A Comprehensive Study of Mobile Sensor Clouds

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With the growing popularity of smart phones, almost everyone in the world has a sensor device in their hands in one form or another. Cloud specialists and technologists are trying to connect all these devices to a cloud environment and obtain useful information from it. The data obtained can be very useful in fields such as Health care , Manufacturing, Retail, Media and Insurance etc. In this paper, we have discussed about state of the art technologies that exist in the current world and also proposed few novel applications for smart cities. We have also discussed about various cloud platforms and their infrastructure. The research challenges, current state of art methods and future directions are discussed in this paper.

1 Introduction

The rapid advancement in the field mobile computing technology and wireless networking has led to the development of a new field in the form of mobile cloud sensing. Mobile sensor cloud computing is probably the "Next big thing" that is going to revolutionize the field of computers. Mobile sensor clouds can offer viable solution for various problems. They could be used in various fields such as weather monitoring, traffic monitoring, pollution level monitoring and control etc. As the application of mobile sensor cloud computing is very wide, we need to classify them based on various parameters such as data source, infrastructure, ease of implementation and inferred data etc. The mobile cloud can get data through various sources such as WiFi, 4G/3G/2G data and Ethernet etc. In this paper we are going to concentrate on mobile clouds that receive data through cellular phones. The source could be anything like 4G/3G/2G data or through Wireless Fidelity.

1.1 Definition and Concepts

Mobile sensor cloud computing is the extension of cloud computing. It is the combination of hardware, software and latest cloud technologies, which combined together forms the cloud ecosystem. [1] With the ever growing world of smart phones, mobile sensor cloud computing is the hottest technological advancement of the hour. The combination of the latest technologies such as cloud computing and mobile sensors can be very helpful in a variety of fields.

1.2 Scope of Mobile Sensor Cloud Computing

Environmental Monitoring, Social Network, Health care are the three major fields where mobile sensor cloud computing can be applied. These are hot research topics and mobile sensor clouds can play a vital role. [2] The scope of mobile sensor cloud computing is so huge that, it is not easy to measure it. The entire utilization of mobile sensor cloud computing can be made only if all the sensor devices are connected to a common cloud platform. It is also important to have the supporting infrastructure. The cloud platforms must not only save the data, but also compute and obtain meaningful information from it. In this paper we compare and contrast various cloud platforms and their utility in the real world scenario.

1.3 Features and Differences

1) It must be able to support various mobile phone sensing applications on different smart phone platforms. 2) It must be energy-efficient. 3) It must have effective incentive mechanisms that can be used to attract mobile users to participate in sensing activities. In this paper, we identify unique challenges of designing and implementing a SaaS cloud, review existing systems and methods, present viable solutions, and point out future research directions. [2]

1.4 Benefits Objectives and Advantages

Almost all mobile devices today come with a sensor. The proper application of mobile sensors for research purpose is one of the main motives of mobile sensor cloud is to utilize this feature of mobile sensors and combine it with cloud computing and apply it in various fields like environmental management, social networking and health care systems. The main objective of mobile sensor cloud computing is to utilize the maximum out of mobile sensory devices. Mobile sensory devices including smart phones send data to cloud platforms. It is up to the cloud platforms to validate and compute meaningful information from it. The main objective of mobile sensor cloud computing is to collect data from as many devices as possible and obtain meaningful information from them. The accuracy of the data increases when the number of sampling values increase. The real utility of mobile sensor clouds can be obtained only when all the sensory device that are connected to the cloud interact with each other rather than interacting with the cloud alone. This concept is closely linked with the concept of Internet of things. The advantages of a fully functional mobile sensory cloud is that, each device in the network can interact with every other device and can simplify the human lifestyle.

1.5 Organization of Report

In Section 1, we introduce the basics of mobile sensor clouds, its advantages and objective of this paper. In Section 2, we have proposed an architecture and the system design for mobile sensor clouds. In Section 3, we have discussed about three cloud platforms namely Axeda, Xively and Ubidots. We have also compared and contrasted the various features of these cloud platforms. In section 4, we have disccused about State of the art technologies in Mobile Sensor clouds. We have also proposed some ideas for smart cities using mobile sensor clouds.

2 Proposed Architecture and Design

The concept of using sensor clouds to collect various types of environmental data has existed for a while but the idea of using mobile phones as a sensory source for such data is a recent one. This is due to the fact that in addition to improvement in software, nowadays mobile phones have a plethora of sensors built into them. Hence there is no single fixed architecture of solution for its design. This being said, most of the research on the issue points to the fact that a tiered architecture would be the most practical solution for the problem. Here we study and analyze the different parts of the architecture including the components and the design constraints to come up with a comprehensive view of the same.

Lets take a look at some basic requirements for a mobile sensor cloud. First the mobile device must have the required sensors to be able to collect the data. The mobile device should also have the required permissions to use the sensors for data capture. Once the above conditions are satisfied and the data is captured, the captured data should then be sent over a network like internet or Bluetooth, etc to a receiver which will be responsible for communicating with the mobile device. The data is then transferred to a cloud environment where it will be processed and stored in a database. Now we need some kind of mechanism that will be able to sort the data and extract the useful information from it. After extraction, this information obtained from the data should then be provided as a service to people or customers for consumption.

From the above scenario we can see that an architecture to implement a mobile sensing cloud should have at least three tiers. Figure 1 shows the tiers of such an architecture.

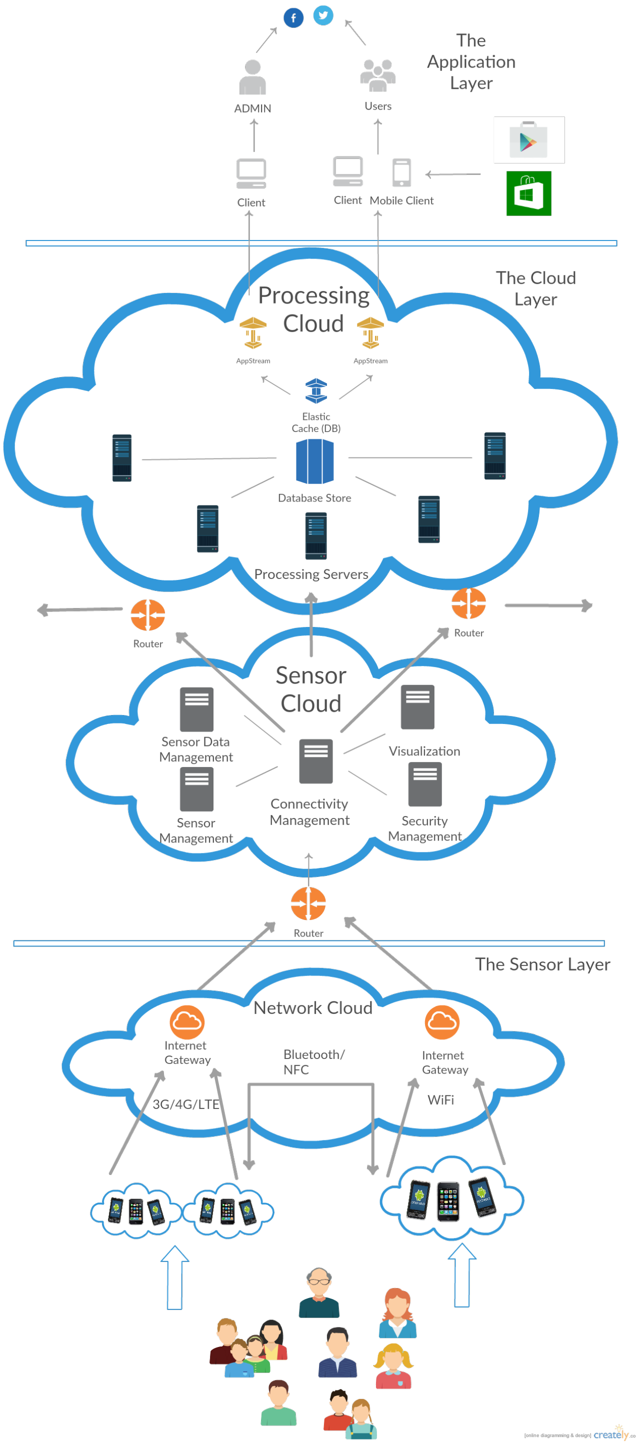

Fig. 1. This proposes a 3-tier architecture of a Mobile Sensor Cloud

The Sensor For any sensor cloud, the sensor is a very integral part. In mobile sensor clouds the mobile devices that we carry around everyday are the sensor devices that will be used to gather data. Since the concept of using mobile phones as sensors is new and the research done on this is still in its infancy, we will be concentrating more on this section of the architecture.Lets take a look at some basic requirements for a mobile sensor cloud. First the mobile device must have the required sensors to be able to collect the data. The mobile device should also have the required permissions to use the sensors for data capture. Once the above conditions are satisfied and the data is captured, the captured data should then be sent over a network like internet or Bluetooth, etc to a receiver which will be responsible for communicating with the mobile device. The data is then transferred to a cloud environment where it will be processed and stored in a database. Now we need some kind of mechanism that will be able to sort the data and extract the useful information from it. After extraction, this information obtained from the data should then be provided as a service to people or customers for consumption.

The Cloud Environment All the data that has been collected from the mobile devices have to stored and processed upon. This part of the process will happen on the Cloud environment. TAsks such as communication with the sensors, Sensor data management, Visualization and Security are also performed by the cloud. Hence the Cloud is a very important component in a mobile sensor cloud and the whole system is built around it. Cloud computing has become extremely popular in recent times due to its desirable characteristics. First, it is device and location independent [3]. This is a very useful feature as our mobile sensors will be spread across a huge region and will constantly be on the move. Since Cloud is accessible from anywhere, the end users will also be able to connect to it easily and finally consume the final information that is obtained. Cloud is also extremely reliable, scalable and efficient [3]. Hence it will be able to handle the huge volume of data and process it in a sufficiently short time period.

The User Application Layer The concept of sensor clouds is to gather useful information from a variety of sensory devices spread over a region of area and provide it to the end user for consumption. Once the data has been obtained and processed by the cloud there should be a mechanism or service that will be able to provide the correct user with the correct information. In this section we will be looking into such mechanisms.

Now let us discuss the three layers in detail.

2.1 The Sensor

In a mobile sensor cloud, a mobile device such as a mobile phone acts as the sensory device. This is possible only due to the recent developments in mobile hardware where more and more sensors come along with the phone as standard. Traditionally sensor clouds are only used to monitor environmental factors such as temperature, humidity animal migration patters and so on. With the advent of mobile sensor clouds this data can also be personalized for an individual. This is one of the many advantages of this system.

Fig. 2. An off the shelf Samsung Galaxy S6 with its list of sensors.

First let us look into a modern mobile phone and list some of the sensors that are packaged into it. Figure 2 shows the array of sensors available in an Samsung Galaxy S6. In addition to conventional sensors like camera, microphone, accelerometer, compass, and GPS, there are a variety of new sensors that haven't been seen on mobile devices like barometer, gyroscope, heart rate monitor, fingerprint reader, light sensor and thermometer.

Data from these sensors especially heart rate monitor and gyroscope can provide new types of data which can be personalized for an individual. GPS can provide location data which can be used to monitor traffic flow. Microphones can be used to collect audio data from the surroundings which will be used to detect the levels of noise pollution. By measuring the temperature and pressure, the barometer along with the thermometer and GPS can assist in predicting weather patters and storms.

These sensors can not just be used to collect general data but also be used to collect data which can show personalized information to the user. For example, the microphone can also collect the user's voice data and conversation to better understand the user's preferences and routines. The accelerometer along with the light and proximity sensor can be used to get the position of the user's phone as in if it is inside the pocket or if the user is holding it and so on. This context can be useful to decide the quality and validity of the data obtained. The heart rate monitor can monitor the

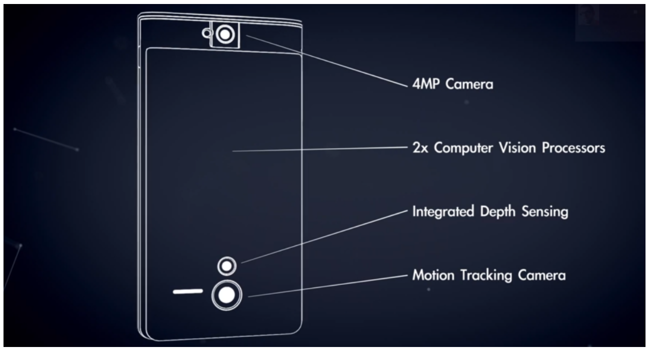

Fig. 3. The image shows the different cameras that project Tango uses

user's hear rate and compare with the results from other people nearby to show health comparisons and can also identify conditions like hypertension and etc. The camera in the device can be used to tract the user's eye movement and also can be used by the user to upload information such as potholes on roads.

With the advancement in technology it is going to be very interesting to see what new types of sensors future mobile devices may posses. For example, mobile phones can have an in built depth sensor that can be used to map a 3 Dimensional space. is currently working on such an implementation called project

[4].

Figure 3 shows the sensors that Google's Project Tango uses.

2.1.1 Data Controller

In this section we are going to discuss using mobile phones as sensory nodes for a mobile sensor network. Hence, in this specific case we should look into the ownership of data that will be transmitted. In this scenario there are two major possible controllers - The device manufacturer or The Telecommunication Provider.

The device manufacturer has complete control over the design and specification of the device. They can design the device and sensors in such a way that monitoring and transmission of data from the device becomes very efficient. The most important part of any sensor network is the sensor and if the device manufacturers put more effort and time to optimize these devices then the feasibility of such networks will improve and the costs will decrease.

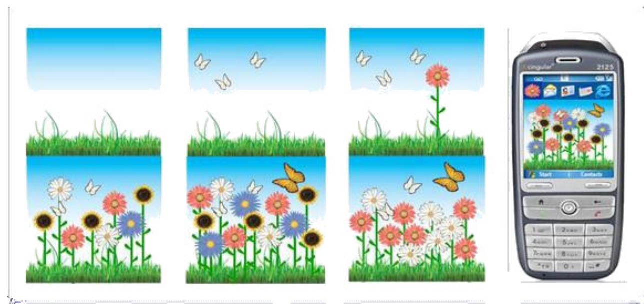

Fig. 4. The image shows the garden bloom in relation to achieving the fitness goal

Nowadays most mobile phones are being sold under a contract from a telecoms service provider. In this case the service providers can assert their influence over the data captured. This can considerably change the thinking towards problems bandwidth and data costs where the network provider might take up the cost of data transmission in return for the data itself.

2.1.2 Sensing Scale

As discussed before the mobile sensor cloud can generate data not only for a generic case but also for an individual. Hence we must talk about the scale of operation of mobile sensor clouds. The final aim of the system is to provide data to the users. There are three different types of sensing scales in this scenario. They are Personal Sensing, Group Sensing and Community Sensing [5].

The first type of sensing is and personal sensing. The data collected from the mobile device can be used to target the specific needs of the user itself. An example of this is the UbiFit Garden [6]. It is a personal fitness application. The idea is to motivate the user to achieve their personal fitness goal on a daily basis. As shown in Figure 4 the garden blooms in relation to the achievement of the goal.

When a group of individual users share data to achieve a common goal then it becomes the case of Group Sensing. These individuals are usually aware of and trusted by each other. Example of group sensing can be users taking pictures of pot holes in the streets to inform local residents. In this case a user sends data which is to be consumed by other people. Here the concept of privacy arises.

It is very important to design the system in such a way that the users retain their anonymity and privacy.

The third sensing scale is Community Sensing. In community sensing a large group of people anonymously share data that will help the community as a whole. A common example can be the traffic flow information on the roads. Using the GPS information of the users currently driving it is possible to calculate the traffic congestion and hence let other people know if it can be faster to take a train instead. In this scenario again privacy is very important.

2.1.3 Sensing Context

Once the scale of sensing has been established, we now focus on the sensing context. There are two types of sensing contexts. They are participatory sensing and opportunistic sensing [5]. In participatory sensing the user decides when to record data using the sensors. The control of data collection is with the user. In opportunistic sensing the mobile device will be able to gather data from the sensors without any input or aid from the user. Let us look at both these paradigms and compare them bases on privacy, data quality, time sensitiveness and hardware limitations.

First lets compare with respect to privacy. In participatory sensing, the user has to actively participate in the data collection process. It is therefore in his discretion to decide as to what sensors to access and what data to send. As long as this data is being collected anonymously the privacy of the user should not be violated. In the case of opportunistic sensing, the device will decide when to access what data from the sensor. This is a huge privacy issue. Accessing user data and resources without their consent or proper authentication may even be illegal. Therefore the user has to give consent to the device that it can use any sensor at any point of time.

Second lets compare with respect to data quality. In participatory sensing, since the user has to manually send the data it is being checked by the user before being sent. Hence the data being sent will be comparatively more reliable and be of better quality. This is under the assumption that the user will not knowingly provide fake and invalid data. On the other hand, the phone sends data as and when it is required. In this scenario the data accuracy and quality will be severely hindered.

Mobile phones are devices that are used everyday in many scenarios and locations. Suppose assume that the mobile device is requested to send temperature and noise data to the cloud server. If suppose at this point in time, the device is indoors and is kept inside the pocket of the user, then both the data transmitted over the network will be highly inaccurate. Since it is indoors the temperature can be different from the temperature outside and since the mobile is inside the pocket the surrounding noise might be extremely muffled and not recognizable. This can also be the case if the light sensor data is requested but the phone is kept turned down on a table thus indicating that it is night time while in fact when the sun is out.

A possible solution here would be to use the other sensors to determine the context and accuracy of the data. Fro example if requesting light sensor data, using the accelerometers if we find out that the phone is turned upside down or is kept inside the pocket then we would know that the data is not going to be very accurate.

Next we compare with respect to time sensitivity. In participatory sensing, the data being collected cannot be time sensitive. Time sensitive data means that the data is required for calculating and obtaining information that will be used in the very near future. This could be anywhere from a few seconds to a few hours. Example of such time sensitive data is the GPS data obtained from the sensors which is used to calculate traffic congestion. During this time if the user does not participate by allowing access to the GPS to send information then that information will be lost and could even lead to decrease in accuracy of the resulting information obtained from other devices. More the data sources and data points obtained, more is the accuracy of the system.

Even though mobile devices are a great source of data, we must keep in mind that they are small and are used throughout the day. They also have a very small battery and battery life. Also the processing power and memory of a mobile phone is very limited. When extracting data out a mobile phone these factors should be considered. The hardware and power limitation of mobile phones is one of the major limitations and hindrance to the success of mobile sensor clouds. These limitations do not play a huge role in participatory sensing as the user will have control over all these variables.

Battery life of a mobile phone is one of the biggest concern when it come to opportunistic or continuous sensing. Each of these sensors in the phone require power to run. Also when these sensors are active the processor also has to be running in order for it to retrieve information from these sensors. The processor in general consume many fold time the power consumed by these sensors. Also during this time the processor spends most of its time without anything to compute and wastes most of its cycles [7]. This makes the whole process very energy inefficient. Data extraction should not drain the battery from the mobile phones of the users.

There have been many efforts to address this issue. Microsoft have come up with the Little Rock Project [8] which aims to enable continuous sensing in mobile phones with low power overheads. ARM has also come up with a mobile processor architecture called the big.LITTLE architecture [9]. "Big.LITTLE technology is a heterogeneous processing architecture which uses two types of processor. LITTLE processors are designed for maximum power efficiency while big processors are designed to provide maximum compute performance." [9]. As we can see, the less powerful processor can be used to operate all the sensors and can also be responsible for communication with the Cloud service thereby reducing power consumption. Fig 5 shows the basic architecture of the ARM Big.Little architecture [9]. One of the first processors to use this technology is Exynos 5 Octa which used four ARM A15 processor cores as the 'Big' processor and four ARM A7 processor cores as the 'Little' processor [10].

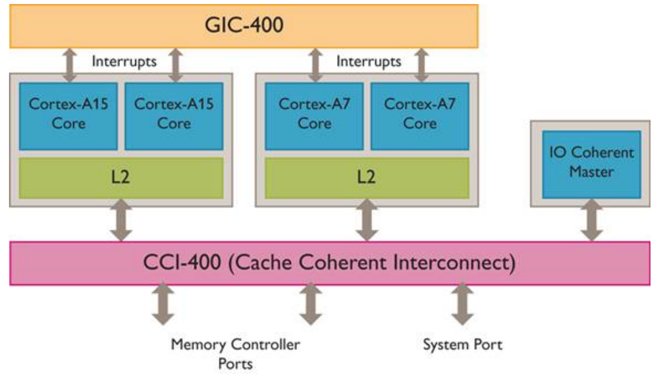

Fig. 5. The image shows the garden bloom in relation to achieving the fitness goal

Storage and Memory are also limited in the mobile environment. Care must therefore be taken not to take too much memory space while storing the sensor data before sending it to the cloud. Also in depth processing of the sensor data should also not happen on the mobile as it requires a lot of memory and processing powers. This in turn can hamper the user experience on the mobile device.

While discussing hardware limitations another resource that we must look into is the network bandwidth. In the case of continuous sensing, there are two options for the mobile device to communicate with the cloud server. The mobile device can send the sensor data to the cloud server as and when it receives it from the sensors. This poses a few problems. If the data and frequency is too large then the cost of transmitting that data will be very high as it will utilize a large network bandwidth. Hence we have to make a decision here. We have to choose between the cost of transmitting and the cost of data. If the priority of the data is more than the cost incurred due to its transmission then in such cases the transmission costs can be neglected. This decision will also depend on how accurate and reliable the data obtained is.

There are several ways in which the sensor can transmit the data. Connectivity to the sensor is very important. In this case, a mobile phone acting as a sensor can connect to the internet over a WiFi network or over telecommunication services by either using 3G or 4G/LTE connectivity. The difference in cost to transmit data over these connections should also be considered.

In the case where the telecoms operation has control over the device and the sensor data, they may choose to only upload the data over their network by either using 3G or 4G/LTE connectivity. In case the device manufactures have control over the sensor data then they may want to upload the data over very secure networks. Transmitting this data over Wifi connections can sometimes be a cause for security concerns. Many public WiFi hot spots are very insecure and can be an easy target to Man In The Middle Attacks [11].

This is where the Network Cloud comes in. The network cloud will be owned by the same people who will have power over the access of the sensor data. Here they can decide which sensor or group of sensors they wish to communicate with and how. This also consists of Internet Gateways which will be responsible for access to a group of sensors.

In the second scenario the mobile device can continue sensing and store all the sensory data locally until it has a stable and viable network connection to communicate with the cloud and send all the data collected in one go. This seems like a logical solution to the network bandwidth problem, however this solution will not work with time sensitive data which will be required by the cloud immediately after its been extracted from the sensors.

2.2 The Cloud Environment

The Oxford Dictionaries defines Cloud Computing as "The practice of using a network of remote servers hosted on the Internet to store, manage, and process data, rather than a local server or a personal computer" [12]. In the beginning we have discussed the characteristics of Cloud and its advantages in general. Now let us into how Cloud Computing helps us in the construction of Mobile Sensor Cloud architecture. Figure 6 [13] shows a proposed architecture of a cloud computing environment that can be used as a part of the Mobile Sensor Cloud. It depicts the flow of information through the system and also specifies particular components of the cloud like databases, sensing servers and load balancers. We will be looking into the details of building a cloud infrastructure for mobile sensor clouds and the desirable properties such an infrastructure should posses in this section.

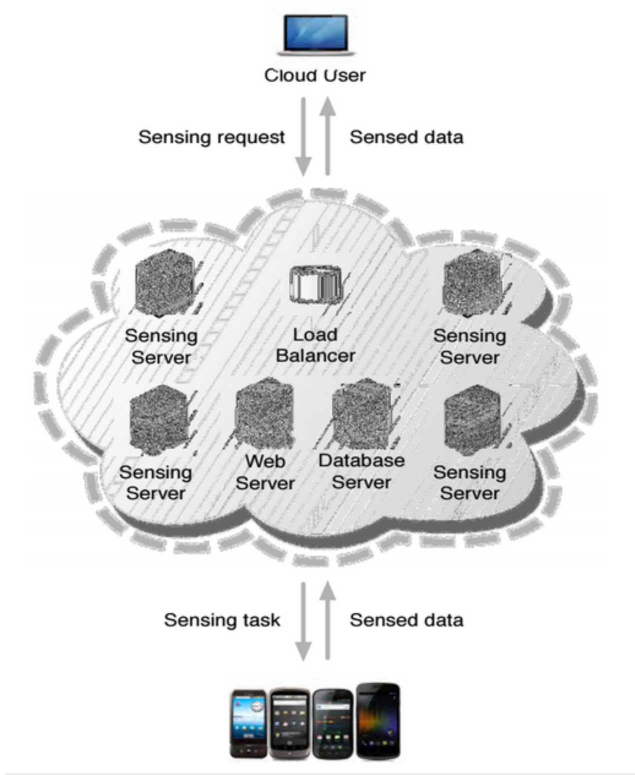

Fig. 6. This shows a typical Mobile Cloud Environment

Lets first discuss the part the cloud plays and the flow of the entire Mobile Sensor Cloud system. In mobile sensor clouds, the mobile phone acts as the sensory device which collects information from its environment. This data is then sent over a network to a cloud platform where it is stored and processed upon. The final information extracted from the data is then served to the user based on specific requirements. Hence the basic goal is to provide users with the required data collected from the sensors upon request. This is again served over a network from the cloud.
This specification has resulted in proposals of a system where the cloud is designed to be supporting *Sensing As a Service (S^2AAS)* [13]. Now lets look closer into the concept if S^2AAS.

2.2.1 The Flow

The whole flow a of mobile sensor cloud can be described as following. (1)The end user has access to a user interface either on the web or on a mobile which enables him to send information request to the cloud server over the network. (2) The cloud server has to then use its communication modules to contact mobile devices and sensors which satisfy the requirements such as ones that lie inside a predefined Geofence and try to recruit them. Weather these devices will responds depends on many factors that have been thoroughly discussed in the previous subsection. (3) These mobile devices which are active then spring into action and start collecting sensor data and sends the data over to the cloud server. (4) The cloud has components like sensor data management, Security management and visualization which will take care of communication and secure transfer of data from the sensors. (5) The cloud server then processes the data and stores this data in its database, analyzes it and extracts the required information. (6) It then passes this information back to the user who requested it. The load balancers then makes sure that there is no latency of the access of that data and the resources of the cloud are managed efficiently. This is the typical flow of a S^2AAS based on mobile sensor cloud.

We propose a slight modification to this design where the sensor cloud will consist of two components

The Sensor Cloud
The Processor Cloud

Henceforth, these two components will together be refereed to as the Sensor Cloud or Cloud Environment. Now lets look into each of the components in detail.

2.2.2 Communication to the Sensor

The sensor cloud should have a component that allows it to detect and communicate efficiently with the sensors that lie within its overview. This part is the sensor network. As soon as a request for information comes in from the user, this module should be able to broadcast a signal requesting sensor data from all the mobile sensors that have been registered with it. It should also be able to route these requests over other communication endpoints.

Here we propose a new concept of using a Broadcast Polling mechanism [14] for the process. Depending on the responses from the mobile devices for the broadcast signal, the cloud should be able to effectively have a list of active devices and be able communicate with each of these devices individually. This is where the scalability feature of cloud comes into play. As cloud computing can be efficiently and easily scaled to work with large number of connections.

The data transfers can occur in data interchange formats such as JSON or XML. The cloud should be able to efficiently establish secured TCP connections to each of the mobile devices it wishes to communicate with. Once the required data has been received, it should terminate these connections properly thus ending the session.

Once the data has been received by the Sensor Network, it is then forwarded to the processing Cloud which will process the sensor data to retrieve the required information. This information will then be stored in a database for further use.

These Sensor Networks and the processing cloud will be owned by either the device manufacturers or the Telecom Service Providers.

2.2.3 Security and anonymity

Security is an important aspect in any kind of system. However, since mobile sensor cloud deals with private data for public consumption, the concept of anonymity also plays an important roles. In mobile sensor cloud systems the sensor data transmitted over the network is susceptible to attacks and interceptions. These data can be intercepted and collected illegally or can also be spoofed to produce inaccurate data. Hence the connections between the cloud and the mobile device should be very secure. Along with this, raw sensor data should never be transmitted over the network. This will case a lot of security issues with respect to the validity of data.

The raw sensor data should be be processed on the mobile device and encrypted before sending. As mentioned earlier the mobile has very limited resources with respect to memory and network. So a decision as to how much and what type of processing can be done on the phone should be looked into. The task of processing the data can be distributed between the cloud server and the mobile device based on this study. Also to minimize network bandwidth consumption, the data should also be compressed before being transmitted.

Location based sensors on mobiles can be a very valuable source of data but getting the user's location for public consumption can cause serious privacy issues. Users will be hesitant to the idea that their location is being continuously tracked. Hence the concept of anonymity is very important here. We should have a mechanism that in some way guarantees the user that their privacy will not be violated. Research on this area basically suggest a few principles to follow to achieve this. [15–17]. They propose methods such as Decentralizing Sensitive data, Node Mobility, Policy Based Approaches and Information Flooding to ensure privacy of the user.

2.2.4 Storage and Databases

The basis of using mobile phones as sensors is due to the fact that they are readily available and are distributed throughout the world. There are millions of mobile devices that are active today. The sensor data from such a number of devices will be very big. Given a large enough sensory devices, it is possible to collect even terabytes of sensory data on a daily basis. Hence these database have to be very flexible and be able to efficiently handle such a huge volume of data.

Using a traditional RDBMS for collecting and storing data can cause a lot of problems with respect to mobile sensor clouds. A centralized database is very vulnerable as it is a central point of failure. Further, there arises problems of data redundancy. One way to deal with the issue is that instead of querying the mobile devices for every request, the data from the mobile devices could be stored in the database and upon receiving queries, this data can be operated on to get the required information.

2.3 The User Application Layer

The main goal of mobile sensor cloud is to get relevant information to end users that have been extracted from mobile sensors. Hence the highest level of the system will be the end users. The application layer consists of components such as an user interface for the user to interact with where he can request information and view it. The second component will be the communication module which will handle communications between the application and the cloud server. We will be viewing these main components in this section.

2.3.1 User Interface

The user interface for the application can either be a website or a mobile application. The mobile applications should be accessible to the user from a central installation source. Examples of such sources are Google Play store for Android devices and the iTunes store for Apple devices. The application must validate the user using trusted credentials and authentication. Then the user will set up his preferences as to what type of data is required such as data only from predefined Geofences and so on. Once this is done, the backend service should be able to start providing the required information.

2.3.2 The communication service

The communication service must be able to effectively decide what information it should request from the cloud server. Instead the server collecting data to satisfy each mobile request, the applications can connect to a cloud-bases *Coordination Service* [18]. In this, every mobile device will send a single request to the server for data.

The exact mechanism is described as "Different applications connect to this service and describe their information requirements as a tuple $<M,Q>$ where M denotes the set (explicit or implicit) of mobile devices/sensors that are needed to satisfy the query and Q specifies the query processing logic. This coordination service then takes this entire collection of information requests (i.e., the set of <M,Q > tuple) and then continuously optimizes, on a global basis (across all queries), the tasking of individual sensors on individual phones.” [18]

The important requirements for building this architecture is also established as: [18]

Significantly Reduce Energy and Bandwidth Costs
Scaling Both Sensors and Applications
Avoiding Privacy Leaks
Providing an Easy To Use Programming API

3 MSC Platforms and classifications

Sensors are a staple of Mobile phones as much as any other components. The sensors ranging from barometer used for improving accuracy of the GPS to proximity sensors switches off the screen when the user brings the phone close to the ear, are used extensively in mobile phones. When one starts using the data presented by these mobile phone users, there arises a need for specialized platforms for handling the huge amount of data. In this section we present our analysis on some of the existing Mobile sensor cloud platforms.

3.1 Axeda

Axeda provides cloud based softwares and services for building and deploying machine-to-machine(M2M) and Internet of Things(IoT) applications [19]. It aims to provide a secure platform It was developed by Axeda Corporation in 2009. In 2011 they introduced a pay-as-you-go business model comparable to Amazon Web Services [20] . Axeda Corporation was later acquired by PTC on July, 2014 to compliment PTCs IoT portfolio. The Axeda platform can be broadly divided into four functional components Application Services, System Management, Data Management and Communication.

3.1.1 Application Services

The Application Services provides a host of Scripting and Web Services APIs. It uses SOAP or RESTful web services for communication. The Developers can use Groovy programming language to run their scripts which can make use of the information from the Axeda Platform. The developers can also script their own web services with the help of Axedas Scripto functionality. A well defined Integration Framework exists where the user gets reliable support for many modern protocols like Transport Layer Security(TLS), HTTP/HTTPs etc.

3.1.2 System Management

The Axeda Platform lets you manage your system, with the help of Axeda Console. The console provides dashboard for monitoring your Assets and SIM. The users have the option of viewing the Assets in a tree structure or geotagged in maps. Based on the type of asset, dynamic information like data readings, alarms, events and the connectivity options are displayed in the dashboard for monitoring assets. Similarly for SIMs the device information like carrier network, rate plan, network usage, signal strength etc. are displayed for the user.

3.1.3 Data Management

The Axeda Platform contains a data processing engine for handling sensor data like alarms, events, locations etc. An IoT Rules Engine provides a specialized console for the users, with which rules can be created for handling the events. It also provides a rules scheduler for customizing the schedules for the rules that the user creates. The Data from sensors are processed as name-value pairs, example - Air pressure-10.

3.1.4 Communication

Axeda provides specialized software agents, services and toolkit for establishing connectivity between the mobile sensor devices and Axeda platform. Tools like Axeda Builder provides a Graphical User Interface for configuring the sensor devices and deploying Axeda Software agents for handling sensor data and events. Based on the type of device there are three connectivity solutions available.

Axeda firewall-friendly agents for intelligent, configurable software that runs on Windows or Linux

Axeda Protocols and Toolkits for M2M communications using AMMP(Adaptive Machine Messaging Protocol)
Axeda AnyDevice Code Service for non-programmable devices

3.2 Xively

Internet of Things is no more a futuristic term. We are already into the age of IOT plus. Xively is one of the most widely used sensor cloud platforms in the current technological world. It helps enterprises to build products and connect them through internet. Xively provides a common platform/eco-system, through which IOT devices could interact with each other. The real utility/application of IOT could be done only if devices communicate with each other. One good example to that is the water sprinkler system. Whenever a fire hazard is created, the sensors detect the fire. Instead of communicating the hazard to the fire department, this sensor device communicates with another device such as the sprinkler system and water is sprinkled to put out the fire. This kind of device to device interaction can be achieved through Xively. [21]

The application is mainly based on three concepts: connection, management and engagement. Xively includes data services, directory services, security services and a web based management system. The messaging system of Xively is built on MQTT protocol. The Xively API supports REST, MQTT and Web Sockets. MQTT is a light weight, TCP based protocol used for messaging over cloud networks. [22]

3.3 UBIDOTS API

Ubidots is a cloud platform that enables users to capture data from sensors and obtain meaningful information from it. This platform can be used to send data to cloud from any internet enabled devices. Once the platform receives data, it could be configured to set and receive alerts. It also allows a REST API to read and write data. This API supports both HTTP and HTTPS. For additional security, it also requires an additional API key [23]. It is very flexible and it gives its users the choice of programming language. Users can choose any of the programming languages such as Java, Python, C, Node and Ruby.

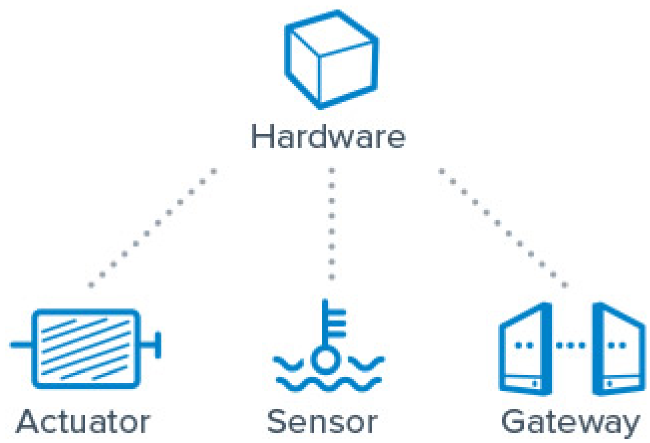

Fig. 7. Xively System Architecture

	Axeda	Xively	Ubidots
Scalability	Scalability on Demand	Scalable	Scalable
Security	HTTPS, PKI and up to 256-bit AES encryption	HTTPS over SSL/TLS with API keys	HTTPS over SSL and Token based authentication
Flexibility	Groovy with JS support	C,C++,GO JAVA,JS, Python,B#, RUST, Parasail, Assembler, Forth	Java, Python, C, Node, Ruby
Cost	Pay per use	NA	0−48 per month
API	SDK/REST API	REST API	Flexible API/REST API
Type	Public	Public/Private	Public/Private
Ipv6 support	Yes	Yes	Yes

The best feature about Ubidots is that it accepts data from different sources. Meta data can be added in such a way that, it identifies the source from which data is obtained. For security, a token based security authentication is used. There is also an additional security through HTTPS/SSL encryption layer. One of the best features of this API is its alert trigger mechanism. Users can set alerts/triggers through mail or receive it through SMS.

4 State of the art in Mobile Sensor CLOUDS

4.1 Mobile cloud sensors in Healthcare

Mobile cloud sensors are very useful in healthcare services particularly for aiding elders and patients. The breakthrough in this area has been the recent introduction of the Bluetooth 4.0 standard. The wearable devices that use this standard are very low-powered, meaning that they can run for a year on a single battery; earlier Bluetooth devices used more power, and their batteries had to be replaced every week or two. Additionally with large scale commercial production of devices for fitness trackers like Nike FuelBand, Fitbit Charge, Garmin VivoFit and many other such products have brought in customers from various age demographics. Taking this to next level by processing of data using various smartphone apps like Microsoft HealthVault, Google Fit, Health Tap, and Hello MD etc. using the sensors built in the smartphones. Fall detection, Gait Analysing and Heart rate sensing are some of the key areas to assist elders and patients. Sleep sensing and Heart rate sensing are few popular sensing services used by common people. The analytics, processing of data derived from the mobile sensors and storing them are done in their respective cloud infrastructure.

4.2 Micro Blogging, Party Thermometer and Citizen Journalist - Applications

The Micro blogging [24], party thermometer and citizen journalist are similar applications based on crowd sourced sensor cloud. They can be classified as dynamic moving sensors in a dynamic environment.They leverage on the time and location of the mobile devices based on the sensors. These applications [25] posts alerts only to people present in a particular area based on their real time location input provided by the sensor. The user can respond back with data such

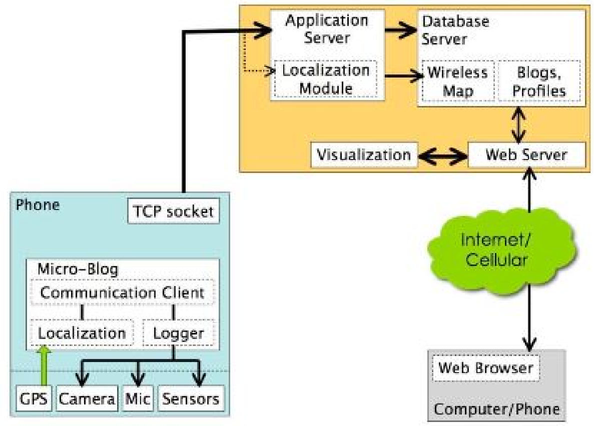

Fig. 8. Roomit Application

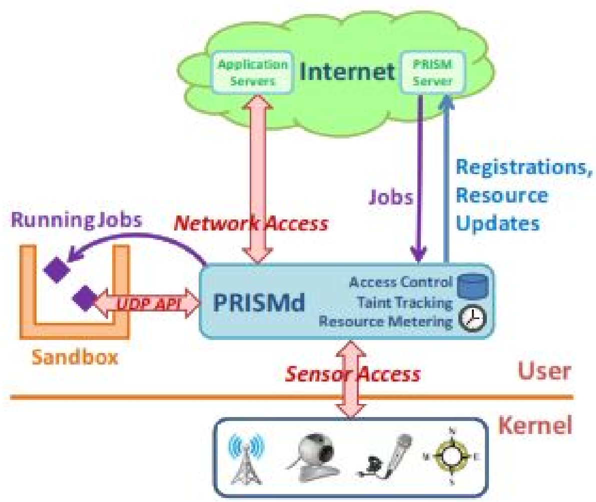

Fig. 9. Prism server based IOT

as photos and other multimedia element. The micro blogging application provides the user with the scope to query the posted data, on the other hand citizen journalist publishes the data in their journal. In party thermometer the user will be in a better position to decide about party based on the reply from the people in the party. The sensor can reach out to the prism server using the mobile networks.The anonymous layer on the PRISM server9 provides user the control over the data for their privacy.

The purpose of introducing the above 3 applications is to highlight the difference between an IOT based system and a mobile sensor cloud.

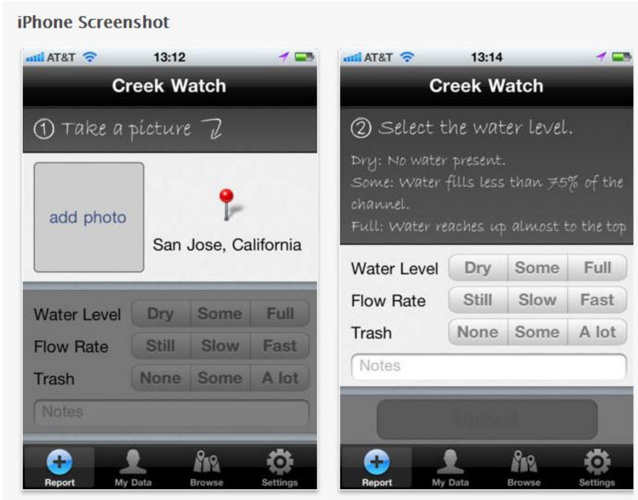

Fig. 10. The UI design of the Creekwatch application in iPhone

As shown in the Fig 8 there is no cloud layer abstracting the sensors hence these can be classified as an IOT based systems. These applications involves inherent issues and will not provide Scalability, multi-tenancy and other typical properties in cloud based system. The application cannot function properly on a large user base thus the system might become very slow to respond to user requests. Therefore the application does not support service on demand during its peak traffic. If the system architecture can be modified (similar to the Fig 1) to include cloud properties and also to support the data processing and analytics thus reducing the work load in the servers and smart phones thereby improving the overall stability of the system. The applications mentioned further discuss on the cloud properties and how they improve their system.

4.3 CreekWatch - A sensor based approach for monitoring local water shed

Creek Watch [26] is a project developed at IBM Research - Almaden in consultation with the California State Water Resources Control Board's Clean Water Team. A sensor based iPhone application that allows users to monitor the health of their local watershed. Based on the location GPS sensors and data tabulated by the user at period time mentioning amount of water and trash found is stored and processed over cloud. The data is compared to later time period to find the effectiveness or change due to various factors. This data helps watershed groups, agencies and scientists track pollution, manage water resources, and plan environmental programs. Web data submission is common now empowering with the sensors that are present in iphone thereby providing a convenient means to collect and send time and location tagged data. Engaging the citizens to gather a crowd sourced data has great benefits such as creating a social awareness in a peer level thereby educating and motivating to not only retaining their participation but also exponentially increasing the participation further more citizens. The project is a collaboration between Governments which enforces regulations on pollution, water usage etc. The private groups work closely with the government to evaluate the proposed schemes. The volunteer groups have citizens who orchestrate the movements for a regular check-ups of their local water sheds and also plan on clean-up programs.

Creeks watch is a typical example of mobile sensor cloud. It is widely used and has very large users thus supporting scalability on their service. The data is crowd sourced and can be viewed by all the stake holders of the system. It has an easy user interface for both the mobile thin client and on the web console. The application can run on WIFI or mobile network.

4.4 Irrigation Water Usage - Intelligent Sensor Cloud System

The Application [27] aids as a support to farmers to decide on buying extra water for irrigation on a particular day. Three sensor database SILO, CosmOz and AWAP are integrated using the unified Resource Description Framework (RDF). Unified knowledge RDFs were created for all of the three data sources based on pre-processed data, available Meta data, and original provenance information. This integrated system is processed in CSIRO cloud. The data is sent in a JSON format which is parsed by the Andriod app client like a traffic signal display for easier understanding. The big data analytics of the integrated databases and decision support system which are processed in CSIRO Sensor Cloud is the one of the key

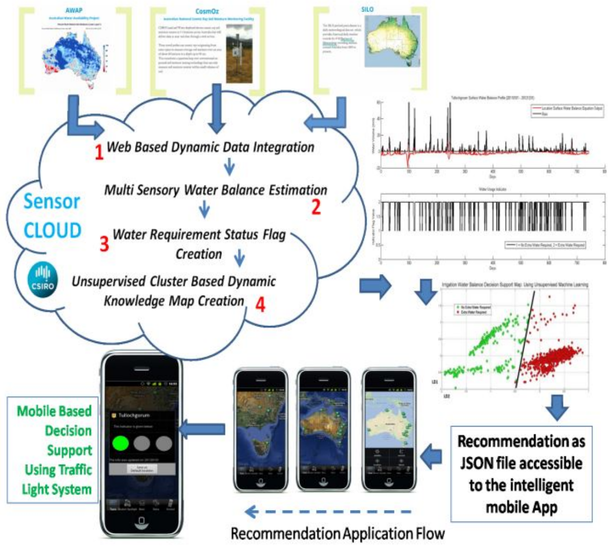

Fig. 11. Architecture Design Of the Irrigation Application

highlights of the project. The project serves as template for application on many other natural source management programmes.

4.5 Motivating ideas for Smart City

4.5.1 Vehicle sensor based cloud system

Currently vehicles contains inherently built in sensors like Wheel Speed Sensor, Tire Pressure sensor (TPMS), Intake/Ambient Air Temp (IAT), Cam Position (CMP), Parking Sensors etc. These sensors has their own designated purpose. But currently there is no provisions for storing or transmitting of the data inferred from the sensors. If the data from the sensors are transmitted to Cloud infrastructure, we can query a lot of interesting information by processing the data. By using data analytic techniques we can use it for various applications.One such application could be to create a safety quotient deriving from mining of data transmitted by sensors for average traveling speed, signal skipping, moving very close to other vehicles on the road. Currently there are 5.25 million driving accidents that take place per year. The very essence of this application will be to provide a personalized feedback to individual drivers by using classification algorithms to realize on the idiosyncrasies of their driving. Thus in turn serves as a framework for improving their driving skills thus reducing the average number of accidents.

Another interesting application would be to provide a framework for inter vehicular communication on roads. The current air horn system might be simple however its a very primitive mechanism developed during 20th Century during the period of locomotive trains. The technology around has developed tremendously yet we have not moved on from using air horns. Air horn is one of the most significant contributors to noise pollution. The San Francisco Department of Public Health has ranked ”highly annoyed” areas of the city - neighborhoods. It says that noise is so loud and so constant it could cause psychological and physical harm.Noise especially at night - can keep people awake, adding to their stress level. And that, in turn, can contribute to high blood pressure, heart diseases and depression. The proposed application of inter vehicular communication can use bluetooth, zigbee or any wireless technologies to communicate with other vehicles on the road. A simple dashboard with light emitting diode signals can be considered as an effective user interface for the system. A sensor cloud is pivotal to the framework for the above mentioned applications since the system requires scalability when a larger number of users are connected. The application needs to have pay as you go model to provide flexibility for the users to subscribe the service on demand whenever they need.

4.5.2 Library Infrastructure Management

Currently Library meeting rooms are integral part of students education process to collaborate with colleagues and also to work on their curriculum. The meeting rooms are booked through online console of the library based on first come first served basis. In the events of participants not showing up to the rooms or leaving early than from the end time there is an under-utilization of the resources. Using our cloud service, we could build an application that monitors ambient light and sound levels of the meeting room (using microphone and light sensor data) to detect when a meeting has truly ended.The same can be either reflected back into the console for online booking of the rooms immediately or can be routed to Front desk at the library for on the spot booking of rooms.

5 Conclusion

This paper discusses about the current scenario in Mobile Phone sensing and Sensor Clouds. We have also proposed and discussed an architecture for the same. We have also discussed a couple of novel ideas for Smart City projects. We have looked into the physical/Hardware problems current mobile phones have and also proposed solutions to overcome them. We have also discussed about privacy and security of data involved in the process. Mobile Sensor Clouds has a huge potential to become a big Enterprise. The main issues are more technical in nature rather than a shortage of Infrastructure. The solution is to concentrate more on privacy sensitive and resource sensitive model.Thinking ahead in the same lane would be to handle the challenges associated with the virtualization of the sensors to handle failure of physical sensors and maintain the integrity of the data derived from the sensors. Also on such scenarios, due to virtualization of sensors the volume of data flowing to the cloud will increase exponentially thereby creating a need to handling big data analytics at the sensor node level.

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