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# Integrating IoT and Cloud Computing for Wireless Sensor Network Applications

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***Abstract***
The next industrial revolution is the Internet of Things (IoT) and Cloud Computing, on integrating both the technologies for Wireless Sensor Network (WSN) applications, a user can get an access to data that is managed at a remote server. At the source end, IoT generates huge data, cloud computing can process this huge data and provides a pathway that sends the data to the destination. Both the technologies can work hand in hand to improve the effectiveness of day to day life. In a world filled by digital inventions, privacy, security, reliability, availability, portability and cost are of major challenges. This chapter will focus on discussing WSN in IoT and Cloud platform. The first section covers an introduction to IoT Cloud and WSN architecture. The second section discusses the challenges and opportunities of IoT Cloud. The third section is a case study, where an application of WSN in IoT Cloud framework is discussed. Finally, the chapter ends with the conclusion, future of WSN and its areas of deployments in the fourth chapter.

***Keywords*:** Cloud computing, IoT, IoT cloud framework, wireless sensor network

## 7.1 Introduction

IoT together with Cloud computing and Wireless sensor networks will empower our lives. It was expected that by the year 2020, around 40 billion smart devices will be connected with each other by integrated technologies.

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To understand the applications powered by these technologies the basic architectures should be examined.

### 7.1.1 IoT Architecture

IoT is the buzz word in today's world, where IoT in combination of other technologies makes living easy. Architecture is designing a complex real-world concept. The IoT architecture varies according to applications and solutions, but the major layers remain the same, below as shown in Figure 7.1 are some layers of IoT architecture that best explains a conceptual design of the structure and working [1].

*Sensor Layer:* The boundary sandwiched between the level of the physical biosphere and the information dominion is said to be a sensor layer. It is also the base of the Internet of Things [2]. It possesses bar code, positioning, and sensor technology to gather information with the benefit of regulatory objects by the actuator [3]. The key component consists of a camera, code reader, RFID tags, and various types of sensors. Thus, the sensor layer has the foremost purpose of data collection, statistical observation at the completion of the control object.

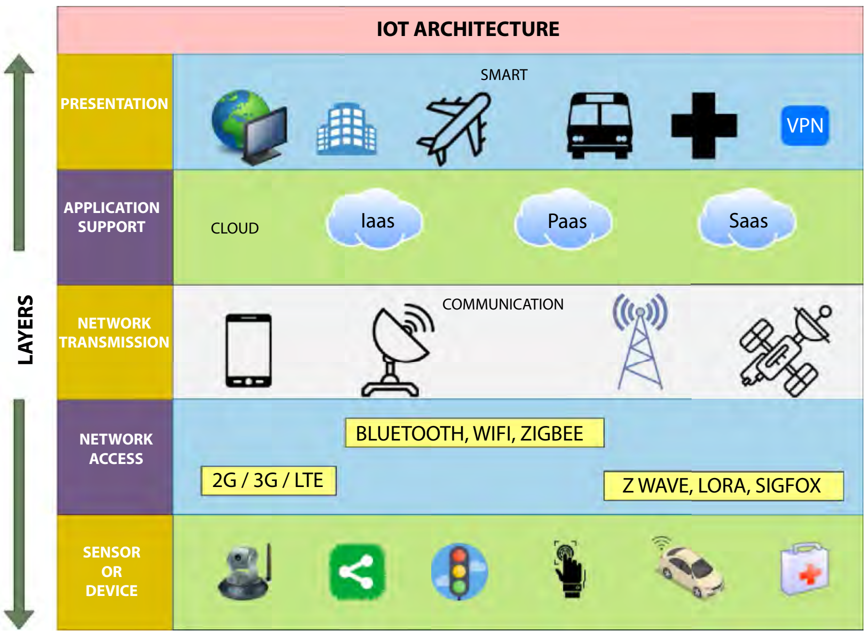


**Figure 7.1** IoT architecture.

*Network Access Layer:* This layer possesses a base station and an access gateway. It is used for data fusion of each node and forwards the information to the network transmission layer. When the sensor layer has ample data, it uploads the information and focuses the transmission to the nearby base station. In return, the base station receives information via the access gateway and is forwarded towards the network transmission layer. Similarly, the data downlink happens when the application layer sends the data to the network access gateway, from there it is then forwarded to the base station node and finally to the sensor layer [4]. Hence, the advancing of information is done by the interface among sensor and the network transmission layer. Some existing methods in this layer are 2G/3G, ZigBee, WIFI, Bluetooth, Lora, Sigfox, etc.

*Network Transmission Layer:* This layer is important to exchange information during transmission. The network transmission provides required applications and facilities for a wide range of communication such as mobile communication, satellite communication, the internet, so on and so forth. The neutral access and unified combination of diverse networks the modes of communication, the method of broadcast and interchange volume with end to end are the roles of this layer.

*Application Support Layer:* IoT design architecture uses cloud computing at the application support layer. The essential characteristics of cloud are well-known, scalability and elasticity, on demand service, broadband access, resource sharing and multi-tenancy, etc. Big data analytics, machine learning, data mining, deep learning tools can be deployed on the cloud by the developers.

IaaS refers to Infrastructure as a Service, it is a cloud infrastructure service that allows users to access resources when needed on demand rather than purchasing the hardware. Through virtualization technology, the operating systems, memory, servers, etc. are delivered to the customer. Infrastructure as a Service cloud be considered as a virtual centre for data.

The Platform as a Service (PaaS) allows developers to use the virtually deployed software and customize their applications. This service contributes a platform over which a software can be created. So the user need not have to invest money on the operating system, memory and other infrastructure.

Software as a Service (SaaS) is an application service hosted by the cloud. With internet a user can access the applications through a web browser. This greatly decreases the time, effort and cost being invested on software installation and maintenance.

*Presentation Layer:* The key feature of the presentation layer is the growth of several IoT applications based on the processing of information in the previous layer and also customs technology intelligent transportation, virtual reality, and an interface between human and computer is built for the boundary of smart application among the Internet of things and the user.

IoT Device Layer Architecture

The device layer in the IoT architecture in turn comprises four layers. The base layer contains IoT devices like sensors that possess the skill to compute, sense and connect additional devices. The IoT gateway also known as aggregation layer is the second layer, and it collects statistics from many sensors. These two layers are joined to form a data aggregation. The succeeding layer built on cloud, named processing engine or else event processing layer which holds abundant algorithm and data processing elements. The last layer is termed as the API management or application layer, it provides a boundary between infrastructure and third-party applications. The complete architecture is maintained by device managers and is used to provide security.

The IoT device layer architecture consists of four layers. The key component of the architecture is the device layer which holds devices (sensors). It is directly linked to the communication layer. The gateway or communication layer owns Representation State Transfer (REST) related and extra application protocols [5, 6]. The bus layer otherwise called aggregation layer performs as a message dealer that customs a bond between the data as well as the communication layer. It is supported by the HTTP server and the MQTT server and facilitates communications by bridges and gateways. The subsequent layer is the analytics and event processing layer that drives data then delivers transformation. This can be fed into the API management systems [7]. This system helps to communicate the systems outside the network using a machine to machine communication.

### 7.1.2 Cloud Front End and Back End Architecture

Cloud is a data center that consists of servers made up of many computers. Among the servers, some are devoted to respond to the requests from end users. Roughly any kind of programming package can be executed in a cloud model. Any program of its kind will have its own devoted server that is dedicated to respond to the request from the user. This includes major process like traffic monitoring and load balancing and authenticates the smooth conduction of the process. Data cloning is done, that is creating multiple copies and distributing the copies to all the computers in the network, this facilitates redundancy, this is the way servers are connected and they communicate internally. This also allows the data to be available even after replacing any computer. For user of the cloud infrastructure, the architecture remains like a black box, everything looks simple even though the data centre handles most complicated things. The user needn't have to maintain the hardware and software involved in cloud, while it's enough to manage the application alone. Figure 7.2 shows the Cloud Architecture.

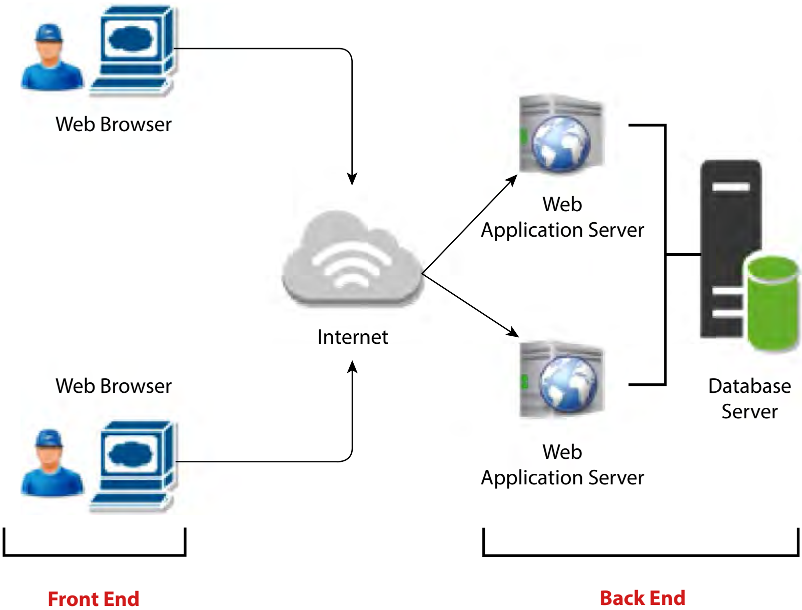


**Figure 7.2** Cloud architecture.

### 7.1.3 Wireless Sensor Network

Wireless Sensor Network follows ad hoc fashion where sensors are deployed in an area with no central controller i.e. decentralized self-organized with self-healing and self-reconfiguration capability. The information is collected and communicated via wireless links. The sensor nodes could be equipped with many types of sensors for different applications like measuring the heat (thermal sensor), measuring the pressure (pressure sensor), measuring the weather (temperature sensor), measuring acoustics (sound sensor), measuring the light intensity (optical sensor) etc. [8].

*Architecture of WSN*

WSN architecture trails the OSI model as shown in Figure 7.3. This architecture comprises of 5 layers and 3 cross layers. The layer's work together to accomplish a particular task that makes the network complete and efficient. Starting from the lower edge is the physical layer followed by data link layer and network layer and following next is the transport layer and then the application layer and the three cross planes are task, mobility and power management planes [9, 10].

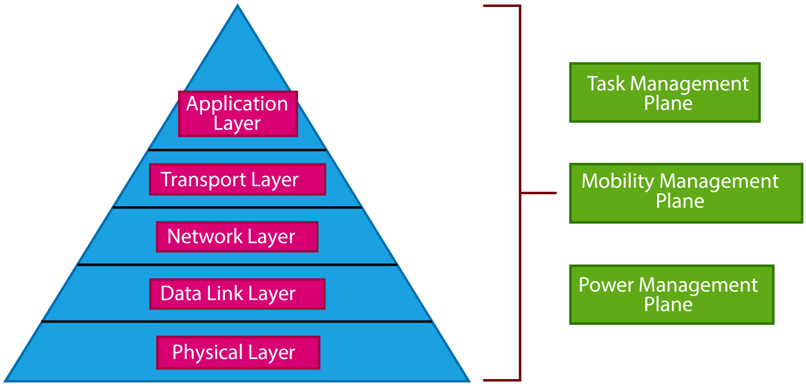


**Figure 7.3** WSN architecture.

*Physical Layer:* This layer is a physical medium that carries the data as a stream of bits. Frequency generation for carrier signal, modulation, demodulation, encryption and decryption functions are carried out based on the data at the physical layer. A wireless sensor network IEEE 802.15.4 supports low data rate with low cost at low range but improved battery life [11]. This IEEE 802.15.4 has many versions for different applications. To prevent pollution of data at this layer CSMA/CA protocol is used.

*Data Link Layer:* It is the second layer that is responsible to transfer data between nodes in a network. For data transfer this layer uses MAC protocol that solves the problem of cochannel interference. The data link layer is held accountable for error control and trustable point to point and point to multipoint communication.

*Network Layer:* In computer network each device has an IP address for identification among networks and has a central controlling device, whereas in a sensor network the sensors do not have a network ID and no central controller to control them, and the senses should possess the capability of self-organizing. Routing is the major role of a network layer, along with this function the layer has to be watchful of power conservation and memory conservation. For routing, the layer uses routing protocols, they can be categorized into hierarchical routing, flat routing, time driven, event driven and query driven routing protocols [12]. The sensor nodes will be deployed over an area. Each node generates data and these data are collected and processed by data aggregation and data fusion methods.

*Transport Layer:* This layer is in charge of end to end communication and it produces logical connection between network components. It ensures reliability and avoids congestion both on downstream and upstream that is from the sink node to the user and from the user to the sink node. In WSN it is hop by hop communication instead of end to end communication. Generally, the transport layer protocols are split up into packet driven and event driven. There are upstream and downstream protocols that facilitate transmission between the sink node and the user. Some popular protocols are Sensor Transmission Control Protocol (STCP), Price Oriented Reliable Transport (PORT) protocol and Pump Slow Fetch Quick (PSFQ) protocol. The STCP mainly aims to provide reliability by detecting congestion and avoiding it. PORT Protocol in increasing the sink information with reduced cost and reduced congestion. PFSQ uses timers to retrieve missing packets by retransmission and eliminates redundant broadcast.

*Application Layer:* It performs as an edge that connects the host and the network. It is in this layer different applications are deployed; these applications are data in an understandable format. Applications can be developed for medical field, military, industry, environment, education, agriculture etc. In addition to the above, this layer also performs traffic management, error control, retransmission etc. [13].

## Characteristics of WSN

- The sensor nodes in WSN are smaller in size, limited or restricted memory and uses very low energy
- Sensor nodes can be deployed in moderate as well as extreme environments, they could be easily attacked by enemies
- Since WSN does not have a central controller, the network possesses the capability of cell organization
- Ad hoc sensor network collection of sensor nodes joining a temporary network in the absence of stationary any stationary infrastructure.

## Applications of WSN

- It is used in battle field for surveillance and monitoring.
- Monitoring of environmental factors such as air pressure, temperature, humidity
- Observing the noise level and gather information
- Used in the medical field for patient diagnosis
- It is helpful for agriculture and the Internet of Things (IoT)

### 7.1.4 IoT Cloud and WSN Architecture

This section explains the IoT Cloud and WSN architecture together. The end users are sensors that are connected to the Wireless Sensor Networks. The sensors may be of various types: light sensor, smoke, gas, accelerometer, temperature, pressure, IR sensor, ultrasonic sensor, etc. Each sensor uses different communication protocols and could be of analog or digital type that sense analog or digital signals [14]. The WSN consists of actuators that are responsible to act to the commands received from the sensor nodes, where this data is collected, interpreted and then processed by the cloud. The natural idea of this integrated architecture is to create a smart environment. Inside the cloud, a Virtual Sensor Network can be built. A separate routine program is executed within the cloud layer to virtually connect the physical sensor and the virtual sensor. Figure 7.4 shows an integration of IoT, Cloud and WSN architecture [15, 16].

### 7.1.5 Research Motive

The integration of WSN with Cloud Computing has potential applications in almost all the fields, like agriculture, transportation, Healthcare, industry, military, etc. [17, 18]. The sensors produce sensory data of temperature, pressure, smoke, gas, light, etc. These are then gathered by the WSN and are forwarded to the cloud layer. The cloud is a powerful storage and computation unit that processes the sensory data and offers to the users on demand. The cloud user can access the data using REST API which is a lightweight mechanism that facilitates access to the data on the cloud that

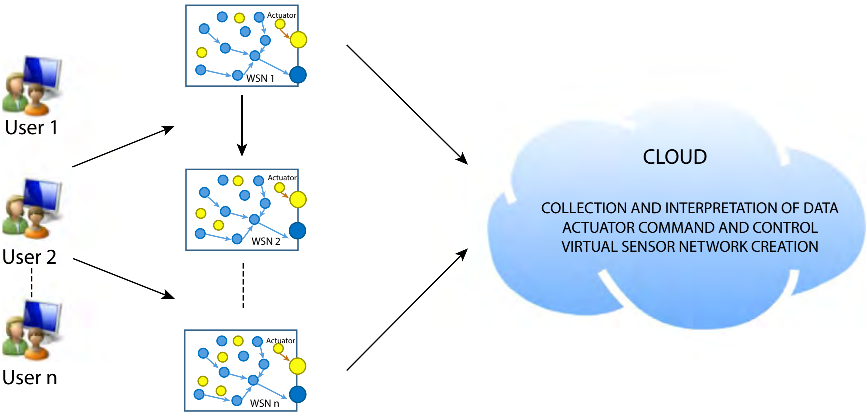


**Figure 7.4** IoT Cloud and WSN architecture.

uses commands like POST, GET, PUT, UPDATE. The retrieved data can be in the form of XML or csv or JSON.

## 7.2 Challenges and Opportunities

In order to accomplish an integrated framework that includes various technologies, challenges and opportunities are inevitable [19, 20]. Only on a clear understanding of both, a system can be designed successfully that meets the goal [21]. In this section the challenges and opportunities of IoT Cloud are discussed.

### 7.2.1 Challenges IoT Cloud Faces

*Security and Privacy*

The data stored in the cloud is not always secure and private despite of many privacy and security policies [22]. Yet confidentiality can be provided to the data when it is inside the cloud, when confidentiality is compromised the Cloud Service Provider (CSP) will be held responsible. Similarly, when a user's data is stored elsewhere, privacy is also at stake; it is like an external party is monitoring the data. One solution to this challenge is that, the user should periodically monitor the data, on any suspicious activity identified [23, 24], where it can be brought to the notice of the CSP. Another solution is signing up for a secured private cloud for highly confidential data [25].

*Bandwidth Constraints*

When data is sent at a very slow rate bandwidth required is low but when data is sent at a very high rate the bandwidth requirement is very high. Hence for data intensive applications one should invest a lot on bandwidth. There is no investment done for purchasing hardware and maintaining the hardware, nor there is no investment for software. As a coin has two sides though the above points are advantages, requirements for bandwidth and huge investment for it cannot be overcome. Since cloud handles IoT data, that is big data and bandwidth requirement is very high.

*Migration of Data to Cloud*

The strategies to be followed to migrate into a cloud or export all data from a cloud or change from one CSP to another CSP are very tedious. The cost, the huge time required for transferring the data, the security of the data during the migration process, the uninterrupted work flow increases the challenges.

*Reliability and Availability*

The cloud service is expected to be available 24/7. IoT generates a huge volume of data that has to be monitored and stored spontaneously on to the cloud. Hence the downtime of cloud should be very less as it would miss critical data there by reducing the availability [26]. The cloud should be robust enough to handle IoT data at a higher rate in a particular time and lower rate at another time which is a challenge.

### 7.2.2 Opportunities IoT Cloud Offers

IoT platform demands sharing of resources which is the multitenancy feature that is provided by the cloud platform. These resources can be shared and can be accessed from anywhere and everywhere. Cloud also allows for maximizing or minimizing resources that is its elasticity property. Cloud supports virtualization that makes IoT devices homogeneous. Combining IoT and cloud allows data to be accessed near the edge of the network. This saves time, reduces conditions and allows quality data without much loss. Hence IoT combined with cloud allows IoT devices widely available geographically that leads to real time data handling.

## 7.3 Case Study

Polluted air contains toxic chemicals in the atmosphere that leads to environmental threats and health issues. Some air pollution is due to natural sources, like wild fire, volcanic eruptions, etc. Eventually the significant contribution to air pollution is due to human actions, such as transportation, manufacturing, electricity generation, etc. which in turn is responsible to discharge greenhouse gases that affects the ozone layer. Air pollution results in climate change, this climate change thereby results in increase in global temperature. To understand the quality of air and its effects on humans, there are parameters like Air Quality Index (AQI), Air Quality Health Index (AQHI), the basic idea of these will be of great help while designing a pollution control system. Hence this section describes the parameters used to find air pollution level and then discusses two architectures that will facilitate in reducing the air pollution, mainly pollution due to vehicles.

## Air Quality Index

The regular air quality status is examined using the Air Quality Index generally represented by AQI. It is a tool used by several agencies to offer the public with well-timed and tranquil that comprehend information on native air quality and whether the air pollution level stance health distress rises in air pollution have been associated with shrinkage in lung function and hike in heart attacks. The AQI articulates the public how fresh the air is. It is mostly built on health effects that can happen within certain hours or a few days after inhaling contaminated oxygen in the atmosphere based on the occurrence of numerous pollutants. There are eight different pollutants such as Carbon monoxide, ozone, PM2.5, nitrous oxide, ammonia, sulfur dioxide, lead, and PM10 [27]. The AQI is divided into 6 groups based on the pathological state. When AQI values reach to peak, the risk of air pollution in the surrounding also increase. The 6 AQI categories represent the health hazards as shown in Tables 7.1 and 7.2.

**Table 7.1** AQI and air pollution scale.

| AQI categories | Color code | Description |
|---|---|---|
| 401 to 500 | Dark Red | Hazardous |
| 301 to 400 | Light Red | Very Unhealthy |
| 201 to 300 | Orange | Unsafe |
| 101 to 200 | Yellow | Ill health for sensitive groups |
| 51 to 100 | Light Green | Mild |
| 0 to 50 | Dark Green | Excellent |

**Table 7.2** AQI and health hazards.

| AQHI scale | Color code | Description |
|---|---|---|
| 1 to 3 | Blue | Minor |
| 4 to 6 | Orange | Moderate |
| 7 | Pale red | Huge |
| 8 to 10 | Red | Very High |
| 10+ | Dark Red | Serious |

The whole human population is prone to be affected by harmful health effects.

## Air Quality Health Index (AQHI)

Mostly, the general public should pay attention to the health advice of the AQHI. It means precise health risk of air impurity based on air quality. In order to help the public and explain to them about the health issues associated with air pollution AQHI is identified by WHO [28]. The AQI scale is categorized into 5 groups along with its risk factor levels.

When the health risk category is low or moderates our daily activities can be continued. In the case of high the children, the elderly, and patients with heart or respiratory diseases should reduce outdoor physical activities. Additionally, if the category is very high or serious avoid outdoor physical exertion and take appropriate protective measures should be taken, this is shown as a color scale in Figure 7.5. Furthermore, AQHI possesses two different types. They are General AQHI and Roadside AQHI [29]. Those who spend most of the time far away from the roadside are referred to as General AQHI. Others who spend time near the roadside with heavy traffic is said to be Roadside AQHI.

## AQI Mechanics

The calculation of the final AQI value is done either per hour or 24 h. If the AQI value is calculated per 24 h, then $SO_2$, PM2.5, PM10, CO, $NO_2$ concentrations are measured as the average per 24 h, while $O_3$ concentrations are measured as the maximum 1-hour average and the maximum 24 h moving average.

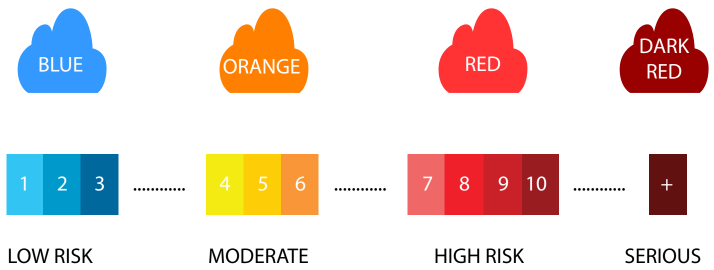


**Figure 7.5** Health risk scale.

On understanding the risk, the system models described below uses IoT, Cloud and WSN to calculate the amount of air pollution and take necessary action to keep the pollution under control.

### 7.3.1 Case 1 Improved Pollution Monitoring System for Automobiles Using Cloud-Based Wireless Sensor Networks

Toxic air pollution causes vigorous health problems in humans. They lead to cancer, birth deficiencies, reproductive impediments, etc. The aim is to overcome the adverse and serious complications due to air pollution because of transportation. For this an IoT and Cloud-based Wireless Sensor Network is modeled as shown in Figure 7.6. The system designed can monitor the toxic gases present in the atmosphere using gas sensors like MQ135 and can alert the control team that is responsible for taking immediate actions, this greatly reduces pollution and would be one of the best solutions that will serve the world at large [30]. This system allows continuous monitoring of toxic gas emitted by a vehicle by using sensors that senses the gases and sends the data to the IoT connect and further to the cloud which then notifies the authorities incharge who can take action accordingly [31].

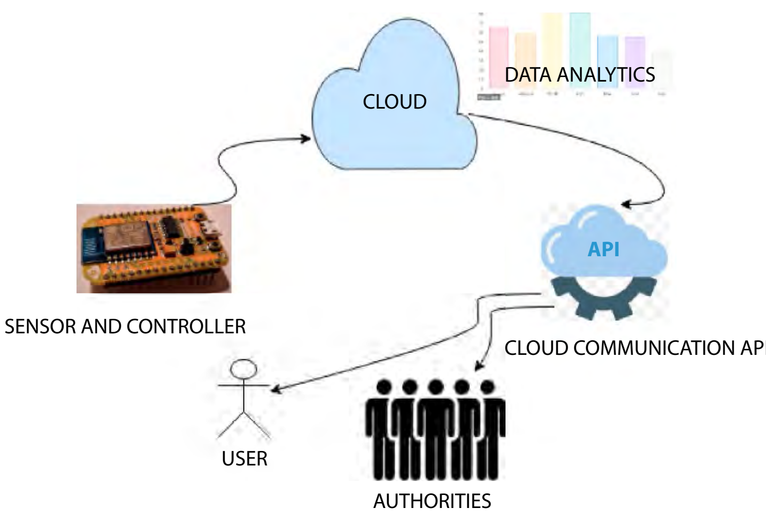


**Figure 7.6** System architecture.

*Sequence Diagram*

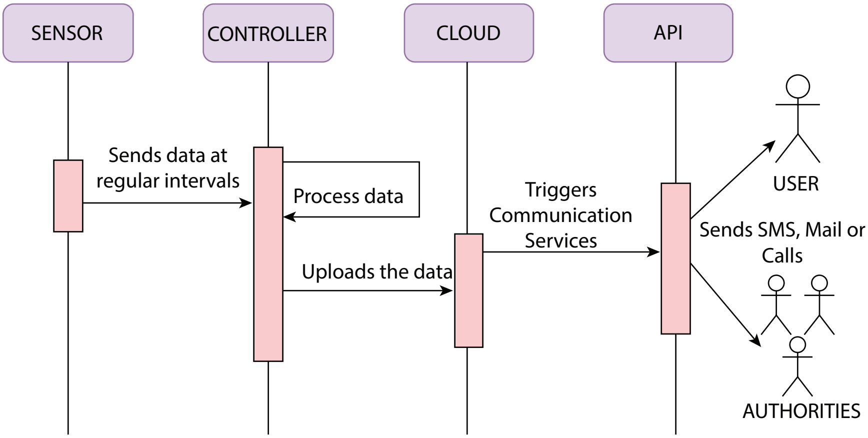


**Figure 7.7** Sequence diagram.

The elements in the sequence diagram as shown in Figure 7.7 indicates the interaction among modules over a time frame, the elements are placed horizontal and time is represented vertical. The process starts when the user starts his vehicle, once vehicle is started the sensor reads the data i.e. the smoke emitted from the vehicle. In the next step it uploads the data on to the cloud. Processing of the data is done on the cloud, where the sensor readings is compared with the threshold value [32, 33]. If the uploaded readings are less than the threshold, no action is taken, if the uploaded reading is greater than the threshold value and alert message in the form of Short Message Service (SMS), email or a call is sent or initiated to the authority in charge and the owner of vehicle as a notification [34].

### 7.3.2 Case 2 Hybrid Electric Vehicle

In order to increase vehicle proficiency and reduce CO2 emission along with greenhouse gas emission Hybrid E Vehicle is used [35]. This type of vehicle possesses both electricity as well as fuel [36]. The IC engine also known as the Internal Combustion engine and electric motors are helpful for driving the wheels of the vehicle. The batteries are meant to store and distribute energy resources. The two different propulsion techniques are implemented in HEV (Hybrid E Vehicle) which function with consistency. At first, the fuel such as biofuel, gasoline, or diesel present in an IC engine performs two different tasks. It provides enormous power and helps the battery in the vehicle to get charged. Secondly, based upon the manufacture the batteries are situated at various places inside the vehicle. To drive the wheels, the motors are associated with the transmission lines. The battery or series of batteries is a filled component that reserve and dispatch electricity. There is no need for the batteries to be plugged in since the charging is met by the administration of the vehicle. So, the E bill or E grid will not be drawn. The HEV batteries last throughout their period of existence. All these technologies controlled by the hybrid vehicle is compared to a machine control expert which is a series of computer. They are used to determine the to and fro of the power in the vehicle. The condition of the charging technique is analyzed 1,000 times/s and evaluated what the driver instructs. Here is the philosophical example for the kinds of choice, the vehicle makes the driver drive in different conditions. If the driver drives for 20 km/h the vehicle demands the battery whether it possesses adequate power. And if the motor with electric power responds yes, the IC engine stops. Now the vehicle starts to run on electric power by pleading the battery wealth. Subsequently, if the power of the battery is less the engine returns back to the IC engine of the vehicle and starts recharging the battery [37]. If the speed of the vehicle is increased, the dual techniques (IC engine along with electric motor) are used. The fuel is saved by turning the engine to the off condition. A regenerator braking mechanism takes place whenever the brake is applied, the power gets back to the batteries. The energy exported from the rotational wheels looks similar to battery fed by a power station in which the charges are stored for upcoming usage. The HEV is more reliable. A huge number of design attributes and technology with top efficiency are pre owned by hybrid vehicles. Among the two different worlds, HEV ranks as the best one. They possess a pollution free electric motor power along with less fuel consumption. The pollution sensor inbuilt in vehicle sends regular updates to the centralized entity. Here the cloud acts as a centralized entity in which prediction also takes place. When the vehicle is moving the whole route is being predicted. Additionally, it also helps to analyses the traffic. Based upon these conditions the vehicle switches from the internal combustion engine to the electric motor. To enhance the effectiveness of fuel in the vehicle and to decrease the level of $CO_2$ outflow and minimize the fuel cost Hybrid Electric Vehicles are suggested.

## 7.4 Conclusion

This chapter discusses IoT, Cloud and Wireless Sensor network architectures, it exhibits working of the system, the protocols used and the design issues. A good understanding on the individual architectures paves way to build applications based on the integrating all three technologies. An architectural model connecting all three technologies are also discussed which is a challenging topic and is under research. On understanding the integrated architecture, the opportunities and challenges are dealt in detail which becomes necessary to accomplish the goal while working with the technology. Finally proposed models for air pollution monitoring system using all the three technologies IoT, Cloud and WSN are reviewed as case study. The booming future market for WSN are Embedded and Semiconductor based industries, Security regulatory bodies, Automation and Control sectors, Consumer electronics, etc. for tracking and monitoring applications.

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