Integration of Wireless Sensor Network to Intelligent Transportation System for Environmental Monitoring

ALESSANDRO SANTOS¹, CLAUDIO MARTE¹, LEOPOLDO YOSHIOKA¹, JORGE CINTRA¹, CAIO FONTANA²

¹ Escola Politécnica
Universidade de São Paulo - USP
Av. Luciano Gualberto, Cidade Universitária – São Paulo, SP
BRAZIL
alesan.sp@usp.br; claudio.marte@usp.br; leopoldo.yoshioka@usp.br; jpcintra@usp.br

² Departamento Ciências do Mar
Universidade Federal de São Paulo
Av. Alm. Saldanha da Gama, 89 – Santos, SP
BRAZIL
ciao.fernando@unifesp.br

Abstract: - The environmental issue is currently one of the key concerns that remain on the agenda of public managers, and urban traffic is considered as one of the key influencers in gas emissions and impacts on quality of life caused by traffic jams. It is a challenge to define technological mechanisms to measure the rates of these effects; however, it is important to create measurement instruments that allow the public manager to get an overview of these indexes, thus aiding strategies for improving the living conditions of citizens. Accordingly, this paper proposes a wireless sensors network, hosted on urban public transport vehicles that will collect environmental information. We propose to establish models for communication using realistic mobility patterns of a bus corridor in São Paulo city (Brazil), in order to define the technological standards aiming at the better dissemination of the information collected by sensors embedded.

Key-Words: - ITS; WSN; environment; gas emissions

1 Introduction

The Intelligent Transportation Systems (ITS) refer to the state of the art technologies to provide better mobility experience. These systems involve vehicles, drivers, passengers, road operators and managers, as well as covering the interactions between these components and the environment, linking them to core infrastructures [1]. In other words, Intelligent transport systems (ITS) link information technologies with transport engineering [2]. Furthermore, the ITS services are standardized [3] and categorized in eleven service domains, such as, Operation and traffic management, public transport, and climate and environmental monitoring.

Urban mobility is already included as a priority in the agenda of big cities, including discussions in respect of the impacts and benefits generated by transport. In São Paulo, there is a restriction for vehicles in limited areas, as well as discussing various initiatives to minimize the effects of CO2 emissions. A program called "EcoFrota" - which encourages the use of buses with emission characteristics below traditional levels - and it has been identified with a successful initiative, with more than 2500 deployed units, reaching 16% of Fleet [4].

In the context of cities, the question arises how to measure the rates of environmental pollution, so that we can evaluate if emissions mitigation initiatives are having the desired results. In addition to the goals of emission reduction, an analysis of other factors (level of noise, light, efficient traffic flow, etc.) could be used to support the decision of the public manager to define strategies for improving the quality of life of citizens.

In this sense, technological advances have provided new possibilities in the analysis of urban perspectives. The Wireless Sensor Networks (WSNs) belong to a particular case of ad-hoc networks, sharing their main characteristics as...
flexible routing and latency management strategies among others. A WSN is composed by a set of interconnected sensor nodes. Sensor nodes are small devices, commonly consisting on a microcontroller, a short range radio unit and one or more transducers acting as sensors [5]. In other words, WSN is an event based system with several sensor nodes. Reliable data transfer at the sink is based on collective information provided by sensor nodes [6].

Using this environment, the cities can rely on an arsenal of technological devices (especially sensors) that collect information from urban scenarios in an automated way, creating a knowledge base that enables correlation of historical information and real time measurable factors of an urban conglomerate. These correlations allow the creation of an intelligent layer to make the city more efficient. However, the urban conglomerates should be rethought to adapt and take advantage of new opportunities, motivating a new vision of public management.

An alternative to creating a technological framework for collecting environmental information is instrumenting the entire city with sensors to collect data. There is a variety kind of sensors, these could collect information, such as: CO; Noise; Microphone; Dust; PM-10; Ultrasound (distance measurement); Temperature; Humidity; Luminosity; Pressure/Weight; Bend; Vibration; Impact; Hall Effect; Tilt; Liquid Presence; Liquid Level; Presence (PIR); Stretch. See Fig. 1.

Fig. 1- Sensors. Source: [7].

Provide a comprehensive view would require a large number of sensors, in addition to a constant increment of these, driven by the growth of the city itself. A particular look shows that the network of public transportation can cover the major populated areas, having a characteristic dynamic growth and adaptation consistent with the mutability of population and geographic cities. Taking advantage of these principles, the buses could be host of sensors that capture the environmental characteristics during journey, thus covering a geographic region with periodic readings according to routine work, sending this information to Intelligent Transportation Systems.

This paper presents a proposal for sensor networks to be embedded on units urban public transport (bus), making it a host of environmental sensors that roam the city will collect information and send them to the monitoring centers. The scenarios were simulated with different communication technologies to assess the feasibility of the solution of sensor networks as a mechanism for data collection.

This will provide information to ITS, enabling visualization of the environmental conditions of the city in real-time or historic way, via Geographic Information Systems (GIS), Fig. 2.

Fig. 2- Simplified Architecture for monitoring.

This architecture enables the public administrator a comprehensive view of the conditions of the city and may also correlate strategies adopted to mitigate the undesirable effects generated by transport in big cities.

2 Vehicular Ad-hoc Networks

Many researchers have been studying sensor networks for vehicular settings, this environment being characterized as VANET (Vehicular Ad-hoc Network) which is a special kind of Mobile Ad-hoc Network (MANET) [8]. In these types of networks, one of the most important properties is mobility, which must be modelled in a simulation system. Thus, simulations of VANETs should consider traffic models and mobility.
In the community transport, traffic models are usually classified according to their level of detail [9]:

- **Macro Models**: where vehicles are not considered individually but are incorporated into the models directly related to fluid dynamics.

- **Mesoscopic Models**: usually describe in detail the individual entities, but ignore the interactions between vehicles.

- **Micro Models**: represent the entities and interactions with a high level of detail. The behavior of a vehicle depends on the state of neighboring cars and even the characteristics of the driver.

This section provides a discussion of related work, considering architectures and methodologies employed in micro simulation models for VANETs.

A related work explores the possibility of placing "mobile gateways" for select vehicles to provide connectivity to other vehicles in their neighborhood [10]. Their simulations used a scenario where nodes and mobile gateways were uniformly distributed on a long straight road. In addition, they assume Markov models to characterize the motion of vehicles. Our work adopted mobility pattern, which considers realistic paths and movements of buses in a metropolitan city, particularly a bus corridor in the city of São Paulo (Expresso Tiradentes).

Another scenario proposes the "application of mobile devices" in ad hoc networks, for use in a taxi dispatch system in order to investigate the technical and financial viability [11]. In his assessment was used a model city as a grid of size 5 km x 5 km, with 300 taxis distributed within this area. They assessed the effect of such parameters as the density of nodes, congestion, and coverage where it was concluded that the net effect is satisfactory under most operating conditions. The focus, however, was to study the performance of an application on a purely ad hoc network, unlike our work which verifies the feasibility of capturing information in a Delay-Tolerant Network (DTN), where latency is not a primary factor.

In another study [12], a case study was conducted to use buses as Data Mules to collect information from traffic sensors (detecting and counting vehicles) deployed on urban streets. Data can be collected by bus and then sent to a central traffic management through a few gateways static or mobile. Although a similar scenario to that work, it performs a statistical study and not through simulation, another difference is the fact that the bus is host of sensors.

### 3 Scenario

This paper analyzes a realistic scenario of public transport (bus) that hosts environmental sensors, which have an inherent mobility, and provide a path that enables a good geographical coverage of the city.

In this sense, the network of urban bus corridors in the city of São Paulo was selected for the base simulations, such as conceptual approach of the project (Fig. 3).

![Network of bus corridors in Sao Paulo city](image)

**Fig. 3**: Network of bus corridors in Sao Paulo city, highlighting the Expresso Tiradentes. Source: [13]

The corridor Expresso Tiradentes (highlighted in Fig 3) has features that are favorable for the simulation:

- Average speed constant;
- Regular distance between bus stops.
- Regular Stop time at bus stops.
- Geographical coverage of a certain region well above the traditional flow of vehicles.
- Number constant bus in the corridor with regular programming.
Fig. 4: Aerial view from Expresso Tiradentes.

Fig. 5: Path and markers of bus stops on Google Earth.

For a real scenario, we identified the path of the bus and the bus stops of the Expresso Tiradentes, via Google Earth (Fig. 4 and Fig. 5). The latitude and longitude positions were obtained by visual location in Google Earth, and were converted to UTM coordinates (x, y, z in meters) via online services INPE [14]. In addition, the coordinates of the Terminal Parque Dom Pedro (TPDP) were used as the zero reference in the simulation environment (Table 1).

### Table 1: Coordinates of the key points of the Expresso Tiradentes.

<table>
<thead>
<tr>
<th>Coordinates in Google Earth</th>
<th>Link Google Maps</th>
<th>Terminal I Bus Stop II</th>
<th>Bus Stop III</th>
<th>Bus Stop IV</th>
<th>Bus Stop V</th>
<th>Bus Stop VI</th>
<th>Terminal II</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lon</td>
<td>-46, 6290</td>
<td>View</td>
<td>View</td>
<td>View</td>
<td>View</td>
<td>View</td>
<td>View</td>
</tr>
<tr>
<td>Lat</td>
<td>-23, 5472</td>
<td>View</td>
<td>View</td>
<td>View</td>
<td>View</td>
<td>View</td>
<td>View</td>
</tr>
<tr>
<td>X</td>
<td>546</td>
<td>0</td>
<td>223</td>
<td>14,0</td>
<td>937</td>
<td>237</td>
<td>79</td>
</tr>
<tr>
<td>Y</td>
<td>376</td>
<td>0</td>
<td>1295</td>
<td>184</td>
<td>3001</td>
<td>4848</td>
<td>791</td>
</tr>
<tr>
<td>Reference coordinates for simulation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>X</td>
<td>0</td>
<td>223</td>
<td>1493</td>
<td>182</td>
<td>2685</td>
<td>3243</td>
<td>3314</td>
</tr>
<tr>
<td>Y</td>
<td>0</td>
<td>376</td>
<td>1295</td>
<td>184</td>
<td>3001</td>
<td>4848</td>
<td>5601</td>
</tr>
</tbody>
</table>

The flow of vehicles along this corridor is exclusive for buses, traveling in an elevated section. The bus lines circulating in Expresso Tiradentes has an average speed of 35 km / h without crossings semaphore. At peak times, departures occur every two minutes.

### 4 Simulation

To evaluate the feasibility of the use of wireless sensor networks with ITS scenarios for environment scenarios was necessary to use tools for simulation of urban mobility, and set up what are the types of wireless communication standards to be assessed.

#### 4.1 Simulation tools

After analysis of a series of options of tools [8], this article will use the ns2 network simulator and traffic simulator of urban mobility, called SUMO [15].

The SUMO is an open source simulator for micro traffic simulation models. Because of its high portability and license to use, SUMO has become the most used traffic simulator for vehicular networks [8].
A key component for VANET simulations is a realistic model of mobility to ensure that the conclusions of the simulation are closer to actual implementations. In this sense, an approach to create a more realistic model is presented by the tool MOVE (MObility model generator for VEhicular networks) [16]. Beyond the capabilities of automatic generation of artifacts for simulation, this exposes a methodology that involves the development of urban street maps, defining the flow of movement and the creation of network traffic (Fig.6).

**Fig.6. Methodology to simulation. Source: [17].**

This study used the methodology and tool presented by MOVE mapping scenario Expresso Tiradentes, considering the positions of bus stops, the average speed of the stretch, the flow of city vehicles during peak hours, etc. In this regard were prepared Mapping Map, the mobility pattern and configuration of network simulator.

### 4.2 Standards and parameters for simulation

Different scenarios were simulated to evaluate the alternatives of communication, involving the following models of wireless networks:

- **Ad-hoc Networks (802.15.4):** in this model the transmission is propagated between nodes in communication towards a concentrator (sink). This model is traditionally used by wireless sensor networks.
- **Wifi (802.11):** This model is the most popular wireless networks, which uses the central points (Hotspot), which communicate with the sensors within a radius of action.
- **GPRS cellular network:** Network communication data present in GSM cellular networks, which use narrowband and proprietary network of mobile operator, with associated cost.

This paper conducted simulation *Ad-hoc* models and *Wifi*, which can be configured using the own network of communication with the amortized cost, due to the establishment of corporate network infrastructure. In this case, the communication network via GPRS is only used for calculating transmission volume monthly, to estimate the cost.

Table 2 presents the parameters incorporated for simulations.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>values</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Number and direction of flow of buses:</strong></td>
<td>30 vehicles in the direction of the city downtown to the neighborhood and another 30 in the reverse direction.</td>
</tr>
<tr>
<td><strong>Number of bus stop</strong></td>
<td>6</td>
</tr>
<tr>
<td><strong>Terminals</strong></td>
<td>2</td>
</tr>
<tr>
<td><strong>Speed average</strong></td>
<td>35 km/h</td>
</tr>
<tr>
<td><strong>Periodicity departures</strong></td>
<td>2 minutes</td>
</tr>
<tr>
<td><strong>Distance</strong></td>
<td>~8 km</td>
</tr>
<tr>
<td><strong>Sink position</strong></td>
<td>Simulation in all bus stops and terminals</td>
</tr>
<tr>
<td><strong>Simulation time</strong></td>
<td>3600 s</td>
</tr>
</tbody>
</table>
5 Results

The ns2 simulator built the trace files for assessments of indicators of performance. The specific trace (Nam trace) is used by NAM tool to visualization of simulation (Fig. 7). In this figure is presented the visualization of running simulation with nodes, sinks and communications waves.

![Fig. 7. Visualization of Wifi simulation in NAM tool.](image)

Other indicators was used, the throughput (amount of data in bytes per second), this was the main factor assessed. This was estimated from the data received by sinks from the nodes at a rate of 70bps. Each simulation used different positions of the sink, making it possible to evaluate the best position to host the sink. Figs 8 and 9 show the throughput values” for Adhoc network and WiFi.

![Fig. 8. Throughput from sink in Ad hoc network.](image)

![Fig. 9. Throughput from sink in Wifi network.](image)

The total volume of incoming data is presented in Table 3.

<table>
<thead>
<tr>
<th>Terminal</th>
<th>Bus Stop I</th>
<th>Bus Stop II</th>
<th>Bus Stop III</th>
<th>Bus Stop IV</th>
<th>Bus Stop V</th>
<th>Terminal II</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>4757,3</td>
<td>614,8</td>
<td>637,1</td>
<td>655,8</td>
<td>680,8</td>
<td>603,3</td>
</tr>
<tr>
<td>II</td>
<td>4706,0</td>
<td>618,2</td>
<td>640,3</td>
<td>660,4</td>
<td>685,5</td>
<td>608,6</td>
</tr>
</tbody>
</table>

Table 3: Volume of data received with Wifi networks (Kbytes)

6 Discussions

The analysis showed some common points, the Throughput revealed that both a higher data transmission when the sink is in any of the terminals. The parameters such as transmission rates, latency time for connection, range, disposal of antennas are taken into consideration by the network simulator ns2, this is one of the causes factors of low transmission in breakpoints. When buses are stopped at the terminals favor the formation of Adhoc networks, where each node can forward the data to the sink node neighbor. In the case of Wifi networks, the style of the antenna allows multiple buses will be within the same coverage area.

In view of the sink at the bus stop, the sensor node is almost alone in communications, and has only the stopping time to communicate (3 min), and for the two types of networks, the throughput values are not significant. The simulation setup and deployment models in sections of stops could be improved, however, would always be less efficient than if installed in terminals.

Another difference is the greater "transmission rate" Wifi Networks compared to Adhoc networks,
however, depending on the size of the terminal will need to integrate more Wifi hotspots in infrastructure. This fact, in the Adhoc network is minimized, since the model allows reconfiguration of routes, transmitting data from the sensor nodes to the sinks, for alternate routes to other sensor nodes.

With respect to the model GPRS Table 3 shows the amount of data generated by the model of Wifi Network (~ 4MBytes) per terminal during the period of 1 hour, which is a reference value for evaluating the cost of the major cell phone operators. Table 4 presents pros and cons of technologies

<table>
<thead>
<tr>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Adhoc</strong>-hosted in <strong>terminal s</strong></td>
<td></td>
</tr>
<tr>
<td>1. Infrastructure costs: Low</td>
<td>1. Lower capacity data transmission</td>
</tr>
<tr>
<td>2. Adaptive routing allows routing information of sensor nodes to the sink via support from other sensor nodes</td>
<td>Update time greater than or equal to the time to travel between the terminals</td>
</tr>
<tr>
<td><strong>Wifi</strong>-hosted in <strong>terminal</strong></td>
<td></td>
</tr>
<tr>
<td>1. Infrastructure costs: Median</td>
<td></td>
</tr>
<tr>
<td>2. Good Capacity and Volume Data</td>
<td></td>
</tr>
<tr>
<td><strong>GPRS</strong></td>
<td></td>
</tr>
<tr>
<td>1. Real-time response of the information collected by sensors</td>
<td>1. High Cost of transmission if the operators charge for data volume.</td>
</tr>
</tbody>
</table>

7 Conclusion

With the results we conclude that the sinks are best used if hosted at the terminals I and II, because the bus stops do not get the best conditions for reading the data from the sensors.

The sensors in urban vehicles will provide information on environmental conditions and send them to a central monitoring station, which contain additional technological resources for processing the data and perform the historical correlations and spatiotemporal. Thus, the public manager will obtain tools for evaluating the conditions of the city, especially in times where the smart cities are as discussed.

References:


