A Comprehensive Study of Mobile Sensing and Cloud Services

Archana Ramalingam, Clinton Rego, Dan Lu, Sreekar Medarametla
Computer Engineering Department
San Jose State University CA

***Abstract*-Mobile sensors revolutionized the world with their wide scale availability, high computational capability, large storage capacity and diversified applications. The subtle differences between the traditional sensors and smartphone sensors led to a new era of sensing which is mobile phone sensing as a service. In this paper we will introduce you to the concepts of mobile sensing like the architecture of mobile sensing as a service model, cloud enabled sensing, mobile sensor networks, their architecture and the protocols they follow, different mobile sensor network platforms, challenges and motivations of different concepts, the diverse mobile sensor platforms available and the Internet of Things based cloud sensor networks**

***Keywords* – Cloud computing, Mobile cloud computing, Wireless sensor networks.**

I. Introduction to Mobile Sensing Cloud and Services

A. Report Structure

Chapter 1 briefly explains the different concepts of mobile sensing, a generic description of sensing as a service and cloud enabled sensing concepts. Chapter 2 elaborates on the infrastructure, architecture and types and comparisons of various types of sensors like healthcare, environmental, transportation and smart city. Also cloud platforms that is available for storing and processing the sensor data from sensors are also discussed. Chapter 3 explains about the mobile sensor networks, the architecture of sensor networks. Chapter 4 explains briefly about sensor cloud infrastructure and mobile sensor cloud system.

B. What is mobile sensing?

Senses play an important role in human beings, as they feel the whole world and bridge the gap between them and the beautiful nature. Similar definition can be applied for mobile sensing as today's mobile phones are embedded with sensors, which are made of commodity hardware. Few of the sensors include global positioning system, camera, microphone, biometric sensors. The most beautiful part of sensing is, it is accurate, secure and trustworthy. The mobile sensing applications are quite easy to handle now, as compared with the previous generations, where the sensing with mobile is a cumbersome task, as the mobile sensing applications need to be deployed separately whereas the present day phones are largely compatible and they can support wide range of technologies. The ability of these networks to be to be mobile is the greatest advantage they have, compared to static networks as the accessibility to data is made very easy. This in turn increases their number of applications drastically. They can find applications in houses for security purposes, outside houses in gardens/farms for irrigation, watching over cattle and maintaining the temperature and food for them and vehicles both manned and unmanned.

The diversity in mobile technology is one factor that slows its progress. Diversity can be both in terms of hardware and as the accessibility to data is made very easy. This in turn increases their number of applications drastically. They can find applications in houses for security purposes, outside houses in gardens/farms for irrigation, watching over cattle and maintaining the temperature and food for them and vehicles both manned and unmanned.

The diversity in mobile technology is one factor that slows its progress. Diversity can be both in terms of hardware and software.

1) *Comparing traditional and mobile sensors.*

Today's mobile phones are embedded with diverse sensors which makes the life a lot easier, some of them include the biometric sensors like finger print sensors or image recognition sensors, which helps for secured access so that we don't need to take the extra care by remembering the password which some hackers may hack, the global positioning system sensors for tracking our movement, helping us by directing us to destination etc. All these astounding tasks can be easily accomplished with the mobile sensors, the possibility of self-driving cars, unmanned aerial vehicles and drones, path followers, which are revolutionizing the world, are feasible only with sensors. And one more beauty of sensing is by applying the proper analytics to sensor data, the results obtained can disrupt the economy. Computing everywhere, is like wireless networks placed at home, in furniture, water etc. [1] Sensor based web mix the data of distributed bots, satellites, ships and pricy smartphones and related mobile sensor computing devices All these platforms together will build a rich sensor based platform. Mobile sensing architecture comprises an application that runs on mobile platform, reads the data form the phone sensor or from a sensor network, transmit data to the application.

Consider, from the table 1, few properties where we can compare both mobile sensors and traditional sensors. The computational capability of mobile sensors is very high compared to traditional sensors whose computational power is very low. One more interesting comparison is with storage, where the mobile sensors have high storage capabilities in contrast with traditional sensors which have very low storage capacity. Also the mobile sensors are secure as they follow secure protocols whereas traditional sensors do not.

These mobile sensors in contrast to traditional sensors play an important role as they are widely available on a large scale and the prominence of these sensors can disrupt the world in novice areas in the coming future.

Property	Mobile Phone as sensors	Traditional Sensors
Computational capabilities	High	Very limited
Storage	High storage capabilities	Very Limited
Power	Rechargeable	Battery-powered; needs maintenance
Connectivity	Occasionaly disconnected; Support wide range of technologies	Tied to specific technology
System Action	Can make decisions	No decision making
Data	Raw or Processed	Raw
Mobility	Unpredicatable mobility	Regular/ Random
Security	Security protocol for mobile phones	Limited
Role in Sensor Network	Sensing node, sink, actuator	Sensing node
Ownership	User	Company

Table 1: Comparing traditional and mobile phone sensors

Advantages of mobile sensing

Consider the scenario of traffic controlling systems where most of incident detection [2] is done by fixing sensors and inspecting cameras. The biggest drawback of this system is, it is expensive to maintain and install. To overcome this problem, we can take advantage of mobile sensors to collect traffic data, incident detection can be performed by speed of data collected through mobile sensors, by this way we can cut cost.

Consider the case of activity cautious systems which recognize the pattern from human activities like, by detecting the pressure on the floor or reflection of rays gives an alert and the door can be opened. Also in health applications like fit-bit, where based on the heart beat rate the quality of sleep can be assessed, also while jogging or during any physical activity blood pressure can be checked based on these activity sensors.

C. Why do we need mobile sensing?

Mobile action based frameworks have propelled for novel client interfaces in advanced mobile environments, for surveillance, disaster response management and critical military missions. In these critical scenarios using traditional sensors may not be completely affective and there is a need to bridge the gap in such emergency scenarios with effective system. This gap gave the scope for mobile sensing to show its prominence using the mobile phone sensors along with traditional sensors. Frameworks that distinguish human exercises starting with body-worn sensors further open those ways in our current reality for social insurance applications, wellness monitoring, elder care support, long haul preventive and ceaseless care and cognitive support, also the case of helping physically challenged persons etc. Wearable networks need it for ceaseless functionality.

1) Mobile Sensing System Applications

For example, consider the flood emergency systems where we can use the relying technologies i.e. space technologies, together with mobile sensing and the cloud computing platforms to provide a fast, reliable, flexible and scalable system. To utilize all these platforms to great extent and solve the problem, a novel service has been proposed that uses cloud for computing solutions and mobile sensing by letting users report on status using mobile devices. They can report by text or images or binary values. After this, all the geo-located reports are integrated with earth observations to develop a decision system for pre indicating the users with places by providing cast maps which show the places where floods might affect. The service oriented architecture of Floodis is shown in fig.1, where the architectures is 3 tier based consisting a database of SQL Azure for manipulating and storing huge volumes of data, business logic objects and the user interface for interacting with users through this. The object relation mapper used is hibernate and also uses Microsoft azures cloud service as the layer of service.

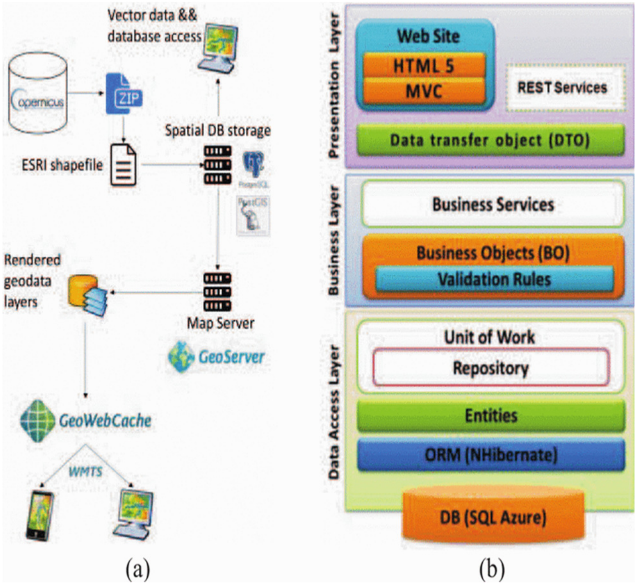

Fig.1. Floodis Architecture

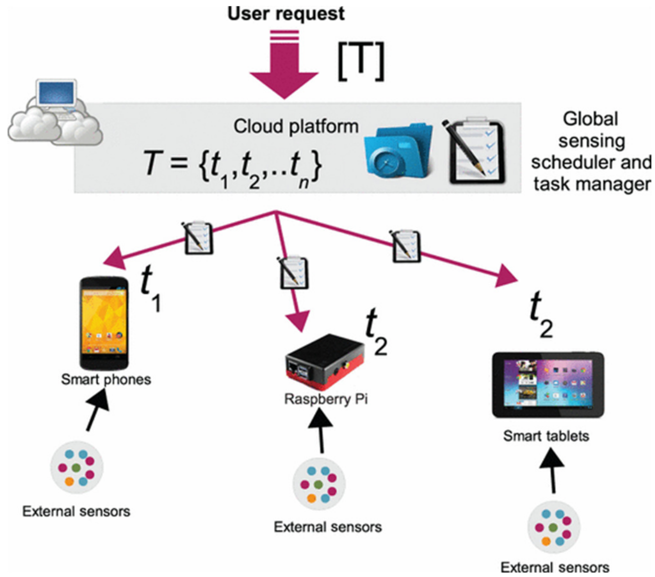

Fig.2. IOT Cloud Sensing Platform

Azure SQL database collects all the textual info, messages and uses the Azure storage service for logs. The web services are implemented in Representational State Transfer Style. The format for data transfer is Java Script Object Notation, the authentication is maintained by using Oauth2.0 protocol, the controller followed is Model View Controller style. The Floodis is a novice system which can help in a sensible way to solve the problem of floods, where the normal traditional sensors may not be that effective. Use of this mobile sensing strategy might yield the fruitful results. In turn, the cell phones forward this available data to access points (third layer), such as cell towers, and the data are uploaded into a centralized database server [3].

One more key area which also contributes a significant portion to sensing is Internet of things, where we have large amount of sensor data generated form mobile phone sensors, which can be analyzed in different aspects and also using the big data technologies the data can be considered as an important resource and can be played in many ways. As pay as you go infrastructure is gaining prominence, [4] cloud integrated mobile crowd sensing platforms capable of capturing sensor data, on demand based conditions can be applied as enforced by customers. Consider a use case like monitoring the air pollution in cities, the portion of pollution caused by moving buses for this communication devices are fitted into the bus and using the bus's wireless fidelity connection the data can be pushed onto the cloud as in fig 2.

D. Mobile Sensing services

1) Concepts

Mobile phone sensing system which are in an emerging phase have the large scale wireless sensing capability and they also minimize the need for setting up the wireless network for collecting the sensor information in IoT domain. Mobile sensing can be implied on numerous scenarios like mobile-health systems, environmental monitoring, vehicle ad hoc network etc. In mobile sensing systems, smartphones are sensor devices for tasks, the sensing systems can be applied.

2) Mobile Host Sensing as a Service

Mobile Host is dual or hybrid mobile device capable of accomplishing two tasks like consumer and provider. [5] The sensing of data through embedded web services, and by taking the advantage of cloud services, smartphone can provide sensing as a service to large number of clients. Sensing as a service is introduced with the purpose of enabling users to share their sensing data to consumers as in fig 3.

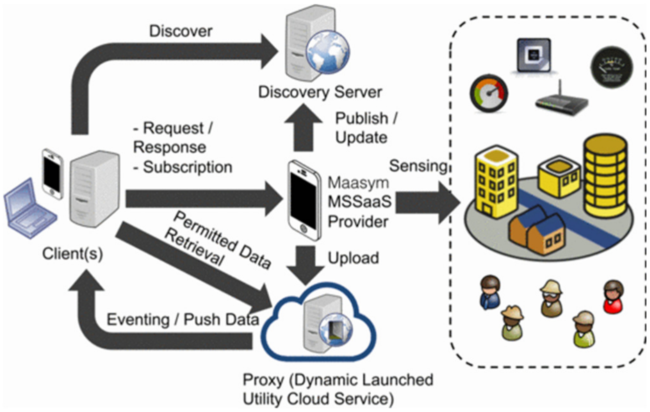

Fig.3. Host Sensing Architecture

Above figure depicts the sensing as a service architecture, where mobile host utilizes its inbuilt functionalities. Architecture uses Amazon EC2 as utility cloud for data delivery.

3) Mobile participatory sensing

This is a transit kind of real time service using mobile crowd sensing where the data collection helps for making live updates for necessary communication. *Architecture*: The server used is XMPP server, and a mobile client application, and a gets analytic module. Gets emulator enables live feedback data from the user are broadly 4 types of sensor platforms as follows:

E. Cloud enabled sensing

The popular and well provisioned smartphones utilized the cloud resources for collecting and processing sensor data generated by smart phones and hence we have interesting applications like real maps and advertisements. [6] The good point of cloud based is to cognizant and coordinate the sensing and content succumbing from wide variety of mobile devices. This is important to every application as they can achieve significant results like saving the bandwidth. Cloud enabled sensing enables the sensing to a large context and also provides the added benefits as the cloud is enabled, the large scale data can be computed in a short time and also in a limited time, the user base can be easily checked. The important part of the cloud is load balancer which balances the sensing servers based on the requests generated, cloud user can see the whole thing as service. General architecture of sensing service in cloud is depicted in the figure 4.

1)Uses of cloud enabled mobile sensing:

Limitations of wireless sensor networks among many things like memory space, computation capability, network of communication and elastic scalability and finally efficient management of large number of sensor networks are critical issues to check. These factors lead to finding of high computational capable and magnificent performance and huge storage capable and the real time processing compatible infrastructure like cloud.

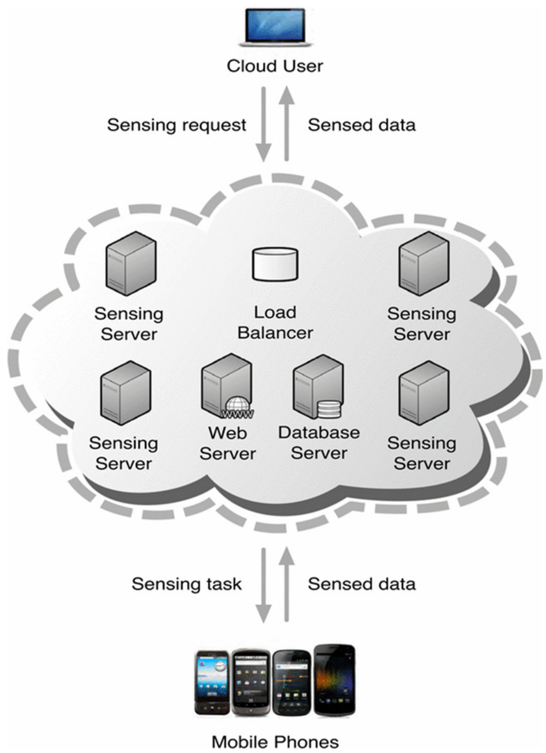

Fig. 4. Sensing as a Service Cloud

The cloud is a solution to majority of the problems with the quick fix of computational, storage-based and service based and easily accessible to any one with the internet and also cheaper. [7] Sensor cloud gained prominence in current scenarios as it can provide a cheap, reliable and compatible infrastructure. Cloud based mobile sensing can take the applications across wide range of devices, it can have a great impact on energy and significant impact on bandwidth costs by following the strategy of pull based approach, where the sensing work is adjusted using different phones, by scaling the applications to a large extent, avoiding privacy leakage using a secure cloud and developing the common platform application programming based interface

II. Mobile Sensors and Classifications

A. Architecture

1) Layout

The purpose of sensor cloud is to virtualize the physical sensors on the cloud platform. The first stage contains the virtual sensors of various types, grouped dynamically, with their data used as and when an application demands. In some cases, an application might require more than one sensor data, which is when cloud processing comes into picture as the second stage. It takes input data from multiple sensors and processes it using a relevant algorithm and gives the output to the next stage. The output from second stage is used to determine the necessary results or conclusions, for the application, in the third and last stage.

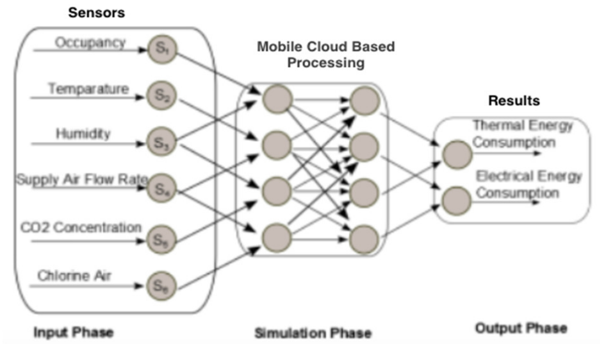

Fig.5. Mobile sensor layout [8]

2) 3-layer architecture

The purpose of the architecture is to combine the mobile network and sensor network with the cloud computing. The 3-layer architecture is proposed to understand the layout and life cycle of the mobile sensing cloud.

Layer 1, as seen in Fig.6, is a wireless sensor network, where different kinds of application specific sensor nodes capture the data and transfer it to a receiver node, like, accelerometer, light sensor, magnetometer, temperature sensor, humidity sensor. The receiver node, also called as sink node, receives all of the sensed data, which can be in the form of text, audio or video, from sensors and stores it in its external memory. The stored data is then sent to layer 2.

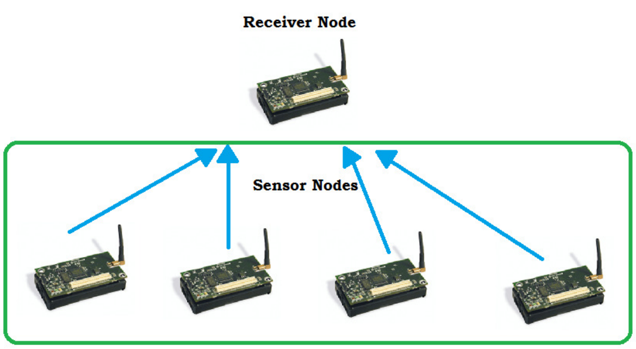

Fig.6. Layer 1 - Wireless sensor network

The layer 2 is mobile network layer. Once the sensor data is received by the mobile device in this layer, it sends them to the base station (BS) it is connected to. Mobile device can be a smartphone, tablet or laptop. The base station then sends the data to a remote server. When indoor, the device can connect via Home node BS (HNB) or a light weight AP (LWAP), which provides faster connection than a BS. HNB forwards data to remote server, while if connected WLAN via LWAP, then there exists a local server with a cloud environment. From the local server, sensor data is uploaded to remote cloud server.

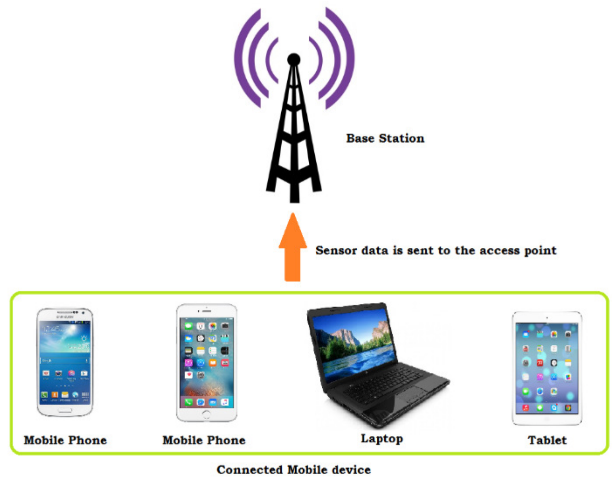

Fig.7. Layer 2 - Mobile Network layer

The layer 3 is cloud computing layer. In this layer, the remote server is present where the data is stored, processed and accessed inside the cloud. Now users can access the sensed data present on the cloud anytime from anywhere using a mobile device. [9]

Fig.8. Layer 3 - Cloud computing layer

The services offered in the cloud are:

Infrastructure as a service (IaaS): Storage and computing abilities are provided on an on-demand and pay-per-use basis. Features offered are Elasticity and Scalability, which is controlled by the customers. Types of resources offered are virtual machine, server, network, storage and firewall. IaaS offers storage and computational capabilities for the sensor data sent to the cloud.

Platform as a service (PaaS): It provides tools to develop, debug, test and deploy on an on-demand and pay-per-use basis. The resources offered are database, web server, operating system, programming language execution environment. To process the stored sensor data to derive any useful information, PaaS provides the crucial resources required to perform the task.

Software as a service (SaaS): It offers various application and process oriented service, that run on the cloud. Users can use this either as on-demand or pay-per-use basis. To access sensor data in cloud, application software is necessary to provide user interaction, which is provided by SaaS.

B. Types of Mobile Sensors

Depending on the type of data collected by the sensor, they are classified into various categories. The most prominent ones are discussed in this section along with some example real-time use cases. [10]

1) Environmental mobile sensors

How they work?

By monitoring strain, light, sound, temperature, barometer sensor, it is possible to detect emergencies like earthquake, volcano, Tsunami [11] or predict disasters and provide early warning by observing Earth using GPS data, etc. [12] Data from this sensor can be combined in parallel with those from healthcare sensors to prevent casualty and agriculture sensors to avoid the damage by the hazard or weather. Also toxic gases' level in the air is measured by some sensors.

The measurement of these data are done predominantly by 3 methods: chemical interaction, spectroscopy, and ionization There are mobile and web applications that display air quality based on already recorded data. We are going to discuss about the kind of sensors that are portable and personal or which can be used with smartphones, making them mobile, real-time and cloud based. These sensors are usually Wi-Fi or Bluetooth enabled, making precise data collection through crowdsourcing possible for future use. Since we are discussing about sensors measuring different data, we have chosen the best available sensor in each section.

State of the art:

AirBot: Developed by Carnegie Mellon University to help Asthma patients. It measures the level of airborne pollutants in the environment. This device performs this task by counting the number of particles in the air. Six prototypes have already been built and is ready for release. Its pocket-size feature is the first of its kind to come to the market for personal use. The drawback being that it does not measure basic air qualities like humidity, temperature.

WaterBot: Also developed by Carnegie Mellon University, it tests the water quality. When one end of the device is immersed in a water body, it updates the pollution data onto a web interface for easy viewing for awareness for people living around the water body. It uses ZigBee installed module for the upload. Its important feature being its high rate of data collection, allowing it to detect events that cannot be detected by any other kind of sensor.

Sensordrone: It is a sensor that can sense multiple data from the environment including but not limited to temperature, gases and humidity. Since it pairs with the phone, we can run specific apps to test for information required by the user. It only measures basic air qualities.

Lapka: A set of a few environmental sensors that can be plugged into the phone to measure humidity, radiation, nitrates in food, electromagnetic waves. From basic to advanced air quality parameters, it measures all of it.

Sensaris: It is a wearable wrist watch that measures air quality. It transmits the measured data to the mobile phone via Bluetooth. The advantage here is, it can be worn at all times, unlike other devices that have to be plugged in to power it or data upload.

TZOA: A small sensor that can be clipped to our clothes to measure atmospheric pressure, air quality, temperature, humidity, UV exposure and ambient light. The data is sent to the smartphone, which uploads it to cloud for public availability.

AirBeam: It is a wearable device measuring the air quality. Light scattering is the method used to measure the tiny particles that enter our lungs. It connects to cloud via a smartphone application. The data is then publicly available for other people to view and decide on polluted and clean areas.

Comparison: Out of all the sensors, except WaterBot, every sensor measures air quality. Out of this Lapka, Sensaris, TZOA, AirBeam measure advanced air quality parameters too. Hence out of all these, the wearables are preferred for the easy way to carry around. With the smallest size, intuitive design and decent price TZOA wins the competition.

2) Healthcare mobile sensors

How they work?

With today's technology, biological data (heart rate, blood pressure, temperature, Blood sugar) from human body can be monitored by sensors in wearable devices and loaded into the cloud for long term analysis. Filtering mechanisms are used to filter out the noise data. This data is immensely useful when it comes to patient monitoring, seeking help at the right time, etc [13]. This data is either displayed on a smaller personal digital assistant display or a larger device in the hospital for the doctor to take a look. However, these wearable devices must have a Bluetooth wireless interface to be able to connect to smartphone devices, which acts as a bridge between the remote server and the sensor. Fitbit, Apple watch are a few examples of wearables that monitor health parameters.

Based on the kinds of sensors used, the types are: Temperature sensors, glucose sensors, ECG sensors, Blood oxygen sensors, pressure sensors. They can be *stickable strip*: Wearable skin sensor from KTH Royal Institute of Technology, Sweden, which based on placed on which part of the body, it measures data like Electrocardiography (ECG) on chest and brainwaves (EEC) on the skull, *wearable:* GoogleX's smart contact lens that measures glucose level in tears, *implantable:* blood analyzer and brain activity sensors, *invasive, non-invasive:* Blood monitor or *digestible:* biomedical sensor from Proteus.

State of the art:

Apple Watch uses the technology called photoplethysmography to measure heart rate. Photo diodes along with green LED lights is used to detect amount of blood flow. Blood flow is maximum when heart beats and minimum in between, so blood absorbs green light, using which heart rate is measured.

Gyroscope and accelerometer is available in most smartphones today, whose combined data is used to measure the body movement for conditions like Parkinson disease. The former measures stability while the latter measures movement in terms of steps or distance walked and calories burnt. All these data are uploaded to the cloud, where it is encrypted and only available to the user and sometimes to the doctor. The top wearable fitness brands are for various parameters in the Table 2 below. It is worth to mention that pebble is the pioneer in the smart watch market.

	Apple watch	Pebble watch	Garmin Vivosmart	Fitbit charge 2	Misfit Ray
1	✔	✔	✔	✔	✖
2	✖	✔	✔	✔	✔
3	✔	✖	✔	✖	✖
4	✔	✔	✔	✔	✔
5	✖	✖	✖	✔	✖
6	✔	✔	✔	✔	✔
7	✖	✖	✖	✔	✖
8	✔	✔	✔	✖	✖
9	18 hrs	6 days	5 days	7 days	6 months
10	✖	✔	✔	✔	✔
11	✔	✔	✔	✔	✔

1. 24/7 heart rate monitoring, 2. Sleep, 3. GPS, 4. Steps, 5. VO2 Max (Scientific fitness gauge), 6. Touch Display, 7. breathing training, 8. Swim, 9. Battery duration, 10. Android Compatibility, 11. iOS Compatibility

Table 2: Health Monitoring Wearable Sensors comparison

3) Mobile sensors for transportations and smart city

How they work?

With existing GPS and additional sensors, we can track vehicle's current location, total travelled distance, fuel level, driver's alcohol intake, predict arrival time, etc. [14] When this data is available on cloud, a centralized web platform can be used to display the above measured parameters, which are also hence easily accessible by the vehicle owner.

Different sensors are involved in IoT, resulting in heterogeneous data, which is very helpful in building a smart city. Hence, sensor networks will play a crucial role in the future smart cities. [15] [16] Basically self-driving cars and traffic signal that adjusts based on traffic flow are just the beginning of a smart city. Few other concepts that have been proposed are explained below.

A smart station is a place where people are provided with variety of transportation services. Availability of real-time information of traffic, parking conditions, warning of any incident and alternative transit options. Use of sensors to monitor as well as improve mobility, emissions and safety. Most important factor in connecting everyone in a smart city, is the traffic conditions. So we will discuss about various ways to measure the same. Also it should be noted that all kinds of sensors discussed before come together when it comes to smart cities.

State of the art:

Intelligent traffic system (ITS) is the integral part of a smart city. The part more focused currently is the traffic monitoring systems. Video recognition and inductive loops is the currently used to collect traffic data. While the former fails to work in extreme weather conditions, the latter requires the road to be cut off and interrupt traffic. Also, when it comes to large scale deployment, this solution proves to be expensive. Hence for scalability, lower cost and performance, we choose WSN (Wireless sensor network) as the better alternative.

In order to use WSN, commonly used method is to detect the vehicles. Out of the kinds of sensors used for vehicle detection, magnetic sensor stands strong through rough weather conditions too. The problem however is the high noise on cluttered roads. We can use a FIR (Finite Input Response) to smooth out the signal received before applying a threshold to identify a vehicle. Again the threshold can either be pre-defined and fixed or dynamically changed, using an algorithm, with respect to the environment conditions. Also vehicle speeds need to be detected, for which multiple sensor nodes are placed at fixed intervals, along the road, to measure speed. Another cost effective solution for this is use of acoustic sensors that measure sound. However, due to high noise conditions on road, there is a requirement for a complex algorithm on order to get useful information from acoustic sensor data.

With the upcoming technology trends, mobile sensor seems to be an intuitive solution, to provide real time data, in comparison with stationary WSN discussed above. Autonomous cars have gained huge attention in the research field. Many companies are working towards a fully autonomous functional car for mass production. These kind of cars are equipped with huge number of sensors. It is the large untapped resource for a smart city. With sensors on taxis and personal cars, the amount if data and information available could be overwhelming.

The kinds of sensors used in autonomous vehicles (AV) are classified based on the kind of function performed. The Input for the Self-driving cars is typically the Perception/Sensing System which includes Sensors like Lidar, Radar, Cameras, Ultrasonic, etc. The sensors indicate the presence of obstacles in the environment around the car.

RADAR and LIDAR provide adaptive cruise control (ACC), a function where the car's speed is adjusted with respect to the car in front of it and also traffic conditions in that location. There are stereo vision cameras that helps the car to 'look' at the road. The data from camera can be used to capture image of a location used in detecting or tracking applications, condition of a location, detect slippery roads due to rain. Wheel encoders provide a data as to where the car is positioned. Night vision sensors use infra-red light sources to view the road under less illumination.

The Global Positioning System (GPS), though not a sensor by itself, provides huge amount of data. It provides the position and time along with stop sign and other sign locations on road. A position sensor data can help in self-parking, Rain sensors detect rain and operate the windshield, fogging sensor detects and maintains the temperature and humidity within the cabin. Pressure sensor measures barometric pressure, temperature sensor provides weather data. Ice detection on roads using tire to road friction ultrasonic noise. There are other sensors to measure driver safety, speed, Diagnostics.

The AV only combines all the sensed data to get a picture of the road and its condition. But the data from individual sensors can be uploaded to cloud and available for the drier, third-part drivers, research and analysis purposes. With this information location of traffic accidents, road work, rerouted roads, environment conditions, health of the driver can be known and used in a smart city landscape. In the fig.9 below, the sensors used in an AV is shown.

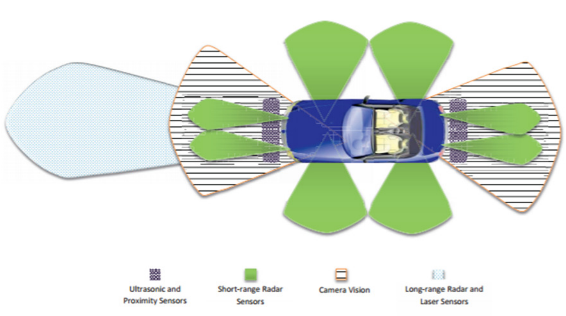

Fig.9. Vehicle based mobile sensors [22]

Urban vehicle sensing information has already been deployed to various platforms [22]. *MobEyes* monitors and stores data in cloud and advertises it for use by third party users. For example, license plate information of a car sensed by another car can be used by the police. *Vehicular Information Transport Protocol (VITP)* is another platform that allows user to query a location for data and data available is routed back from the location. All communication is carried out via intermediate cars.

CarTel is a platform unlike the ones above which requires a vehicle-to-vehicle communication. It is a web based platform that collects, processes locally and uploads to the servers through internet. It is a delay tolerant platform. *Pothole Patrol (P2) system* aims at road monitoring and detecting and reporting location of potholes. This is made possible with help of GPS and 3-axis acceleration sensors. *CarMote* is another platform that focuses on monitoring road features.

WreckWatch [23] is a mobile client-server application used to detect road accidents. GPS, accelerometers and compasses in a smartphone are used to detect an accident and the mobile internet is used to upload to cloud. It also notifies emergency responders along with any images or video gathered from the bystanders. Built using Android for client and Java/MySQL with Jetty and the Spring Framework on the server.

ParkWhiz: shop for parking and save money, *ParkingPanda*: find a parking spot near any event, *SpotHero*: reserve a parking spot with the phone and get good discounts, *Airport Parking Reservations*: Find spots in an airport at discounted price.

4) Other important sensors

Wildlife monitoring is used to monitor sanctuaries, forests and endangered species. Tunnel monitoring where the light levels inside a tunnel are constantly monitored to avoid accidents and save energy in real-time. Agriculture and irrigation control uses air, temperature, CO2 concentration and soil moisture sensor data uploaded to the cloud, to monitor health of the crops in the field by the field owner or farmer. Sensor cloud platform is used in Telematics to deploy smooth transmission of information to long distances.

C. Existing applications

A number of existing services, based on sensor-cloud, are introduced and compared here. [17]

1) Nimbits

It is a free social service, where users can store and access sensor data on the cloud platform. Text based, XML, JSON or GPS values can be fed into it by having a new data point in the cloud. It also provides data processing, data compression and alert management system on the sensor data using simple algorithms.

2) Pachube Platform

It is known for being one of the first to make it possible to connect web and sensor data. It provides a real-time platform to store, access and discover sensor data from multiple sensors including environment and healthcare sensor data with the help of an intuitive website and a free usage and several interfaces to manage the application on the cloud framework.

3) iDigi

It is a machine to machine PaaS, which minimizes cost and increases scalability to combine enterprise applications with devices. It uses iDigi Dia software to simplify the connectivity of remote devices to the applications in order to connect, manage and move sensor data across the platform.

4) ThingSpeak

An open source IoT based application used to store and access data from mobile devices using LAN or HTTP via the internet. Processing of numeric data like summing, median, rounding, scaling is also available. Sensor logging and location tracking applications can be implemented in this intuitive platform which features JavaScript based chart and time-zone management.

Although these services provide a platform to store, access and process data from sensor, they have not taken security and interoperability into account.

III. MOBILE SENSOR NETWORKS AND SERVICE PLATFORMS/FRAMEWORKS

A. What are mobile sensor networks(MSN)?

Mobile sensor networks are sensor networks that have their sensor nodes mobile. It consists of various nodes which have a wide variety of computation capabilities. They can vary from sensing to communication with many other connected devices and they also have locomotion capabilities.

The ability of these networks to be mobile is the greatest advantage they have, compared to static networks as the accessibility to data is made very easy. This in turn increases their number of applications drastically. They can find applications in houses for security purposes, outside houses in gardens/farms for irrigation, watching over cattle, maintaining the temperature and food for them and in vehicles both manned and unmanned.

The diversity in mobile technology is one factor that slows its progress. Diversity can be both in terms of hardware and software and hence developing standards is key to the success of mobile sensor networks.

1) Motivations

Mobile sensor networks are very versatile and are much smaller that their static versions. Hence they find many applications in the surveillance and monitoring industry. This makes them deployable in environments that are not fit for humans to monitor or analyze certain aspects of the environment. It also makes it possible to access details of environments that are very far apart. For example, if a person wants to take a look at the interiors of his house in another state or watch over his farm, this can be made possible through mobile sensor networks.

Consider, a scenario involving a hazardous materials leak in a damaged structure. We would like our sensor network, whose nodes are equipped with chemical sensors, to rapidly deploy throughout the environment and return real-time data indicating the location and concentration of hazards [18]. These kind of applications can make us proactive and help prevent, monitor and plan for many such situations in advance.

Another advantage of MSNs is that they are always connected to the network and hence they can return real-time data that can be very accurate for timely decisions. They also deal with very small data sets and hence it helps in quick delivery given a fact that they are constrained in computation resources.

2) Advantages

There are many advantages and benefits in using mobile sensor networks that can make the existing process more efficient and smarter.

Coverage area

One such advantage is the coverage area. Unlike static networks the nodes in mobile sensor networks can be repositioned. This helps them to cover more geographic areas and collect data in a real-time manner. Static networks may not be able to cover some areas and sometimes if there are any disconnections from one node then there is a probability that a large part of the network could be unreachable.

Power Consumption

Another advantage of mobile sensor networks is that they are efficient in power consumption. The power consumption can be controlled in a mobile sensor network mainly due to the fact that the nodes are mobile. One such way of doing it is by choosing a better path to access nodes. For example, going for the shortest path to reach a particular node. Another technique that can be combined with the shortest path way is to choose nodes that have higher power capacities compared to nodes that have lower battery power left.

Connectivity

Connectivity is a good advantage of mobile sensor networks too. They are able to remain connected to the network longer that static nodes as they have better algorithms DARA and PADRA [19] that help analyze the current task requirements and allot the best possible network by relocating the nodes in the network.

Handling Load Efficiently

Handling load in an efficient manner is possible in mobile sensor networks. This load balancing advantage is made possible due to the mobility of the nodes, which can help balance the data traffic across all nodes evenly to maximize performance. Some nodes can act as mobile relays this can help respond back to the caller much faster that traditionally having to hop over many nodes to fetch data. This has a huge performance gain and increases the throughput of the system. Mobile sensor networks can make deployments also easy as the nodes are mobile and do not have an extensive cost on relocating nodes to meet the deployment requirements.

B. MSN Classifications

Mobile sensor networks can be classified on a wide variety of categories some of them are protocols, architecture, topology etc.

2) MSN Architecture

Mobile sensor networks have three types of architectures as shown in Fig 10. Flat layer, two-layer and three-layer architecture. The Flat layer architecture is also called one layer or planar architecture. The devices in such a network are heterogeneous in nature, i.e. they can be mobile or stationary. Here the mobility and overall coverage and be a little lower compared to two and three layer architectures. Two layer architectures have sets of sensor nodes; one set would be mobile whereas the other would be static. Here the mobile sensor nodes would have higher processing power. They will be able to communicate over longer distances. They are capable of extending the coverage of the entire network by moving around to achieve maximum coverage amongst all the nodes in the network.

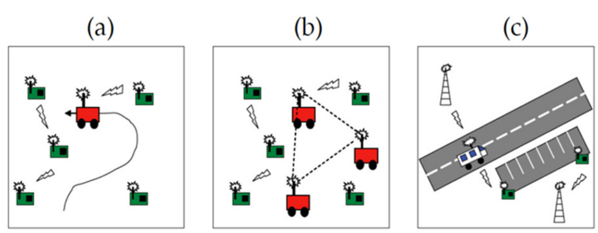

Fig. 10. (a) 1-Layer (b) 2-Layer (c) 3-Layer architecture

Like the other 2 layers the three-layer architecture is also a heterogeneous senor node network. But apart from the mobile and static nodes, it has a third layer of access point nodes. This structure helps it in wider areas of coverage. It can also cater to many applications at the same time. The sensor network (first layer) broadcasts availability updates to compatible mobile devices (second layer), such as cell phones or PDAs that are passing by. In turn, the cell phones forward this availability data to access points (third layer), such as cell towers, and the data are uploaded into a centralized database server [20].

This broad level of classification can also be further divided at the node level. This is done base on what roles they are assigned or perform. Base on node roles they can be classified into Mobile Embedded sensors, Mobile actuated sensors, Data Mules and Access Points. Mobile embedded sensors are attached to a moving object so their motion is basically controlled by other moving objects. Mobile actuated sensors can increase the coverage area as they can move about the entire sensing area. Data mules are mobile too and travel larger areas as their jobs are to collect data from other sensor nodes and deliver it to the sink/base. Access points are sensor nodes that help extend the coverage area of already existing networks by filling in any network failures or node failures. They can connect one network with a totally unknown network and this can go on and on, making their reach have no end.

The mobile sensor network architecture is in line with the OSI model which consists of application layer, transport layer, network layer, data link layer and physical layer. In order for the mobile nodes to work efficiently and maximize performance of the network there are 3 more layers that are added and are called cross layer planes. The 3 layers are Task Management plane, Mobility Management Plane and Power Management Plane as in Fig. 11.

The Mobility Management Plane can detect any kind of movement in the sensor nodes. Additionally, incase its neighbors need to be communicated with this is also done by the mobility management plane, as it tracks adjacent nodes too. Gauging the power consumption or capacities is done by the Power Management Plane. This plane also helps in deciding if a task is too heavy for a particular node which would be more in time and power. This helps in distributing equal power consumption across nodes. The Task Management Plane helps in managing tasks across the sensor in the network. It helps in scheduling tasks so that they are started on the right nodes for the faster throughput. It also manages inter-task communication so as to help one task start on a node immediately after its previous task finishes keeping in mind its closest neighbors so as to achieve maximum performance.

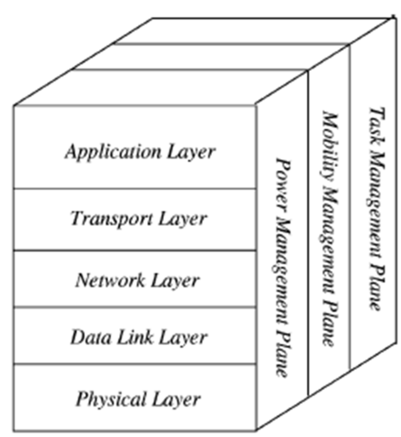

Fig. 11. Cross layers

The transport layer helps ensure all communication is done in an efficient manner with minimum loss of packets, high reliability and without causing any bottlenecks. It makes sure that these properties are taken care of for both upload from user to the sink and download from sink to user. The protocols that the transport layer uses help it in ensuring these quality factors. It has mechanisms to ensure loss detection and recovery too while communicating with other nodes in the same network or with other networks.

The network layer takes care of routing of between the nodes. It also makes sure that routing is done keeping in mind the computing power of the nodes such as memory, power etc. The challenge here is that a different routing mechanism much be chosen from application to application. The protocols for this layer is mainly divided into hierarchy and flat routing.

The data link layer helps in ensuring reliability of point to point to point to multi-point due to failures that may arise form co-channel interference or multipath fading and shadowing.

3) MSN Protocols

The routing protocols can be divided into categories, Position based and Non-position based protocols.

Position based protocols have the position of the nodes with them so as to minimize message transfers amongst nodes. The location of other nodes helps identify the closest nodes or shortest paths to deliver messages. This also requires an initial transfer of messages to discover the location of other nodes. This initial transfer can help prevent a whole flood of messages later on, thus reducing the overall latency. Some of the protocols are Greedy perimeter stateless routing(GPSR). It uses sends the location of the nodes in a packet and if it fails it uses face routing. MANET protocols are not feasible for MSNs because they have relatively fewer nodes and also higher capabilities. Distance Routing Effect Algorithm for Mobility (DREAM) is a protocol that sends all data in a particular direction. This mechanism is called directional forwarding. It manages a routing table and this could get larger as the number of nodes increase. There are 2 energy efficient protocols called Geographical Adaptive Fidelity (GAF) and Geographical Energy Aware Routing (GEAR). GAF forms a grid which consists of many cells. Each cell consists of many nodes and keeps only one cell awake so as to conserve energy. GEAR calculates the cost of reaching a nodes neighbors. Through this mechanism it reduces the energy used. Mobility Aware Routing or MAR is a routing protocol that assess the mobility of nodes in the networks. A mobility factor is calculated based on how much a node moves. This is done to identify a head to form a cluster. Many such clusters exist that are allotted heads based on the least mobility of the node. This is not energy efficient as it doesn't look to save energy in all the communication and also doesn't account for the packet loss that occurs. The short comings of MAR are overcome by the protocol called Geographic robust clustering (GRC).

Non-Position based protocols do not require to check for the location of the nodes hence reducing an extra message transfer. Some non-position based protocols are direct diffusion, LEACH SPIN, DECA and DEMC. DECA or Distributed Efficient Clustering Approach is a protocol in which all the nodes hold a list of neighboring nodes and their weights based on connectivity and energy. Through periodic messages a node is selected as a head by itself or selects another node as head. The downside in this protocol is that the transmission of messages to identify nodes is an overhead which heavy of energy and the due to the mobility of the nodes there could be packet loss between clusters. DEMC or Distributed Efficient Multi-Hop Clustering is a better version of DECA as it involves the nodes to send a message only once to identify itself. This happens once in a cluster phase. This prevents message overloading in the network and eases up the head selection. There is no table for head lookup too.

In the transport layer there are protocols for upstream and downstream. The upstream ones are DSTN, ESRT and STCP. The downstream protocols are PSFQ and GARUDA.

STCP stands for Sensor Transmission Control Protocol and is used ensure reliability. After the initiation packet is sent from the node to the sink, the sensor node waits for an ACK. If there is a failure in any packet delivery, then an NACK is sent by the sink. PORT is another protocol and stands for Price-Oriented Reliable Transport Protocol. It is a downstream protocol. It measures message delivery through 2 methods- by measuring the total number of transmissions and using end to end communication cost. The communication cost helps in deciding if there is a network congestion. Increase in cost signifies congestion has occurred. PSFQ or pump slow fetch quick is also another protocol for the downstream communication. Pump, fetch and report are 3 functions that are used. The pump operation has timers that help decide where there was a failure. Based on this decision a fetch is issued in case of failures. A report operation is issued to provide a feedback to the issuer.

In the network layer the protocols are divided into hierarchical and flat routing protocols. The hierarchical protocols consist of GAF, ASCENT, CLD, PEAS, SPAN and LEACH. LEACH is the most widely used protocol. It is a clustering based protocol that utilizes randomized rotation of the cluster heads to evenly distribute the energy load among the sensor nodes in the network [21]. In the data link layer, a MAC protocol is used to ensure low latency, high efficiency and reliability. This is explained in detail in [22]. The physical layer uses IEEE 802.15.4 standard. This is low cost and power consumption standard which is ideal for devices on a mobile sensor network as they are constrained in terms of resources.

3) MSN Protocol Comparison

There are many protocols for mobile sensor networks as seen in the previous section and there are many metrics too to gauge them. The metrics are network lifetime, packet loss, control packets and delivery ratio. Network lifetime is calculated based on the energy consumption of a node in one round of communication. Packet loss is the percentage of lost packets to the number of sent packets. Control packets is the packets sent for operation. An average number of control packets are used as a metric. Delivery ratio is the total packets received to the total packets sent. A comparison of the major protocols on these factors can be seen in table 3.

Protocol	*Network Lifetime*	*Packet Loss %*	*Avg. number of control packets*	*Packet delivery ratio*
DECA	Medium-Low	High	High	Low
DEMC	High	Medium	Low	Medium-Low
GRC	Medium	Medium-low	Medium	High
MAR	Low	Low	Medium-Low	Medium

Table 3: Protocol Comparison

4) MSN Types

Mobile sensor networks are of many types. This is due to the fact that the nodes in the network are mobile. They can be deployed anywhere on land or water or a combination of environments. The major mobile sensor network types are, Terrestrial MSNs, Underground MSNs, Underwater MSNs and Multimedia MSNs.

Terrestrial MSNs are those that have their sensor nodes on the ground. Terrestrial MSNs themselves can be of 2 types,

structured and unstructured MSNs. In structured MSNs the sensor nodes are deployed in a fixed manner like a grid. This is done to make sure that the connectivity is at its best between the nodes. It also helps in giving the best possible throughput as the nodes are placed away from obstructions and most effective distances from each other. In unstructured MSNs the nodes are place in a random fashion unlike the structured MSNs. To extend the power of terrestrial MSNs they are fitted with solar cells. Underground MSNs have their sensor nodes placed below the ground. This makes many operations difficult for example, maintaining the nodes, troubleshooting faulty nodes, optimizing signals from them etc. It also makes recharging the batteries difficult which is very important for these sensors as they have limited battery power. Underwater MSNs are similar to underground MSNs except for the fact that they have the sensor nodes place inside water as show in Fig. 12.

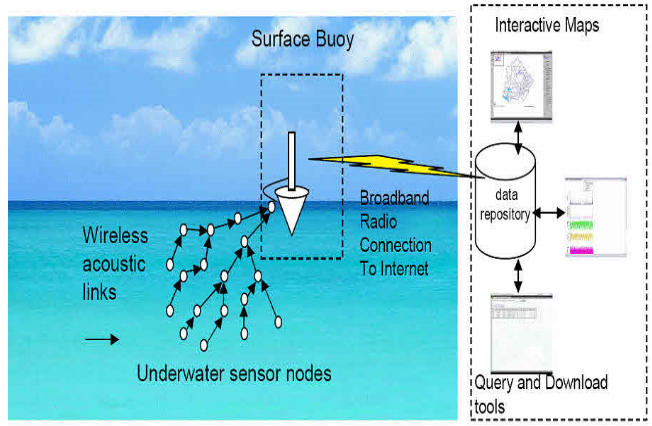

Fig. 12. Under Water MSNs

The collection of data from these nodes are done with autonomous underwater vehicles. They face the same issues like underground MSNs like battery and connection interferences. Multimedia MSNs are sensor nodes with capabilities for video, audio and imagery. They are generally used for surveillance and monitoring purposes and are fitted with cameras and microphones. These networks require high bandwidth networks and good compression techniques to work efficiently which is a tough task to achieve.

C. *MSN Service platforms/frameworks*

4) Concepts

Mobile sensor networks comprise of nodes that perform a variety of functions from sensing to message transfer to processing and also cluster computations. These tasks all need to be done keeping in mind the limited amount of power consumption, bandwidth and the latency of the application. In order for such features to be implemented the platform selection of MSNs too should be done wisely. There are a variety of devices that operate in MSNs for example custom small sized silicon chips, cells phones, laptops, wearables wireless cameras and microphones, motion sensors, temperature sensors etc. These variety of devices need to be wisely placed across the network where they perform best. Each of these devices can be divided into different platform areas as shown in Figure 13.

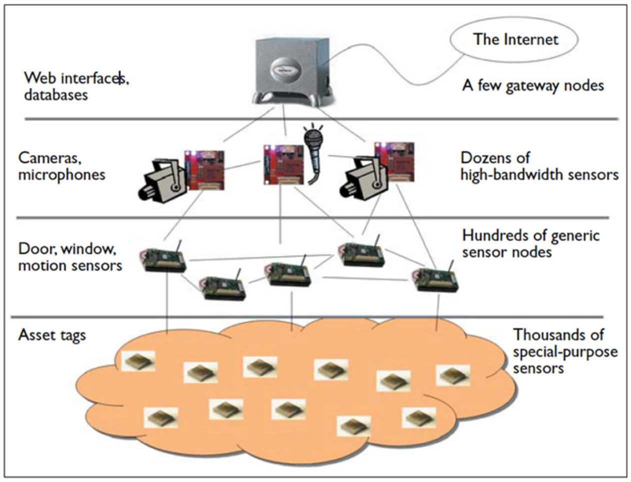

Fig. 13. Security sensor network with multiple platforms

The figure shows a highly sophisticated security system of multiple sensor devices some that monitor motion and some that capture video for any intrusions. These send their data to the main gateway so that everything can be visible to the user or guard in real time.

5) MSN Challenges

Mobile sensor networks have been very advantageous compared to the static sensor as we have seen but they have their shortcomings too. There is a tradeoff of the features that MSNs have in terms of power, energy, computing power, time, etc. Different networks have different priorities and hence the MSNs are configured differently as per their need. Some of the challenges are:

Mobility Related

Mobility brings in a lot many challenges to the MSN networks. Due to change in location of the nodes a lot more power and time needs to be put in to efficiently send messages through the network.

Power consumption

Power consumption in MSNs is much more compared to the static networks. The is extra power consumed due to mobility. Every time a node changes it location it needs to broadcast its new location and notify all other nodes of its change. In some protocols it needs to recalculate the head of the cluster. Such scenarios could lead to failures which require additional power. Due to this the nodes are given a higher power capacity. Many networks are solar operated so as to help recharge the nodes continuously.

Topology changes

The topology of the network also changes very often. This happens mainly because the nodes are mobile. Due to this many calculations have to be done again. These cannot work on existing wireless network protocols. Due to this more power and bandwidth are required.

Communication with sink

Communication to the sink is another challenge in MSNs. This is because in some network the sensor nodes need to send back the data collected to the base station or sink so as to further process the data. This causes an overhead in the network. Some networks reduce this overhead by making the sinks mobile. This way the sinks move about in the network and collect data from the different nodes.

6) Types of MSN Platforms

There are broadly 4 types of sensor platforms, they are as follows:

Special Purpose Sensor platforms

There are special purpose sensor nodes that are custom made for a particular purpose such as to fit in small unreachable areas or be underground or underwater. Sometimes nodes need to be made so that they are not very expensive and still produce the expected output. An example of special purpose nodes is the Spec 2003, which is very good for low power tasks.

General Purpose Sensor platforms

General purpose sensor nodes are nodes that are highly flexible. They can connect to a variety of other sensors and can perform tasks for a many requirements. Some examples of generic sensor nodes are Rene 1999, Telos 2004, Mica-Z 2004 and Mica-2 2001. A sample Mica-2 sensor node is shown in Fig. 14.

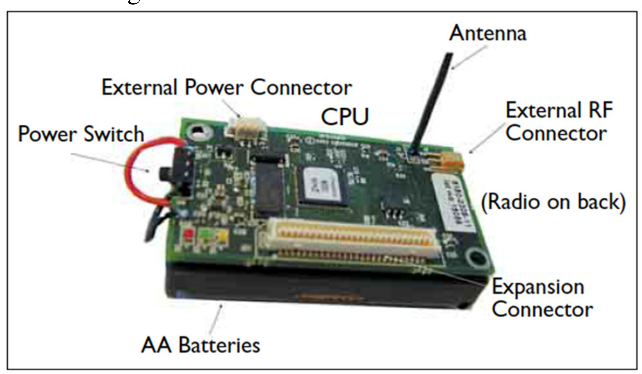

Fig. 14. Mica 2 sensor platform

High Bandwidth Sensor platforms

Some nodes are required to perform high quality video surveillance or other image capturing task these are generally high-bandwidth nodes. These nodes are more expensive than nodes in other networks and are meant to fulfill real time communications with minimum latency. Some examples of high bandwidth nodes are BT Node 2001 and Imote 1.0. 2003.

Gateway sensor platforms

In 3 layer architectures there are nodes that help pass on the data form data collectors to the base station or sink. Such nodes are called gateway nodes. Some examples of gateway nodes are Stargate 2003, Inrysnc Cerfcube 2003 and PCI04. All these sensors node platforms have many challenges and performance considerations that need to be taken care of when building a mobile sensor network.

7) Comparison of MSN Platforms

In Table 4 is a comparison of mobile sensor platforms for general purpose nodes. This comparison is done on a metrics such as CPU, power, I/O and sensors, radio and memory.

Node	*CPU*	*Power*	*I/O and Sensors*	*Radio*	*Memory*
Telos	Motorola HS08	.001mW sleep 32mW active	USB and Ethernet	250Kbps	4K RAM
Rene	ATMEL 8535	.036mW sleep 60mW active	Large expansion connector	10Kbps	512B RAM 8K Flash
Mica-Z	ATMEGA 128	-	Large expansion connector	250Kbps	4K RAM 128K Flash
Mica-2	ATMEGA 128	.036mW sleep 60mW	Large expansion connector	76Kbps	4K RAM 128K Flash

Table 4. Platform comparison of Generic sensor nodes

Table 5 shows a comparison between high bandwidth nodes and gateway nodes. In high bandwidth nodes the connection with cell phones is easier and they support TinyOS, they also use multihop via scatternets and Gateway nodes have flexible I/O [23].

Node	*CPU*	*Power*	*I/O and Sensors*	*Radio*	*Memory*
Imote 1.0 2003	ARM 7TDMI 12-48MHz	. 1mW idle 120m W active	UART, USB, GPIO, 12C, SPI	Bluetooth 1.1	64KB SRAM 512KB Flash
BT Node 2001	ATME L Mega 128L 7.328M hz	50MW idle 285M W active	8-channel 10-bit A/D, 2 UARTS Expandab le connector s	Bluetooth	128KB Flash 4KB EEPRO M 4KB SRAM
Stargat e 2003	Intel PXA25 5	-	2 PCMICA/ CF, com ports, Ethernet, USB	Serial connection to sensor network	64KNSR M
PC104 nodes	X86 process or	-	PCI Bus	Serial connection to sensor network	32KB Flash 64KB SRAM
Inrysnc Cerfcu be 2003	Intel PXA25 5	-	Single CF card, general-purpose I/O	Serial connection to sensor network	32KB Flash 64KB SRAM

Table 5. Platform comparison of High bandwidth and Gateway nodes

TinyOS is a software framework that has been developed to work on such platforms. Mobile sensor nodes require OS that understands the fact that resources are constrained in terms of memory and processing power this needs to be used wisely by the OS. This OS was developed by the University of California, Berkley. It also provides a very good connectivity with other wireless networks and networking operations. The framework performance also depends on the type of platform its running on. For example, gateway nodes perform a lot of computation and storage on behalf of the other nodes and hence they require frameworks that can meet their demands of multiprocessing, virtual memory computing, drivers for many different network devices.

IV. IoT Sensing and Mobile Sensor Cloud Infrastructures and systems

A. Overview

Mobile devices have become an essential part of human daily life and work. With the explosion of mobile applications and mobile computing technology evolution, one important trend is to move the data processing and storage from mobile devices to centralized computing platforms, taking advantage of mature and widely recognized mobile cloud computing (MCC) paradigm [24]. In the meantime, Internet of Thing (IoT) has been gaining massive attraction in industries such as logistics, e-commerce, retailing, etc. IoT is a global network infrastructure composed of numerous connected devices that rely on sensory, communication, networking, and information processing technologies [25]. One of the main problems of IoT is lacking of uniform infrastructure and architecture to integrate heterogeneous networks and sensing devices. Wireless Sensor Network (WSN), a foundational technology of IoT, establishes and organizes interconnected sensors to provide intelligent sensing and monitoring.

However, WSNs are considered with high heterogeneity because different networks use different proprietary or non-proprietary communication protocols and solutions. These wide range of solutions is currently hindering large-scale application and deployment of WSN technologies. In order to solve interoperability issue among heterogeneous sensing systems, one important trend is to use open Internet Protocol to achieve connectivity and intercommunication between WSNs and traditional internet, taking advantage of internet gateways or IoT gateways [27, 32]. This motivates the integration of WSN technology and mobile cloud computing, which applies the traditional cloud computing and storage paradigm to mobile sensor networks, inspiring the emerging of cloud sensing and sensing-as-a-service. Also, the connectivity between various wireless sensor network and internet make it possible to build IoT mainly on open standards and identification mechanism. The emerging mobile sensing technology also provide us new ways to conquer the limitations of traditional sensor networks in terms of energy, computing resource, communication, scalability and network management [28].

B. Mobile Sensor Cloud

Traditional sensor networks collect sensor data and send these data to centralized data storage systems using a large variety of communication protocols. Different sensors are deployed and utilized by their specific applications for ether different or similar purposes. The sensor resources as well the network infrastructure are used exclusively by specific users, causing wastage of sensing and computing resources and high cost to build sensor networks. Also, the scale of sensor networks has been increased explosively, generating massive amount of sensory data, making the storage, aggregation, analytics more and more challenging. In order to address these challenges of sensor networks, several mobile sensing models have been proposed.

Service-centric-models [33] are applied on wireless sensor network and the network itself is considered as a service provider. The service-centric-model has multiple layers to encapsulate low level layers' functionalities.

The message bus paradigm commonly used in internet industry is extended to the edge node of sensor networks [30]. Also, Service Oriented Architecture are applied to build sensing services contained in the sensor networks.

Sensing-as-a-service [30, 31, 34] concept has been brought up, aiming to provide sensor data access through general service interfaces. As a step further, cloud-based sensing-as-a-service [35] are also proposed, emphasizing on sensor virtualization, multi-tenancy, dynamic provisioning of services.

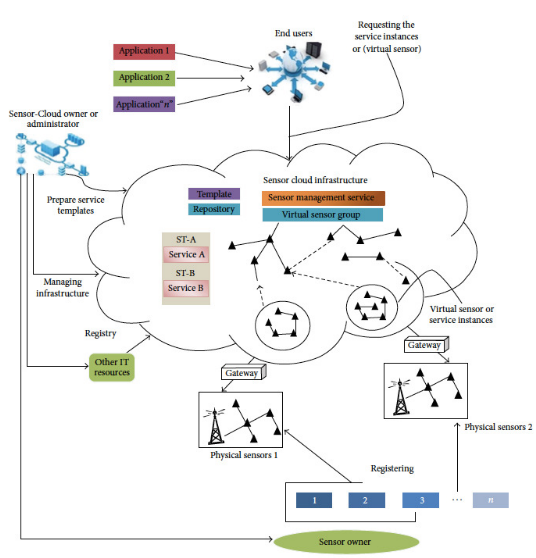

Fig.15. Typical infrastructure of Sensor Cloud

Recently, with the prosperity of mobile cloud computing, sensor cloud [36, 39, 41], as a new paradigm of wireless sensor network, has become a hot research topic and gained a lot traction. Sensor cloud is defined as an infrastructure that makes truly pervasive computation using sensors as interface between physical and cyber worlds, the data-compute clusters as the cyber backbone and the internet as the communication medium [41]. A typical sensor cloud architecture is demonstrated in Fig 15 [36].

Some major functionalities that sensor cloud provide are:

- Offers scalable and configurable storage for sensor data
- Offers flexible computation resource for applications
- Integrates large-scale computation and storage resource sharing and collaborations among users on the cloud
- Enables dynamic provisioning of sensors on the cloud
- Supports complete sensor data life cycle from data collection to the data analytics
- Provides data visualization for monitoring and analysis purposes

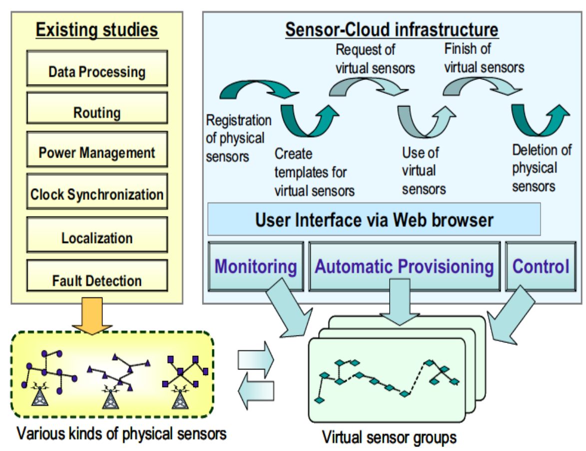

Fig.16. Overview of Sensor Cloud Architecture [37]

In sensor cloud, physical sensor are virtualized as resources on cloud computing platforms. These virtual sensors are dynamically registered, configured and provisioned. The details of physical sensors, data collections are transparent to end users. Physical sensors and cloud are interconnected by gateways. Users are able configure their sensors in a on-demand pattern.

Fig 16 illustrates the workflow and lifecycle of sensor cloud service. From user perspective, Sensor cloud system is a multi-tenant platform which permits multiple user to register and request virtual sensor resources on demand, without impacting each other. The change initiated by one user will be transparent to other users.

Sensor cloud user joining the sensor cloud first need to create account and establish authentication mechanism. After that, users are able to register and deploy physical sensors on the assigned logic space of the sensor cloud. The sensor cloud platform need to provide certain customization tools and general templates for the sensor definition and configuration. When the user submits the registration request with the configuration, the platform is able to provision and prepare the required virtual sensor resource automatically. When the user want to remove certain sensors from the cloud, the platform is able to delete the association of those sensor and release the virtual sensor resource gracefully upon request. The dynamic provision and deletion of sensors are the key functions of the sensor cloud platform and these process happen on the background without human's intervention. Also, the user interface will be provided to facilitate a user to submit various requests and control commands to their sensors. Typically, monitoring dashboard will also be integrated in the user interface, enabling users to monitor their sensor system's status.

Mobile sensor cloud is an extension of sensor cloud to mobile devices and mobile sensors. Because of the constraints of computing resources, mobile devices are not able to perform heavy computations. Also, the limited power of mobile devices and sensors add more difficulties to build a reliable mobile sensor cloud. Compared with sensor cloud, mobile sensor cloud has following major differences:

1) Sensor Mobility

Although it is hard to distinguish mobile sensor and traditional sensor. Sensors in sensor cloud are usually fixed at one place. Typical example includes temperature sensor used to monitor certain place's temperature. Mobile sensor cloud usually contains sensors move around by time. The mobility pattern of sensors is determined by specific applications.

2) Sensor Diversity

Mobile sensor cloud tends to contains large variety of sensors, ether mobile or immobile. Also, different type of sensors can coexist and collaborate with each other to fulfill the application's needs. This make the sensor virtualization more difficult.

3) Data Locality

Data in typical sensor cloud are collected from stationary sensor and it only reflect on single location's information. While in mobile sensor cloud, data can be collected from ranges of locations, either in a continuous way or discrete way. This make the sensory data richer and more reliable.

4) Range of Application

With more flexibility and diversity, mobile sensor cloud can be applied in more application scenarios. Especially, the pervasiveness of mobile devices and existing technology make the deployment and establishment of mobile sensor cloud more acceptable.

C. Mobile Sensing Service Type

Mobile sensing technology has a wide range of applications. Some of the emerging sensor cloud applications are described below:

Healthcare Monitoring: We could collect patient's health-related data by using wearable sensor devices which include temperature sensors, accelerometer sensors in order to tracking patient's blood sugar, sleep activity pattern, body temperature, and other respiratory conditions

Agriculture and environmental monitoring: It is difficult for a farmer to analyze conditions like infected crop from a 100 to 200 hectare field, bad weather etc. which may leads to huge damage. Sensor Clouds can be used for to collect readings on temperature, soil &moisture levels and to collect the data and recommend when to start planting or what crops may be well-suited to a specific field. Sensor Clouds also can be used for emergency or disaster detection. For example, detect earthquake and volcano explosion before eruption become possible by using several different sensors through the Sensor Cloud infrastructure.

Smart City: A smart city is an urban development vision to integrate multiple information and communication technology and Internet of Things solutions in a secure fashion to manage a city's assets–include local departments' information systems, schools, libraries, transportation systems, hospitals, power plants, water supply networks, waste management, law enforcement, and so on. Through the use of sensors integrated with real-time monitoring systems, data are collected from citizens and devices - then processed and analyzed to make the city evolving, provide a quality of life.

Google Traffic: Unlike earlier existing technologies like GPS navigation can only track the status and current location of vehicle, vehicle monitoring is implemented using sensor cloud, collected sensor data can be stored into centralized server in the cloud. The vehicle owner can access this data on cloud via web portal, then the information like predicting the time of arrival, the total distance to a destination, the current location can be get by vehicle owner in real time.

Wildlife Monitoring: Sensor Cloud can also be used for tracking the activity of endangered wildlife. For example, ZebraNet is a mobile, wireless sensor network system aimed at improving tracking technology via energy-efficient tracking nodes and store-and-forward communication techniques. ZebraNet s most immediate focus is wildlife tracking across large regions with little communications infrastructure, its broader goals concern the deployment, management, and communications issues for large numbers of both static and mobile sensors [40].

In general, the services the mobile sensor networks provide fall into a couple of major categories [26].

1) Identity-Related Services

Identity-Related Services are services for identify things. Usually, objects in such network are assigned a unique identifier such as RFID tag or IP address. These identifiers are reported or monitored regularly for different purposes.

2) Information Aggregation Services

Information aggregation services refer to the process of collecting data from multiple sensors, aggregating the data, and transmitting the aggregated data to centralized data storage for analysis. As the number or type of sensors being deployed get larger, these aggregation service becomes more and more critical to ensure the quality of services.

3) Collaborative-Aware Services

Collaborative aware services are services that use the received aggregated data to make decisions or trigger actions. Behind the scenes, large amount data processing and analysis may be involved.

D. Issues and Challenges

1) Connection Reliability

New mobile sensing technology like sensor cloud and IoT require reliable interconnectivity between sensors and internet. Internet Protocol provides end to end communication solution between devices without any requirement of an intermediate protocol translation gateway. However, considering the heterogeneity of various sensor networks, reliable and general bridge solution between internet and sensor networks still need to be investigated.

2) Data Storage

Massive data can be generated as the sensor network grows in a ubiquitous way. The storage volume required for sensing data can be huge and will be constantly increasing. Traditional data storage solution like distributed database may not be suitable for sensory data. New storage solution may be required to address the characteristic of sensor data.

3) Energy Efficiency

Energy efficiency is still an issue that blocking the large scale deployments of sensors devices. Depending on where and how the sensor is used and deployed, the power collection methods may vary (For example: RF, solar, sound, vibration, heat, etc.) [29]. Intelligent power management with collaborative-awareness may increase the energy efficiency of sensor networks.

4) Security

As the mobile sensing is started to be applied to applications with privacy sensitive data, security of sensor network need to be seriously considered. For ensuring confidentiality, a large number of standard encryption technologies exists for use. However, the main challenge is to make encryption algorithms faster and less energy-consuming. Also, new security problems may arise due to the special requirement for sensory data.

5) Collective intelligence

The large amount of heterogeneous real-time sensor data makes comprehensive collective intelligence possible. Taking advantage of information fusion and machine learning technology, sensor networks can make smarter and better decision based on the analysis [11, 15]. How to maximize the intelligence based on the sensory data will be a big challenge.

V. CONCLUSION

Mobile sensor networks as we have seen have a wide variety of applications in different fields. They help in surveillance, monitoring, effective temperature control, managing controlled conditions in an environment etc. We have also come across various limitations to these networks such as power consumption, memory, bandwidth and processing power. The mobility and wide coverage areas of these networks have been seen as the biggest advantages over static sensor networks. This paper helps in providing a broad survey on mobile sensing its basic concepts, challenges, architecture and applications. Various types of mobile sensor networks, frameworks, their comparisons and cloud services in IoT for mobile sensing have been discussed. However, the challenges faced are discussed below:

- Though various kinds of sensors are available separately, there is not one single device that senses all parameters either in environmental or healthcare category. For efficient cloud usage, lesser devices with more information is crucial. Can this level of innovation be achieved?
- When the above challenge is solved, there could be personal mobile devices that can diagnose a disease with multiple body parameters. It makes it easy for the patient and doctor to keep track of a set of relater parameters only.
- The size of certain environmental sensors is not small enough to be user-friendly. Innovation and research needs to go a long way in this domain. Will this be able to reach customers without being expensive?
- AV has already been doing numerous things namely sensing, processing and deriving information from the data. Though AV have

computationally efficient computers, uploading the huge amount of data to cloud requires a lot of time and power. This function can be outsourced to a different mobile device either explicitly designed for this or a smartphone.

- One of the challenges while dealing with mobile sensors is the users of smartphones must be attracted towards the sensing service companies, so it is a challenge to the company to bring the user sensor data form the users smartphone. But with the current resources is this possible?

Future work

We have come a long way from fixed traditional sensors to mobile sensors to mobile cloud computing. This paper only discusses the basic concept about mobile cloud sensing. The research can be extended beyond our scope into the following domains:

- We have discussed about individual physical sensors and their functions. The next step is Sensor fusion (software sensors). Machine learning along with sensor fusion can perform wonders.
- There are various open source cloud platforms but for a smart city, with huge amount of data, it is crucial to research on a unified architecture and platform that is secure, reliable, cheap, scalable and easily accessible by everyone.

ACKNOWLEDGMENT

We would like to thank Dr. Jerry Gao of San Jose State University, for giving us this opportunity to do a comprehensive study on mobile sensor cloud computing.

REFERENCES

[1] R. Mizouni and M. El Barachi, "Mobile Phone Sensing as a Service: Business Model and Use Cases," *2013 Seventh International Conference on Next Generation Mobile Apps, Services and Technologies, Prague, 2013, pp. 116-121. doi: 10.1109/NGMAST.2013*

[2] C. Siripanpornchana, S. Panichpapiboon and P. Chaovalit, "Incidents detection through mobile sensing," *2016 13th International Conference on Electrical Engineering/Electronics,Computer, Telecommunications and Information Technology (ECTI-CON), Chiang Mai, 2016, pp. 1-6*

[3] C. Rossi, A. Favenza, F. Scullino, V. Macchia, G. L. Spoto and F. Dominci, "Evaluating FLOODIS: Mobile sensing for a flood emergency service in the cloud," *Cloud Technologies and Applications (CloudTech), 2015 International Conference on, Marrakech, 2015, pp. 1-6.*

[4] C. Perera, D. S. Talagala, C. H. Liu and J. C. Estrella, "Energy-Efficient Location and Activity-Aware On-Demand Mobile Distributed Sensing Platform for Sensing as a Service in IoT Clouds," *in IEEE Transactions on Computational Social Systems, vol. 2, no. 4, pp. 171-181, Dec. 2015*

[5] C. Chang, S. N. Srirama and M. Liyanage, "A Service-Oriented Mobile Cloud Middleware Framework for Provisioning Mobile Sensing as a Service," *Parallel and Distributed Systems (ICPADS), 2015 IEEE 21st International Conference on, Melbourne, VIC, 2015, pp. 124-131*

[6] N. Cao, S. Brahma and P. K. Varshney, "Towards cloud sensing enabled target localization," *Communication, Control, and Computing (Allerton), 2014 52nd Annual Allerton Conference on, Monticello, IL, 2014, pp. 537-544*

[7] Misra, A. and Lim, L. "Optimizing Sensor Data Acquisition for Energy-Efficient Smartphone-based Continuous Event Processing". *IEEE MDM, 2011*

[8] Y. X. Lai, Y. W. Ma, Y. M. Huang, J. L. Chen and S. C. Mukhopadhyay, "Ubiquitous motion sensing service using wearable shoe module and mobile device," *2013 IEEE International Instrumentation and Measurement Technology Conference (I2MTC), Minneapolis, MN, 2013, pp. 1376-1379*

[9] N. Cao, S. Brahma and P. K. Varshney, "Towards cloud sensing enabled target localization," *Communication, Control, and Computing (Allerton), 2014 52nd Annual Allerton Conference on, Monticello, IL, 2014, pp. 537-544*.

[10] X. Sheng, X. Xiao, J. Tang and G. Xue, "Sensing as a service: A cloud computing system for mobile phone sensing," *Sensors, 2012 IEEE, Taipei, 2012, pp. 1-4. doi: 10.1109/ICSENS.2012.6411516*

[11] Misra, A. and Lim, L. "Optimizing Sensor Data Acquisition for Energy-Efficient Smartphone-based Continuous Event Processing". *IEEE MDM, 2011*

[12] H.-H. Tran and K.-J. Wong, "Mesh networking for seismic monitoring - the Sumatran cGPS array case study", *2009 IEEE Wireless Communications and Networking Conference, Apr. 2009*.

[13] G. Demiris, B. K. Hensel, M. Skubic, and M. Rantz, "Senior residents' perceived need of and preferences for 'smart home' sensor technologies*", International Journal of Technology Assessment in Health Care, vol. 24, no. 01, pp. 120–124, Jan. 2008.*

[14] Alexe A., Exhilarasie R.Cloud computing based vehicle tracking information systems, International Journal of Computer Science and Telecommunications, 201121

[15] Mitton, N., Papavassiliou, S.; Puliafito, A., Trivedi, K., "Combining Cloud and sensors in a smart city environment". *EURASIP J. Wirel. Commun. Netw. 2012, 247, 1–20*.

[16] Hancke, G.P.; Silva, B.C.; Hancke, Jr., G.P. The Role of Advanced Sensing in Smart Cities. Sensors 2013, 13, 393-425.

[17] A. Alamri, W. S. Ansari, M. M. Hassan, M. S. Hossain, and A. Alelaiwi, "A survey on sensor-cloud: Architecture,

applications, and approaches", *International Journal of Distributed Sensor Networks, vol. 2013, pp. 1–18, 2013*.

[18] A. Howard et al., “Mobile Sensor Network Deployment using Potential Fields: A Distributed, Scalable Solution to the Area Coverage Problem” *in Distributed Autonomous Robotic Systems 5, Springer Japan, 2002, pp 299-308*

[19] S. Poduri and G.S. Sukhatme, “Constrained coverage for mobile sensor networks” in *IEEE International Conference on Robotics and Automation, May 2004, doi: 10.1109/ROBOT.2004.1307146*

[20] S. A. Munir et al., “Mobile Wireless Sensor Network: Architecture and Enabling Technologies for Ubiquitous Computing” *AINAW '07. 21st International Conference on Advanced Information Networking and Applications Workshops, May 2007, doi: 10.1109/AINAW.2007.257*

[21] Q. Jiang and D. Manivannan, “Routing protocols for sensor networks” *in First IEEE Conference on Consumer Communications and Networking Conference, Jan 2004, doi: 10.1109/CCNC.2004.1286839*

[22] S. Abdelhamid, H. S. Hassanein, and G. Takahara, "Vehicle as a mobile sensor," *Procedia Computer Science, vol. 34, pp. 286–295, 2014.*

[23] C. Thompson, J. White, B. Dougherty, A. Albright and D.C. Schmidt, "Using smartphones to detect car accidents and provide situational awareness to emergency responders", *MOBILWARE'10 (Chicago IL USA), pp. 29-42, 2010*.

[24] Hoang T. Dinh, Chonho Lee, Dusit Niyato, Ping Wang, “A survey of mobile cloud computing: architecture, applications, and approaches”, *Wireless Communications and Mobile Computing, Volume 13, pp. 1587-1611, December 2013.*

[25] Li Da Xu, Wu He, Shancang Li, “Internet of Things in Industries: A Survey”, *IEEE Transactions on Industrial Informatics, Volume: 10, Issue: 4, pp. 2233-2243, Nov 2014*.

[26] M. Gigli and S. Koo, "Internet of Things: Services and Applications Categorization", *Advances in Internet of Things, Vol. 1, pp. 27-31, 2011.*

[27] Luca Mainetti ; Luigi Patrono ; Antonio Vilei, ”Evolution of Wireless Sensor Networks towards the Internet of Things: a Survey”, *Software, Telecommunications and Computer Networks (SoftCOM), pp. 15-17 Sept. 2011.*

[28] D Bandyopadhyay, J Sen, “Internet of Things: Applications and Challenges in Technology and Standardization”, *Wireless Personal Communications, Volume 58, Issue 1, pp 49–69, May 2011.*

[29] X Sheng, J Tang, X Xiao, G Xue, “Sensing as a service: challenges, solutions and future directions”, *IEEE Sensors Journal, Volume: 13, pp. 3733 - 3741, Oct 2013.*

[30] J. Ibbotson, C. Gibson, J. Wright et al., “Sensors as a service oriented architecture: middleware for sensor networks”, *Proceedings of the 6th International Conference on Intelligent Environments, pp. 209–214, Kuala Lumpur, Malaysia, July 2010*.

[31] V. Rajesh, O. Pandithurai, and S. Mageshkumar, “Wireless sensor node data on cloud”, *in Proceedings of the IEEE International Conference on Communication Control and Computing Technologies (ICCCCT ’10), pp. 476–481, IEEE, Ramanathapuram, India, October 2010.*

[32] Q. Zhu, R. Wang, Q. Chen, Y. Liu, and W. Qin, “IOT gateway: bridging wireless sensor networks into internet of things”, *in Proceedings of the IEEE/IFIP 8th International Conference on Embedded and Ubiquitous Computing (EUC ’10), pp. 347–352, Hong Kong, December 2010.*

[33] D. Graˇcanin, M. Eltoweissy, A. Wadaa, and L. A. DaSilva, “A service-centric model for wireless sensor networks”, *IEEE Journal on Selected Areas in Communications, vol. 23, no. 6, pp.1159–1165, 2005.*

[34] A. Zaslavsky, C. Perera, and D. Georgakopoulos, “Sensing as a service and big data”, *in Proceedings of the International Conference on Advances in Cloud Computing (ACC ’12), pp. 21–29, Bangalore, India, July 2012.*

[35] Mihui Kim, Mihir Asthana, Siddhartha Bhargava, Kartik Krishnan Iyyer, Rohan Tangadpalliwar, Jerry Gao, “Developing an On-Demand Cloud-Based Sensing-as-a-Service System for Internet of Things”, Journal of Computer Networks and Communications, Volume 2016, Article ID 3292783.

[36] [Atif Alamri, Wasai Shadab Ansari, Mohammad Mehedi Hassan, M. Shamim Hossain, Abdulhameed Alelaiwi, M. Anwar Hossain, “A Survey on Sensor-Cloud: Architecture, *Applications, and Approaches”, International Journal of Distributed Sensor Networks Volume 2013 (2013), Article ID 917923.*

[37] Madoka Yuriyama, Takayuki Kushida, “Sensor-Cloud Infrastructure Physical Sensor Management with Virtualized Sensors on Cloud Computing”, *2010 13th International Conference on Network-Based Information Systems, Sept 2010.*

[38] Ting Liu, Christopher M. Sadler, Pei Zhang, Margaret Martonosi, Implementing Software on Resource-Constrained Mobile Sensors: Experiences with Impala and ZebraNet, 2004.

[39] Chandra Shekhar, Piyush Singh Katiyar, Simranjeet Singh, Yasham Singhal, “A Comprehensive Study of Mobile Sensor Clouds”, *International Journal of Advanced Research in Computer Science & Technology, Vol. 4, Issue 1, PP. 35-51, Jan-Mar 2016.*

[40] J Gao, L Lei, S Yu , “Big data sensing and service: a tutorial", *Big Data Computing Service and Applications (BigDataService), 2015 IEEE First International Conference on, pp. 79-88, April 2015.*

[41] Kian-Lee Tan, “What’s Next? Sensor Cloud?”, *Proceeding DMSN '10 Proceedings of the Seventh International Workshop on Data Management for Sensor Networks, pp. 1-1, ACM New York, 2011.*