Acoustic noise pollution monitoring in an urban environment using a VANET network

Abstract—**The main objective of this work is the development of a VANET network to collect data from GPS equipped mobile phones used as noise detectors. In this system, sensor nodes perioadically transmit acoustic noise levels to neighboring cars, data packets being shared and temporary stored by participating VANET nodes and ultimately forwarded to a collector node connected to the Internet, providing public real-time data. A routing technique based on OLSR that takes into account the spatially separation between the multiple paths is used, for better transmission reliability and congestion avoidance as well as for control message overhead minimization.**

Index Terms—**acoustic noise pollution monitoring, VANET, multiple paths**

I. Introduction

The fact that environmental noise pollution has negative effects on human health is no longer questionable. High noise levels exposure can have metabolic consequences for the cochlea as well as produce mechanical trauma [1]. Only in the European Union more than 270 millions citizens are affected by noise pollution caused by traffic, industrial and recreational activities.

In this context, the definition of an adequate strategy is an important political issue in many countries. The European Commission (EC) addresses noise in the environment as one of the main environmental problems in Europe [2]. Section 9 of the Handbook on the Implementation of EC Environmental Legislation refers to noise legislation [3]. This EC directive targets a common approach to the avoidance, prevention and reduction of the harmfull effects of exposure to environmental noise. Because available data on noise exposure is generally poor in comparison with other environmental problems, the document specifies common noise indicators and assessment methods for data collection, with the purpose of generating strategic noise maps. Environmental noise to which humans are exposed is taking into consideration, particulary in public parks, quiet urban areas, quiet areas in the open country, areas near schools, hospitals and other sensitive buildings. The main focus is explicitly on major roads, railways and airports. Through progressive implementation, the aims of this directive are:

- Strategic noise mapping: determining noise exposure using common noise indicators and methods of assessment;
- Informing the public: providing information on environmental noise and its effects;
- Adopting action plans: based on the results of noise mapping, seeking to reduce noise where necessary and protect environmental noise quality where it is good.

The required data collection process is the first step to noise mapping and can be an expensive and complex task. Technical approaches that provide better efficiency in terms of reliability and costs are highly in demand. Various solutions for monitoring noise pollution are proposed in the literature.

In this paper authors propose a promising approach for noise pollution mapping of urban areas using a mesh network composed of mobile phones as noise detectors and a V2V VANET (Vehicle Ad Hoc Network) for noise data transport. The main chalenge of this approach for noise monitoring is the reliable transportation of noise measurements over VANET's. Because of the high mobility of VANET nodes, data packets can be easily lost. To preserve the integrity of the data, a multipath routing protocol based on OLSR [4] is used.

A. Related works

In NoiseTube prototype [5], citizens are enabled to measure their own exposure to noise, contributing to the noise mapping of the cities. Data collected by GPS-equiped mobile phones (used as noise sensors) can be sent and shared online.

In [6] authors also use mobile phones for noise data collection and propose compact and privacy preserving representations of data (sketches), that allow them to compute statistics over data without disclosing users sensitive information (e.g. locations). Experimental results show that sketches can be employed to produce accurate environmental maps, at the same time preserving users privacy. Other possible applications that use mobile phones as sensing devices can be found in [7].

A noise pollution monitoring application using a distributed system adapted for Wireless Sensor Networks (WSN) is presented in [8]. Sensor nodes have a multi-agent structure that allows them to execute a set of applications (such as measurements and actions), manage sensor services, and communicate with other sensors and a computer.

WSN's are also used in [9] and [10] for the collection and logging of indoor and outdoor noise pollution data. The results show the general suitability of wireless sensor nodes to be used as noise pollution sensors and also depicts the practical limits of today's commercial platforms (e.g. uncalibrated nodes microphones produce misaligned acoustic responses).

B. VANET networks

Many of the current solutions proposed for noise pollution monitoring make use of WSN's. Among their main limitations WSN's have energy restrictions and constrained computational power and storage. To overcome this problems, VANET's represent a possible candidate for data collection and temporary storage of noise pollution data. This type of network is an application of Mobile Ad Hoc Networks (MANET's) and is emerging as a new technology that integrates the capabilities of new generation wireless networking to vehicles [11].

The main purpose of VANET's is to provide connectivity on the road to mobile users and efficient vehicle-to-vehicle communications. This features enable a variety of applications such as cooperative traffic monitoring, traffic flows control, blind crossing, prevention of collisions, nearby information services, and real-time routes computation. Even though VANET is a form of wireless ad hoc network, it has its unique characteristics due to the high nodes mobility and unreliable channel conditions:

- Highly dynamic topology;
- Frequently disconnected network;
- Various communications environments;
- Sufficient energy, computational power and storage;
- Hard delay constraints.

These characteristics pose many challenging research issues, including routing, data dissemination, data sharing and security. Finding and maintaining routes becomes a delicate task in VANET's. Several approaches and architectures have been proposed in order to implement VANET's [12]:

- A pure wireless Vehicle-to-Vehicle ad hoc network (V2V) with no infrastructure support;
- An Infrastructure-to-Vehicle (I2V) architecture and wireless last hops;
- A hybrid architecture that exploits the fixed infrastructure using V2V.

The remainder of this paper is organized as follows. In Section II, noise pollution assessment details are given. Section III describes the proposed monitoring system. Section IV presents the obtained results. Finaly, Section V concludes the paper.

II. Noise pollution levels assessment

The typical procedure for noise pollution levels collection, described in [9], is carried out by designated officers. They use sound level meters or other microphone equiped devices at a location of interest for short time periods (e.g. 30 minutes) . The collected data is stored in a register for further analysis and noise mapping of the monitored area and can serve as input of computational models used for estimating the noise level of unaccesible areas. This method of noise monitoring is inefficient and expensive. Also, the lack of fine-grained noise measurements in time and space can become critical if this data is used to develop and validate urbanization projects or traffic management plans.

A noise level indicator is needed to be able to monitor noise pollution. The equivalent continuous sound pressure level L_{eq} (Equation 1) is an indicator that complies with the guidelines specified by EC and can be used for noise mapping.

$$L_{eq} = 10lg\left(\frac{1}{T}\int_0^T \frac{p(t)^2}{{p_0}^2}dt\right) \tag{1}$$

where T is the time interval over which L_{eq} is computed, $p(t)$ is the root mean square of the instantaneous sound pressure produced by an acoustic wave and p_0 is the standard reference value corresponding to the minimal human audible signal (20 μPa). L_{eq} is measured in decibels (dB) and represents the sound level of a constant noise source over the time interval T that has the same acoustic energy as the actual varying sound over the same interval.

For the preparation of the noise maps European member states must provide two common noise indicators: L_{den}, to assess annoyance, and L_{night}, to assess sleep disturbance [13].

A. Acoustic noise measurements

To provide a better understanding of the data type used in the simulations, noise measurements were taken on Aurel Vlaicu Boulevard and Mihai Viteazu Square in Cluj-Napoca, Romania, for a 30 minutes time interval starting from 9.00 AM. The sky was partially cloudy and also a weak wind was present on the day that measurements took place. These measurements were taken using Blue SOLO and Meßtechnik HGL-104 noise meters. The maps of the measurements points are presented in Figure 1 and 2.

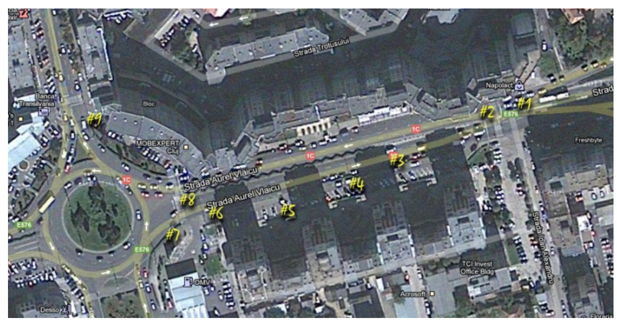

Fig. 1. Location of the noise measurements points on Aurel Vlaicu Boulevard, Cluj-Napoca, Romania

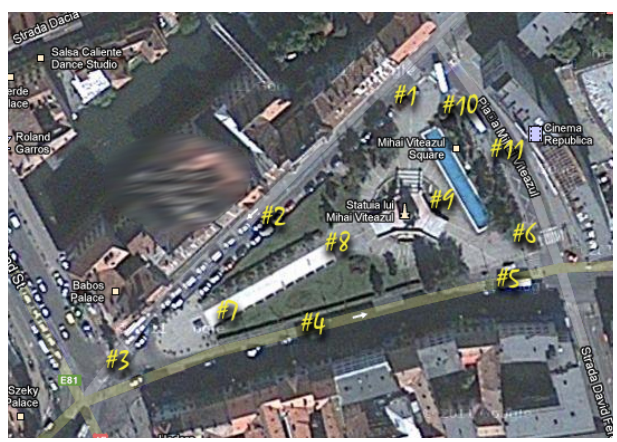

Fig. 2. Location of the noise measurements points on Mihai Viteazu Square, Cluj-Napoca, Romania

Table I and II present the average measured values obtained in each point.

TABLE I
AUREL VLAICU BOULEVARD ACOUSTIC NOISE VALUES

Measurement point	Noise level dB		
	Min	Average	Max
#1	73	80	96
#2	72	83	103
#3	70	79	100
#4	69	78	90
#5	69	76	85
#6	72	81	98
#7	72	82	103
#8	70	81.5	93
#9	76	83	97

TABLE II
MIHAI VITEAZU SQUARE ACOUSTIC NOISE VALUES

Measurement point	Noise level dB		
	Min	Average	Max
#1	74	81	93
#2	71	82	99
#3	76	82	93
#4	69	78	90
#5	75	80	93
#6	73	78	88
#7	75	80	89
#8	74	80.5	93
#9	71	77	88
#10	73	77	88
#11	71	79	95

Figure 3 shows the variation of the measured acoustic signal in point #1 on Aurel Vlaicu Boulevard. The measurements data rate is approximately 8 samples/min.

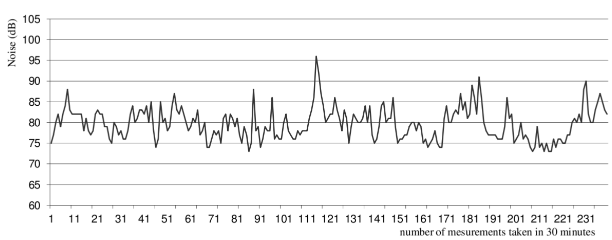

Fig. 3. Noise mesurements in point # 1 on Aurel Vlaicu Boulevard

The maximum value of 103 dB obtained from the measurements (Aurel Vlaicu Boulevard, Table I) is considered to be very loud for the human ear and can be produced by various sources such as motorcycles, heavy vehicles and heavy city traffic. Aproximately 80 dB (moderately loud) is the average value obtained for acoustic noise in both experiments.

III. VANET NOISE POLLUTION MONITORING SYSTEM

The proposed VANET Noise Monitoring System, called simply VNMS, uses a VANET network for data collection from noise detectors (GPS equipped mobile phones). Detector nodes periodically transmit noise levels to neighboring cars, data packets being shared and temporary stored by participating VANET nodes and ultimately uploaded to a collector node connected to the Internet, providing public real-time data.

VNMS is composed of three main components: noise detectors, VANET nodes (used as data carriers) and collector node which is also a mobile node in the VANET network. The proposed network topology is presented in Figure 4.

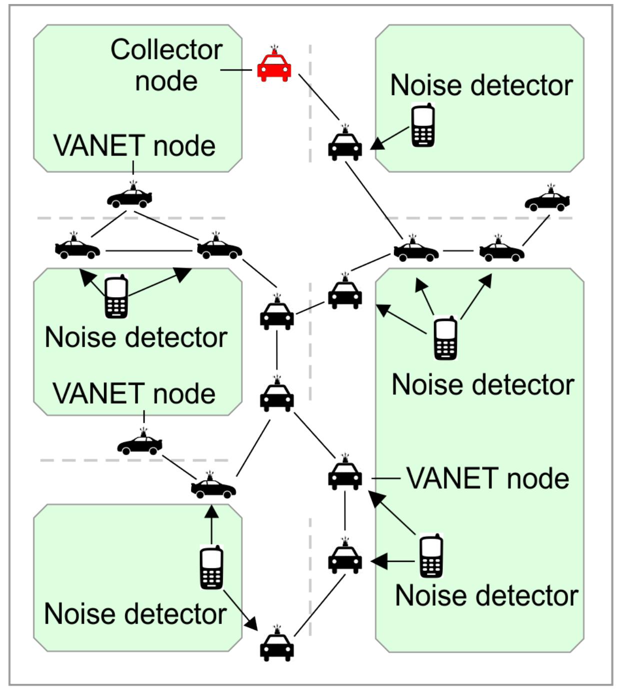

Fig. 4. Noise pollution monitoring using a VANET network

There are four steps in VNMS message forwarding:

- Detector node sends measured noise data to the nearest VANET node;
- VANET node forwards the received data to in range neighbors;
- Noise data is forwarded over multiple hops in the VANET network;
- Noise data is sent to collector node.

In VNMS VANET nodes share their own available noise records with other nodes they meet on the road. Each sensor node temporary stores its own noise level records and those data of other nodes that were in range in the past.

The main advantage of VNMS is the ease of deployment, all the components of the system being available and ready to be used without the need of any pre-installation. Also, all the tasks regarding routing and resource usage are transfered from sensing devices (which have limited resources) to VANET nodes. In this way the noise sensors do not have any role in message forwarding and data storage processes. Their only role is noise level detection and data transmission to the nearest VANET nodes. This network is used as a data carrier, knowing that it has theoretically unlimited resources in terms of data storage, energy and computational power.

A. OLSR routing protocol

OLSR (Optimized Link State Routing) protocol proposed in [4] is an optimization of link state protocol. This single path routing approach has the advantage of having routes immediately available when needed (proactive routing). OLSR reduces the size of control packets through multipoint relay selection mechanism, declaring only a set of links with his neighbors, instead of all the links. Another advantage of using multipoint relays (MPR) is the flooding minimization, only MPRs of a node retransmit the packets from that node. OLSR functions are: neighbor sensing, MPR selection, MPR information declaration, routing table calculation. OLSR protocol has low latency and performs best in large and dense networks.

In [14] OLSR and AODV are tested against node density and data traffic rate. Results show that OLSR outperforms AODV in VANETs, providing smaller overhead, end-to-end delay and route lengths. In terms of Packet Delivery Ratio (PDR), OLSR may be outperformed by AODV only after a certain threshold, the performance loss being limited to 10%.

OLSR can also be adapted to VANET scenarios for better QoS performances. In [15] authors describe a method that uses the available knowledge about the networks topology to improve the routing protocols performance through decreasing the probability of path breaks.

B. MP-OLSR routing protocol

Multipath disjointness can be used as a metric for describing multiple paths generated by routing algorithms. Protocols that provide multiple paths with high overall node disjointness can benefit from better transmission reliability and congestion avoidance as well as from control message overhead minimization.

In this paper authors use MP-OLSR (Multiple Paths OLSR) [16] routing protocol based on OLSR, that makes use of spatially separated multiple paths to forward packets in the VANET network. MP-OLSR exploits simultaneously all the available and valuable multiple paths between a source and a destination to balance traffic load and to reduce congestion and so packet loss. Also it provides a flexible degree of spatial separation between the multiple paths by penalizing edges of the previous paths. The algorithm for MP-OLSR multiple paths generation is detailed in Algorithm 1.

Where $(s,d) \in \mathcal{E}^2$ is a pair of vertices and $\mathcal{G} = (\mathcal{V}, \mathcal{E}, c)$ is the graph composed of the vertices set $\mathcal{V}$, the edges set $\mathcal{E}$ and the associated costs set c. The algorithm uses $\mathcal{G}$ to generate N (s,d)-paths betwen a source and a destination. Standard $Dijkstra(\mathcal{G}, n)$ algorithm provides the source tree $SourceTree$ of the shortest paths from vertex n in $\mathcal{G}$. $GetPath(SourceTree, d)$ function returns the shortest path to n from the source tree. $Reverse(e)$ gives the opposite edge of e and $Head(e)$ provides the vertex edge to which f_e points. f_p and f_e are two incremental functions used to increase the cost of the arcs. f_e penalizes arcs that belong to the previous path P_i or the opposite arcs belonging to it and f_e increases the cost of the arcs that lead to vertices of Pi.

Algorithm 1 Compute N paths from s to d in $\mathcal{G}$

function MULTIPATHDIJKSTRA$(s, d, \mathcal{G}, N)$
  $c_1 \leftarrow c$
  $\mathcal{G}_1 \leftarrow \mathcal{G}$
  for $i \leftarrow 1$ to N **do**
    $SourceTree_i \leftarrow Dijkstra(\mathcal{G}_i, s)$
    $P_i \leftarrow GetPath(SourceTree_i, d)$
    for all arcs e in $\mathcal{E}$ **do**
      if e is in P_i OR $Reverse(e)$ is in P_i **then**
        $c_{i+1}(e) \leftarrow f_p(c_i(e))$
      else if the vertex $Head(e)$ is in P_i **then**
        $c_{i+1}(e) \leftarrow f_e(c_i(e))$
      else
        $c_{i+1}(e) \leftarrow c_i(e)$
      end if
    end for
    $\mathcal{G}_{i+1} \leftarrow (\mathcal{V}, \mathcal{E}, c_i + 1)$
  end for
  return $(P_1, P2, ..., P_N)$
end function

IV. SYSTEM EVALUATION

A. Monitoring system simulation

1) Network scenario: We use Qualnet 5.01 version as a discrete event network simulator. The detailed parameters for the network configuration are listed in Table III.

For the simulations we design a VANET (Figure 4) composed of 16 randomly placed nodes in a 600 square meters topology. We consider this topology as a good trade off between a quite dense VANET and computational complexity. For the VANET scenario, a vehicle mobility pattern was manually created and used as an input for Qualnet simulator. This mobility pattern allows different maximal speeds for the vehicles: 10, 20, 30, 40 and 50 km/h (close to vehicle mobility within city). The data traffic is provided by 8 fixed CBR sources randomly distributed over the grid.

TABLE III
QUALNET SIMULATOR PARAMETER SET

Parameter	Values
Routing Protocol	OLSR and MP-OLSR
Simulation Time	100 seconds
MAC Protocol	IEEE 802.11
Physical Layer Model	PHY 802.11b
Pathloss Model	Two Ray Ground
Shadowing Model	Constant
Shadowing Mean	4.0 dB
Transmission Range	270m
Data Rate	11Mbps
Background traffic	8 fixed CBR sources
CBR packet size	512 bytes
CBR Transmission Interval	0.01 s

For MP-OLSR 3 multiple paths (N) are used.

2) Simulation results: For each routing protocol a number of 50 simulations were executed. Figures 5 and 6 show the

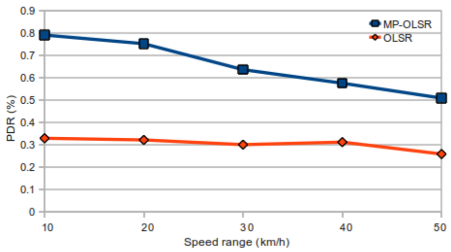

Fig. 5. Average Packet Delivery Ratio for the 8 CBR sources

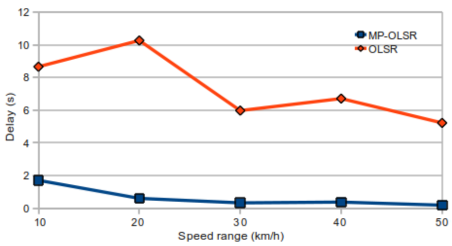

Fig. 6. Average End-to-end Delay for the 8 CBR sources

QoS performance of MP-OLSR and OLSR in terms of PDR and End-to-end Delay as an average of all 8 CBR sources.

From the obtained results it can be seen that PDR decreases lightly with mobility as expected. For the proposed VANET scenario MP-OLSR delivers an average of 35% higher PDR than OLSR protocol, with a maximum PDR of almost 80% at 10 km/h. Spatially separated multiple routes provide approximately 10 times lower delays (in average) than single path.

V. Conclusion

We described VNMS system as a possible approach for acoustic noise pollution monitoring, which uses a VANET network to collect data from noise detectors (mobile phones), and through a collector node uploads them online for noise mapping and public access.

MP-OLSR is the proposed routing solution for data forwarding in the VANET network. The protocol allows data repartition over multiple paths avoiding congestions and packet loss.

We also presented the multiple paths generation algorithm for MP-OLSR which alows a flexible degree of disjointness between the multiple paths through the cost functions.

Qualnet was used as a network simulator for the routing protocols evaluation. Results in terms of PDR and Delay were presented for OLSR and MP-OLSR protocols. We show that spatially separated multiple paths provide better QoS performances in the proposed VANET scenario.

Data packets are vulnerable to packet loss without taking into consideration the transport level. Also, the low data rate for noise measurements makes data protection mandatory. As a future work we plan to increase data reliability using FEC (Forward Error Correction) protection scheme over multiple paths and also deploy VNMS on a real testbed.

Sampled data contains users GPS locations that can be easily intercepted by malicious nodes and could lead to a low willingness of participation among the users. For this reason, the preservation of privacy in VNMS will be also taken into consideration as a future work.

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