Mobile Cloud Enabled Sensor Services: Opportunities, Challenges and Approaches

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***Abstract*—Cloud-enabled sensor services have had a profound impact on many facets of mobile computing in the Internet of Things "IoT". Not the least of which includes the control of the mobile sensor data stream by existing cloud services architecture. The challenges associated with these mobile sensors are virtually infinite as more devices are added to the IoT every second. In order to maintain a high degree of volume control and performance throughput as well as data quality, powerful cloud architectures must be designed, deployed and maintained. In addition to handling the high volume from existing sensor devices, additional tracking and control problems result from "humans as a sensor". These challenges will provide many opportunities for cloud based sensors services. Our research seeks to predict and explore the various opportunities, challenges and approaches in mobile sensor clouds and devices over the next few years.**

Keywords- (mobile sensing, cloud services)

I. INTRODUCTION

In the context of Internet of Things (IoT), sensor service clouds are destined to provide the infrastructure for mobile sensor management especially in regards to data collection, storage and analytics. As business and technology continue to indicate, cloud services are providing many unique opportunities and challenges for mobile devices. Few opportunities in mobile computing have had as much impact as cellular technology. However, many aspects of mobile computing are yet to be exploited, as we will explore in the following sections.

Current trends in mobile computing reveal three main challenging areas: (1) mobile sensing in a static environment, (2) mobile sensing in a mobile environment, and (3) static sensing in a mobile environment. Each of these areas has their own set of challenges and approaches that we explore in the following sections. To fully define the potential of cloud enable sensor services, we propose a systems architecture designed to handle the anomalies associated with mobile sensing. To resolve these challenges, the architecture has multiple specialized levels, each for handling an important aspect of mobile sensing. When implemented properly these levels are fully integrated and allow applications running on the network to share and consume vital information. These interdependencies strength the web services cloud and provide a strong foundation for data sharing and analytics.

The physical layer of any sensor cloud services architecture must be able to support a diverse group of challenges related to deployment, collection, consolidation and reporting. The mobile sensors can be self-controlled, in which case they have to have a certain amount of control management or human control. If the sensors cannot be controlled (humans, animals), then they must be categorized. Since the sensor devices are mobile, they are limited in resources such as power supply, environmental conditions and sensor limitations. For this reason, mobile sensors require a high degree of maintenance in order to operate efficiently within a low margin of error.

Some of the challenges for mobile sensors include virtual sensor networks "VSN", ownership issues, centralized/decentralized control and data virtualization. VSN's are basically subsets of sensor networks in which the sensor membership is constantly changing. This dynamic membership mobility issue creates coordination and tracking issues for the sensor net. Ownership issues can create moral, ethical and legal dilemmas prompting a need for participatory or opportunistic sensing. The control and collection aspect of mobile sensing clouds can be centralized or decentralized. Centralized control provides consolidation and reporting advantages since all data trafficking is handled in one location, but can create a bottleneck effect. Decentralized controlled can effectively address performance issues by creating a geographically dispersed distributed mobile cloud. Data virtualization allows consolidation of a variety of data streams from many different sources into a single data presence.

II. SENSOR CATEGORIES

In this section, we describe the three mobile sensor/environment configurations including: mobile sensor/static environment, mobile sensor/mobile environment and static sensor/mobile environment. Since we are only researching mobility sensing, static sensors in static envrionments (e.g. home security, industrial robotics) will not be evaluated.

Our mobile sensors are comprised of three basic levels of control: (1) sensors we can fully control, (2) sensors we semi-control, (3) sensors we cannot control. (Table 1.0) With fully control sensors (car, plane, drone, etc.), we implement control management techniques. Sensors in which we have semi control, we implement control management or categorization of the sensor. For sensors we cannot control (animals, humans), we must categorize them. e.g. ubiquitous crowd sourcing [1], best effort sensing [2] and encounter-based sensor tracking [3].

Device/Environment	Mobile Category	Control Level
Mobile Sensor (w/Static Environment)	Device Sensor	Full-control
	Animal Sensor	Semi-control
Mobile Environment (w/Mobile Sensor)	Artificial Environment	Semi-control, uncontrolled
	Natural Environment	Semi-control, uncontrolled
Mobile Environment (w/Static Sensor)	Artificial Environment	Full-control, Semi-control
	Natural Environment	Semi-control
Static Sensor Static Environment	n/a	n/a

Table 1.0 - Mobile Device/Environment Control Levels

A. Mobile Sensor/Static Environment

Certain mobile sensors acting within a static environment have a very high degree of control. These sensors are usually attached to a device that is directly controlled by human interaction. One example would be car sensors assisting a driver while parking. Another would be the video sensor feeds streaming from an aerial drone controlled by an operator sitting at a remote console. This type of full control management of the sensor/device allows the human operator to monitor the progress of the device and apply necessary adjustments in a real-time fashion. In these cases, control management techniques can be applied to the sensor device in order to assure proper function and maintainability.

Other mobile sensors are much harder to control and applying adjustments may become impossible even if the environment is fully static. In these semi-controllable situations, the control of the sensor device is completely dependent on the carrier and must be categorized rather than controlled. A prime example of categorization is crowd sourcing, in which a human carrier cannot be controlled directly, but they can be observed remotely by crowd sourced video devices such as Google Glass [4] . Other semi-controlled sensor categories could include an animal tracking sensor system such as the Princeton's ZebraNet project, in which biologist track animal herd migrations across the great plains of Africa. [5]

B. Mobile Sensor/Mobile Environment

Mobile sensing, as mentioned in section A, can be controlled or semi-controlled depending on the carrier of the sensor. However, the control factor drops considerably when the environment is dynamic. When these situations do not allow for a great deal of control, they must receive some level of categorization. When both the sensor and the environment are dynamic (natural, artificial), the best-case scenario is frequently a semi-controllable environment. Also, note that a sensor in a natural environment is less controllable than an artificial (or manmade) environment.

Mobile sensor deployment in an artificial environment is an attempt to bring semi-control into an otherwise uncontrollable situation. A good example would be a rescue robot that navigates burning buildings in search of potential survivors. In this case, the mobile, remotely driven robot is continuously sensing its dynamic environment for danger signs while simultaneously searching for victims of the disaster. Another example would be the monitoring and transportation of live animals on a train or an airplane, which presents a tremendous amount of problems. During live transport, the static sensors, such as temperature and chemical sensors, on aquatic transportation tanks are used to monitor the well-being of animals, such as whale sharks, seals and dolphins.

Natural dynamic environments and mobile sensors usually require extra monitoring in order to maintain a level of semi-control. Underground and dense canopy dwelling animals are virtually impossible to track constantly due the dynamic nature of their environment and the limitations of GPS tracking. However, efforts are being made through encounter-based tracking to predict animal migrations through vector analysis and localization algorithms [3]. Other examples of mobile sensors in a natural, dynamic environment include autonomous underwater vehicles "AUV's" navigating ocean currents and aerial military drones searching for troops.

C. Mobile Environment/Static Sensor

The characteristics of a mobile environment become more controllable if the sensor can be applied to a static mount. Full control can almost be obtained if the sensor(s) is mounted to an artificial setting (man-made lake) as opposed to a natural one (river or ocean). When the environment is dynamic, full control of both the sensor and the environment cannot be maintained.

A good example of an artificial environment with a static sensor would be the chemical sensors in a man-made drainage lake for a manufacturing facility. The most common sensors (temperature and chemical) are mounted into a station gathering readings from the flowing water. Since the water is in motion, it is dynamic and can be unpredictable during heavy rains, thus making it a challenge to maintain consistent readings at all times. A similar situation exists in community swimming pools, public sewage treatment plant and water flow sensors in a hydroelectric dam.

The most common environmental uses for WSN's are the application of static sensors to natural environments. One popular usage is the deployment of temperature sensors to monitor the pollution discharge in a river. These sensor stations are fixed in the river, but the water flow is unpredictable, making consistent readings much harder than in a man-made, controllable lake. Because of the dynamic nature of large flowing bodies of natural water, this environment can only be semi-controlled.

III. System Architecture

A cloud enabled architecture (Figure 1.0) for mobile sensor collection and reporting must be assisted by multiple levels of web services. At the lowest level are the physical mobile sensors that collect specific environment information and transmit data streams to a centralized control. The tracking and control level consolidates, synthesizes and streamlines the sensor information before transmitting it to the cloud. The cloud services act as a data collection, storage and analytics repository and transfer requested information to the applications enabled by the cloud.

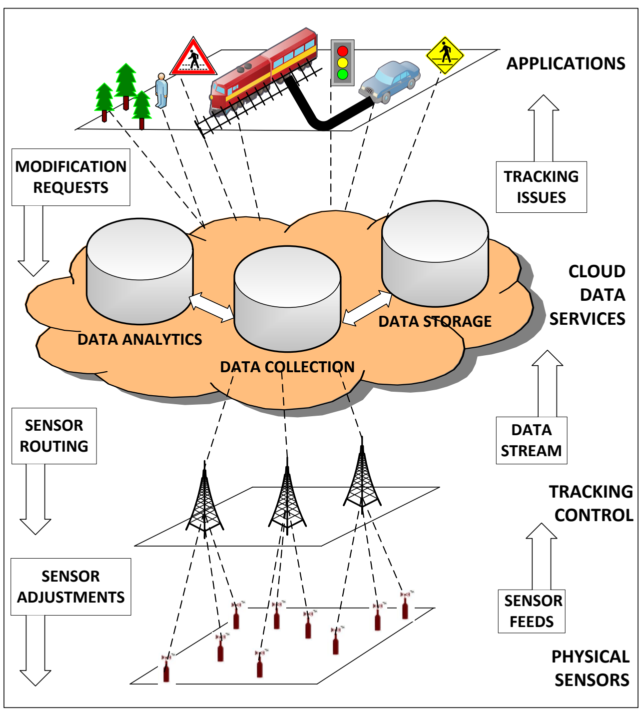

Figure 1.0 - Mobile Sensor Services

Mobile physical sensors devices are responsible for collecting a variety of data in both a static and/or dynamic environment. The mobile sensors are more complex than the average sensor network device or "mote". These devices frequently contain a variety of sensing mechanisms and complex software. The software allows the device to transmit sensor feeds as well as receive sensor adjustments. Examples of these devices could include smart phone sensors, air/land/sea vehicular sensors, tracking device sensors for animals and customizable WSN sensors. [6]

The tracking and control modules are setup to monitor and maintain a wide variety of sensor data streams. These modules transmit data stream information to the cloud as well as receive sensor routing requests from the cloud. This is accomplished through algorithms designed to optimize the data quality as well as the performance of the data stream feeds. The tracking algorithms ensure that the mobile device feeds are timely, accurate and error free. The control services utilize these algorithms to determine if neighboring sensors can help resolve DQ errors such as downtime or transmission problems, or otherwise drop the feed. In addition,, the control services allow modification requests to be applied to the sensors based on various requests from the applications.

The mobile cloud data services are divided into three main areas: data collection, data storage and data analytics. Data collection modules are responsible for the gathering and maintaining of all of the mobile data streams and the customization of the streams for applications. The data storage allows persistent historical archiving of specific characteristics of the streams including performance and data quality attributes. Data Analytics are performed on the mobile sensor data to match various streams to their proper application domains.

Many independent software applications are effected by sensor service clouds. (Figure 1.0) The most prominent include: environmental and disaster management, urban policing and traffic control, military and civil defense systems and agricultural applications. These application domains can be fully integrated through the utilization of the cloud services. With cloud enabled sensor services, traffic systems, railroads, pedestrian crossings and environmental monitoring systems can be fully integrated. Examples of existing applications include Google traffic monitor and John Deere tractor sensing systems.

IV. CHALLENGES AND APPROACHES

A. *Physical Layer*

The physical layer (Figure 1.0) has to handle a diverse set of challenges including device deployment, data sampling, detection of erroneous devices, data quality aspects, sensor health monitoring platform to perform analytics, membership formation and deformation in virtual sensor network and data virtualization. Although the mobile sensors have an advantage on cost effectiveness in terms of number of nodes and efficiency of coverage, each of the challenges permute and widen to include newer issues such as mobile connectivity, locality information and dealing with missing data. Broadly speaking, the movement of mobile sensors can be categorized as self-controlled where the sensor have decision making capability of next path it should take vs human controlled where the devices such a smartphones go wherever the owner goes also termed crowd sensing.. Again, the locality and security comes as great challenge in case of crowd sensing through mobile phones.

Sensor deployment influences the integral property of sensor lifetime, connectivity, overall cost and coverage.

Considering an application where a group of mobile sensors are to be deployed to monitor the environment specifics for example measuring radioactive radiation levels where human reach is unsafe. Randomly dropping the sensors might not be a good solution because a) The sensors might land at a zone from where it can't move b) The sensors with such facility are generally expensive so it would need more number of sensors to provide adequate coverage thus wasting lot of capital c) The sensor might get damaged due to unsafe landing. Thus, rather than randomly dropping the sensors through an aircraft, they could be initially placed at certain safe levels. The mobile sensors need to communicate among themselves and deploy themselves to strategic points to improve the field coverage. The entire decision making process could be taken through centralized communication where each mobile sensor reports to a controller which would run computations and provide feedback to each mobile sensor for the direction it should move. Otherwise, it would need a more intelligent distributed mode of communication for every mobile sensor that can communicate and coordinate with each other. The overall goal of such strategies is important in providing a good balance of integral property described earlier. In cases where the sensor are from the smartphones where humans take the decisions of movement and mobile sensors are part of monitoring for a short period of time, a much more complex strategy needs to be devised to maintain the monitoring goals.

Mobile sensors have several resource restrictions such as limited computational power, expensive bandwidth and limited energy sources. Previous research has shown that the data sampling and transfer takes a major chunk of sensor energy. Mobile sensors in particular need to keep a holistic view of its own and other sensor data collection and location information for optimal data sampling. Besides, harsh environment and aged sensors can lead to sensor defects and thus faulty data. An appropriate sensor health check-point algorithm for detection, correction and exclusion of faulty sensor for future application use must be in place at the data cloud layer. Some of the approaches as indicated in Sharma et al al [7] can be used to detect such short and continuous noise. Doing so would ensure that any further dynamic deployment of sensors as a group doesn't end up at non-optimal location. One of the research directions is from Ramaswamy et al [8] and Kothari et al [9] which provide a significant contribution to agile sensor data quality in federated sensor services cloud. The data quality aspects such as sensor accuracy, the frequency with which the data is being collected by the sensor and the delay with which the data is being transmitted from the sensor to the cloud are key aspects considered in their multi-dimensional data quality model.

The energy aware devices are used in myriad of application some requiring just data storage to some requiring data processing and data transfer. To save energy which would otherwise seem to be wasted by either performing the entire computation within the sensor system or by transferring entire data over wireless to a cloud server for processing, the sensor system may partition the analytics task and just perform the cursory task within its system while outsourcing the computational intensive task to a cloud server. The processed data can then be sent back to the mobile sensor for subsequent decision making. Mobile phones to monitor health as contributed by Greef et al [10] is one of such examples. If the data processing is iterative and computationally intensive, then an essential strategy would be to move the task at the data cloud. New frameworks and protocols needs to be developed to support this. In application where sensors are deployed in remote area with connectivity issues, a drone could be employed to collect the data. Such approach would need to consider the optimal time when the drone should take off , the exact location and the path it should take to visit each of the sensor node.

Another approach could be to use crowd sensing to collect the data from low connectivity area and avoiding the need to make a significant investment. Such crowd sensing might be used in delay tolerant networks because it is uncertain when the data is available at the cloud for processing. The Demov article [11] provides a broader distinction of crowd sensing in two major classes a) involvement of user in crowd sensing process, further classified into participatory and opportunistic crowd sensing depending upon the involvement of the user and b) the type of measurement phenomena depending upon whether an environmental or infrastructure or social life data is being measured. CyanoTracker [12], CreekWatch [13], and Nericell [14] are such examples which call fall in class (b) of crowd sensing. Also the data types would vary greatly; e.g. text, number and multimedia. Thus, the analytics and control layer would need to be interoperable to do the analytics and control the device action.

B. Virtual Sensor Network

The concept of Virtual Sensor Network (VSN) was introduced by Jayasumana at al [15] providing the protocol for collaborative wireless sensor network. Like the dedicated sensor network where each of the sensor nodes function in a particular application, a VSN tries to utilize a subset of the sensor dedicated to a certain task or application at a given time. The sensors membership constantly changes as per the change in application. Determining which nodes should join in subset formation, maintaining the membership and energy efficient communication between VSN groups is quite challenging in static sensor environment. The challenges increase manifolds when the sensors are mobile as one has no pre-knowledge when the sensor will leave the group and disrupting the overall service. New mobile sensors can join after a VSN has been formed, thus the overall protocol must be built keeping in view the futuristic opportunities.

Due to the heterogeneity of mobile sensors, enabling the communication would need an open protocol.

In the case of static environment, the task could be achieved as most of the mobile sensors may become static for a period of time, thus a repetitive and incremental formation and deformation of the VSN may be needed less frequently. But in case where the environment is moving at a pace much slower or much faster than the mobile sensor, the overall problem of membership formation and deformation would be highly challenging.

C. Ownership

Ownership and control of mobile sensor determine the majority of how the mobile cloud sensor services would be enabled. The mobile sensors ownership might be divided in three categories: sole ownership, general partnership and public entity. Sole owners are just one single owner of mobile sensor. The personal smartphone or the mobile sensor deployed by private organization is one of the examples of sole ownership. The general partnership is when two or more people agree to take the ownership of mobile sensor. For example a nationwide chemical company and local government body may setup a mobile sensing station in a water body to detect the water contamination. The data which could be considered as confidential for one company may not be confidential for another. Thus, if they are willing to participate in crowd sensing, an additional measure of filtering might need to be taken care to form a VSN or data sharing. The last is public where the mobile sensors are deployed and could be used by anyone with unlimited access to the data. The control of the mobile sensor may not be in the hands of general public but the collected data is free to be used by the public. NASA's CubeSat Launch Initiative [16] is one such effort where several small satellite called nanosatellite payloads developed by different organization can be launched on one rocket to sense and explore the earth. The acquired data will then be relayed to the individual organization who would then share the data with public.

These types of owners can contribute towards participatory or opportunistic sensing. Formation of VSN in such distinct ownership environment is daunting task as it remains uncertain when a sole or general partnership owner of mobile sensor may stop participating or shutdown their devices. So the entire architecture has to be highly dynamic and autonomic. Security and trustworthiness would be another aspect that would determine the preference of choosing a particular mobile sensor over another. [17] An intrusion and randomly introduced fake data would provide incorrect information to the end application and the whole meaning of relying on crowd sensing would simply fail.

D. Centralized vs Decentralized Architecture

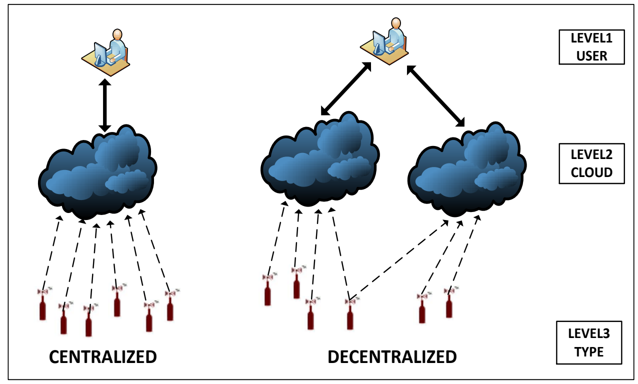

Figure 2.0 - Centralized and Decentralized Cloud Services

For the ubiquitous sensor network and third party data availability, cloud services are a very economical and technically sound solution. But depending upon the requirement, this layer could be either centralized or decentralized as shown in figure 2. In centralized architecture many mobile sensors would solely provide data to one data cloud layer. All the data analytics and the decision of formation of VSN are taken at a single cloud platform. The users would just need to provide the application they are interested in and the middleware in cloud would then appropriately chose the right set of sensor feed if it can find to serve the application. As discussed previously, the middleware must consider the ownership, data quality and availability parameters before rightly choosing a sensor or set of sensors. Standards like fault tolerance are important to consider to ensure that the end user gets the right data quality with the subset of mobile sensors allotted for the application.

While the centralized architecture for mobile cloud seems to fit perfect and serve applications to best, its hard to implement the true sense of pervasive mobile cloud sensing with such strong centralization. . Heterogeneous devices, geographical distributed sensing, ease with which data must be shared needs a decentralized architecture where there would be several cloud vendors primarily receiving data and controlling its own device. To facilitate the service discovery and collaboration mechanism among the cloud entities new protocols and policies needs to be designed. Multiple levels of data access and privacy needs to put in place for such distributed cloud approach.

E. Data Virtualization.

A variety of sensing devices are placed on the mobile sensor nodes that allows to measure variety of parameters. Also as discussed, the ownership and geographical distribution of data would seek out for decentralized architecture solution of cloud. Some of the data might be available to public for free and some would be sold at a price. In crowd sensing systems where the data might be sent and stored on different cloud vendors, the entire data must still look as being in a single server. Hence there needs a logical view or data virtualization of the entire data surpassing the complexities of decentralized cloud architecture from downstream application and providing seamless access to data within disparate systems.

Master data management could be used to keep track of the master data in various cloud servers but adhering to real time application would need more complex framework. For example imagine a radioactive leak in a city which could spread thousands of miles. In such fast moving disaster management application, data from multiple clouds needs to be collected and analyzed at the application level in real time. For this, an end user need not know the physical location of the server with its IP address and access details. The physical layer must be transparent from the application layer and any discrepancy in mobile sensor data feed must quickly be resolved maintaining high availability.

V. CONCLUSION

The Internet of things has been profoundly been affected by a wide variety of mobile sensing device systems including cell phones, animal and human tracking, civil and military sensing and environmental sensor networks. However, the future effect will be even greater as more devices are being created to explore and consolidate data streams and produce data analytics on every natural and artificial facet of our world. This paper outlined our vision for the variety of challenges and opportunities for mobile cloud services that will evolve through the utilization of the variety of mobile sensor devices.

From this perspective, we build the concepts for a mobile sensor services cloud. Our architecture is built upon four main levels: physical, tracking and control, cloud services and applications. These levels allow mobile sensors to be controlled or categorized, e.g. crowd-sourcing. Each level has their own unique set of challenges as well as possible opportunities as the growing trend in mobile sensing expands. The overwhelming flood of data produced from the horde of sensors will have to be addressed with a big data architecture built on algorithms designed to handle high volume while maintaining efficient throughput.

Our work builds upon the concepts of Big Data based cloud services. These services will handle the high intensity volume of data as well as implemented data quality control measures. This will be necessary as consumers want the most up-to-date and accurate data streams that can be provided by current sensor systems architecture. In addition to handling volume, mobile sensing has the added control management challenges of physical tracking, virtual networks, ambiguous ownership, data virtualization and centralized versus decentralized control.

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