Wireless Sensor Network for Real Time Pollution Monitoring and Smart Grid Applications

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This thesis entitled 'Wireless Sensor Network for Real Time Pollution Monitoring and Smart Grid Applications' by Mirza Sami Baig is approved for the degree of MS by Research from IIT Hyderabad.

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Secondly, I would like to extend my gratitude and thanks to my family, who has been supportive throughout my years of study. I am truly grateful for their love and support. I thank them for making my student life easier and enjoyable.

Finally, I thank my colleagues and friends for the happy time they have shared with me.

Dedicated to

My Family.

Abstract

Wireless sensor nodes are electronic boards made up of sensors, processor and communication modules. Generally they are battery powered which limits its functionality, reliability and durability in many aspects. These nodes are use to collect information from various environments which extend from favorable one such as office environment to very harsh environments such as factories, deserts and forests. It is very important for the sensor nodes to provide the reliable information as based on these certain control systems will be planned. Apart from on-board challenges, pervasive sensor network will face many different challenges depending on the environment in which they are deployed. Every different use case has a different set of problems to be answered to make the network robust and reliable.

In this thesis, we have studied the challenges of pervasive sensor network for two different applications viz., Air Pollution Monitoring and Smart Grid. We have employed a real time implementation technique to understand and analyze the problems of sensor network for Air Pollution Monitoring. As an outcome of our research, we have developed a low cost sensor node, which answers few of the problems associated with sensor networks.

To study the application and challenges of pervasive sensor network in smart grid, we have adopted simulation method. Different communication technologies are simulated viz., Wi-Fi, Cognitive Radio and Cellular Networks to understand the pros and cons of each of them so that to analyze whether they meet the latency and other criteria of smart grid applications. Cognitive radio is found to be promising in providing free long distance communication for non-real time application such as Field area network within smart grid paradigm whereas Wi-Fi could be consider as fall back medium in presence of primary user of licensed spectrum. Spectrum sensing turns out to be the biggest problem in cognitive radio technology.

Contents

Chapter 1

Introduction

1.1 Motivation for the Research

Air forms an envelope around the Earth and it is a mixture of different gasses. Each gas is supposed to be in certain proportions. Air gets polluted when some external pollutants get added or the proportion of these gases gets disturbed due to addition of some gases by different sources. Deforestation and heavy increase in traffic are among the main reasons for this. Global warming and acid rain are few harmful effects caused by the air pollution. Air forms an envelope around the Earth and is a mixture of various gasses. Each gas should be in some proportions. When some external pollutants are added, air becomes polluted or the proportion of these gasses is disturbed by the addition of certain gasses from different sources. One of the main reasons for this is deforestation and heavy traffic growth. There are few harmful effects of air pollution caused by global warming and acid rain. Air pollution is usually defined as the oxygen and atmospheric contamination around us. Air pollution occurs when the air contains harmful amounts of gases, dust, fumes, chemicals, biological materials or odor. That is, amounts that may be harmful to human and animal health or comfort, or that may cause plant and material damage. Air pollution is caused by pollutants. The atmosphere is a complex natural dynamic gaseous system essential for supporting life on planet Earth. Due to air pollution, stratospheric ozone depletion has long been recognized.

Governments have put tremendous efforts on monitoring air pollution to mitigate the impacts of air pollution on human health, the global environment, and the global economy. A system of manual monitoring consumes a great deal of human and material resources. Air pollution situation is traditionally monitored with stationary monitors by conventional air pollution monitoring systems. These monitoring stations are highly reliable, accurate and capable of measuring a wide range of pollutants using conventional analytical tools like gas chromatograph-mass spectrometers. The disadvantages of conventional monitoring tools are their large size, heavy weight and extraordinary cost.

These lead to the monitoring stations being sparsely deployed. The situation of air pollution is updated every hour or even every day. The air pollution maps created by conventional air pollution monitoring systems are therefore with extremely low spatial and temporal resolutions.

Monitoring environmental background with low spatio-temporal resolution is sufficient but inadequate for public awareness and personal health risks cannot be properly identified. Evidence shows that some health events or diseases may be triggered or worsened by acute exposure or short-term change of pollutants. Spatio-temporal resolution of air pollution can be increased with the help of low-cost portable ambient sensors in combination with wireless sensor network under the paradigm of Pervasive Sensor Based Air Pollution Monitoring System.

1.2 **Research Objectives**

Following are the main objectives of this thesis:

- To study the network architecture, characteristics and the wireless sensor network for monitoring and control.
- Determine the hardware challenges to setup a wireless sensor network for a typical application using the state of art commercial hardware
- Derive methods to mitigate the issues for reliable operation of such a system
- Determine the communication challenges in wireless sensor network for a typical application using simulation environment.
- Propose appropriate solutions to the problems identified during the research activity.
- The solution should cover the challenging problems: scalability, reliability, and collaboration

1.3 Research Contributions

The primary contribution of this paper are as follows:

(i) It describes the design of a Real Time Air Pollution Monitoring system that leverages on commercial hardware to collect and share pollution data. The sensors equipped in the system include a temperature sensor, a relative humidity sensor, carbon dioxide sensor, and the oxygen sensor. All of these sensors data can be visualize through a web application running on a remote server.

(ii) An extensible server and a user-friendly front end for data analysis are used. The server interacts with the sensor network via an Asynchronous JavaScript and XML-(AJAX-) based Web application. The data will be collected and stored in database every second. A user-friendly graphical user interface (GUI) is developed to facilitate data analysis and remote sensor control.

1.4 Overview of Thesis

Introduction to wireless sensor networks (WSN) is presented in chapter 2. It also describes the elements of network and node architecture that constitutes the WSN. Chapter 2 also lists the network and node characteristics, which are unique for WSN. By the end of this chapter, different applications are briefly described.

Chapter 3 introduces the concepts of Smart grid to its readers. The architecture of smart grid extending from generation to end user is presented briefly. The scope and functionality of different communication networks that comprises the smart grid are described. The constraints that get impose on communication networks due to inherent nature of smart grid are discussed in detail. The chapter concludes by listing few of the applications of smart grid.

Chapter 4 starts with describing the current state of air quality monitoring systems present across the globe. Then it talks about the need for real time systems. Later the chapter describes the calibration techniques that are employed during the deployment of real time of Air pollution monitoring system. Describing the system architecture, the chapter concludes by discussing the observations from the setup.

Chapter 5 describes the field area network (FAN) and its requirement. It describes the Dynamic Spectrum Access (DSA) algorithm proposed in the thesis to meet the latency constraints of FANs. The communication range of different frequencies is establish with a range test simulations. The chapter then describes the different test and analysis that were performed as part of this thesis to find out the feasibility and benefits of cognitive radios when compared to legacy ISM bands. The chapter presents results of different test performed during the simulations viz., Hop count analysis and packet delay analysis.

Finally, the thesis gets concluded in the 6th chapter by describing the finding of real time experiments and the simulation analysis that were performed to analyse the benefits, limitation and improvement scopes of Wireless Sensor Networks in different applications.

Chapter 2

Real Time Air Monitoring System

2.1 Current State of Air quality monitoring

The Clean Air Act enforces EPA to set Standards for air pollutants commonly found in the country to measure Air Quality. There are six common pollutants that could be found in air and they are carbon monoxide, nitrogen dioxides, sulphur dioxides, ground-level ozone, particulate matter, and lead.

Carbon Monoxide (CO): The carbon monoxide is emitted from motor vehicles exhaust which is a poisonous, colourless and odourless gas. Carbon Monoxide blocks oxygen from reaching brain and heart and induce reduced oxygen-carrying capacity in the blood. Excessive levels of carbon monoxide will cause death.

Sulphur Dioxide (SO2): Sulphur dioxide is emitted from Motor vehicles and power plants when they burn sulphur-containing fuel like diesel. Sulphur dioxide causes respiratory ailments such as airways constriction and asthma symptoms.

Ground level Ozone (O3): Ozone is present both in upper regions of the atmosphere and also at ground levels. Oxides of Nitrogen (NO/NO2) reacting with volatile organic compounds (VOC) cause ozone at ground level. Ground level ozone is generated by increased traffic and industries. Ozone can irritate the airways, causing coughing and reduced lung capacity.

Particulate matter (PM2.5/PM10): The larger ions known as PM10 (2,5 to 10 micrometers) and the lower crystals known as PM2.5 (less than 2,5 micrometer) are divisible into two large organizations by volume. PM10 is primarily dirt, dust and smoke produced in manufactures and highways, whereas PM2.5 includes car and metal handling materials and poisonous organic compounds. PM2.5 can remain longer in the atmosphere and travel longer than PM10 being heavier. Any part of the oxygen that is breathed is also breathed and readily passed through the breathing scheme. PM2.5 may have worse health impacts, because PM2.5 is more poisonous (such as heavy metals and organic carcinogenic compounds). Substance exposition contributes to asthma, vomiting, wheezing, respiratory and cardiovascular disease, and even pulmonary disease.

Lead: cars emit guide that does not use unleaded petrol. Exposure to lead improves the chance that kids will experience stroke and heart attack and behavioral diseases.

In 2010 indoor emissions caused 3.2 million fatalities worldwide, up from 800 thousand just 10 years earlier, according to "The Global Burden of Disorders, Injuries, and Risk Factors Study for2010. Given that automotive consumption is increasing at an increasing rate in emerging nations, such as India and China, we hope to worsen the human health consequences of air emissions in the near future.

EPA needs to track and evaluate concentrations of air pollution across Canada with growing issues over the health consequences of air pollution. There are about 4,000 surveillance facilities throughout the USA, which track air emissions within the SLAMS network. There are nineteen stationary air monitoring stations in New Jersey, for instance, of which only six have coal monoxide.

Establishing and maintaining a stationary air pollution control scheme is costly, and requires a large amount of overhead servicing, because air pollutants have to be tested, measured, registered, analyzed and distributed over lengthy periods and have a large geographical region to cover. Such air pollution control centers are usually situated in fields where the air pollution is considerable, such as sectors and elevated demographic densities, such as large towns. However, there is a severe limit to the strategy of settled air pollution surveillance stations when we want to determine the amount of exposure to air emissions outside the fields served by these stations.

Different techniques for measuring air emissions are applied in stationary stations. In one method, sampling is automatically performed by means of chemical luminescence, UV fluorescence, IR absorption, and difference optical absorption spectroscopy techniques, which are evaluated in real time. The information collected from multiple locations is then processes for getting insights. The other procedure consists of active sampling where a known volume of air is pumped for a period through a filter or chemical collection and a laboratory analysis is performed on the sample. In particular, infrared intake testing can be used to estimate pollutant concentrations in the atmosphere. Due to low pollutant concentration, these techniques are not applicable. Therefore, the main methods of measuring air emissions require removing contaminants from the atmosphere by using the nature of elevated air gas transport. The simplest way to distinguish the gasses is to transfer one element of the air pollutant into a non-volatile element, which can be measured by chemical evaluation or absorbed by a chemical response.

Changes in air emissions are vibrant and change nearly every hour or more. Air specimens and later pollution measurements merely provide us with a snapshot at a certain moment and location of an aerial pollution index. Whilst multiple dispersion models can be used to assess air pollutant concentration as it disperses away (e.g. vehicles and trucks), such designs are subject to vibrant metrological information like wind velocity, temperature, rain / fog and landscape information. Using the distribution system is costly to vibrant reviews to passengers and has a very restricted significance on the highway for an average traveler. The traveler needs a tool, which constantly monitors air pollutants and has to interpret the measurements that are impractical and not financially scalable. We therefore need an strategy and template for evaluating air pollution concentrations in real time at places traveled by commuters and sharing this data with individuals that do not have a monitor for air pollution.

2.2 Need for Real-time Air Quality Information

In our dissertation we focused on the surveillance and exchanging of pollution concentrations of carbon monoxide (CO). People must be worried about the concentrations of air emissions, in particular cardiovascular, cardiac and hazardous air pollutants, such as carbon monoxide (CO), which are already subjected to air emissions, must monitor for additional exposure. The adverse impacts of air emissions are not reversible, particularly for carbon monoxide (CO); so we must be vigilant in order to decrease likelihood of any extra health hazards if we are subjected to certain concentrations. Greater CO exposures can contribute to higher concentrations of nervous, blood vessel and cardiovascular poisoning, which may result in mortality. Increased air pollution irritates lungs and causes aggravation of asthma. A real-time alerting scheme that constantly controls air pollution concentrations and warns consumers of hazardous exposures to air toxins would be of real benefit for such susceptible groups of individuals. Most of us believe that the implementation of catalytic converters in engine vehicles helps to decrease CO concentrations and other pollutants.

However, we have a mistaken feeling of warmer water at the cold beginning because CO is odourless, less coloured, in the cold climate, catalytic transformers are not effective at cold beginning and lead to even hazardous exposures, such as more than 100 ppm of CO. For a catalytic converter to warm up to be efficient it requires at least five minutes. The air supply also draws straight from the exhausts of neighbouring vehicles in high voltage bumper-to-bumper traffic. The model suggested in this dissertation helps teach passengers in possibly damaging CO concentrations. Health-conscious travellers may use such schemes in order to schedule safer alternative paths, choose distinct travel times of the day, use the government transport network and increase car-pooling. This data could also allow the scheduling, establishment of sector and the placement of fresh sectors, regulating policy and support for decisions on fresh Community growth projects for schools and housing areas.

Current measurements of ambient air emissions include measurements of an instant atmosphere particular air pollutant. EPA has an air pollutant-specific reference technique. For example, carbon monoxide (CO) requires a NDIR, a continuous infrared sensor used to detect CO levels through the absorption of a particular wavelength in infrared light, which is used as an infrared spectroscopic device. NO / NO2 is evaluated by the level of oxygen response of chemiluminescence. Ozone is evaluated with ethylene by the frequency of chemical light response. Particulate material (PM2.5 and PM10) will be evaluated with gravimetric samples of filtration. Such equipment is best used in laboratory environments and costly. Furthermore, the generation of warning and alert texts of excess air pollutant concentrations requires comprehensive manual or automatic test collection, test evaluation, information collection, evaluation, information modelling and pollution prediction methods. The prevalent traveller is out of reach with these complicated instruments and analytical designs. This means that a cheap, easy air quality monitor can be used to readily obtain and share pollution information by frequent passengers in their vehicle.

An option method for measuring and detecting damaging gas in the environment is provided by electro-chemical gas detectors. By responding with a particular gas, electrochemical devices work by generating an electrical signal proportionate to the gas concentration. An electrochemical detector normally comprises a detector electrode and an electrode counter divided by a small electrolyte layer. This particular air pollutant gas moves through an opening and spreads over a hydrophobic obstacle, allowing an adequate quantity of gas to respond with detecting electrodes to generate the electric signal needed either through oxidation or decrease reactions by electrode material created for a particular gas. Carbon monoxide (CO), nitrogen oxides (NO / NO2), ozone (O3) and sulphur gases (SO2) can be used for measurements using electrochemical detectors. Due to their portability and low energy usage, Electrochemical detectors are ideally suited to monitor air emissions in real time.

A variety of screens are accessible for individual use on the customer sector using electrochemical detectors. These gas screens show air pollutant concentrations on LCD screens, with an easy procedure of buttons on or off. They burn less energy and can run for up to two years and price only a few hundred US bucks. One feasible alternative is for commuters to purchase and maintain these gas sensors in vehicles. These monitoring devices could instantly warn commuters that poisonous air pollutants such as Carbon Monoxide are subjected to greater levels. No credible route is at present available to share and warn other passengers who could intend to use the same congested roads simultaneously. We need a way of sharing air pollution information with other commuters with a handful of passenger vehicles in their vehicles.

2.3 Calibration of Gas Sensors

Each gas sensor is unique, meaning that while the sort and the sensed gas are equal, the output features of distinct sensors may vary. Each sensor must therefore be calibrated[1] before interfacing with the mote wireless sensor for precise measurements. Calibration by exposing the detectors to various gas levels is performed in the laboratory.

Fig.2.1 shows the different steps engaged in the method of calibration. An in-room layout is particularly structured at a temperature of 25ºC and a moisture of 45 to 50% RH. The House has provision for the shipment of gas and electricity. Gas from extremely accurate systems can be sent, with the MASS Flow Controllers, to keep steady flow rates. Precise GCC equipment is used to evaluate PPM (parts per million) gas that runs through the narrow air chamber. The measuring device is used in the GCC. The raw voltage measured from the sensor is extremely volatile and very small. In the course of calibration, signal conditioning systems have been intended to stabilise and amplify sensor measurement. The sensors and the conditioning system are placed in the room and measurements are recorded for periodic gas PPMs. The voltage value of each detector corresponds to the gas input concentration. These observable values are traced and the respective PPM-concentration trait equation is developed for map-voltage signals. In the following parts the O2 and CO2 calibration procedure is discussed in detail.

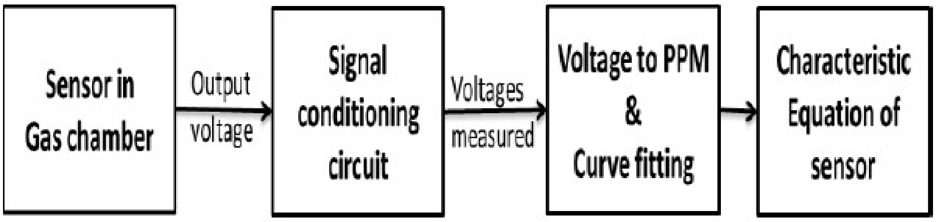


Fig. 2.1: Gas Sensor Calibration Steps

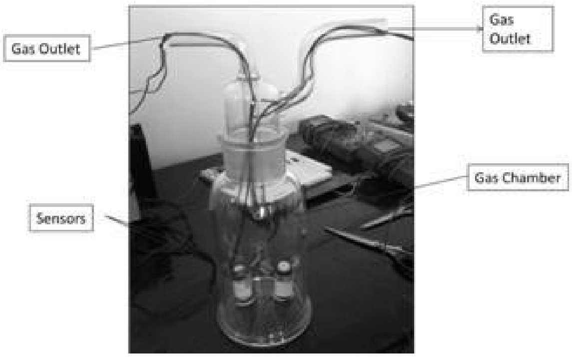


Fig. 2.2: Gas Calibration Chamber

2.3.1 Calibration of Carbon dioxide Sensor

The TGS4161 (Fig. 2.3) of Figaro is a strong electrolyte (a strong status sensor type) CO2 sensor of 350 to 5000ppm of detection range[2]. A solid electrolyte created between two electrodes and a printed hot surface are part of the delicate component of the sensor. The CO2 concentration is assessed by the Electromotive Force Change (EMF) monitoring between the two electrodes. This sort of solid electrolyte detector is selective for tiny, low-cost, targeted and long-term target gas[3][4].

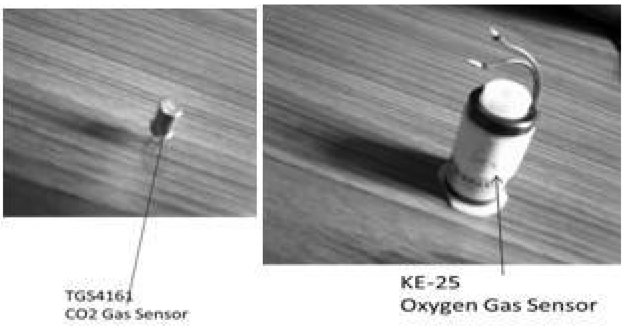


Fig. 2.3: CO_2 and O_2 sensors

The measured sensor TSG4161 was calibrated using a closed gas chamber shown in Fig. 2.2 in the laboratory setting. For calibration, the sensors were put in the container. The test gas consists of 10 000 ppm of balanced N2 carbon dioxide gas and 10% hydrogen synthetic air. The sensors range from 350ppm (atmospheric concentration) to 2000ppm for calibration with CO2 concentration. The resistive sensors are susceptible to temperature modifications and the calibration ambient temperature in the space is kept at around 25 degrees. The flow rate in closed chamber during experiments was retained at 200 ml / min. Cross-checked the gas concentration with the gas analyzer. The gas analyser has revealed that a 2–5% difference in the gas concentration was observed between 350ppm to 1200pm. There have been five calibrated sensors of the same kinds. The sensor was subjected 350 ppm to atmospheric CO2 concentration for 10 minutes before testing each concentration. The gas concentration will return to 350ppm after each test before the next experiment begins. The measured sensor signal resistance for the CO2 sensor was typically 220mV and was extremely volatile with an atmospheric concentration of 350ppm. The signal conditioning circuits with an amplifier and filter during the calibration phase were used to stabilize and amplify the measured signals Fig. 2.4.

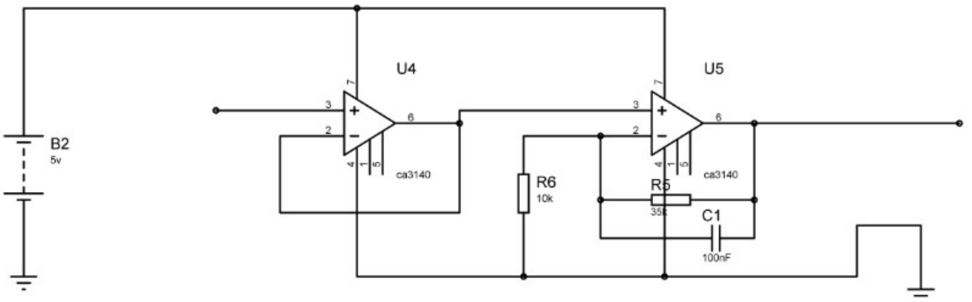


Fig. 2.4: Signal conditioning circuit for CO2 sensor – TGS 4161

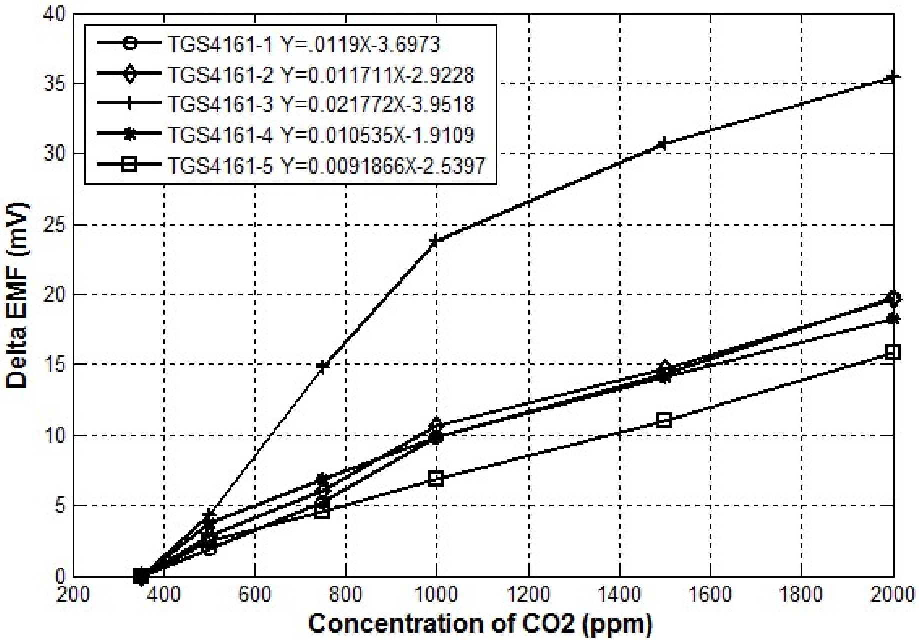


Fig. 2.5: Calibration result for Figaro TSG4161 CO_2 sensors

The figures of Fig. 2.5. Show the outcomes of the calibration of the five various CO2 sensors of TSG4161. The output of TGS4161 was noted to be linear up to 1000ppm in semi log scale, and then deviates slightly and is roughly linear. The equations for every sensor provided in Fig. 2.5 are achieved by curve fitting. CO2 Sensor Calibration Equation

For Sensor1, $y = P1 * x + P2$,

where,

y : Measured Voltage

x : CO2 Concentration

P1: 0.011992

P2: -3.6973

For the rest of the sensors, the equation is given in Fig. 2.5.

2.3.2 Calibration of Oxygen Sensor

The KE-25 oxygen sensor (Fig. 2.3) from Figaro is the distinctive oxygen type galvanic cell sensor created in Japan in 1985. It delivers a linear output tension signal relative to the oxygen level in a given atmosphere. The sensor is long-life, good chemical resistance and has no CO2, CO, h2S, nox, h2[5] influence. It also works at regular ambient temperatures without requiring warm up, which is suitable for the surveillance of oxygen for portable applications.

With the exception of the oxygen used by the oxygen generating system, the configuration for calibration of KE-25 was the same as the calibration for CO2 detectors and is dilute in synthetic atmosphere. The K-factor was 1,24 for H2S calibrated oxygen gas, two MFCs were used. The synthetic gas K-factor calibrated with hydrogen was 1.48. Calibration was carried out at around 15 ° C at room temperature and the flow rate in the sealed gaseous chamber kept at 300 ml / min. At 5 percent from 15 percent to 50 percent, the sensor is tested at distinct levels.

We have seen that a negligible impact on sensor performance is the impact of temperature and humidity. With an amplitude between 11-14 mV in ambient air, the KE-25 provides very stable voltage. We have used a high impedance sensor conditioning circuit, followed by an amplification increase of 100 in the calibration process Fig. 2.6.

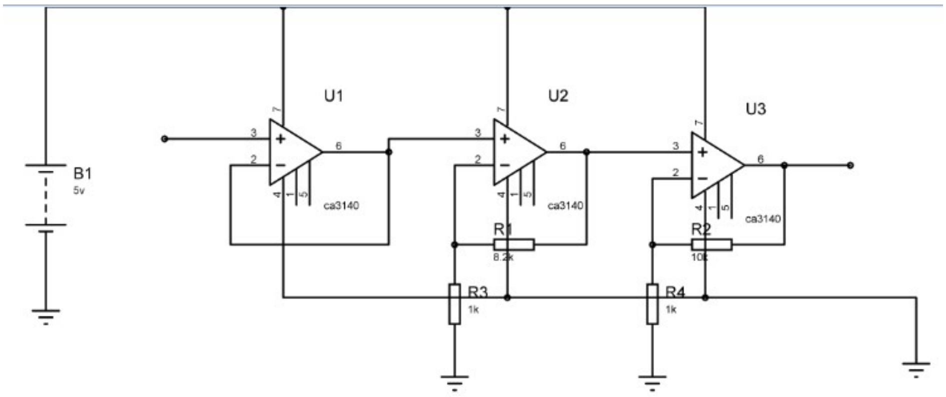


Fig. 2.6: Signal conditioning circuit for O2 sensor – KE-25

Fig. 2.7 demonstrates three distinct KE-25 O2 sensors calibration results. The output of the oxygen detector (KE-25) is shown to be linear for all oxygen levels. The relationship between output voltage and gas levels can be shown

$$O2 = (V_a - V_0)/(V_{100} - V_0) \qquad \ldots\ldots (1)$$

where,

O2 = measured concentration of O2 gas

Va = Output Voltage of the sensor at tested concentration.

V0 = Output Voltage of the Sensor at 0% oxygen concentration

V100= Voltage of the Sensor at 100% oxygen concentration

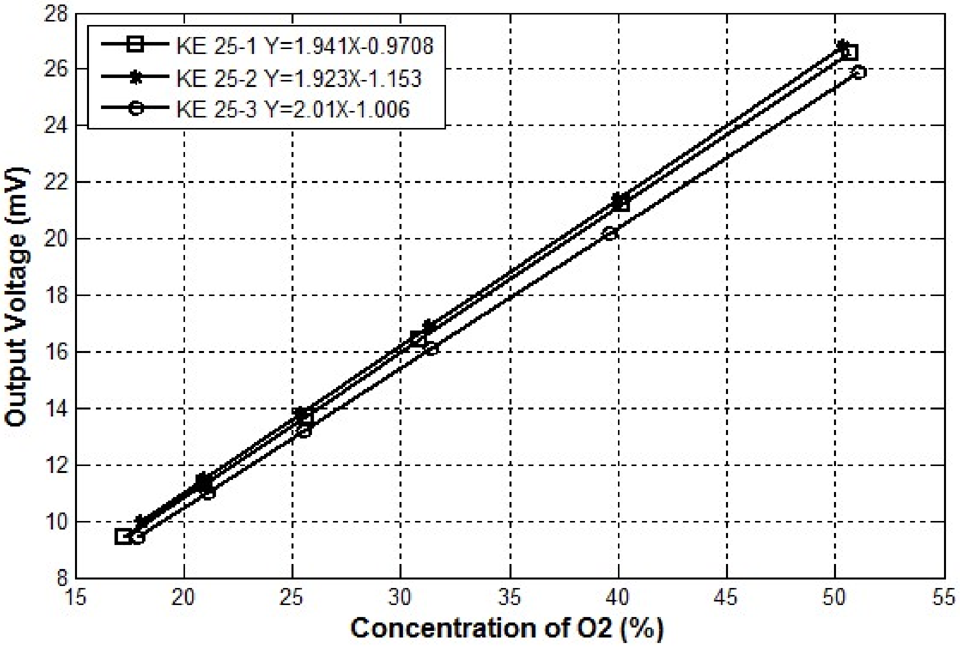


Fig. 2.7: Calibration Result for Oxygen sensor KE-25

The calibrated equation is provided in Fig. 2.7 for each of the sensors acquired after the test. The system architecture with which these sensors are interfaced is discussed in the following chapter after calibration of the sensors.

2.4 Real Time Testbed Deployment

In order to obtain the fine grain pollution data of gasses like CO2, O2, NO2, CO together with other parameters such as the temperature, humidity and pressure, a real-time wireless system has been developed. The surveillance system architecture is illustrated in Fig. 2.9. The following steps are the design and creation of the pollution control scheme.

1. Gas sensor calibration (Section II Discussed)
2. Setting up air pollution surveillance wireless sensor nodes
3. Middleware development
4. Deployment of fields.

2.4.1 Configuration

The commercially accessible gas sensors are connected to motors / modules of wireless sensors via a gas sensor board, which are programmed to monitor air pollution. As the core wireless communication module, which includes a processing unit and a communication unit Fig. 2.8, Libelium WASP motes are used. Wireless node ports ADC (analog to digital) are scheduled to periodically sample the different gas sensors, which rotate in interface with the sensor panel. The samples gathered are packaged and sent from each sensor node, forming the mesh network (Fig. 2.9) at periodic intervals to the base station[6][7]. Multihop information aggregation algorithm[8] was introduced to boost the surveillance variety. Signal conditioning and other modules on WASP are referred to as[9] for configuring the RF Xbee module. The pollution control test bed in real time has been created and implemented with a network of five nodes.

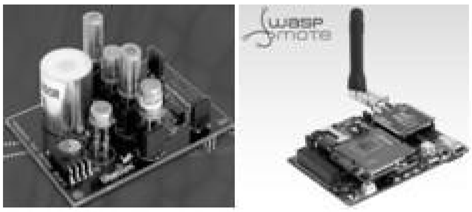


Fig. 2.8: Libelium WASP mote and various gas sensor panel

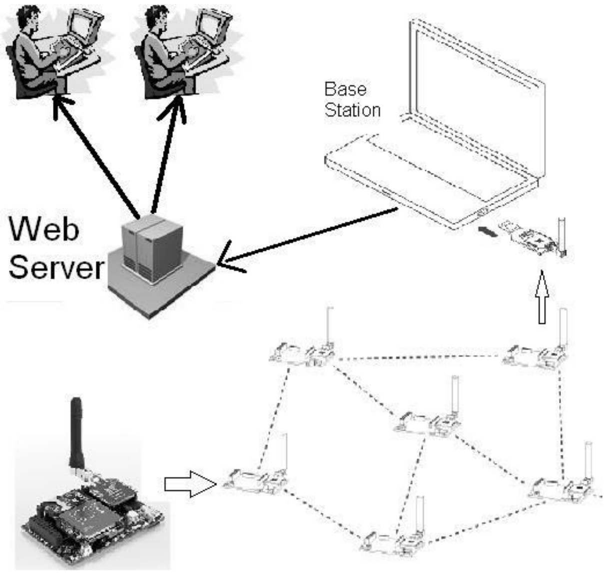


Fig. 2.9: Architecture of multihop network network

2.4.2 Middleware and Web Interface

The base station or sink node gets information from the deployed network at periodic intervals. For efficient data storage and retrieval, lightweight middleware is created. Visual studio is used to develop an application to read and transform serial port information to a suitable format. The parsed information in tables and the time stamp for each packet are entered into the database. To view live information in a format number and graphs available from anywhere on the Internet a web-based graphical user interface (GUI) is created.

Through a multihop network, the data is sent to the base station. It requires an efficient, effective and secure information repository. This repository should have an efficient database access facility for both web-based services and sms-based mobile services. Repository data should also be aimed for enabling the internet sensor, i.e. for sensor data with geo-spatial information. Standardization of gas sensor technologies should be created, such as the protocol TML[10], to exchange live streaming and/or archived data from any sensor scheme, to (i.e. control information) and/or sensor data. An interoperability data repositories are also integrated (technologies such as WIFI, Bluetooth, etc.).

2.4.3 Pilot Deployment

Two distinct locations, namely IIT Hyderabad campus and Hyderabad cathedral–Kukatpally –were used for the pilot deployment of the wireless air pollution surveillance scheme. The aim is to obtain information on fine grain pollutants in these fields. Fig. 2.10 shows the five node pollution surveillance test bed deployed on IITH campus (30 kilometers) from the polluted urban area. The gasses such as CO2, O2, CO, and NO2 were put at various campus places. In addition to gasses, temperature, moisture and pressure parameters were tracked at these sites. The middleware and the GUI trace real-time plots of these gases and other parameters. The observed information for all mots on the IITH campus appear to mostly represent a standard atmospheric gas concentration (CO2-350 ppm, O2-21%, NO2–0.7 ppm and CO-0.1 ppm). Testing was conducted by showing various physical circumstances at some of the sensor nodes of the network. Therefore, the motocycle exhaust was located close to one of the sensor nodes (mote1). The information gathered from this node indicates CO2 levels of 900 to 1000 PPM with variations in bicycle acceleration. It also has been noted that the CO2 concentration of the motorcycle is turned off and returns to its standard level atmosphere, from PPM 350 to PPM 380. Fig. 2.11 is declining together with temperature and humidity changes other significant findings are O2 concentration.

Fig. 2.10: IITH's wireless air pollution monitoring system

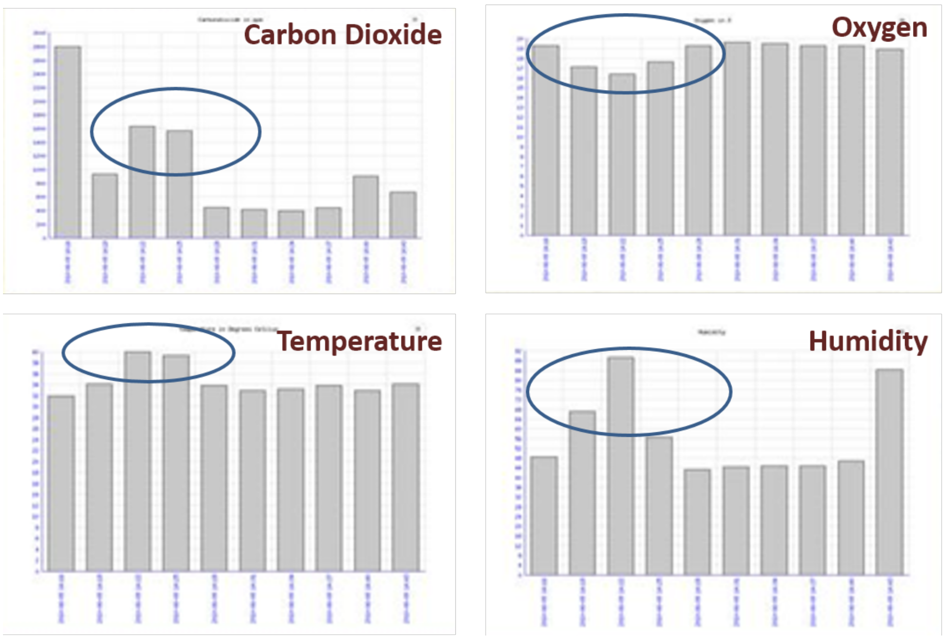


Fig. 2.11: Mote-1 gas concentration close to the motorcycle exhaust

2.5 Results and Discussion

Resistive heating-based sensors are air pollution sensors like CO2, CO and NO2. The battery of wireless nodes consumes a lot of energy, which is harmful to the lives of networks. The sensors Chemical / MOSFET need much less energy but are too expensive. For exact measurements, the impact of temperature and humidity is to be regarded on resistive gas sensors. Periodical calibration is required, but for a big number of sensors in the sector it is hard. Sensor life (typically 6-9 months) is very short[11]. Furthermore, the expenses were too big for Libelium Motes. We intend to create and create cost-effective architectures for the next stage of the project. Energy should be optimally used for the wireless sensor nodes. The sensed information of each node is transmitted regularly. Algorithms for data compression and information modelling help to save node energy by decreasing redundancies. For better data visualization or analysis, data should have geospatial information. The capacity to estimate and quantify information should be provided by sensor nodes. Sleep modes should also be included with regard to the received data statistics.

Chapter 3

CR based WSAN

3.1 Introduction

The current electricity grid infrastructure is old and has not long been renewed or updated. It suffers from energy deficiency, small power losses and low reliability. The Smart Grid idea was suggested to solve these problems. It is a technology designed to integrate intelligence into electrical energy generation, transmission and distribution systems. The concept is to gather information on the operation, status and requirements of the grid and to make the necessary choice to fit the scenario. Evolution of intelligent real-time decision-making algorithms has contributed to the quick and reliable resolution of the multiple issues related to electricity grid[12].

The backbone of the intelligent power grid is an effective and reliable communication system. A large amount of sensor units and actuators must be connected, and state and control messages must be transmitted throughout the grid. There is no single protocol or network which meets all smart grid communication demands. Different protocols for multiple smart grid functionality have therefore been suggested.

To automate the Smart Grid distribution system, a wider Field Area Network (FAN) is needed. FAN's geography and functionality are covered in an extensive field. These features have a high degree of bandwidth and latency. The seamless transmission of data from the neighboring hood network (NAN) aggregators into the substation is, for example, required to support a 5 Mbps bandwidth, while the FAN has a maximum of 100ms of latency[13] to support distributed energy resources (DER) Islanding. Due to the problems addressed by the writers in [14][15], Power Line communication can not be a feasible option. Therefore, the Field Area Network requires a Wireless Sensors and Actuator Network (WSAN).

WSAN application in the power grid demands a high performance and low end-to-end delay. The Cellular network, ZigBee, Wifi or Wi-Fi protocols may be some of the feasible communication protocols. The current mobile network, however, is not reliable. Control messages may not satisfy late demands during peak network congestion and may therefore cause critical systems to fail. It also fails to reach all areas, particularly rural[16][17], in a reliable manner. The ZigBee protocol has very small performance and is not able to satisfy FANs ' (DA) elevated information requirements[18]. As suggested in the literature[13][17], WiMAX could provide the best alternative for FAN, but WiMAX infrastructure is not fully installed and even its popularity is quickly losing.

Therefore, a better technology needs to be explored. The other wireless alternatives available that are very close to the requirement are Wi-Fi, because they have low assembly costs and elevated information rates. However, there are different problems related to Wi-Fi, such as reduced ranges and heavy interference from other protocols, such as ZigBee and Bluetooth. One can believe of mesh or multi-hop networks in order to solve these problems. Although these network kinds help to overcome the problems in the spectrum, they do not solve the issue completely. To promote DER in the distribution grid, a network for the field area must have a maximum latency of 100ms. If the amount of hops in a mesh network is higher then this demand can most likely not be met.

On the other side, spectral sensor studies have shown that the UHF-band is assigned to television broadcasting and has a small operating cycle and not used in all geographical settings for transmission[19]. Cognitive radio (CR) technology can use such a spectrum of white spaces. A software-determined radio is a cognitive radio, capable of reconfiguring its own settings based on its own channel and performance evaluation[20]. CR technology can be used in FANs for distribution grid to increase the efficiency of the Wi-Fi protocol. This document presents the relative Wi-Fi performance analysis in the 2,4-GHz band and CR-based Wi-Fi in the 680MHz band. The benefits of the WSAN CR protocol in a FAN are described through simulations and analyses.

3.2 Field Area Network

Sensors / acuators, called intelligent electronic systems (IEDs) installed in critical distribution grid points, such as transformer devices, lightning arrests, circuit breakers, condenser shells, junctions and others, are knots other than NAN aggregators that belong to

FAN. These IEDs are accountable for tracking their health, reporting it to the substation and taking preliminary control measures in the event of failure or malfunctions. A FAN is presented in the Fig. 3.1. The following functionalities should be allowed in the grid by FAN[12].

1. Automation distribution.
2. Integration of energy production and storage alternatives distributed.
3. Relaying the NAN to substation smart meter information.
4. Electric Plug-in (PEV) Charging pumps are being integrated.

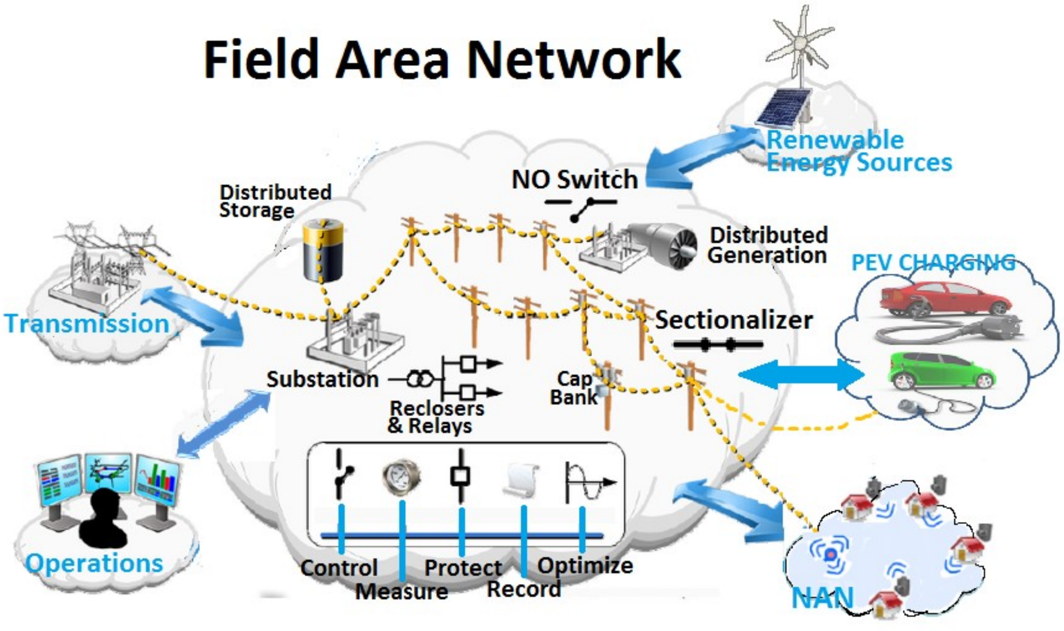


Fig. 3.1 : Field Area Network

The above-mentioned FAN features demand a WSAN implementation of critical machinery. There are therefore tight delay and output limitations. This article tries to assess CR technology's performance improvement over Wi-Fi for WSAN and fulfill FAN demands.

3.3 DSA Model for CR-WSAN

One of the main enabling characteristics of CR technology is the Dynamic Spectrum Access (DSA). It is determined as the capacity to dynamically switch channels on a communication device (Secondary User or SU), allowing it to pick the best channels to spread. However, care must also be exercised so that the channel proprietor (primary user or PU) does not interfere with transmission. Spectrum sensing and frequency agility are necessary for the application of DSA. Spectrum detection relates to the current channel surveillance for PU presence detection. Frequency agility can be changed to a different channel if the PU begins transmitting on the current channel.

The most significant issue for the implementation of DSA in CR is non-interference with the PU. In order to preserve signal integrity in the PU, certain regulatory restrictions need to be complied with. Certain DSA parameters are Incumbent Detection Threshold (IDT), Channel Detection Time (CTT), Channel Closing Transmission Time (CCTT), Probe Detection (PD), Maximum Probability for False Alarm(PFA). In[21] they are further defined. The value of these parameters is the main and secondary user networks of the channel we use. The IEEE Standard, IDT=-116dBm, CDT= CCTM= 2s, PD=90%, PFA=10% [19] describes the DSA facilitators in TV broadcast stations.

A major element of DSA model is spectrum sensing. This task is allocated to few nodes, which reduces total energy use for other nodes. The spectrum sensing coordinator is a feasible alternative because it is a highly calculating powered tool. The geographical region of the distribution grid covered by the FAN is sufficiently low to suppose that distinct consumers for various places in this region will not be present.

Transmission from all FAN nodes must be interrupted for a period of moment known as Quiet Period (QP) in order to have reliable PU sensing. These broad network periods may be likened to the on-off data transmission model so that consumers can transmit information during non-QPs (in phases), while transmission during QPs (off time) has to be closed. This benefits from PU detection at extremely low IDT values and helps to prevent false alarms[22]. The QP repeats all QP intervals and lasts QP. The model used in this thesis assumes that the QP interval is 2s, the optimal sensing time for reliable outcomes is 802.22, the CDT and CMT specifications, and the QP duration 50ms. In the Fig. 3.2, you can see the time diagram for the DSA model.

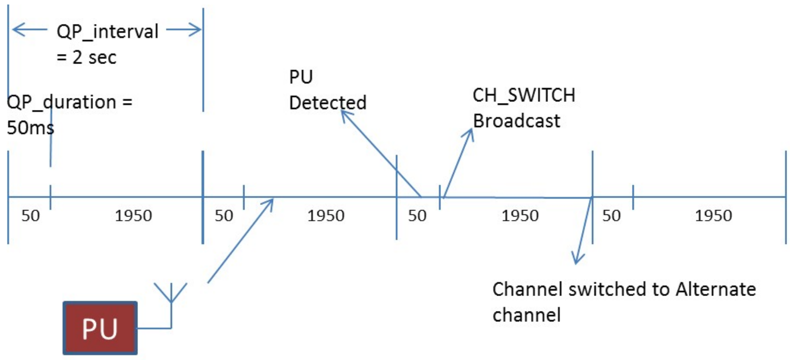


Fig. 3.2: DSA Model

The working channel, which is a random event, can have a PU appear at any moment. This is why a appropriate random variable has been designed. Once the PU is identified by a QP coordinator, a Channel Switch command is broadcast, which includes data on the next channel chosen. At the beginning of the following QP, all nodes are shifted to fresh channel.

3.4 Range Test

The 2.4GHz channel communication range and a 680MHz CR channel are contrasted at the same transmitting energy. Sender and recipient antenna gains are corrected to -86dB, and a model for a space loss free route is used. In this model, quadratic path loss as shown by the author is calculated[23]. The transmission capacity is diverse in steps and the transmission range for the two channels is shown in Fig. 3.3. The range here is taken as a stage where the receiver stops getting any packet from the transmitter altogether.

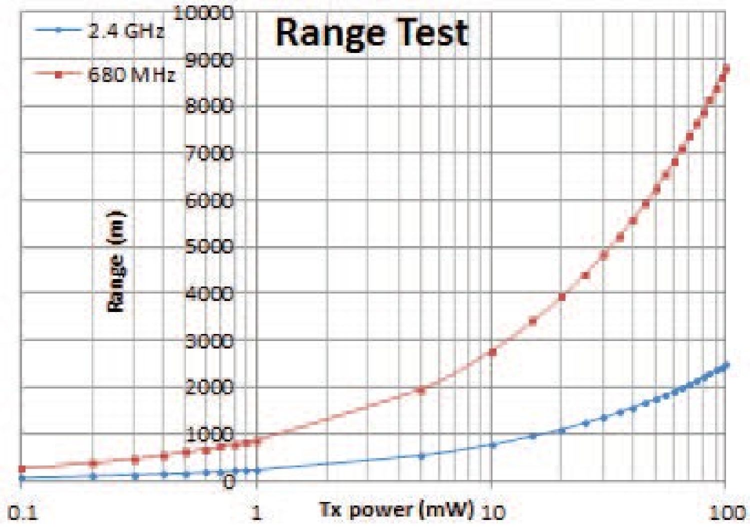


Fig. 3.3: Semiological Range Test Plot

As shown in the Fig. 3.3, the 680MHz channel range is more than three times as high as that of 2.4GHz channels for the same transmitter energy. The greater loss of propagation at greater frequencies can explain this. The communication-acquired improvements can reduce transmitter energy or use fewer sensor nodes for a specified region.

3.5 Network Scenario

Two kinds of topologies have been assessed for distribution grid automation. First of all, as shown in Fig. 3.4, a scheduled topology and the other, as shown in Fig. 3.5, constitutes a consistently distributed topology. 6. With 36 sensor nodes and a coordinator, every topology is intended.

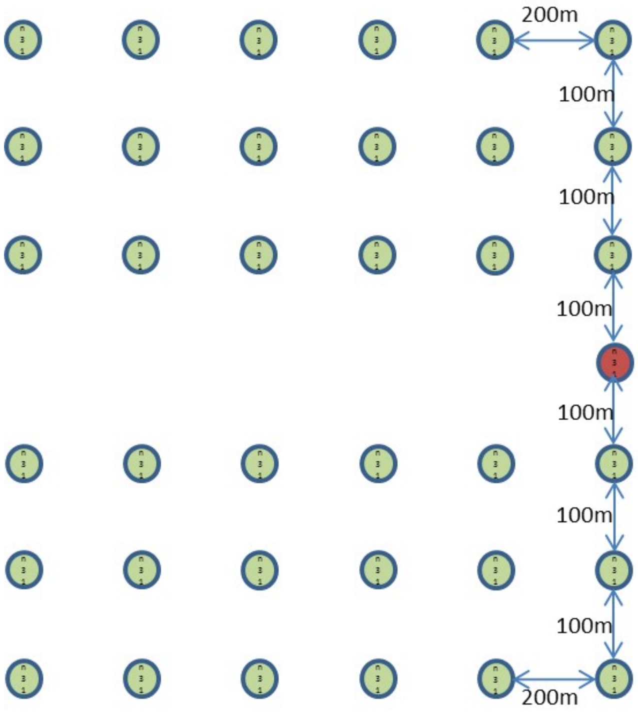


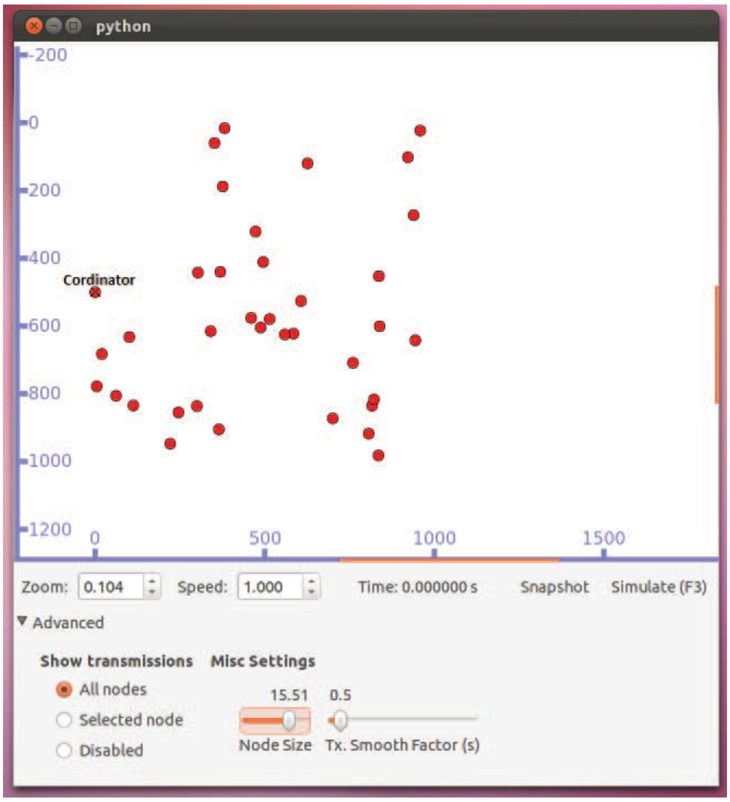
Fig. 3.4: Planned Topology

The anticipated FAN traffic is:

1. NAN aggregated intelligent meter information.
2. DER Coordination to and fro information.
3. Health surveillance information for critical equipment.
4. IED measurement information for the management of energy quality.
5. Check substation and/or IED utility data.

In our simulations, this information traffic scenario is represented as two distinct packets. Status paquets of 256 bytes are sent every 0.25 seconds by the sensor notes to the coordinator. The selection of packet size is[22] with the premise that the converter resolutions are 8-bit, instead of 16-bit. Every 2 seconds, the Coordinator sends a 256-byte control packet to all nodes. The Channel Switch command for CR simulations consists of a third category of packets. Each moment PU is identified in any PQ, it is broadcasted from the coordinator to all nodes.

Priorities are set for all three kinds of packets. The Channel Switch command packet, followed by the control packet and lastly the status packet have the greatest priority.



Zoom: 0.104

Speed: 1.000

Time: 0.000000 s

● All nodes

Node Size 15.51

Tx. Smooth Factor (s) 0.5

Fig. 3.5: Random Topology

The 2400 MHz channel provides a Wi-Fi protocol. We regarded two centre-frequency channels 680 and 702MHz and a bandwidth of 20MHz, which can be used for data transmission, respectively for the execution of the CR model. We also take into account that the other one is released for use by SU once the PU begins to transmit on a single channel. Spectrum sensing at the coordinator alone shall be presumed. These assumptions are comparable to those in[24], but PU is only shown once throughout the simulation. We model PU as a random variable Bernoulli with 30 percent chance of achievement (SP) in our simulations. The absolutely worst SP situation is also considered to be = 100%, i.e. in every quiet period the PU appears in the working channel.

Both protocols have a transmission capacity of 1mW (0dBm). This value is taken with an idea of low node energy consumption. OLSR protocol is used to allow multi-hop transmission. Since OLSR doesnot supports the multi-hop broadcasting of control and channel command packets, we have established a flooding based protocol for this purpose.

3.6 Hop Count Analysis

The amount of hops is registered and a hop count analysis is provided for each data packet. Hop count implies the amount of hops removed from each sensor node by a packet transferred to the coordinator.Fig. 3.6 and Fig. 3.7 displays statistics of the hop count for both scheduled and random topologies. As shown in Figures, because of its greater communication spectrum, the CR protocol introduced on the Wi-Fi model considerably lowers the hops for all packets. The drop rate of the packets is also decreased substantially.

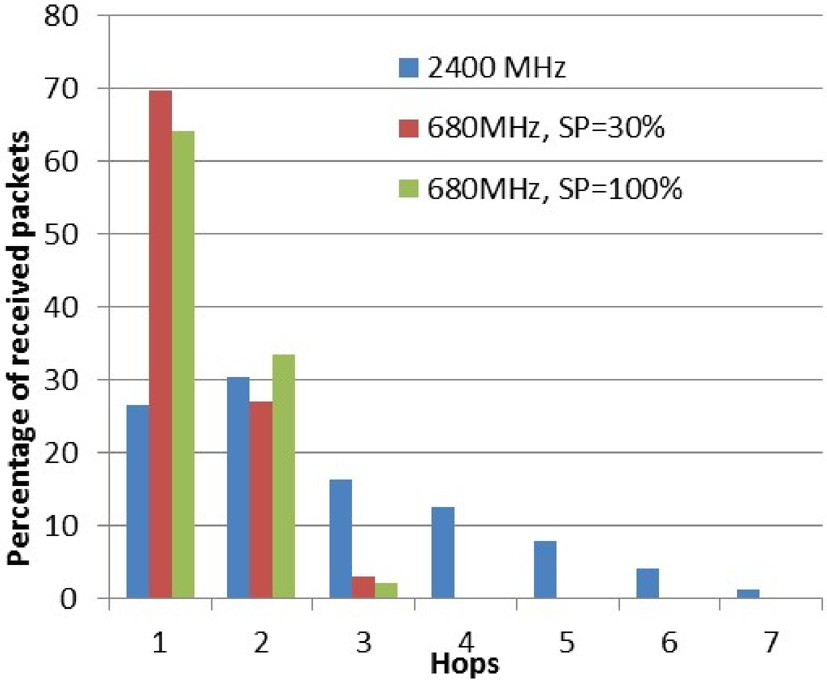


Fig. 3.6: Planned Topology Hop Count Analysis

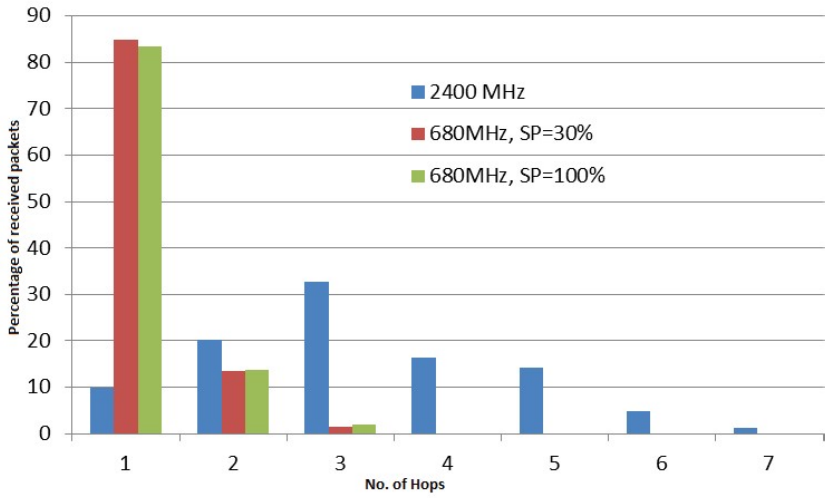


Fig. 3.7: Random Topology Hop Count Analysis

3.7 Packet Delay Analysis

Delay is an significant WSAN network performance criterion. In order to implement real-time surveillance and control schemes for the intelligent distribution grid, critical sensor information and high priority control actions must be transferred in a specified period. Data acquisition and processing, poor channel conditions, low information rates and bandwidth, and greater nodes in the broadcast channel containment and multihopping could be the possible cause of information latency in a communication network. The delay of end-to-end of each packet was logged and the collected data was analyzed statistically. Table 1 shows the maximum and average delay rates for the three simulated situations.

Table 1. End-to-end delay performance statistics

	Maximum Delay (ms)		Average Delay (ms)	
	Planned Topology	Random Topology	Planned Topology	Random Topology
2400 MHz	934.1	236.9	70.0	49.2
680 MHz, SP=30%	380.4	581.4	18.2	10.7
680 MHz, SP=100%	1615.5	2305.6	40.3	26.45

The average delaying efficiency of a 30 percent SP CR model can be seen in Table I even after the QP and channel switching overheads is better than that for legacy Wi-Fi models. Even for the worst case scenario where PU appears in every QP on the working channel, the mean delays are better than traditional Wi-Fi. The reason why channel switches have a greater peak delay. If the network switches to a later channel, ancient network data such as a routing table is void and this time consuming must therefore be re-established. Any way we do not see that even a 30% SP channel is used for cognitive radio communications (3 seconds on average free). Instead, a free channel is regarded for CR apps for a few minutes (say, 10 minutes leading to 0.33 percent SP). Therefore, even in the application requirements, we expect the highest delay.

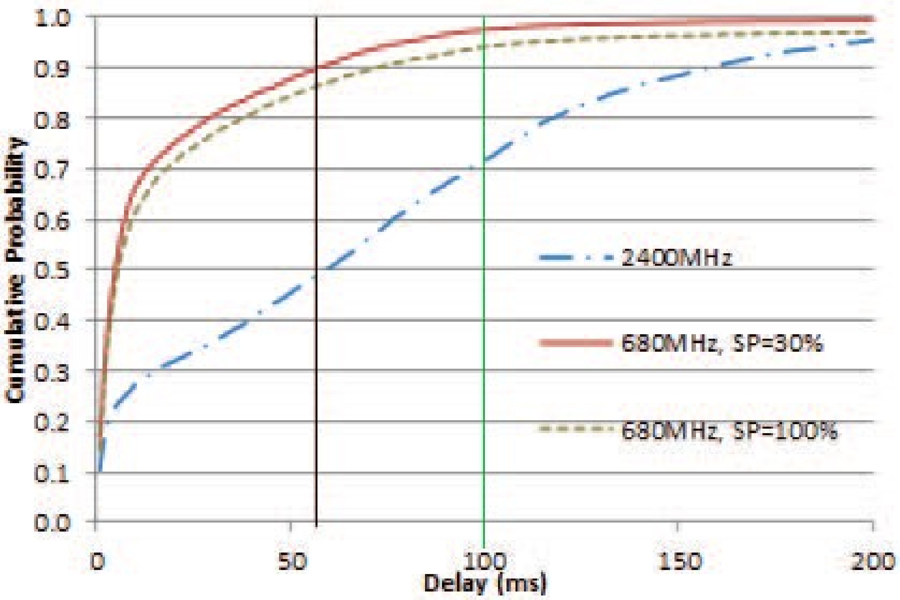


Fig. 3.8: Packet delay CDF for planned topology

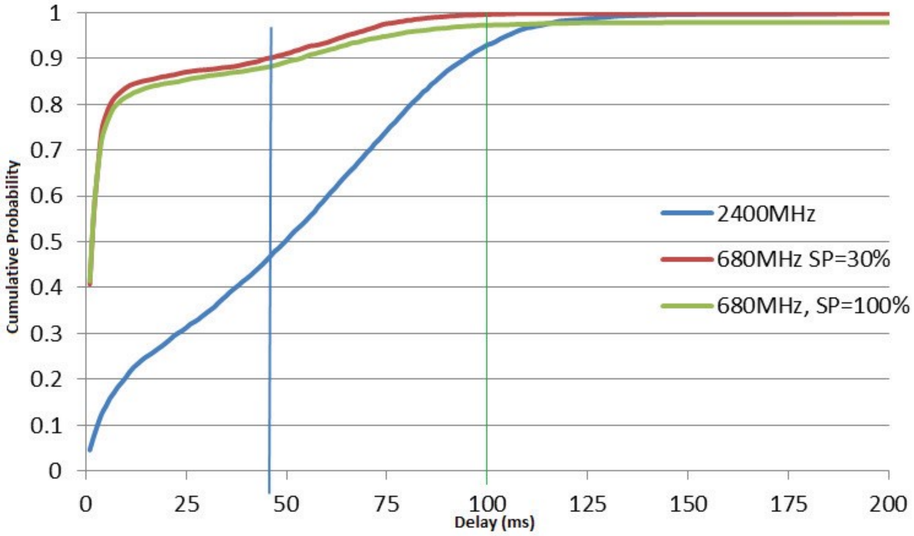


Fig. 3.9: Random topology packet delay CDF

Fig. 3.8 and Fig. 3.9 demonstrate the Cumulative Distribution Function (CDF) packet delay data for the scheduled and random topology. The CR protocol is much less time consuming for most packets. For instance, nearly 100% of packages for the CR models were delayed by less than 100 mm while only 70% for legacy Wi-Fi with a scheduled 60 m delay, and less than 90% for random topology, achieved their destinations. Due to the fact that the WSAN cognitive radio meets best fans ' requirements in the intelligent grid with the latency of less than 100 sms for 100 percent of packets.

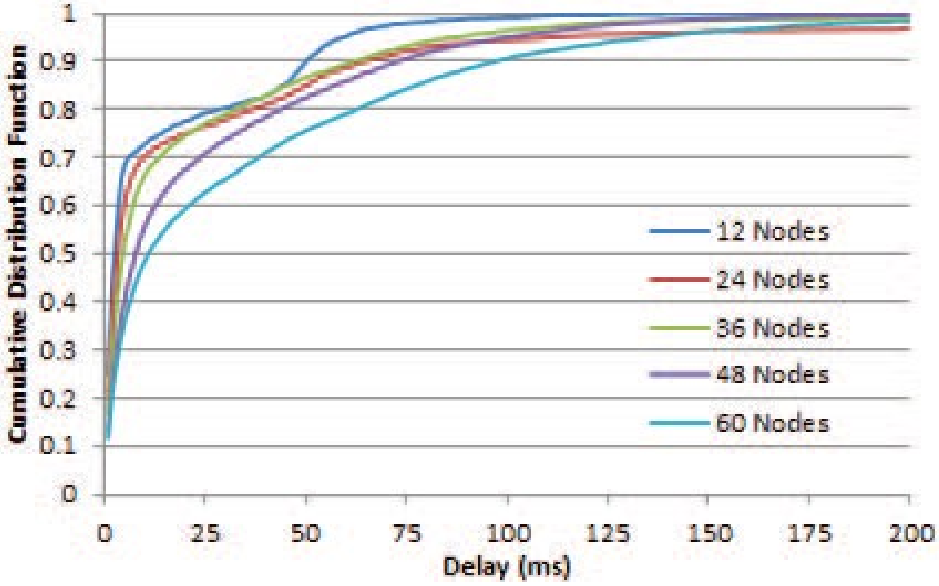


Fig. 3.10: Packet delay CDF plot for varying number of sensor nodes in planned topology

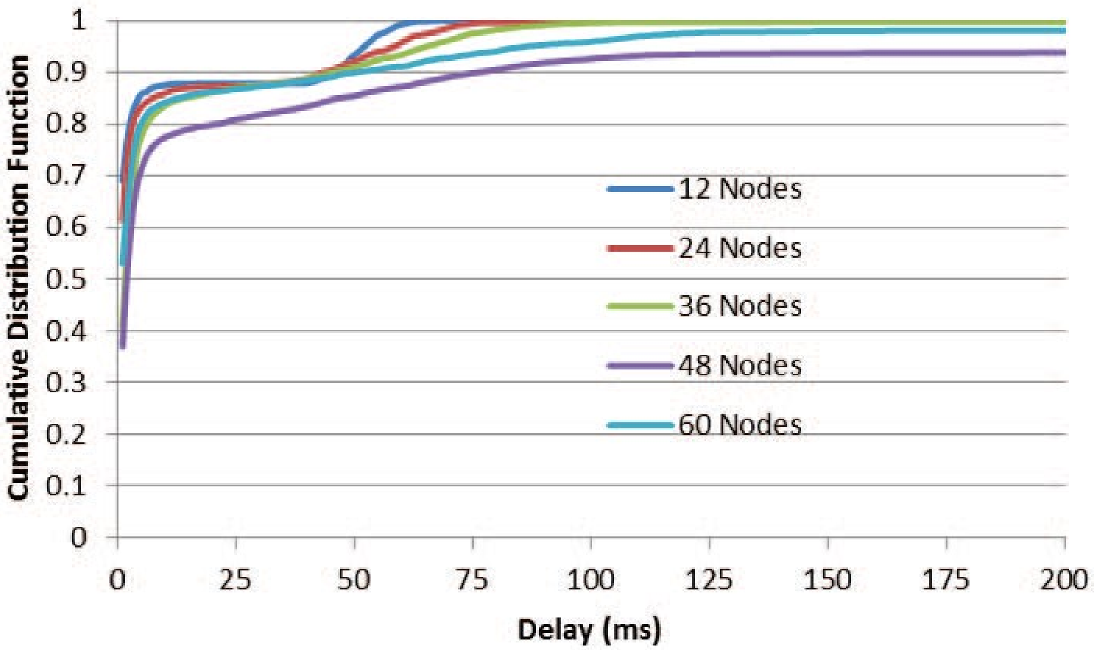


Fig. 3.11: Packet delay CDF plot for varying number of sensor nodes in random topology

In terms of delayed results, we also evaluated the scalability of the network. There are different amount of sensor nodes, with delays in each situation being logged. The CDF of packet delays is shown in Fig. 3.10 and Fig. 3.11. The findings show that latency output with the increase in sensor node density does not deteriorate significantly.

Chapter 4

Conclusion

The importance of real-time wireless air pollution monitoring system is investigated considering the vital technical and economic issues for vast area deployment. Commercially available gas sensors were calibrated using the appropriate calibration technologies. These pre-calibrated sensors are then interfaced with the wireless sensor motes forming multi hop mesh network. A light weight middleware and web based interface were developed for online monitoring of the data in the form of charts from anywhere on internet. Pilot deployment of the system was carried out at the campus and at the Hyderabad city. Experimentation carried out using the developed wireless air pollution monitoring system under different physical conditions show that the system collects reliable source of real time fine-grain pollution data.

The FAN is the most critical network of an intelligent grid communications infrastructure thanks to tight delay and throughput requirements. In terms of latency, energy effectiveness and network simplicity, we conclude that the CR model is better than traditional Wi-Fi in terms of hops, greater range and therefore less hops. The rate of packet loss is also significantly improved. We also found that the variation in network topology does not alter significantly in results. We assume that a CR model can perform even better if the MAC protocol is more deterministic than a random CSMA. Dynamic QP duration can be used to reduce the overall QP charge. This might be an important subject for studies. The other significant benefit of CR is that the transmission at a reduced frequency can improve in the urban situation with multi-track fading. Further study will concentrate on the development of FANs in urban regions.

Publications

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