A Study on Air Pollution Monitoring and Optimization of Traffic Congestion for Smart City Using Wireless Sensor Networks

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Abstract—Wireless Sensor Networks (WSN) is an emerging technology that can help to reduce the problem of traffic congestion and air pollution. This paper proposes a mechanism for finding the alternate path in case of increased traffic congestion and accidents. The paper also brings into light the various techniques and technologies that are proposed and implemented to combat the problem of air pollution. The model of clustering of nodes is taken into consideration for extraction of the data.

Index Terms—Smart City, Air Pollution Monitoring, Air Quality Index, WSN, Intelligent Traffic System.

I. INTRODUCTION

The concept of smart city can be implemented successfully using Wireless Sensor Networks (WSN). Wireless Sensor Networks are the networks deployed densely in an application area. The sensor nodes in wireless sensor networks form an appropriate structure in order to collaboratively perform a particular task which supplements them to form powerful clusters. Wireless Sensor Networks, commonly referred as WSNs are the networks which consist of sensor nodes organized spatially in their respective networks that are used to monitor various real life situations. Health monitoring, Traffic congestion optimization, Air pollution monitoring, Process management, Pollution monitoring, Earth sensing, Intelligent traffic system (ITS), Structural health monitoring are some of the examples where WSNs have contributed significantly. The concept of “smart city” comprises of two important parts. First is the “Optimization of traffic congestion” and another is “Air pollution monitoring”.

A) Wireless sensor networks are often deployed in the dense regions by integrating them to form the cluster using various techniques. Few of the characteristics of WSNs are: they are wireless, have scarce power, work in real-time, utilize sensors and actuators as interfaces and are deployed in variable physical and environmental conditions. These sensor nodes are deployed in large number depending upon the requirements of the application and are used to collect the data to the base station typically referred to as “sink” [1]. Each node individually comprises of one or more microcontrollers, memory, RF transceiver and have a power source (e.g., batteries and/or solar cells), and accommodate different sensors and actuators [10]. The memory can be of different types like flash, program, data, etc. The RF transceiver is usually configured with a single Omni-directional antenna. Some of the platforms for WSNs are tabulated as under:

<table>
<thead>
<tr>
<th>Sensor node name</th>
<th>Microcontroller</th>
<th>Compatibility of platforms</th>
</tr>
</thead>
<tbody>
<tr>
<td>PowWow</td>
<td>MSP430F1612</td>
<td>Open source; Open Hardware; Research Platform</td>
</tr>
<tr>
<td>Tiny node</td>
<td>Texas Instruments MSP430 microcontroller</td>
<td>Tiny OS</td>
</tr>
<tr>
<td>WASPMOTE</td>
<td>Atmel Atmega 1281</td>
<td>GPRS, Bluetooth, GPS modules, sensor boards</td>
</tr>
<tr>
<td>Sun Spot</td>
<td>Atmel ARM920T</td>
<td>Squawk Java ME Virtual Machine</td>
</tr>
</tbody>
</table>

Table 1: List of Sensor nodes and their platforms

II. LITERATURE REVIEW

Many studies have been conducted to control the traffic congestion, improving the flow of traffic and congestion mitigation in WSNs. Also various ideas are proposed for combating the issue of air pollution. Some of these are reviewed as under:

Reference [3] put forward the concept VANETs (Vehicular Ad hoc NETworks) based IVTIS (Intelligent Vehicle Traffic Information System) model which can run in the simulation platform by using the secondary development platform of traffic simulation software. The model of IVTIS is found worth reasonable in some of the aspects like self-collection and diffusion of crucial information. Reference [7] provides the use of WSNs in Intelligent Traffic System and provides the comprehensive study of the architectures for the deployment of the same. Reference [8] does the feasible comparison of the TAG (Tiny Aggregation) with or without data aggregation in wireless sensor networks in terms of energy efficiency and increased scalability. Reference [1] makes the use of VANETs and the RSUs (Road Side Units) for reduction of traffic congestion and provides an efficient algorithm for solving it. It also propose inter-vehicular interactions and the interaction
of vehicles with WSN deployed infrastructure.

Reference [5] provides the design of the model that is integrated system containing various parts such as ATMEGA16 microcontroller, ZigBee modules, Sensor arrays consisting of two gas sensors (CO₂ and Nitrogen Dioxide (NO₂)). The architecture creates the interaction amongst the sensors nodes and between the base station and the motes. In this model the data sensed by the motes is sent to the central database that holds the data with proper storage. Reference [4] creates the deep survey of various sensors that can be used and are used for the air pollution monitoring like Waspmote, GUSTO-An Open Path Air Pollution Sensor, CitiSense, Netatmo-Creator of the world's first personal weather station with air quality sensors. It also reviews about pollution monitoring systems like GPRS-Sensor Arrays, Indoor Air Quality Monitoring, and Mobile Air Quality Monitoring Network (MAQUMON).

Reference [2] provides the Recursive Converging Quartiles (RCQ) algorithm for Air pollution monitoring called as the Wireless Sensor Network Air Pollution Monitoring System (WAPMS). Also the paper provides the hierarchal routing protocol for better power management which causes the nodes to sleep during the idle time. The authors of reference [9] extend their contribution to data aggregation algorithms by proposing lossless algorithm, controlling the degree of aggregation and managing the buffers.

III. PROPOSED MODEL

Proposed work is classified into two categories as under:
A. Intelligent Traffic System
B. Air Pollution Monitoring

They are described in detail in the proceeding sections:

A. Intelligent Traffic System (ITS):

The conventional road system has width of each lane about 12 feet. The study was conducted at 190 intersections in Tokyo, Japan and 70 intersections in Toronto, Canada. The conclusion was deduced that wider the lanes, greater are the chances of road accidents. The length of lane for safe transport is expected to be in the range of 10 feet to 10.5 feet. Hence, the proposed transport system takes into consideration the length of lane to be 10.2 feet as some extra lanes are also required for the selection of alternate path in case of emergency. Few of the important modules of the ITS are VANETs and data aggregation in WSN. They are briefed below.

VANETs:

VANET stands for Vehicular Ad-hoc network (actually the special case of Mobile Ad-hoc Network), constitute vehicles equipped with advanced wireless communication devices and self-controlled networks built up from moving vehicles [6]. Safety and delay are the two crucial aspects in ITS model, where the safety model should be delivered to each neighbouring node in the network without any delay [1].

Data Aggregation in Wireless Sensor Networks

After the data is sensed from the different vehicles, there is need to store and process it for producing the desired result. The process of collecting sensed data from different sensors is called data aggregation. The data can be aggregated from sensors using different algorithms. The most frequently used and recommended algorithms for data aggregation are LEACH (Low Energy Adaptive Clustering Hierarchy), TAG (Tiny Aggregation), etc. with the help of these algorithms the sensed data can be collected from different stations and processed further.

The approach used in the proposed model for data aggregation is clustering. Clustering is the process of grouping the nodes together in the dense network. With clustering in the network, the nodes are spatially distributed from the Central Base Station (CBS). Here the nodes installed along the road side units would act as the cluster heads and communicate with the CBS. The moving nodes will send their sensed data to the cluster heads and the cluster heads in turn would send the sensed data to the CBS. With clustering approach it becomes easy to implement various data aggregation algorithms especially LEACH for collecting the data. When the data will be sensed by the vehicles, query will be generated and will be processed to produce the desired result. The query is processed by different query languages. Tiny DB is the database for the Tiny OS which is explicitly used for the processing of the data sensed by the WSN. The query language used in Tiny DB is Tiny SQL. The syntax of Tiny SQL is nearly non-different from the SQL used conventionally [8].

In the proposed model, the data will be sensed from the vehicles on the road. The vehicles will be moving in the different parts of the city. Hence each sensor node cannot directly report to the CBS with its sensed data. Therefore, there is need to create the sub-base stations for few nodes (vehicles). These nodes will provide the sensed data to their respective base stations. These base stations act as individual sink nodes to the CBS and provide the sensed data to the CBS. The data from the individual nodes is then successfully reached to the CBS. The schematic representation of the data aggregation in the proposed work is as shown below.

![Figure 1: Data Aggregation Using Clustering](image)
Proposed Model: Design of WSN Based ITS For Optimization of Traffic Flow

In this paper we take into consideration small area for studying the traffic congestion optimization. The mechanism gives the congestion status of the traffic created by the vehicles and send signals as per the degree of the congestion detected. Sensor nodes count the number of vehicles passing per second and a certain threshold permissible value is set as reference. If the actual traffic exceeds this reference number, base station sends appropriate signals to the respective cluster head nodes and then these signals further can be sent to traffic control system for diverting the traffic.

A) Avoiding traffic congestion due to high traffic density:

The vehicles considered in our paper are assumed to be mounted with sensor nodes and they are communicating to the cluster head nodes. Also the infrastructure of the road is assumed to have sensor nodes mounted along the Road Side Units (RSUs), thereby having Vehicle to Infrastructure (V2I) communication [1]. These RSUs are built on the space along the right side of the roads (along the dividers) rather than the left sides so as to minimize the trouble caused to the sensor nodes by the pedestrians. The data sensed by the sensor nodes will be sent to the cluster head nodes and then to the base station which will control the operations based on the flow of data. An administrator assigned for the administration of the same will take care of the activities to perform in case of emergency situations.

Figure 2: Alternate path selection mechanism

The value of optimum traffic density for the distance equal to the distance between the two cluster heads in the proposed model is defined as five vehicles per second. The value of optimal traffic density is fed in the cluster heads along the dividers. If the flux exceeds the optimum value of traffic density, traffic gets diverted to alternative road.

We have also proposed in our traffic system that the Heavy Weight Vehicles (HWV) will move along the left lane and the Light Weight Vehicle (LWV) will move along the right lane. This consideration is made because in case if HWV chooses alternate path, it require more space to make a turn as compared to the LWV, thereby creating the congestion for the nodes following it. The sensors mounted alongside the road are not randomly communicating with moving nodes. Rather they communicate in the alternate fashion. Odd nodes
communicate with one side of the road and even nodes communicate with the other side. For instance X₁, X₂, X₃ will communicate with one side while X₄, X₅ will communicate with other side. These nodes are actually the cluster heads that send the sensed data from the moving nodes (vehicles) to the CBS for further processing.

B) Avoiding traffic congestion due to road accidents:

There will be a minimum safety distance of 1 meter between the two nodes such that there is no accident between them. The safety distance will be defined individually both for the nodes moving parallel to each other and those moving in one behind the other fashion. If the distance is less than the minimum safety distance, then the buzzer will be alarmed, thereby warning all the nodes. The alarms will be mounted along with the RSU infrastructures. The value of minimum safety distance to be zero depicts that there is collision between the two vehicles and there are chances of traffic congestion due to the same. To reduce this congestion, there is an emergency route built. By taking this route they can reduce the congestion and effective transportation time for the same. In case of collision between two nodes, the buzzer will be alarmed and ambulance will be sent for the help by the administrator at the base station. This will reduce the congestion to the considerable extent. Also it will improve the conventional flow and administration of the traffic.

Air Pollution Monitoring

Air pollution is a real threat these days to public health and environmental problem that can lead to—among other things—global warming, acid rain, and the deterioration of the ozone layer. Air pollution monitoring is also another important aspect in providing the healthy environment. Air pollution monitoring deals with the monitoring of the different chemicals and the gaseous elements, specifically pollutants, that are released in the air by the vehicles and the industrial waste. These chemicals are hazardous to the health of the mass and may also prove lethal. Below is the list of few such common pollutants that are let out in the atmosphere and have sometime long lasting hazardous effects on the environment.

i. Ozone: Ozone is not created directly, but is formed when nitrogen oxides and volatile organic compounds mix in sunlight. Ozone near the ground can cause a number of health problems. Ozone can lead to more frequent asthma attacks in people who have asthma and can cause sore throats, coughs, and breathing difficulty. It may even lead to premature death. Ozone can also hurt plants and crops.

ii. Carbon monoxide: Carbon monoxide is released when engines burn fossil fuels. Emissions are higher when engines are not tuned properly, and when fuel is not completely burned. Furnaces and heaters in the home can emit high concentrations of carbon monoxide,
too, if they are not properly maintained. Exposure to carbon monoxide makes people feel dizzy and tired and gives them headaches. In high concentrations it is fatal. Elderly people with heart disease are hospitalized more often when they are exposed to higher amounts of carbon monoxide.

i. Particulate matter: Particulate matter can be divided into two types—coarse particles and fine particles. Coarse particles are formed from sources like road dust, sea spray, and construction. Fine particles are formed when fuel is burned in automobiles and power plants. Particulate matter that is small enough can enter the lungs and cause health problems. Some of these problems include more frequent asthma attacks, respiratory problems, and premature death.

ii. Nitrogen dioxide: Nitrogen dioxide mostly comes from power plants and cars. Nitrogen dioxide is formed in two ways—when nitrogen in the fuel is burned, or when nitrogen in the air reacts with oxygen at very high temperatures. High levels of nitrogen dioxide exposure can give people coughs and can make them feel short of breath. People who are exposed to nitrogen dioxide for a long time have a higher chance of getting respiratory infections. Nitrogen dioxide reacts in the atmosphere to form acid rain, which can harm plants and animals.

These are few of the most common pollutants frequently found in the atmosphere and are the driving agents in deteriorating the normal environmental balance. Various technologies are being developed, implemented and reviewed in this subject matter but are not 100% applicable in general situations. The technologies reviewed in this context are created keeping in mind some particular environmental elements (pollutants) rather than generalizing this subject matter which makes it difficult to cope up with real time generalized pollution issues.

Few of the instruments along with the gas sensors are developed to counter the problem of air pollution. Some of the technologies and ideas regarding the same are reviewed as under:

i. Waspmote: Waspmote is an open source wireless sensor platform specially focused on the implementation of low consumption modes which allows the sensor nodes (“motes”) to be completely autonomous that is battery powered. Lifetime of Waspmote sensor nodes may go from 1 to 5 years depending on the duty cycle and the radio used. Waspmote is able to sense nitrogen dioxide, carbon monoxide, carbon dioxide, methane, hydrogen sulphide, hydrocarbons, ozone, etc. [4].

ii. GUSTO [4, 11]: Generic Ultraviolet Sensors Technologies and Observations (GUSTO), is based on open-path technologies capable of measuring the volume of key urban pollutants. It has a short time scale and volume mixing ratios can be determined.

iii. CitiSense: An instrument named CitiSense, is developed by the researchers at University of California, equipped with the sensors that measures ozone, carbon monoxide and nitrogen dioxide and monitors the real time pollution levels [4].

iv. Authors in reference [2] propose the idea for the monitoring of the air pollution in Mauritius with the use of routing protocols and Air Quality Index (AQI). AQI helps in checking out the levels of the air pollutants in the real times live or in different intervals. With the help of AQI, quality of the air can be determined with great efficiency and monitoring can be done more precisely.

The main issue that rises up in designing the system for air pollution monitoring is the instability of the pollutants both in quality and quantity and also the life of sensors. Also sometimes the hazardous chemicals and gaseous elements are let out as the industrial waste get mixed with pollutants released by the vehicle and are practically most of the times unable to identify. Also as the different sensors are deployed and are on all the time, the life of sensors reduces drastically even if it sometimes does not sense the data. This problem serves as an obstacle in providing the maximum efficiency for air pollution monitoring system.

The problem of air pollution is something that can never be completely solved. Rather it is possible to monitor the pollution of air and take some preventive measures. The proposed air pollution monitoring system makes the use of Air Quality Index (AQI). AQI is the parameter that plays the key role in governing the quality of air. The different levels in AQI is the result of instability of the pollutants that are released in the air. In the proposed system, the quality of air is completely governed by categorizing the AQI into six different categories- Good, Satisfactory, Moderately Polluted, Poor, Very Poor and Severe. The Central Pollution Controlling Board (CPCB) along with State Pollution Control Board (SPCB) has operating the operation of monitoring air pollution levels in 240 cities with the consideration of eight pollutants- PM\(_{10}\), PM\(_{2.5}\), NO\(_2\), SO\(_2\), CO, O\(_3\), NH\(_3\), PB.

Based on the value of AQI, there is impact on the human health as well. The value of AQI is never stable, because the proportion of different pollutants keep on changing the atmosphere, corresponding to the amount of chemical effluents released from vehicles and the industries. The standard range of the AQI and the corresponding impacts are tabulated as under:

<table>
<thead>
<tr>
<th>AQI Range</th>
<th>Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good (0-50)</td>
<td>Minimal Impact</td>
</tr>
<tr>
<td>Satisfactory (51-100)</td>
<td>May cause minor breathing discomfort to sensitive people.</td>
</tr>
<tr>
<td>Moderately polluted (101-200)</td>
<td>May cause breathing discomfort to people with lung disease such as asthma and discomfort to people with heart disease, children and older adults.</td>
</tr>
<tr>
<td>Poor (201-300)</td>
<td>May cause breathing discomfort to people on prolonged exposure and discomfort to...</td>
</tr>
</tbody>
</table>
Table 2: List of AQI values and their impacts

<table>
<thead>
<tr>
<th>AQI Level</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very Poor</td>
<td>May cause respiratory illness to the people on prolonged exposure. Effect may be more pronounced in people with lung and heart diseases.</td>
</tr>
<tr>
<td>Severe</td>
<td>May cause respiratory impact even on healthy people, and serious health impacts on people with lung/heart disease. The health impacts may be experienced even during light physical activity.</td>
</tr>
</tbody>
</table>

Proposed Model: Monitoring of Air Pollution using AQI and policy of periodically sensing the data

The paper proposes an idea for the air pollution monitoring system that can assist to monitor the air pollution and to some extent combat the problem concerned with the life of the sensors. The air pollution level will not be monitored for 24 hours a day. Instead, the monitoring will take place in fixed time slots, thereby retaining the life of the sensors. The data, collected from the nodes, will be aggregated at the base station. The sensors for the above mentioned pollutants will be deployed at the regular distances along the Road Side Units (RSUs). The data will be sensed for the limited number of time at regular intervals. The policy of sensing the data for the limited number of time is to retain the battery-life of sensors for the long period of time. The aggregated data will be continuously cross-checked against the AQI’s standard range of values. If the AQI crosses the value of 300, the buzzer will be alarmed thereby notifying the administrators to take the preventive measures. The traffic can be diverted through other areas of the city.

The data will be collected at the regular intervals, hence the amount of data collected will be large in amount. The heavy weight public transport vehicles run on diesel. Diesel is the most contributing fuel to the air pollution. Hence, in the proposed model we expect the transport vehicles like truck, buses to use CNG.

We propose the policy of monitoring the AQI levels periodically rather than 24hrs a day. Initially few of all the pollutant sensors will be turned on and the sensed data will be sent to the base stations. Based on the aggregated data, we will make the list of pollutants that are most frequently sensed and then cross-check them against their AQI. Few of the sensors of the elements with good AQI and least sensed can be turned off. The remaining sensors of the pollutants that are having the worst AQI and mostly sensed can turned on. This would effectively increase the battery life and bring out some sort of efficiency. This process is to be done by the administrator periodically based on the locations where the data is sensed. For an instance, if the data is sensed form the place where the industry/factory is located, then it can be turned off and on periodically based on the fixed timing of the industry/factory when it lets the waste out. Also if the data is sensed from the place with maximum traffic congestion and industry/factories nearby then the sensors with capabilities of sensing the data from the both the places can be turned off and on as per the requirement. Also, post-midnight, the traffic density comes down to considerable extent. Hence few of the sensors of the pollutants emitted by the vehicles, that does not pass through the road post-midnight, especially the light-weight vehicles, can be turned off.

IV. FUTURE SCOPE

With the launch of Smart City initiative by the Government of India, this paper has lot of relevance to the smart cities. With the increasing popularity for Internet of Things (IoT) and advancement in WSN, the proposed idea can be implemented in the cities nominated in the smart city list which could tackle the problem of air pollution and traffic congestion. Penalty can be imposed on the vehicles which are polluting the city by tracking the vehicles using WSN. This technology can also be used in developing the model for Smart parking system that would help to park the vehicles as per their weight.

V. CONCLUSION

In this paper we proposed a solution to combat the problem of traffic congestion caused due to excessive traffic and road accidents using the wireless sensor network technology. We considered all vehicles as the moving nodes mounted with the sensors on them which create a network to have communication between the vehicles and base stations. Also vehicles which are polluting the most could be penalized by tracking them with the help of WSN. The idea of increasing the life of the batteries by periodically turning them on and off as per the requirement would drastically increase the life of wireless sensors. Regular maintenance of the sensors under the periodical observation of the administrator, would help a lot in monitoring of the air pollution. The ideas proposed in this paper will prove to be a good module for creating the infrastructure for the smart city.

REFERENCES


