented. This architecture contains a multitier organization in which the applications can be able to execute on objects and communicate with each other in the smart city environment. The proposed architecture reduces latency and increases the efficiency of services between objects with various facilities by improving energy provisioning. FOCAN devices consist of three types of communications including inter-primary, primary, and secondary communication for handling applications while satisfies the QoS standards for the IoE (Internet of Everything). The main advantage of FOCAN is the capability of providing the energy-efficient services by devices. The outcomes show the high effect of the proposed architecture in energy efficiency through communication among different categories of objects in smart cities.

4.3.1. Analysis of the reviewed smart city applications

Table 6 describes the classification of the above papers and the important aspects to evaluate the smart city approach in IoT

Table 6
Classification of recent studies and other information in smart city applications.

Research	Main context	Case study	Advantage	Weakness	New finding
Montori et al. [52]	Semantic-aware mobile crowd-sensing	Service composition in smart city	–Low response time –High reliability	–Not considering users' privacy –Not supporting scalability	–Architecture
Zia et al. [53]	Digital forensics	–Smart city –Smart home –Wearables	–Applying in analyzing the variety of evidence of forensics in variable IoT systems	–Not considering IoT security protocols	–Exploratory model –Prototype
Lingling et al. [54]	Vehicular Monitoring	Vehicular monitoring	–Increasing the dynamic resources management of the road network –Improving the management control of emergency conditions	–Not evaluating cost	–Framework –Prototype
Distefano et al. [55]	Mobile Crowd Sensing Services	Mobile crowd sensing	–Improving the response time, reliability and energy consumption	–Not evaluating cost	–Framework
Lin et al. [56]	Location finding trough including updating location configuration features	–Dog tracking –Emergency informing –Checking the PM2.5 –Monitoring indoor conditions	–Improving the balance between tracing precision and use of energy for the IoT devices without positioning sensors	–Not presenting the sensor solution	–Algorithm
Zhou and Zhang [57]	Integrated message-oriented architecture for IoT applications applying MQTT protocol	Smart home	–Improving reliability –Applicable for limited network bandwidth, storage, computing, and energy resources	–Not evaluating cost	–Architecture –Prototype
Zeng et al. [58]	IoT Big Data processing	Smart home	–Providing an environment to analyze IoT applications on top of CloudSim	–Not supporting stream processing dealing with low latency and real time necessities	–Simulator
Duttagupta et al. [59]	Analysis and predicting the performance of applications deployed on a scalable IoT platform	Smart home	–Clarify essential hurdles in modeling IoT-based applications by means of standard modeling methods	–The analysis is based on data mined from production environment with restricted performance assessments	–Algorithm
Chen et al. [60]	Adaptive computation offloading	Vehicular monitoring	–Decreasing execution time	–Deficiency of different algorithms in the decision module	–Framework
Urbieta et al. [61]	Context-aware service composition	Smart city	–Improving performance, quality of the outcomes and correctness of service composition engine	–Not supporting the user tasks where the number of capabilities is increased	–Framework
Ara et al. [62]	Semantic ontology based service composition	Urban computing	–Ability of processing natural language to help the users to define the requests	–Not presenting any comparison with the same existing models	–Architecture –Algorithm
Seo et al. [63]	Service composition in Cloud Computing	Vehicular monitoring	–High performance for mobile applications	–Not evaluating reliability	–Framework –Algorithm
Li et al. [64]	QoS-aware service composition	Smart home	–Improving response time and cost	–Not considering reliability	–Algorithm
Lee et al. [65]	QoS-aware service composition	Smart home	–Lower memory consumption, minimum response time and high speed up CPU ratio	–Considering a small-level environment for showing the efficiency	–Algorithm
Akbar et al. [66]	Managing scalable heterogeneous data streams	Weather systems	–High scalability –Reliability	–High cost	–Architecture –Algorithm
Sun and Ansari [67]	Dynamic resource caching management	Street parking system	–Low energy consumption –Low response time	–High cost –Low scalability	–Algorithm
Sun and Ansari [68]	Traffic load balancing management	–	–Low latency –Low response time –Low energy consumption	–Low scalability	–Algorithm
Chai et al. [69]	Secure Mobility Management	–	–Low latency –High reliability	–High cost	–Algorithm
Chien et al. [70]	Service oriented load balancing schema	–	–Low response time –Low cost	–Low scalability	–Framework –Algorithm
Krishna et al. [71]	Real-time low power routing protocol	–	–Low energy consumption –Low response time	–Low scalability	–Architecture –Algorithm
Naranjo et al. [72]	Fog-supported architecture for management of applications in the IoE	Smart city	–Low latency –Improving energy efficiency –High scalability	–Not considering cost	–Architecture

Table 7
Comparison of the existing evaluation factors in smart city applications.

Research	Availability	Response time	Energy consumption	Cost	Reliability
Montori et al. [52]	√	√	√	√	✗
Zia et al. [53]	√	√	√	✗	√
Lingling et al. [54]	✗	√	✗	✗	✗
Distefano et al. [55]	√	√	√	✗	√
Lin et al. [56]	✗	√	√	✗	✗
Zhou and Zhang [69]	✗	√	√	✗	√
Zeng et al. [58]	✗	√	✗	√	✗
Duttagupta et al. [59]	√	√	√	✗	✗
Chen et al. [60]	√	√	✗	√	✗
Urbieta et al. [61]	✗	√	✗	✗	✗
Ara et al. [62]	√	✗	✗	✗	✗
Seo et al. [63]	√	√	✗	√	✗
Li et al. [64]	✗	√	✗	√	√
Lee et al. [65]	√	√	✗	✗	✗
Akbar et al. [66]	✗	√	✗	✗	√
Sun and Ansari [67]	✗	√	√	✗	✗
Sun and Ansari [68]	✗	√	√	✗	✗
Chai et al. [69]	✗	√	✗	✗	√
Chien et al. [70]	√	√	✗	√	✗
Krishna et al. [71]	✗	√	√	√	✗
Naranjo et al. [72]	✗	√	√	✗	✗

applications. The case studies in the smart city approach include smart home and wearables systems, vehicle monitoring, mobile crowd sensing, tracking systems, urban computing and emergency informing systems.

Table 7 shows an evaluation for the above papers applying the evaluation elements in smart city IoT applications. The following parameters include availability, response time, energy consumption, cost and reliability. In the smart city approach, most research studies assessed their offered approach in response time and energy consumption properties.

4.4. Commercial applications

Alodib [73] presented a model-driven method to automate the QoS-aware service composition including real-time monitoring. As specified in this paper, the violation of the SLAs defined by different users in numerous locations is a significant concern. Therefore, the SLAs stated by the users in diverse sites are mapped into a Petri net to integrate the Petri net model with the UML QoS model. In this paper, the diagnosis theory of Discrete Event System (DES) motivates the proposed algorithm, which is applied to the Petri net for generating the composite service. Introducing a cost-effective investigation to assess the performance of objects in the IoT environment to satisfy QoS requirements is the main advantage of this paper is to. The weakness of this work is that the scalability is not supported.

Han and Crespi [74] suggested an architecture of semantic service providing for smart objects. The main goal of this work is to deliver the smart object services to the web and make them manageable by several common APIs with regard to their limitation such as resources (ROM, RAM, and CPU), low speed communication links and low power microcontrollers. The proposed architecture was assessed in various environments by a number of samples and applications on web which were simulated by Contiki Cooja in the IoT testbed. Strengthening IoT applications on web with enhancing important factors such as security, scalability and reliability for service provisioning is the advantage of the suggested architecture. Not presenting any precise comparison with other similar works is the weakness of this paper.

Huo et al. [75] proposed a new multi-objective model for service composition with regarding cost-effective optimization. In this paper, the QoS attributes including response time, availability, throughput and reputation is evaluated. The suggested service composition model was developed through Artificial Bee Colony algorithm according to the aim of maximization the mentioned QoS factors and minimization of cost. The developed service composition model was assessed by means of two datasets. Improvement the efficiency and quality of the proposed model in contrast with other solutions is the benefit of the suggested model. The weakness of the model is the absence of supporting the environments such as clouds with rapid data flow which generates extra severe necessities.

Liu et al. [76] offered a cooperative evolution solution for QoS-based web service composition which was implemented by means of PSO algorithm. In this paper, a number of algorithm features are considered that include related evolutionary optimization for the variety of population, a self- adapting method of learning quantities for balancing the convergence speed and the optimized final result, an enhanced local best first method for choosing the candidate service in order to meet the global minimum or maximum QoS factors, a global best approach beside the global best particle to avoid getting the outcomes in a local optimization. To demonstrate the fast convergence in getting an optimized outcome, several algorithms such as Genetic algorithm and Particle Swarm is applied in this solution. The advantage of this work is improving the QoS factors such as response time, availability, reliability and cost. The weakness of the suggested solution is that not supporting the large scale data, therefore confirming the intelligent adaptation of the presented solution is hard to verify.

An artificial bee colony algorithm was proposed by Huo and Wang [77] regarding cross-modified technique to choose the proper composite services in a dynamic manner. The proposed algorithm presents appropriate response time and high accuracy in comparison to other methods like genetic algorithm, especially in chaotic solution space. The quality factors are considered with respect to the IP case study to achieve the optimum answer for the service selection and composition proposed approach. The experimental outcomes in MATLAB demonstrate low response time and low mean convergence iteration for the suggested method. The weakness of this study is that the serial optimization of the task nodes for evaluating the proposed method was not considered.

Temglit et al. [78] proposed a QoS-aware web service selection and composition using multi-agent approach in the IoT device layers. The proposed service composition approach is based on a context-aware distributed optimization approach for service choreography architecture. To avoid the communication overheads,

Table 8
Classification of recent studies and other information in the commercial applications.

Research	Main context	Advantage	Weakness	New finding
Alodib [73]	QoS-aware service composition	–Introducing a cost-effective analysis to assess the performance to satisfy QoS requirements	–Not supporting scalability	–Algorithm
Han and Crespi [74]	Semantic-aware service composition	–Improving security, Scalability and reliability of service composition	–Not presenting precise comparison with other similar works	–Architecture
Huo et al. [75]	QoS-aware Multi Objective service composition	–Improving response time, availability, throughput and reputation	–Not supporting clouds with rapid data flow	–Algorithm
Liu et al. [76]	QoS-aware service composition	–Improving the response time, availability, reliability and cost	–Not supporting large scale data	–Algorithm
Huo and Wang [77]	QoS-aware service composition	–Low response time and the mean convergence iteration for proposed algorithm	–Not considering the serial optimization of the task nodes	–Algorithm
Temglit et al. [78]	QoS-aware multi-agent service composition	–Low response time	–	–Algorithm
Kleinfeld et al. [79]	Joining data gathered from Web-based IoT devices and Web service	–Focusing on IoT mashups and their combination with Web services	–Not presenting evaluation to show the efficiency of the presented platform	–Platform
Cao et al. [80]	Relational service recommendation system	–Low response time –Low cost	–Low availability –Low scalability	–Algorithm
Cuomo et al. [81]	Financial data flow system	–Low response time	–High energy –High cost	–Algorithm –Implementation
Pustišek and Kos [83]	Ethereum Blockchain systems	–Low latency	–High time –High cost	–Algorithm

this paper presents a QoS-aware distributed multi-agent approach to orchestrate and compose the multiple services execution. Also, the authors used the simple additive weighting (SAW) method to perform the efficiency of the QoS factors in the selection and composition of existing services in IoT. The main advantage of this paper is applying the graph theory to illustrate low response time and best composited service in comparison the other composition approaches.

Kleinfeld et al. [79] presented a platform for wiring data gathered from Web-based IoT devices and Web service. In this paper, the features of real-time communication such as MQTT, CoAP and Web Sockets, data stream mashups, actions or triggers and distributed placement of these mashups and finally device integration, are used in technology which is called glue-things. The glue-things approach as Web of Things (WoT) hub for mobiles, TVs, home and wearable appliance was presented in this paper. The advantage of this study is opening the doors to focusing on IoT mashups and their combination with Web services especially intelligent services such as Google Speech to provide advanced IoT applications for the market. The weakness of this study is that there is not any evaluation to show the efficiency of the presented platform.

Cao et al. [80] presented a QoS-aware service recommendation solution for IoT Mashup application by means of applying Relational Topic Model (RTM) and Factorization Machines (FMs). In this paper, the relation between Mashup and services are represented via RTM in order to retrieve the concealed topics, and FMs is applied to learn them and model entire communications between input variables with enormous scarcity and various information and finally forecast the relation among Mashup and services. The experimental results show that the proposed method meaningfully increases precision of service recommendation.

Cuomo et al. [81] presented a utilization of one-step HullWhite model [82] in an IoT financial flow that is considered by these phases: (1) extraction from varied databases; (2) investigation and checking; (3) reporting. The collected information is applied to assess the interest rate in a HullWhite model with constant factors via software R. the main advantage of this study is decreasing time complexity by proposed parallel technique.

Pustišek et al. [83] proposed three potential architectures for the front-end blochchain (BC) applications in IoT environment. The proposed architectures vary in locating of ethereum blockchain clients such as local object or distant server, and in placing of important store which is required for the outgoing operations administration. The restrictions of the proposed architectures are the location and organization of the blockchain node and the location and the access to the ethereum main store and the volumes of data. Also, the authors discussed the applicability of the proposed architectures with an exclusive communication between the remote blockchain client and IoT device to improve security and decrease the network traffic. The suggested architectures can be applied over low bitrate and restricted power in mobile technologies.

4.4.1. Analysis of the reviewed commercial applications

Table 8 describes the classification of the above papers and important parameters to evaluate the proposed commercial approach in IoT applications. The most important main contexts in this approach are context-aware, QoS-aware and semantic-aware attitudes in service composition.

Table 9 describes an evaluation for the above papers applying evaluation elements in commercial IoT applications. The following parameters include availability, response time, energy consumption, cost and reliability. In the industrial IoT applications, especially with service composition approach, most research papers assessed their suggested approach in response time, cost and availability properties.

4.5. Industrial applications

Li et al. [84] presented a three-layered scheduling approach for services-oriented IoT devices, based on QoS factors. A Markov decision procedure is proposed to improve the services quality of services using top-down decision-making process in the application layer of the IoT devices. The Matlab tool as the simulation environment is applied to evaluate the proposed scheduling approach. Some QoS factors such as response time, latency, service availability and network bandwidth are considered for evaluation in the simulation process. Improving the latency is the advantage of this

Table 9
Comparison of the existing QoS factors in the commercial applications.

Research	Availability	Response time	Energy consumption	Cost	Reliability
Alodib [73]	√	√	✗	√	√
Han and Crespi [74]	√	√	√	✗	✗
Huo et al. [75]	√	√	√	√	√
Liu et al. [76]	√	√	✗	√	√
Huo and Wang [77]	✗	√	✗	√	✗
Temglit et al. [78]	√	√	√	√	√
Kleinfeld et al. [79]	✗	√	✗	✗	✗
Cao et al. [80]	✗	√	✗	√	✗
Cuomo et al. [81]	✗	√	✗	✗	✗
Pustišek and Kos [83]	✗	√	✗	√	✗

paper. The proposed scheduling approach is just evaluated through the simulation. Therefore, the suggested approach needs to be assessed in real IoT environments.

Abdullah et al. [85] proposed an IoT message scheduling algorithm considering QoS awareness. In this paper, messages are divided into the high precedence messages that are urgent and the best effort messages that are non-duty urgent. The main purpose of this paper is to offer an enhanced QoS-aware scheduling and routing algorithm according to decreasing the energy consumption. To ensure minimizing the delay of end-to-end data broadcast, the suggested algorithm regulates to the necessities of IoT applications and firstly, schedules immediate requirements with the uppermost precedence and then, schedules the non-duty urgent messages regarding prevent starvation in distribution of messages. A simulation in Matlab was applied to show the performance of the proposed solution. Decreasing the latency and improving energy consumption are the advantages of this paper. Using restricted kinds of scheduling approaches inside the similar service variation is the deficiency of the presented algorithm.

Yang et al. [86] presented a novel routing method for transmitting the electrical information flow, based on distributed agents with several QoS restrictions. In this paper, it is mentioned that the real-time information communication of electrical power consumption is the main requirement of the smart grid systems, to preserve the capability of control and stability. Therefore, developing a network architecture which can afford reliable and secure bidirectional communication between intelligent electrical meters, consumers and power supply system is essential. According to assuring the flexible and reliable last mile communication based on the IoT technology and wireless sensor networks, the suggested algorithm applies these infrastructures. In this paper, it is pointed that the Boolean controlling variables of switchgears, feeder voltage or current of signals, and improper data files are the various electrical parameter flows that transmitted in smart grid which are not similar in their QoS necessities. Therefore, this issue leads to deal with a NP-complete problem to realize multi-QoS flow necessities in one connected communication networks. To assess the performance of the presented method, a simulation was implemented to assess the factors such as average end-to-end delay, overhead of routing and ratio of bandwidth occupation. Improving the mentioned QoS factors is the advantage of this work. However, the proposed algorithm should be assessed in real IoT environment.

Venticinque and Amato [87] presented an approach for placement the IoT applications in Fog in order to solve the Fog service deployment issue, which is made up of discovering the optimal representing between computational resources and IoT applications. The case study in this paper is the smart energy field in IoT applications. The advantage of this study is providing automatic learning of energy outlines and improving the platform operation by users through presenting different computational resources. The main achievement of this paper is improving the energy consumption at deployment phase.

Jin et al. [88] suggested a content-based cross-layer scheduling approach named as CONCISE for industrial IoT applications, which presents a novel model to direct and collect data in a content centric manner by means of Time Synchronized Channel Hopping (TSCH) scheduling. The advantage of this study is balancing the traffic load. Also, the experimental results show reduction of network traffic congestion, improving communication reliability and decrease end-to-end latency according to suggested scheduling method.

Kiran et al. [89] presented a new paradigm for analyzing the performance of IEEE 802.15.4-2015 MAC layer for beacon and nonbeacon-enabled Personal Area Network (PAN) in industrial IoT applications. In this paper, a Markov chain and a mathematical construction for delay of successful packet broadcast, reliability and power feeding of the nodes were developed. The main advantage of this study is improving the network operational effectiveness.

Ahmad et al. [90] presented an ultra-low power robust TFET SRAM cell for varied range of IoT applications which need particularly severe energy-efficient task and ultra-low power to work with energy gathered from the environment or sustain battery life. The proposed TFET SRAM cell can be widely applied in a broad range of IoT applications including wearable health monitoring, environmental sensing, traffic monitoring and other similar monitoring systems that require low energy consumption operations in the IoT environment. The proposed cell presents upper mean value of write margin, reduced write delay, decrease in average energy consumption and write energy per operation and leakage power saving in comparison to the former 9T TFET (7T FET) cells.

4.5.1. Analysis of the reviewed industrial applications

Table 10 describes the classification of the above papers and the important aspects to evaluate the industrial approach in IoT applications. The main contexts in the industrial approach include QoS-aware scheduling for service-oriented IoT architecture, QoS-aware message scheduling and QoS-aware routing algorithms in WSN.

Table 11 describes an evaluation for the above papers applying assessment elements in industrial IoT applications. The following parameters include availability, latency, energy consumption, cost and reliability. In the industrial IoT applications, especially with scheduling direction, most research studies evaluated their proposed approach in the latency factor.

4.6. General aspects in IoT applications

Diro et al. [91] suggested an integrated architecture for SDN and IoT/Fog. This architecture uses the degree of flow space allocation difference for assorted IoT applications in any flow classes according to precedence of QoS necessities in order to fulfill some important factors such as decreasing packet delay and probability of misplaced packets through flow space conflict, and get the greatest throughput. The main emphasis of this paper is variance and urgency of flow space allocation that is considered to earn

Table 10
Classification of recent studies and other information in industrial applications.

Research	Main context	Advantage	Weakness	New finding
Li et al. [84]	QoS-aware scheduling for service-oriented IoT architecture	–Improving latency	–Not assessing in real IoT environments	–Algorithm
Abdullah and Yang [85]	QoS-aware message scheduling	–Decreasing latency –Improve energy consumption	–Using restricted types of scheduling approaches inside the similar service variation	–Algorithm
Yang et al. [86]	QoS-aware Routing Algorithm in WSN	–Improving average end-to-end delay, overhead of routing and ratio of bandwidth occupation	–Not assessing in real IoT environments	–Algorithm
Venticinque and Amato [87]	Fog service placement methodology	–Improving load time –Increasing service availability	–Not evaluating in dynamic deployment strategy	–Algorithm
Jin et al. [88]	Content–based cross-layer scheduling approach	–Low response time –Low cost	–Low availability –Low scalability	–Algorithm
Kiran and Rajalakshmi [89]	Nonbeacon–enabled personal area network	–Low response time –High scalability	–High cost	–Algorithm
Ahmad et al. [90]	Ultra–low power robust cell	–Low cost High availability	–High response time	–Algorithm

Table 11
A side by side comparison of the existing QoS factors in the industrial applications.

Research	Availability	Latency	Energy consumption	Cost	Reliability
Li et al. [84]	✗	√	✗	✗	✗
Abdullah and Yang [85]	√	√	√	√	√
Yang et al. [86]	✗	√	√	√	√
Venticinque and Amato [87]	√	√	✗	✗	✗
Jin et al. [88]	✗	√	✗	√	√
Kiran and Rajalakshmi [89]	√	√	✗	√	✗
Ahmad et al. [90]	✗	√	√	✗	√

vital and precarious flows and justify fairness between the ordinary packet flows in communication model of Fog to things by means of the programmability of SDN method. The analytical outcomes reveal that critical flow classes are assisted more capably than Naïve method without dealing with fairness of distribution for typical flow classes. The advantage of this study is improving the QoS factors such as latency, probability, throughput and utilization. Not considering the systems with multiple/ virtualized controllers is the weakness of this paper.

Vinueza Naranjo et al. [92] proposed a method for resource management regarding energy efficiency for virtualized networked Fog architectures in order to provision instant support for IoT applications. The suggested architecture works at the Middleware layer to support the dynamic instantaneous scaling in networking and computing virtualized resources. The main advantage of this study is satisfying the QoS factors such as energy consumption without any former statistics and information predicting of the input workload.

Chen et al. [93] presented a novel model of resource-efficient edge computing in order to apply in smart IoT applications. In this paper, a resource-efficient computation offloading method as a hybrid device-based approach was developed. The main aim of this study is that each different smart IoT device user attempts to reduce the cloud resource usage regarding QoS constraint. The advantage of this study is improving the performance of suggested algorithm in the aspect of resource efficiency.

Mangia et al. [94] proposed a method for rakeness-based compressed sensing for IoT applications. This method is applied to multiple-graph signals as an operative manner to manage the optimal balance between short and long variety communications in a general IoT development which uses geographic data hubs and local WSN. The experimental results show that the utilization of the proposed method causes about 25% of power saving.

Taghadosi et al. [95] presents a completely integrated and high efficient energy saving rectifier circuits for IoT sensor applications. In this study, an analytical model is provided to support the rectifier circuits model that are designed regarding two upgraded fabricated by means of 65 nm CMOS GF RF process and Dickson charge circuits. The presented model applies flip-chip technology to prevent performance reduction. The outcomes of simulation show the high performance of both rectifiers. The advantage of this paper is high sensitivity of the proposed circuit model.

Alabady et al. [96] presented an error detection and correction code termed Low Complexity Parity Check (LCPC) code. In this study, BER performance evaluations are prepared among the suggested LCPC codes and BCH, binary and non-binary LDPC codes. The experimental results confirm the improvement in the BER performance of proposed LCPC code in contrast to the well-known LDPC, Hamming codes, RS and BCH. The advantage of this paper according to high performance of the suggested method is that the proposed code is more appropriate for WSNs IoT applications.

Moon et al. [30] presented an investigation of Simple Power Analysis (SPA) scenario to protect IoT applications. In this paper, the experimental results show the risk of private key leakage in prior additive modulus operator. The advantage of the suggested additive modulus operator is decreasing the overhead and high protection of the private key of Ring-LWE (which is a modified of Learning With Error) even in the environments where the attacker can use SPA and selected cipher-text .the weakness of this paper is that the proposed method was developed on a controller with 8-bit, therefore it is applicable in the IoT environments with limited resource.

Ouedraogo et al. [97] presented a solution for an independent and dynamic management of the QoS preferred by applications in heterogeneous IoT environments. In this paper, a case study demonstrates the concern of development of a QoS-based network function via the traffic made by a middleware-oriented application. The authors developed a rerouting network function which is worked with no disturbing the data transmission in a dynamic manner.

Kolomvatsos [98] proposed an intelligent distributed model for updating management in IoT applications in order to enhance the independent nature of the IoT nodes. In the proposed scheme, each node initiates and completes the update operation autonomously by monitoring some network performance factors and an artificial neural network, to select the proper period to accomplish the update operation. Also, in this paper, a solution was proposed for the load balancing issue in the recovery of the update process. The advantage of this paper is that the presented scheme avoids of excessive message and retrievals. Therefore, maximum bandwidth is used to decrease energy feeding and improve the lifetime of the IoT nodes and the network. Moreover, the network is not overloaded through update messages. So, a proper level of performance of each node is achieved in comparison to centralized systems.

Limonad et al. [99] presented a general model for the expression of hazard-centric enterprise IoT applications based on the idea which named “Shield”. The suggested model is the foundation of the IoT approaches developed for user’s everyday life activities including home insurance, personal wellness and job-related safety. The presented “Shields” model is responsible for the main ideas required and developing hazard-oriented IoT applications. The main operability of these applications is determined via recognizing threats in the related environment of the application. The proposed Shields model is based on the physical computational topology that may possibly applied. The authors tested three different topologies including mobile-based, a cloud centric and an edge topology. These topologies present exclusive problems according to the facets including the dynamic orchestration of the performance of the shields through several computational nodes. In this work a tool was implemented based on the proposed model for communication between basic components in the procedure of collecting the demands and domain assessment. The main advantage of this work is that the proposed model is appropriate for analyzing and developing any type of IoT application. The main defects of this study are the lack of a verification technique for evaluating the proposed model and also not considering any QoS property.

Abedin et al. [100] concentrated on guaranteeing the QoS for the end users by allocating the restricted network resources efficiently to the assorted IoT applications. In this paper, an analytic hierarchy process based matching approach was proposed for self-configuring, and dispersed user groups and resource allocation that are appropriate and scalable for the thick Fog environments. The authors also provided a real sample to prove the suggested solution for resource allocation and user association in the Fog environment. The efficiency of the proposed resource allocation method and the stability of the user association with higher effectiveness are the advantages of this paper.

In [101], a Software-Defined WSN architecture was proposed to work with the application-specific demands of IoT, with dynamic nature. In this work, a controller and sensor node architecture was provided to assist SDN in WSN. Two components including the controller device manager and topology manager were proposed that the first one is applied for managing the device-specific tasks and the second one is used for handling the network topology to guarantee QoS of the network. The advantage of this study is that, the offered solution comparing to the present SDN approaches for WSNs, emphasizes on both topology and device management in the network. Also, experimental results reveal that the suggested solution is useful for application-aware service providing in IoT, while optimizing the network performances with traditional sensor networking methods. In this paper, decreasing the network delay and also control message overhead were not considered.

In [102], a virtual machine architecture named Velox, was presented to make a resource-efficient and safe environment for IoT applications. The main feature of the proposed architecture is a fine-grained resource that guarantees the valid access of applications to any resources. Velox provisions an environment for high-level programming languages which support bytecode format. Evaluation results reveal the improvement of computational cost and memory usage of IoT applications in the proposed solution.

4.6.1. Analysis of the reviewed general aspects in IoT applications

Table 12 describes the classification of the above papers and the important aspects to evaluate the general approach in IoT applications. The main contexts in the general approach include energy-efficient resource management approach, resource-efficient edge computing, managing software updates and dynamic management of the QoS.

Table 13 describes an evaluation for the above papers applying assessment elements in general IoT applications. The following parameters include availability, latency, energy consumption, cost and throughput. In the general approach for IoT applications, most research studies assessed their offered approach in the latency and cost properties.

5. Discussion and comparison

Previous sections explained the review method of the selected studies in IoT applications. In this section, a statistical analysis of indicated application approaches in IoT is presented. Furthermore, some analytical reports regarding the planed analytical questions in Section 3 were presented as follows:

- AQ1: Which domains are categorized in IoT applications?

Fig. 4 presents a comparison of the IoT applications percentage up to now according to the provided taxonomy in Section 4. We considered six IoT application domains that include healthcare, environmental, commercial, smart city, industrial and general aspects. The smart city approach has the highest percentage of the application domains by 30% usage in the literature. Of course, health-care applications have 20%, commercial applications have 14%, environmental applications have 12%, general applications have 12% and industrial applications have 10% usage in IoT.

- AQ2: Which main contexts are considered for IoT applications?

The main contexts of IoT applications are shown in Fig. 5. We observed that QoS-aware approaches have the most usage with 21 studies, and intelligent monitoring has 17 studies.

- AQ3: What evaluation environments are used for evaluating the IoT applications?

According to Fig. 6, we observed that 24% of the research studies have implemented proposed approach to develop IoT application. In addition, we observed that 58% of the research papers applied simulation tools to assess the offered case studies in the IoT platform. Also, 14% of the papers have not presented any implementation or simulation for the mentioned application domain. Finally, we observed that 4% of the current papers applied the analyzing approaches such as prediction and testing to evaluate their case studies by using data sets.

- AQ4: What are the evaluation factors usually applied in IoT applications?

The QoS factors as the evaluation parameters are compared to the IoT applications in Fig. 7. The statistical percentage of the assessment shows that the response time has the most percentage in the evaluations of the application approaches by 27%, cost has 18%, energy consumption has 18%, availability has 14%, reliability have 14%, Throughput have 5% and security have 4% of quotas in the studies.

Table 12
Classification of recent studies and other information in general aspects in IoT applications.

Research	Main context	Advantage	Weakness	New finding
Diro et al. [91]	SDN-based allocation method	–Improving utilization and throughput	–Not assessing in multiple controllers	–Algorithm
Vinueza Naranjo et al. [92]	Energy–efficient resource management approach	–High density consolidation –Minimum energy consumption	–High migration time	–Framework –Algorithm
Chen et al. [93]	Resource–efficient edge computing	–Improving efficiency –Low response time	–High latency	–Framework –Algorithm
Mangia et al. [94]	Rakeness-based compressed sensing for IoT applications	–Low energy consumption –Low response time	–Low availability –High cost	–Algorithm
Taghadosi et al. [95]	High efficient energy saving rectifier circuits	–High saving energy –Low latency	–Low scalability –High redundancy	–Algorithm
Alabady et al. [96]	Low Complexity Parity Checking method	–Low response time –Low cost –High availability	–Low scalability	–Algorithm
Moon et al. [30]	Simple power analysis (SPA) scenario	–High availability –Low response time	–Resource limitation –Low scalability	–Framework –Algorithm
Ouedraogo et al. [97]	Independent and dynamic management of the QoS	–Low response time –Low cost	–Low scalability –Low availability	–Framework –Algorithm
Kolomvatsos [98]	Managing software updates	–Eliminating bottlenecks –Low latency –Improving energy feeding	–High time complexity	–Algorithm
Limonad et al. [99]	Hazard-oriented Analysis and Implementation of IoT Applications	–Appropriate for analyzing and developing any type of IoT application	–Lack of a verification technique for evaluating the proposed model –Not considering any QoS property	–Algorithm –Tool
Abedin et al. [100]	Resource Allocation for Mobile Broadband IoT Applications in Fog Network	–Improving the throughput –Low latency	–Not comparing the proposed method with other existing solutions	–Algorithm
Bera et al. [101]	Software-Defined WSN Management System for IoT Applications	–Low energy consumption –Low message overhead –Improving packet delivery ratio	–Not considering the network delay –Not considering the control message overhead	–Architecture
Tsiftes and Voigt [102]	Safe execution environment for resource-constrained IoT applications	–Low computational cost –Low memory usage –Resource efficient	–Not considering rapid prototyping and remote installation	–Architecture

Table 13
Comparison of the existing QoS factors in the general aspects in IoT applications.

Research	Availability	Latency	Energy consumption	Cost	Throughput
Diro et al. [91]	✗	√	✗	✗	√
Vinueza Naranjo et al. [92]	✗	√	√	√	√
Chen et al. [93]	✗	√	✗	√	✗
Mangia et al. [94]	√	√	√	√	✗
Taghadosi et al. [95]	✗	√	√	√	✗
Alabady et al. [96]	√	√	√	√	√
Moon et al. [30]	✗	√	✗	√	✗
Ouedraogo et al. [97]	√	√	✗	√	√
Kolomvatsos [98]	√	✗	√	✗	✗
Limonad et al. [99]	✗	✗	✗	✗	✗
Abedin et al. [100]	✗	√	✗	✗	√
Bera et al. [101]	✗	√	√	✗	✗
Tsiftes and Voigt [102]	✗	✗	√	√	✗

5.2. Open issues

Due to applying the SLR process on the study assortment of IoT applications, the following research challenges as the open issues are presented as the AQ5.

- AQ5: What are the future researches directions and open perspectives of IoT applications?

Security and privacy: Since IoT has no uniform architecture and, has less protection. Therefore, diverse types of attacks threaten the different parts of the IoT architecture, like unauthorized access to tags, denial of service attack and malicious code injection. IoT objects are more defenseless to these attacks since they are simple and some security measures cannot be applied. Therefore, security and privacy issues need to be more considered in IoT environment, as the IoT security issues potentially cause severe disaster to us, especially in critical application such as health-care and financial applications. Thus, authentication at several development stages of the IoT applications is also a main challenge for which an optimal explanation is yet to be recognized [103]. In recent years, the privacy issue is considered as an important challenge in IoT. Some topics including resource scheduling [104], service composition, resource provisioning and load balancing approach [105] can create a roadmap for future studies.

Context-aware computing: IoT imagines an environment wherein a huge number of sensors are connected to the Internet.

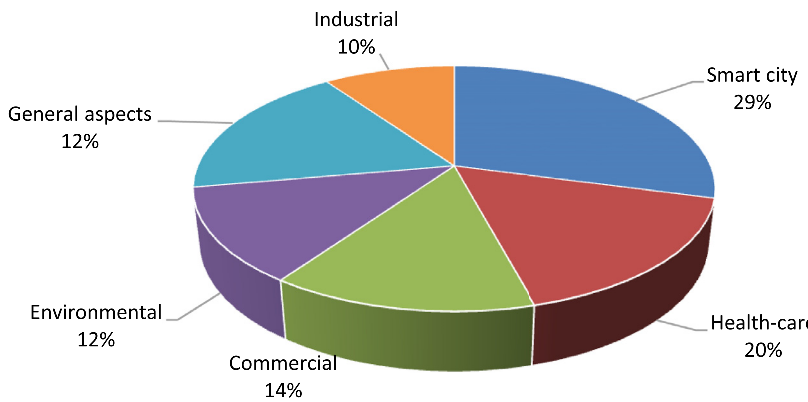

Fig. 4. Percentage of the presented IoT applications.

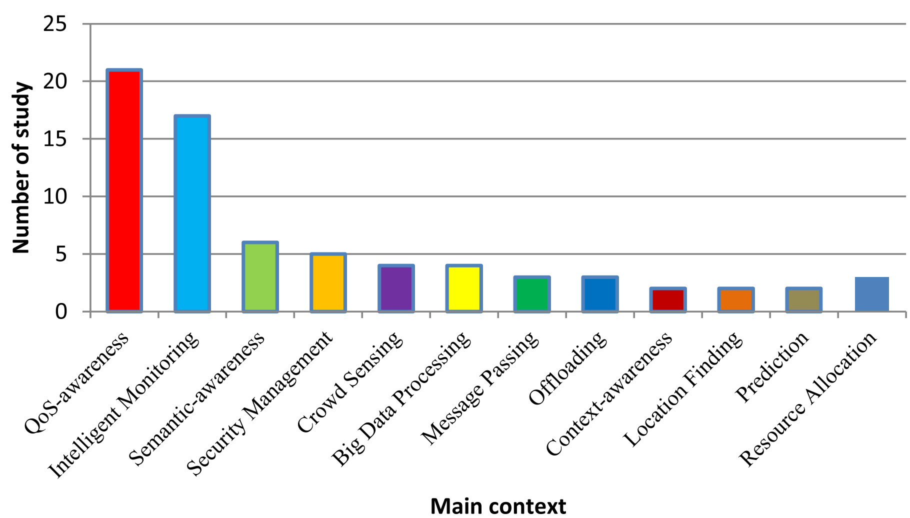

Fig. 5. Percentage of the main contexts for IoT applications.

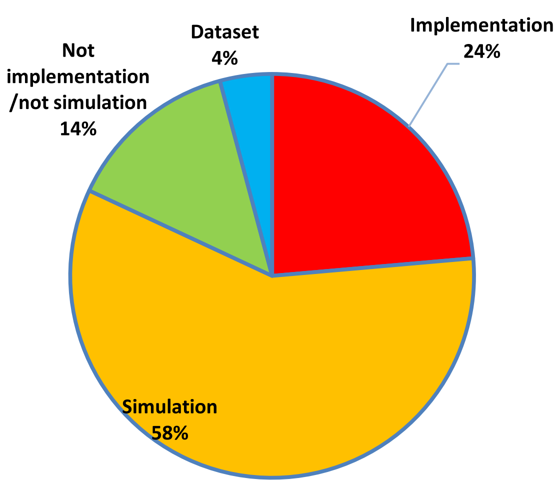

Fig. 6. Percentage of the presented evaluation environments in the literature.

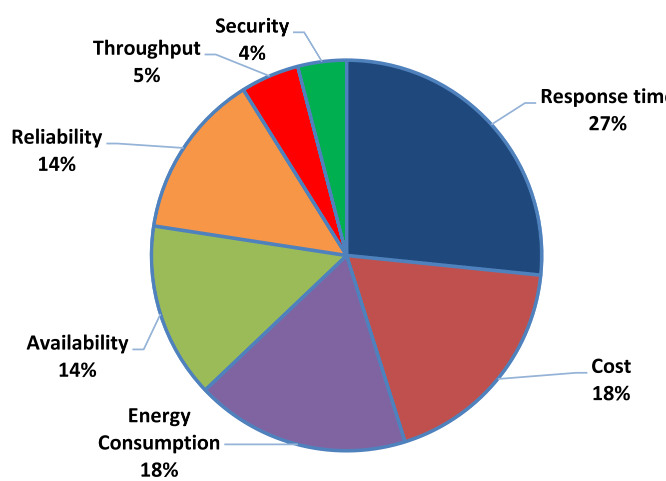

Fig. 7. Percentage of evaluation factors of IoT applications.

Consequently it is not possible to process all collected data by them that generate big data. It means that the collected data may not have any value without analyzing, interpreting, and understanding them. Context-aware computing makes it feasible to store context information related to sensor data. Therefore, the interpretation of them can be done simply and more expressively. Furthermore, awareness of the context information makes the machine to machine communication performance more easer. Context-awareness as an important challenge that play a serious role in deciding what data needs to be processed, arises when large numbers of sensors are deployed, and producing data. Therefore, the old-style application based approach becomes inefficient. In order to cope with this infeasibility, major amounts of middleware solutions are presented, that highlight different features in the IoT, especially context-awareness. Thus, a main remaining challenge is to develop the context-aware applications [106]. These sorts of applications generally apply the frameworks, libraries and tools to achieve context information collection, preprocessing, keeping, and reasoning tasks. Also, the other type of context-aware applications apply a context management infrastructure or middleware solution for context collection, pre-processing, keeping, and reasoning independently outside the application [107]. Furthermore, on-the-fly architectures that lead the user communications on the existing smart objects in IoT applications, is considered as another challenge in this topic.

Interoperability: While different IoT devices and applications have been already developed, they commonly result in poorly interoperating of things [108]. Interoperability as the important challenge of IoT interactions between the smart objects and enterprise systems provides a framework for the IoT applications communications [109,110]. The key challenges in this area include scalable architectures for interaction with sensors, actuators, and enterprise frameworks for self-adaptive IoT applications.

Formal verification: Formal specification and verification approach provides an effective mathematical method to assess the accuracy of the application approaches in IoT platforms [111–113]. Evaluating the correctness of the user interaction applications in the IoT health-care systems is a main challenge [114]. So, evaluating the accuracy of the IoT applications via applying formal verification method is a significant challenging issue [115].

Energy consumption: One of the most important challenges in IoT is reducing the energy consumption. As a key concept, green IoT is a direction for developing various technologies and issues that try to achieve a sustainable smart world wherein the energy consumption of smart IoT objects should be reduced [116]. Many issues such as green radio frequency identification, green wireless sensor network, green machine to machine, green cloud computing and green data centers enable green IoT. Therefore, all the mentioned technologies can be considered as different challenges. Future efforts in these topics including the design of green IoT, understanding the characteristics of different IoT applications and service necessities for these applications and presenting proper energy consumption models for different parts of IoT systems, will assist to address the challenge of energy consumption [116].

New application domains: up to now, several IoT applications can be developed in some domains such as IoT-retail, smart buildings, smart logistic, smart farming, and smart metering as the open issues in this topic. Supporting high-dependent QoS factors can influence on usage level of IoT applications for users.

6. Conclusion

In this review, an SLR-based method is presented on IoT application. During this study, a comprehensive understanding of the IoT applications and considerations on open issues was achieved. In this literature, we presented the SLR-based process by using the exploration query on 185 papers that were published from 2011 to 2018. Finally, we analyzed 72 papers that emphasized on IoT applications. The smart city approach has the highest percentage of the application approaches by 29% of quotas in the literature. Of course, health-care applications have 20%, commercial applications have 14%, environmental applications have 12%, general aspects in IoT applications have 12%, and industrial applications have 10% of portions in IoT according to AQ1. According to AQ2, We observed that QoS-aware approaches have the most percentage with 21 studies, and intelligent monitoring is in 17 studies. Also, with respect to the AQ3, we observed that 24% of the research studies have implemented proposed approach to develop an IoT application. To compare the evaluation factors, the response time factor has the most percentage in the evaluation of the composition approaches by 27%, the cost has 18%, energy has 18%, availability has 14%, reliability has 14%, throughput has 5% and security has 4% of studies based on AQ4. Regarding the SLR-based method, we may not have analyzed all the existing studies. Consequently, non-English, non-peer reviewed and editorial papers, book chapters and survey articles were omitted. In this review, we performed a comprehensive research of the IoT applications approaches, through findings of more than 100 authors and different studies. However, by considering the increasing number of studies in this field, it is not possible to ensure that all the studies were covered, because the research ended in November 2018.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.comnet.2018.12.008.

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