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# A Comprehensive Study of Mobile Sensing and Cloud Services

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*Abstract* — **Mobile Sensing is an emerging technology being researching extensively in the past decade. This research survey paper studies the concept of mobile sensing, mobile sensor network and mobile sensing in integration with cloud services. It discusses the various mobile sensors available and their classifications. It studies the needs and limitations of mobile sensor network, in terms of storage, computation, energy efficiency and scalability. The paper highlights important research areas to enhance the efficiency in managing data, in order to maintain a powerful and high-performance computing storage for real-time and offline processing and complex analysis. It also examines, classifies and analyzes IoT sensing and mobile cloud services in different applications, including the Infrastructures for mobile sensing and services. The research analyzes the existing solutions and approaches of sensor-cloud infrastructure -- including reconfigurable platforms for monitoring and controlling, as well as provides future research direction on mobile cloud in general.**

## I. INTRODUCTION

### *A. What is Mobile Sensing and Mobile Cloud Services*

Mobile sensors are gaining popularity because of its various functionalities and vast usage's. Data accumulated from such mobile sensors can be used for developing a large number of next generation smart applications in different domains such as healthcare, transportation, safety, security, environmental monitoring, etc. [1.2], [1.3].

Mobile sensor applications need mobile cloud services for computing and processing the sensor data. Many mobile sensor cloud services with different functionalities are available in today's market to meet the different needs of mobile applications e.g., Apple's "iCloud", Microsoft's "LiveMesh", and Google's "Google Drive". Based on the application usage situation such as device type, available network access rate and location an optimal mobile cloud service can be selected [1.5]. There are two type of mobile phone sensing paradigms - *Participatory Sensing and Opportunistic Sensing* [1.3]. In Participatory sensing, mobile users actively engage in sensing activities such as when, where, what and how to sense. In opportunistic sensing, sensing activity is done automatically without the intervention of the mobile user [1.3].

### *B. Why mobile sensing and cloud services*

Mobile sensing cloud services is a combination of cloud computing and mobile computing and has the advantages of convenience of data access at any time and any place with no terminal hardware limitations [1.5]. With the rise of many micro mobile devices, mobile sensing systems has the potential to reach a very large user population [1.9]. It is convenient and economical to use the sensors available in the mobile devices, or externally add sensors to the mobile devices to gather data and develop useful applications. Smart phones are used in everyday life and have existing built-in sensors, such as gyroscope, accelerometer, camera, radio, digital compass, microphone, along with Internet readiness, which make them powerful devices [1.1]. As an IoT solution, various smartphone apps are ported with complex algorithm, which uses various sensors. Sensors, such as magnetometer, along with Wi-Fi can be used to detect the presence of person's zone in a building during an emergency evacuation [1.1]. Wearable devices, vehicles and smartphones give rise to two of the most important mobile sensing applications mobile health and vehicular applications [1.6]. The mobility of vehicles makes them popular for covering many mobile sensing applications. Using smartphones as a sensing device avoids additional costs to invest in placing standard expensive PC-like devices in people, buses or cars [1.6]. Monitoring environmental pollution is one of the uses of mobile sensing. Mobile sensors can be used to monitor air pollution which is economical compared to the expensive and hard to install fixed monitoring stations [1.4].

### *C. Needs of mobile sensing system*

The basic needs of a mobile sensing system are that a user level application needs to be running on the mobile device, secondly required mobile sensors for collection of the data must be present on the device, and the device should have an Application Programming Interface (API) to manage data and reporting [1.8]. Since the mobile device have constraints such as limited storage capacity and memory, restricted CPU processing capabilities, etc. The computation is offloaded into a mobile cloud service [1.7]. The cloud services should comply with web service standards - Simple Object Access Protocol (SOAP) and Representational State Transfer (REST). Mobile applications should be developed to access RESTful and SOAP services [1.7].

### *D. Challenges and Concerns*

There are a number of design challenges in the software architecture of mobile devices such as energy efficiency, resource adaptability [1.9]. Energy efficiency is the energy required to deliver a mobile service at a given quality of service (QoS). Energy efficiency becomes a top concern since the mobile device is impacted by the use of high energy consumption sensors, heavy computation load, screens etc [1.9]. Resource adaptability is the ability to adapt flexibly to environment changes. For examples, fluctuating availability of sensing, network availability and accessibility, wireless communication options etc. [1.9]. Battery life, CPU and network overhead are the main crucial issues in smartphones [1.1]. Moreover, mobile Cloud services has a disadvantage of limited network bandwidth and a weak power endurance provided by a mobile device [1.5].

There are two major concerns in mobile sensing. First is user participation, user has to trigger the sensors to measure the data, which may consume much power. also user needs to upload the data which will consume 3G data quota or user might need to move to a particular location to sense the data [1.10]. Second is privacy, private information can be obtained from the users' contributed data. Such privacy concerns and extra efforts required by the user to gather the data may hinder the user's participation [1.10].

### *E. Goal of the Report*

Unlike other research work, in this paper, we discuss mobile sensor in an integrated view with Cloud Computing. The paper first categorizes mobile sensors in 3 major categories: environment, healthcare and transportation. Besides, it provides some basic concept of mobile sensor networks and classifies them. Mobile sensor service platforms and frameworks are also presented. Then, it discuss IoT sensing and mobile sensing in an integration with cloud computing. Some detailed discussion and comparisons are given to show their distinct features and improvements. Finally, we address the important issues and challenges in mobile sensing cloud computing for future research in different areas, including bandwidth limitation, big data analysis, power efficiency..

### *F. Structure of the Report*

The remainder of the paper is organized as follows: section II consists of a list of mobile sensors and their classification. Section III describes the mobile sensor network and service framework. Section IV discusses IoT sensing and mobile sensor cloud infrastructures and systems. Finally, section V concludes the paper.

## II. MOBILE SENSORS AND CLASSIFICATION

Mobile sensing, a branch of mobile and wireless computing [2.4], came into existence in late 1980's. It was initially used to monitor the phenomena of interest like monitoring atmosphere, odor measurement via gas sensor, and potholes on road surface. Wearable objects with mobile sensors came into existence in early 1990's to monitor and map movement patterns of living organisms like animals, birds, humans, etc. In mid 2000's smart phones came into play with a number of mobile sensors like GPS, accelerometer etc. Today the use of mobile sensor is diversified and is used in various sectors of economy [2.1]. Scientists are of the belief that this trend of increased network bandwidth and speed, fused with the advanced sensing and fast processing nature of smart phones is going to change the landscape of mobile sensing in the future [2.4].

### *A. Sensors and Mobile Sensors:*

Sensors are devices that can detect and respond to some kind of input from the physical surroundings. The input could be of the type, pressure, heat, light, moisture, motion or any of the phenomena of environment. The result or the output is signal which is generally in the form of human-readable LED display or transmitted over a physical or wireless network for analysis or further processing [2.2]. These sensors are generally stationary sensor nodes in a network topology. Mobile sensors are wireless sensors in a wireless sensor network(WSN). The sensor nodes in WSM are mobile. This nature of mobility of the sensors in a mobile wireless sensor network(MWSN) made a crucial spot in smart phones.

Mobile sensors have grown as a vital data source on the web, satisfying companies to analyze and investigate methods of building WSNs and to capture, process and generate hidden patterns using sensors generated data. An apprehension on the advantages [2.1] of mobile sensors over stationary sensors have created ways of sensor integration into mobile phones.

A comparison [2.1] of sensors and mobile sensors is done in the figure 2.1

| | Sensor | Mobile Sensor |
|---|---|---|
| Motion | Stationery | Mobile |
| Area Constraints | Yes | No |
| Power Management | More | Less |
| Cost | High | Low |
| Maintenance | High | Low |

*Figure 2.1: Comparison between sensors and mobile sensors*

*B. Classification and Comparison of mobile sensors based on their nature:*

Mobile sensors, in a broad sense can by classified [2.1] based on their nature or type. They are classified as:

1) Digital and Analog Sensors
2) External and Embedded sensors
3) Proprioceptive and Exteroceptive sensors
4) Active and Passive Sensors

*1)Digital and Analog Sensors*: Analog sensors measures quantities such as current, voltage, pressure, gas, humidity, temperature, position, light, magnetic field, vibration and force etc. and gives output as continues values. Digital sensors are slightly complex than analog sensors, as the input is analog and output is digital.

*2)External and Embedded sensors*: Embedded sensors are integrated parts of a device and is accessed by pre-defined interface. Eg: Accelerometer in smart phones. External sensors are not internal parts of a device, they are present in the surrounding of the environment and the devices communicate with them via communication channel and wireless protocols. Eg: Bluetooth etc.

*3)Proprioceptive and Exteroceptive sensors:* Proprioceptive sensors measure/determine physical properties which are related to internal conditions of a system/device. Exteroceptive sensors gets information from the surrounding in an environment external to a device.

*4)Active and Passive Sensors*: Passive sensors determine/measure the energy generated in the surroundings in an environment external to a device. These sensors don't need supply of power or charged battery. They gain power from electromagnetic waves generated by requesting device. eg: RFID. Active sensors generate energy into the surrounding of the environment and later measure the generated reaction. Eg. LiDAR. These sensors battery or power supply to operate.

A comparison [2.1] of mobile sensors based on their nature or type is done in the figure 2.2.

| Gerenral Classicfication (Category) | Sensor Type | Embedded(Em) or External(Ex) | Proprioceptive (PC) or Exteroceptive (EC) | Active (A) Or Passice(P) |
|---|---|---|---|---|
| Tactile Sensors | Proximity Sensor | *Em/Ex* | EC | P/A |
| Acceleration Sensors | Accelerometer Sensor<br>Gyroscope Sensor | Em<br>Em | PC<br>PC | P<br>P |
| Thermal Sensors | Temperature Sensors | Ex | EC | P/A |
| Image Sensors | CMOS Camera Sensors | Em | EC | P/A |
| Light Sensors | Ambient Light Sensor<br>Back-Illuminated Sensor | Em/Ex<br>Em | EC<br>EC | A<br>A |
| Water Sensors | Moisture Sensor<br>Humidity Sensor | Em<br>Ex | EC<br>EC | P<br>P |
| Location Sensors | Digital Compass<br>GPS sensor | Em<br>Em | EC<br>EC | P<br>A |
| Height Sensors | Altimeter Sensor<br>Barometer Sensor | ---<br>Em | EC<br>EC | P<br>P |
| Medical Sensors | Heart Rate Monitor Sensor<br>Biosensor | ---<br>--- | EC<br>EC | P<br>P |
| Acoustic Sensors | Microphone Sensor | Em | EC | P |
| Radio Sensors | RFID<br>Bluetooth | ---<br>Em | EC<br>EC | A<br>A |

*Figure 2.2: Comparison between mobile sensors based on their nature or type [2.1].*

*C. Classification and Comparison of mobile sensors based on their use:*

Mobile sensors can be classified based on their uses in the sector of the economy:

1) Smart phone mobile sensors.
2) Environmental mobile sensors.
3) Healthcare mobile sensors.
4) Transportation mobile sensors.
5) Smart City mobile sensors.
6) Wild Life mobile sensors.
7) Social networking mobile sensors.

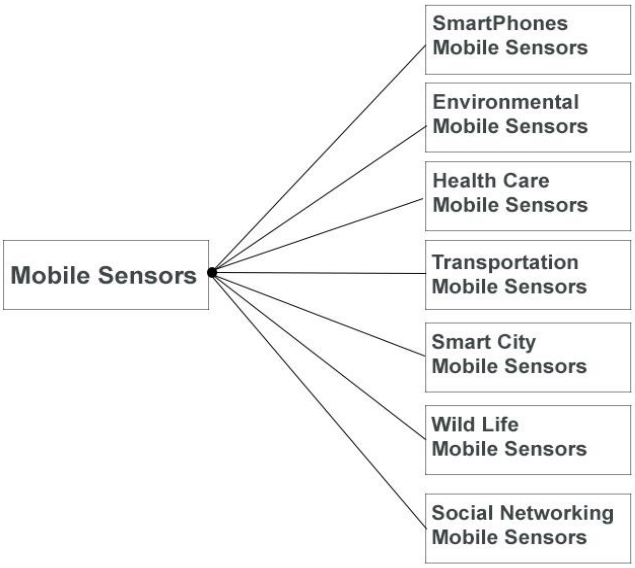


*Figure 2.2: Classification of mobile sensors*

*1) Smart Phone mobile sensors:*

Sensors are available on almost every smart phone available today. Most of the mobile phones include the following sensors: GPS for location, an Accelerometer Sensor(AS) to determine acceleration, a Compass Sensor(CS) to measure angle of rotation of the phone with respect to the earth's magnetic north and south poles, a Gyroscope sensor(GS) to determine the angular rate of how fast the object turns, An Image Sensor(IS) to takes images and videos, an Ambient Light Sensor(ALS) to find how much luminance is present, Touch Sensors(TS) to find out the location and presence of a touch with a stylus pen or a finger within the display area, a Proximity Sensor(PS) to find out how close the mobile phone is to the body of the user. Atmospheric Sensors(APS), Humidity Sensor(HS) and Temperature Sensors(TS) to detect real time environmental atmospheric pressure, humidity and temperature, respectively.

Mobile phone operating systems provide an Application Programming Interface(API) to manage mobile phone's sensors. Classification and comparison of mobile sensors based on smart phones manufacturing companies and API's is summarized in the figure 2.3

| | | |
|---|---|---|
| BlackBerry | AccelerometerData and AccelerometerSensor | AS readings. AS changes can be detected using the interface AccelerometerListener |
| | GPSSettings and GPSInfo | They provide access to the GPS. |
| | TouchEvent, TouchGesture and Touchscreen | TouchEvent contains touch input events originating from the user. TouchGesture detects gestures. Touchscreen provides low-level access to the touch screen. |
| WindowsTM Mobile® | Microsoft.Devices.Sensors | AS, CS, and GS readings. Motion class handles the low level sensor calculation and allows applications to obtain the device's attitude, rotational and linear acceleration. Other classes are: Accelerometer, Compass and Gyroscope. |
| | System.Device.Location | It exports the Windows Phone Location Service API enabling the development of location-aware applications. |
| Symbian | Sensors | API for receiving events from AS, ALS, CS, GS, PS, light, magnetometer, orientation, rotation, and tap sensors. |
| | Location | API that gives users the capability to develop location-aware applications. |
| | Multimedia | API that gives developers a simplified way to use audio and video playback, and access IS functionality. |
| Android | SensorManager | Class to access and list sensors (getSensorList() method), register sensor event listeners (registerListener()), and acquire orientation information. |
| | Sensor | Class representing a specific sensor (some methods: getResolution(), getPower(), getMinDelay() and getMaximumRange()). |
| | SensorEvent | Class to create a sensor event object to know the type of sensor that generated the event, the accuracy of the data, and the time at which the event happened. |
| | SensorEventListener | Interface to create two callback methods that receives notifications (sensor events) when sensor values change or when sensor accuracy changes. |
| iOS | CMMotionManager, CMAccelerometerData, CMAttitude, CMDeviceMotion, | CMMotionManager for AS, magnetometer and GS readings. Processing data of attitude, rotation rate, |

| | | |
|---|---|---|
| | CMGyroData and CMMagnetometerData | calibrated magnetic fields, the direction of gravity, and the acceleration. CMAccelerometerData represents an AS event. CMAttitude offers three different representations of attitude. CMDeviceMotion to know values of the attitude, rotation rate, and acceleration of a device. CMGyroData contains a single measurement of the device's rotation rate. CMMagnetometerData which encapsulates measurements of the magnetic field made by the device's magnetometer. |

*Figure 2.3: Classification and Comparison of mobile sensors based on smart phone manufacturing company and API functions.[2.3]*

*2) Environmental mobile sensors:*

Researcher invested their intellectual and started building advanced algorithm for data mining sensors which help to monitor the environment [2.5]. For air quality monitoring, the classic and traditional focuses are on using either fixed or mobile sensing nodes. E.g. OpenSense project in Switzerland. OpenSense has installed sensors on top of public transportation vehicles like trams and buses to provide real time monitoring of quality of air. With fast and rapid development of mobile end techniques, researchers started using independent moving devices to monitor the environment. Smart phones provide a large potential for flexible sensing and monitoring the surrounding in the environment using their embedded sensors.

The mobile phone audio sensors are used to generate noise pollution maps and to monitor them. The accelerometer sensors are used to create a community seismic network to detect earthquakes. Mobile phone sensing has gone beyond embedded sensors. Recently, an integrative sensor which is USB pluggable are build for smart phones to detect a better quality set of air information. E.g. the pluggable $O_3$ sensor (ozone).

Environmental mobile sensor also finds its application in detecting earthquakes [2.8]. The USGS offers a service named ShakeMaps. This service provides ground motion maps of earthquakes and shaking intensity, minutes after an earthquake event happens. ShakeMaps has a networks of regional stations to create estimation of ground motions. Growing number of smart phone users, specifically in urban areas, a denser mesh of mobile sensors nodes helps in creating a spatial intensity map.

*3) Healthcare mobile sensors:*

Healthcare [2.6] access, quality and affordability are problems all around the globe. There are disparities based on geography and income, and the high expenditure on healthcare present challenges for millions of different people. Not everyone receives the quality healthcare that they need.
Mobile sensing technologies offers ways to overcome with these challenges. By using mobile health applications, medical devices, and remote patient monitoring products. there are possibilities through which health care delivery can be improvised. These technologies can provide lower costs facilities of delivery care and connecting people to their health care providers.

There has been a growth in wearable sensors and remote monitoring sensor devices. Researcher have developed a *mobile electrocardiogram(ECG) system* for high risk cardiac patients. It makes use of a smart phone attached to heart monitors to transmit the data of the hearth rhythm to health providers.

Researchers have developed an inhaler with asthma sensor inbuilt. The sensor keeps a track of the environmental conditions that provides a possible danger to asthma sufferers. This device tracks how often a person is taking medicine and it provides health keepers informed about the disease management.

The following is a list [2.6] of usages of mobile sensors in medical healthcare:

- use sensors or lead which is connected to a mobile platform to determine and display the electrical signal which heart produces.
- use sensors or electrode connected to the mobile platform or within the tools of the mobile platform like speaker and microphone to electronically amplify and transmit sounds associated with the veins, arteries and heart and other organs.
- use a sensor to determine physiological parameters during cardiopulmonary resuscitation.
- use a sensor to measure and analyze eye movements for use in the balance disorder diagnosis.
- use a sensor which examine degree of tremor which is caused by certain diseases, blood glucose levels or blood oxygen saturation, electrical activity of the brain.
- Connecting a sensor to an existing device for purposes of controlling its functions, operations or energy sources.

*4)IoT, Smart city and Transportation mobile sensors:*

The Internet of Things(IoT)[2.9] is a recent communication mechanism, which has bright aspect in near future, in which objects of everyday life will be installed with transceivers, microcontrollers and suitable protocols to communicate with each other. IoT has enabled interactions and easy access to wide variety of devices such as surveillance cameras, home appliances, monitoring sensors, displays, actuators, vehicle and so on. The IoT will foster a number of application development that make use of the data generated by such objects to give new services to companies, citizens and public administrations.

A Smart city is an urban vision development to integrate IoT and information and communication technology(ICT) in a secure fashion to manage a city's assets. A smart city, indeed, may bring benefits in optimization and management of public services such as parking and transport, surveillance, lighting and maintenance of public areas, garbage collection, preservation of cultural heritage, salubrity of school and hospitals etc..

List of services provided by urban IoT sensors are given below.

*Structural Health of Buildings*: The urban IoT sensors provides a distributed database of building structures, extracted by sensors located in the building, such as deformation sensors to monitor stress of the building, vibration, humidity and temperature sensor etc.. to identify the health of the buildings.

*Waste Management*: To determine smart waste management service, the IoT sensors connect to end devices like intelligent waste containers and measures the optimal management of the collector truck

*Air Quality*: Urban IoT can provide ways to monitor the air quality in crowded areas, fitness trails or parks. In this way people can find a healthiest place for outdoor activities.

*Noise Monitoring*: Urban Iot can determine noise monitoring service to calculate the quantity of noise produced at a given hour in a place which has this service. By this service we can determine the noise polluted areas and people can choose to live in the area which are less noise polluted.
Urban IoT also provides a number of services in transportation sector. The following services are a few.

*Traffic Congestion*: Traffic monitoring is done using the GPS installed on the vehicles and the sensing capabilities also by adopting a combination of acoustic sensors and air quality sensors on a given road. By this service the driver can determine which route to take to reach the destination faster.

*Smart Parking*: This service is based on intelligent display and road sensors that direct driver along the best route for parking. This service can be integrated in the smart city infrastructure. Use of RFID and Near Field Communication(NFC) determines electronic verification system of reserved slots parking permits, parking for future residents and parking for disabled people.

*5) Wild Life mobile sensors:*

Mobile sensors in wild life is largely used to monitor the behavior of wild life animals. The sensors used here is call badger [2.7]. The monitoring system consist of distributed wireless sensor network which are designed to monitor wildlife. Active RFID transmitters are attached directly to the badger as wearable collars. This wearable collars are attached to the wild life like birds and ground animals. The activities of the animals is monitored and reported to the zoologist.

| **Badger Properties** | **Comment** |
|---|---|
| Power consumption | Low |
| Cost | Less |
| Deployment on other devices | Done easily |
| Storage | Less storage |
| Algorithm processing | Done on wireless nodes in the WSN |

*Figure 2.4: Properties of a mobile sensor badger.*

*6) Social networking mobile sensors:*

Social network [2.3] sensing includes interaction such as face-to-face interactions, co-located, chatting, social network activities and all other kinds of electronic communications. Crowd++ is a mobile app for counting number of people in different conditional or geographic scenarios. The smart phone camera is used to determine or measure body orientations. The accelerometer is used to detect vibrations from chest wall and hence activity of speech.

The challenges [2.3] of social sensing and a middleware, like Comm2sense, uses WiFi signal to recognize physical proximity that have been produced. A survey on future applications of mobile sensing reviews various ways to do mobile sensing, challenges on mobile sensing and use the web services for mobile sensing and introduce social and community aware intelligence.

## III.MOBILE SENSOR NETWORKS AND SERVICE PLATFORMS/FRAMEWORKS

### *A. Definition, motivations, advantages and challenges of mobile sensor networks*

With the increasing needs for reliable communications and sensing functions to support the ubiquitous networked computing, research on wireless, distributed and sensing nodes in network systems have been the areas of main focus these days. Study on distributed mobile wireless sensor network (*MSWN*) is an emerging topic in this area. Also known as wireless sensor network (*WSN*), *MSWN [3.1]* is a collection of small, portable and lightweight embedded mobile sensor devices with networking capabilities. Sensor is developed to monitor features such as temperature, pressure, humidity, illumination intensity, vibration intensity, sound intensity, chemical concentrations, and vital body function [3.1]. Commonly, sensor node in mobile network consists of transducer – responsible for generating electrical signal based on sensed physic effects, transceiver – receives commands from central computer and transmit data, and microcontroller powered by battery.

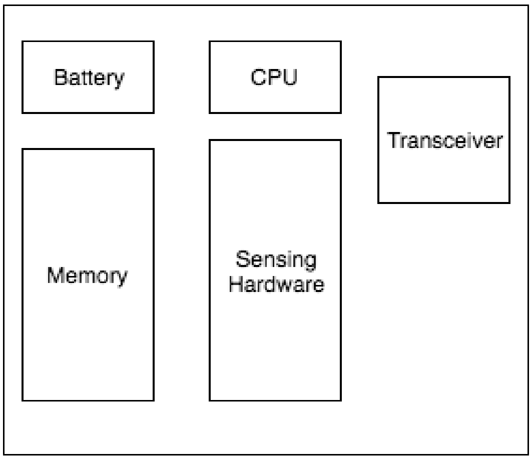


*Figure 3.1 Mobile sensor components*

Mobile network sensor is much more versatile than normal static and individual sensor networks, due to its distinguish characteristics:

1) Ability to cover wider ranges of sensing and cope with rapid network topology change.
2) In network, sensor nodes are responsible to combine data and collaborate to increase the accuracy of change data.
3) It also provides the extended functionalities, such as forwarding service.
4) Flexible to be deployed in any scenarios.

There are various types of applications in the sensor networks. Examples can include physical security for military operations, bio-medical applications, health and wellness monitoring, environmental monitoring water and air soil, industrial automation, seismic detection, and consumer applications such as smart home. Despite the diversity, sensor network poses design and technical issues, such as:

1) *Hardware constraint*: Every sensor node needs its own sensing, processing, transmission and power supply unit, in addition to built-in sensors and devices if required. Any additional functionality will require more cost and consume more power.
2) *Energy efficiency*: Limited battery power, storage and computation. [3.3] In extends, it affects production cost and reduce the network lifetime.
3) *Localization*: sensor nodes are deployed in ad hoc manner – in which sensor nodes are deployed in regions that have no infrastructure, have to identify themselves in some co-ordinate section. [3.2]
4) *Fault tolerance and vulnerability*: once deployed, sensor nodes take parts for reconfiguration in case of changes. [3.3]
5) *Routing*: Due to the energy considerations – demand that only essential minimal routing be done, traditional routing scheme could no longer be used.
6) *Dynamic change*: One of the most important challenges to improve the system, sensor network system has to be adaptable to changing connectivity, as well as changing environmental stimuli.

Large number of algorithm, techniques, and protocols has been developed to reduce energy consumption, maintain sensor network topology, and extend the lifetime of the network. Solutions for conserving energy on each network layer are also proposed as the following: [3.2]

| | |
|---|---|
| *Physical layer* | Lower power circuit design, which has adaptive RF power. |
| *MAC sub-layer* | This layer has energy-effective MAC protocol, and is responsible to reduce re-transmission and transceiver on times. |
| *Link layer* | This is link packet length-adapt layer. |
| *Network layer* | Route caching, energy aware-routing algorithm. |
| *Application layer* | Compression and frame-dropping application, layer has in-network data aggregation and fusion. |

*Figure 3.2 Energy conservation on network layer*

*B. Mobile sensors network structures.*

Wireless sensor network consists of various topology structures to support radio communication.

1) *Star network (single point-to-multipoint):* This type of network requires that the base station must be within radio transmission range, while allowing low latency communications between

the remote node and the base station. This structure provides simplicity and ability to keep the remote node's power consumption to a minimum. [3.2]

2) *Mesh network (multi-hop communications):* Node communicates with another node that is out of the radio communication ranges through intermediate forward node. Though this type of network has high power consumption, it provides redundancy and scalability the system needs in order to prevent failure of a single node crashes the systems.

3) *Hybrid Star – Mesh network:*

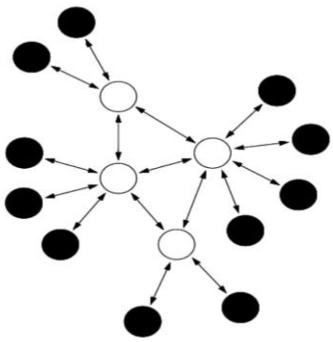

*Figure 3.3 Hybrid Star – Mesh network* [3.3]

In hybrid Star-Mesh network, "sensor nodes with lowest power are not enabled with the ability to forward messages". [3.3] In this network structure, the nodes with multi-hop capability have higher power, and are often plugged into electrical main lines. This is a robust and versatile network that also keeps minimum power consumption.

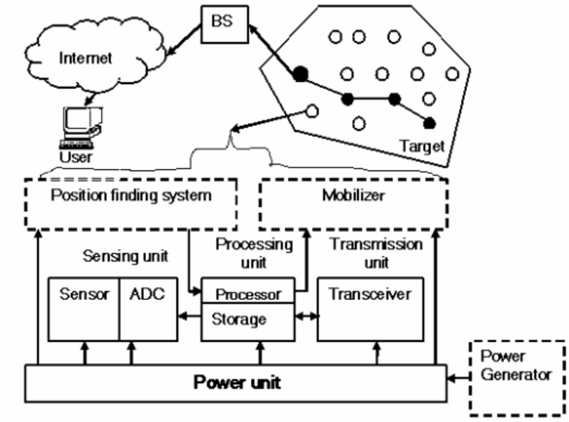


Figure 3.4 Basic architecture of mobile sensor network [3.3]

Mobile sensor network structures are usually studied in network and nodes level. Mobile network architecture can be classified into three types: [3.12] [3.3]

1) *One-layer (Flat or planar network)*: In this architecture, heterogeneous devices communicate with each other in an ad hoc manner. All communications happen over the same network, and the devices can be mobile or stationary [3.12]. However, with the ad hoc model, planar network poses some disadvantages on network performance. When data sent from one node to the next in a multi-hop network, there is a possibility that a packet may be lost. When a node sends a packet to neighbor node, and the neighbor node do the forwarding, the process takes energy. The bigger the network is, the more nodes must forward data and more energy is consumed.

2) *Two-layer network*: The network architecture consists of a combination set of stationary nodes and mobile nodes. The mobile nodes form an overlay network and act as data mules to help moving data through network. The overlay network includes mobile devices, which have greater processing capability, higher bandwidth and longer communication range. The density of overlay network is structured in the way that all nodes are always connected. When nodes become disjoint, mobile entities position themselves to re-establish connectivity, to ensure network packets to reach the intended destinations. There are 2 common types in two-layer network structure: (1) two-tier sensor network

with ad hoc configuration and (2) two-tier sensor network with no ad hoc overlay. [3.3] In the first structure, all the mobile agents are self-organized into an ad hoc network; the slower the mobile agents move, the more stably the overlay can be persisted. Some wireless techniques, such as Bluetooth and IEEE 802.11, are suitable for this structure. However, when mobile phone is small or belongs to sparse network, the second structure is preferred in order to avoid data loss in node forwarding. In two-tier sensor network with no ad hoc overlay structure, when each mobile phone gathers some data from sensor nodes, it caches the data in its available memory, and does not forward to access point or peers simultaneously – which improve performance in packet forwarding.

3) *Three-layer network*: The network architecture consists of a set of stationary sensor nodes passing data to a set of access points. It is designed to cover wide network areas and can be compatible with several applications simultaneously. For example, to monitor parking space availability in parking garage: the first layer senor network broadcasts availability to update to the mobile devices (second layer), the second layer – such as cell phones or PDAs, will forward this availability data to access points (third layer) to upload into a centralized database server.

At the nodes level, mobile sensors are categorized based on roles in sensor networks: [3.3]

1) *Mobile embedded sensor*: In this architecture, the external forces direct the motion of sensor network – such as when attached to shipping container.
2) *Mobile actuated sensor*: Sensor nodes have locomotion capability, which enables them to move throughout the sensing region. This control mobility enables the accuracy of the deployment specification and maximizes the coverage.
3) *Data mule*: Mobile device needs to collect data to deliver to base station.
4) *Access point*: Mobile nodes can position themselves to maintain network connectivity in spare networks, or when a node drops off the network.

*C. Mobile sensors network protocols and comparison*

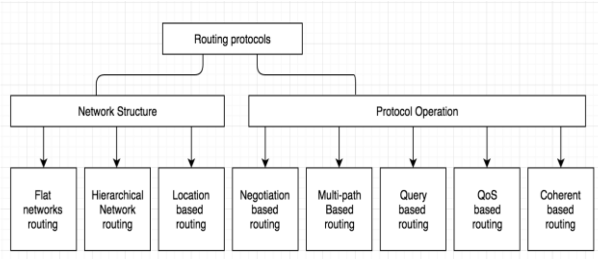


*Figure 3.5 Routing protocols taxonomy in WSN*

Routing techniques are required for sending data between sensor nodes and the base stations for communications. In general, the design of routing protocols in mobile sensor network is influenced by many challenging factors such as node deployment and link heterogeneity, energy consideration, data delivery model, fault tolerance, connectivity, scalability, data aggregation, coverage and quality of service. Routing protocols algorithms are classified based on different parameters and criteria, such as hierarchy role of nodes in network, data delivery model and optimization techniques for routing in Wireless Sensor Networks. Routing protocols are divided into seven categories, which are structured to serve different purposes, in mobile sensor network [3.7, 3.8]. The following table shows each type of protocol classifications: [3.9]

| **Category** | **Representative Protocols** |
|---|---|
| *Location-based protocols* | GEAR (Geographic and Energy-Aware Routing), GAF (Geographic Adaptive Fidelity), TBF (Trajectory-Based Forwarding), BVGF (Bounded Voronoi Greedy Forwarding), MECN (Minimum Energy Communication Network). |
| *Data-centric protocols* | SPIN (Sensor Protocols for Information via Negotiation), Directed Diffusion (DD), Rumor Routing, COUGAR, ACQUIRE (Active Query Forwarding in Sensor Networks), EAD (Energy-Aware Data-Centric Routing), Information-Directed Routing, Gradient-Based Routing, energy-aware Routing, Information-Directed Routing, Quorum-Based information Dissemination. |
| *Hierarchical* | LEACH (Lower-energy adaptive |

| | |
|---|---|
| *protocols* | clustering hierarchy), PEGASIS (Power-Efficient Gathering in Sensor Information Systems), TEEN (Threshold Sensitive Energy Efficient Sensor Network Protocol), HEED (Hybrid, Energy-Efficient Distributed Clustering), APTEEN (Adaptive Periodic Threshold Sensitive Energy Efficient Sensor Network Protocol) |
| *Mobility-based protocols* | SEAD (Scalable Energy-Efficient Asynchronous Dissemination), TTDD, Data MULES, Dynamic proxy Tree-Base Data Dissemination |
| *Multi-path based protocols* | Sensor-Disjoint Multipath, Braided Multipath, N-to-1 Multipath Discovery |
| *Heterogeneity protocols* | IDSQ (Information-Driven Sensor Query), CHR (Cluster-Head Relay Routing) |

*Figure 3.6 Classifications of Mobile Sensor Routing Protocols* [3.9]

*1) Location-based Protocols*: Sensor nodes are addressed by means of their location, the model calculates the distance between two particular nodes so energy consumption can be estimated.

*2) Data Centric Protocols*: data is sent from source sensors to the sink. When the source sensors send their data to the sink, intermediate sensors can perform some form of aggregation on the data originating from multiple source sensors and send the aggregated data toward the sink. This process requires less transmission, which can result energy saving.

*3) Hierarchical Protocols*: This model breaks the network into clustered layers: nodes are grouped into clusters with a cluster head or base stations. Data travel from the lower clustered layer to a higher one, and this hop covers larger distance, which moves data faster to the base station.

*4) Mobility-based Protocols*: To guarantee data delivery from source sensor, sink mobility requires energy-efficient protocols.

*5) Multipath-based Protocols*: In this routing algorithm, each source sensor finds the first k-shortest paths to the sink and divides its load evenly among these paths. Multipath communications can be accomplished in two ways: [1] one path is established as active communication routing while other paths are stored for future need when the current path is broken; [2] Distribute the traffic among the multiple path.

*6) Heterogeneity-based Protocols*: In this network architecture, sensors use available energy efficiently by minimizing the potential of data communication and computation.

*7) QoS-based Protocols*: The architecture focuses on supporting reliability, delay and fault tolerance in routing in mobile sensor network. For instance, a routing protocol could be designed to extend the network lifetime while an application demands sample rate which forces periodic transmissions and energy consumptions.

The study surveys the characteristics of different routing protocols and result the comparison table for hierarchical and flat routing: [3.9]

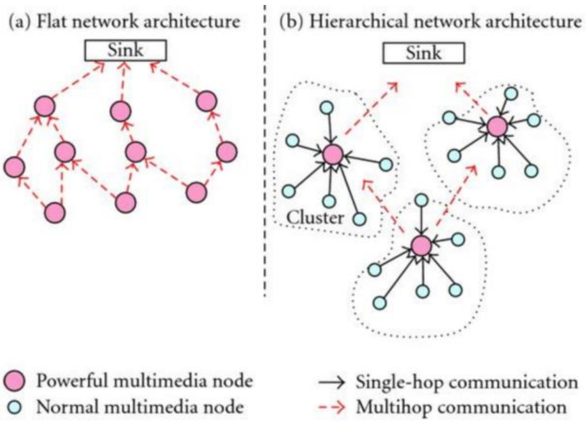


*Figure 3.7.1 Comparison between hierarchical and flat topologies routing [3.10]*

| Flat routing | Hierarchical routing |
|---|---|
| Scheduling type is contention-based. | Scheduling type is reservation-based. |
| In this type of routing, collision overhead might happen. | Collision can be avoided. |
| Node on multi-hop path aggregated the neighbors' incoming | Clustered head is responsible for data aggregation. |

| | |
|---|---|
| data. | |
| Routing is made to be optimal, but can be added with complexity. | Non-optimal routing and simple routing. |
| Links are formed on the fly without synchronization. | Routing requires global and local synchronization. |
| Routes are formed only in regions – which have data for transmission. | Clusters formation happens throughout the network overhead. |
| Latency will wake up intermediate nodes and setting up the multipath. | Multiple hops network, which usually has a lower latency, formed by cluster-heads always available. |
| Energy dissipation can adapt to traffic patterns. | Energy dissipation cannot be controlled. |
| By controlling sleep time of nodes, the routing can have variety of duty cycle | Duty cycle is reduced, due to periodic sleeping. |
| Fairness not guaranteed. | Fair channel allocation. |

*Figure 3.7.2 Hierarchical vs. flat topologies routing [3.9]*

Popular protocols are also surveyed and compared in power usage, position awareness, data aggregation, localization, QoS, scalability and state complexity.

| | | Mobility | Position Awareness | Power Usage | Negoti-ation based | Data Aggregation | QoS | Localization | State Comple-xity | Scalab-ility | Multi-path | Query-based |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | GEAR | Limited | No | Limited | No | No | No | No | Low | Limited | No | No |
| 2 | SPIN | Possible | No | Limited | Yes | Yes | Yes | No | Low | Limited | Yes | Yes |
| 3 | LEACH | Fixed BS | No | Maxi-mum | No | Yes | Yes | No | CHs | Good | No | No |
| 4 | TTDD | Yes | Yes | Limited | No | No | No | No | Mode-rate | Low | Poss-ible | Possible |
| 5 | DD | Limited | No | Limited | Yes | Yes | No | No | Low | Limited | Yes | Yes |
| 6 | TEEN | Fixed BS | No | Maxi-mum | No | Yes | Yes | No | CHs | Good | No | No |
| 7 | SPEED | No | No | N/A | No | No | No | Yes | Mode-rate | Limited | No | Yes |

*Figure 3.8 Network protocol comparison [3.9]*

### *D. Mobile sensor service platforms and comparison*

By definition, sensors on mobile devices can enable attractive sensing applications in different domains, such as healthcare, transportation, environment monitoring, and social network. [3.10] Sensing as a service is a new concept, which provides sensing services using mobile phone via cloud computing system. The platform need to meet the following requirements in architecture:

1) Sensing as a service should be able to support various mobile sensing applications on different smartphone platforms.
2) The system manages energy efficiently.
3) The system has effective incentive mechanisms, which are used to attract mobile users to participate in sensing activities.
4) Service should address potential privacy threats and security concerns.

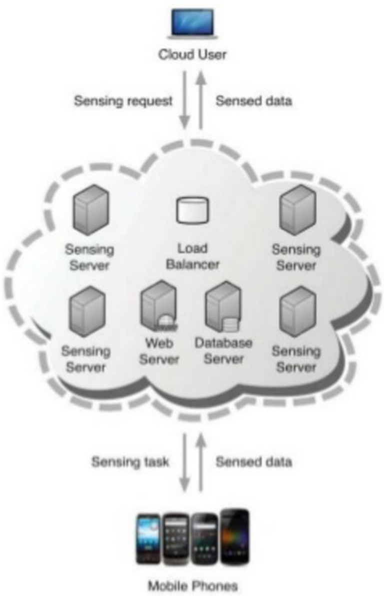


*Figure 3.9 Sensing as a service architecture [1.3]*

Figure 3.9 illustrates how sensing as a service work. When a cloud user initiates a sensing request (Eg: through an online form in a web server from mobile devices), the request will be forwarded to a sensing server. This server then will push the request to a subset of mobile phones that happen to be in the area of interest. The corresponding sensing task will be fulfilled by these mobile phones. The sensed data will then be collected by a sensing server, stored in the database and returned to the requester. [1.3]

Primarily, there are two main mobile sensing paradigms:

1) *Participatory sensing*: Mobile users actively engage in sensing activities, manually determine how, when, what and where to senses.

2) *Opportunistic sensing*: In this model, sensing activities are fully automated without involvement of mobile users.

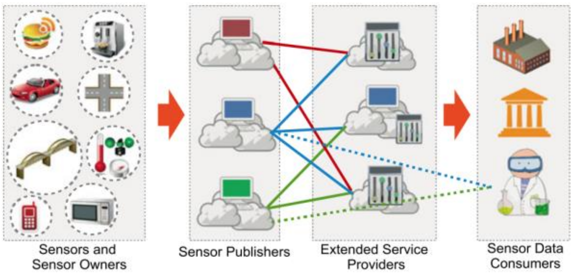


Figure 3.10 Model architecture of sensing as a service [1.3]

In details, the "sensing as a service" consists of four conceptual layers:

1) *Sensor and sensor owners layer*: The sensor owner makes the final decision on whether to publish the sensors that he owns in the cloud. This model protects the security and privacy, and prevents unwanted data published to SP layer.

2) *SPs layer*: By obtaining permission to publish to cloud, SPs layer collects information about the owner preferences, the sensor availability, and the expected returns and restrictions. The examples on open sources library are Xively, and OpenIoT.

3) *ESPs layer*: This is considered intelligent layer, whose services could be widely ranged from one provider to another.

4) *Sensor data consumer layer*: This model consists of sensor data from consumers. All sensor needs to registered with a valid certificate in order to consume data. Sensor data consumers do not directly communicate with sensors or sensors owner: all the transactions are performed through either SPs or ESPs.

In this study, we are comparing two popular sensing platforms Arduino and Raspberry Pi. Arduino is a true trailblazer in the microcontroller area, while Raspberry Pi is the start for microprocessor revolution. The table below display differences in these two platform [3.11]

| Arduino Uno | Raspberry Pi |
|---|---|
| ATMega 328 Processor | Arm11 Processor |
| 16MHz in speed | 700MHz in speed |
| 2KB RAM size | 512MB RAM size |
| No audio and video support, no Ethernet support | Support HDMI, Analog and Ethernet |
| I/O: 14GPIO, 6 10-bit analog | I/O: 8GPIO |
| | Operated on Linux operating system. |

*Figure 3.11 Arduino and Raspberry Pi comparison*

## IV.IOT SENSING AND MOBILE SENSOR CLOUD INFRASTRUCTURES AND SYSTEMS

### *A. Overview of mobile sensor-cloud infrastructure*

1. What is Internet of things?

The term "Internet of Things" was first used by Kevin Ashton in 1999, when he presented about supply chain management. Up till now the term is extended with the broaden of "things" that went out the border of supply chain management. One of the most popular definitions which is currently in use is:

> *"The "Internet of Things" is the general idea of things, especially everyday objects, that are readable, recognizable, locatable, addressable, and controllable via the Internet - whether via RFID, wireless LAN, wide-area network, or other means."* - U.S. National Intelligence Council

2. IoT sensing and mobile sensor:

Study about IoT Cloud Computing architecture is mostly at early stages. Most of the researches are coming from the wireless sensor network (WSN) architecture perspective. However, they proved to be successful because of the similarities between IoT Sensing and Mobile sensors. With the popularity of wearable devices such as smart phone, smart watch, Google class…which is integrated with internal sensors and actuators, each "thing" now become a mobile sensor

3. Mobile sensor cloud computing infrastructure

Mobile sensors have big advantages over static sensors that come from their mobility nature. For instance, when measuring the pollution of city base on the CO2 level, instead of deploying thousands of sensor around the city, equip those sensors on garbage collector truck will provide bigger geo-coverage and the transient from low to high level of CO2 between area or time during the day.

Combination of WSN and cloud computing bring the power of cloud technology to solve the existing problem with mobile sensing: distributed data integration, big data analysis, storage…especially the limited computing power of mobile sensor hardware. The overview infrastructure of Mobile sensor cloud can be depicted as in Figure 4.1 below:

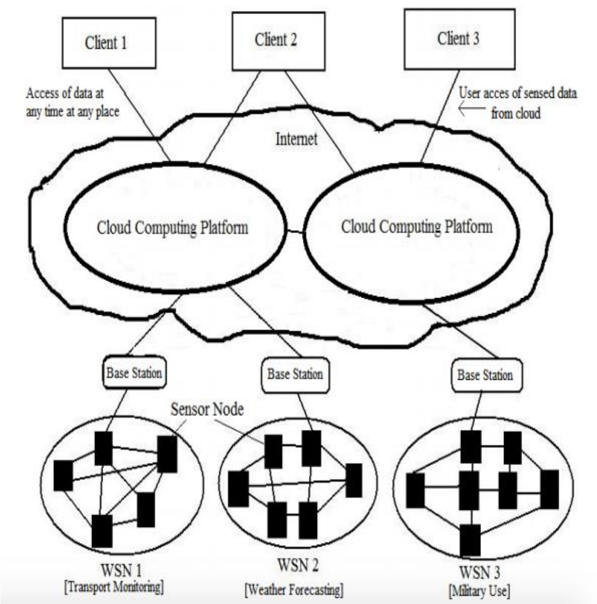


*Figure 4.1 high level overview of WSN Cloud infrastructure*

Each rectangle in the bottom stands for a WSN which connect to the cloud through a base station. Each mobile sensor is a node in a particular WSN. The connectivity to each mobile sensor is managed by that WSN (cellphone GSM network, Wifi network, WiMax..).

Fig4.2 depicted how WSN integrate to the cloud. Sensors owner can easily join the cloud infrastructure. Sensor management service makes it easy to register or remove their sensor off the grid, while maintains the quality and loyalty of sensor owner.

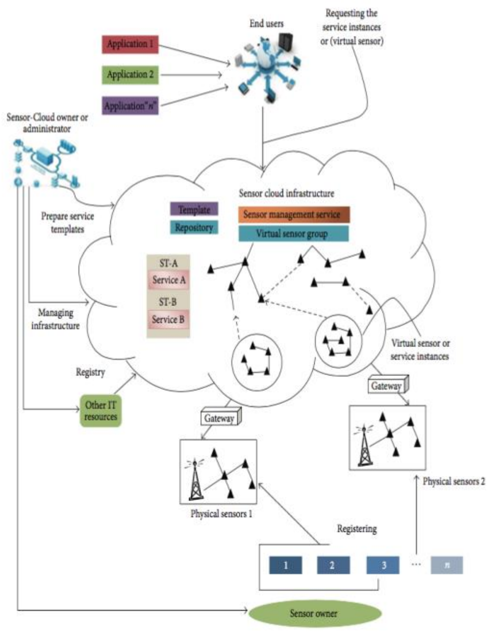


*FIGURE 4.2: Overview of Mobile Sensor-Cloud and service life-cycle architecture [4.9]*

At a more detail level, the sensor cloud infrastructure can be divide into 3 layers as in Fig.4.3. Layer 3 responsible for dealing with physical sensor and their heterogeneity nature. Layer 2 provides an abstract container in the form of Virtual Sensor, make it easily for physical sensor to be shared and allow multi tenancy. Users request virtual sensors or virtual sensor groups by selecting templates, provisioning and release them when they become unnecessary. A friendly web GUI makes it easy for user to access the Mobile Sensor Cloud Infrastructure.

Users can control their virtual sensors directly or via their Web browsers. Mobile Sensor-Cloud infrastructure also provides the users with monitoring functions for the virtual sensors.

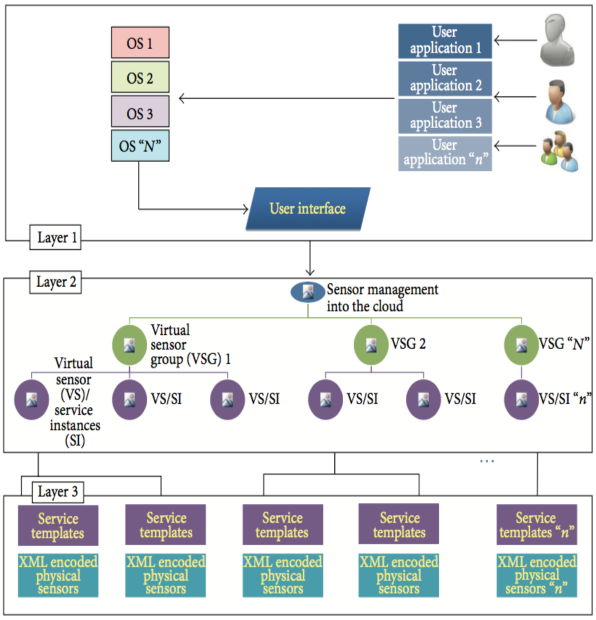


*Figure 4.3. Relationship among Virtual Sensor Groups, Virtual Sensors, and Physical Sensors [4.8]*

There are many various physical sensors owned by different owners. When an application or middleware needs to use some sensors, the required sensors should be dynamically organized. Below are some key characteristics that the infrastructure must have in a mobile sensor cloud:

a) Virtualization: things or mobile sensor are highly heterogeneity and scattered. An abstraction layer is necessary to hide the locations and the specifications of physical sensors. Fig.4.3 describes the relationship among virtual sensor groups, virtual sensors, and physical sensors. Each virtual sensor is created from one or more physical sensors. A virtual sensor group is created from one or more virtual sensors. Base on their need, users will create virtual sensor groups and include all the sensors they need. They can activate or inactivate their virtual sensors, check their status, and set the frequency of data collection from them...

b) Standardization: different kinds of "things" and physical sensors have different mechanism to control and collect data.. By virtualizing the physical sensor and define standard functions for virtual sensors, we enable users to access sensors with the standardized functions without concern for the differences among the physical sensors. Mobile Sensor-Cloud infrastructure translates the standard functions for the virtual sensors into specific functions for the different kinds of physical sensors.

c) Automation: Mobile Sensor-Cloud infrastructure is an on demand service delivery and supports the full lifecycle of service delivery from the registration of physical sensors through creating templates, requesting of virtual sensors, provisioning, starting and finishing to use virtual sensors, and deleting the physical sensors. These forms of support are automatic and delivered without human operations. This will help improve the service delivery time and reduce the cost.

d) Monitoring: mobile sensors have more connectivity problem than static sensors. There're higher chance they're off the grid due to numerous reasons. Applications owner will need tool to monitor availability of sensors to sustain the quality of their services.

e) Grouping: Mobile Sensor-Cloud infrastructure can provide virtual sensors as virtual sensor groups. Users can control each virtual sensor and virtual sensor groups, set the access control and the frequency of data collection for virtual sensor groups.

f) Service Model: Mobile Sensor Cloud Infrastructure support multi-tenant, sharing various sensors as a service. Mobile Sensor-Cloud infrastructure is responsible for maintaining the quality of the service. We define the roles assigned to the participants joining the service, considering their merits and creating an appropriate cost model to support the service.

4. Comparison between approaches [4.8]:

| | **Pros** |
|---|---|
| Sensor-Cloud Infrastructure | - End users can use sensors without worrying about the details<br>- End users can control their virtual sensors freely.<br>- End users can monitor the status of their virtual sensors.<br>- End users can start to use the virtual sensors quickly by automatic provisioning and release them when they become unnecessary.<br>- End users can create the group of sensors dynamically by virtual |

| | |
|---|---|
| | sensor groups<br>- Sensor owner can check the usage of their physical sensors. |
| Direct Sharing Physical sensors | Direct sharing physical sensors does not have to prepare IT resource or the templates.. |

And cons:

| | Cons |
|---|---|
| Sensor-Cloud Infrastructure | - Sensor-Cloud infrastructure should prepare IT resource.<br><br>- Sensor-Cloud administrators have to prepare the templates for virtual sensors. |
| Direct Sharing Physical sensors | - End users cannot check the status of the sensors.<br>- End users should know the details of the sensors..<br>- End uses cannot select the sensors dynamically.<br>- End users cannot use the sensors only during the sensors are needed. |

*B. Services of IoT & Mobile sensor cloud:*

1. Services life-cycle

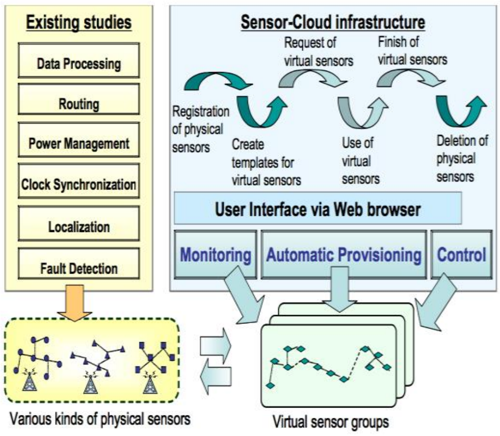


*FIGURE 4.2. Overview of Mobile Sensor Cloud Infrastructure [4.8]*

We define the participants in the service as actors and describe them in next section

2. Actors on Sensor-Cloud Infrastructure [4.8]

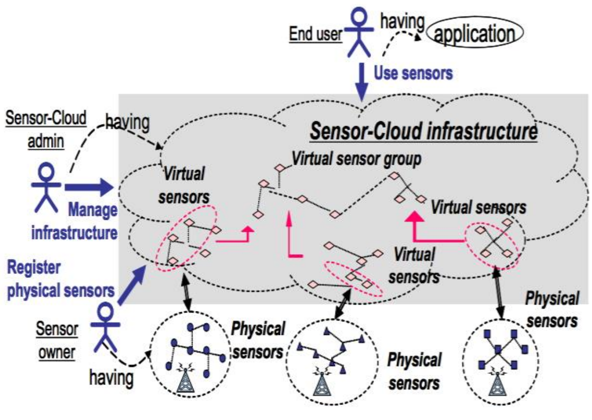


*Figure 4.4 Relationships between actors and mobile sensor cloud Infrastructure [4.8]*

a) Sensor Owner: A sensor owner is an actor who owns physical sensors.

- Registers the physical sensors with their properties to Mobile Sensor-Cloud infrastructure
- Deletes the registration of sensor when s/he quits sharing them.
- Get rental fee for using the physical sensors. The fee reflects the actual usage of the physical sensors.

b) Mobile Sensor-Cloud Administrator: manage all the services provided by Mobile Sensor Cloud

Infrastructure.

- Manages the IT resources for the virtual sensors, monitoring, and the user interfaces.
- Prepares the templates for the virtual sensors and for some typical virtual sensor groups.
- Charge the end users for the delivery of the Sensor-Cloud infrastructure service.
- Paid the sensor owner base on the usage on their sensor

c) End User: the actor with one or more applications or services that use the sensor data with no detailed knowledge about the physical sensors.

- Requests the use of virtual sensors or virtual sensor groups that satisfy the requirements from the templates.
- Use/modify existing template of virtual sensor group created by Mobile Sensor Cloud Administrator or creates a new template. End user can share their template.
- Control her/his virtual sensors directly or via a Web browser.
- Monitor the status of the virtual sensors. When they become unnecessary, end user can release them.
- Paying for usage of sensor data/actuator

2. Services and comparison [4.10]:

| Services | Functionalities |
|---|---|
| SaaS (Sensing as a Service) | Providing ubiquitous access to sensor data; |
| SAaaS (Sensing and Actuation as a Service) | Enabling automatic control logics implemented in the Cloud; |
| SEaaS (Sensor Event as a Service), | Dispatching messaging services triggered by sensor events; |
| SenaaS (Sensor as a Service) | Enabling ubiquitous management of remote sensors; |
| DBaaS (DataBase as a Service), | Enabling ubiquitous database management; |
| DaaS (Data as a Service) | Providing ubiquitous access to any kind of data; |
| EaaS (Ethernet as a Service) | Providing ubiquitous layer-2 connectivity to remote devices; |
| IPMaaS (Identity and Policy Management as a Service), | Enabling ubiquitous access to policy and identity management functionalities |
| VSaaS (Video Surveillance as a Service), | Providing ubiquitous access to recorded video and implementing complex analyses in the Cloud. |

*C. Involved issues and Challenges*

1. Design Issues. The complexity to build an application on Mobile Sensor Cloud is huge, besides there's great amount of issues to be handled. One particular issues with mobile sensor is a reliable and continuous transfer of data from mobile sensor devices to the server. For example, the connectivity from the mobile sensor to the gateway can be lost when the sensor moves out of coverage area. [4.8] [4.9]

2. Power (Battery)/energy efficiency Issues. Wireless connection uses more energy than a wired connection. This issues become more severe when mobile sensor usually has low power battery and the continuous data transmission to the would drain the battery very quickly. Thus, energy saving is a major issue and energy efficient management is more than desirable [4.8]

3. Event Processing and Management. There're many complex event processing and management issues to be solved [4.8]:

(a) The events may come from different sources in different time. With delay in network, how the events should be synchronized?

(b) Change management. When event-processing rules change, how to apply it without affecting the system?

(c) Different sensors come with different type of messages and events. How the messages and events of varying types are supported?

(d) The number of events and its conditions is enormous, how to support in an optimal way?

4. Service Level Agreement (SLA) Violation. End-

users demand a specific level of Quality of Service. So, we need a reliable dynamic collaboration among cloud providers. Agreement between cloud providers to provide a single standard of QoS to end-user is still a big challenge in terms of cost, time, and discrepancy. [4.8]

5. Security and Privacy Support Issues. As not just sensors but "things" are connected to the internet. It's very dangerous if a hacker can hijack into the system, take control and get very private and sensitive info from wearable devices of sensor's owner. Worse, hacker can take control and send command to the actuator to initiate action in physical world and cause harm to the sensor owner.

6. Real-Time Multimedia Content Processing and Massive Scaling. Current technologies have their limitation and cannot completely solve all issues related to the complexity of big data. Data from IoT sensing is huge and require great processing power. The gap between data available and data can process is getting wider. New technologies and data processing techniques are required to analyze large volumes of data faster with efficient resource and power consumption [4.8]

7. Bandwidth Limitation. Bandwidth limitation is one of the current big challenges that have to be handled in Sensor-Cloud system. The number of sensor devices and their cloud users increases dramatically [4.12]. The number of IoT devices will reach 50 billion by 2025 (Cisco estimation). It's a very difficult task to manage the bandwidth allocation for a gigantic infrastructure consisting of huge number of device assets and cloud users. [4.8]

8. The need for standard. IoT is highly heterogeneity so a standard protocol, architecture and APIs are very necessary to facilitate the interconnection between IoT and services that interact with IoT [4.13]. [4.8]

9. Pricing Issues. The services of Mobile Sensor-Cloud involve both the sensor-service provider (SSP) and cloud- service provider (CSP). Therefore, both SSPs and CSPs have to solve the differences in their customer's management, services management, and modes and methods of payments and pricing. [4.8]

10. Maintenance Issues. In order to keep the end users' loyalty, the cloud should cope with the service failure. For this a regular maintenance is needed and redundancy techniques should be implemented to ensure the smooth and continuous flow of services. [4.8]

## V.CONCLUSION AND FUTURE WORK

In this paper we have presented our research on the topic "mobile sensing and mobile cloud services". Enlisted and compared the various existing mobile sensors and how they can be used in developing smart applications. Discussed the different mobile sensor networks and service platforms. Provided the advantages of mobile sensors over static sensors and how it aids in developing a Smart City. Threw some light on IoT sensing. Since IoT sensing is a new topic our research is based on the findings of Wireless Sensor Network architecture because of its resemblance to IoT sensing. In reality the actual findings of IoT sensing and architecture is yet to be researched in depth.

One of the future directions for mobile sensing and cloud services would be in the development of context-awareness applications. This can be achieved by eliminating the present software architecture challenges in mobile devices such as bandwidth limitations, power (battery) issues, energy efficiency, security and privacy etc. and design a context-aware framework application which has a fine balance between power efficiency, application accuracy, adaptability to user preferences and applies lesser computational workload [5.1]. Existing research on ubiquitous sensing has proved that introducing artificial intelligence and situational awareness could enhance the quality of lives [5.1].

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