

# An Efficient Routing Protocol for Green Communications in Vehicular Ad-hoc Networks

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## ABSTRACT

Vehicular *ad hoc* networks (VANETs) provide the communications required to deploy *Intelligent Transportation Systems* (ITS). In the current state of the art there is a lack of studies on *Green Communications* (energy-efficiency) in VANETs. However, due to the possible interaction with devices that are fed with different electrical sources and the proliferation of electrical vehicles, the power consumption by the wireless communications might become a major concern in VANET design. In this paper, we study the energy-efficiency of a quality-of-service optimized version of OLSR by means of Differential Evolution (DE-OLSR). We have conducted a series of VANET simulations aiming at analyzing the power consumption and the QoS in order to compare DE-OLSR with the standard version of OLSR. An extensive performance evaluation shows that DE-OLSR clearly outperforms the standard version in terms of energy consumption, while offering a competitive QoS.

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Vehicular *ad hoc* networks (VANETs) provide the communications required to deploy *Intelligent Transportation Systems* (ITS). In the current state of the art there is a lack of studies on *Green Communications* (energy-efficiency) in VANETs. However, due to the possible interaction with devices that are fed with different electrical sources and the proliferation of electrical vehicles, the power consumption by the wireless communications might become a major concern in VANET design. In this paper, we study the energy-efficiency of a quality-of-service optimized version of OLSR by means of Differential Evolution (DE-OLSR). We have conducted a series of VANET simulations aiming at analyzing the power consumption and the QoS in order to compare DE-OLSR with the standard version of OLSR. An extensive performance evaluation shows that DE-OLSR clearly outperforms the standard version in terms of energy consumption, while offering a competitive QoS.

## Keywords

Vehicular ad-hoc network (VANET), Green Communications, OLSR, Metaheuristic, Differential Evolution

## 1. INTRODUCTION

Intelligent Transportation Systems (ITS) emerge as transportation systems that apply information and communication technologies to enhance safety, mitigate traffic congestion, and reduce the impact on the environment. One of the most promising technologies is the vehicular *ad hoc* network (VANET) [11]. VANETs are self-configuring networks where the nodes are vehicles (equipped with on-board computers), elements of roadside infrastructure, sensors, and pedestrian personal devices, e.g., smartphones. Over the last years, IEEE working groups are completing the final drafts of the family of standards for Wireless Access in Vehicular Environments (WAVE) [25], IEEE 802.11p and IEEE 1609, specifically designed for VANETs. This special kind of network offers the possibility of applying information technologies to deal with the problems of energy costs and the global  $CO_2$  emissions generated by the road transport [11].

Currently, wireless transceivers on-board vehicles are not highly energy constrained because they can benefit from the vehicle's electricity. Nevertheless, vehicular communications can involve other wireless devices such as pedestrian smart-phones, road transceivers, and sensors, that are fed with batteries or other energy sources. In these cases, the energy consumption ( $CO_2$  emissions) by wireless communications becomes a major concern and the use of environmentally sound communications (*Green Communications*), as power-aware network architecture and protocols design, are highly desirable. Limiting the energy consumption may help the use of green renewable energy sources as solar cells installed in the used wireless devices. Additionally, with the proliferation of electrical vehicles powered by finite batteries, any power consumption should be minimized to extend the range of vehicles.

In VANETs, the WiFi limitations in coverage and capacity of the channel, the high mobility of the nodes, and the presence of obstacles generate frequent topology changes and network fragmentation, with the consequent reduction of its quality-of-service (QoS). Therefore, routing is a challenging task, since there is no central entity manager in charge of finding the routing paths among the nodes in these volatile networks [20]. Recent studies show that, in mobile *ad hoc* networks (MANETs and VANETs), the proactive routing protocols, generally, outperform the reactive ones in terms of network goodput and end-to-end delay [10, 26]. However, proactive protocols suffer from a higher routing overhead, limiting their performance in terms of energy-efficiency [3].

In the present work, we are aimed at studying the energy-efficiency of DE-OLSR routing protocol [23], a QoS optimized version of OLSR [5] by means of the Differential Evolution (DE) metaheuristic [19]. DE-OLSR does not use any energy-efficient algorithm, but instead, in this work we want to analyze the power consumption of this optimized routing protocol against the standard version of OLSR presented by IETF RFC 3626 [5] when both are used in VANETs. We have chosen OLSR because few authors consider proactive protocols to efficiently manage the energy consumption [6, 16]. In turn, OLSR presents the main advantage of finding routing paths spending very short times, fulfilling the real-time requirements of safety VANET applications [24].

The performance evaluations have been carried out by means of VANET simulations by using ns-2 [2]. In order to obtain accurate results, the VANET instances have been defined by using real data (roads specification and mobility models) concerning urban areas of Málaga (Spain), including definitions of real IEEE 802.11p devices and the urban Nakagami radio propagation model [21].

The main contributions of this work are:

- Generating urban VANET instances following real data, including IEEE 802.11p definition, to achieve accurate simulations.
- Studying an energy consumption model in order to use it in the protocol comparisons.
- Analyzing the performance of both OLSR versions in terms of the energy-efficiency and the routing QoS in order to compare them.

The remaining of this paper is organized as follows. In the next section, we introduce some related works about *Green Communications* in *ad hoc* networks. Section 3 summarizes the routing protocols taken in account in this work (OLSR and DE-OLSR). Section 4 details the experiments carried out to analyze the performance of these routing protocols. Section 5 presents the results, performance analysis, and comparisons. Finally, conclusions and future work are drawn in Section 6.

## 2. RELATED WORK

The energy-efficiency in wireless networks has been mainly treated in the fields of mobile *ad hoc* networks (MANETs) [22] and wireless sensor networks (WSNs) [15]. More recently in VANETs, different authors have dealt with this problem mainly because the communications can be carried out among devices which employ batteries and solar cells as energy sources [8, 27]. Different mechanisms for saving energy in wireless communication systems have been proposed.

The application of transmission range adjustment to reduce the energy has been analyzed by several authors. Different algorithms have been proposed to compute optimal transmission range adjustments based on the geographic data and some energy model [4, 13].

Another approach to improve the energy-efficiency in *ad hoc* networks consists in putting as many as possible nodes into the *sleeping* state. The power consumed in this state is smaller than in the *listening*, *transmitting* or *receiving* states. Some authors analyzed the efficiency of this idea that is developed in IEEE 802.11 power save mechanism (PSM) [14]. In turn, a routing protocol was proposed based on this idea [17]. Some other approaches utilize transmission range adjustment and PSM together to achieve energy-efficiency [9].

In this study, we deal with the energy-efficiency problem in routing protocols. The type of routing protocol affects the energy dynamics of the nodes in two different ways: first, the routing network load has influence on the amount of energy used for sending and receiving routing control messages, and second, the generated routing paths affect to which nodes will consume energy in forwarding the packets. In addition, the energy conservation techniques applied in VANETs communications must ensure real-time transmissions, satisfying strict delay aware requirements [24].

In the literature we can find different approaches that modify existing routing protocols in order to save energy. For example, some authors have extended the standardized OLSR [5] by including new MPRs selection and topology control strategies taking into account battery capacity information to obtain more energy-efficient protocols [6, 16].

## 3. OLSR AND DE-OLSR

Optimized Link State Routing protocol (OLSR) [5] is a *proactive link-state* routing protocol designed for mobile *ad hoc* networks (MANETs and VANETs) with low bandwidth and high mobility. As a proactive protocol, the nodes periodically exchange topology information to establish the routes through the network nodes

from any source to any destination. OLSR relies on employing an efficient periodic flooding of control information messages using special nodes that act as *multipoint relays* (MPRs). The use of MPRs significantly reduces the size of control messages and the number of required transmissions [18]. This way, the energy spent by the routing protocol operation is decreased too. According to the topology network information, OLSR computes the routing tables by means of Dijkstra’s algorithm [7].

The core functionality of OLSR consists in two processes:

- *Neighbourhood discovery*: Each node acquires information of its one-hop and two-hop neighbourhood by periodically exchanging *HELLO* and *MID* (multiple interface declaration) protocol information messages. Using this information, each node selects its own set of MPRs among its one-hop neighbours in such a way that its MPRs covers all its two-hop neighbours.
- *Topology dissemination*: Each node maintains topological information about the whole network obtained by *TC* (topology control) messages that are broadcasted by MPRs nodes.

The OLSR mechanisms are regulated by a set of parameters predefined in the IETF OLSR RFC 3626 [5] (see Table 1). These parameters are: the time-outs before resending *HELLO*, *MID*, and *TC* messages (*HELLO INTERVAL*, *REFRESH INTERVAL*, and *TC INTERVAL*, respectively); the “validity time” of the information received via these three message types, which are: *NEIGHB HOLD TIME* (*HELLO*), *MID HOLD TIME* (*MID*), and *TOP HOLD TIME* (*TC*); the *WILLINGNESS* of a node to act as MPR (to carry and forward traffic to other nodes); and *DUP HOLD TIME*, that represents the time during which the MPRs record information about the forwarded packets.

DE-OLSR [23] is an efficiently and automatically tuned version of OLSR by means of an off-line optimization strategy. The main idea consisted in finding an efficient parameters setting in order to optimize the QoS provided by OLSR in terms of *Packet Delivery Ratio (PDR)*, *Normalized Routing Load (NRL)*, and *Average End-to-End Delay (E2ED)* of data packets in VANETs. This was carried out by coupling an optimization algorithm, the Differential Evolution (DE) metaheuristic [19], and a simulation procedure using ns-2 [1]. DE was chosen to optimize the OLSR configuration because this algorithm is specifically designed to optimize real valued (continuous) parameters with different ranges [19]. Table 1 presents the DE-OLSR protocol parameterization that was obtained automatically by using DE.

Table 1: OLSR RFC 3626 and DE-OLSR Parameter Settings.

Parameter	OLSR-RFC	DE-OLSR
HELLO INTERVAL	2.0 s	3.138 s
REFRESH INTERVAL	2.0 s	3,150 s
TC INTERVAL	5.0 s	45.245 s
WILLINGNESS	3	1
NEIGHB HOLD TIME	6.0 s	3.561 s
TOP HOLD TIME	15.0 s	103.139 s
MID HOLD TIME	15.0 s	141.053 s
DUP HOLD TIME	30.0 s	67.791 s

A performance evaluation by means of VANET simulations showed that DE-OLSR was able to outperform the standard OLSR configuration and even parameters set by human experts in this matter [23]. We observed that the highest improvements were reached in terms of NRL and E2ED. As DE-OLSR reduced the routing network load and the packets required shorter times to reach the destination node, in this study we aim at analyzing the possible improvements in terms of energy-efficiency of the DE-OLSR against the standardized OLSR.

#### 4. METHODOLOGY

The overall goal of this paper is to study the possible energy savings in the nodes of VANETs when they use DE-OLSR against to the standardized version of this protocol (OLSR). Thus, we will start with a global comparison about the energy consumption of both protocols. In turn, we have measured some routing QoS metrics of both protocols to study their trade-off between power consumption and performance. Later, we detail the experiments carried out that consist on different urban VANET simulations by means of an accurate VANET simulator based on ns-2 [2].

##### 4.1 VANET Scenario Definition

We have created three different urban VANET scenarios named U1, U2, and U3 from real areas of the downtown of Málaga, Spain (see Figure 1). These instances cover three different sizes of the same metropolitan area and they have different number of vehicles moving through the roads. Table 2 summarizes the main features of these VANET scenarios. We have used SUMO [12] for generating the realistic simulation mobility models where vehicles move following the real traffic rules (traffic lights and signs) during three minutes (180 seconds) with velocities between 0 and 50 km/h.

Additionally, for each VANET scenario, we have experimented with two different communication situations (A and B). These two situations differ from each other by the network data traffic overhead (data flows) generated during the simulations. In A, the number of data transfers between pairs of nodes is 1/2 of the number of vehicles, and in B, it is 3/4 (see Table 2).

Table 2: VANET scenarios details.

Scenario	Area Size	# of Vehicles	# of Data Flows
U1	120,000 $m^2$	40	A=20
			B=30
U2	240,000 $m^2$	50	A=25
			B=38
U3	360,000 $m^2$	60	A=30
			B=45

The experiments with three scenarios (U1, U2, and U3) and two different data flows (A and B) may help us to analyze how do various network sizes and level of communications affect the network performance.

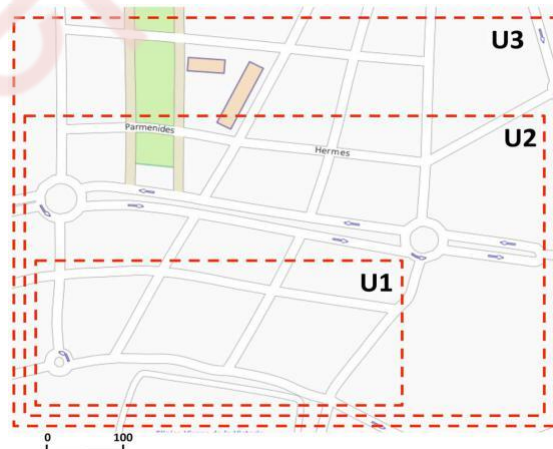


Figure 1: Málaga urban areas taken into account in each VANET scenario.

## 4.2 Network Specification

An important issue in simulation is to reflect the network interactions in a trustworthy manner. Ns-2 has been widely used for this purpose in the current state of the art of VANET simulation and evaluation [2]. However, most of the authors have not simulated VANETs configuring the wireless communications with the WAVE standards for physical and medium access layers. In the experiments carried out in this study, we have used two ns-2 modules (Mac802\_11Ext and WirelessPhyExt) that provide a significantly high level of accuracy and can be tuned to simulate the IEEE 802.11p standard [1]. In turn, we have included in the simulations the fading urban Nakagami radio propagation model representing the WAVE radio propagation in urban scenarios [21].

The data flows have been modelled by different number of sessions of a constant bit rate (CBR) data generator depending on the VANET scenario (see Table 2). The CBR operates over UDP (User Datagram Protocol) transport layer defined in the nodes (vehicles). Thus, the interconnected vehicles exchanged the data generated by the CBR agents during 15 seconds, transferring packets of 1024 bytes (1 kByte) with a data rate of 1 Mbps. We chose a fixed data rate since we did not aim to study the maximum throughput, but we wanted to investigate the energy-efficiency of OLSR in VANET scenarios. The remaining simulation parameters are summarized in Table 3 for future reproduction purposes.

Table 3: VANET instance specification

Parameter	Value or Protocol
Propagation model	Nakagami
Carrier Frequency	5.89 GHz
Channel bandwidth	6 Mbps
PHY Layer	IEEE 802.11p (Unex DCMA-86P2)
MAC Layer	IEEE 802.11p
Routing Layer	OLSR or DE-OLSR
Transport Layer	UDP
CBR Packet Size	1024 bytes
CBR Data Rate	1 Mbps
CBR Time	15 s

The configuration of the WAVE standard has been completed by using the characteristics of Unex DCMA-86P2, a real WiFi transceiver designed specifically to support IEEE 802.11p in vehicular environments (Unex website: <http://www.unex.com.tw/>).

## 4.3 Energy Consumption Model

In a wireless network, the network interfaces can be operating in one of the following four states: *transmitting*, *receiving*, *idle* or *sleeping*; consuming different levels of energy. *Transmitting* and *receiving* states are for sending and receiving data, requiring  $P_{send}$  and  $P_{recv}$  power, respectively. In the *idle* mode, the node keeps listening and the interface can change the state and transmit or receive packets. This is the default mode in *ad hoc* environments. Finally, when the radio of the node is turned off, *sleeping* state, and the node is not capable of detecting any signal, the energy consumption is extremely low.

The energy consumption model used in this work is based on the study presented in [3]. Here, the energy is computed according to the network interface card (NIC) characteristics of electric current ( $I_{send}$  and  $I_{recv}$ ) and power supply ( $V_{send}$  and  $V_{recv}$ ) during the different states, the size of the packets, and the used bandwidth (see equations 1 and 2). Although the network interfaces consume energy also during idle and sleep modes, the authors assumed in this model that these states are energy free, since the energy used by the nodes when they are not transmitting or receiving in the compared routing protocols is similar [3].

The following equations represent the energy consumed when the packets are transmitted ( $E_{send}$ ) and when the packets are received ( $E_{recv}$ ).

$$E_{send} = P_{send} \times Time = (I_{send} \times V_{send}) \times \frac{PacketSize}{Bandwidth} \quad (1)$$

$$E_{recv} = P_{recv} \times Time = (I_{recv} \times V_{recv}) \times \frac{PacketSize}{Bandwidth} \quad (2)$$

According to the specification of the Unex DCMA-86P2 NIC modelled in our simulations, the energy consumption is from 440 mA in transmitting mode, and 260 mA in receiving mode and it is fed with 5.0 V. Thus, the energy consumption in transmitting and receiving states (Joules) are presented in equations 3 and 4, respectively (packet size is represented in bits).

$$E_{send} = (440 \times 5) \times \frac{PacketSize}{6 \times 10^6} \quad (3)$$

$$E_{recv} = (260 \times 5) \times \frac{PacketSize}{6 \times 10^6} \quad (4)$$

Finally, we have to take into account that the total cost of a packet transmission is the sum of the costs incurred by the sending node ( $E_{send}$ ), and all receivers ( $E_{recv}$ ), whether they are or not the destination nodes. Equation 5 presents the total energy cost per packet ( $E_{total.cost}$ ) when there are  $r$  receiver nodes in the communication range of the sender.

$$E_{total.cost} = E_{send} + \sum_{i=1}^r E_{recv} \quad (5)$$

## 5. RESULTS

This section presents the experimental results of simulating both, DE-OLSR and OLSR, protocols. First, we analyze the performance of these routing protocols in terms of the energy consumption and, next, we extend our work with a study about some QoS metrics related with routing approaches. These results have been employed to compare both protocols to check which one offers the best trade-off between power consumption and performance.

### 5.1 Energy Consumption

During the simulations we have separately measured the energy consumed by the routing protocols and the rest of communication operations (see Table 4). Thus, we analyzed the energy-efficiency of DE-OLSR and OLSR in two different ways: first, the power consumption by the routing protocol operation (control message exchanges), and second, the energy by the CBR packets forwarding and the medium access control (see Section 2). We will refer to the second type of energy consumption as *CBR/MAC/PHY* in the rest of this article.

The energy consumed per node for each VANET scenario is highlighted in Figure 2. As shown in this figure, the energy consumption increases with the network size, principally because the number of nodes is higher and the collision avoidance method requires more medium accesses (CSMA/CA). Thus, the nodes were in *transmitting* and *receiving* states during longer times. However, the energy required by the routing protocols does not increase directly with the network size, since the maximum consumption by the two routing protocols occurred in the scenario U2 and not in the largest one (U3). For the three defined scenarios, the nodes consumed lower energy when they were configured with DE-OLSR routing protocol.

If we focus on the average power consumption results depending on the two studied data flows, A and B (see Figure 3), the energy consumed increases when the vehicles transfer a higher amount of data. In this case, as it happened during the analysis of the three studied VANET scenarios, the use of DE-OLSR produces energy savings over using OLSR. Moreover, DE-OLSR consumed a lower amount of energy during the transference of the B data flow (6342.40 J) than OLSR when exchanging the A data flow (6628.68 J).

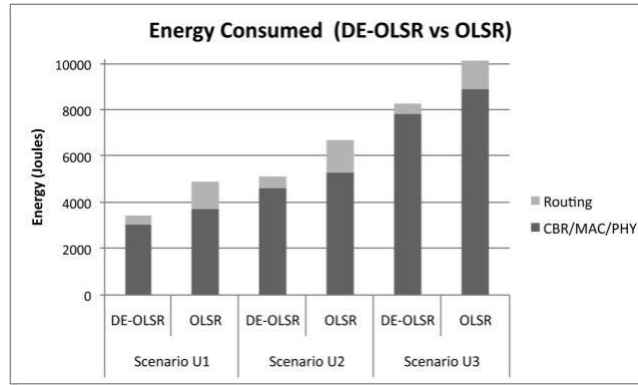


Figure 2: Energy per node consumption grouped by the three VANET scenarios (U1, U2, and U3).

Table 4: Average energy consumed per node (in Joules) by routing and the rest of communication operations for both routing protocols (DE-OLSR and OLSR), both data flow types (A and B), and three scenarios (U1, U2, and U3). Percentage of energy saved by using DE-OLSR against OLSR (two last rows).

		Scenario U1		Scenario U2		Scenario U3		Average (U1,U2,U3)	
		DE-OLSR	OLSR	DE-OLSR	OLSR	DE-OLSR	OLSR	DE-OLSR	OLSR
A	Routing	407.62	1191.33	524.44	1506.94	556.80	1452.04	494.97	1372.72
	CBR/MAC/PHY	2505.94	3032.94	4272.97	4513.64	6431.01	7543.28	4580.76	5255.95
	Total	2910.57	4224.27	4796.41	6020.59	6987.80	8995.32	5075.73	6628.68
B	Routing	401.70	1127.03	452.55	1314.28	329.99	1054.73	394.75	1165.35
	CBR/MAC/PHY	3563.74	4388.94	5008.47	6061.06	9260.83	10255.19	5947.65	6901.73
	Total	3975.36	5515.98	5461.03	7375.35	9590.83	11309.93	6342.40	8067.08
Avg. (A,B)	Routing	404.66	1159.18	487.99	1410.61	443.39	1253.39	445.35	1274.39
	CBR/MAC/PHY	3038.31	3710.94	4640.72	5287.35	7845.92	8899.23	5174.98	5965.84
	Total	3442.96	4870.13	5128.72	6697.97	8289.32	10152.62	5620.34	7240.24
% Routing Energy Saved		65.09%		65.40%		64.62%		65.05%	

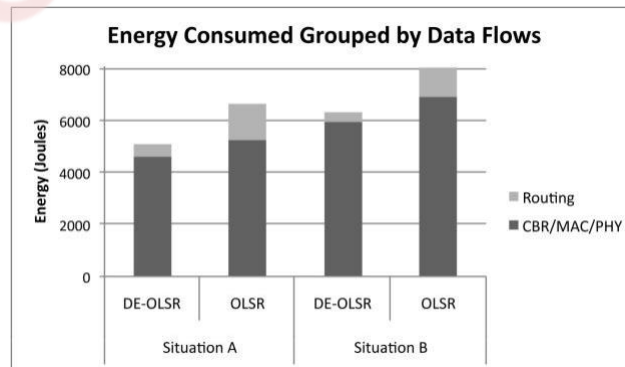


Figure 3: Energy per node consumption grouped by the two network uses (A and B).

If we analyze the energy consumed just by the routing protocols for the three studied VANET scenarios and both data flows, DE-OLSR has lower power consumption than OLSR. On average, in our simulations, the routing protocol operations consume 445.35 J when using DE-OLSR and 1274.39 J when using OLSR. Thus, DE-OLSR saves a 65.05% of energy consumption compared to OLSR. Regarding the three scenarios, the maximum energy saving (65.40%) is achieved in the scenario U2, when the routing protocols consume the largest amount of energy.

After studying the power consumption by the routing protocols, now we focus on the energy-efficiency in the other network layers because of medium access control and forwarding the packets through the computed routing paths (see *CBR/MAC/PHY* in Table 4). Globally, this energy consumption increases with the size of the network (see Figure 2) and with the data traffic generated (see Figure 3). In this case, for all scenarios and network uses, the nodes configured with the standard OLSR consume more energy than when they use DE-OLSR as their routing protocol. On average, the vehicles save 790.86 J when using DE-OLSR. Therefore, the network maintenance and packet exchange generate a lower power consumption when the nodes use DE-OLSR.

According to these results, DE-OLSR offers more energy-efficiency than the standard version of OLSR when used in VANETs. DE-OLSR provides power savings for both ways of energy consumption, consuming 65.05% less for routing operations and 13.25% less in packet forwarding and medium access control, in comparison to the standard version. On average, DE-OLSR consumes 23.69% less energy than OLSR (see Table 4).

## 5.2 Quality of Service

In order to extend the comparison, in this section we analyze some QoS metrics related to the performance of the routing protocols. In this case, we will study the over-load generated by the routing protocol (Normalized Routing Load, NRL) and the quality of the generated routing paths in terms of the number of hops and the time spent until reaching the destination node (End-to-End Delay, E2ED). The results are summarized in Table 5.

According to the configuration of the two versions of OLSR compared in this work (see Table 1), the standardized version exchanges control messages more frequently than DE-OLSR. For this reason, the network load generated by OLSR for the whole experimentation is higher than the one generated by DE-OLSR. On average, OLSR generates a normalized routing load of 34.34% against the 23.58% of DE-OLSR. Therefore, the standardized version can provoke network congestion more likely than DE-OLSR.

In turn, it should be noted that NRL decreases when reducing the density of vehicles in the roads (number of vehicles per square meter). This is because the traffic generated by exchanging routing protocol information is forwarded to the nodes within the neighborhood (the range of the network interface). So, if the VANET density is lower the number of the nodes (cars) within the neighborhood is also lower, generating lesser routing information exchange within the same area. For this reason, the maximum NRL appears in the scenario U1 ( $3.33 \times 10^{-4}$  vehicles/m<sup>2</sup>) and the minimum in the scenario U3 ( $1.66 \times 10^{-4}$  vehicles/m<sup>2</sup>) for both routing protocols.

Table 5: QoS resulted by using DE-OLSR and OLSR protocols in U1, U2, and U3 scenarios.

Metrics	Scenario U1		Scenario U2		Scenario U3		Average	
	DE-OLSR	OLSR	DE-OLSR	OLSR	DE-OLSR	OLSR	DE-OLSR	OLSR
NRL (%)	31.33	43.35	20.05	33.16	19.37	26.50	23.58	34.34
Number of Hops	2.12	1.47	2.29	1.41	3.11	1.73	2.51	1.54
E2ED (ms)	374.60	391.82	242.68	327.87	169.74	291.46	262.34	337.05

In terms of the routing paths generated by the analyzed protocols, the higher the size of the VANET scenarios the longer the required routing paths (see Table 5). This is because the behaviour of the nodes is different in larger VANET scenarios since their mobility increases caused by the existence of more roads to travel through. The packets transferred through the routing paths computed by OLSR do not use longer than two hops to reach the destination node. On average, the OLSR routing paths have 1.54 hops (see Table 5). In contrast, DE-OLSR employs more than two hops to transfer the packets in the three simulated scenarios. On average, the routing paths computed by DE-OLSR have 2.51 hops. Comparing the paths generated for both routing protocols, OLSR finds shorter ones than the DE-OLSR computed ones in the three scenarios.

Finally, as shown in Table 5, the transmission times re-quired to reach the destination nodes (E2ED) are longer when increasing the size of the VANET scenario, except the case of the scenario U2 when OLSR is used. Unlike what happens with size of the routing paths, the delay times are shorter when the VANET nodes are configured with the op-timized protocol. On average, the E2ED is 262.34 ms when the packets are transferred through the DE-OLSR routing paths and 337.05 ms when using OLSR.

Therefore, although the routing paths are longer when us-ing DE-OLSR, the packets spend less time to travel through the network and reach the destination nodes. This is due to the impact of the routing load generated (NRL) and, consequently, the congestion problems that may arise. As DE-OLSR generates fewer NRL than OLSR, the collision avoidance method (CSMA/CA) requires less medium ac-cesses and, therefore, the network nodes require less time to send the packets. The communication delays are important, since the real-time transmissions are of crucial importance for ITS applications [24].

According to these QoS results, we are able to claim that DE-OLSR routing protocol outperforms OLSR by generat-ing a lower routing load and by delivering faster the pack-ets. Although OLSR computes shorter routing paths, the network overload produces medium accesses too often, with the associated congestion problems caused by the collisions. As the real-time transmissions are important, the difference between the size of the routing paths is negligible.

## 6. CONCLUSIONS

The power consumption by wireless communications is be-coming a major concern in VANETs and the use of environ-mentally sound communications is highly desirable. In this work we have addressed a preliminary study about *Green Communications* in VANETs by employing DE-OLSR, a QoS optimized routing protocol by means of the Differential Evolution metaheuristic. For this task, we have compared the energy-efficiency of the DE-OLSR and the standard ver-sion of OLSR. In order to assess these protocols, we have carried out a set of simulations over three different urban VANET instances based on real data of the downtown of Málaga (Spain). Additionally, we have defined two different data flow exchanges for each scenario. Finally, the perfor-mance in terms of routing QoS has been analyzed to extend the evaluation of both protocols and to study the trade-off between the energy consumption and the performance. In the light of the experimental results we can conclude that:

- VANET nodes consumed less energy when they used DE-OLSR as routing protocol for the three analyzed scenarios. On average, DE-OLSR offered energy sav-ings about 65% in routing control message exchanges and 13% in data packet forwarding and medium access control.
- The standard version of OLSR generated a routing load more than 10% higher than the one generated by DE-OLSR. This produced problems of congestion and, even though OLSR computed shorter routing paths (less number of hops), the packets took longer times to reach the destination nodes. Therefore, DE-OLSR also outperformed OLSR in terms of routing QoS.
- Finally, analyzing the power consumption and the QoS obtained for both routing protocols in our experi-ments, we have observed that globally the optimized DE-OLSR offered better trade-off between energy-efficiency and QoS than the standard version of OLSR in VANETs.

It is also important to note that the DE-OLSR configura-tion can be used to improve other existing methods in the literature that apply energy-efficient algorithms over OLSR.

DE-OLSR is an optimized routing protocol in terms of QoS but its authors did not take into account the energy-efficiency when it was proposed. Therefore, the methodology of obtaining efficient routing protocols by using metaheuris-tics can be extended by taking into account the power con-sumption, defining new environmentally efficient protocols.

As a matter of the further work, we are currently an-alyzing the application of metaheuristic algorithms to obtain QoS efficient protocols for *Green Communications* in VANETs. In addition, we are extending our experiments with new still larger urban and highway VANET instances. Finally, we are planning outdoor tests (using real vehicles travelling through different kinds of roads) in order to vali-date the simulation results.

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