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# OSA: A Vanet application focused on fuel saving and reduction of CO2 emissions

AVO: una aplicación para redes Vanet enfocada en el ahorro de gasolina y la reducción de emisiones de CO2

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## Abstract

With the growth in the number of vehicles moving through the streets, high vehicular flow has become a mobility and public health problem for governmental institutions and people since time of travel, gasoline consumption, and greenhouse gas [GHG] emissions have suffered an important increase. Hereby, policies and actions are required to reduce the impact of this increase. In this context, we have developed an application for the simulation of Vehicular Ad hoc Networks [VANET] using two software applications: SUMO and OMNeT++. The application we developed optimizes fuel usage and reduces GHG emissions; showing that vehicles following a preset speed (previously studied), gasoline consumption and GHG emissions present a considerable decrease compared to vehicles not running at that speed.

## Resumen

Con el aumento en el número de vehículos en las carreteras, el elevado flujo vehicular se ha convertido en un problema de movilidad y de salud pública para las instituciones gubernamentales y para las personas; ya que el tiempo de viaje, la gasolina consumida y las emisiones de Gases de Efecto Invernadero [GEI] han aumentado considerablemente. Por esto se requieren políticas, medidas y acciones para disminuir el impacto que está teniendo dicho incremento. Bajo este contexto, se ha desarrollado una aplicación para redes vehiculares en los simuladores SUMO y OMNeT++ que optimiza el consumo de gasolina y disminuye las emisiones de GEI, demostrando que si los vehículos respetan una velocidad preestablecida y estudiada anteriormente, el consumo de gasolina y las emisiones de GEI disminuyen considerablemente en comparación a los vehículos que no siguen dicha velocidad.

## I. Introduction

The development of this fast-paced society has pushed trends and behaviors upon in people, which were considered as low-occurrence events in the past. Particularly, buying a new vehicle or motorcycle is not anymore a luxury and now it is a primary need. Until October of 2013, total sales of new vehicles were 241,508 units (DANE, 2013). This suggests a positive variation of 1.8% in relation with the same period of 2012, when sales registered a negative variation of 1.9%; consequently, traffic jams have been increasing since then.

This increase in traffic jams has been directly proportional to commute time, gasoline consumption and Greenhouse Gas [GHG] emissions, causing annoyances and discomforts to drivers. For instance, in 2010 Americans spent 34 hours and 14 gallons of fuel on average per year due to traffic jams. In comparison with 1982 data (14 hours and 6 gallons of fuel), it is clear that growing traffic volume is an issue for current transportation systems (Greene, 2011).

Therefore, Vehicular Ad hoc Networks [VANET] present alternatives to current transportation systems for being, not only more efficient but also safer, reliable, and comfortable. These networks are considered as a *must have* of the Intelligent Transportation Systems [ITS], given their interoperability with vehicles, traffic lights, pedestrians, and other acting elements on the road. Furthermore, VANETs are an excellent tool to reduce gasoline usage and GHG emissions since they do not necessarily require fixed infrastructure and they are monitoring continuously the condition of the roads (Tsugawa & Kato, 2010).

This paper focuses in answering the question of how to increase energy efficiency of moving vehicles (i.e. reduce fuel consumption and GHG emissions, particularly $CO_2$) depending on the route they present. The result is the design, development and performance evaluation of Optimal Speed Advisory [OSA] application.

The rest of the document is organized as follows. Section II summarizes previous work focused in energy efficiency. Section III shows particular details about the application, its logic, and operation at PHY and MAC levels. Simulation scenarios and parameters are exposed in Section IV. Section V presents and discusses obtained results. Finally, Section VI expounds conclusions and future work.

## II. Related work

Research on ITS topics has grown in the last years, mainly because this field represents a huge market potential and impact on society. Within ITS, vehicular networks can significantly increase people's quality of life.

Orozco, Orozco and Llano (2014) summarize the particular features of VANETs

on their work. Consequently, vehicular networks present additional requirements and challenges not present in other wireless networks. Senouci, Moustafa and Jerbi (2009), Stampoulis and Chai (2007) and Guo (2009) agree that the most relevant requirements for VANETs are as follow:

» *Coexistence with other wireless networks*: VANETs must operate without causing any interference to other wireless systems operating in similar frequencies.

» *Sturdiness in connections*: connections between nodes (vehicles) must be robust in order to provide low latencies, minimize packet loss, and provide appropriate throughput depending of the application.

» *Failure recovering in connections*: due to the inexistence of nodes and equipment redundancy, VANETs must be capable of recovering missing links quickly and without user intervention.

» *Support of numerous data rates*: a complete support of varying rates between 10 kbps until several Mbps is required to satisfy application requirements.

» *Safety and privacy*: privacy and security of transmitted information in VANETs must be ensured with authentication and encryption mechanisms in order to avoid data loss and theft.

Challenges that face vehicular networks represent additional requirements that should be considered once the network is in operation. Di Felice, Ghandour, Artail and Bononi (2012), Jakubiak (2008), Qian and Moayeri (2008), and Karagiannis et al. (2011) have shown that the most relevant challenges are the following:

» *Authentication vs. security*: Notwithstanding safety is a primary objective in VANETs, some drivers might not agree leaving their anonymity sharing information about their position, speed, and other variables. Hence, equilibrium between shared information and user privacy is needed in order to guarantee information robustness.

» *Impersonation*: A safety scheme to avoid nodes and drivers impersonation is required in order to prevent fake alerts and network congestion, i.e. high data flow generated by malicious people.

» Network availability to support real-time communications, multi-hop communications, and other types.

» Wide law and policies range related with vehicular traffic varies from country to country; therefore, these discrepancies might be an inconvenient for VANET's implementation.

» Incentives not only to manufacturers, but also to governments need to be granted to push up implementation of vehicular networks in the near future.

Several vehicle manufacturing companies have performed researches focused on reducing automobiles environmental impact. The Ford Motor Company has a sustainability plan for vehicles, carried out by key-people like its Chairman and Chief

Executive Officer. This plan is mainly focused on a sustainability strategy looking forward the conservation of environment and reduction of GHG emissions (Ford Jr., & Mulally, 2013). General Motors finances the Collaborative Research Lab in association with the Carnegie Mellon University (General Motors, 2013) and the BMW Group has the BMW Group Research and Technology, which is focused on increasing vehicles efficiency (Draeger, 2007).

In Europe, the Car 2 Car Communication Consortium [C2C-CC] is, maybe, the most known. It was created by vehicles manufacturer companies and currently, it is financed by auto part companies, research centers, and other partners (see Figure 1). Its main objective is "increase safety and efficiency in the roads throughout Cooperative Intelligent Transportation Systems" (C2C-CC, 2007) and it presents several sub-projects specialized in different areas. Two of these sub-projects are focused on environmental sustainability and energy efficiency: *iMobility Support* (Konstantinopoulou, 2012) and *iTetris* (Idigoras, 2009).

The IBM Corporation (2010) proposes the "intelligent transport" case. The paper approaches in the hypothesis that not only with the construction of new roadways, traffic jams and energy inefficiency will be ended; consequently, it is necessary to increase network transport capacity, create new business models, and developing advanced traffic control systems to provide solutions based in ITS. Mehta, Kottapalli, Mahmassani and Bhat (2010) propose a methodology to link the studies about the ITS impact in mobility and sustainability carried out in different cities to avoid duplicate researches.



**Figure 1.** C2C-CC consortium partners

The International Telecommunications Union (ITU, 2007) presented a report defining a set of standards named CALM [Continuous Air-interface for Long and Medium range communications]. These standards aim to increase VANETs coverage area through the support of several wireless technologies, e.g. the four generations of cellular networks, satellite networks, microwave networks, WiMAX®, and Wi-Fi®. Moreover, CALM seeks to "reconcile" different standardization entities of United States, Europe, and Japan; which have individually modified basic standards for ITS and VANETs.

*EcoTrec*, a novel "eco-friendly" routing algorithm is proposed by Doolan and Muntean (2013). This algorithm considers features like pavement temperature, weather information and also road traffic conditions with the purpose of improving fuel saving and reducing carbon dioxide emissions. The authors claim that vehicles using their algorithm save up to 20% of gasoline in comparison with cars not implementing it.

## III. Application design

The main objective of the OSA application is to notify drivers about the speed where $CO_2$ emissions and gasoline consumption are considerably reduced without impacting commute time drastically. The main idea is that carbon footprint left by vehicles reduces whilst speed optimization is performed.

### A. Physical level

OSA is based in the IEEE 802.11p standard for its physical layer. This standard is part of the set called Wireless Access in Vehicular Environments [WAVE] and it employs the 5.9 GHz frequency band given by the Dedicated Short Range Communications [DSRC] technology (IEEE, 2010). DSRC defines seven 10-MHz channels each one. Figure 2 (Jian & Delgrossi, 2008) illustrates additional information of these channels.

Channel 184 or *High Power Public Safety* [HPPS] is the one OSA employs. This, because every node moving through application's Zone Of Relevance [ZOR] is expected to correctly receive packets. Table 1 (Kenney, 2011) summarizes maximum Equivalent Isotropically Radiated Power [EIRP], coverage range, and communication type per channel.
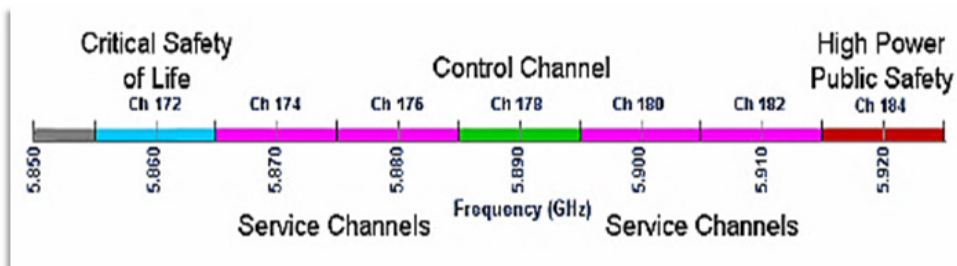


**Figure 2.** DSRC channels

**Table 1.** DSRC channels features

| Channel | Max. EIRP | Coverage Range | Communication Type |
|---------|-----------|----------------|--------------------|
| Ch. 172 | 33 dBm (2 W) | High (~1 km) | V2V |
| Ch. 174 | 33 dBm (2 W) | Medium (~600 m) | V2V, V2I |
| Ch. 176 | 33 dBm (2 W) | Medium (~600 m) | V2V, V2I |
| Ch. 178 | 44.8 dBm (30 W) | High (>1 km) | Control |
| Ch. 180 | 23 dBm (0.2 W) | Low (~250 m) | V2V, V2I |
| Ch. 182 | 23 dBm (0.2 W) | Low (~250 m) | V2V, V2I |
| Ch. 184 | 40 dBm (10 W) | High (>1 km) | V2V, V2I |

### B. Superior levels

In the superior levels, OSA is mainly highlighted in employing *broadcast* routing, since it is desired to establish connection with every node as possible. Moreover, WAVE Short Message Protocol [WSMP] is utilized as transport protocol to provide low-latency packets (Li, 2012).

In the application level, OSA classifies in the *Traffic Efficiency* category (Orozco et al., 2014) since its main focus is to optimize the mobility of vehicles over the roadways. Furthermore, it is important to underline that the communication scenario used by the application is the I2V (Infrastructure to Vehicle) one (Orozco et al., 2014), in which Road-Side Units [RSU] send beacons to nodes continuously. Table 2 summarizes application features.

Description of elements in Table 2 is given by Bai, Krishnan and Sadekar (2006) and it is exposed in the next paragraphs.

**Table 2.** OSA Application features

| Feature | OSA |
|---------|-----|
| Application Type | Traffic Efficiency |
| Communication Type | I2V |
| Region of Interest | Medium |
| Trigger | Periodic |
| Recipient Pattern | One-to-Many |
| Time To Live [TTL] | 20 s |
| Frequency | 5.92 GHz |
| Channel | HPPS |
| Required Infrastructure? | Yes |
| Packet Format | WSMP |
| Routing Process | Broadcast |
| Network Protocol Initiation Mode | Event-triggered |
| Transport Protocol | Connectionless |

- » *Application Type*: defines if the application classifies into the safety, traffic efficiency, or infotainment category.
- » *Communication Type*: focuses on how nodes can communicate (which communication scenarios are implemented); i.e. I2V, V2V, V2I scenarios, among others.
- » *Region of Interest*: it is the geographic range supported by the application. It can be large (> 1km), medium (~ 1km) or short (< 500m).
- » *Trigger*: initialization method of the application. Its possible options are periodic, event-driven, or user-initiated.
- » *Recipient Pattern*: it specifies the user relation that manages network packets. That is, one-to-one, one-to-zone, one-to-many, or many-to-one.
- » *Time to Live*: time in seconds elapsed before packets that do not reach their destination are dismissed.
- » *Frequency*: central operation frequency of the application in GHz.
- » *Channel*: working DSRC channel of the application. CCH channel is exclusively for safety applications; SCH channels are adequate for infotainment and traffic efficiency applications, and HPPS channel is reserved to traffic efficiency applications.
- » *Packet Format*: it depends of the selected network and transport protocols, i.e. TCP/IP corresponds to a normal IP packet and WSMP for a WSMP packet (defined by the IEEE 802.11p standard).
- » *Routing Process*: routing is related with *pattern* option, i.e. broadcast routing carries *one-to-many* pattern; geocast routing brings *one-to-zone* pattern; unicast routing implies *one-to-one* pattern, and aggregation routing is related with *many-to-one* pattern.

## C. Simulators and application logic

As Orozco et al. (2014) explain, chosen simulators for the development of OSA application were SUMO and OMNeT++. This due to the support of real scenarios, IEEE 802.11p and IEEE 1609 protocol implementations, freedom in licenses (freeware), and comfortable Graphical User Interfaces [GUI].

With this two software tools, the framework named Veins (Vehicles in Network Simulation) was utilized. This framework bi-directionally couples SUMO and OMNeT++, increasing simulations' computational efficiency.

In OMNeT++, a routing module was previously implemented (Orozco, Michoud & Llano, 2012) capable of providing OSA specific requirements. In addition to that, the application module was adjusted. These modifications are shown in Figure 3.

Figure 4 shows the sequential logic of the application, i.e. if a node is detected moving in the ZOR, the RSU send notification messages to these nodes containing information about optimal speed in the zone and the RSU saves the data.

Figure 5 describes the hierarchy for sent and received messages processed by the nodes. It also shows the components of an OSA message.
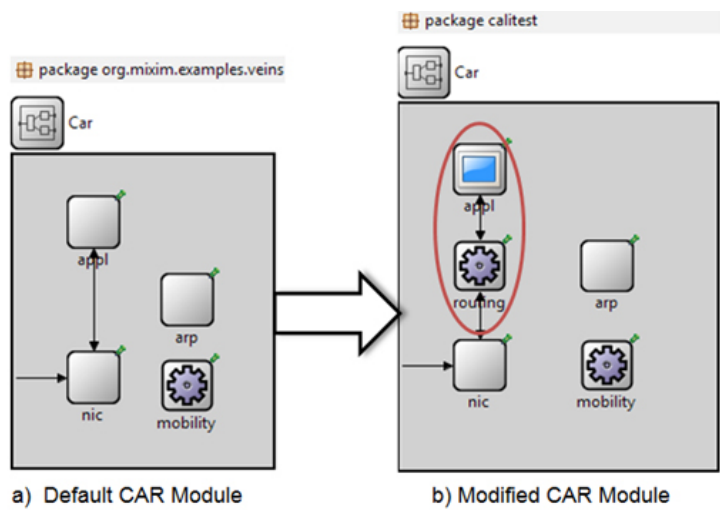
**Figure 3.** CAR module in Veins



**Figure 4.** OSA application logic



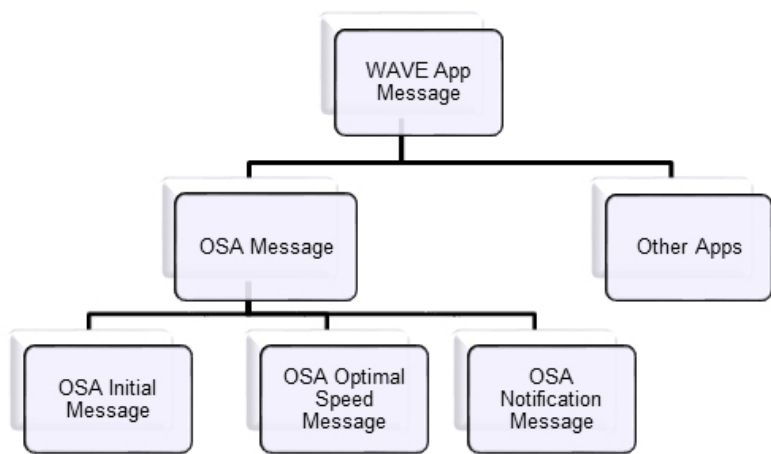**Figure 5.** Hierarchy in application messages

The event diagram for RSUs is shown in Figure 6. "Car-in-the-Zone" and "Optimal-Speed-Reached" signals are handled by SUMO, whereas message transmission and routing process are controlled by OMNeT++. On the other hand, Figure 7 describes the event diagram for the nodes, where data storage and I2V feedback is implemented.
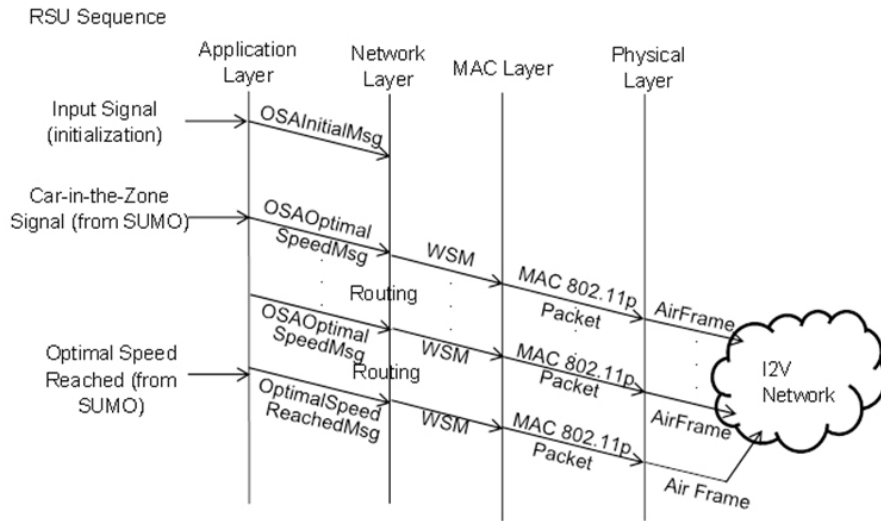
**Figure 6.** Event diagram in RSUs



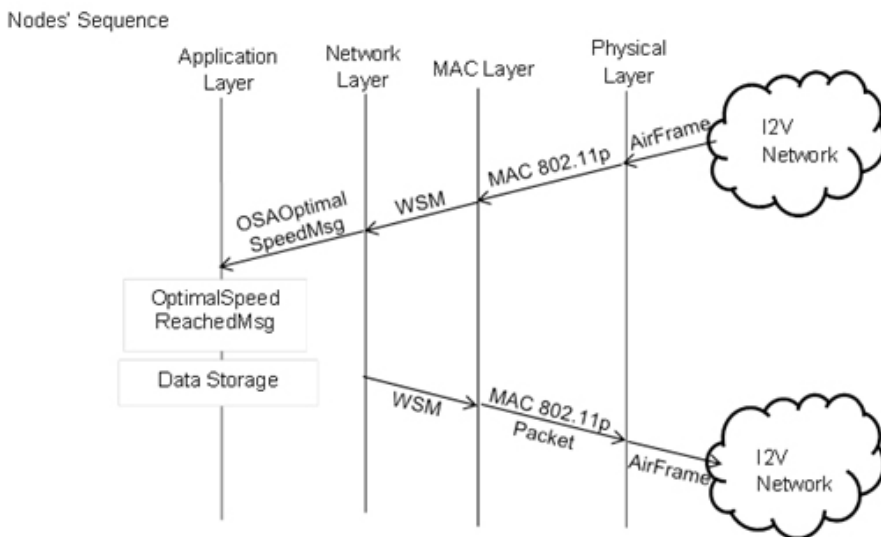**Figure 7.** Event diagram in nodes

## IV. Simulation Parameters

The specification of simulation parameters and subsequent results analyses were performed following Ülgen (2006) methodology. This author suggests four steps in his methodology:

» definition of simulation scenarios and cases;

» definition of common features in communication scenarios;

» execution of simulation tests; and

» results analyses.

## A. Simulation scenarios and cases

Simulation cases and scenarios were defined taking in consideration two variables: *number of present nodes* and *type of node* (i.e. different styles of vehicles like public service buses, heavy duty trucks, cargo vans, and sedans). Figure 8 shows graphically this definition.

In Scenario 1, the total number of vehicles traveling through the network is 100, which 50 respect optimal speed and the other half ignores informative messages. Scenario 2 is a low-users one (up to 24 nodes) but it maintains scenario 1 proportion; i.e. 12 nodes respect optimal speed and the others do not. Case 1 considers only sedan/compact vehicles and Case 2 presents the four types of vehicles previously mentioned.
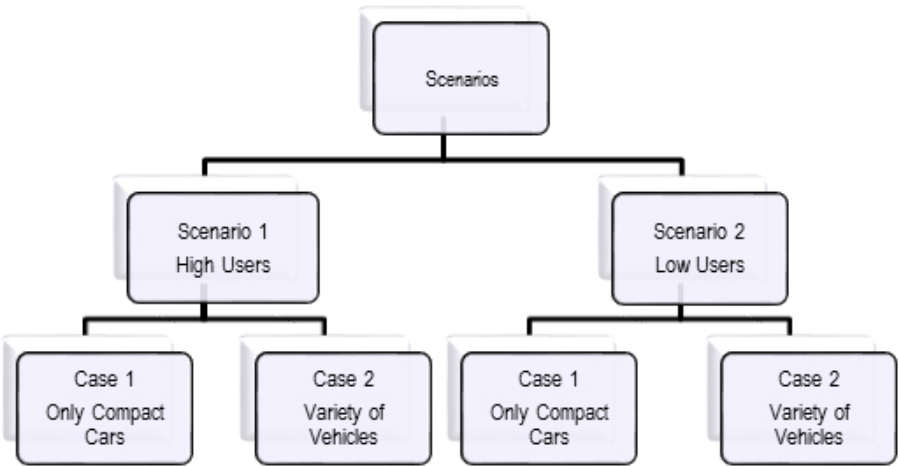


**Figure 8.** Simulated scenarios and cases

## B. Common features of scenarios

Previous scenarios described share common features among them. The following entries explain those features:

- » *Data in Simulators*: Two files that rule nodes movement were implemented in SUMO. Simulation time was *600 seconds* in Scenario 1 and *450 seconds* in Scenario 2. Sampling every *2 seconds* and IDM (Intelligent Driving Model) Mobility Model defined by Kesting, Treiber and Helbing (2008) were set to describe the movement of nodes.

- » Figure 9 displays the configured parameters of the IDM mobility model in SUMO. This configuration file is used to establish node routes; furthermore, in Table 3 the rest of the configuration data in the simulators are summarized.

- » *Simulation Area*: To evaluate the performance of the OSA application in terms of fuel consumption and $CO_2$ emissions, a highway where vehicles can travel at high speeds and constant traffic flow are required. Thus, Simón Bolívar highway located

at south of Cali (Colombia) was chosen and nodes go throughout 5 kilometers in both ways (*south-north*, S-N and *north-south*, N-S); besides, four RSUs are located at the road-sides. Figure 10 illustrates the mentioned area.

## C. Execution of simulation tests

The execution of simulation tests was performed using the previously chosen simulators: SUMO controls vehicular traffic flow, OMNeT++ as a platform of data implementation, and Veins as a simulation frame integrating them. Five iterations per scenario and case were carried out.

## D. Results analyses

After the execution of scenarios and cases previously described, results related with the subsequent topics were obtained:

- » optimal speed vs. packet loss graph;
- » non-Optimal speed vs. packet loss graph;

```
<routes xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance" xsi:noNamespaceSche
   <vType id="carro_obediente_NS" length="4.2" maxSpeed="16.7" color="1,1,0" gui
      <carFollowing-IDM accel="2.00" decel="3.00" timeHeadWay="1" minGap="1"/>
```

**Figure 9.** IDM configuration parameters in SUMO

**Table 3.** Configuration data in the simulators

| Feature | Route and Behavior | | | |
|---|---|---|---|---|
| | North-South | | South-North | |
| | Obey | Not Obey | Obey | Not Obey |
| Maximum Speed | 60 km/h | 80 km/h | 45 km/h | 65 km/h |
| Mobility Model | IDM | | | |
| Driver Type | Aggressive, Timid, Normal, Truck | | | |
| Car Type | Sedan car; Bus; Heavy Duty Truck; Cargo Van | | | |
| Transmission Power | 0.8 W | | | |
| Reception Threshold | -85 dBm | | | |
| Sensitivity | -95 dBm | | | |
| Receiver Noise Floor | -105 dBm | | | |
| Fade Margin | 10 dB | | | |
| Bit Rate | 6 Mbps | | | |
| Modulation | *Quadrature Phase Shift Keying* (QPSK) | | | |
| Channel Coding | ½ | | | |
| Propagation Models | Two-ray Interference Model; Simple Obstacle Shadowing Model | | | |
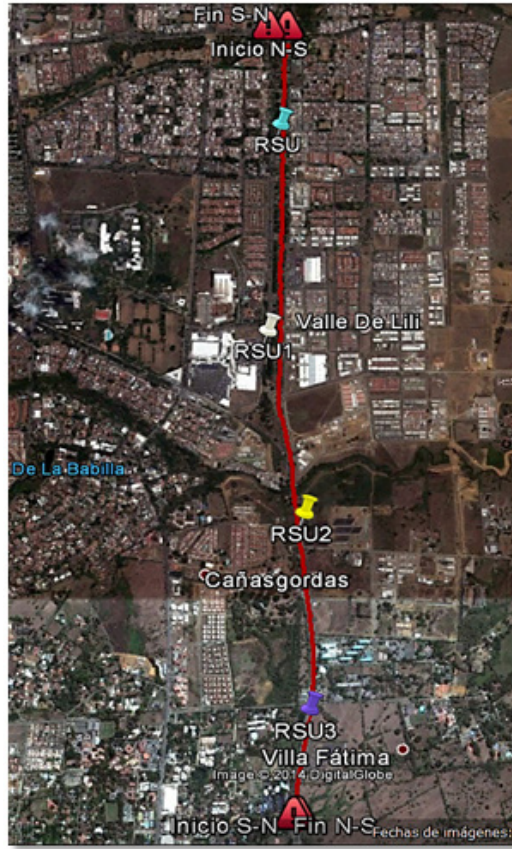
**Figure 10.** Simulation area in Google Earth

» fuel consumption comparison;

» $CO_2$ emissions comparison;

» $CO_2$ emissions vs. gasoline consumption graph; and

» Packet Error Rate (PER).

Discussion and details of these results are detailed in the following section.

## V. Performance Evaluation

Performance evaluation of OSA application was carried out taking in consideration a small number of nodes in order to analyze fuel usage, $CO_2$ emissions, packet loss, and PER. Carbon dioxide emissions data are calculated by SUMO based on the Handbook Emission Factors for Road Transport [HBEFA] (Hausberger, Rexeis, Zallinger, & Luz, 2009), which *provides emission factors for all current vehicle categories.*

### A. Scenario 1, high users

In the Scenario 1, twelve nodes of the total number of nodes were analyzed; six nodes respect optimal speed and the rest do not.

### 1. *Case 1, only sedan/compact vehicles*

In this case, every vehicle traveling through the road remains into sedan/compact category. Table 4 exposes relevant information about $CO_2$ emissions in parts per million [ppm] and grams, gasoline consumption in milliliters [ml], and processed packets per node.

**Table 4.** Processed packets, $CO_2$ and gasoline consumption per node. Scenario 1 case 1

| Node | Route | Respect optimal speed? | Received packets | Lost-Collided packets | PER | Average $CO_2$ emitted (ppm) | Total $CO_2$ emitted (g) | Gasoline consumption (ml) | Annual $CO_2$ emissions (kg)[2] |
|------|-------|----------|------|-------|-----|------|-------|-------|--------|
| 0 | N-S | Yes | 97 | 8 − 6 | $76 \times 10^{-3}$ | 1498 | 841.3 | 304.2 | 2523.9 |
| 28 | N-S | Yes | 90 | 6 − 5 | $63 \times 10^{-3}$ | 1513 | 850.0 | 313.7 | 2550.0 |
| 49 | N-S | Yes | 91 | 7 − 6 | $71 \times 10^{-3}$ | 1505 | 849.8 | 313.2 | 2549.4 |
| 2 | N-S | No | 68 | 10 − 7 | $128 \times 10^{-3}$ | 2068 | 899.6 | 325.0 | 2698.8 |
| 22 | N-S | No | 80 | 11 − 6 | $121 \times 10^{-3}$ | 1996 | 884.5 | 323.2 | 2710.4 |
| 43 | N-S | No | 69 | 12 − 8 | $148 \times 10^{-3}$ | 2014 | 887.8 | 324.1 | 2663.4 |
| 57 | S-N | Yes | 124 | 4 − 3 | $31 \times 10^{-3}$ | 1196 | 741.2 | 294.6 | 2223.6 |
| 69 | S-N | Yes | 127 | 8 − 6 | $59 \times 10^{-3}$ | 1175 | 732.9 | 294.1 | 2198.7 |
| 88 | S-N | Yes | 120 | 7 − 5 | $55 \times 10^{-3}$ | 1200 | 744.3 | 297.5 | 2232.9 |
| 50 | S-N | No | 82 | 10 − 7 | $109 \times 10^{-3}$ | 1701 | 865.8 | 319.0 | 2597.4 |
| 78 | S-N | No | 85 | 12 − 9 | $124 \times 10^{-3}$ | 1683 | 872.1 | 318.1 | 2616.3 |
| 98 | S-N | No | 87 | 14 − 11 | $139 \times 10^{-3}$ | 1696 | 865.7 | 318.9 | 2597.1 |

Information in Table 4 shows that vehicles moving throughout the simulation area in direction S-N present, on average, more received packets in relation with nodes circulating in direction N-S. This is due to the route speed specified in Table 3, where S-N route imposes lower speeds than the other route. As a result of that, interaction between nodes and RSUs is higher in S-N route. On the other hand, nodes which do not follow the optimal speed present, on average, higher gasoline consumption and PER values than the ones following it. Therefore, an increase in the speed negatively affects lost packets. Meanwhile, $CO_2$ emissions and fuel usage are reduced in 500 ppm (on average) and 15 ml respectively in nodes which respect preset speed.

Annual carbon dioxide emission analyses demonstrate that nodes respecting optimal speed stop emitting among 113.4 kg and 511.7 kg of this gas; supposing an annual car mileage of 15000 km. This result represents a reduction of emissions between 5.2% and 18.9%. Reductions of this order are recommended by the United States Department of State (2010) as strategies for climate change mitigation.

Figure 11 displays "node [0]" speed and the instants where packet loss is presented. The majority of these losses in this and every node following N-S route occur in the first half of the trip, no matter if they either follow or not the optimal speed. Additionally, Figure 12 describes "node [50]" speed, which has S-N route and now packet loss tendency is at the end of the trip. This is mainly because in the north of the simulation area is where vehicular flow and vehicle density drastically increase; incrementing packet loss due to collisions and low power.

*2. Case 2, several types of vehicles*

In this case, six sedan/compact cars, two busses, two heavy duty trucks, and two cargo vans were analyzed; this, in order to observe the possible impact of the introduction of various types of vehicles in the simulation. Table 5 shows relevant data about $CO_2$, PER, processed packets and gasoline consumption for this case.
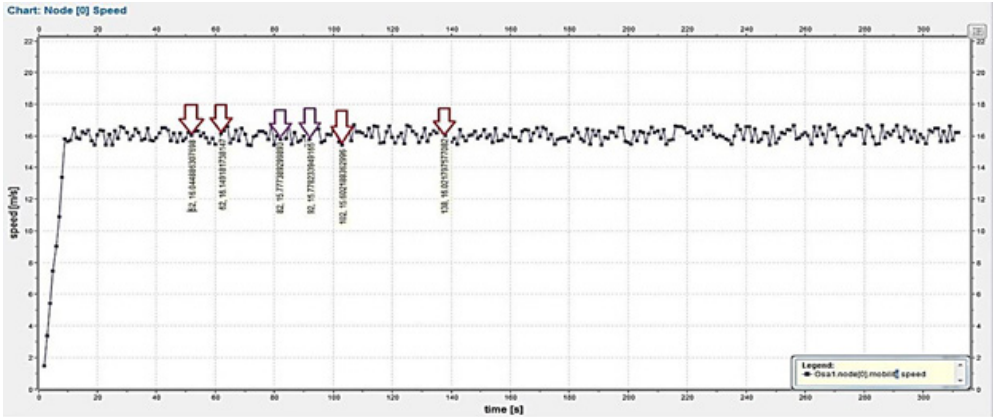


**Figure 11.** Speed and lost packets, node [0]

**Table 5.** Processed packets, CO2 and gasoline consumption per node. Scenario 1 case 2

| Node | Type of vehicle | Route | Respect optimal speed? | Received packets | Lost-Collided packets | PER | Average $CO_2$ emitted (ppm) | Total $CO_2$ emitted (g) | Gasoline consumption (ml) | Annual $CO_2$ emissions (kg) |
|------|-----------------|-------|------------------------|------------------|-----------------------|-----|------------------------------|--------------------------|---------------------------|------------------------------|
| 0 | Sedan | N-S | Yes | 113 | 3 − 3 | $26×10^{-3}$ | 1516 | 848.9 | 308.8 | 2546.7 |
| 30 | Van | N-S | Yes | 95 | 6 − 4 | $59×10^{-3}$ | 1655 | 904.4 | 332.3 | 4522.0[3] |
| 42 | Sedan | N-S | Yes | 101 | 10 − 6 | $90×10^{-3}$ | 1550 | 873.3 | 315.9 | 2619.9 |
| 11 | Truck | N-S | No | 101 | 22 − 16 | $179×10^{-3}$ | 8695 | 4883.1 | 1881.5 | 24415.5[3] |
| 32 | Sedan | N-S | No | 81 | 15 − 10 | $156×10^{-3}$ | 2031 | 892.9 | 325.5 | 2678.7 |
| 48 | Truck | N-S | No | 87 | 19 − 13 | $179×10^{-3}$ | 9122 | 5122.9 | 1981.5 | 25614.5[3] |
| 55 | Bus | S-N | Yes | 122 | 9 − 8 | $69×10^{-3}$ | 3525 | 2576.2 | 954.1 | 10304.8[3] |
| 73 | Sedan | S-N | Yes | 125 | 14 − 11 | $100×10^{-3}$ | 1125 | 793.4 | 286.6 | 2380.2 |
| 89 | Bus | S-N | Yes | 117 | 11 − 9 | $86×10^{-3}$ | 2977 | 2124.4 | 746.4 | 8497.6[3] |
| 51 | Sedan | S-N | No | 96 | 17 − 7 | $150×10^{-3}$ | 1890 | 904.5 | 329.0 | 2713.5 |
| 82 | Van | S-N | No | 84 | 14 − 10 | $143×10^{-3}$ | 2026 | 1104.1 | 355.1 | 5520.5[3] |
| 92 | Sedan | S-N | No | 68 | 13 − 9 | $160×10^{-3}$ | 1837 | 897.7 | 328.2 | 2693.1 |
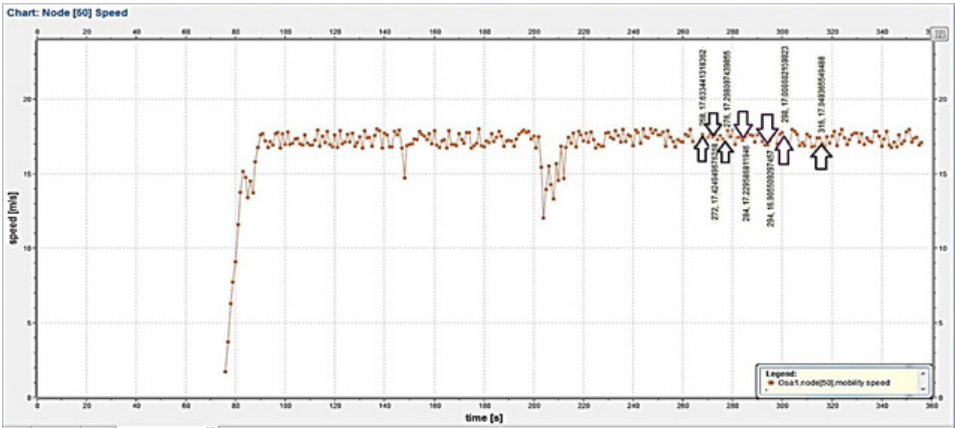
**Figure 12.** Speed and lost packets, node [50]

Data in Table 5 shows that, sedan/compact cars present similar behavior in relation with case 1 (see Table 4); although heavy duty vehicles stand out for their gasoline consumption and $CO_2$ emissions. PER values and fuel usage still continue to be minor in nodes following the optimal speed, confirming OSA efficiency. In those heavy duty vehicles, the increase of carbon dioxide emissions and fuel consumption is because of the weight, type of engine, and petrol used (diesel); expected $CO_2$ emissions increased up to 25 tons for trucks and up to 10 tons to buses. On the other hand, PER values in nodes not following optimal speed are bigger than the ones in Table 4 due to vehicles size; i.e. congestion is more suitable to appear when heavy duty vehicles are presented.

From the information in Table 4 and Table 5, it is clearly observed that there is a direct relation between carbon dioxide emissions and fuel consumption. This relation is graphically displayed in Figure 13 for one node; nevertheless every studied node imitates this tendency where high $CO_2$ emissions imply high gasoline usage.
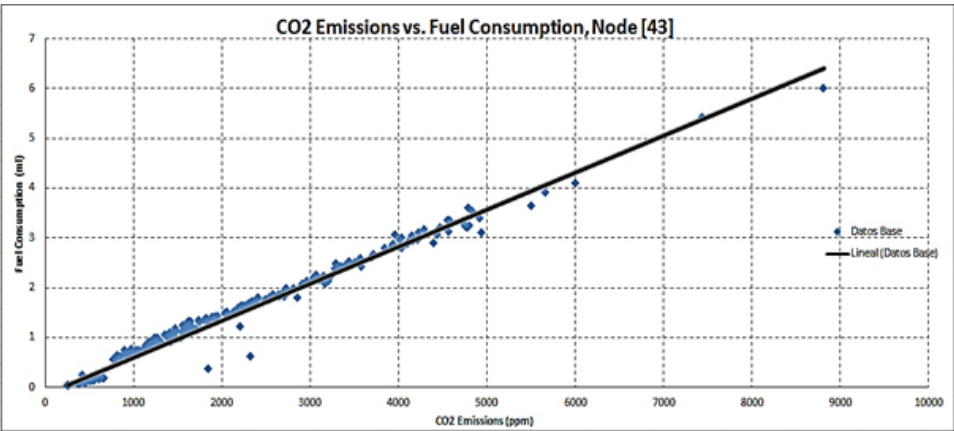


**Figure 13.** Relation since fuel usage and carbon dioxide emissions

## B. Scenario 2, low users

In this scenario, 24 vehicles travel throughout the simulation area, where 12 respect optimal speed and the other ones do not. Just as scenario 1, twelve nodes were analyzed.

### 1. Case 1, *only sedan/compact vehicles*

Table 6 summarizes processed packets, carbon dioxide emissions and fuel consumption for the case which only sedan/compact cars are considered. From this table, it is clear that collision packet loss is lower in comparison to Scenario 1; mainly because there are less vehicles traveling through the simulation area (i.e. the possibility of packet collision is considerably reduced). The tendency described in Scenario 1 continues whereas nodes respecting optimal speed present better efficiency in the processing of packets, fuel usage and CO2 emissions. Besides, annual emissions of this gas are reduced between 3.2% and 17.4% per 15000 km of car mileage.

### 2. Case 2, *several types of vehicles*

Table 7 displays relevant information about carbon dioxide, PER and gasoline consumption when light and heavy duty vehicles are considered. Just like the previous case, collision packet loss is lower compared to data in Scenario 1; furthermore, nodes following optimal speed still present better PER values and energy efficiency. Save percentage in $CO_2$ emissions and fuel is now between 5.3% and 11.6% for sedan/ compact vehicles; whilst for cargo vans it increases up to 26.6%. Hence, for heavy duty vehicles, OSA application offers more efficiency and provides a best way to reduce annual carbon dioxide emissions.

Finally, Figure 14 shows $CO_2$ in-time behavior in ppm for "node [28]". At the beginning of the simulation is where higher emissions are presented, this as a result of the cold-start in every node (i.e. nodes start from repose). Subsequently, the graph shows a "stabilizing tendency" reaching maximum and minimum values depending of node's acceleration. This behavior was obtained for every analyzed node.
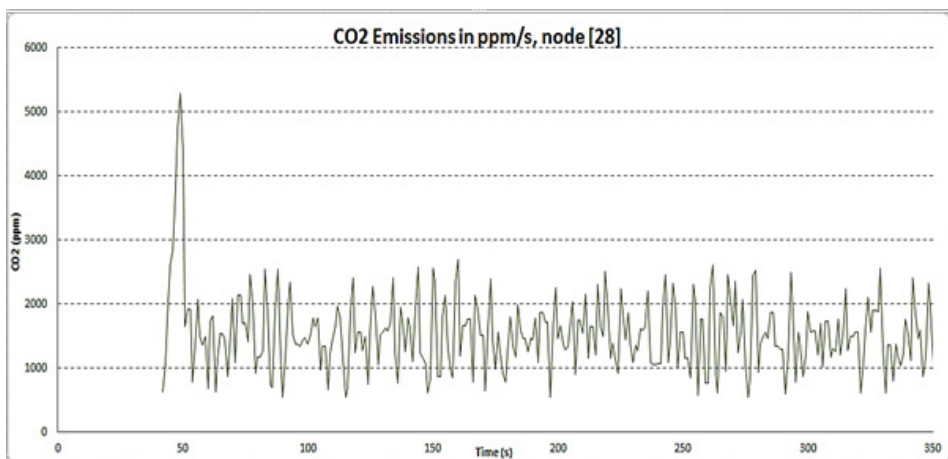


**Figure 14.** CO2 in-time behavior, node [28].

**Table 6.** Processed packets, $CO_2$ and gasoline consumption per node. Scenario 2 case 1

| Node | Route | Respect optimal speed? | Received packets | Lost-Collided packets | PER | Average $CO_2$ emitted (ppm) | Total $CO_2$ emitted (g) | Gasoline consumption (ml) | Annual $CO_2$ emissions $(kg)^2$ |
|---|---|---|---|---|---|---|---|---|---|
| 0 | N-S | Yes | 103 | 8 − 3 | $73 \times 10^{-3}$ | 1522 | 855.0 | 308.3 | 2565.0 |
| 8 | N-S | Yes | 103 | 8 − 2 | $73 \times 10^{-3}$ | 1502 | 848.7 | 306.6 | 2546.1 |
| 20 | N-S | Yes | 103 | 8 − 3 | $73 \times 10^{-3}$ | 1472 | 832.0 | 300.1 | 2496.0 |
| 2 | N-S | No | 72 | 10 − 3 | $122 \times 10^{-3}$ | 1999 | 894.9 | 329.9 | 2684.7 |
| 10 | N-S | No | 63 | 9 − 4 | $127 \times 10^{-3}$ | 2066 | 899.3 | 331.7 | 2697.9 |
| 22 | N-S | No | 68 | 10 − 4 | $128 \times 10^{-3}$ | 2010 | 899.1 | 331.5 | 2697.3 |
| 5 | S-N | Yes | 125 | 12 − 5 | $88 \times 10^{-3}$ | 1217 | 789.3 | 297.0 | 2367.9 |
| 13 | S-N | Yes | 121 | 9 − 3 | $69 \times 10^{-3}$ | 1209 | 785.4 | 296.1 | 2356.2 |
| 17 | S-N | Yes | 118 | 10 − 4 | $78 \times 10^{-3}$ | 1112 | 749.0 | 290.4 | 2247.0 |
| 7 | S-N | No | 98 | 15 − 6 | $133 \times 10^{-3}$ | 1725 | 887.7 | 326.8 | 2663.1 |
| 15 | S-N | No | 91 | 14 − 5 | $133 \times 10^{-3}$ | 1712 | 882.1 | 325.5 | 2646.3 |
| 19 | S-N | No | 82 | 17 − 7 | $171 \times 10^{-3}$ | 1781 | 906.5 | 335.5 | 2719.5 |

**Table 7.** Processed packets, CO2 and gasoline consumption per node. Scenario 2 case 2

| Node | Type of vehicle | Route | Respect optimal speed? | Received packets | Lost-Collided packets | PER | Average $CO_2$ emitted (ppm) | Total $CO_2$ emitted (g) | Gasoline consumption (ml) | Annual $CO_2$ emissions (kg) |
|---|---|---|---|---|---|---|---|---|---|---|
| 0 | Sedan | N-S | Yes | 82 | 6 – 1 | $68\times10^{-3}$ | 1522 | 857.4 | 310.1 | 2572.2 |
| 14 | Van | N-S | Yes | 93 | 9 – 3 | $88\times10^{-3}$ | 1688 | 951.0 | 366.3 | 4755.0 |
| 12 | Sedan | N-S | Yes | 101 | 5 – 2 | $47\times10^{-3}$ | 1516 | 854.0 | 310.0 | 2562.0 |
| 8 | Truck | N-S | No | 101 | 15 – 4 | $129\times10^{-3}$ | 8827 | 4957.3 | 1913.4 | 24786.5 |
| 18 | Sedan | N-S | No | 79 | 12 – 2 | $132\times10^{-3}$ | 2015 | 899.6 | 331.5 | 2698.8 |
| 22 | Truck | N-S | No | 104 | 17 – 6 | $141\times10^{-3}$ | 8575 | 4831.0 | 1876.9 | 24155.0 |
| 5 | Bus | S-N | Yes | 122 | 10 – 5 | $76\times10^{-3}$ | 3584 | 2619.2 | 1000.1 | 10476.8 |
| 9 | Sedan | S-N | Yes | 136 | 12 – 4 | $181\times10^{-3}$ | 1206 | 793.3 | 286.8 | 2379.9 |
| 23 | Bus | S-N | Yes | 129 | 11 – 6 | $78\times10^{-3}$ | 3447 | 2512.5 | 944.1 | 10050.0 |
| 16 | Sedan | S-N | No | 83 | 12 – 4 | $125\times10^{-3}$ | 1771 | 892.1 | 330.0 | 2676.3 |
| 21 | Van | S-N | No | 75 | 13 – 5 | $148\times10^{-3}$ | 2043 | 1296.3 | 413.4 | 6481.5 |
| 11 | Sedan | S-N | No | 82 | 13 – 6 | $137\times10^{-3}$ | 1793 | 896.3 | 333.3 | 2688.9 |

## Conclusions and future work

This paper proposed, designed and developed an application that optimizes the energetic efficiency and reduces the environmental impact of vehicles informing the optimal speed in a selected area. It combines the advantages of VANETs related with portability and scalability in order to reduce carbon dioxide emissions and fuel consumption. Simulation results verify the benefits of this application when nodes respect optimal speed; i.e. $CO_2$ emissions and gasoline usage considerably lower down their values compared with nodes not respecting it. In every scenario and case studied, OSA demonstrated reliability and robustness as long as PER and packet lost values were lower in nodes using the application. This improvement in the energetic efficiency was presented for every type of vehicle simulated: sedan/compact cars, buses, cargo vans and heavy duty trucks.

Future work will be oriented in designing and developing another application capable of sending notification messages to drivers about up-ahead traffic jams in real time, with the purpose of avoid these bottlenecks and reduce unnecessary fuel consumption and $CO_2$ emissions.

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