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Data Collection in Studies on Internet of Things (IoT), Wireless Sensor Networks (WSNs), and Sensor Cloud (SC): Similarities and Differences

IHSAN ALI¹, (Senior Member, IEEE), ISMAIL AHMEDY¹, (Member, IEEE),
ABDULLAH GANI^{1,2}, (Senior Member, IEEE), MUHAMMAD UMAIR MUNIR^{1,3},
AND MOHAMMAD HOSSEIN ANISI⁴, (Senior Member, IEEE)

¹Department of Information Systems, Faculty of Computer Science and Information Technology, Universiti Malaya, Kuala Lumpur 50603, Malaysia

²Faculty of Computing and Informatics, University Malaysia Sabah, Labuan 88400, Malaysia

³Faculty of Information Technology, University of Central Punjab, Lahore 54000, Pakistan

⁴School of Computer Science and Electronic Engineering, University of Essex, Colchester CO4 3SQ, U.K.

Corresponding authors: Ihsan Ali (ihsanalichd@siswa.um.edu.my), Ismail Ahmedy (ismailahmedy@um.edu.my), and Abdullah Gani (abdullahgani@ums.edu.my)

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ABSTRACT Data collection is an essential part of sensor devices, particularly in such technologies like Internet of Things (IoT), wireless sensor networks (WSN), and sensor cloud (SC). In recent years, various literature had been published in these research areas to propose different models, architectures, and contributions in the domains. Due to the importance of efficient data collection regarding reducing energy consumption, latency, network lifetime, and general cost, a momentous literature volume has been published to facilitate data collection. Hence, review studies have been conducted on data collection in these domains in isolation. However, a lack of comprehensive review collectively identifies and analyzes the differences and similarities among the data collection proposals in IoT, WSN, and SC. The main objective of this research is to conduct a comprehensive survey to explore the current state, use cases, contributions, performance measures, evaluation measures, and architecture in the IoT, WSN, and SC research domains. The findings indicate that studies on data collection in IoT, WSN, and SC are relatively consistent with stable output in the last five years. Nine novel contributions are found with models, algorithms, and frameworks being the most utilized by the selected studies. In conclusion, key research challenges and future research directions have been identified and discussed.

INDEX TERMS Data collection in sensor cloud (SC), data collection in wireless sensor networks (WSNs), data collection in Internet of Things (IoT), sensor cloud, similarity and difference, architecture, models, algorithms, frameworks.

I. INTRODUCTION

Wireless sensor networks (WSNs) are the most significant component of the Internet of things (IoTs) [1]. IoT and WSNs have been implemented in many applications, such as transport system [2] building automation [3], agriculture [4], [5], health monitoring [6], [7] and so on. However, the battery capacity, storage capability, and data transmission rate of the sensors are known to be insufficient, which can affect the network lifetime. The study of Piyare *et al.* [8] proposed

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an adaptable and dynamic architecture for combining WSN with the cloud to improve the transmission speed and network lifetime. The integration of WSN and cloud in the sensor cloud (SC) not only improves WSN lifetime but also service quality, computation latency, and energy consumption [108]. The main objective of the SC is that it allows a single WSN to generate sensing services for various applications concurrently [109]. Over the past decade, numerous studies have proposed various solutions in these research domains. These studies contributed state-of-art solution proposals, evaluation mechanisms, performance metrics, and distinct architectures in IoT, WSN, and SC [9]–[11]. However,

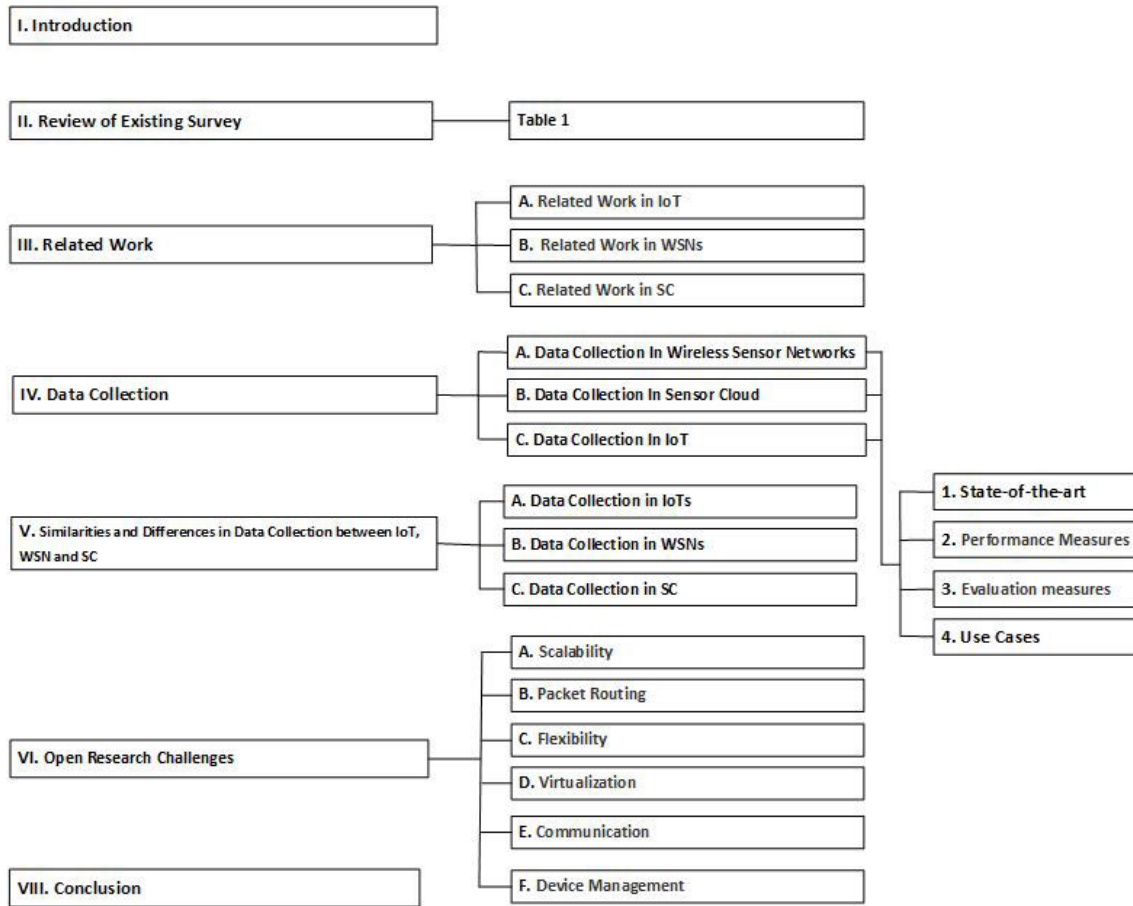


FIGURE 1. Overview of the paper.

to date, no study has yet for comprehensively examining the differences and similarities among IoT, WSN, and SC. Hence, to fill this research gap, the current study conducted a comprehensive survey in the IoT, WSN, and SC research areas to learn about the contribution, present state, performance measurements, use cases, architecture and evaluation measures. A thorough and comprehensive search process was conducted to ensure that relevant studies on the three selected domains in the last decade (2010–2020) were identified and retrieved. This survey also presented results based on the selected studies’ (SS) characteristics, the proposed contributions, the use cases of the SS, the evaluation mechanisms used by the SS, the performance measures of the studies, and the architectures used. The contributions provided by this study are as follows:

- A comprehensive review of the three selected domains: IoT, WSN, and SC.
- Analysis and synthesis of current works in this research domain.
- Finding the similarities and differences between the three selected domains.
- Identifying existing research challenges and areas that need attention from the research community in this domain.

The rest of the article is organized as follows: the related works are assessed and presented in Section III, Section IV describes the data collection processes in the selected domains, Section V presents and discusses the similarities and differences, Section VI outlines the open research challenges, and finally, the study is concluded in Section VII. Figure 1 represent a road map of the paper. All abbreviations used in this paper are given in table 9.

II. REVIEW OF EXISTING SURVEYS

We have reviewed some of the exiting review and survey paper in this section and a detail comparison of the exiting related work with our presented work are given in Table 1.

In [12] the author introduced a data gathering technique known as Location based Clustering and Opportunistic Geographic Routing (LCOGR), in which it used a Location Point (LP) to pick the Cluster Head (CH), confirming the uniform distribution of CHs and increasing energy efficiency. Furthermore, the author introduced BYPASS beacon-based spatial routing, which transmits data to the Base Station (BS) while maintaining consistent connectivity. Authors in [13] developed Minimum Edge-shared Vertex Path Selection (MEVPS) for WBAN attempts to alleviate

TABLE 1. Existing review and survey papers.

Ref.	Year	Title	Limitation
[12]	2022	An efficient data collection using wireless sensor networks and internet of things to monitor the wild animals in the reserved area	<ul style="list-style-type: none"> • Not focused on data collection in IoT, WSNs and SC Combinedly. • Similarity and differences between IoT, WSNs and SC are not discussed. • Mainly focuses on data collection using WSNs and IoT for consistently monitoring wild animals in a specific area
[13]	2022	Edge device based efficient data collection in smart health monitoring system using wireless body area network	<ul style="list-style-type: none"> • Not focused on data collection in IoT, WSNs and SC Combinedly. • Similarity and differences between IoT, WSNs and SC are not discussed. • Efficient data collection in smart health monitoring system using wireless body area network.
[14]	2021	Using UAV to Detect Truth for Clean Data Collection in Sensor-Cloud Systems	<ul style="list-style-type: none"> • Not focused on data collection in IoT, WSNs and SC Combinedly. • Similarity and differences between IoT, WSNs and SC are not discussed. • Primary concerned to detect accurate Data collection in SC system using UAV.
[110]	2020	Data Collection in Sensor-cloud: A Systematic Literature Review	<ul style="list-style-type: none"> • Not focused on data collection in IoT, WSNs and SC Combinedly. • Similarity and differences between IoT, WSNs and SC are not discussed. • Primary concerned with data collection in SC.
[15]	2020	Data Collection in Sensor Cloud: Recent Advances, Taxonomy, Use Cases and Open Challenges	<ul style="list-style-type: none"> • Similarity and differences between IoT, WSNs and SC are not discussed. • Discuss the general introduction of data collection in WSNs, SC and IoT. • Mainly focused on data collection in SC.
[16]	2019	A survey on wireless sensor network databases	<ul style="list-style-type: none"> • Not focused on data collection in IoT, WSNs and SC Combinedly. • Similarity and differences between IoT, WSNs and SC are not discussed. • Mainly focused on existing sensor database approaches in WSNs.
[17]	2018	Data collection in smart communities using sensor cloud: recent advances, taxonomy, and future research directions	<ul style="list-style-type: none"> • Not focused on data collection in IoT, WSNs and SC Combinedly. • Similarity and differences between IoT, WSNs and SC are not discussed. • Mainly focused on Data collection in smart Communities using SC.
[18]	2018	Data collection for security measurement in wireless sensor networks: A survey	<ul style="list-style-type: none"> • Not focused on data collection in IoT, WSNs and SC Combinedly. • Similarity and differences between IoT, WSNs and SC are not discussed. • Mainly focused on Data collection for security measurement in WSNs.
[19]	2017	Approximate sensory data collection: A survey	<ul style="list-style-type: none"> • Not focused on data collection in IoT, WSNs and SC Combinedly. • Similarity and differences between IoT, WSNs and SC are not discussed. • Primary discussed on the state of the art of approximate data collection algorithms.
[20]	2017	Survey of delay-constrained data collection with mobile elements in WSNs	<ul style="list-style-type: none"> • Not focused on data collection in IoT, WSNs and SC Combinedly. • Similarity and differences between IoT, WSNs and SC are not discussed. • Investigated delay-constrained data collection methodology using mobile elements through several kinds of classification.
[21]	2016	Data collection and wireless communication in Internet of Things (IoT) using economic analysis and pricing models: A survey	<ul style="list-style-type: none"> • Not focused on data collection in IoT, WSNs and SC Combinedly. • Similarity and differences between IoT, WSNs and SC are not discussed. • Focused on data collection and communication in IoT using economical analysis and pricing models.
[22]	2016	Data gathering techniques for wireless sensor networks: A comparison	<ul style="list-style-type: none"> • Not focused on data collection in IoT, WSNs and SC Combinedly. • Similarity and differences between IoT, WSNs and SC are not discussed. • Discussed the problems of data collection in WSNs by comparing several approaches. • Derived analytical model which can able to predict the energy efficiency and reliability of different data gathering techniques.
[23]	2015	A survey on data collection in mobile wireless sensor networks (mwsns)	<ul style="list-style-type: none"> • Not focused on data collection in IoT, WSNs, and SC Combinedly. • Similarity and differences between IoT, WSNs and SC are not discussed. • Surveyed on state-of-the-art data collection strategies in MWSNs.

congestion and reduce latency during emergency packet delivery. Authors applied the Ant Colony Algorithm to update the neighbour information, a minimum edge-shared vertex path between the source and the Base Station (BS) is built (ACA). Furthermore, the authors also proposed system's body controller incorporates a packet discard policy to reduce data traffic entering the network. In [14] the author presented the idea to send the accurate data from sensing devices and MEUs to sensor cloud systems, and the author presented a unique strategy to build a clean data gathering platform which verifies the truthness of data in two aspects. Firstly, verify the sensing devices' received and sent data packets, and then assessed the degree of trust, while in second aspect author compared the data packets sent by the sensing devices to MEUs with the data packets sent by MEUs to the platform, for MEU credibility, resulting in a clean data collecting sensor cloud network. In [15], the author presented data collection methods in WSNs, sensor cloud, and IoT. Furthermore, the author also categorized and classified the data collection methods in WSNs, sensor cloud, IoT and developed a taxonomy based on these classifications. In [110], the authors presented a systematic review on data collection in Sensor Clouds. The main aim of this study was to identify, categorize, and synthesize important studies in the field of sensor clouds. The authors present 10 proposal contributions out of these 10 systems, the framework and algorithms are the most used in the selected studies. Authors can further present key research challenges and future directions for the researcher. In [16], the author presented the existing sensor database approaches in WSNs. Initially, the author defined the sensor database definition by presenting the sensor database architecture and characteristics. In addition, the authors also presented and compared the existing sensor database systems and ended with the discussion of open research challenges in the field of sensor database. In [17], the authors examined the major advancements in sensor clouds in terms of data collecting. Furthermore, the author proposed a taxonomy diagram based on numerous parameters such as goal, application, communication technology, collection type, discovery, data type, and categorization to categorize and classify the literature. To underline the relevance of cloud sensors in supplying high computing skills, the authors gave application cases. The authors concluded by discussing a number of open-ended research challenges and topics, including big data concerns, deployment concerns, data security, data aggregation, control, message transmission, and timeliness. Finally, the authors suggested future study directions based on the issues [24]. The authors of [18], provide a summary of WSNs and classify the attacks in WSNs based on protocol stack layers. The authors also show how to detect eleven common assaults using the associated detection methods. The author describes the assault detection methods of eleven mainstream assaults for WSN security measurement. Authors retrieve security data that is crucial in detecting security threat anomalies with security measurement. The author also delves into the

benefits and drawbacks of existing detection technologies using a set of evaluation criteria.

In this paper, [19] approximate data collection in WSNs algorithms was reviewed by the authors, classified into three main categories: model-based, compressive sensing-based query-driven based. The advantages and disadvantages for each category of algorithms were elaborated, and based on these, the authors identified certain challenges and unresolved problems. In [20], the author thoroughly investigated delay-constrained data collection methods with mobile elements. Initially, the author summarised the characteristics of delay-constrained mobile data collection methods using a novel classification and compared them to one another using a series of key parameters. Furthermore, the authors analyzed the benefits, drawbacks, and application scope of delay-constrained mobile data collection methods. Finally, they summarized the main problems by pointing the future outlook on research and application directions. The authors of [21] investigated how economics and price models, often defined as adaptive rationale judgement approaches, may be applied to build responsive protocols for wireless sensor networks. Moreover, the authors examined several pricing techniques for incentivizing phone users to contribute their sensing data in crowd sensing applications. In addition, the author looked at how different pricing models could be used in machine-to-machine (M2M) communication. Lastly, some important open research topics and prospective research directions for applying economic and pricing models to the Internet of Things are discussed. The authors of the [22] investigated the challenges of data collection in WSNs and compared numerous strategies from various research fields such as signal processing, compressive sensing, information theory, and network engineering data collection methodologies, as well as presenting a simplified mathematical model for predicting the energy efficiency and reliability of various data gathering methods (i.e., number of nodes, transmission range, and sparsity). The authors published a survey on recent improvements in state-of-the-art methodologies in data collecting in MWSNs in [23]. Mobile wireless sensor networks (MWSNs), a subtype of WSNs including one or more mobile network devices, have gradually proliferated. In MWSNs, mobility plays an important role in the sensor network's functionality. As a result, in recent years, the WSNs community has focused on mobility as a research topic. Several protocols and models that target one or more features of MWSNs have been developed in the literature in order to improve the data gathering and dissemination process, which is the ultimate goal of any sensor network.

III. LITERATURE REVIEW

The existing review and survey studies in the IoT, WSN, and SC research domains are highlighted and discussed in this section. The subsections listed below are used to classify the research fields. The relevance of doing this type of survey can be reinforced by presenting and debating these studies.

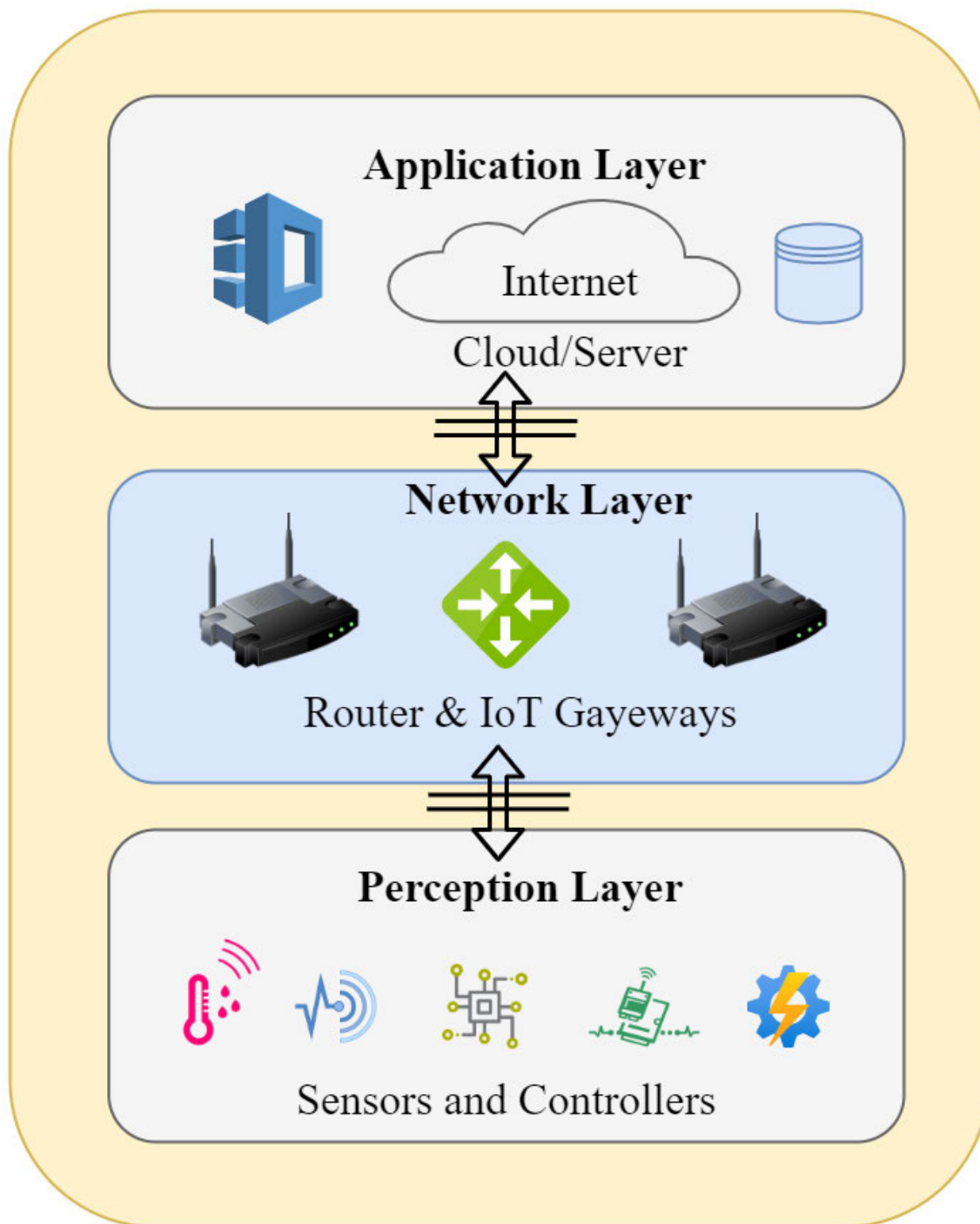


FIGURE 2. Basic architecture of IoT.

A. RELATED WORK IN IoT

Xu *et al.* presented a survey of IoT in industries [25] in which they systematically summarized and highlighted the current state of IoT in industry. The study focused on identifying the context and classifying the existing studies in IoT in an industrial setting. Although the study highlighted the challenges and opportunities in IoT for novel and veteran researchers in this domain, only related articles published

in the web of knowledge database from 2009–2013 were used in the study. Meanwhile, another study reviewed the existing technologies of IoT and sensor networks [26] in which the authors defined a six-layered architecture of IoT and highlighted related issues and challenges. However, the study limited its scope to architecture issues and challenges. In Fortino *et al.*, a comparative study was presented wherein the authors proposed a comparison based on IoT

layer's vital characteristics and the kind of architecture being used [27]. Similarly, Ferrag *et al.* surveyed existing blockchain protocols used in IoT networks and highlighted the existing studies that focused on blockchain and further described the identified blockchain [28]. That study also discussed blockchain application domains in IoT as well as provided a taxonomy and state-of-the-art methods used in the reviewed studies for securing and privacy-preservation of blockchain technologies. Additionally, Luong *et al.* surveyed data collection and wireless communication in IoT by utilizing pricing models and economic analysis [21]. The authors reviewed the existing literature on pricing models, applications, and economic analysis for data collection and wireless communication in IoT. Furthermore, the survey highlighted research problems with future research directions for applying pricing and economics to IoT. Basic Architecture of IoT is presented in Figure 2.

B. RELATED WORK IN WSNs

In Rawat *et al.*, a survey on potential synergies and recent developments in WSNs was presented [29]. The survey described the synergy between WSN and other technologies as well as presented the existing challenges and issues of WSN and future research directions. The survey conducted by Pantazis *et al.* discussed energy-efficient routing protocols in WSNs and highlighted extensive issues in each of the routing protocols [30]. The study's classified energy-efficient routing protocols included topology-based reliable routing, network structure, and communication model. The protocols' weaknesses and strengths were also presented to enable researchers to choose an appropriate protocol to suit their needs. However, the paper did not discuss significant performance metrics in WSN, such as reliability, scalability, efficiency, and so on. Oliviera and Rodriques presented a survey on WSN solutions used in monitoring environmental applications [31]. The authors critically analyzed related projects on environmental monitoring with real deployments and highlighted future studies' challenges. Hence, the paper focused on monitoring environmental application use cases. In another study, Yang *et al.* conducted a survey describing the IoT security and privacy issues [32]. The study started by presenting the solutions to the IoT device limitations and then highlighting the current IoT attacks' taxonomy. The authors further reviewed the IoT access control schemes, authentication, and architectures of the existing studies. However, only limited solutions were reviewed to address the study's challenges. Hodge *et al.* surveyed WSN technology in the railway industry [33], focusing on practical engineering solutions where sensor devices were used. However, the paper only examined the railway industry use case. Similarly, Das *et al.* presented a survey study on WSN virtualization [34], which provided a forum where multiple applications can exist in a single framework of sensor infrastructure, thus minimizing the deployment cost, the number of sensors, and so on, of the sensor infrastructure. Another study surveyed data collection in WSNs, provided a

standard classification of WSN architectures, and discussed the process of data collection and the current problems [35]. The study also described other important data collection processes, such as performance measures and evaluation mechanisms not discussed in other studies. In a survey by [36], the authors discussed the existing works on WSNs and WSN packages, such as design features, applications, and lifetime prediction models. Another study presented a comprehensive survey of existing studies concentrating on using WSNs for structural health monitoring [37]. The authors focused on WSN telecommunication in the existing structural health monitoring (SHM) studies and highlighted the challenges and future trends in the application of SHM to WSNs. Figure 3 shows the general architecture of WSN.

C. RELATED WORK IN SENSOR CLOUD

In a study by Alamri *et al.* [38], the authors presented a comprehensive study on SC infrastructure. They reviewed SC constraints, including architecture, applications, use cases, and definitions. That work also highlighted the challenges, proposed, solutions, techniques, and directions for future research. However, the paper neither discussed the performance metric and system models adopted in the SC nor provided a detailed evaluation of the facets considered. [39] used cloud computing to survey typical SC network applications and reviewed how cloud computing applications were combined with WSNs in use cases like environmental monitoring, weather prediction and forecasting, healthcare, transportation business, and military application. Notably, the paper did not discuss the significant SC data collection process. The survey on SC studies conducted by Ansari *et al.* [38] highlighted the architecture, definitions, and processing time of SC and the layered approach of SC. Dwivedi *et al.* [40] presented a survey study that described the security attacks on SC. The authors also discussed the existing studies' defence mechanisms to protect SC from security attacks. Although the literature indicates a significant number of surveys in IoT, WSN, and SC, to the best of our knowledge, existing works dedicated to surveying the specific relations among the three domains (IoT, WSN, and SC) are nonexistent. Therefore, this paper surveyed to explore the state-of-the-art, use cases, contributions, performance measures, evaluation measures, and architecture in the IoT, WSN, and SC research domains. Hence, we extracted information on various evaluation measures, architectures, and use cases in the selected domains. Then, the differences and similarities among IoT, WSN, and SC were identified. A general architecture of Sensor Cloud is presented in Figure 4.

IV. DATA COLLECTION

In this section, studies on data collection of the three facets of this research (data collection in IoT, WSN, and SC) are presented and critically discussed in detail.

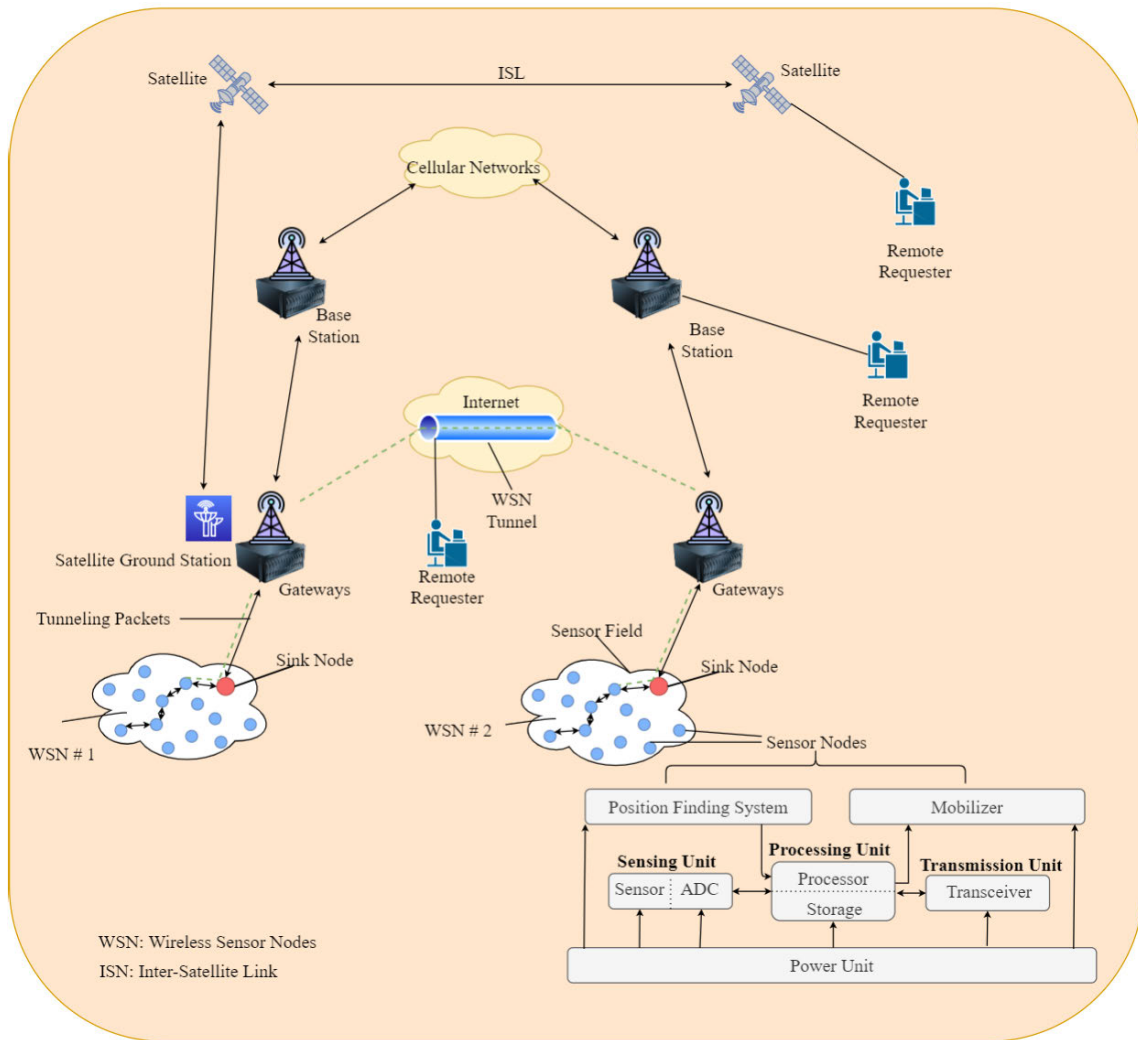


FIGURE 3. Basic architecture of WSN.

A. DATA COLLECTION IN THE INTERNET OF THINGS

This subsection outlines the detailed discussion and analysis of data collection related to IoT. Details on the current state, proposals, performance measures, evaluation measures, and use cases were outlined and discussed.

1) STATE-OF-THE-ART

In a study by Hu, the authors proposed a software-defined Industrial IoT (IIoT) architecture to provide a solution to holistic IIoT system challenges [41]. The proposed architecture was formulated based on novel networking technologies, such as software-defined networking (SDN) and constrained application protocol (CoAP). Rao *et al.* proposed a prototype model that describes how IoT and cloud computing collaboratively work and address big data issues [42]. In a study by Savale *et al.*, the authors proposed a framework that connects IoT with agriculture to provide links between farms and with agronomists, thus increasing agricultural product harvests [43]. The study provides a comprehensive system designed to achieve higher

precision in agricultural production. Sheng *et al.* proposed a lightweight approach that allows for the device management of wireless sensor devices [44]. They were inspired by the recent development of the IPv6 protocol, which they adopted in their proposed approach. The study developed a prototype to ascertain the proposed approach's efficiency in managing wireless sensor devices, thus facilitating IoT development. Feng *et al.* identified the feasible, best, and practical wireless communication technologies applied in precision agriculture [4]. They also conducted experimental agricultural scenario analyses and detected three WSN architectures. They then proposed and developed a novel NB-IoT technology-based precision agricultural system. Kumar and Ramudu developed a comprehensive system to aid precision agriculture [45]. The proposed approach provides instant output regarding crops and land to enable farmers to make the best agricultural decisions. Kamalinejad *et al.* proposed a unit for wireless energy harvesting in IoT called WEH-IoT [46]. They further analyzed the WEH-IoT lifetime based on two scenarios in IoT systems. The simulation

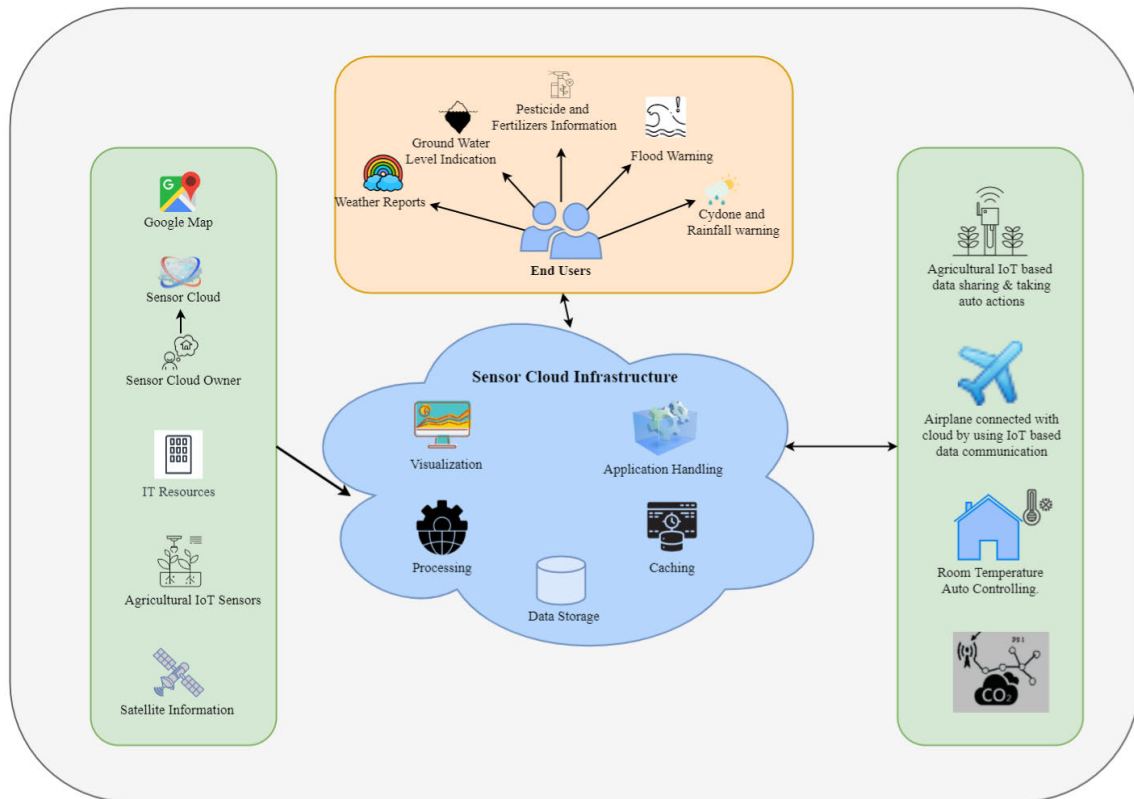


FIGURE 4. Basic architecture of sensor cloud.

results show that the lifetime improved by using the proposed techniques. Kirichek *et al.* [47] proposed a model that provides a comprehensive review of the peculiarities of IoT devices, applications, and protocols. Another study proposed a scheme for cognitive radio sensor networks (CRSNs) [48]. In the CRSN architecture, the sensor nodes can access the harvested energy from ambient radio-frequency sources. The authors then introduced a new energy management scheme, which allows sensor nodes to achieve energy harvesting and cluster head selection algorithm [49]. The study also conducted a simulation experiment to ascertain the scheme's effectiveness over compared schemes. Ilyas *et al.* introduced a trust-based energy-efficient routing protocol (TBEERP) that aims to overcome IoT challenges to extend network lifetime and decrease latency [50]. The study was evaluated based on a comparison and with existing algorithms. The simulation results revealed a good performance when equated with existing algorithms. Meanwhile, Alam *et al.* introduced an IoT framework to support connected object sensor reasoning and processing by providing a semantic overlay of the primary IoT cloud [51]. They then validated the framework through a prototype implementation on a real-life battery driven motor. Chen *et al.* tailored a system that can promote the popularity of narrowband-IoT [52]. The tailored system consisted of basic components integrated. Huh *et al.* developed a novel system using Ethereum, a blockchain computing platform, to control and configure

IoT devices. They used Raspberry Pis for the proposed IoT system simulation. Orsino *et al.* proposed a device-to-device-based approach [53], which they evaluated using simulation analysis to ascertain its performance in broad scenarios, thus identifying attainable gains in terms of energy efficiency-based IoT data collection. Li *et al.* developed an optimal computing resource allocation-based algorithm [54]. The results of the theoretical analysis and simulations of the proposed algorithm show that it is efficient and can provide good business strategies for consumers and retailers in the field of computing resource. Siboni *et al.* introduced an innovative framework for the IoT devices [55]. The proposed framework handles security and privacy threats in the IoT devices. Ahmed *et al.* investigated and discussed the state-of-the-art research conducted in the domain of IoT-based smart environments [56]. The study highlighted the significance of IoT and smart environment integration and further detailed the taxonomy of IoT in such environments. It also conducted a case study in IoT-based smart environments. Antao *et al.* highlighted the conditions for Cyber Physical Production Systems and Industrial IoT by proposing a requirements list for validation [57]. Yang *et al.* highlighted the research issues of IoT-enabled manufacturing [58] IoT's core technologies to be used in addressing the manufacturing challenges are radio frequency identification, WSN, cloud computing, and Big Data. Soldatos and Serrano proposed IoT cloud environment design principles and framework to converge

IoT Infrastructure with cloud-based computing models and applications into the cloud [59]. The study analyzed state-of-the-art results and efforts concerning cloud computing and IoT convergence. The authors also presented the framework building block, which emphasizes the formation of IoT services based on Internet-connected objects. The study by Atzori *et al.* presented opportunities obtained from the incorporation of networking concepts into the IoT and found the stages of increasing levels of social involvement [60]. Zimmermann *et al.* investigated mechanisms for IoT decision-controlled architectures and micro-services by evolving reference models and architecture [61]. The Ray study presented a novel H3IoT architectural framework to monitor the health conditions of elderly individuals [6]. The framework showed good performance in terms of its utilization for wellness and decreasing the present healthcare system's strain points. Brooks *et al.* described an IoT component-based software architecture wherein the proxy accessories interact with one another [62]. Sisinni *et al.* highlighted the concepts of IoT, industrial IoT, and industry 4.0; described the benefit generated by this paradigm shift; and discussed the related issues [63]. Qu *et al.* presented a summary of privacy issues and possible attacks based on newly designed IoT features [64]. They conducted three case studies to classify the schemes. Chamoso *et al.* reviewed IoT studies on the so-called "smart cities," provided an analysis of the concept and current platforms, and proposed a model for designing a smart city architecture [7], [65]. Kovatsch *et al.* presented a Cloud/IoT architecture based on the Constrained Application Protocol (CoAP), typically used in low-cost IoT devices [66]. The study systematically evaluates the system architecture and protocol performance in cloud environments. The evaluation results show that the CoAP framework provides higher throughput than high performance. Wang *et al.* presented an ontology for the IoT domain by incorporating models during the modelling process of the IoT, providing support for IoT tasks, and exploiting the existing efforts' synergy [67]. Korzun *et al.* highlighted their experiences while using smart space applications [68]. They performed experiments to estimate the response time of the Smart-M3 platform, and determined its applicability in current computing environments. Liu *et al.* proposed LightChain, which is suitable for power-constrained industrial IoT [69]. An experiment conducted showed that LightChain decreased the computational cost and sped up the block generation process. In another study, a technique called FaBric blockchain-based data transmission was proposed for industrial IoT data transmission [70]. Experiments showed the high reliability and security of the optimized FaBric power data storage and transmission. Liu *et al.* adopted the use of unmanned aerial vehicle (UAV) to assist in emergency communications in a heterogeneous IoT (Het-IoT) environment [71]. Similarly, the authors proposed nonorthogonal multiple access (NOMA) and a multiobjective resource allocation (MORA) scheme to handle the communications of the remaining users and IoT devices

for the UAV-assisted Het-IoT. Their simulation results confirmed that the scheme provides efficient performance for the users and devices. Chen *et al.* proposed an online and polynomial-time complexity algorithm. Experimental results showed the effectiveness of the proposed algorithm in reducing energy consumption. Alamed presents a middleware framework that incorporated the IoT, Fog, and Blockchain technologies [72]. Table 2 presents the details of the data collection studies.

Figure 5 shows the respective publication channels identified from the studies on data collection in IoT. Hence, the number of studies for data collection in IoT is also given in the Figure 5. We have identified three publication channels, which are journals, conferences, and magazines, with journals having the highest number of studies (16), followed by conferences (12), and magazines (1).

2) PERFORMANCE MEASURES

In this section, the SS's performance measures are outlined and presented. These performance measures are also presented in Table 2 with the respective studies that considered them. However, only the performance measures of data collection studies on IoT are given in this subsection. We have identified 19 performance measures used by the SS. We found that the most considered performance measures are network lifetime, performance, and privacy. However, we observed that the 12 studies did not clearly outline which performance measures they utilized in their respective studies; hence, they were categorized as "Nil."

3) EVALUATION MEASURES

From Table 3, the reader can observe that the evaluation measures for each study are provided. For the analysis in this section, we have identified four evaluation measures: Experiment - adopted by 5 studies, Simulation - adopted by 11 studies, case study - adopted by 5 studies, and Hybrid (the combination of two or more evaluation measures) adopted by 2 studies. Figure 6 highlights each evaluation measure's detailed breakdown with respect to the years of use in line with the respective studies. For Simulation, which is the most commonly used by studies on data collection for IoT, 2019 was the most active year, with four studies utilizing this method.

4) USE CASES

This section presents the use cases of data collection in IoT. From the SS, we identified several use cases, namely, agriculture, augmented reality and environment monitoring, smart environments, manufacturing and smart cities, trade, health, mechanical sector, software engineering, collaborative work, tourism, and mathematical analysis. In our sub-categorization, we categorize discussions with other use cases as "others" because only a few studies have used such cases. Agriculture Data collection in agriculture has become imperative in today's farming, where sensor

TABLE 2. Analysis of the studies on data collection in IoT.

Ref	Proposal	Architecture	Use cases	Year	Publication channel
[73]	System	IIOT sensor cloud, IIOT gateway, and IIOT field device	Nil	2015	Conference
[43]	System	Central server, gateway, and Internet	Agriculture	2015	Journal
[44]	Framework	Nil	Smart Environment	2015	Journal
[4]	Framework	IOT, gateway, and network server	Agriculture	2019	Journal
[45]	System	Central server, gateway, and Internet	Agriculture	2019	Journal
[46]	System	Sink node, gateway, and Internet	Agriculture	2015	Magazine
[47]	Model	Cloud-based IOT platform, gateway, software defined network, WSN, and indoor location system	Nil	2016	Conference
[48]	Algorithm	Network manager, cloud, and cognitive radio sensor network	Nil	2018	Journal
[50]	Protocol	Cluster gateway, sink node, cluster head, and cluster members	Smart environment	2020	Journal
[51]	Framework	IOT cloud, semantic overlay layer, service virtualization layer, and real world access layer	Mechanical sector	2010	Conference
[52]	System	NB-IoT cloud platform, data receiving and transmission networks, NB-IoT terminals, and application server	Academic research	2017	Journal
[9]	System	Nil	Nil	2017	Conference
[53]	Algorithm	Nil	Smart city environment	2016	Journal
[54]	Algorithm	Nil	Trade	2019	Journal
[55]	Framework	Security testing module, management and report module, security testing manager module and measurements and analysis module	Nil	2019	Journal
[56]	Nil	Nil	Smart environment	2016	Journal
[57]	Framework	Application layer, business layer, middleware layer, perception layer, and network layer	Software engineering	2018	Conference
[57]	Nil	Nil	Manufacturing	2016	Conference
[74]	Nil	Gateway, network domain	Nil	2016	Journal
[59]	Framework	Nil	E-science, manufacturing and smart cities	2012	Conference
[60]	Framework	Application layer	Smart environment	2014	Magazine
[61]	Model	Devices, communication protocol, bus layer, processing and analytics, Web	Mechanical sector	2017	Conference
[6]	Framework	Internet application layer (IAL), local communication layer, physiological sensing layer, information processing layer, and user application layer	Health	2014	Conference
[58]	Framework	Nil	Smart things	2018	Conference
[7]	Model	Application layer, service system layer, physical layer, and IoT gateway	Health and smart city environment	2018	Journal
[66]	System	Network, application protocol, and root	Nil	2014	Conference
[70]	Approach	Nil	Nil	2019	Conference
[71]	Model	Nil	smart environment	2019	Journal
[75]	Algorithm	Nil	Nil	2019	Journal
[72]	Framework	IoT nodes, blockchain, cloud, and fog	Nil	2019	Journal

technologies are utilized in the process. Hence, the sensed data are to be collected effectively. Results show that most of the studies reviewed investigated the IoT in an agricultural setting [4], [42], [43], [45]. This is because IoT is used to monitor and select crop growth and provide irrigation decision support, among others, [42] illustrated data collection in IoT using software and applications for agriculture. Recent studies [4], [43], [45] have investigated wireless communication technologies for IoT data collection to improve agricultural precision. Smart environment Smart environments have become very popular in recent years,

with ever-increasing technologies being deployed to improve technological and data accessibility awareness. Looking at our environment, IoT and sensing devices are deployed at a large scale without noticing. Hence, with this large deployment of sensing devices, finding methods of collecting key data from the sensing devices is crucial. From our review, we have identified a few studies that worked for data collection for smart environments. For instance, some studies proposed energy-efficient IoT data collection in smart cities by exploiting various communication technologies, while others studied the issue holistically [41], [44], [50], [53],

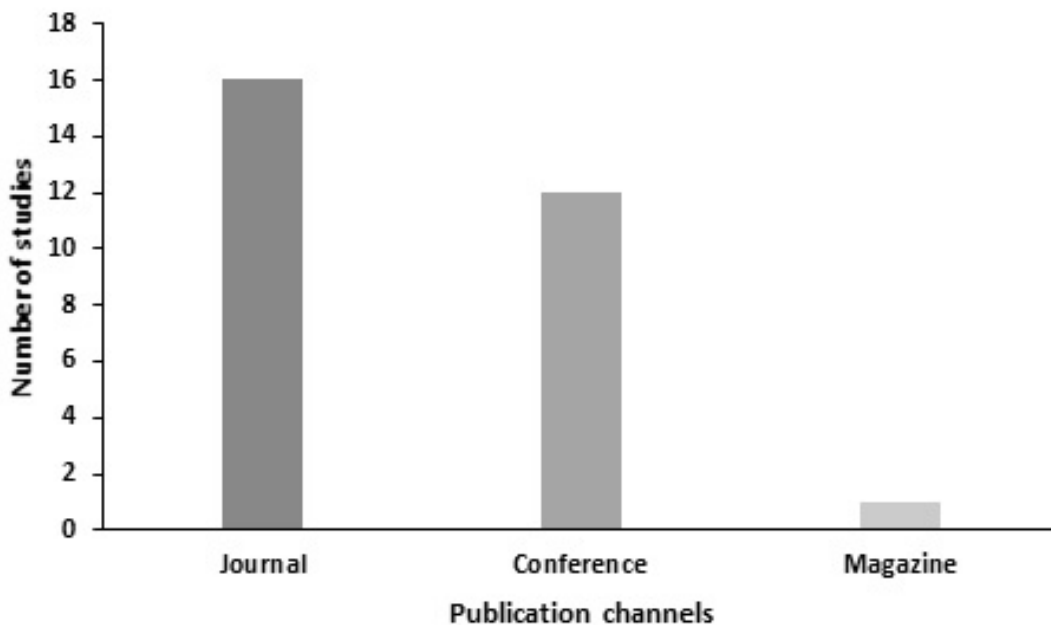


FIGURE 5. Analysis of the publication channels for DC studies in IoT.

TABLE 3. Performance measures and evaluation metrics with respect to the studies on IoT.

Ref	Performance measures	Evaluation measures	Year of publication
[73]	Scalability, security, and performance	Experiment	2015
[43]	Nil	Nil	2015
[44]	Latency and performance	Simulation	2015
[4]	Energy consumption	Experiment	2019
[45]	Nil	Simulation	2019
[46]	Network lifetime, energy consumption	Simulation	2015
[47]	Performance	Simulation	2016
[48]	Network lifetime, Network performance	Simulation	2018
[50]	Throughput, latency and network lifetime, energy consumption	Simulation	2020
[51]	Lifetime	Case study	2010
[52]	Nil	Nil	2017
[9]	Nil	simulation	2017
[53]	Performance and data transmission	simulation	2016
[54]	Efficiency	Simulation and theoretical analysis	2019
[55]	Security and validity	Simulation	2019
[56]	Nil	Case study	2016
[57]	Accuracy, security and privacy, and reliability	Case study	2018
[58]	Nil	Nil	2016
[76]	Privacy	Nil	2016
[59]	Nil	Nil	2012
[60]	Nil	Nil	2014
[61]	Nil	Case study	2017
[6]	Nil	Nil	2014
[62]	Security, privacy, and network latency	Experiment	2018
[7]	Nil	Case study	2018
[66]	Throughput and performance	Simulation and benchmark comparison	2014
[70]	Reliability, security, performance, and data transmission	Experiment	2019
[71]	Performance, data transmission, and communication	Simulation	2019
[75]	Energy consumption, accuracy, and performance	Experiment	2019
[72]	Nil	Simulation	2019

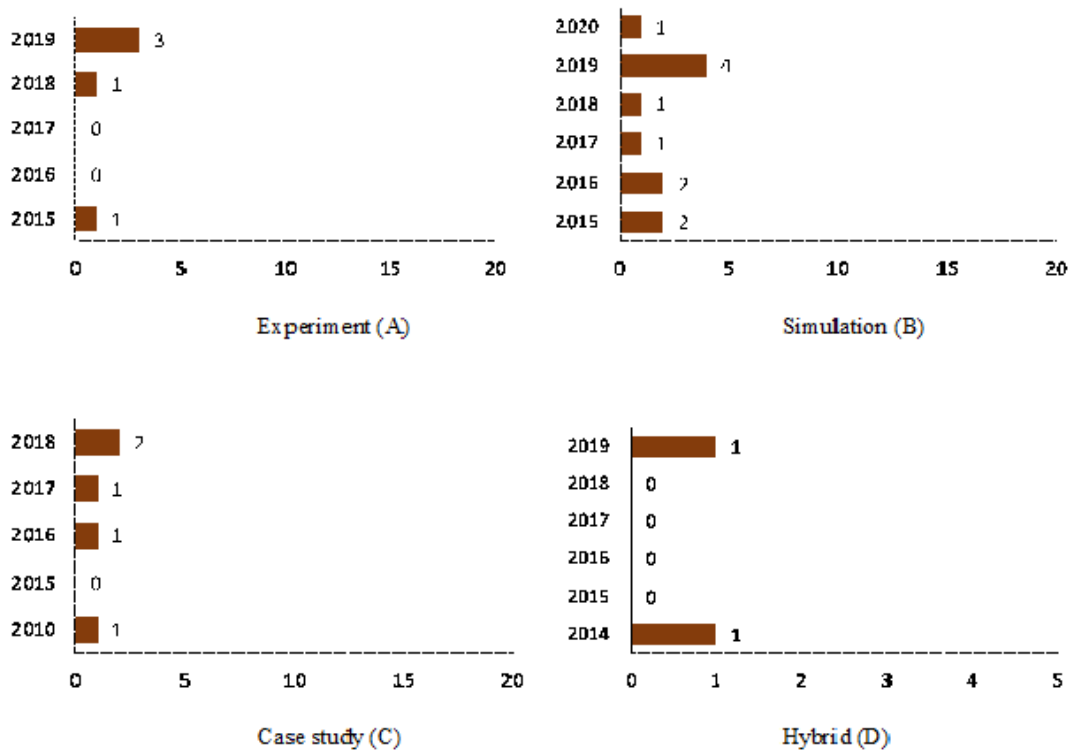


FIGURE 6. (A–D). Breakdowns of evaluation measures used in the respective years of evaluation.

[53], [56], [60]. Manufacturing We identified several studies that utilized IoT in data collection for manufacturing [32], [63]. Due to the importance of IoT in the manufacturing environment, various data collection mechanisms are needed, as the precise collection of data in this field is imperative. Hence, we recommend the research community to focus on this area due to its importance. Health care The health care sector is another important area in which a great deal of data is generated with increased IoT technology use. Hence, collecting precise data for patients’ diagnosis is very important. One study utilized IoT in healthcare and smart environment [7], while another [6] concentrated on building a health-related IoT framework. Others The rest of the studies [32], [51], [59], [61] used IoT in the mechanical sector. [4] used IoT in trade, Chen *et al.* [52] used the technology in academic research [56] and Wang *et al.* [67] used it in software engineering, and finally, [52] used it in mathematical analysis.

B. DATA COLLECTION IN WIRELESS SENSOR NETWORK

This subsection outlines the detailed discussion and analysis of data collection with respect to WSNs. Several aspects, such as state-of-the-art proposals, performance measures, evaluation measures, and use cases, are outlined and discussed in this section.

1) STATE-OF-THE-ART

Piyare *et al.* introduced a WSN architecture derived from cloud-based sensor data platform open.sen.se [8] in which the architecture display, access, and sharing of the infographic of different data streams from anywhere can be achieved with Internet connectivity. An experiment was conducted and the results were evaluated to assess the alert notification time, accessibility, and battery consumption. The results demonstrate improved performance in these aspects. Porambage *et al.* introduced an authentication mechanism for WSNs in distributed IoT devices [77]. The developed mechanism uses a multiple-phase authentication protocol, which enables the user and sensor nodes to authenticate and establish connections. The experimental results reveal that the protocol is feasible for use in WSNs. Kaiwartya proposed a framework that will provide optimized fault tolerance (FT) during WSN virtualization [78]. The framework focuses on heterogeneous networks for IoT applications. They conducted a case study-based simulation to assess the performance of the framework. Duan *et al.* used a game approach to propose an energy-aware, and to manage overhead and ensure acceptable WSN security, a trust derivation mechanism can be implemented [74].The strategy not only reduces energy usage but also maintains considerable network security, according to their simulation results.An approach for data dissemination called transmission with multiple

load balancing schemes (TMLBSs) has been proposed by Liu *et al.* [79]. The strategy uses a nature-inspired approach and colony optimization. The authors conducted simulations to validate the approach's performance, and the results proved its superiority and effectiveness in terms of load balance level and network longevity. [80]. conducted a performance investigation on the IoT-enabled intra-vehicular wireless sensor networks (IVWSNs). Meanwhile, Thombre *et al.* adopted open technologies to WSN stacks [81] and simulated the stack using a Contiki network simulator (Cooja) with varying conditions, which helped to understand the performance of the stack and benchmark analysis. Dong *et al.* proposed a method that collects data with energy efficiency and reliability requirements called reliability and multipath encounter routing (RMER) [1]. The RMER approach provides an improved network lifetime and event detection reliability while reducing energy consumption. The experimental simulation results indicate that the proposed techniques outperform other solutions in event detection. [82] proposed a software-defined WSN architecture to manage WSNs, while [83] proposed a lightweight algorithm called adaptive transmission power control (ATPC) in WSN. The algorithm manages the differences in radio communication and low-power sensor devices. The simulation experiments results show that ATPC achieves more significant energy savings and is robust even with environmental based on the timing. Mainetti *et al.* [3] discussed solutions to integrate heterogeneous WSNs and proposed a harmonized framework that will allow new installations and legacy ones. The proposed framework is currently being tested in building automation scenarios and provides a logical overlay on sensor networks, which exploits the virtual sensor concept. Lee and Cheng in [84] proposed fuzzy-logic-based clustering approach to improve the WSN lifetime through workload distribution. The experimental simulation results revealed that the approach is more efficient than the compared algorithms in terms of network lifetime. Li *et al.* in [85] introduced a CS-based framework for WSNs and IoT, which offers a stable approach for compressible signals and data in information systems. Guo *et al.* in [86] proposed opportunistic flooding, which is delay-driven flooding method that is developed for low-duty WSNs. Their simulation results revealed that the performance of the proposed method is close to the optimal. The proposed approach also achieved short flooding delay compared with improved traditional flooding. Another study adopted realistic simulation models under the many-to-one communication approach to highlight and evaluate techniques to examine how information can be collected from a WSN ordered as a tree [87]. Liu *et al.* in [88] proposed techniques for data collection schemes for WSNs. The study adopted a power-law decaying data model to propose an estimation algorithm. The techniques require lesser zipped measurements, which reduces energy consumption. The evaluation results indicate that the proposed algorithm prolongs the network lifetime compared with existing approaches. Authors in [89] integrate WSNs, the concept of big data, and big data systems

to provide an efficient operation of WSNs. They also presented a survey of distinct energy-efficient techniques for handling big data in WSNs. Meanwhile, authors in [2] proposed an efficient architecture that will use the WSN and Bluetooth protocol to improve road travel safety. The experimental results revealed that integrating the sensor and Bluetooth technology improved road travel safety. One study proposed an architecture with distributed and hierarchical controllers [90]. Their experimental results revealed that the architecture reduces the influence of software-defined networking control traffic in WSNs and the data flow installation time on the network. authors in [91] introduced an approach-based trustworthy architecture for WSNs and reported that the proposed approach outperforms the existing trust management techniques for WSN. Lounis *et al.* developed an architecture for accessing and collecting a large volume of data produced by medical sensor networks [92]. The authors also proposed a flexible and effective security mechanism to outsource the collected medical data. [5] summarized the attacks and their classifications in WSNs and explored the security mechanisms widely used to handle those attacks. Khan *et al.* [93] proposed a data annotation architecture for semantic applications in virtualized heterogeneous WSNs. They built a prototype that they then deployed in the cloud environment using the Google App engine. The initial performance measurements presented the efficient nature of the proposed architecture. Doddapaneni *et al.* [94] proposed a framework that would allow developers to model the software architecture of WSNs distinctly. Table 4 highlights the details of the data collection studies on WSNs. Figure 7 shows the respective publication channels identified from the studies on data collection in WSN. For WSN studies, we identified three publication channels, namely, Journal, Conference, and Symposium. Journal has the highest number of studies (14), followed by Conferences(3), and Symposium (1).

2) PERFORMANCE MEASURES

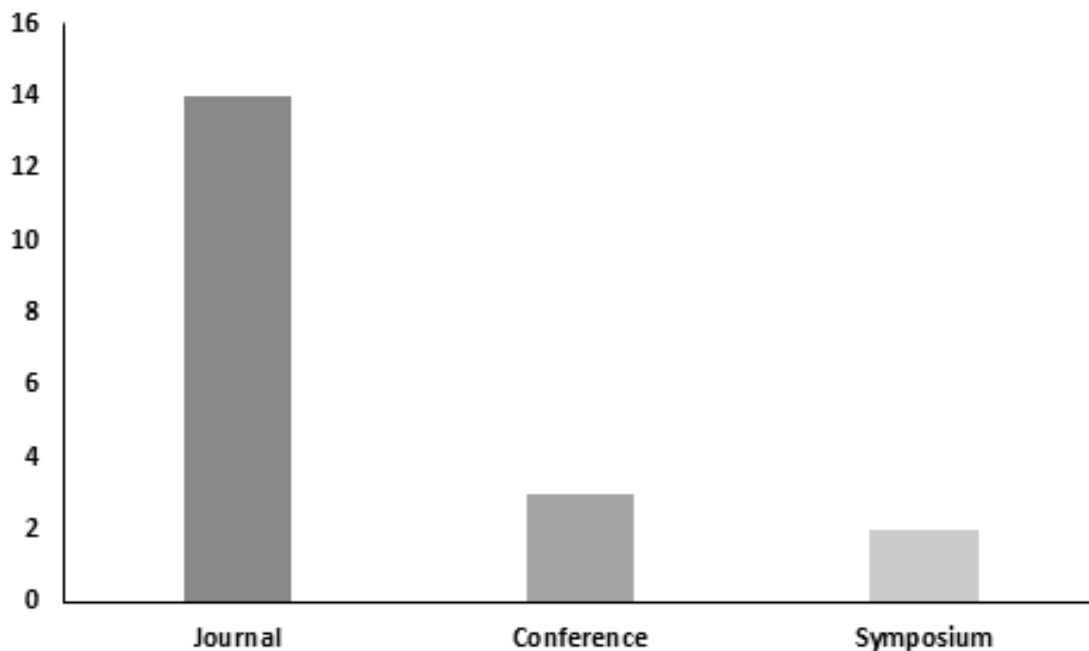
In this section, the performance measures utilized by the respective data collection studies on WSNs are outlined. Table 5 provides detailed information about the performance measures and evaluation measures used by each study.

3) EVALUATION MEASURES

This section identified three evaluation measures used by WSN studies, namely, Experiment adopted by 4 studies, Simulation adopted by 12 studies, and Hybrid adopted by 1 study. Figure 8 highlights each evaluation measure's detailed breakdown with respect to the years of utilization in the respective studies. For Simulation, which is the most utilized by data collection studies on WSNs, 2012 was the most active year with 4 studies utilizing it, followed by 2016 with 3 studies. The trend shows that Simulation's utilization is declining, with no more than one study published each year from 2017 to 2019. This section presents the use cases of data collection in WSNs. Therefore, we identified some use

TABLE 4. Analysis of the data collection studies on WSNs.

Ref	Proposal	Architecture	Use cases	Year	Publication channel
[8]	System	Sensor layer, coordinator layer, and supervision layer	Smart environment	2013	Conference
[77]	Protocol	IoT Cloud, gateway node, and certificate authority	Smart Environment	2014	Conference
[78]	Framework	Nil	Nil	2018	Journal
[74]	Model	Nil	Nil	2014	Journal
[79]	Approach	Nil	Nil	2019	Journal
[80]	Architecture	Information acquisition and information processing	Nil	2017	Journal
[81]	Stack	Application, networking, and sensing	Flood detection (smart city)	2016	Journal
[1]	Approach	Nil	event detection distortion	2016	Journal
[82]	Architecture	Nil	Nil	2012	Journal
[83]	Algorithm	Node, packet, and radio range	Nil	2016	Journal
[84]	Algorithm	Nil	Smart Environment	2012	Journal
[85]	Framework and algorithm	Internet network, data acquisition network, and data analysis network	Nil	2013	Journal
[86]	Approach	Nil	Nil	2014	Journal
[87]	Algorithm	Nil	Nil	2012	Journal
[88]	Algorithm	Nil	Nil	2015	Journal
[91]	Architecture	Nil	Nil	2012	Journal
[92]	Architecture	Cloud server, WSN, monitoring application, and health care authority	Health	2012	Conference
[93]	Architecture	Non-semantic application, semantic application, and application overlay layer	Nil	2015	Symposium

**FIGURE 7.** Analysis of the publication channels for data collection studies on WSN.

cases, namely, smart environment, flood detection, building automation, transport system, health, and mechanical sector.

4) USE CASES

Smart environments Similar to IoT, WSNs were used in smart environments in most of the studies reviewed [8], [77], [84]. These studies utilized WSNs with sensing devices to collect

data in smart environments. Hence, with these technologies, useful key areas in a given environment can be understood, environmental planning can be standardized, and important areas in the smart environment can be tracked. Therefore, the data collected in such environments can be very useful, and effective data collection methods are essential. Flood detection and control The studies we reviewed [81], [86]

TABLE 5. Performance measures and evaluation metrics with respect to the studies on WSN.

Ref	Performance measures	Evaluation measures	Year of publication
[8]	Energy consumption, accessibility, and data transmission	Experiment	2013
[77]	Performance	Experiment	2014
[78]	Sensor communication	Case study-based Simulation	2018
[74]	Performance, energy consumption, latency, and sensor security and efficiency	Simulation	2014
[79]	Data transmission	Simulation	2019
[80]	Performance and throughput	Simulation	2017
[81]	Throughput and latency	Simulation	2016
[1]	Energy consumption, network lifetime and data transmission	Simulation	2016
[82]	Network throughput	Simulation	2012
[83]	Energy consumption and data transmission	Simulation	2016
[84]	Performance and network lifetime	Simulation	2012
[85]	Network life time and energy consumption	Simulation	2013
[86]	Flooding delay and energy consumption	Simulation	2014
[87]	Network size and performance	Simulation	2012
[88]	Energy consumption, network lifetime	Simulation	2015
[91]	Communication overhead, memory consumption, energy consumption, and performance	Simulation	2012
[92]	Data transmission and security	Experiment	2012
[35]	Scalability and delay	Experiment	2015

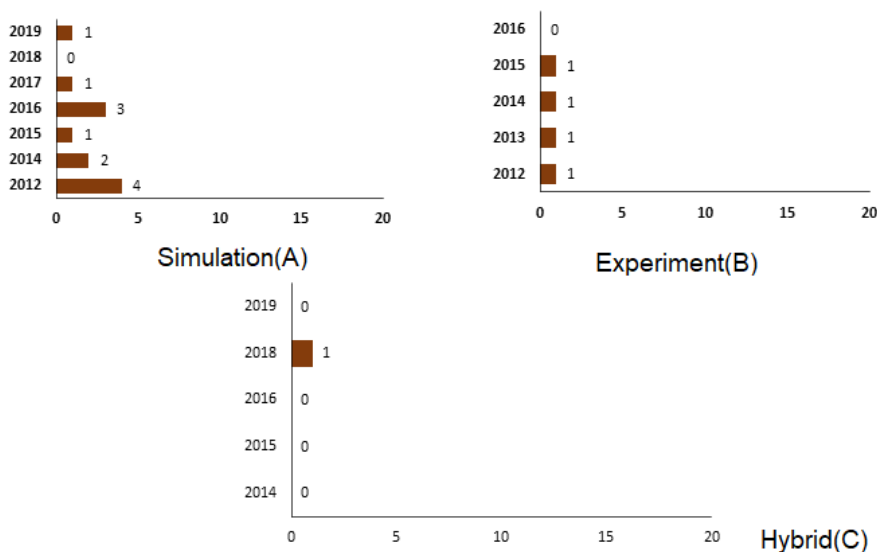


FIGURE 8. (A–C). Breakdowns of evaluation measures used in their respective years.

investigated data collection in WSNs. This use case is particularly critical to many countries, as flood detection and control are crucial in saving lives. Hence, with effective data collection mechanisms to collect data in studying the nature of floods, better detection and control methods can be devised and implemented.

5) OTHERS

Various applications were also recorded in other use cases. For example, the authors in [1] applied WSN in event detection and distortion, [3] in building automation, [2] in the transport system, [92] in health, and finally, [93] in a semantic application.

C. DATA COLLECTION IN SENSOR CLOUD

This subsection outlines the detailed discussion and analysis of data collection with respect to SC. Facets, such as state-of-the-art proposals, performance measures, evaluation measures, and use cases are outlined and discussed.

1) STATE-OF-THE-ART

Wang *et al.* in [95] proposed a mobile edge computing-based intelligent trust evaluation scheme to assess sensor nodes' efficiency by utilizing a probabilistic graphical model. They also proposed a moving algorithm for mobile edge nodes. The experimental evaluation was compared with the traditional scheme. The evaluation results revealed that the proposed scheme decreased energy consumption and

effectively reduced mobile edge nodes' moving distance. Zhu *et al.* in [96] incorporated five SC pricing models to propose a comprehensive pricing model. The model's analysis shows that it can be very useful for researchers investigating SC pricing mechanisms. To increase the lifetime of WSN, Dinh and Kim in [109] proposed an efficient model for physical sensors and information providers. When the sensor nodes produce sensing information, then the information provided will provide sensing services to the information consumer. The evaluation results revealed that the model improved WSN energy efficiency and service availability compared to the existing models. Zhu *et al.* Authors in [97] introduced a scheme called multi method data delivery (MMDD), which incorporated the concept of heterogeneous delivery. The evaluation results show that MMDD can decrease delivery time and cost for the SC users. Srinivasa *et al.* detailed the framework PARASENSE architecture, which integrates WSN with IoT [98]. Their results showed that the PARASENSE architecture facilitated the applications' real-time deployment. In another study of Dinh and Kim (2017a), an integrated SC efficient model was proposed to enable the SC to offer sensing services for multiple applications with different latency requirements [109]. The experimental results demonstrate the effective model control sensing of flow latency compared to existing models. Meanwhile, the study of Misra *et al.* addressed the theoretical characterization and analysis in SC by presenting a mathematical formulation of SC, which will help learn the behavior of WSN-based applications in the SC platform [99]. The analysis results show that the SC architecture outperforms WSN by decreasing the energy consumption and increasing the lifetime of the sensor. Zhou *et al.* developed an approach that integrates IoT and cloud computing [100]. The study analyzed the current state of IoT and cloud integration as well as the proposed the cloud things architecture cloud-based IoT that houses CloudThings. Zingirian and Valenti (2012) presented a novel SC paradigm for vehicle communication platforms (VCPs) [101]. Based on the paradigm, VCPs will avail all sensor components, such as vehicle sensors and devices, to third-party vehicle monitoring applications. The study further developed a SC service prototype that supports real-time intelligent truck monitoring (ITM). The study of Kumar and Madria proposed techniques that will enable the efficient and secure code dissemination in SC due to its focus on WSN by the existing code dissemination techniques [102]. Berrahal *et al.* proposed a model that depends on incorporating heterogeneous WSN and cloud computing to build distributed public safety databases [103]. The proposed approach is evaluated through a simulation. Huang *et al.* studied random early detection-based (RED-based) congestion control for data transmission in SC and the proposed an improved RED (IRED) algorithm [104]. The results of the experimental simulation show some promise. Iacono *et al.* Authors in [11] introduced the adoption of standard cloud file synchronization services (CFSS) to manage WSNs in the SC. They experimented using SC to

validate the proposal. Liu *et al.* optimized intrusion detection strategy to reduce energy consumption and decrease alarm messages in SC [105]. The simulation results demonstrate some improvement. Tao *et al.* [106] introduced a cache network scheme, which is built based on cache nodes in edge networks. They also formulated the data replica placement problem as a mixed-integer programming (MIP) problem to reduce storage, access, and placement costs. Then, they reduced this to a linear programming problem, which is more straightforward to resolve than the original MIP problem. Lawson and Ramaswamy in [107] introduced cloud monitoring service techniques that know the data quality and energy efficiency tradeoff levels. They also developed an optimized energy architecture that enables WSNs to provide an effective data stream and meet consumer data quality needs. Guerreiro *et al.* proposed a sensor cloud model that suits emerging IoT sensing applications as a business model, and their evaluation results revealed that the best approach for resource allocation depends on the supplier/consumers scenario. In another study, Guerreiro *et al.* proposed a resource allocation model to assign sensors and cloud resources to clients [10]. The evaluation results show that the model can incorporate techniques that allocate fewer devices while selecting adequate ones for application requirements. Ahmed *et al.* in [56] introduced IoT-based smart environments and focused on the current state classification and open research challenges. The identified publication channels with respect to the number of studies published are presented in Figure 9. Table 6 highlights the data collection studies on SC in detail.

2) PERFORMANCE MEASURES

Table 7 highlights the performance and evaluation measures utilized by the respective SS. Among these, performance measures, such as energy consumption and data transmission, are the most utilized measures by studies on SC.

3) EVALUATION MEASURES

Table 7 provides the evaluation measures for each study. For the analysis in this section, we have identified four evaluation measures: Experiments adopted by 6 studies, Simulation adopted by 6 studies, case study adopted by 2 studies, and Hybrid adopted by 1 study. Figure 10 presents the detailed breakdown of each evaluation measure with respect to the years of utilization in line with the respective studies.

4) USE CASES

This section presents the use cases of data collection studies on SC. We identified very few studies in this area. Hence, only four use cases were identified. These use cases include [44] in smart surveillance systems, [99] and [96] in business, [101] in intelligent truck monitoring, and [109] in smart environments. As an extension of WSN, SC's application in various domains is important to ensure efficient and effective data collection. We recommend that researchers focus more on data collection using SC in various

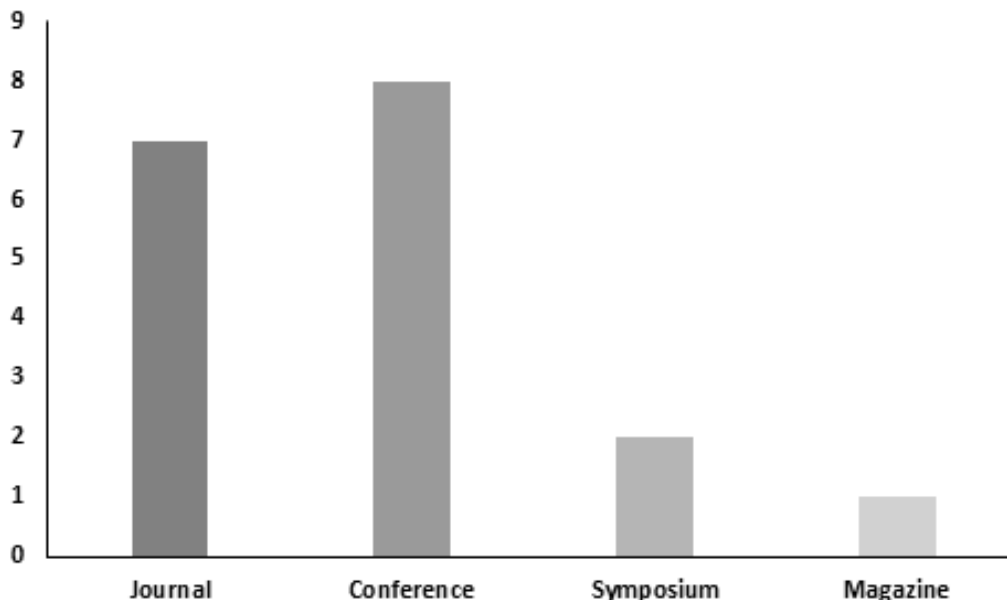


FIGURE 9. Analysis of the publication channels for data collection studies on SC.

TABLE 6. Analysis of the data collection studies on SC.

Ref	Proposal	Use Cases	Year of publication	Publication channel
[95]	Evaluation Scheme	Smart surveillance system	2020	Journal
[96]	Model	Business	2015	Conference
[109]	Model	Nil	2017	Conference
[97]	Scheme	Nil	2017	Magazine
[108]	Model	Smart environment	2017	Symposium
[99]	Model	Business	2017	Journal
[100]	Approach	Nil	2013	Conference
[101]	Architecture	Nil	2012	Symposium
[102]	Approach and algorithm	Nil	2014	Conference
[103]	Approach	Nil	2016	Conference
[104]	Algorithm	Nil	2014	Journal
[11]	Model	Nil	2017	Journal
[105]	Model	Nil	2018	Journal
[106]	Algorithm	Nil	2015	Journal
[107]	Architecture	Nil	2015	Conference
[10]	Model	Nil	2019	Journal
[103]	Architecture	Nil	2016	Conference

environments. Table 8 highlights the use of cases in the three domains (IoT, WSN, and SC).

V. SIMILARITIES AND DIFFERENCES IN DATA COLLECTION BETWEEN IoT, WSN, AND SC

In this section, the similarities and differences in data collection among IoT, WSN, and SC are discussed. Due to the multifaceted nature of this paper, this section is broken down into different subsections that target specific analyzed factors, such as use cases and architecture. This is done in order to specifically discuss each factor with respect to the similarities or differences related to each factor among the respective facets. Table 8 presents the use cases utilized in IoT, WSN, and SC based on the SS in terms of use cases. These three facets' applications and services were adopted in a range of use cases, such as health care, environmental

monitoring and industrial task surveillance, senior residents monitoring, and so on. The three selected domains were all applied in smart environments, as shown in Table 8. The SC and WSN were also applied in weather forecasting and flood detection [41], [81], [86]. The findings show that none of the IoT studies reviewed focused on weather forecasting, environmental monitoring, and disaster detection even though these technologies can be used to efficiently monitor the vibration in a building during an earthquake. Moreover, the three research domains were applied in the smart environment use case to enhance and support the capabilities of its users in executing their tasks.

A. USE CASES

The smart environment is one of the use cases utilized by the selected domains, in which sensors are connected

TABLE 7. Performance measures and evaluation metrics with respect to the studies on SC.

Ref	Performance measures	Evaluation measures	Year of publication
[95]	Energy consumption and performance	Simulation	2020
[96]	Performance and data transmission	Analysis	2015
[109]	Temperature and humidity and energy efficiency	Nil	2017
[97]	Data transmission	Case study	2017
[108]	Latency, energy consumption, and temperature and humidity	Experiment	2017
[99]	Fault tolerance, energy consumption, and lifetime of a sensor node	Case study	2017
[100]	Temperature	Case study	2013
[101]	Nil	Experiment	2012
[102]	Data transmission and energy consumption	Simulation	2014
[103]	Data privacy and availability and reliability	Simulation	2016
[104]	Throughput, data transmission, and performance	Simulation	2014
[11]	Data transmission and communication	Experiment	2017
[105]	Energy consumption and data security	Simulation	2018
[106]	Performance	Experiment	2015
[107]	Data transmission and energy efficiency	Nil	2015
[10]	Scalability	Experiment	2018
[10]	Data transmission	Experiment	2019
[103]	Nil	Simulation	2016

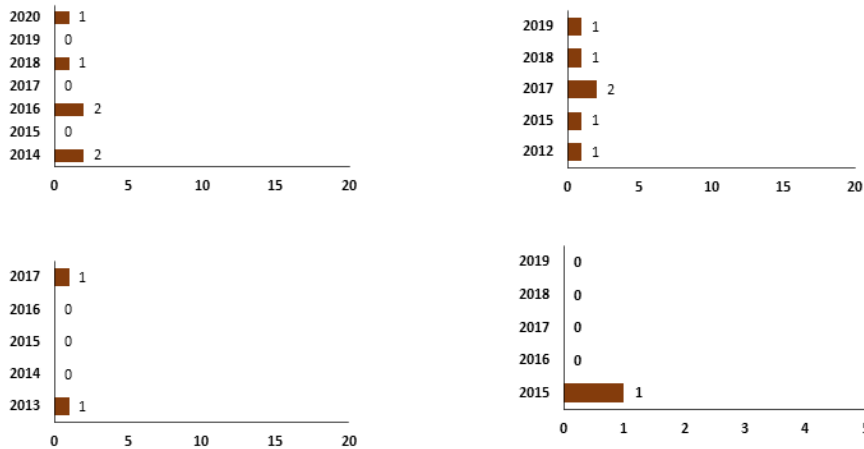


FIGURE 10. 4 (A–C). Breakdowns of evaluation measures used in their respective years.

TABLE 8. Use cases in three selected domains.

Use Cases	IoT	WSNs	SC
Agriculture	✓	✓	X
Smart surveillance system	X	X	✓
Building automation	X	✓	X
Smart environment	✓	✓	✓
Mechanical sector	✓	X	X
Event distortion detection	X	✓	X
Academic research	✓	X	X
Business/trade	✓	X	✓
Software engineering	✓	X	X
Flood detection	X	✓	✓
E-science	✓	X	X
Healthcare	✓	✓	X
Transport system	X	✓	X
Semantic application	X	✓	X
Weather forecasting	X	✓	✓
Intelligent truck monitoring	X	X	✓
Mathematical analysis	✓	X	X

through networking devices to collaboratively work and make human lives easier [56]. Similarly, in agriculture, it has been shown that there is no existing study that implemented SC technology. However, a few have applied WSNs and IoT in

their work. While the IoT improves agricultural productivity and efficiency, the WSN serves as a driver of smart agriculture [4], [42], [43], [45]. However, there is an increased need for decision support systems in precision agriculture, which are built using WSN [43]. Precision agriculture provides a wide range of solutions to water scarcity, food shortage, and deterioration of soil properties [4]. Manufacturing, industry and E-science are some of the other use cases highlighted by this study. The Internet of Things (IoT) allows the linking of the physical world and cyberspace, presenting a potential possibility for manufacturing applications and the development of powerful services [58]. Furthermore, through integrated architecture, the rise of industrial IoT results in device monitoring and connectivity possibilities [9].

Our analysis results show that only the transport system has been implemented in the WSN use case from the selected domains. In the healthcare system, both IoT and WSN have been adopted, which may be due to the fact that IoT and WSN can be utilized in multiple devices, such as cameras and bed, heat, stove, and accelerometer sensors [63].

B. ARCHITECTURE

Architecture refers to the extensive description that helps detect challenges and issues for application scenarios [63]. Different architectures with varying typologies have been used in the three selected domains. The studies reviewed for IoT architecture have utilised various architectural frameworks. Such architectures as cloud-based IoT platforms, software-defined networks, and various novel communication platforms have been proposed and utilized [41], [44], [50], [53], [56], [60]. Blockchain technology framework has also been utilized in this domain for data collection. For WSN, the architectural framework is mainly the same, consisting of sensor nodes and based stations with distinct data collection and routing mechanisms. The application often gets altered if customized applications are used in other use cases [8], [77], [84]. The aim is to connect and improve data collection efficiency in WSN framework. The SC architecture framework comprises a WSN framework and cloud computing. Hence, SC is the combination of these two technologies. Therefore, WSN and SC architectural frameworks are similar. From the reviewed studies in SC, virtual sensors, fog computing, SC databases, and Internet protocol (IP) module are generally utilized in the architecture [44], [96], [99], [101], [108]. Hence, data collection is done from sensor devices to the cloud. We conclude that WSN architecture is more similar to SC architecture than IoT architecture. Therefore, IoT architecture is less similar to the two technologies (WSN and SC). Concerning the performance measures and evaluation measures, they are generally similar for the studies reviewed in the three domains. Performance measures, such as throughput, energy consumption, latency, and network lifetime, are all used in all the domains' respective studies. Likewise, evaluation measures like simulation experiments, and case study are similar. Hence, with respect to these facets (performance measures and evaluation measures), the three domains are similar.

VI. OPEN RESEARCH CHALLENGES

This section highlights the research challenges identified from the previous sections' results. It further provides the direction for future works, which will aid both new and veteran researchers in the selected domains.

A. SCALABILITY

This is the first challenge identified in this study. The term "scalability" refers to the capabilities of a network or system to handle the rising scale of any environment. The study of Zhou *et al.* incorporated cloud computing and IoT to propose an architecture that conveniently allows scalable network access to shared computing resources [100]. Hence, scalability with respect to data collection has proven to be challenging in IoT and WSNs work. However, this challenge has been resolved by the introduction of data collection strategies using SC. Nevertheless, scalability is

TABLE 9. Definitions of all acronyms mentioned in the paper.

Abbreviations	
ATPC	Adaptive Transmission Power Control
CFSS	Cloud File Synchronization Services
CoAP	Constrained Application Protocol
CRSNs	Cognitive Radio Sensor Networks
DC	Data Collection
Het-IoT	Heterogeneous IoT
IoT	Internet of Things
IP	Internet Protocol
IREDD	Improved RED
ITM	Intelligent Truck Monitoring
IVWANs	IoT-enabled intra-Vehicular Wireless Sensor Networks
MIP	Mixed-Integer Programming
MMDD	Multimethod Data Delivery
MORA	Multi-Objective Resource Allocation
NOMA	Nonorthogonal Multiple Access
RED	Random Early Detection-based
RMER	Reliability and Multipath Encounter Routing
SC	Sensor Cloud
SS	Selected Studies
SHM	Structural Health Monitoring
SDN	Software Defined Networking
TBEERP	Trust-Based Energy-Efficient Routing Protocol
UAU	Unmanned Aerial Vehicles
VCPs	Vehicle Communication Platforms
WSNs	Wireless Sensor Networks

still a key concern in the respective research domains. Our findings indicate that the novel SC technologies improve the scalability and storage capacity and enhance the efficiency of packet delivery.

B. PACKET ROUTING

Another challenge identified by this study is how the routing packet can be transmitted between the packet source and its destination without delay and congestion. In all the domains, packet routing is a key issue because it determines the data transmission speed and time during data collection. Hence, an efficient routing protocol that effectively and proficiently transmits data from source to destination in IoT, WSN, and SC is still needed.

C. FLEXIBILITY

Based on our analysis, flexibility has been identified as a concerning the challenge, particularly in WSN. The study of [8] highlighted the flexibility issues and centralized decision-making process in WSN. The authors further designed and implemented a more flexible architecture that integrates WSN to the cloud to improve flexibility and decision-making capabilities. However, flexibility is still a growing concern.

D. VIRTUALIZATION

The results also revealed that virtualization is another challenge in the selected domains. Virtualization refers to the ability of multiple devices in IoT, WSN, and SC to share hardware resources. The virtualization process also allows multiple software applications to run on the same server by creating more than one virtual machine. The study of [78] addressed communication failure in WSN

environments with the aid of IoT virtualization. Similarly, [72] developed an IoT virtualization framework based on the sensor as a service notion, which comprised of three layers: the semantic layer, real-world layer, and virtualization layer for IoT virtualization. The framework can provide efficient IoT virtualization. However, despite the authors' efforts, efficient virtualization mechanisms and framework are still needed, particularly in SC architecture.

E. COMMUNICATION

Another issue identified in the selected domains is communication. There is an absence of a typical platform that conceals the heterogeneity of communication technologies and offers a straightforward naming service to different applications. The obvious communication heterogeneity issue is resource sharing in heterogeneous sensor networks [71]. Furthermore, the sensor nodes in a WSN might be shared by various applications with disparate objectives. In this manner, with an expansion in the utilization of WSNs, there is a need to create mechanisms that can proficiently serve numerous applications simultaneously. In an existing study, WSNs were used to develop a cooperative communications technique to provide efficient battery usage in WSNs and energy savings [29]. The cooperative communications technique can improve the WSNs' reliability. Hence, more works on developing new techniques that will address communication issues are needed.

F. DEVICE MANAGEMENT

IoT, WSN, and SC device management is a challenging issue that has to be addressed. The study of [9], used Ethereum and blockchain to develop a framework to manage IoT devices. [91] proposed an approach-based trustworthy architecture for WSN, which deliberates on the system's challenges and focuses on the collaborative mechanisms for trust evaluation, maintenance, and management techniques for WSNs [91]. Another study proposed an architecture that will address the issue of data management in WSNs by accessing and collecting a large volume of data produced by medical sensor network [92]. Therefore, an efficient device management architecture in IoT, WSN, and SC during data collection is optimal.

VII. CONCLUSION

This study presented a comprehensive survey that investigates the data collection methods employed in studies regarding three selected domains: WSN, IoT, and SC. The survey was conducted by searching and categorizing all existing and available studies in the selected domains. Only the relevant papers were selected during the search and selection process of the thousands of papers identified in the first database search. The finding of this study is set to equip the research community with detailed descriptions of data collection and the similarities and differences among the three selected domains. In terms of the publication source, we found that conference papers occupy a larger proportion of the papers

used in this study, followed by journal articles, symposiums, and magazines. Furthermore, our analysis showed the existence of nine contributions in the three selected domains, namely, framework, algorithm, model, protocol, approach, method, architecture, system, and topology. However, it is observed that the model, algorithm, and framework are the most proposed contributions in the selected domains. Additionally, five evaluation mechanisms were identified to be utilized by the SS: experiment, case study, simulation, theoretical analysis, and comparative analysis. Moreover, the experimental simulation was adopted by most of the studies in the domains selected. Finally, this study highlighted the research challenges and future research directions for new and veteran researchers in this field.

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IHSAN ALI (Senior Member, IEEE) is currently working as a Research Associate with the Faculty of Computer Science and Information Technology, University of Malaya. He has published over 60 high impact research journal articles, including highly reputable journals, IEEE COMMUNICATIONS SURVEYS AND TUTORIALS and IEEE COMMUNICATION MAGAZINE, with more than 250 cumulative impact factor. He has been actively involved in research and teaching activities for the last ten years in different country, including Saudi Arabia, USA, Pakistan, and Malaysia. He is a member of the editorial board of different journals, including *Wireless Communications and Mobile Computing* and *Journal of Computer Networks and Communications*. He is also a Lead Guest Editor of Special Issue on Data Collection in Resource-Limited Networks (WSNs, the IoT, and Sensor Cloud). He has served as a technical program committee member for several well-known conferences, including IWCMC2017-2018, AINIS 2017, Future 5V 2017, ICACCI-2018, INAIT 2019, DiCES-N19, CCNC2020, ICCAIS2020, and CSNT2020, and an Organizer of the Special Session on Fog Computing in Future 5V 2017. He has also participated in and organized several conferences and workshops in different countries. He is also an active reviewer for several high reputed journals, including *Computers and Electrical Engineering*, *KSII Transactions on Internet and Information Systems*, *Mobile Networks and Applications*, *International Journal of Distributed Sensor Networks*, *Journal of Advanced Transportation*, IEEE TRANSACTIONS ON INTELLIGENT TRANSPORTATION SYSTEM, *Computer Networks*, IEEE ACCESS, *Wireless Communications and Mobile Computing*, and *IEEE Communication Magazine*. His research interests include wireless sensor networks, cloud computing, sensor cloud, fog computing, the IoT, and underwater sensor networks.



His research interests include wireless sensor networks, the Internet of Things, optimization algorithms, and energy management. He was a recipient of the Full Scholarship for his master's degree.



ABDULLAH GANI (Senior Member, IEEE) received the Diploma degree in computer science from ITM, the B.Phil. and M.Sc. degrees in information management from the University of Hull, U.K., and the Ph.D. degree in computer science from The University of Sheffield, U.K. He is currently a Professor and the Dean Faculty of Computing and Informatics, University Malaysia Sabah. He is also an Honory Professor with the Department of Computer System and Technology, Faculty of Computer Science and Information Technology, University of Malaya, Malaysia. He obtained tertiary academic qualifications from the University of Hull. He has vast teaching experience due to having worked in a number of educational institutions locally and abroad—schools, Malay Women Teaching College, Melaka, Ministry of Education, the Rotherham College of Technology and Art, Rotherham, U.K., The University of Sheffield. His interest in research kicked off, in 1983, when he was chosen to attend the three-month Scientific Research Course at RECSAM by the Ministry of Education, Malaysia. Since then, more than 150 academic articles have been published in proceedings and respectable journals internationally within top 10% ranking. He received a very good number of citations in Web of Science and Scopus databases. He actively supervises numerous students at all level of study, such as the bachelor's, master's, and Ph.D. degrees. His research interests include self-organized systems, machine learning, reinforcement learning, and wireless related networks. He also serves as a reviewer to several high-quality journals, and the Chief-Editor of the *Malaysian Journal of Computer Science* and ISI-indexed journal.



MUHAMMAD UMAIR MUNIR received the B.S.C.S. degree (Hons.) from the University of Central Punjab, in 2017, and the master's degree in computer science from Universiti Malaya. He worked as a Research Assistant with Universiti Malaya and took part in many conferences. He is currently teaching with the University of Central Punjab as an Associate Lecturer. His research interests include the Internet of Things, wireless sensor networks, vehicular communication, and software quality.



MOHAMMAD HOSSEIN ANISI (Senior Member, IEEE) is currently an Associate Professor with the School of Computer Science and Electronic Engineering, University of Essex, U.K., and the Head of the Internet of Everything (IoE) Laboratory. Prior to that, he worked as a Senior Research Associate with the University of East Anglia, U.K., and a Senior Lecturer with the University of Malaya, Malaysia, where he received the Excellent Service Award for his achievements. He has published more than 100 articles in high-quality journals and several conference papers. His research interests include the IoT, WSN, green and energy-efficient communication, and vehicular networks. He has received several international and national funding awards for his fundamental and practical research as a PI and a Co-I. He is an associate editor of several journals and has been lead an organizer of special sessions and workshops at IEEE conferences.