Background on Air Pollution

Pollution is defined as the addition of the contamination of the environment which induced hostile changes. It may be in the form of gases or solid particles. This can lead to air pollution, water pollution or noise pollution. In this thesis, the main focus is on air pollution as discussed further in this chapter.

2.1 Air Pollution

Air pollution is occurred due to the addition of an injurious or immoderate proportion of substances which includes gases, small particles and biological molecules are injected into the environment. It may lead to the short and long term diseases, allergies and it can also cause the death of the human being.

2.1.1 Category of Air Pollutants

In this thesis, mainly three type of air pollutants has been considered namely green house gases, acid rain and particulate matter. along with these pollutant some weather parameter like temperature, humidity, dew point and wind speed also taken into the consideration.

- **Green house gases:** Carbon Dioxide (CO_2), Methane (CH_4), Ozone (O_3) and Carbon Monoxide (CO)
- **Acid rain:** Oxides of Nitrogen (NO_X) and Sulfur Dioxide (SO_2
- **Particulate matter:** ($PM_{2.5}$) and (PM_{10})

2.2 AQI

Air Quality Index is a method for representation of air quality status to the common man in the easiest way which they can understand. It changes over complex air quality information of different contamination into a single number (index value), terminology and colour.
This AQI is divided into categories, viz. Good (0-50), Satisfactory (51-100), Moderately polluted (101-200), Poor (201-300), Highly Poor (301-400), and Severe (401-500). Every

one of these classifications is chosen depending on encompassing focus estimations of air contamination and their conceivable health impacts (known as health breakpoints).

Health breakpoints and AQ sub-index of eight pollutants are provided for (O_3,NO_2, SO_2, CO, NH_3,PM_{10}, $PM_{2.5}$, and Pb) for which short-term (up to 24-hours) National Ambient Air Quality Standards (NAAQS) are prescribed.

Sub-index is calculated based on the measured ambient concentrations value of a pollutant, which is a linear function of concentration value (e.g. the sub-index for PM2.5 will be 51 at concentration 31 µg/m3, 100 at concentration 60 µg/m3, and 75 at a concentration of 45 µg/m3). The worst sub-index determines the overall AQI. Health breakpoints and AQI categories for the eight pollutants are as given below:

AQI Category	AQI	Concentration range*							
		PM_{10}	$PM_{2.5}$	NO_2	O_3	CO	SO_2	NH_3	Pb
Good	**0-50**	**0-50**	**0-30**	**0-40**	**0-50**	**0-1.0**	**0-40**	**0-200**	**0-0.5**
Satisfactory	**51-100**	**51-100**	**31-60**	**41-80**	**51-100**	**1.1-2.0**	**41-80**	**201-400**	**0.5-1.0**
Moderately polluted	**101-200**	**101-250**	**61-90**	**81-180**	**101-168**	**2.1-10**	**81-380**	**401-800**	**1.1-2.0**
Poor	**201-300**	**251-350**	**91-120**	**181-280**	**169-208**	**10-17**	**381-800**	**801-1200**	**2.1-3.0**
Very Poor	**301-400**	**351-430**	**121-250**	**281-400**	**209-748***	**17-34**	**801-1600**	**1200-1800**	**3.1-3.5**
Severe	**400-501**	**430+**	**250+**	**400+**	**748+***	**34+**	**1600+**	**1800+**	**3.5+**

*CO in mg/m^3 and other pollutants in µg/m^3 ; 2h-hourly average value for PM_{10},$PM_{2.5}$,NO_2,SO_2,NH_3 and Pb. and 8-hourly value for CO and O_3.

Figure 2.1: Health breakpoints and AQI categories by CPCB [1]

2.2.1 Calculation of AQI by CPCB

There have been several propositions in the past regarding an index which can be utilized for getting a semi-quantitative or quantitative idea of air pollution. The index adapted currently in India is proposed by CPCB, and is given by sub-index [1],

$$I_i = f\left(X_i\right) \tag{2.1}$$

where i = 1, 2, 3…….., n

$$I = \alpha X + \beta \tag{2.2}$$

where, α is the slope and β is the intercept at $X = 0$.

$$I_i = \frac{I_{hi} - I_{lo}}{B_{hi} - B_{lo}} (C_p - B_{lo}) + I_{lo} \tag{2.3}$$

$$AQI = \sum_{k=1}^{n} W_i I_i \tag{2.4}$$

where, $\sum_{k=1}^{n} W_i = 1$ and B is the break-point concentration, C is the current concentration and W is the weight assigned to the respective pollution parameters.

2.3 Calculations Various Parameters for Proposed System

The calculation for various parameters such as dew point, wind speed and AQI based on particulate matter only is done.

2.3.1 Dew Point Calculation

We are calculating dew point based on temperature (T) and relative humidity (RH) by August-Roche-Magnus Approximation as-

$$\textit{Dew Point} = 243.04 \times \frac{\left(\frac{\ln(RH)}{100}\right) + \left(\frac{17.625 \times T}{243.04 + T}\right)}{17.625 - \ln\left(\frac{RH}{100}\right) - \left(\frac{17.625 \times T}{243.04 + T}\right)} \tag{2.5}$$

2.3.2 Wind speed calculation

Calculation of wind speed based on the sensor output values provided by anemometer is done using two points line equation-

$$\textit{Wind Speed} = 20.25 \times V - 8.1 \tag{2.6}$$

Where, V = sensor output voltage.

2.3.3 AQI Calculation Only Using $PM_{2.5}$

Air Quality Index Calculation based on PM2.5 (By using US EPA) using two-point line equations-

For $PM_{2.5}$ Value 0 to 12

$$AQI = 4.167 \times PM_{2.5} \tag{2.7}$$

For $PM_{2.5}$ Value 12.1 to 35.4

$$AQI = 2.1 \times PM_{2.5} + 25.55 \tag{2.8}$$

For $PM_{2.5}$ Value 35.5 to 55.4

$$AQI = 2.46 \times PM_{2.5} + 13.58 \tag{2.9}$$

For $PM_{2.5}$ Value 55.5 to 150.4

$$AQI = 0.51 \times PM_{2.5} + 122.34 \tag{2.10}$$

For $PM_{2.5}$ Value 150.5 to 250.4

$$AQI = 0.9909 \times PM_{2.5} + 51.85 \tag{2.11}$$

For $PM_{2.5}$ Value above 250.5

$$AQI = 0.7963 \times PM_{2.5} + 101.52 \tag{2.12}$$

Proposed IoT Architecture

Internet of Things (IoT) means the number of devices interconnects to each other and remotely accessible by using the internet. This chapter highlights the proposed four layers IoT architecture as shown in the figure below. These layers are application layer, middleware layer, communication layer and sensing layer. Further, we will be discussing detail description of each layer.

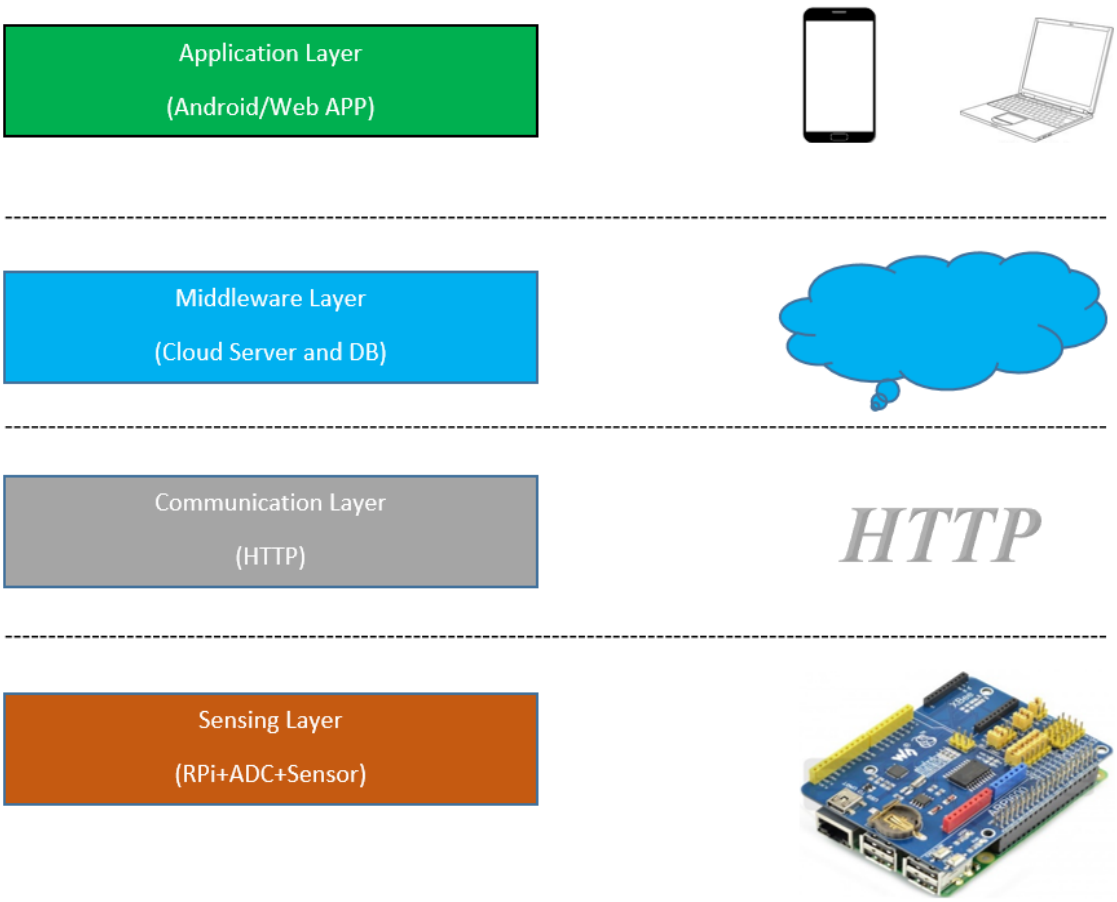

Figure 3.1: Four layered IoT architecture

3.1 The Application Layer

This is the topmost layer of our architecture. This layer acts as the user interface for the user and interacts with the user via smartphone (Android/iOS app) or web application. This layer also provides the facility to the user to provide his profile detail such as diseases and allergies. It is also used to display the pollution level and healthier path by fetching data from the lower layer.

3.2 The Middleware Layer

This is the second layer in the architecture and plays an important role in data storage and processing. This layer consists of the cloud server and cloud database. In this case, the cloud server used is the PARSE and the cloud database is MongoDB. The MongoDB is a NoSQL (unstructured) database which is supported by the PARSE server. The PARSE server used here is hosted by the Amazon AWS.

3.2.1 Server

In general, a server is a program or a machine which provides service for other programs or machines, classified as ”clients”. This architecture is basically known as the client–server model, and a single computation is broadly dispersed across various processes or machines. They can provide numerous functionalities, usually known as ”services”, such as sharing of data or resources among multiple clients, or performing computation for a client. A single server can serve number of clients and vice-versa. A client process may connect over a network to a server on another machines or may run on the same machines. [13].
Here, we are using two type of servers namely PARSE Server and Firebase server. These servers are application server and categorised as follow -

PARSE

It is an open source server for Backend-as-a-Service (BaaS) framework which is developed by Facebook. This platform now has an effective and robust society of obsessive developers who thrives regularly for innovating the already splendid and modular platform. Some of the important features of parse server are given below :

- *Easy to deploy*
  Parse Server requires a framework that runs on Node.js and it also reinforces web application schema. As your database is ready, you don’t require much to alter into the client code for running your application.

- *Data storage*
  Parse uses MongoDB as a database and for storing a file system, it uses the Amazon S3

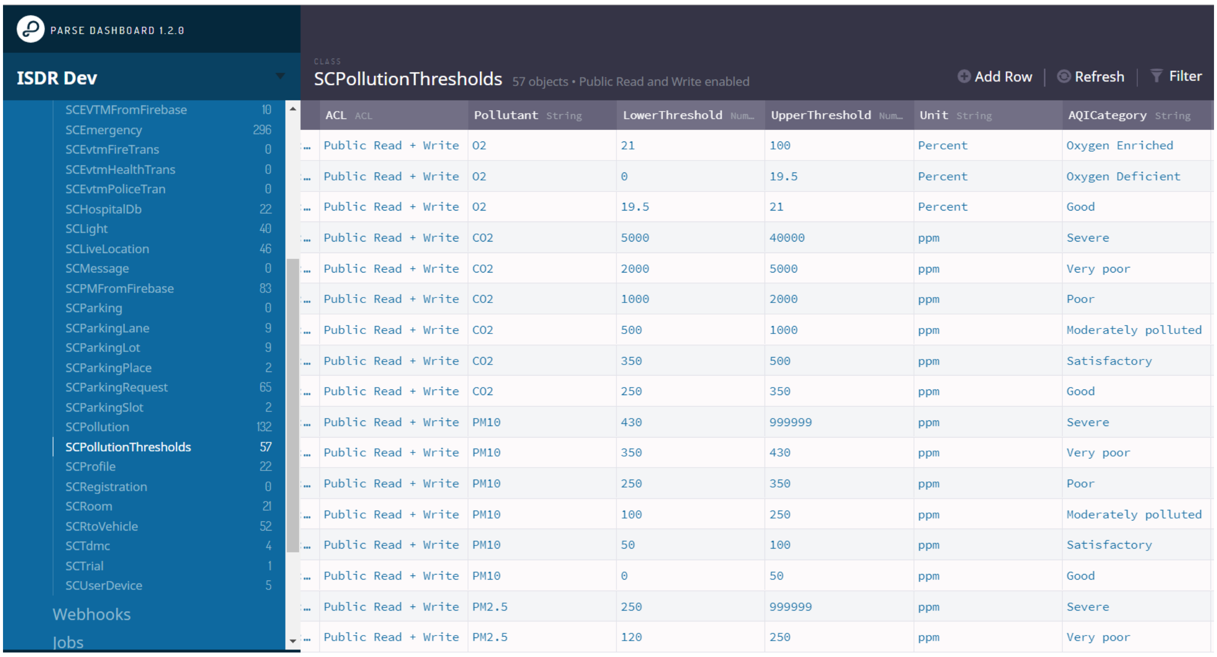

Figure 3.2: Sever side representation of threshold value of the pollutants based on CPCB guidelines .

bucket. It has ubiquitous database services such as performance refactoring, restoring, indexing and data backup.

Parse provides the facility to the users for choosing a file system of their choice. It also provides an alternate for backup to store files in JSON format. If there is a requirement for JSON it can be imported.

Parse does not have any limitations for the queries, database triggering and cloud functionalities.

- *Pointer permission*

  Parse Server ensures data security without altering the client code. The most recent update for the parse server is pointer permission and all latest Versions of parse supports it.

- *Dashboard*

  Parse was recognized for its dashboard. The Parse Server facilitates all the dashboard features of Parse. The dashboard permit users to administer their applications and send push notifications.

- *Live Queries*

  It is not necessary to make queries at a regular interval. Users can create a query and Parse Server will fetch real-time data and provide the results if it detects any change.

Firebase

It is another cloud server for hosting android, iOS and web application is Firebase from Google. Some important features of Firebase which look advantageous to the developers are :

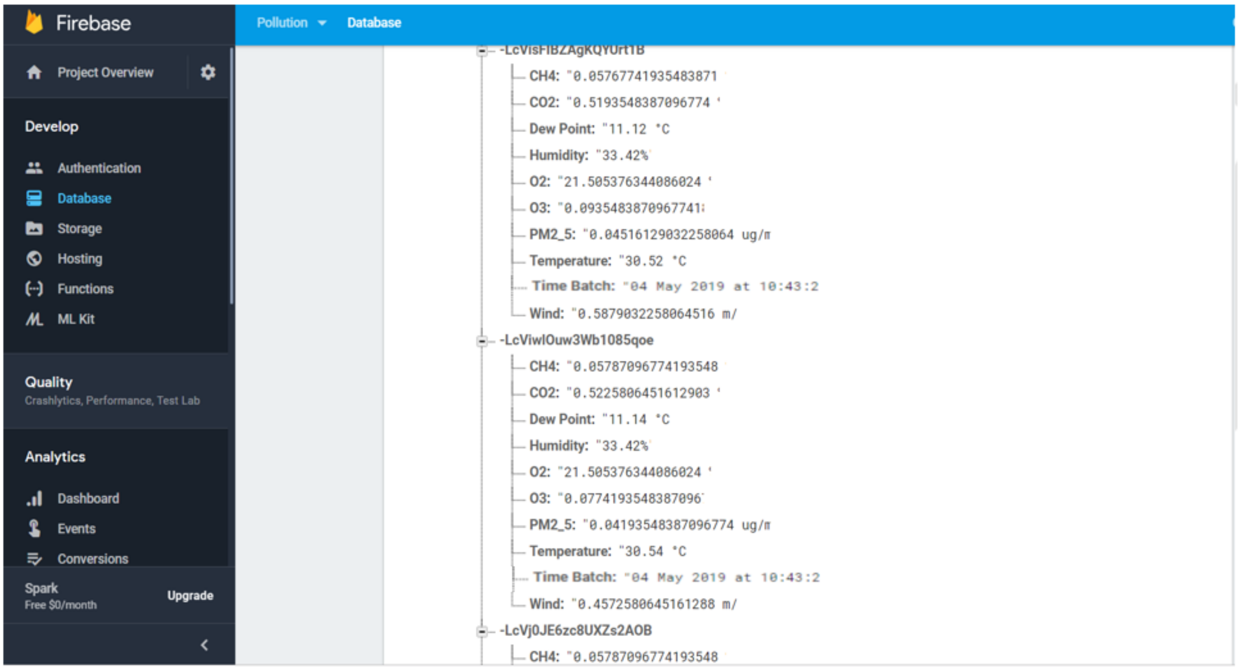

Figure 3.3: Real-Time database logging in the Firebase.

- *DataStorage*
  Firebase supports JSON format for storing the data. JSON data is easily feasible through REST API's or by the use of client libraries. It stores the data into the cloud and hence, it can be accessed from anywhere.

- *Real-time data sync*
  Firebase is developed with a model-observer strategy which has an importance for interactive apps. If there is any change in the server data it will update the registered clients in real-time. There is an immediate synchronization of data on client devices. Remote customization of applications and cloud messaging facilitates to update the app variables instantly.

- *Authentication and data security*
  It is a powerful, cross-platform APIs for Android and iOS applications. It supports Javascript with highly malleable security API. It also validates authentication through Google, Twitter and Facebook.

- *Central Database*

  The hosting of data will be taken care of, by the Firebase hence users need not worry about it. It will provide a Central database and update all the users in real time.

3.2.2 The Database

The database used here is a NoSQL database (i.e. MongoDB). NoSQL databases are used because there are various limitations of conventional relational database technology. In the comparison of relational databases, NoSQL databases provided with wide scalability and exceptional performance, and their data model pointed several drawbacks of the relational model.

The advantages of using NoSQL are:

- Huge volumes of structured, unstructured, and semi-structured data.
- Agile sprints, instantaneous iteration, and numerous code push.
- Uses Object-oriented programming which is simple and malleable.
- Adequate, scale-out architecture instead of extravagant, monolithic architecture.

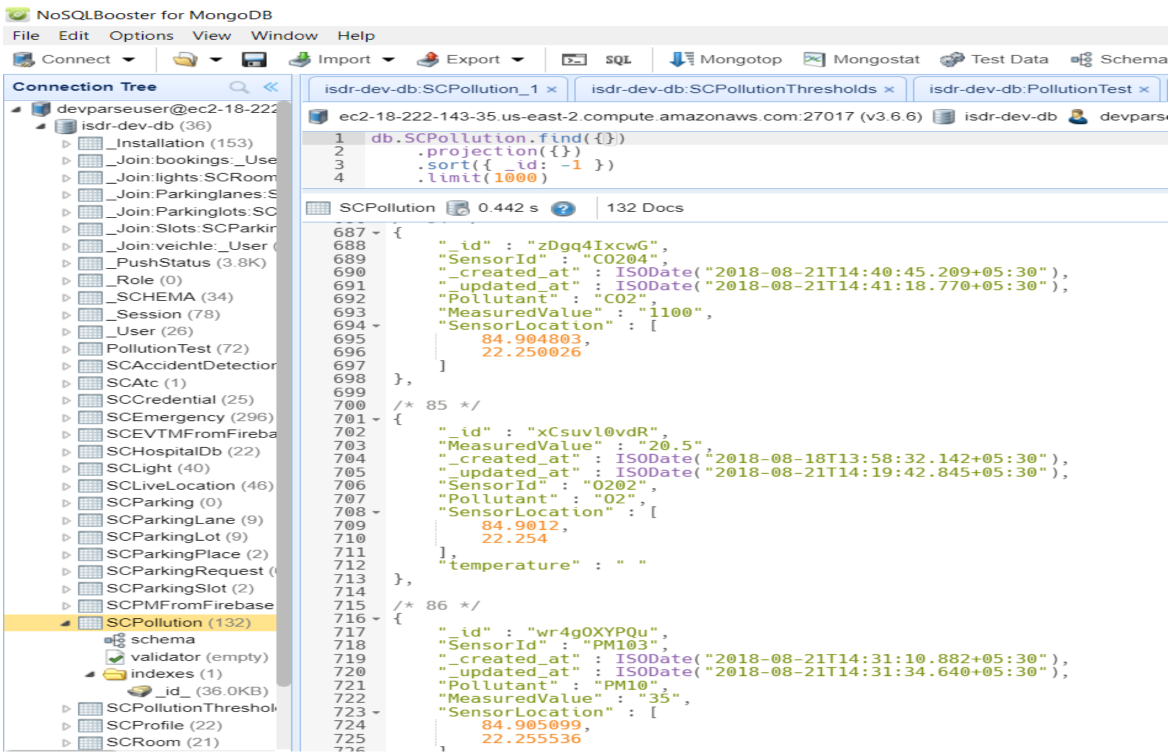

Figure 3.4: Data logging into MongoDB database.

3.3 The Communication Layer

The third layer of the architecture is the communication layer. The importance of this layer is to make the connection between the hardware (i.e. sensing layer) and the software (i.e. to application layer through middleware layer). This uses the HTTP communication protocol to transfer the data from the hardware.

3.4 The Sensing Layer

This is the last and most important layer of the IoT architecture. This is a hardware layer which consists of the processor, sensors and communication medium. It allows us to connect the various sensors to a processor (in this case a raspberry pi). most of the sensors are analog type so there comes the need for an ADC which is ARPI6000 ADC module which is used to convert the analog value into the digital data. The raspberry pi allows us to connect our system to the internet via Wi-Fi or Ethernet. whereas to increase the communication options a SIM7000C module is also used to enable the communication through 3G/LTE or NB-IoT technologies.

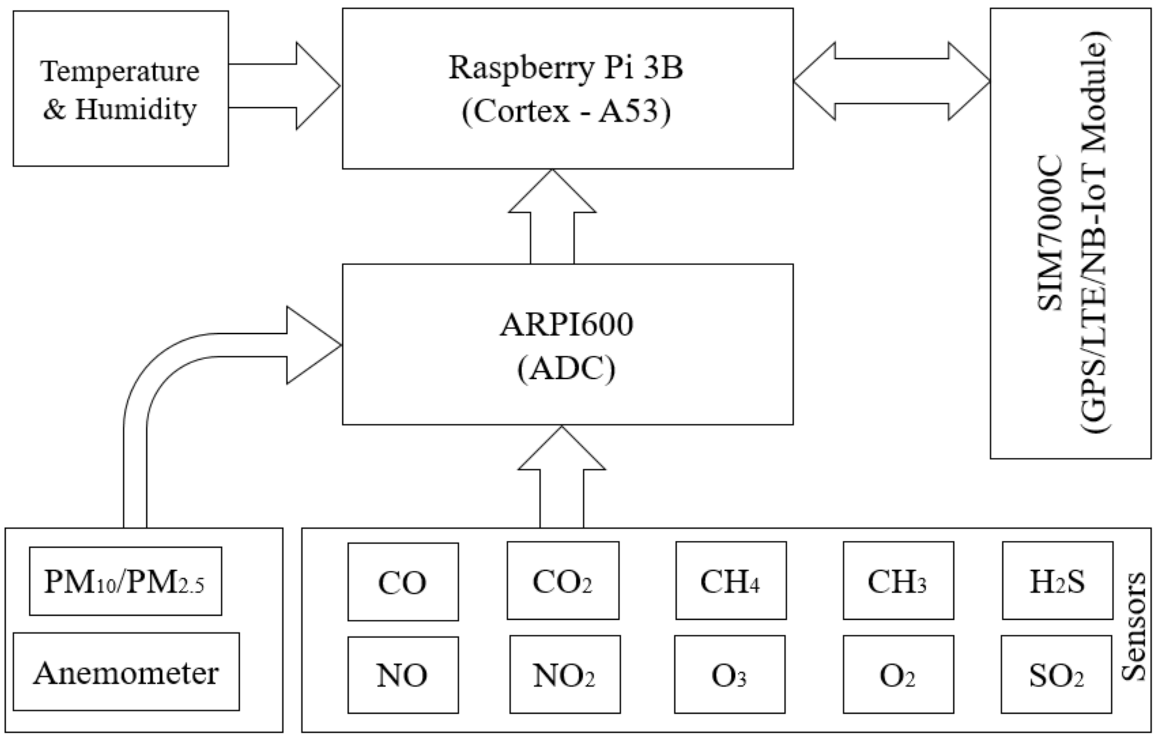

Figure 3.5: Block representation of sensing layer internal structure.

Hardware Development of Pollution Monitoring System

It deals about personalized pollution monitoring. As we know that every individual is having different health conditions i.e. he/she will have different diseases and allergies. Based on his diseases and allergies, PPM system provides information about the specific harmful pollutants to the user and also display an appropriate message of action by using an algorithm. For this purpose, we have implemented a system which includes the hardware and software.

4.1 The Sensor Node Hardware Module

The sensor node hardware module as shown in figure 1. Which consists of a sensing unit, processing unit (cortex A53 Microprocessor and an analog to digital converter), a communication module (SIM7000C), and a power supply unit.

4.1.1 Sensing Unit

The sensor unit includes the ten gas sensor, one dust sensor, one wind speed sensor and one integrated sensor for temperature, humidity and dew point. The gas sensors used are Carbon dioxide (CO_2), carbon monoxide (CO), nitrogen dioxide (NO_2), nitric oxide (NO), ammonia (NH_3), hydrogen sulfide (H_2S), sulfur dioxide (SO_2), methane (CH_4), oxygen (O_2), ozone (O_3). The gas sensors provide the concentration of various gases present in the open environment at a particular place. All the gas sensors are of the electrochemical type which generates an analog output. The dust sensor will provide the reading of particulate matter ($PM_{2.5}$ and PM_{10}) present in the air measured in parts per millions (ppm) and will generate output in the form of analog voltage. The temperature and humidity sensor will give the value of temperature and humidity as digital output and hence do not require a dedicated ADC. The dew point is calculated on the basis of temperature and relative humidity values. The wind speed sensor is an anemometer which used to measure the speed of the wind at a particular place and it will also provide output in the analog form.

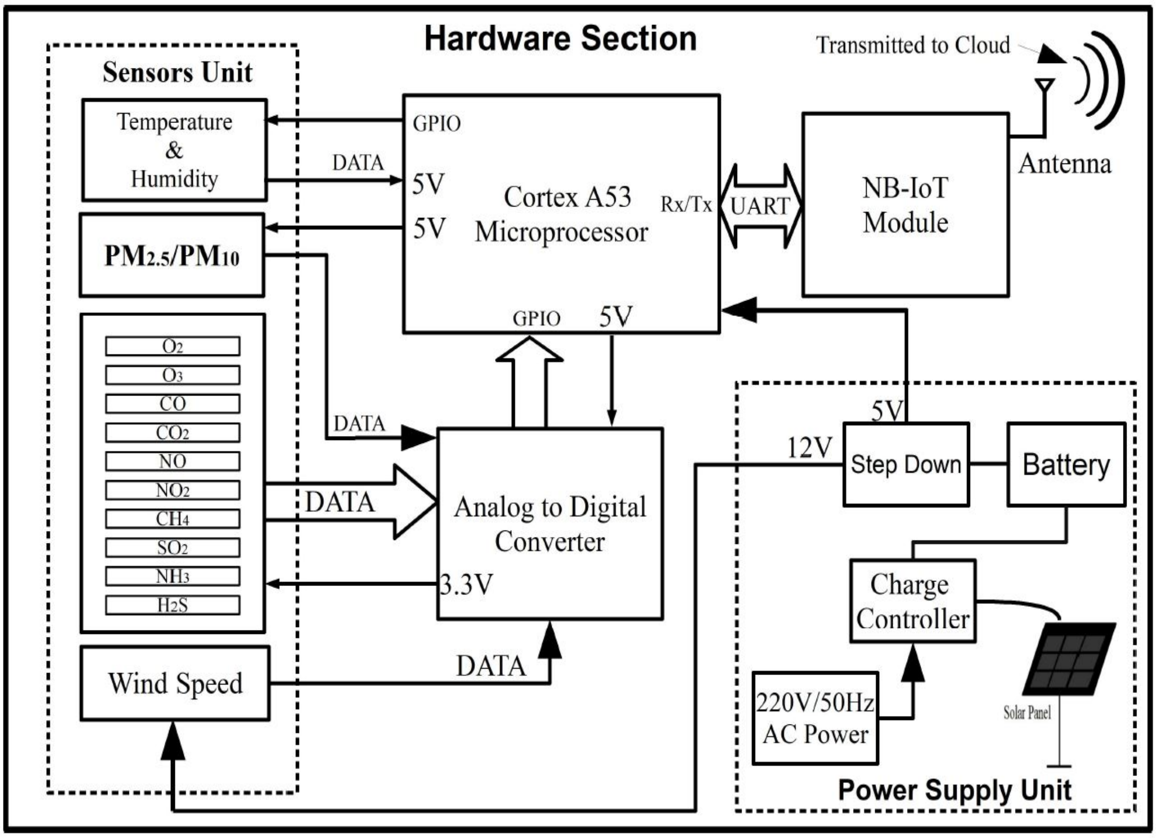

Figure 4.1: Block representation of end node hardware.

4.1.2 Processing Unit

The processing unit (cortex A53 Microprocessor) is a raspberry pi 3 model B which is capable of processing the data received from various sensors with the help of an ADC (ARPI-600). Analog to digital converter is a module used for converting received analog data from various sensors into its digital form which can be interpreted easily in the processor. Specification of the processor and ADC are given in table 1 and table 2 respectively.

4.1.3 Communication Module

The communication method used here is NB-IoT and Wi-Fi/Ethernet. NB-IoT module will provide us with the use of various communication technology viz. LTE/GSM/NB-IoT. It can use any of the technologies depending on the network coverage of the place where the hardware module will be deployed, most preferably Ethernet/Wi-Fi in smart cities and/or LTE/GSM in the remote locations. NB – IoT communication technology is not that much popular in India, but in coming future, it can be one of the best technology for remote utilities and machine to machine (M2M) applications. This module will send the data to the cloud database using an the antenna provided in the module. NB –IoT device can also provide the GPS location of the hardware module.

Parameters	Specification
System on	Broadcom
	LPDDR2(900MHz)
Networking	10/100 Ethernet,2.4Ghz, 802.11n Wireless
Flash Storage	MicroSD
GPIO	40-Pin header
Power Supply	5V,2A

Table 4.1: Specification of the Raspberry-Pi 3 Model B

Parameters	Specification
Chip Used	TLC1543 AD converter
Compatibility	Raspberry Pi, Arduino UNO, Leonardo
No. of Channels	11 channels (6 channels for Arduino interface, 5 channels for sensors)
On board RTC	PCF8563
ADC Resolution	10 bit
Sampling Rate	38KSPS
GPIO	40-Pin header
Power Supply	3.3 - 5V,2A

Table 4.2: Specification of the ARPI600 ADC

The specification of the SIM7000C eMTC/NB-IoT/EDGE module is given in the table 4.4.

4.1.4 Power supply unit

Power supply unit consists of a step-down circuit, a battery, a charge controller, and power input to the controller. It may be a solar panel and/or domestic AC power supply. The solar panel will receive the solar energy and convert it into electrical energy. This electrical energy from solar panel and AC power supply will be directed to charge controller which will convert it to dc for recharging the battery, it's specification is 12.8V/20Ah. The proposed hardware requires a different level of voltages 3.3V, 5V and 12V so for that purpose a step-down circuit is used.

Parameters	Specification
Communication Bands	Quad-Band FDD-LTE B1/B3/B5/B8 GPRS/EDGE 900/1800 MHz
Output power	**GSM900:** 2W **DCS1800**: 1W
Data Transmission Rate	**LTE** : Uplink up to 375kbps, Downlink up to 300kbps **NB-IoT :** Uplink up to 66kbps, Downlink up to 34kbps **EDGE Class :** Uplink up to 236.8Kbps, Downlink up to 236.8Kbps **GPRS :** Uplink up to 85.6Kbps, Downlink up to 85.6Kbps
Protocol Supports	TCP/IP, UDP, PPP, FTP/HTTP
Navigation Supports	GNSS (GPS, GLONASS, BeiDou, Galileo, QZSS)
Power Supply	3.0 - 4.3V

Table 4.3: Specification of the SIM7000C eMTC/NB-IoT/EDGE Module.

4.2 Proposed Software Model

As shown in figure 4.2, software model is the combination of cloud database unit and user interface unit. Cloud database unit is having a cloudware which includes the cloud database and a cloud server and displays the received signal from the hardware module. The user interface unit is the graphical user interface (GUI) part which may be an Android/iOS application or/and web application for smartphones, smart watches and laptop/desktops.

4.2.1 The Cloudware

Cloudware is the combination of the cloud server (i.e. PARSE) and cloud database (i.e. MongoDB). It receives data from the hardware unit through the internet and store it in the cloud database for user application purposes while the cloud server will provide the hosting of the Android/iOS/web application and back-end support.

4.2.2 The User Interface

The user interface unit is for the application. It is a front end GUI for smartphones, smart watches, PCs and many other smart devices. These devices would interact with the cloudware using wireless links i.e. the internet.

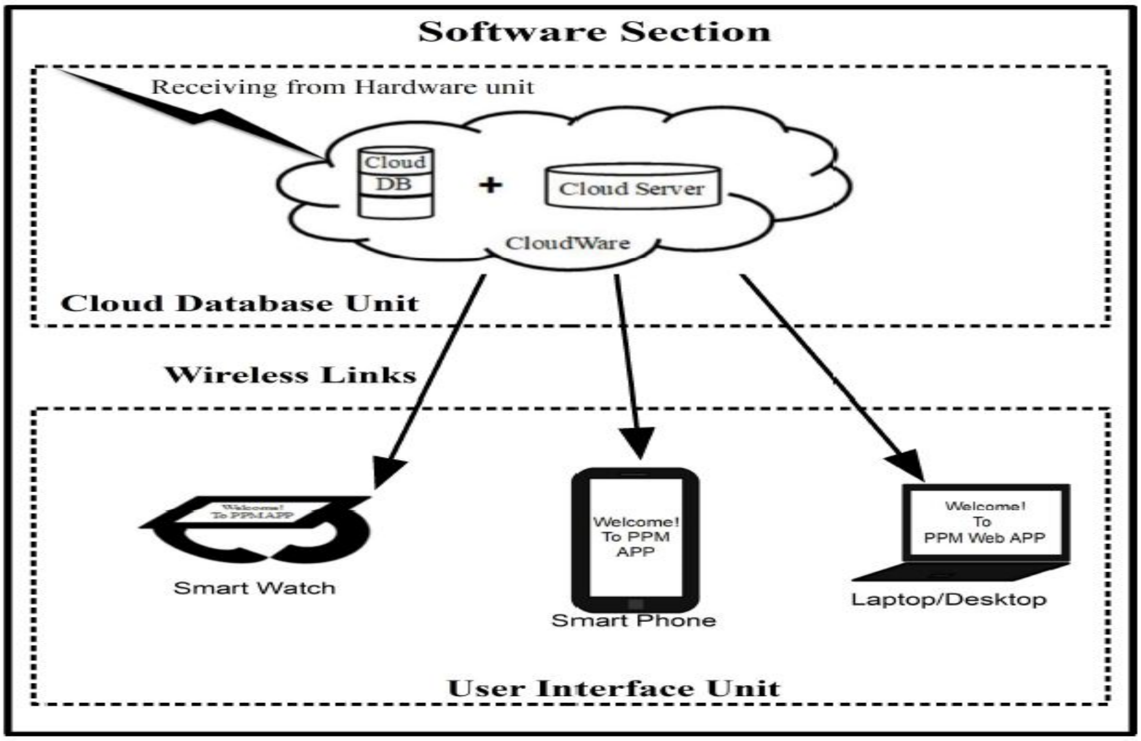

Figure 4.2: Block representation of software part.