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Cloud-Based Large-Scale Sensor Networks: Motivation, Taxonomies, and Open Challenges

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Abstract— **Recently, the integration of ubiquitous wireless sensor network (WSN) and powerful cloud computing (CC) has attracted growing attention and efforts in both academic and industry. In this new paradigm, cloud computing can be exploited to perform analysis of online as well as offline data streams provided by sensor networks. This can help to deal with the inherent limitations of WSN in combining and analyzing of the heterogeneous large number of sensory data. The study we present in this paper provides a comprehensive analysis and discussion of the representative works on large scale WSNs, the need for integrating sensor with cloud, the main challenges deriving from such integration, and future research directions in this promising field.**

Keywords- Cloud computing, integration, heterogeneous, Sensor-Cloud infrastructur.

I. Introduction

A. Motivations

The rapid evolution of wireless technologies and continuous advances in the areas of sensor networks have greatly improved living standards of mankind, and almost influenced every aspect of daily life in some ways. Sensor networks offer a powerful combination of distributed sensing, computing and communication capabilities to monitor the environment conditions and fetch data about the surrounding [1]. The report in [2] indicates that the market for industrial wireless sensor network size is estimated to grow at a yearly rate of 12.96% and reach $944.92 million by 2020, with many new applications and business opportunities that arise every day. Figure 1 shows the trend of market rising in WSN from 2010-2014. However, the full potential of WSN is bounded by the limitations of sensor nodes in the terms of processing power and communication bandwidth and the model of computation that is used to handle them [4].

In this regard, the emergence of many new technologies such as smart phones, PDAs, RFID devices, and IP cameras, creates new computing paradigm and applications in the area of sensor networks. This led to the development of sensor networks as a way to converge the different sensor devices into a cooperative network [5]. With increasing the number of nodes and expansion of coverage area, the amount of data gathered by sensor network will increase. This situation creates many challenges in the terms of sensing and computational resources and storage capacity,

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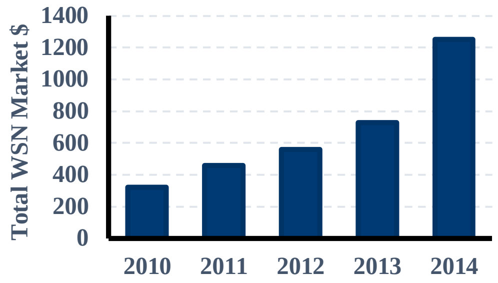

Fig 1. WSN market 2010-2014(Millions$) [3].

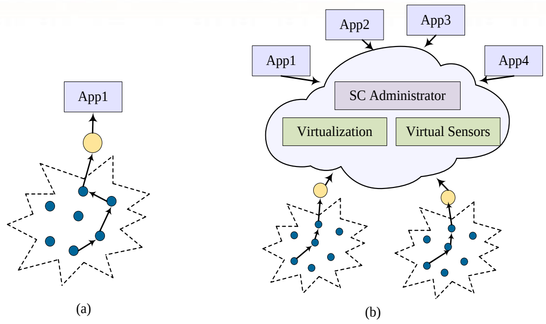

Fig 2. Comparison of traditional WSNs (a) with Sensor-Cloud(b)

because it needs more IT resources to process, manage, and store data emanating from sensor networks [6]. On the other hand, the design requirements of a sensor network tied to the network testbed [4]. In particular, a typical sensor network is usually designed and deployed for a specific application service. Thus, sensor data used for relevant application cannot be freely used by other group of applications. This is wastage of valuable sensor resources. All these limitations on sensor networks would probably impact on the service performance, and converges toward designing a better data and communication management system for WSN. In the midst of these issues, the emergence of cloud computing provides an efficient solution for these challenges.

Cloud computing emerges as a new computing paradigm to provide convenient and on demand network access, unlimited resources and reliable service delivery through virtualization technologies [7]. It allows the systems and users to access applications, data and virtual servers without concerning about locations and detailed specifications [7]. These features supply measures to enhance existing capabilities of WSNs, and simplify the management of computing resources. Cloud computing is a promising solution to solve several inherent WSN shortfalls such as scalability, flexibility, agility, and so forth. Most of WSN applications (e.g. health care monitoring and military services) contain highly sensitive data, which need a better infrastructure with special tools to handle them in real time. Hence, integrating cloud computing with wireless sensor networks is becoming one growing trend to solve the issues encountered by large-scale sensor network applications.

Sensor-cloud Infrastructure (SCI) is a new paradigm for cloud computing to manage the sensor nodes which are scattered throughout the network [9]. In fact, SCI is an intermediate stratum of processing between the physical sensor nodes and end users. It provides sensor management approaches to facilitate sensor data sharing by virtualizing the physical sensors on the cloud platform. Users possess their own applications and retrieve sensed data by requesting to the sensor-cloud infrastructure (Figure 2). These requests are interpreted and replied by forming the corresponding virtual sensors at SCI, as per requirements. This method enables the end-users to envision the physical sensors simply as Sensor-as-a-Service (Se-aaS), rather than as a typical hardware component. Se-aaS renders highly cost effective on-demand services compared to the traditional WSNs. Hence, researchers suggest a technology shift to the sensor-cloud infrastructure [10, 11, 12, 13]. Major advantages and benefits of sensor cloud infrastructure include.

1) Scalability: Sensor-Cloud enables several sensor resources to be added to the system dynamically for meeting the increasingly requirement and bringing flexibility. In other words, as the need for resources change, organization can scale up or scale down the operation and resources quickly to suit the situation without having to invest heavily for these additional hardware resources [14].

2) Analysis: Integrating massive quantities of sensing data with cloud computing provides a scalable processing power for various kinds of analyses required by users. The usage of the IaaS-inspired computing framework with highly scalable big data analytics system can help in the provisioning of more intelligent services for users and enterprises [4].

3) Flexibility and Resiliency: The property of rapidly adapting to massive updates and fast evolutions of big data repositories provides much flexibility for users. They can easily access data from anywhere and use random applications in any number of times under flexible usage environment [15]. SCI dynamically reacts and adapts to changes in the sensing infrastructure too, thus providing resiliency and redundancy to its users. This aspect improves the robustness and flexibility of activities in contrast to traditional applications [16].

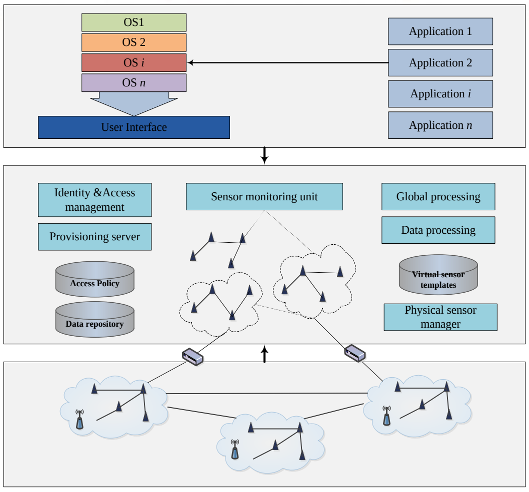

Fig 3. The layered structure of sensor-cloud.

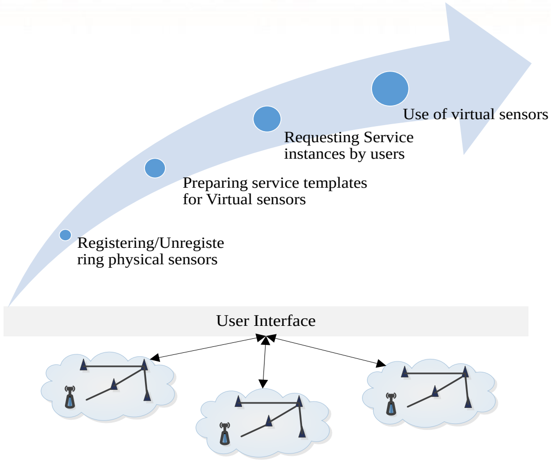

Fig 4. The life-cycle of the Sensor-Cloud.

4) Shared resource pooling and Collaboration efficiency: SCI provides a pool of computing resources that can be shared among multiple applications. The physical resources are dynamically assigned to compute requests through virtualization and provisioning of virtual resources [11]. Collaboration in Sensor-cloud enables consumers to communicate and share the huge sensor data more easily outside of the traditional methods.

5) Agility of services and Quick response time: Regarding the characteristics of cloud computing and flexibility of services, users can quickly expand low-cost technological infrastructure resources [17]. SCI allows users to choose the services and applications that best suit their preferences with minimum effort in customizing the applications. It also swifts the data processing faster and provides quick response to the consumers using immense processing power of the cloud. The property of quick response time allows users to make critical decision in near real time [10].

6) Self-manageability and automation: One major aspect in Sensor-Cloud is the property of automatically adapting the framework configuration to rapid changes in a dynamic environment [16]. Self-management capabilities enable SC to operate in a dynamic environment and achieve the mentioned goals.

7) Virtualization: Sensor-Cloud platform provides a virtualization API, which enables instant access to all the gathered sensor data from several device assets. Through the virtualization, end users can remotely use cloud-based sensor services and other IT resources without knowing their exact locations.

8) Multitenancy: Several services owned by multiple providers are pooled to serve multiple consumers using a multitenant model, in sensor-cloud infrastructure. Sensor-cloud allows the accessibility and sharing of data centers placed anywhere on the network world with lower costs [9].

9) Utility-based pricing: Resource usage can be monitored, controlled and reported automatically to provide transparency for both the providers and consumers of the utilized services. This implies that services are charged per usage metrics by a pricing model in SCI [18].

B. *Sensor-Cloud Implemetation: Architectural Overview*

In this section, we briefly review the layered structure of sensor-cloud infrastructure, which is illustrated in figure 3. It divided mainly into three major layers: user and application layer, middleware and virtualization layer, and physical sensor layer [4].

The first layer deals with the user applications and requests. It provides a platform for users with different OS to access and use valuable sensor data through an Interface. User Interface is primarily a web portal running at the site of the cloud service provider. Users can request for Se-aaS using their web browsers [10].

The middleware layer makes managerial decisions. It also provides secure sensor information services for users by authentication and access management procedures. In this platform, various sensors with different owners can join and run over a shared infrastructure. Service instances are prepared for users to share physical sensors. IT resources, physical sensors, and service templates should be prepared before creating the service instances. Users can request service instances by selecting corresponding templates. They can access cloud-based applications through web-browser-based user interfaces. The operating mechanisms of middleware are described in the following [9].

Identity and Access Management: To access sensor data and information, services need to have keys and mechanisms used to protect them. This unit is responsible to manage user's identity and provide policy-based access control over the cloud resources. It mainly ensures legal user's access to the resources according to the account polices.

Provisioning Server: Upon receiving a resource request from application layer, provisioning server automatically provides virtual sensors for legal users. First, it checks and reserves available IT resources, then it provisions virtual sensor groups based on need, and terminate them easily when no longer required.

Sensor Monitoring Unit: Sensor monitoring unit monitors the status of the servers and virtual sensors by receiving the data about virtual sensors from the agent in the servers. The received data is stored in data repository by sensor monitoring unit. The SC administrators monitor the status of the servers using monitoring information through a web browser.

Global Processing Unit: Global processing unit is responsible for managing resource requirements based on received requests from application layer and system-level performance metrics such as CPU load and available memory of physical and virtual servers. It permanently monitors servers and applications to decide about the allocation/ preemption of virtual sensors or physical servers to the applications based on the server's workload and satisfaction of the applications. It calls provisioning server for providing virtual sensors.

Data Processing Unit: The aggregated sensory data is processed and stored in repository by data processing unit. It can use semantic-based algorithms to process various heterogeneous sensory data.

Physical Sensor Manager: Physical sensor manager gives the catalog menus for sensor owners to register and delete their physical sensors to SCI. It defines some standard mechanisms for accessing sensors without concerning the differences among various physical sensors.

Sensor network owners can register or delete their physical sensors to SCI. The users of the sensors can request the virtual sensors by selecting the appropriate service template. They can access templates through a web Interface. After selecting the templates by users, service instances are provided automatically to the users. They can use their virtual sensors and release them, when they become useless [9]. Figure 4 depicts an overview of the life cycle of Sensor-Cloud.

II. An Overview of Recent Advances in Distributed Large Scale Sensor Networks

A. Potential Synergies

Wireless sensor networks enable the new generation of applications and thus new possible markets. These applications set some new requirements that put several design constraints on them. Conventionally, multiple WSNs are deployed in the same area to satisfy various sensing requirements from different applications. Developing multiple application-specific WSNs by different vendors, lead to service isolation and low utilization. Obviously, this imposes high deployment cost and lead to a waste of valuable sensing resources. Furthermore, it is a difficult and error prone way to alter the existing code on application-specific sensor nodes [19].

In this regard, some studies presented a framework for developing a reconfigurable WSN using XML and SOAP technologies [20]. These systems do not allow the customization of already deployed WSN. To remedy this situation, some researches propose *software-defined sensor network (SDSN)* for dynamically changing the functionalities and properties of sensor nodes [21]. SDSN consists of control servers (i.e., gateways have controller functions) that compute routes and network topology, and a set of software defined sensor nodes that perform only packet forwarding. Gateway in sensor network initially require information of all local sensor nodes, such as location and remaining information. This information is used by gateway to realize optimal routing paths. Then, routing information and tasks is distributed to all the local sensor nodes. According to the real-time sensing requests, gateway delivers various corresponding programs among some of the sensor nodes to deploy new sensing tasks. This idea is based on the principle of supporting OpenFlow by each sensor node. Particularly, sensor nodes should be able to recognize the entry of flow tables. The fundamental assumption of OpenFlow is to make use of high-speed switches and IP routers. These are generally unavailable in WSN and make major challenges in designing sensor OpenFlow [22].

In this way, our perspective moves toward sensor-cloud infrastructure (SCI) as compared to SDSN. Sensor-cloud implies much more than simply interconnecting and sharing sensors among applications. It provides scalable services by virtualizing and managing sensors according to the user needs. The purpose is to implement services to provide indexing and querying methods applied to every kind of distributed sensor. Table I depict the key similarities and differences between SCI and SDSN respectively.

Table 1.
Similarities and differences between SCI & SDSN.

instance	*Brief description of the case*
Programmable sensor network	*SC* develops a cloud-based platform that provides easy and scalable access to every kind of distributed sensor and actuator devices. These devices may be located at different places such as homes, offices, cars, and outdoor areas. Such an infrastructure allows the trading of resources among multiple service providers and application level users. *SDSN* supports multiple application; sensors are not application-dependent but application-customizable. This is achieved by programable data plane, on which various application services are simultaneously available.
Aim & Scope	*SC* builds a cloud of virtual sensors on top of the physical sensors. *SDSN* makes the underlying network programmable by manipulating a user-customizable flow table on each sensor.
Agility	*SCI* swifts the data processing faster and provides quick response to the consumers using immense processing power of the cloud. Low data rate of WSN limits the quantity of SDN control traffic on *SDSN*.
On-demand services	In *SCI*, virtual sensors are provisioned automatically on demand whenever user requests. Resources cannot be instantly provisioned and removed in *SDSN*.
Dynamic Changes	*SCI* automatically adapts the framework configuration to rapid changes in a dynamic environment. Self-management capabilities enable SCI to operate in a dynamic environment and achieve the mentioned goals. Requiring periodic updates from each node on *SDSN*.

B. *Leading Researches and Projects in Sensor-Cloud*

According to [4], sensor- cloud can be defined as follows:

"*An infrastructure that allows truly pervasive computation using sensors as an interface between physical and cyber worlds, the data-compute clusters as the cyber backbone and the internet as the communication medium*."

The goal of sensor-cloud is to develop a cloud-based platform that provides easy and scalable access to every kind of distributed sensor and actuator devices. These devices may be located at different places such as homes, offices, cars, and outdoor areas. Such an infrastructure significantly minimizes the cost of IT resources and WSN infrastructure by allowing the trading of resources among multiple service providers and application level users [23]. Although there are many kinds of physical sensors, the applications do not need to make use all of them at all times. Each application needs pertinent physical sensors for its requirements.

In this context, the integration of WSN and cloud computing is proposed by some researches, before the introduction of SCI [24-25]. The idea of optimal data transmitting from the networks to the cloud was the main focus of these early works. To realize this concept, *publish/subscription* mechanism [26] is being employed to select physical sensors in [27, 28]. The basic model for publish/subscribe system relies on interaction among three entities: a subscriber (end user), a publisher (sensor owner), and a broker (SCI provider). Subscribers register their events without knowing the effective source of these events. Publishers produce sensor data and metadata, and sends the information through a gateway to a publish/subscribe broker. A broker maintains subscription information and delivers information to the consumers [11]. Applications may subscribe to one or more sensor networks for retrieving real-time data from sensors. However, sensor network virtualization concept was not realized.

The design goals for successfully realizing virtualization in WSN have been addressed by [9]. This infrastructure provisions virtual sensors as service instance automatically in response to the requests from users, in such a way that these virtual sensors are part of their IT resources like CPU, memory, etc. [29]. End users can utilize these service instances and their associated data via a user interface on web browser as described in figure 2. In such an infrastructure, user can create virtual sensors (groups) and freely use them as if they owned sensors. They can also control their virtual sensors with monitoring functions that SCI has provided for them. Imran Khan and *et al.* [30] present a comprehensive review of WSN virtualization and its motivations. Virtualization provides many benefits such as abstracting physical resources into logical units for efficient usage of multiple users, eliminating of tight coupling between WSN applications and WSN deployments. In particular, virtualization is a key technique for the realization of SCI and it is pertinent to explore virtualization in the context of WSNs.

Theoretical modeling of sensor-cloud is presented in [10] for the first time. This paper theoretically characterized virtualization, which is a fundamental mechanism for operation in SCI. They analytically proved that SCI outperforms a traditional WSN, with 3.25% increase in sensor lifetime and 36.68% decrease in energy consumption. In [31], authors focus on the problem of Quality of Service (QoS) aware sensor allocation for target tracking in SCI. In SCI, physical sensor nodes are dynamically scheduled and allocated for corresponding target, whenever it enters the deployed zone. The selection of an optimal set of sensors for target tracking is considered in this work. They proposed QoS-aware Sensor Allocation Algorithm for assorting of QoS parameters. Then, they found the optimal solution for allocation of a subset of available sensors using an auction-based mechanism.

Authors in [13] proposed a new dynamic pricing model in SCI, which focuses on determining the price to be charged by sensor-cloud service provider. They discussed in their article that the traditional pricing models proposed in cloud, have been designed for homogeneous types of services such as infrastructure, platform and software. Hence, they are not compliant with heterogeneous architecture of SC. The proposed model consists of two parts: pricing attributed to Hardware (pH) and pricing attributed to Infrastructure (pI). pH concerns the problem of pricing the physical sensor nodes with maximizing the profit of sensor owners, while keeping in mind the user's utility. pI focuses on the pricing issues related to the virtualization of resources. They define the cost incurred by SCSP for creation and maintenance of virtual machine as,

$$C_{vm}(t) = B_{vm}(t) + \sum_{i=1}^{k(t)} B_{vs_i} + \sum_{i=1}^{k(t)} M_{vs_i}(t - t_{0i})$$

Where $C_{vm}(t)$ is the cost of creating *vm* within cloud platform, $B_{vm}(t)$ is the cost of maintain it and $M_{vs_i}(t)$ is the cost for creating its component virtual sensors. So, the final price charged by service providers comprise of cloud resource usage cost and the cost charged by sensor-owners.

An optimal data center scheduling algorithm is proposed in [32] for sensor-cloud infrastructure. This work addresses the problem of routing and channelization of the data to geographically distributed SC data centers (DCs). They designed an algorithm for dynamic scheduling of a particular DC by a collective decision making of various geographically distributed DCs that would serve a particular user application. In this paper, four different types of asymmetry are considered due to two different states of nature (good and bad), and two different alternatives of the DCs (yes or no). They use an optimal decision rule, which focuses on combining the individual options to generate the rules that maximize the profit of organizations.

In addition to research efforts toward SCI, there are also a number of projects which have been using cloud platform in the field of WSNs. For example, Shelburne Vineyard Project [33] uses the integration of WSN and cloud to monitor its vines. There is a wireless environment sensing system that monitor key conditions during the growing season of grapes. An SCI is used to collect and analyze environmental data for creating alerts when environmental thresholds are exceeded. This system provides cost effective condition-based cultivation and harvesting.

III. Research Trends

Although sensor-cloud Infrastructure described above provides many benefits that address the limitations of WSN, a large research effort is still required. In this section, we show the most important issues that need to be addressed to meet the requirements of integrating sensor network and cloud computing. Open issues and research challenges for sensor-cloud scenarios are shown in Table 2.

a. Complexity of Development and Design Issues

Sensor-cloud creates an environment, by which efficient sharing of resources and services is achieved. It unites multiple heterogeneous sensor networks on a platform to provide users with seamless access to the sensor data and efficient utilization of the resources. Although, cloud facilitates better collaboration and information sharing, it adds additional complexity to the design and implementation of services. In order to successfully design, develop, and deploy sensor-cloud services, we need to design service’s software properly. Thereby, the development of software in such an infrastructure faces new challenges and issues [22]. This makes sense to design a middleware for integrating all the sensors having heterogeneous nature and specification with respect to power consumption, processing time, memory and QoS parameters [34].

There are several issues that need to be considered while designing the middleware such as efficient decoupling of events and services, efficient localization and clustering techniques, service and resource discovery algorithms, reliability, adaptability, QoS and context awareness techniques in middleware. However, there are still open issues and questions must be answered in this area.

b. Energy Efficiency

Aggregating WSN with cloud generates repeated data acquisition requests from the applications in the cloud. This can result in significant power consumption of sensor nodes due to the repeated sensor sampling. As sensor nodes are usually equipped with some non-chargeable batteries having limitations in lifetime, continuous transmission of collected data to the cloud can cause early energy depletion for the nodes and reduces network lifetime. So, we must develop optimization algorithms to efficiently manage energy consumption between cloud and sensor networks [35]. Location-based sleep scheduling (CLLS) schemes are proposed in [36] that dynamically determines the awake or sleep status of each sensor node to reduce energy consumption in the integrated WSN with mobile cloud computing. They demonstrate that CLSS could prolong the lifetime of the integrated WSN while still satisfying the data requests of mobile users. CEB architecture [35] measures energy saving using push/pull envelope optimization algorithm. Still more work is required to overcome this problem.

To improve the energy efficiency of sensor-cloud infrastructure, a middleware should be developed to tackle the redundancy of requests directed to a given sensor or subnet. This middleware should be able to compress the sensor data to reduce the amount of data transmission. As a result, energy consumption of sensor nodes will improve due to lower transmission and processing [37].

c. Efficient Data Fusion

In sensor-cloud, an efficient sensor data fusion technology is needed to best extract useful information from multiple sensor observations. Information fusion mechanisms could be conducted over vast amount of sensor data across multiple databases. Fusion of multi-sensor data provides integrated analysis, and more efficient and accurate extracting information than a single sensor. In order to properly implement information fusion in sensor-cloud, information management, system design, and real-time execution must be considered.

d. Security and Privacy

From the security perspective, the involvement of multiple providers for service provisioning in sensor-cloud opens new vectors of security challenges for sensitive data stored in cloud [28]. As data sensed by sensor nodes usually contains sensitive information [38], adherence to data protection requirements is vital in this infrastructure. Data owners may want to conceal sensitive data from other cloud services. Hence, data confidentiality and privacy must be considered while data being stored and processed in cloud. Otherwise, the data owners may completely refrain to the storing and processing data in cloud due to the perception of loss of control over sensitive data [39, 40].

A secure cloud-based architecture is proposed for sensor information system in [6], which ensures legal access and use for sensory data and information in cloud environment. The proposed architecture considers a dedicated security management layer to deal with security issues. It provides strong identity authentication by presenting a certificate authority-based Kerberos protocol. A key management scheme is presented in [41] by combining Group-key and Time-key (COGKTK). It is based on content-based publish/subscribe system for secure delivering of data in SC environment. The objective of this method is to minimize the number of updated keys, when user dynamically leaves and joins the system. In [42], a multi-level authentication technique is used to secure sensory data in the cloud. This technique generates password at multiple levels. To access the cloud services, the passwords should successfully be processed at all levels.

However, these approaches may not be adequate for storing and processing sensitive sensor data in the cloud, because they focus on hard security guarantees by using technologies such as trusted platform modules or encryption. We need approaches that provide the necessary user control over outsourced data in cloud [43].

e. Bandwidth Limitations

Due to the increased number of sensor devices and cloud users, bandwidth limitation is one of the current challenges must be handled in sensor-cloud. For example, it is desirable to monitor and filter operators close to the data sources for optimizing network bandwidth.

However, sensor nodes are resource constraint. So, they may not be able to support stream processing operators [44]. As sensor-cloud environment is highly heterogeneous and dynamic, it is very difficult to manage the bandwidth allocation schemes in such huge infrastructure.

In this regard, the challenge of communicating

Table 2.
Open research issues in sensor cloud.

Open issues	Brief description of the cause
Complexity of development and design issues	SC unites multiple heterogeneous sensor networks on a platform, which adds additional complexity to the design and implementation of services.
Event processing and management	As existing query processing systems have limitations in the complicated query processing and data analyzing and scalability, scheduling and optimizing the stream of query processing and associated analysis technologies in sensor-cloud are still very big challenges.
Massive scale and real-time data processing	The integration of massive amounts of data from heterogeneous sources with cloud is a challenge due to the amount of multimedia data and information to be mined and used in real time.
Energy efficiency	Continuous transmission of collected data to the cloud can cause early energy depletion for the nodes and reduces network lifetime. So, we must develop optimization algorithms to efficiently manage energy consumption between cloud and sensor networks
Efficient data fusion	In sensor-cloud, an efficient sensor data fusion technology is needed to best extract useful information from multiple sensor observations.
Security and privacy	The involvement of multiple providers for service provisioning in sensor-cloud opens new vectors of security challenges for sensitive data stored in cloud.
Bandwidth limitations	As sensor-cloud environment is highly heterogeneous and dynamic, it is very difficult to manage the bandwidth allocation schemes in such huge infrastructure.
Pricing issues	The total pricing techniques for sensor-cloud services involves both sensor-service provider (SSP) and cloud-service provider (CSP) pricing schemes. No comprehensive study yet has been performed for pricing issues in sensor-cloud.

different node technologies in the same platform is studied in [45]. They proposed a channel characterization scheme combined to a dynamic TDMA method with a cross-layer admission control, which share the network resources between nodes in cloud-based multimedia WSN. The behavior of two nodes using different network access technologies and the channel effects for each technology are analyzed in this paper. [46] presents the connector software toolkit that provides file-based elastic data-transfer channels from sensors to cloud. The variation of network protocols, mobility of users and dynamic nature of resources in the sensor-cloud make it difficult to establish a series of elastic data channels from sensors to the mobile users in the cloud.

f. Pricing issues

The total pricing techniques for sensor-cloud services involves both sensor-service provider (SSP) and cloud-service provider (CSP) pricing schemes. Although SSPs and CSPs have different customer's management, services management, and methods of payment and pricing [47], their goal is to maximize the revenues with their employed pricing scheme. On the other hand, end users will favor to obtain the highest level of quality of services with the lowest price. Therefore, satisfying both parties requires an optimal pricing technique. To the best of our knowledge, no comprehensive study yet has been performed for pricing issues in sensor-cloud. Although the work presented in [13], proposed a new model for pricing in SCI, but it does not consider the optimal usage of Infrastructure resources. For decreasing the costs, we need approaches to optimally choose the virtualized resources from the resource pool.

V. CONCLUSION

In this paper, the different aspects of integrating sensor network with cloud computing were surveyed. Since sensor networks are usually designed and deployed for a specific application, the design requirements of a network change with its applications. Sensor-cloud infrastructure provides a federated platform, which enables open, scalable, cost-effective and easy to use network of sensors for numerous applications. Also, the design requirements, opportunities and future research directions of sensor-cloud infrastructure were discussed.

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