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Data Collection in Smart Communities Using Sensor Cloud: Recent Advances, Taxonomy, and Future Research Directions

Ihsan Ali, Abdullah Gani, Ismail Ahmedy, Ibrar Yaqoob, Suleman Khan, and Mohammad Hossein Anisi

The authors investigate, highlight, and report recent premier advances in sensor clouds with respect to data collection. They categorize and classify the literature by devising a taxonomy based on important parameters, such as objectives, applications, communication technology, collection types, discovery, data types, and classification.

Abstract

The remarkable miniaturization of sensors has led to the production of massive amounts of data in smart communities. These data cannot be efficiently collected and processed in WSNs due to the weak communication capability of these networks. This drawback can be compensated for by amalgamating WSNs and cloud computing to obtain sensor clouds. In this article, we investigate, highlight, and report recent premier advances in sensor clouds with respect to data collection. We categorize and classify the literature by devising a taxonomy based on important parameters, such as objectives, applications, communication technology, collection types, discovery, data types, and classification. Moreover, a few prominent use cases are presented to highlight the role of sensor clouds in providing high computation capabilities. Furthermore, several open research challenges and issues, such as big data issues, deployment issues, data security, data aggregation, dissemination of control message, and on time delivery are discussed. Future research directions are also provided.

Introduction

In recent years there has been an unprecedented proliferation of sensors in smart communities. Deployed sensors frequently produce enormous amounts of data, which need to be collected and processed with low latency [1]. However, sensors have limited battery power and processing and storage capabilities to support the transmission of massive amounts of data, and this limitation usually causes network failure [2]. Cloud computing can enhance the processing and storage capabilities of wireless sensor networks (WSNs) and improve the performance of WSNs in terms of energy consumption, analytics, computation power, computing latency, and quality of service (QoS). Therefore, merging WSNs and cloud computing is a trend that is expected to result in a computing paradigm called sensor cloud [3]. Sensor cloud enables users to gather, access, process, visualize, analyze, and store large amounts of sensor data easily by using cloud resources. An illustration of sensor cloud is provided in Fig. 1, which shows various smart community applications using cloud services to manage data generated by sensors.

In sensor clouds, the weak communication capabilities of WSNs prolong data uploading to clouds and may thus impede the realization of this computing paradigm [4]. For example, in smart communities where numerous sensors are deployed to monitor the temperature and humidity level in forests, a delay in transmitting sensed data to managers who have subscribed to cloud services prevents these people from providing timely rescue services. Similarly, data transmission latency can cause serious problems in other smart community applications [5, 6]. For example, when a person suffers from a medical problem while traveling in a car, he or she has to transmit health-related data to the traffic manager for emergency purposes. Transmission latency hinders the uploading of these data to a cloud; hence, the traffic manager cannot provide timely aid.

Although several studies [3, 7] have been conducted on sensor clouds, no study has focused on data collection in sensor clouds. This work investigates state-of-the-art literature on sensor clouds from different perspectives, particularly in terms of data collection. This work also explores recent advances and open challenges in data collection in sensor clouds.

The contributions of the study are manifold:

- We investigate, highlight, and report recent premier advances in sensor clouds from the data collection perspective.
- A taxonomy is devised by classifying and categorizing the literature.
- A few credible use cases are presented.
- We enumerate and outline research challenges that remain to be addressed.
- Finally, several future research directions are presented.

Recent Advances

This section investigates recent research efforts directed at sensor cloud in terms of data collection. The purpose is to analyze the strengths and weaknesses of the literature.

The study in [7] reveals that sensor clouds are largely responsible for the emergence of various smart community applications, such as real-time monitoring of agriculture and irrigation systems, by providing strong computation capabilities. A smart environment usually comprises thousands of dispersed sensors that are deployed to collect

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Ihsan Ali, Ismail Ahmedy, and Ibrar Yaqoob are with the University of Malaya; Abdullah Gani is with Taylor's University; Suleman Khan is with Monash University Malaysia; Mohammad Hossein Anisi is with the University of Essex. Corresponding authors are Ihsan Ali and Ismail Ahmedy.

information on agriculture and irrigation systems. These data can be further stored, processed, and analyzed by using cloud services to constantly track the health of the crops. Furthermore, the study indicates that the data collected from smart transportation systems can also be processed in the cloud. Therefore, the status of the driver and fuel level can be determined, and the arrival time of smart vehicles can be predicted [8]. Similarly, cloud computing plays an important role in data collection and processing in smart lighting systems, in which light sensor nodes are used to sense the level of light in tunnels. Therefore, linking light sensor nodes with cloud computing can help investigate the level and direction of light in tunnels in real time and thus allows adjustments to be made according to the required level of light to save on extra energy consumed through unnecessary lighting usage during daytime.

A major issue in sensor clouds is the transmission of repeated data from a cloud to sensor users, a procedure that usually increases demands on resources, bandwidth, and energy consumption. Another issue arises when multiple sensor cloud users simultaneously request the same data. In this case, large amounts of data need to be transferred concurrently from the cloud to users, leading to the consumption of increased resources in terms of energy and bandwidth. A multi-method data delivery (MMDD) scheme for sensor cloud users has been proposed to overcome these issues [9]. The scheme introduces four types of delivery. The results of MMDD indicate that the scheme performs well in terms of delivery time. However, high complexity is one of the limitations of the scheme.

A trust-assisted sensor cloud model has also been proposed in [10] to improve the user experience. In the model, sensory data are collected from sensor nodes on the basis of the trust value assigned to the sensor node. If the sensor node trust value satisfies a certain threshold, which defines the trust level of the sensor node, then the data will be forwarded to data centers. The high computation capabilities of data centers allow for the efficient storage and processing of large amounts of generated data efficiently while maintaining the trust level. Although this model enables trust-based data collection on sensor clouds, the trust values are defined based on the negative and positive behavior of sensor nodes and data centers, which are not fully justified and may be impractical.

In [11], researchers have also proposed a big data platform called Wiki-Health, which is used to manage large and complex datasets generated by health monitoring sensors. Wiki-Health applies the benefit of distributed computing over Internet of Things (IoT) on an individual's comfort information administration. The platform is a community podium designed for use in information-focused groups, particularly in the areas of health, good breeding, and well-being. The approach allows users to gather, tag, label, interpret, modernize, and share healthcare-related sensor data in an efficient manner. The solution also allows users to reuse and reproduce data analysis outcomes and models in sensor clouds. However, labeling of the collected data may be time consuming because it requires inputs from users.

The study [12] has helped the elderly obtain benefits from smart home technology. In this work, numerous sensors (i.e., motion sensors, bed sensors, gait monitors, stove sensors, and video sensors) were deployed in smart homes to monitor senior residents. The deployed sensors generated information related to resident activity levels, snooze patterns, and possible emergencies. The data were stored and processed in the cloud. To determine the advantages and disadvantages of the specified smart home applications, 14 residents were recruited for the experiment. Although the study revealed certain advantages of smart homes for senior residents, the data collected from the 14 residents were insufficient to perform an analysis. In addition, the lack of privacy solutions during data collection is a remaining concern that needs to be addressed in the future.

The authors in [13] have presented a novel distributed, sustainable framework for data collection in cloud-based crowd sensing systems. The framework incorporates an opportunistic reporting mechanism that minimizes sensing and reporting costs while maximizing the utility of data collection in a smart environment. The framework was deployed in a real urban environment with a large number of participants. This research analyzed the relationship between the cost imposed on participants and the information collected from the proposed framework. The results revealed that the framework helps minimize unnecessary energy consumption during data collection in sensor clouds. However, the presented model still requires caching policies for buffering and delivering data to the cloud.

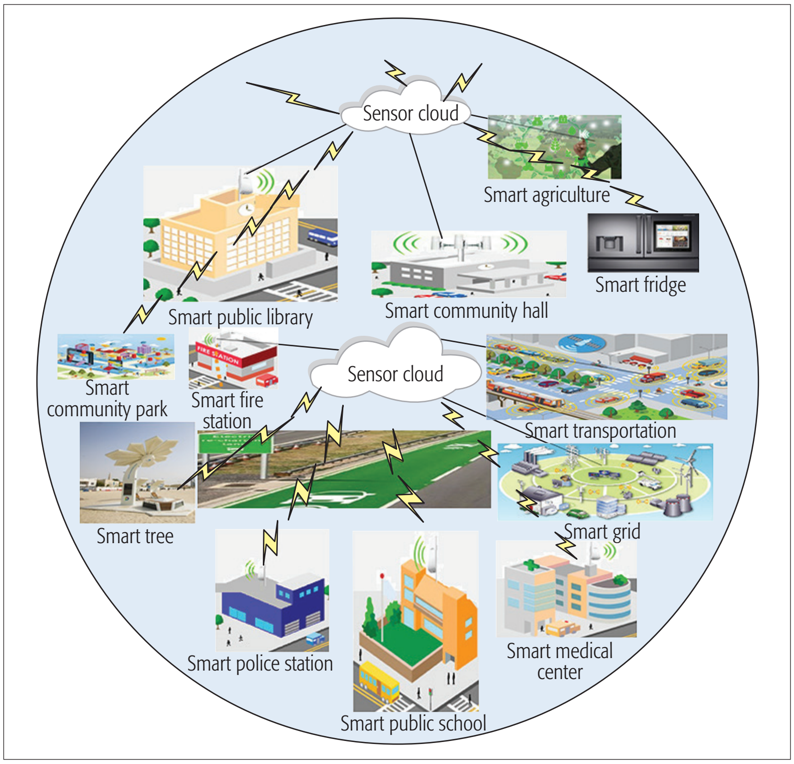

Figure 1. Illustration of smart communities using sensor cloud.

Taxonomy

Figure 2 presents the taxonomy devised based on the objectives, applications, communication technology, collection types, discovery, data types, and classification.

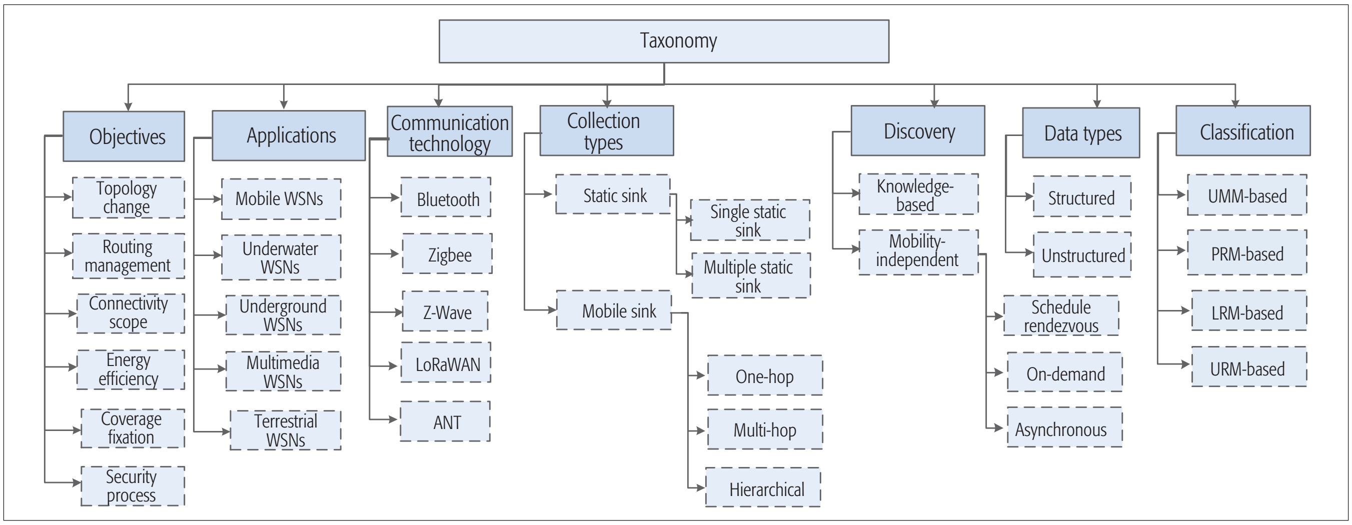

Figure 2. Taxonomy of sensor cloud.

Objectives: The data collected by a mobile sink can help make changes in topology, which lead to efficient data collection in a sensor cloud. The collected data can be used to design efficient route management systems. Extraction of valuable information from the collected data through sensors can also help meet the following objectives in the sensor cloud: connectivity scope (which nodes need to be connected with the mobile sink); energy efficiency (how to save the energy of the deployed sensor nodes); coverage fixation (dealing with the coverage problem by using a mobile sink); and security (strengthening the security of the collected data).

Applications: Data collection using a mobile sink has various applications in the following networks. In mobile WSNs, data are collected in a smart community by mobile elements, and these mobile elements can be either a sensor node or sink. Mobile WSNs are more transitional than static sensor networks. Improved coverage, high energy efficiency, and good channel capacity are several of the advantages of mobile WSNs over static WSNs.

In underwater WSNs, autonomous underwater vehicles are used to gather data from underwater sensor nodes. Several of the challenges in underwater WSNs are long propagation delay, sensor failure, and low bandwidth. Sensor nodes in underground WSNs are hidden in the ground to monitor underground conditions in a smart community. Additional sink nodes are deployed in the ground to relay the data collected from underground sensors to base stations. The data collected by these base stations are uploaded to the sensor cloud for storing and further analyses.

Multimedia WSNs are mainly used to track and monitor events in multimedia applications. The date collected in multimedia WSNs are in the form of images, video, or audio. The nodes in these networks are equipped with a microphone and camera, which are used to record and capture events in smart communities. Several of the challenges in these networks are high bandwidth requirement and data processing and compressing techniques.

In terrestrial WSNs, sensor nodes are deployed in either a structured or unstructured manner for data collection in smart communities. In the unstructured method, the nodes are deployed randomly in the target area. One of the limitations of these networks is low battery power.

Communication Technology: Communication technologies enhance the affinity among variegated smart devices. These key technologies include Bluetooth, Zigbee, Z-Wave, long range wide area network (LoRaWAN), and advanced network technology (ANT). Bluetooth and Zigbee are low-range communication technologies suitable for personal area network-based applications. Z-Wave is a low-power communication technology used for home automation. LoRaWAN is designed to provide low-power WANs with the features specifically required to support low-cost mobile secure bidirectional communication. ANT is an ultra-low-power wireless protocol that helps transfer information wirelessly in a flexible manner.

Collection Types: Collection types can be divided into two categories, namely static sink methods and mobile sink methods. Static sink methods are further categorized as single and multiple static sink methods, which collect data from the entire network in a smart community and upload them to the sensor cloud. In the mobile sink method, data are collected from the entire network using the mobile sink in a smart community. The mobile sink is further divided into three categories, namely sink methods single-hop (data are transmitted to the sink directly), multi-hop (data are transmitted with the help of other nodes), and hierarchical, which is further divided into two types, namely single-sink data collection (only one sink is used for data collection) and multiple-sink data collection (multiple sinks are used for data collection in a network).

Discovery: The discovery parameter explains how a mobile sink node identifies an optimal node to collect data in smart communities. Discovery is a process that allows a sensor node to sense the presence of a mobile sink in its communication boundary. To minimize energy depletion during the discovery process, two approaches, namely mobility-independent and knowledge-based discovery, are often used. There are three types of mobility-independent discovery, namely scheduled rendezvous, on demand, and asynchronous.

Knowledge-based discovery is based on a pre-defined path. The discovery of the mobile sink node is important in the sensor cloud because it needs to transfer the data to the cloud.

Data Types: Data types consist of two categories that can highlight which data are being collected from sensor nodes and uploaded to sensor clouds in smart communities. Data collection can be structured or unstructured. Structured data can be used directly for decision-making purposes in smart communities, whereas unstructured data need to be processed first before they can be used for decision making. This process might be time consuming, but it can be useful because it focuses on key related data that can be used for improved decision making.

Classification: The classification of data collection by using sink mobility can be divided into four main categories, namely uncontrollable-mobility, path-restricted, location-restricted, and unrestricted-mobility models, as explained below.

Mobile sink behavior is unmanageable in the uncontrollable-mobility model, and the main limitation of the model is the unavailability of sink location information to other nodes. In the path-restricted model, the behavior of the mobile sink is defined based on a specific path. The specific path is used by a sink node to collect data from other nodes. In the location-restricted model, the mobile sink stops at a specific location to collect data from other sensor nodes. In the unrestricted-mobility model, the mobile sink is free to move anywhere in the network to collect data.

Use Cases

This section presents five prominent use cases. The purpose is to show how data are collected in smart communities and stored in a sensor cloud. Table 1 summarizes the use cases.

No.	Use cases	Role of sensor cloud
1	Wearable devices	(a) Helps process and analyze the collected data efficiently. (b) Helps doctors and nurses provide on time treatment to patients. (c) Emergency services can be provided quickly to the patients.
2	Underwater world	(a) Helps store, process, and analyze the data efficiently. (b) Helps in finding out oxygen level in the water, temperature of the water, and bacterial contents.
3	Waste management	(a) Provides proficient storing and processing capabilities. (b) Provides efficient waste management services through unlocking the power of the collected data.
4	Agriculture management	(a) Helps monitor crop health, level of water, and pest attacks. (b) Helps the field owner adopt necessary measures, when required.
5	Temperature monitoring	(a) Helps analyze the data on time, resulting in life-saving in different areas, underground mine. (b) Provides real-time data collection and analyses services.

Table 1. Summary of the use cases.

Wearable Devices: Wearable devices are used to monitor the health of patients. Patients are regularly monitored based on their movements and sleeping, walking, and other activities to track their health recovery improvements. Data are collected from wearable devices through ultra wide-band and Bluetooth wireless interfaces and subsequently stored in a sensor cloud. These data are analyzed in different medical reviews for evaluating the health of patients.

Underwater World: Sensors installed underwater are used to collect and forward data to the sensor cloud to determine the water level, pressure, barometer, and sound effects. Such information is useful in determining how efficiently wireless communication can take place underwater. Nowadays, wireless communication underwater requires an underwater information for improved and fault-tolerant communication.

Waste Management: One of the social projects of smart communities is waste management. Sensors installed in the soil, water, and surroundings are used to control waste in the environment. The sensors used in waste management are made of hardware, which is integrated with a waspmote board used to collect data and forwarded them the sensor cloud for further evaluation. Such information helps improve air acoustics, soil moisture, energy efficiency, traffic control, and others.

Agricultural Management: Tiny sensors embedded into plants are used to determine the stages of plant growth. The sensors provide data on water deficiency, sun rays, insect infections, and climate change to the sensor cloud. The data are evaluated in the sensor cloud to provide optimal agricultural solutions for plants planted beside roads, gardens, offices, and shopping malls in smart communities.

Temperature Monitoring: Temperature is usually monitored in tourist places to encourage tourists to attend seasonal and non-seasonal events. Sensors are installed to provide temperature data to the sensor cloud for timely decision-making regarding tourism. The decision may include hotel management, warm clothes, visit timing, and car rallies. Smart communities have many temperature-based sensors that help in making timely decisions.

Open Research Challenges

This section highlights the key research challenges in terms of data collection in smart communities using sensor clouds.

Big Data Issue: The emergence of new technologies with heterogeneous infrastructures boosts the concept of big data. The amount of data increases frequently due to the adoption of new technologies in human life. This situation occurs in WSNs, especially in smart communities. Various collection points in smart communities create a challenging environment for data collection in WSNs. The volume of data may originate from thousands of sensors that need to be uploaded to the cloud on time [14]. This process may not work efficiently because a sensor network has a weak communication capability to upload the large amount of data to the cloud. Moreover, the variety of data generated through numerous devices in smart communities complicates the data collection process. Several devices may send the data quickly, whereas others may do so slowly, resulting in the delay of the entire process. Furthermore, the value of the data makes the data collection process complicated because the number of users increases, ultimately causing more values. The increasing number of users increases the value of data and thus requires the data collection process to be optimal enough to cope with such a complicated situation.

In smart communities, some data need to be processed on a real-time basis, which requires the highest follow-up consideration. Data collection should guarantee that the data are retrieved on time and completely. Incomplete data will also delay the entire data collection process, which will ultimately affect other processes in the sensor cloud.

Deployment Issue: When the data are received from sensors in smart communities, they need to be uploaded to the cloud. A challenge in data collection is where sensor nodes must be deployed in smart communities to enable an efficient data collection process. Sensors deployed close to the cloud collect data faster than sensors deployed far from the cloud. This situation creates a data dependency problem when uploading data to the cloud. The problem is aggravated in the case of smart communities where devices are dispersed from one another. To solve this challenge, smart communities need to adopt best practices from WSN and cloud computing.

Data Security: The data collected from different sensors in smart communities need to be sufficiently secure to be stored in the cloud. A challenging task in data collection is to ensure where security should be implemented (either in the sensor cloud or before the sensor cloud). Ensuring data security at base stations is challenging due to the scarce resources of sensor nodes. However, implementing data security in a sensor cloud does not guarantee that the data sent to the cloud are unaltered during transmission. Data collection in smart communities should ensure that the data are integrated in an authentic and safe manner. A means to solve this issue is to deploy a secure middle-ware application between sensors and the cloud. In this way, data can be checked according to the set security parameters before uploading them to the cloud.

Data Aggregation: The integration of data from multiple resources prior to sending them to base stations is challenging, especially in smart communities. Smart communities contain a large number of nodes that transfer data to key base stations. Base stations are scarce in resource capabilities to accommodate all data in their memory. This situation causes the data to be dropped, resulting in the loss of data integrity. The data aggregation problem also arises when the number of data nodes is increased, which usually occurs in smart communities. The data aggregation problem can be minimized by classifying data based on their domain specification and usage; this allows for easy storage and computation of data in the sensor cloud paradigm.

Dissemination of Control Message: When data are sent from sensors, they are uploaded to the cloud. However, before uploading the data, a base station transfers control messages to the cloud for data uploading. The issue is how control messages can be sent to the cloud without affecting the entire data collection process in terms of low latency and transmission cost. In smart communities, data are received from various locations and need to be disseminated to the cloud. The base station has to manage the control messages for each set of data, which is a challenging task due to the scarce resources.

On Time Delivery: Data collection should ensure that the data are uploaded to the sensor cloud on time to provide synchronization between data in the sensor cloud. A delay in data collection affects the entire sensor cloud data management process. For example, data collected from different wearable devices used by a patient need to be processed in the cloud data management system to provide the latest updated information to the patient about their health on an urgent basis. In smart communities, some data need to be processed on a real-time basis, which requires the highest follow-up consideration. Data collection should guarantee that the data are retrieved on time and completely. Incomplete data will also delay the entire data collection process, which will ultimately affect other processes in the sensor cloud.

Future Directions

This section suggests several future directions in the sensor cloud paradigm. The purpose is to provide guidelines for new researchers.

Efficient Data Collection: Although deployment of cloud computing in WSNs provides certain benefits, collecting data with minimum latency from WSNs to the cloud has become difficult. The lack of strong communication capability of WSNs hinders the uploading of large amounts of sensor data to the cloud in a time-efficient manner. Therefore, efficient data collection algorithms with provable properties, including minimum transmission cost, are required in sensor clouds [13]. In addition, the use of multiple mobile sinks can help enable optimal data collection.

Secure Sensor Cloud: Enabling secure data management is a key requirement in sensor clouds because the characteristics of this paradigm make it easy to be accessed through unauthorized means. In a smart environment where large numbers of sensors are deployed to perform specified tasks, various new threats and attacks can hinder the influence of sensor clouds[15]. In this regard, traditional security mechanisms in standalone sensor networks are no longer applicable to sensor clouds. In the future, the focus should be on enabling secure pre-processing (prior to deployment), secure processing (prior to execution), and secure runtime service in sensor clouds. Secure pre-processing can help identify design problems in advance, and secure processing guarantees privacy and safety procedures at mission time. Secure runtime service ensures trusted operations and key management in sensor clouds.

Unlocking Data Power: Unlocking data power is a requirement in sensor clouds. Collected sensor data need to be analyzed to enhance decision-making capabilities. However, obtaining insights into massively collected data in sensor clouds is challenging. The inapplicability of traditional data and decision-level fusion techniques to sensor clouds is the main hurdle in extracting maximum information from sensor data. Thus, serious attention should be devoted to designing real-time data fusion mechanisms in the future.

Unified Data Format: Sensors deployed in smart environments usually generate data in different formats due to the lack of standardization. When the cloud receives sensor data in heterogeneous formats, merging these data for in-depth analyses becomes difficult. Thus, standards for sensor data representation need to be developed. In addition, several new format unification methods are required to convert data in the same format for subsequent use. In short, to unlock the power of data in sensor clouds, attention should be paid to solving data format unification issues.

Bandwidth Allocation: In sensor clouds, allocating appropriate bandwidth is a crucial requirement that needs to be met even when the numbers of users and sensor devices increase drastically. Although several optimal bandwidth allocation solutions have been proposed, these solutions cannot perform efficiently in sensor clouds where large numbers of devices and cloud users are involved in a dynamic manner. Therefore, in the future, efficient bandwidth allocation solutions must be designed for sensor clouds.

Data Retrieval and Maintenance: Because of the involvement of multiple types of databases in sensor clouds, retrieval of particular information becomes challenging when data are stored in parts. Complex query mechanisms are required to overcome the retrieval issue. Another requirement of sensor clouds is regular maintenance, which prevents service failure. To ensure the smooth flow of services, redundancy techniques should be implemented in sensor clouds. These techniques help back up data regularly in multiple data centers to overcome disaster recovery challenges.

Conclusion

The amalgamation of WSNs and cloud computing has given rise to the sensor cloud paradigm, which collects, processes, and analyzes sensor data in smart communities. Although several studies have been conducted on WSNs and cloud computing, a tutorial on data collection in sensor clouds was still lacking. In this article, we investigated, highlighted, and reported recent research efforts carried out in the sensor cloud paradigm with regard to data collection. Then we categorized and classified the literature by devising a taxonomy. We presented several prominent use cases, enumerated open challenges, and provided future research directions. Finally, we conclude that although cloud computing can extend the computation capabilities and solve various challenges in traditional WSNs, the convergence of these paradigms engenders new research challenges that need to be addressed in the future.

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Biographies

Ihsan Ali is a Ph.D. Student on the Faculty of Computer Science and Information Technology, University of Malaya. He received his M.S. degree in computer system engineering from GIKI, Pakistan. He is a reviewer for *Computers & Electrical Engineering*, *KSII Transactions on Internet and Information Systems*, *Mobile Networks and Applications*, the *International Journal of Distributed Sensor Networks*, *IEEE Access*, *IEEE Communications Magazine*, and *IEEE Transactions on Intelligent Transportation Systems*. His research interests include wireless sensor networks, sensor cloud, and fog computing.

Abdullah Gani [M'01, SM'12] is a full professor at the School of Computing and Information Technology, Taylor's University, Selangor, Malaysia. He received his bachelor and master degrees from the University of Hull, and his Ph.D. from the University of Sheffield. He is the recipient of numerous research grants. His research interests include self-organized systems, reinforcement learning, and wireless-related networks.

Ismail Ahmedy is a senior lecturer with the Department of Computer System & Technology, Faculty of Computer Science and Information Technology, University of Malaya. He holds a Ph.D. in computer science. His areas of expertise are underwater acoustic sensor networks, embedded systems and wireless sensor networks.

Ibrar Yaqoob received his Ph.D. (computer science) from the University of Malaya, Malaysia, in 2017. His research experience spans more than three and half years. He has published a number of research articles in refereed international journals and magazines. His research interests include big data, mobile cloud, the Internet of Things, cloud computing, and wireless networks.

Suleman Khan received his Ph.D. (Distinction) from the University of Malaya, Malaysia in 2017. Before that he completed several Master degrees including M.Sc.-CS, M.B.A., and M.S.-CS degrees from the University of Peshawar, IMSciences Peshawar, and Comsats Abbottabad in 2006, 2008, and 2011, respectively. Currently, he is a lecturer at Monash University Malaysia. His research interests include software defined networks, network forensics, Internet-of-Things, vehicular communications and cloud computing security.

Mohammad Hossein Anisi is a lecturer at the School of Computer Science and Electronic Engineering, University of Essex, United Kingdom. He received his Ph.D. from the Universiti Teknologi Malaysia (UTM) while being awarded as the best post-graduate student. He has worked as a senior lecturer on the Faculty of Computer Science and Information Technology, University of Malaya. His research interests include: Internet of Things, wireless sensor networks, mobile ad hoc networks, and intelligent transportation systems.

Although cloud computing can extend the computation capabilities and solve various challenges in traditional WSNs, the convergence of these paradigms engenders some new research challenges that need to be addressed in the future.