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A Wireless Sensor Networks with Air Pollution Detection

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Abstract—Wireless sensor networks have been deployed for environmental monitoring over the last twenty years. However, this application is not frequently deployed to solve the environmental problems (e.g. air pollution detection) encountered by many Asian countries. This paper develops an architecture based on a Wireless Mesh Network of Sensors (WMNS) to measure air pollution in Indian cities. We are motivated by the fact that air pollution in Indian cities is emerging as a key threat to health, environment, economy and the quality of life for millions of Indians as the level of urbanization, motorization and economic activity increases. We develop a model that takes into account the structure of Indian cities and the lack of Internet access in some urban or rural areas. As a result, the model could help with the implementation
of regulations concerning air quality in India.

Keywords: Sensor Network, Air Pollution, Routing Protocol, Wireless Mesh Network, System Monitoring.

I. I NTRODUCTION

City boundaries as pollution is found on crops far from the city. It also contributes to global environmental issues such as climate change. The future challenge for India is to deploy a suitable network for measuring, forecasting and checking the quality of air. This paper proposes a Wireless Mesh Network of Sensors to measure air pollution in Indian cities. Our model is particularly suitable for Indian cities due to its low deployment cost and minimal Internet access. The main benefit of this study is to provide better knowledge of existing harmful pollutants in India, thus allowing Indian authorities to put in place regulations concerning air pollution. Organization: The remainder of this paper is organized as follows: in Section II, we present definitions concerning Wireless Sensor Networks and briefly survey application areas. In Section III, we describe the air pollution problem encountered in some Indian cities and propose a measurement model based on a Wireless Mesh Network of Sensors. We presented the air pollution monitoring system in Section IV. In Section V, we present the routing protocol used to efficiently disseminate the sensed data. We conclude the paper in Section VI and give some directions for future work.

Currently, intensive research that addresses the potential of sensors in data gathering and processing and in the coordination and management of the sensing activity is being conducted. Many Wireless Sensor Network (W SN) models have been proposed and the number of models will continue to grow over time as wireless sensors become cheaper and more ubiquitous. Many challenges have been addressed in Wireless Mesh Networks (W M N) to bring Internet access to all communities (urban or rural), but there is still a lack of research activity concerning the deployment of W M N for measuring harmful air pollutants in India. Among the reasons is that access communications and telecommunication services in the greater part of India remains difficult due to lack of communication infrastructure.

This paper focuses on measuring of harmful pollutants in air, since several studies show that the air quality in Indian cities is rapidly deteriorating. Urban and rural air pollution in Indian cities is emerging as a key factor in health, environment, economy and quality of life for millions of Indians as urbanisation, motorisation and economic activity increase. Poor air quality especially impacts the poor, elderly and children who suffer disproportionately from its effects. Urban and rural air pollution also has impacts far beyond

II. A REVIEW OF WSN

An ad hoc network is a cooperative arrangement of wireless nodes that communicate over wireless links, without using any pre-existing infrastructure. A wireless ad hoc network is a network in which client devices perform their routing functionality to forward their own data or that of other nodes. When these devices become mobile, they form a class of networks known as mobile ad hoc networks.

Wireless Sensor Networks (W SN s), viewed as one of the most promising technologies, consist of densely-distributed small sensors, which collect and disseminate environmental data. This is possible due to the ability of tiny sensor nodes to detect and forward the data to a central collection point. The challenges in measuring the relevant quantities, monitoring and collecting the data, assessing and evaluating the information are enormous .

A Wireless Mesh Network (W M N) is a type of ad-hoc network that consists of a Mesh Client (M C) and a Mesh Router (M R). The M Cs are typically fixed, but the M Rs have a minimal mobility and form the mesh backbone for the M Cs. Ideally, each sensor node should be connected to at least two nodes, providing full connectivity to the entire network. A mesh network can provide multi hop communication paths between wireless clients serving as a community network or as a broadband access network for the Internet. This is particularly attractive for developing countries and rural communities, where large-scale deployment of wired broadband infrastructure is not affordable. The combination of wireless communication and mesh nodes provides a reliable network with a great deal of fault tolerance in the sense that it provides the capability of adding more devices to an existing network. W M N s are very powerful, providing fault tolerance, self- healing and low deployment cost.

Sensor networks are used for a variety applications including:

Building monitoring and maintenance: W SN s can be used in large buildings to monitor environmental conditions. They could be used to monitor vibration that might damage the structure of a building. Disaster relief: W SN s can be used to map the disaster area in order to direct the nearest emergency rescue teams to affected sites. If some of the sensors are destroyed due to being located in the disaster area, the remaining sensors coordinate their duties and help rescue teams to find safe evacuation paths.

Healthcare: W SN s can be used in medical applications to improve the quality of care received. Sensors are put in the human body to monitor medical problems like cancer. They can also be put in each patient and these sensors relay the data to emergency medical technicians who can use computers to capture patient data, monitoring patients outside the hospital by using 3G (third-generation) wire-less infrastructure.

Environmental and military monitoring: W SN s can be used to monitor and control military systems. Sensors are attached to every vehicle, and the status reporting of equipment can be automated. This information can be aggregated in the base station and sent to commanders.

Other examples include forest fire detection, inventory management, precision agriculture, wireless data acquisition, safety management and many other areas. We will focus only on air pollution measurement in this paper.

The development and implementation of the Volunteer Internet-based Environment Watch in Asia is described in. The system makes use of volunteers and their personal computers to monitor air pollution, and send data to a central server for storage and collation. The system was successfully developed and deployed in a short time, with a small budget and limited human resources. The provision of a dynamic network through the Internet via websites to inform European citizens of air quality status of (N O2 , N O, O3 , CO, CO2) concentrations is discussed in. The information also helps the decision-makers to manage urban air quality by controlling factors such as road traffic. To provide European Union citizens an intelligent air monitoring network (mobile and communicating sensors) covering the whole European continent is deployed.

In, a large-scale deployment of sensor networks is proposed for the monitoring of air pollution due to transport in a dense urban environment. The network includes sensor nodes, cabled gateway nodes linking the wireless mesh to a data repository and a web-server for external Internet access. Each node is linked to its neighboring nodes via a high-speed radio. Ad hoc routing protocols running on each node create and maintain a mesh network, enabling all nodes to communicate with one other. Finally, presents a low-cost wireless Internet connectivity solution for rural areas using mesh networks in India.

III. WSN M ODEL TO MEASURE A IR P OLLUTION

A. India air pollution problem

Many parts of India, especially Indian cities, have experienced air pollution problems. This is caused by multiple sources, including industry, tobacco, domestic waste, floods, droughts, domestic and vehicular fuel combustion. It contains a variable and complex mixture of air pollutants that affect people's health. One of the main reasons for this pollution is that many chemicals industries have established their production centers in urban areas.

In certain large Indian cities, when one steps out of the house and onto the street, there is a cloud of exhaust from cars, motor bikes or scooters which pollutes the air. During rush hours (from 7:00 am to 9:00 am, from 11:00 am to 1:30 pm and from 6:00 pm to 8:30 pm) one can see a cloud of smog suspended in the air at some crossroads. This has an impact on health since there is no national regulation concerning air quality and pollution. Consequently, there is a necessity to give some key indicators concerning pollution in these countries.

However, it is very difficult to deploy a communication system that will measure air pollution since telecommunications systems in India remain inaccessible due to lack of route and infrastructure. Some pollution areas are out of range of a communication service provider because they are located out of town. Consequently, there is no Internet connectivity in such areas. The challenge is the deployment of communication system that will measure air pollution efficiently and protect people when concentrations become critical. The solution to this problem is based on recent research in Wireless Mesh Networks for Internet connectivity in urban and rural areas.
In this paper, we develop a W M N to measure air pollution. Our model could be used to establish Internet connectivity and simultaneously measure air pollution in well defined pollution areas.

B. A Wireless Sensors Network Model

In this sub-section we present a model for the measurement of harmful pollutants in Indian cities. In the study, we assume that the polluted area has no WiFi or WiMax, and hence no Internet connectivity. We establish an Internet communication network for the purpose of measurement. We have identified five harmful pollutants that seriously affect the health of people: Carbon Monoxide (CO), Nitrogen Monoxide (N O), Ozone (O_3), Sulphur Dioxide (SO_2), and Particulate Matter (P M10 or P M2.5).

Taking into account the geographical situation (hills, lack of roads, no urban plan...) of Indian cities, the measurement consists of Fixed Sensors (F S), which are deployed as shown in Fig1, at some location where there is no access by road, such that we can charge their batteries. Mobile Sensors (M S) are carried on vehicles and are deployed in specific areas due to a lack of security (sensors could be damaged or destroyed). Also in industrial areas, fearing of air pollution regulations, some industries prevent the deployment of fixed sensors to measure the harmful pollutants that they emit.

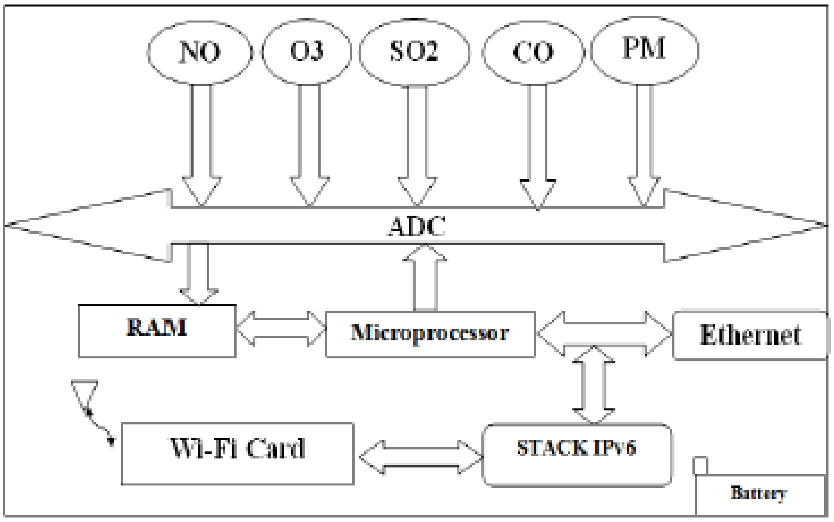

Fig. 2. Sensor Architecture

Sensor Architecture

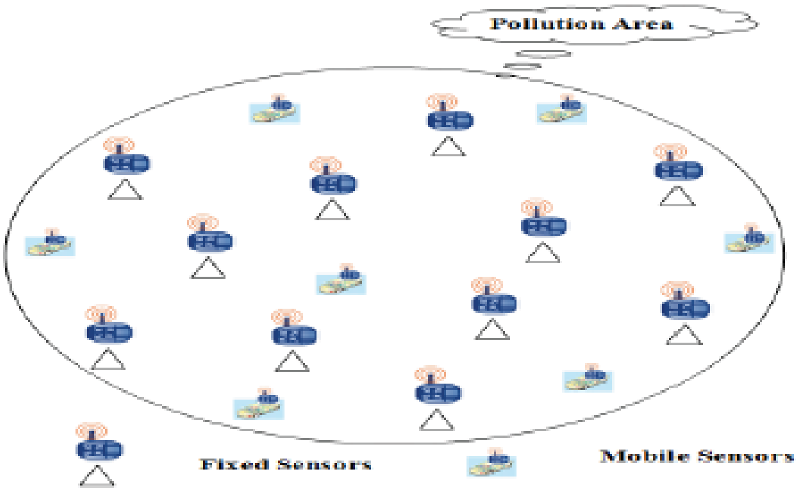

Fig. 1. Sensors Network in pollution area

Sensors Network in pollution area

The fixed and mobile sensors in Fig1 are identical in the sense that they have a unique Internet Protocol (IP) address to provide plug-and-play scalability in the network, the same computing capability to sense and transmit the data, and also the same memory capacity. Generally, in environmental monitoring, sensors are designed to detect only one pollutant. In our model, we design a sensor that has the capability to simultaneously sense the five harmful pollutants described previously, and transmit the sensed data. The sensor designed in this context has four layers as shown in Fig2. The first layer is responsible for sensing and consists of five filters which capture data for each harmful pollutant cited above. The second layer consists of an Analog to Digital Converter (ADC), which is responsible for converting the analog signals into digital signals. The third layer consists of three elements: Random Access Memory (RAM), it is a kind of integrated circuit that permitted to store the sensed data to be access in any order. The microprocessor is used to perform some operations as subtracting, comparing, and fetching numbers from one area to another. Finally, an Ethernet interface supports a wired network connection. The last layer is the radio subsystem which consists of four elements: a W iF i card provides Internet connectivity to other sensors, since the polluted our area has no Internet connectivity. An IPv6 stack allows more IP -addresses and provides improved authentication and encryption methods relative to IPv4. Each sensor is equipped with an omni-directional antenna which is relatively cheaper than directional and provides better Internet connectivity. The sensor is powered by a rechargeable Battery.

C. Network Architecture

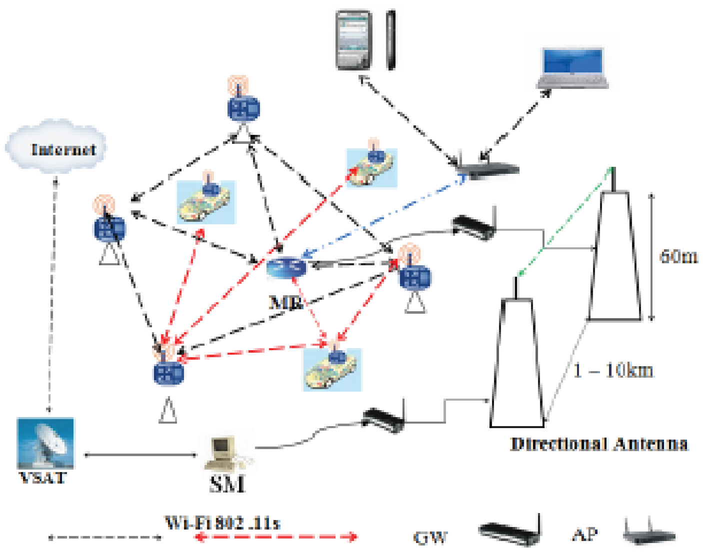

Fig. 3. Architecture of Wireless Mesh Network of Sensors

As Fig 3 shows, the network is made up of Mesh Sensors (M S), the set of Mesh Routers (M R), Gateways (GW), directional antennas, the Server Middleware (SM) and a Very Small Aperture Terminal (V SAT). We deploy this equipment in a polluted area of 5km by 5km representing approximately the size of a rural region in Africa. In order to construct our W M N S, we first evaluate the nature of the polluted area (hill areas, lack of roads...) using a map of the city provided by the local authorities. This evaluation allows us to deploy fixed and mobile sensors in different parts of the area. Using the resulting sensor network topology, we then find the optimum locations for the mesh router and gateway, in order to provide Internet connectivity to each sensor, and to transfer the data to the central air pollution monitoring server. We are able to use several M Rs, some placed in the middle of the fixed sensors network and others are placed in the intersection on the coverage area of the mobile sensors.

The fixed and mobile sensors are connected to the assigned M Rs. Each sensor is connected to at least two other sensors in the network, to allow full fail-over if some sensors move out of the coverage area. Due to the mobility of mobile sensors, they can lose connectivity with the fixed sensors. The placements of M Rs are such that they are always connected to the mobile and fixed sensors in order to receive the sensed data. The M Rs are used to manage the data from the sensors and forward it to the Internet Gateway (GW).

Architecture of Wireless Mesh Network of Sensors gateway, mesh routers, etc).When the DHCP server receives a valid Internet access request from a sensor or an external user, it assigns an IP address, as well as other IP configuration parameters (subnet mask, domain name, etc). The DHCP server permanently assigns a free IP address to a requesting user, but keeps a table of past IP address assignments, so that it can preferentially assign a sensor / user the same IP address that they previously received. As Fig 3 shows, an AP connects external users that are not part of the W M N S. Since the AP is configured to use the same channel CR as the mesh router via the LAN side of the M R, an external user can connect to the AP to obtain Internet connectivity. We use very few wired connections since they need more effort to install and are prone to physical damage.

The GW connects to the M R over its Local Area Network (LAN) Ethernet port to link the W SN to the directional antenna. The directional antennas are linked together using a back-haul link to make a long-distance point-to-point connection, since the polluted area may be distant from the Internet provider. High-gain directional antennas are used to reduce the probability of interference from non-city radio frequency emitters, such as the W iF i radios of private laptops and some Access Points (AP s). The GW is linked to the directional antenna with a wired link. The SM connects to the V SAT on one interface, and has a wired link to the GW on the other. The V SAT allows satellite connectivity with an Internet service that may be far away, providing Internet connectivity to all components of the mesh network.

D. Wireless interconnectivity

Once Internet connectivity has been established, we can begin to interconnect our W SN . In order to reduce interference in our network, we use multiple orthogonal channels. Let C be the set of orthogonal channels that can be used by all the devices in our W M N S. Let CS , CR and CG be respectively the channels used by the mobile and fixed sensors, M Rs and the Internet GW . All sensors are linked together over the single CS channel defined by the proposed 802.11s standard. This provides a proxy mechanism and deterministic network access. The M Rs communicate over the shared channel CR , and use CS to collect the data from the mobile and fixed sensors. Additionally, the GW uses CR to connect all the M Rs, and CG to connect to the directional antenna to provide fast Internet connectivity. Having a complete channel allocation, we are able to allocate IP addresses. This is the responsibility of the SM , which has the main function of sharing a single Internet connection. Additionally, it contains two main sub-entities: (i) the Domain Name System (DN S) which allows the conversion of host and domain names to IP addresses, and (ii) the Dynamic Host Configuration Protocol (DHCP) which manages the IP addresses provided by the DN S, as well as information about the W M N S.

IV. N ETWORK MEASUREMENT

This section describes the Air Pollution Monitoring System (AP M S) that we have configured to collect and analyze the information provided by the W M N S. The system is shown in Fig 4 and is made up of five components. The first is the Data Server (DS) which is directly connected to central SM . All data information about harmful pollutants provided by the sensors in the various polluted areas are stored and centralized in the database of the DS. The DS sends the data to the Data Management (DM) which is equipped with many computers. Each computer is used to analyse at most two pollutants due to the fact that computers in Africa are not powerful and Internet connectivity is very low. The levels of pollution assessed by each computer are received by an Air Pollution Monitoring Toolbox (AP M T) application via a router connected to the DM .

Fig. 4.

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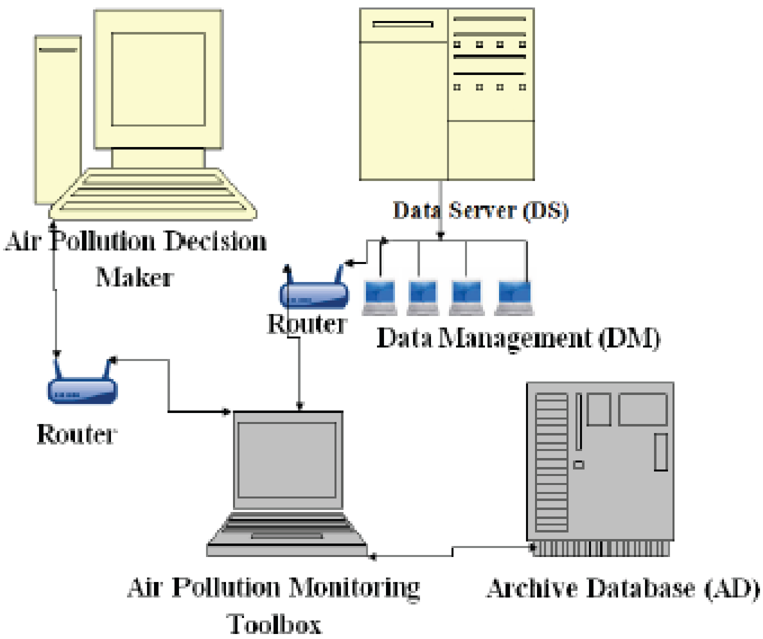

Fig. 4. Air pollution monitoring architecture

Air pollution monitoring architecture

The AP M T shows the pollution level for each harmful pollutant from each polluted area. This pollution level is compared to a "critical level of pollution". Since there is no regulation concerning air pollution in many countries, we use the "critical level of pollution" established by Program Coordinator For The World Bank Clean Air Initiative In Indian Cities. The daily pollution level is archived in the Archive Database (AD) and all critical data are transmitted to an Air Pollution Decision Makers (AP DM) for safety guide lance.

The AD is an important component that helps to establish yearly statistical data for the level of each harmful pollutant. All these data can be accessible at any time by the authority. The AP DM (policy, civil protection, etc.) are connected to the AP M T so as to know the different levels of pollution. In the case where the air pollution level is greater than normal, an AP DM could use radio and television to announce the levels of air quality in each region. It could also send a message to the mobile phones of those in the critical area, in order to reduce the costs of damage, and allow preventive measures to be taken.

V. ROUTING P ROTOCOL

For efficient forwarding of data packets, we have a choice between proactive or reactive protocols. In our model, we use a reactive protocol; the Ad hoc On-Demand Distance Vector routing (AODV), in which the route for forwarding data is created only in response to a demand by the Data Server (see Fig 4). The protocol uses four types of messages to communicate through the network: Route Request (RREQ) and Route Reply (RREP) messages are used to discover the route. Route Error (RERR) and Hello messages are used to maintain the route. When the Data Server needs a specific data item, it sets a Time-To-Live (T T L) in the RREQ and broadcasts it through the network. During the propagation of the RREQ, each sensor participating in AODV routing stores in its Routing Table (RT) the destination address, the destination sequence number, a hop count and the next hop address, allowing the determination of an up-to-date path for the data. During the route discovery process, a sequence number

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is used to prevent loop generation and provides the intermediate sensor with a reply on recent route information. Each sensor receiving the RREQ message checks whether it is the destination or not. If not, it stores a copy of RREQ in its buffer containing all the previously broadcast RREQs, decreases the T T L and rebroadcasts to its neighbors. Then, at any given time when a sensor node receives a RREQ, it checks in its buffer to make sure that it has not already broadcast the RREQ, in order to avoid sending the RREQ many times to the same neighbors. Note that the RREQ in the buffer contains two entities that identify the request through all sensors in the network: the originator sensor RREQaddress and the RREQid . The RREQid is used to specify a request originator by a given sensor.

If the sensor node is the destination, it checks in its RT to see if the route to a defined destination exists, if the T T L = 0, and if this is the case it determines the next hop. It then initiates a RREP and sends it over the reverse path to the originator sensor to updates its RT . If the route does not exist, the sensor saves the RREP message in the queue and generates a RREQ to determine the available route. The destination sensor which initiates a RREP , stores also a RREQid in its buffer to avoid to send many RREP s for duplicate RREQs that may reach from different routes.
To prevent that an originator of RREQ from receiving many RREP s, the originator of RREQ will update its RT and choose the RREP with the greatest sequence number, indicating the most recent route. If two RREP s have the same sequence number, the destination will choose the
RREP with the smallest hop count.

Each sensor has a maximum size for the messages that it can store. The next challenge will be to prevent the amount of RREQ growing in the buffer indefinitely. Each RREQ is provided with a T T L value, such that when the T T L expires the message is just discarded. The T T L value depends on the network's size. In a small network, the T T L value should be small, but in a large network, the T T L value should be large to make sure that any given RREQ can reach to a defined destination. If the originator sensor node does not receive a RREP after a certain period of time, it rebroadcasts a new RREQ message with a greater value of T T L and a new identity id to make it distinct from the old one. If the originator sensor node still fails to receive the RREP message, it considers that the destination may be out of coverage area or subject to power failure and so removes the RREQ message from its buffer and updates its RT .

A. Implementation

The AODV protocol described above was coded into a Network Simulator (N S2). N S2 is a discrete event simulator targeted at networking research. The analysis of our model was carried out using a P C with an AM D Athlon TM 64 X 2 Dual-Core Processor T K-57, 1.9GHz clock and 1024MB of RAM . We have tested our model for a network sizes varying from 10 to 50 sensors. Consider a network consisting of 30 sensors randomly scartered in a square area of side $L = 5km * 5km$. We recall that a direct connection between two neighbor sensors (S_i , S_j) is possible if and only if the $d_{ij} \leqslant D$. Where D is the locality radius. In our implementation we choose D= 200m. We have seen above that whenever the DS needs a specific data from the sensors, it broadcasts a RREQ through the network. A receiving sensor performs a Transmission Delay (TDelay) to check in its buffer, to make sure that it has not already broadcast the RREQ, before it takes the decision to rebroadcast or not. This happens so as to avoid sending the RREQ message many times to the same neighbors. In the simulation, we wanted to study the relation between the number of broadcast RREQ messages and the TDelay during the route discovery process. We can see in Fig 5 that when the TDelay is large, the number of RREQ message is small. More precisely, for a TDelay ≥ 60ms , the total number of RREQ messages is approximately 30.

Evolution of RREQ vs TDelay

Fig. 5.

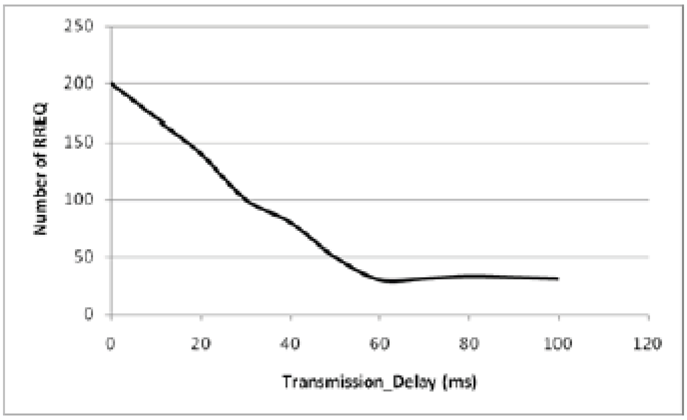

Fig. 5. Evolution of $RREQ$ vs T_{Delay}

This means that when the TDelay is large enough and uniformly distributed over all the sensors, each sensor rebroad- casts the RREQ message only once, resulting in considerable energy savings.

B. Comparison

In the proposed model the transmission of sensed data occurs in real time, resulting in a very high energy consumption and a need in greater bandwidth. Our model is more efficient in terms of energy saving since sensors are energy constrained. The transmission of data from the sensor to the Data Server takes place in non-real time. This means the Data Sever is configured such that, at a certain moment of the day, it automatically generates the RREQ through the network, which allows optimization of energy and bandwidth and consequently increases the network's lifetime. Since we have designed our IPV6 sensors to simultaneously sense five harmful pollutants (see Section III-B), our W M N S is capable of protecting the information they collect from eavesdropping. Each individual sensor performs complex encryption and authentication algorithms. This makes our model more suitable for Indian Countries, and avoid the costs of deploying a security mechanism as in models.

VI. C ONCLUSION & F UTURE WORK

In this paper we have developed a Wireless Mesh Network of Sensors to provide Internet connectivity and measure harmful air pollutants. Our architecture has been developed specifically in the context of Indian cities; particularly these in countries where there is a lack of both telecommunications infrastructure and Internet access in many urban / rural areas. Since there is no regulation concerning air pollution in many countries, we intend in the near future to deploy our model in some polluted area in India. We expect the results to give us more information about the performance and efficiency of our architecture, and to provide data that could allow decision-makers to put in place regulations concerning air pollution.

In the future, a miniature camera could be incorporated into each sensor package, allowing decision makers to see conditions in polluted areas. Security is a further area that should be addressed: the current architecture may allow data on mesh router to be accessed by attackers operating on the same channel. A final challenge is the development of an optimized means of gateway placement, as the location of the gateway is crucial to network reliability and quality of service.

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