Sensor-Cloud: Assimilation of Wireless Sensor Network and the Cloud

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Abstract. A broad ranges of vital applications that acquire and process information from the corporeal world are in the extensive need of Wireless sensor networks. Similarly distributed resource sharing is also in the need of Cloud computing which serves as a standards-based approach. Extension of the Cloud computing paradigm to the sharing of sensor resources in wireless sensor networks results in a much promising technology called Sensor Clouds. The amount of data generated from these vast set of sensor applications is huge. These data if combined with various web-based virtual communities can prove to be beneficial in several significant areas like a virtual community of doctors monitoring patient healthcare for virus infection, portal for sharing real-time traffic information, real-time environmental data monitoring and analyzing, etc. To permit this study, all types of sensor data will require for an increasing capability to do analysis and mining on-the-fly. Since the applications provided by Cloud computing is plenty; it may be combined with Sensor network in the application areas such as environmental monitoring, weather forecasting, transportation business, healthcare, military application etc. The idea that WSNs deployed for various applications are brought under one roof and then seeing it as a distinct virtual WSN unit through cloud computing infrastructure is novel. Sharing and analysis of real time sensor data on-the-fly becomes easier when cloud is integrated with WSNs. Added to it is the benefit of providing sensor data or sensor event as a service over the internet. In this paper, we have addressed numerous issues and challenges in the design of Sensor Clouds and we propose a framework called sensor-cloud to enable this exploration by integrating sensor networks to the talented cloud computing.

Keywords: Sensors, Wireless Sensor Networks, Cloud Computing, Sensor-Cloud, Pub/Sub Agent, Internet.

1 Introduction

The mounting fashion of using cloud environments for storage and data processing needs has led to the ever-increasing popularity of cloud computing in distributed

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computing environment. It is a new period of accessing shared computing resources through Cloud computing which provides applications, platforms and infrastructure over the internet. On the contrary, wireless sensor networks are being seen as one of the most crucial technologies for the 21st century where distributed spatially connected sensor node automatically forms a network for data transmission and receiving among themselves. This is popularly known as Sensor Network [1]. The applications that require the interaction between users and the physical world are deploying Wireless sensor networks as the main platform. Important applications of wireless sensor networks include environmental and habitat monitoring, healthcare monitoring of patients, weather monitoring and forecasting, military and homeland security surveillance, tracking of goods and manufacturing processes, safety monitoring of physical structures and construction sites, smart homes and offices, and many other uses. Another challenging issue is the communication among sensor nodes using Internet. It is quite sensible to integrate sensor networks with Internet [2]. Concurrently the accessibility of the data of sensor network should be made accessible at any time, at any place. Since the assignment of address to the sensor nodes of large numbers is complicated; so sensor node may not necessarily establish connection with internet exclusively. The rising domain of *Sensor Clouds* extends the Cloud Computing paradigm to the sharing of sensor resources in wireless sensor networks. A Sensor-Cloud is the result of the integration of wireless sensor networks with the cloud. There are several motivations for Sensor Clouds. First, on using the computational and data storage resources of the cloud the large amount of data collected by the sensors can be processed, analyzed, and stored. Secondly, under flexible usage scenarios the sensors can be efficiently shared by different users and applications. Users can be able to run a specific application, and to collect the desired type of sensor data by accessing a subset of the sensors during a particular time period. Third, it is more proficient to offload specialized tasks such as image and signal processing to the sensor devices as sensor devices with embedded processors become more computationally powerful. Lastly, access to a wide variety of resources in a pervasive manner is also seamlessly provided by the Sensor-Cloud.

This paper is organized as follows: Section 2 and Section 3 present an overview of Clouds and Sensor Network. Section 4 outlines various issues and challenges in designing sensor-cloud platform. Section 5 describes the proposed sensor-cloud architecture and design and finally section 6 concludes the paper.

2 Cloud: Overview

Cloud computing is a term used to describe both a platform and type of application. A cloud computing platform dynamically provisions, configures, reconfigures servers as needed. Servers in the cloud can be physical machines or virtual machines. It is an alternative to having local servers handle applications. The end users of a cloud computing network usually have no idea where the servers are physically located—they just spin up their application and start working. Advanced clouds typically include other computing resources such as storage area networks (SANs), network equipment, firewall and other security devices. Cloud computing also describes applications that are extended to be accessible through the Internet. These cloud applications use large

data centers and powerful servers that host Web applications and Web services. Anyone with a suitable Internet connection and a standard browser can access a cloud application.

Many formal definitions have been proposed in both academia and industry, the one provided by U.S. NIST (National Institute of Standards and Technology) [3] appears to include key common elements widely used in the Cloud Computing community:

Cloud computing is a model for enabling convenient, on demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction [3].

3 Sensor Network: Overview

A wireless sensor network (WSN) consists of spatially distributed autonomous sensors to cooperatively monitor physical or environmental conditions, such as temperature, sound, vibration, pressure, motion or pollutants.[4,5] The development of wireless sensor networks was motivated by military applications such as battlefield surveillance. They are now used in many industrial and civilian application areas, including industrial process monitoring and control, machine health monitoring [6], environment and habitat monitoring, healthcare applications, home automation, and traffic control [4, 7].Each node in a sensor network is typically equipped with a radio transceiver or other wireless communications device, a small microcontroller, and an energy source, usually a battery. A sensor network is a computer network composed of a large number of sensor nodes. [8] The sensor nodes are densely deployed inside the phenomenon, they deploy random and have cooperative capabilities. Usually these devices are small and inexpensive, so that they can be produced and deployed in large numbers, and so their resources in terms of energy, memory, computational speed and bandwidth are severely constrained. There are different Sensors such as pressure, accelerometer, camera, thermal, microphone, etc. They monitor conditions at different locations, such as temperature, humidity, vehicular movement, lightning condition, pressure, soil makeup, noise levels, the presence or absence of certain kinds of objects, mechanical stress levels on attached objects, the current characteristics such as speed, direction and size of an object. Normally these Sensor nodes consist of three components: sensing, processing and communicating [9].

4 Design Issues and Challenges

This section discusses the important issues and challenges in the design of Sensor Clouds. Most of these design issues and challenges arise due to the inherent limitations of sensor devices such as limited processor performance, small storage capacity, limited battery power, and unreliable low-bandwidth wireless communication and some issue arise due issue de-facto standard of cloud such as reliability, back up, privacy, security ownership etc.

4.1 Sensor Issues

1) *Power Management*: Power management is a major concern as sensor nodes do not have fixed power sources and relies on limited battery power. Sensor applications executing on these devices have to make tradeoffs between sensor operation and conserving battery life. The sensor nodes should provide adaptive power management facilities that can be accessed by the applications. From the Sensor-Cloud perspective, the availability of sensor nodes is not only dependent on their load, but also on their power consumption. Thus, the Sensor Cloud's resource management component has to account for power consumption.
2) *Scalability:* Scalability is the ability to add sensor resources to a Sensor-Cloud to increase the capacity of sensor data collection, without substantial changes to its software architecture. The Sensor-Cloud architecture should allow multiple wireless sensor networks, possibly owned by different virtual organizations, to be easily integrated with compute and data cloud resources. This would enable an application to access sensor resources across increasing number of heterogeneous wireless sensor networks.
3) *Network Connectivity and Protocols:* The network connections are usually fast and reasonably reliable in cloud. On the other hand, the sensor nodes in Sensor Clouds are connected via wireless ad hoc networks which are low-bandwidth, high-latency, and unreliable. The network connectivity of sensor nodes is dynamic in nature, and it might be irregular and vulnerable to faults due to noise and signal degradation caused by environmental factors. The Sensor-Cloud has to gracefully handle unexpected network disconnections or prolonged periods of disconnection. Thus, efficient techniques to interface sensor network protocols with cloud networking protocols are necessary.
4) *Scheduling:* In wireless sensor networks, scheduling of sensor nodes is often performed to facilitate power management and sensor resource management. Researchers have developed algorithms to schedule the radio communication of active sensor nodes, and to turn off the radio links of idle nodes to conserve power. Similarly, for applications like target tracking, sensor management algorithms selectively turn off sensor nodes that are located far away from the target, while ` to improve the availability of sensor nodes are necessary. Sensor Clouds should support job and service migration, so that a job can be migrated from a sensor node that is running out of power or has failing hardware to another node.

4.2 Cloud Issues

1) *Reliability*: Stability of the data storage system is of important consideration in clouds. Generally, people worry about whether a cloud service provider is financially stable and whether their data storage system is trustworthy. Most cloud providers attempt to mollify this concern by using redundant storage techniques, but it is still possible that a service could crash or go out of business, leaving users with limited or no access to their data.
2) *Data Backup*: Cloud providers employ redundant servers and routine data backup processes, but some customers worry about being able to control their own back-

ups. Many providers are now offering data dumps onto media or allowing users to back up their data through regular downloads.

3) *Privacy:* The Cloud model has been criticized by privacy advocates for the greater ease in which the companies hosting the Cloud services control and monitor communication and data stored between the user and the host company lawfully or unlawfully. There have been efforts to "harmonize" the legal environment by deploying local infrastructure and allowing customers to select "availability zones."
4) *Security:* Cloud service providers employ data storage and transmission encryption, user authentication, and authorization. Many clients worry about the vulnerability of remote data to criminals and hackers. Cloud providers are enormously sensitive to this issue and apply substantial resources to mitigate this problem.
5) *Ownership*: Once data has been relegated to the cloud, some worry about losing their rights or being unable to protect the rights of their customers. Many cloud providers address this issue with well-skilled user-sided agreements. According to the agreement, users would be wise to seek advice from their favorite legal representative.
6) *Availability and Performance:* Business organizations are worried about acceptable levels of availability and performance of applications hosted in the cloud.
7) *Legal:* There are certain points of concern for a cloud provider and a client receiving the service like location of the cloud provider, location of infrastructure, physical location of the data and outsourcing of the cloud provider's services etc.

Sensor networks is an emerging area and there are many research issues pertaining to sensor networks such as energy management, coverage, localization, medium access control, routing and transport, security etc. Research in cloud computing is also in fantasy stage. It also has a number of research challenges such as efficient resource allocation, high resource utilization and security etc. Apart from the afore-mentioned research issues in sensor networks and cloud computing, sensor-cloud computing gives rise to additional research challenges, especially when it is used in mission-critical situations. These research challenges are: web services and service discovery which work across both sensor networks and the cloud, interconnection and networking, coordinated quality of service (QoS) mechanisms etc.

5 Sensor- Cloud Architecture and Design

5.1 Sensor-Cloud Organization

A Sensor-Cloud consists of wireless sensor networks (WSNs) and cloud resources like computers, servers and disk arrays for the processing and storage of sensor data. The resources in the Sensor-Cloud are shared by several Organizations and certain resources might also belong to more than one organization. Users from various organizations may access the resources in the Sensor Cloud, even if the resources are not owned by their organization.

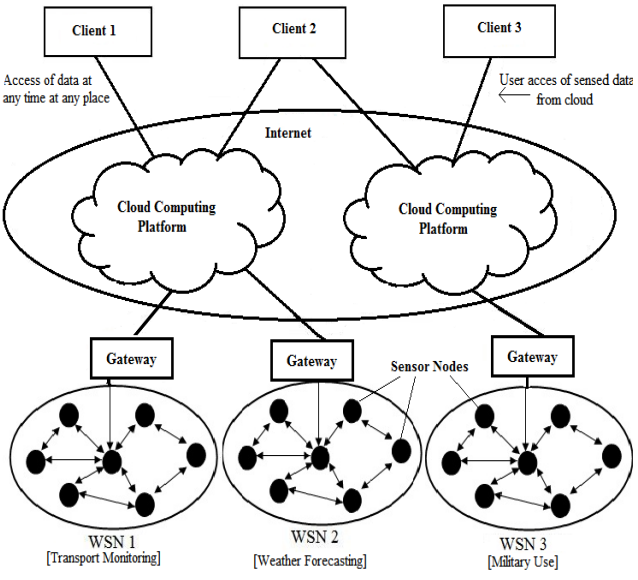

Fig. 1. Sensor-Cloud System Model

Figure 1 consists of WSNs (i.e. WSN1, WSN2, and WSN3), cloud infrastructure and the clients. Clients seek services from the system. WSN consists of physical wireless sensor nodes to sense different applications like Transport Monitoring, Weather Forecasting, and Military Application etc. Each sensor node is programmed with the required application. Sensor node also consists of operating system components and network management components. On each sensor node, application program senses the application and sends back to gateway in the cloud directly through base station or in multi-hop through other nodes. Routing protocol plays a vital role in managing the network topology and to accommodate the network dynamics. Cloud provides on-demand service and storage resources to the clients. It provides access to these resources through internet and comes in handy when there is a sudden requirement of resources. Combining WSNs with cloud makes it easy to share and analyze real time sensor data on-the-fly. It also gives an advantage of providing sensor data or sensor event as a service over the internet. Merging of two technologies makes sense for large number of application such as Transport monitoring, Weather Forecasting and Military Application etc [10].

5.2 Sensor-Cloud Platform

The proposed platform consists of Virtualization Manager, Pub/Sub Broker, Monitoring and metering, System Manager, Service Registry, Stream Monitoring and Processing Component and Application Specific Interface. Figure 2 gives an overview of the components that constitute the WSN-cloud platform.

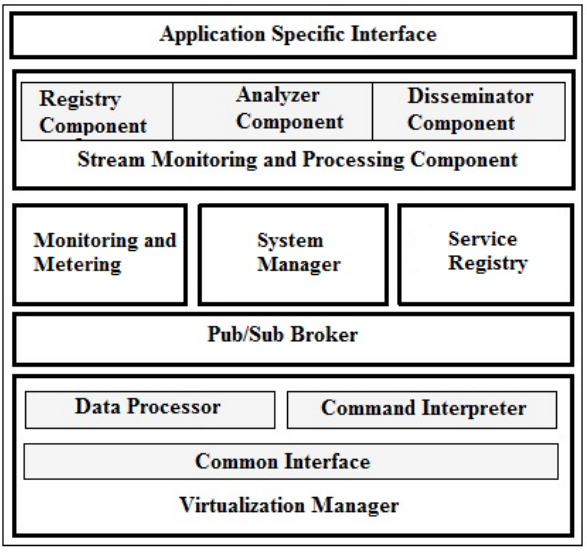

Fig. 2. Sensor-Cloud Platform

I. Virtualization Manager

This component is divided into three subcomponents. They are — Common Interface, Data processor and Command interpreter.

1) Common Interface: Sensor networks are connected with the gateway through common interface in different ways (serial, USB and Ethernet). Gateway receives the raw data from the communication ports and converts it to a packet. The packet is further kept in a buffer for further processing.
2) Data Processor: This component retrieves the packet from the buffer and processes according to its type. The packet type depends on the application being run on the platform.

3) Command Interpreter: This component is responsible for providing reverse communication channel from the gateway to the WSN and for processing and interpreting various commands issued from different applications and generates the code that is understood by the sensor nodes.

II. Publish/Subscribe Broker

This module is responsible for monitoring, processing and delivering events to registered users through SaaS applications.

III. Monitoring and Metering (MaM)

This module tracks the usage of the primary cloud resources. Consumer uses signed web service requests to access the data. Role of MaM deals with handling the request of consumers, checking of registry manager, keeps track of web services etc.

IV. System Manager
This module is responsible for processing and archiving the sensor data and also manages the system resources. Computation cycles are utilized internally to process the data that emanates from the sensors. Storing the sensor data will help to analyze the patterns in the data collected over a period of time.

V. Service Registry
It maintains the credentials of different consumers' applications register to publisher/subscriber system for various sensor data required. For each application, registry component stores user subscriptions, sensor data and sensor event types the application is interested in. Each application is associated with a unique application ID along with the service level agreement (SLA). SLA provides basis for metering and accounting of services to be used, by covering all the attributes of the service customs.

VI. Stream Monitoring and Processing (SMP)
SMP monitors the sensor streams comes in many different forms from different sources and invokes correct analysis method. This module is divided into three sub components — registry component, analyzer component and disseminator component.

1) Registry Component (RC): Registry component stores user subscriptions of different applications and user specific sensor data types of those users who register to Pub/Sub Agent. It also sends all user subscriptions along with application id to the disseminator component for event delivery.

2) Analyzer Component (AC): AC analyzes the incoming sensor data or event to match with user subscriptions in the Service registry. If the sensor data matches with the interest of the subscriber, the same is handed over to the disseminator component to deliver to the appropriate users.

3) Disseminator Component (DC): DC receives the data or event of interest from the analyzer component and delivers the data through SaaS interface to the subscribed applications.

VII. Application Specific Interface
The interfaces give access to the WSN cloud platform web services. Consumers can consume the services through web services that are often referred to as internet application programming interface (IAPI). This allows the users to access the remotely hosted services over network, such as internet. Consumers can build their customer applications by weaving the required services from the WSN cloud platform.

5.3 Sensor-Cloud Architecture

This framework aims at bringing sensor data to a pub/sub Agent through gateways. Pub/sub agent delivers information to the consumers of applications interfaces. The WSN cloud platform web services are granted access through the interfaces built with Web 2.0 technologies. The masking of the lower level details of each WSN cloud in terms of different platforms, sensors being used, and data being generated is done by the Virtualization Manager. The various SaaS applications transfer the information

and subscriptions of the registered users to pub/sub Agent registry. Sensor data, on reaching the system from gateways, are then determined through stream monitoring and processing component (SMPC) in the pub/sub Agent as to whether they need processing or just have to be stored for periodic send or for immediate delivery. If in case sensor data need periodic/ emergency delivery, the analyzer determines which SaaS applications the events belong to and then pass the events to the disseminator. The disseminator then delivers the events for use by finding appropriate subscribers for each application with the help of event matching algorithm. Computational cycles are provided internally by SM as required to process the data emanated from the sensors. SRM manages the users' subscriptions and credentials. MaM calculates the price for the offered services.

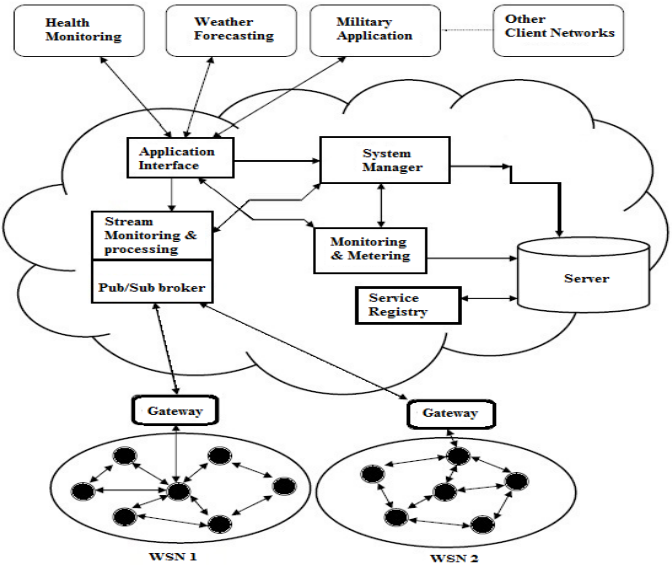

Fig. 3. Sensor-Cloud Framework

6 Conclusion

Combination of the two talented technologies, wireless sensor networks and cloud computing which further results in sensor clouds significantly enhances the prospective of these technologies for new and powerful applications. This further explains the reason of the widespread adoption of this technique in industries. Thus, we believe that sensor clouds will attract growing attention from the research community and the industry.

In this paper, we have examined the important design issues and challenges for sensor clouds. To address these design issues, we proposed a framework for Sensor-Cloud integration. The success of the sensor-cloud computing approach will depend on the ability of the sensor network and cloud computing research communities to work together to ensure compatibility in the techniques and algorithms that will be developed in the future.

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