Chapter 4 – Network Domain Space

4.1 Introduction

Conceptually, the network domain space comes next to application domain space. A three layer network domain space is proposed are 1. Construction of optimized sensor field and sensor network design (physical topology) 2. Networking protocol (logical topology) and 3. Application level performance analysis. To improve the performance of the network, optimizations across three layers are to be analyzed. The network domain space refers to the configuration of connection between peripherals involved in the network like sensor, computer, transmission media and levels of communication. When selecting a network configuration, topology (physical and logical) plays major role. Fixing of sensor node location to effectively monitor interested area, construction of optimized sensor field and sensor network design are the considerations of physical topology.

In this chapter, the possibilities of network design of building an efficient data collecting system for continuous air pollution level monitoring using sensor network in an industrial area, with available resources are discussed. The following are the models proposed based on the knowledge gathered from large scale industrial visit.

- Generic architecture of sensor network in Industrial Air Pollution Monitoring (IAPM) through internet equipped with micro server in industrial premises and meta server in pollution control board
- Design of simple short distance sensor field setup and sample long distance sensor field that is topo sketch showing air quality monitoring sensor locations in XYZ industry
- One of the interesting three dimensional node location scenarios to monitor SPM (Suspended Particulate Matter) level in stack of an industrial area
Large scale industries are having industrial control systems namely Distributed Control System (DCS) to form communication network of various critical infrastructures of electric, water, oil, gas etc., In addition to that it is proposed to form a modern field bus system with Sensors Marshalling Panel (SMP) to collect data from various sensors available in different units of an industry.

- Multi source and single sink topology model to collect air pollution data

### 4.2 Generic architecture of Sensor network in IAPM:

![Generic architecture of Sensor network in IAPM through Internet](image)

**Figure 4.1 Generic architecture of SN in IAPM through Internet**

Generic architecture of Industrial air pollution monitoring through Internet is shown in Fig (4.1). Server in industrial premises (micro server) is used for getting data from sensor node and it can also combine data from different sensor nodes in a sensor field. PCB use Internet or
mobile device for downloading the sensor data from various industrial zones through server in their premise (Meta server). Meta server is necessary for monitoring of hazardous air pollutants in and around industrial areas and to identify and control critically polluting areas.

For efficient implementation of District Industrial Air Pollution NETwork (DIAPNET), district is divided into several industrial zones. One industrial zone may be treated as one sensor field. A sensor field is an area which contains many sensor nodes doing the same work (sensing pollutant level). This application may have high performance analyzers to monitor various pollutant gases. The typical job of an analyzer (Sensor node) is to sense the environment, collect data and route the data to the sink. A network is used to pass the data to micro server and then to meta server.

The above network is a kind of distributed sensor networks, to gather data and communicate it to an uplink point. The information gathered by a particular sensor does not influence the behavior of another sensor. In other words, distributed sensors collect data, while sensor webs are self-informing and modify their behavior on the basis of collective data [72].

Configuration of connections between nodes namely distance between nodes, physical interconnections, transmission rates, and/or signal types are the parameters that also affect actual physical network. The two components of the above generic architecture are sensor field design and single data collection point (sink). These two components are discussed in the following sections.

4.3 Possible sensor field designs

Sensor field design itself is a complex one for this application. Before any system is designed and installed, a detailed understanding of its physical environment and deployment is
required. Deployment means node distribution within the phenomenon field. Three deployment strategies [73] are random deployment, regular deployment and planned deployment. Node deployment for industrial air pollution monitoring must follow rules or norms designed by TNPCB. So, this application requires planned deployment.

In sensor network, the infrastructure plays a significant role in determining the performance of the network. The network domain space means the possibilities of sensor node location and sensor field setup models. Proper planning is executed through different functions that are performed before network installation in order to decide the node architecture, number of nodes, distribution type, deployment type, organization type, protocols and so on. The possible sensor field design based on sensor field size namely short distance and long distance models are pictured.

4.3.1. Short distance sensor field

![Design of short distance Sensor field setup](image)
Simple heterogeneous short distance sensor field setup model is shown in Fig (4.2). For example, an industry emits more than one pollutant and they want to collect all data by using appropriate sensors. Figure shows the real picture of sensor field setup available in an industry XYZ. Figure has four sensors to monitor pollutant levels of Sulphur Oxide (SO\textsubscript{x}), Nitrogen Oxide (NO\textsubscript{x}), Carbon Oxide (CO\textsubscript{x}) and Suspended Particulate Matter (SPM). Like input devices, sensors may also be connected to the local computer’s com port by using cables. Instead of passing data directly from sensor to industrial server (far away from sensor), data may be sent to the local computer which is kept near the sensor. This setup reduces the inbuilt memory within a sensor and avoids long distance communication collapse from sensor to micro server. But hard wired cables are not suitable for certain node locations. For example, in stack monitoring scenario to be explained in next section, the node location must be in 3 dimensions. Hence to fit 2 dimensions and 3 dimensions sensor node locations, it is better to go for wireless medium.

4.3.2 Long distance sensor field :

To collect data from all emission sources (different units of an industry, stack location) located in various distances and height in an industrial area, number of sensors and their location is important. To decide sensor’s location, the following spatial and background knowledge is necessary [12,74,75].

- Pollution affects inside the industry first and then outside. To maintain the permissible levels of certain pollutant in the work environment and to indicate horrific levels, sensors must be fixed inside industrial premise such as chimneys place and other work place (number of units available in an industry).
- As per TNPCB norms outdoor air quality around industrial area must be measured in a 10km radius.

- Predominant wind directions and seasonal variations in temperature play an important role in determining location of monitoring stations. The monitoring stations should be located in areas that are downwind from the sources, which met the criteria for a good site.

- It is meaningless to fix all outdoor sensors at the fence line of an industry or exact 10km radius as per PCB norms, because the concentrations at the fence line of a facility are not necessarily the maximum concentrations.

- Emission rate may vary from day to day due to changes in the production rate.

Fig (4.3) shows sample topo sketch of air quality monitoring sensor locations in XYZ industry. Sensors numbered 1 is fixed at stack, 2-4 are fixed at various units (indoor location) of an industry namely Chlorine Based Product Division (CBPD), Caustic Soda Division (CSD), Poly Vinyl Chloride Resin Division (PVCRD), Iron Oxide Division (IOD) and Thermal Power Division (TPD) and sensors numbered 5-7 are fixed at outdoor location namely Industry entrance, nearby residence area and business complex.

After deciding the number of sensors and their location the next step is possible communication mode. Due to the physical environment, wireless networks often extend to an existing wired infrastructure. The wired infrastructure may be quite complex to begin with, especially if it spans several buildings in a campus setting. Wireless networks depend on having a solid, stable, well-designed wired network in place. If the existing wired network is not stable, another choice is the wireless.
Most of the industries, especially large scale industries are equipped with hard wire cables. So, for cost effective SN in industrial air pollution monitoring, already available wired network may be utilized. If possible Wireless LAN or GSM network for long distance communication may be used. Thus data passed anywhere, that is, to a micro server for better scheme in production activities, and to a meta server for taking action against industry and analyzing air quality. Varieties of short and long distance wireless technologies are available to pass data anywhere.

Figure 4.3: Topo sketch showing Air Quality Monitoring Sensor locations in XYZ industry
The design of the air quality monitoring network basically involves determining the number of stations and their locations, with a view of the objectives, costs and available resources. To assist an industrialist, an expert system should be developed to fix the exact number and distribution of monitoring locations of a sensor. The expert system must contain some guidance to design the final permanent sensor network. Few of them are,

- Number and location of sampling site i.e., sensor location
- Kind of equipment should be used
- Additional background information such as meteorology (conditions in the atmosphere – wind direction, temperature etc), topography (arrangement of the physical features of an area)
- Emission sources
- Various pollutant and their tolerable levels
- Location of sink and number of sink
- Distance between source and sink
- Number of sampling needed and sampling period
- Structure of data to pass (source identification, sensor reading, time etc.)
- Data acquisition system (DAS) to receive all collected values
- Various communication modalities based on distance between source and sink

4.4. Sensor node location at point source stack:

In an industrial point source, emissions emanate from a very small opening such as a stack or vent. Stacks usually emit hot gases forcefully into the atmosphere at a fixed height
above ground level. Samples should be collected under all environmental conditions (temperature, wind speed etc.) that affect pollution levels.

One of the design optimization strategies in WSN is to find out the place of sensor nodes in order to meet the desired performance goals. The placement strategies are static or dynamic and structured or unstructured. The static or dynamic strategies depend on whether the optimization is performed at the time of deployment or while the network is operational. In a structured WSN, sensor nodes are deployed in a pre-planned manner whereas in an unstructured WSN, sensor nodes are deployed in an ad hoc manner [26, 32].

In a structured with static sensor network, sensor nodes are pre-determined to be placed at fixed locations. The choices are grid placement, optimal placement, 2Dimension (D) and 3D placement models. In some real world application scenario, the deployed sensor network operates over a 3D volume rather than in a 2D area. Deployment of WSNs for surveillance of terrains, study of underwater ecosystem, space monitoring and explosion, monitoring air pollution at mountain etc are examples of such application. Industrial Stack monitoring WSN is also one such scenario. This section explains the 3D node location for stack monitoring. 3D Localization scheme, which is identification of sensor nodes position, is also reported in few papers [76, 77].

In industrial Stack monitoring, the nodes can be placed as per the norms of central pollution control board, India [78]. The sampling site or plane is from a disturbance to emission gas flow, such as a bend or a fan. In sampling plane, sensor must be fixed at a point known as sampling point. As per norms, sampling point must be located at least 8* stack diameter height from downstream of a bend and 2*stack diameter height upstream from stack exit, as shown in
Figure (4.4). More than one location may be used as a sampling plane. But smaller number of sampling diameters or points may be adequate [79].

Figure 4.4 Sampling point in a stack.
The implementation of a WSN is prone to multiple factors and is not guaranteed as easily as the cable. The provision of environmental space, the distance between nodes, electromagnetic interference and too many other factors determine the quality of the connection and achieving a wireless communication network. [31] Before installing a network, it is necessary to ensure a degree that it will be successful and functional.

4.5. Single collection point

![Modern field bus system with Sensor’s Marshalling Panel](image)

Figure 4.5 Modern field bus system with Sensor’s Marshalling Panel
Industrial control system (ICS) technology has evolved over the decades. ICS is a general term that encompasses several types of control systems used in industrial production, including Supervisory Control And Data Acquisition systems (SCADA), Distributed control Systems (DCS) and other smaller control system configurations such as skid-mounted Programmable Logic controllers (PLC) often found in the industrial sectors. Large scale industries are having DCS to form communication network of various critical infrastructures of electric, water, oil/gas, chemicals, pipelines, and transportation. The DCS concept came about from a need to gather data and control the systems on a large campus in real-time. Based on the information received from remote stations, automated or operator-driven commands can be pushed to remote station control devices, which are often referred to as field devices. Field devices control local operations such as opening and closing valves and breakers and monitoring the local environment for alarm conditions.

In addition to that it is proposed to form a separate sensor’s marshalling panel to collect data from various sensors available in different units. Marshalling means grouping of I/O devices. Marshalling panel is placed between the DCS system panel and field instruments. From marshalling panel the I/O signals are communicated to the system CPU or controllers. Fig (4.5) shows modern field bus system layout with sensor’s marshalling panel connecting sensors from five different units like CBPD, CSD, PVCRD, IOD and TPD of an industry. Sensors are numbered from S1 to Sn. Thus all sensed data are collected in single collection point.

Now several methods for integration of wireless sensing and control devices with a DCS solution is available. Instead of the traditional DCS, the cost effective digital communication networks may be used, to improve plant performance [80]. There is substantial hardware installation savings associated with field bus system compared to a traditional DCS installation.
in terms of terminations, number of I/O cards, home run wiring, number of transmitters, control room instrument panel space.

Wireless Marshalling Panel (WMP) includes a field device protocol communication link. The WMP is capable of receiving a message from a sensor and transmitting a corresponding message to a process controller via the communication link. Thus, once the data is collected and stored in a sink that data may be passed to any level that is from industrial server to district PCB state PCB, central PCB for better analysis.

4.5 Topology of stack monitoring sensor network

The sensor field designs discussed in this chapter implies the topology of this application is multi-source and single-sink topology (MSSS). MSSS topology in WSN is defined as the network topology, where all sensor nodes can gather and transmit data to the sink. The main advantage of this topology is the failure of one sensor node will not affect the overall task of the sensor network.

In energy constrained WSNs with such topology, one of the design criteria to be considered is network lifetime optimization. The solution to optimum lifetime is considered and reported in some papers [81-85]. From that survey it is concluded that the network lifetime maximization is possible in MSSS topology. So the aim of the further work is limited to test the various sampling mechanism in MSSS network with three dimension sensor node locations needed for stack monitoring.
Conclusion

The purpose of the industrial air pollution monitoring study is to gather real data. To collect absolute and perfect air quality data, continuous air monitoring using sensor network is the only solution. The physical design considerations with focus on proposed sensor network model, sample sensor node location, sample sensor field design and modern field bus system with sensor’s marshalling unit is outlined. And it is concluded that from the available resources it is possible to transfer all sensed data to a single point (SMP) and from there it is also possible to transfer anywhere (DPCB, SPCB, CPCB) in an efficient way.

The design methodology mentioned can be very useful for management and control of environmental pollution, to ensure a pollution free environment and also to get real picture of air pollution models.