Green OLSR in VANETs with Differential Evolution

Jamal Toutouh, Enrique Alba
LCC, University of Malaga
ETSI Informática, Campus de Teatinos
29071, Málaga, Spain
{jamal,eat}@lcc.uma.es

ABSTRACT

Vehicular ad hoc networks (VANETs) provide a communication platform to deploy information exchange applications among road users. The energy consumption of the involved terminals, that rely on limited battery power, has led to research to design energy-efficient communications. In this paper, we reduce the energy consumption of the OLSR routing protocol in VANETs by using Differential Evolution algorithm to search for energy-efficient configurations. The experimental analysis shows that significant improvements over the standard configuration can be attained in terms of energy savings (up to 30%) without degrading the QoS.

Categories and Subject Descriptors

C.2.1 [**Networks Architecture and Design**]: Wireless communication; I.2.8 [**Artificial Intelligence**]: Heuristic methods

General Terms

Design, Experimentation, Performance

Keywords

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

1. INTRODUCTION

Vehicular ad hoc networks (VANETs) are emerging networks that provide the platform for information exchange between adjacent vehicles, roadside infrastructure elements, sensors, and pedestrian personal devices by using wireless ad hoc communications [16]. Such communications mainly rely on the family of standards for Wireless Access in Vehicular Environments (WAVE). Powerful applications capable of gathering, processing, and distributing useful up-to-minute information for road users are being developed using these technologies, thus contributing to the development of intelligent transportation systems (ITS) [16].

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Vehicular networks involve communications not only between on-board vehicle devices, that are not energy constrained, but also with devices fed by limited energy sources such sensors, smartphones, traffic signs, etc. In these cases, the energy consumption of wireless communications and computations becomes a major concern and the use of green communications, as power-aware network architecture and protocols design, are highly desirable [11].

In VANETs, nodes communicate directly with their neighbors and require decentralized routing protocols to propagate the information [27]. However, the frequent topology changes, the network fragmentation, and the medium access problems limit the performance of such protocols, posing a difficult challenge for attaining effective packets exchange between nodes. The studies focusing on topology based routing protocols show that proactive protocols generally outperform reactive ones in terms of network goodput and delays [15]. However, the high routing load generated by proactive approaches could limit their scalability and performance in terms of energy consumption [21].

OLSR [9] is a proactive routing protocol studied to deploy mobile ad hoc networks (MANETs), but also analyzed in VANETs [15, 18]. It adapts well to continuous topology changes, exhibiting competitive delivery ratio and transmission delays. Some studies have analyzed different energy-efficient variants to reduce its power requirements [22]. In addition, [29] presented energy savings by using DE-OLSR, a quality-of-service (QoS) efficient OLSR configuration. However, these results may be improved by finding specifically optimized power-aware configurations for OLSR. The search of the best OLSR configuration is a hard optimization problem due to the huge number of possibilities. Therefore, exact methods are not useful, since they require huge computation resources. In this context, metaheuristic algorithms [5] emerge as efficient stochastic techniques able to address complex optimization problems.

In this work, we aim to achieve green VANET communications by defining an off-line optimization problem to fine-tune OLSR routing protocol. The methodology consists in exploring the search space by using the Differential Evolution (DE) [20] algorithm. The evaluation of the solutions (tentative OLSR configurations) is carried out by analyzing the energy results in simulations of realistic VANET scenarios by using ns-2 network simulator [1]. Finally, the best OLSR configuration found, DE-OLSR, and the standard parameterization (RFC 3626) are compared in 54 different VANET scenarios to validate the results.

In summary, the main contributions of our work are:

1. Proposing an optimization strategy in which the DE algorithm is coupled with a VANET simulator to find energy-efficient (green) OLSR configurations. This methodology can be generalized to be directly used for any other routing protocol or metaheuristic algorithm.

2. Suggesting new OLSR configurations whose energy consumption is lower than the default OLSR version with no significant loss in QoS.

3. Validating the results by comparing a set of OLSR configurations in realistic VANET scenarios taken the metropolitan area of Málaga (Spain).

This paper is organized as follows. In the next section, we introduce some approaches on energy-efficiency in wireless ad hoc networks. Section 3 describes the energy aware routing problem in OLSR. Section 4 presents the power consumption model used here. Section 5 describes the optimization approach followed to tackle the problem. Section 6 presents the experiments carried out, as well as the results, comparisons, and analyses. Finally, conclusions and further work are drawn in Section 7.

2. RELATED WORK

Power consumption is an important concern in wireless networks in which the nodes are fed with limited energy sources, as wireless sensor networks (WSNs) and MANETs, since the capabilities of such networks decrease when the devices run out of battery. Several power-aware techniques are applied to reduce the energy requirements in such networks [19, 28]. Nowadays, VANETs are also using techniques to deal with the problem associated with power consumption [11] and medium access control [23].

Power transmission range adjustment has been applied to deal with the energy consumption problems. Different techniques that use geographical data and some energy models have been proposed to compute the optimal transmission range [23]. Another interesting approach is called *power save mechanism* (PSM), which consists in keeping the node in sleep mode as long as possible. This is because sleeping mode is the operation mode that consumes the least power. Moreover, some authors have applied transmission range adjustment and PSM together [12].

In this paper, we deal with the energy efficiency in the OLSR routing protocol. A node power consumption is affected by the type of routing protocol in two different ways: first, the routing workload generated by the protocol influences on the amount of energy used for exchanging routing control messages, and second, the generated routing paths affect the nodes consumption when forwarding packets.

The literature reveals interesting energy aware techniques applied to existing routing protocols [7]. The node's battery information are used by energy efficient protocols to select the relay nodes [4] and to compute routing paths [22, 25]. Other authors have analyzed the combination of both previous techniques [25]. Additionally, [22] presented *Overhearing Exclusion*, a mechanism that permits energy savings by switching off the wireless transceiver when a unicast message exchange is taken place in the neighborhood.

The impact of using an efficient protocol configuration is presented in [29], in which the authors studied the energy savings when an optimized QoS version of OLSR (DE-OLSR) presented in [30] is used. The experimental results led us to perform an in depth study of the OLSR parameterization in this article, in order to find the *best* energy-efficient configuration in VANETs. The most salient feature of this approach is the possibility of its application together with the previously presented power aware OLSR mechanisms.

Here, we analyze the application of the DE metaheuristic to find energy efficient OLSR parameter settings. We find several studies in the literature that use metaheuristic algorithms to deal with optimization of ad hoc communication protocols. In MANETs, a Cellular Multi-Objective Genetic Algorithm was used for finding an optimal broadcasting strategy [2], the evaluation of six versions of a GA for the design of ad hoc injection networks [10], and a GA for defining a multicasting routing approach [8]. More recently, CellDE (a hybrid multi-objective optimization algorithm) was applied to maximize the coverage and minimize the energy consumption and broadcast time of AEDB protocol [24]. In VANETs, five different metaheuristics were employed to optimize VDTP [14], AODV [13], and more recently OLSR [31] in terms of QoS.

3. POWER AWARE OLSR IN VANETS

Routing protocols are responsible for delivering data packets from one source node to the others, maximizing the reliability and minimizing the delay. These protocols determine the power consumption in the routing table update operations and in the packet forwarding. Here, we deal with the routing energy conservation in VANETs when using OLSR protocol. We have chosen OLSR because it offers competitive QoS, but it suffers from high energy consumption in large and dense networks [21]. In the following section we present this protocol and its problem of energy consumption.

3.1 Optimized Link State Routing Protocol

Optimized Link State Routing (OLSR) is a proactive link-state routing protocol specifically designed for ad hoc networks with low bandwidth and high mobility. OLSR uses a subset of special nodes of the network that acts as *multipoint relays* (MPRs) to periodically broadcast the routing control information. This way, it reduces the number of required transmissions, and therefore, the network workload [9].

The core functionality of this protocol mainly consists in two processes: *neighborhood discovery* and *topology dissemination*, that exchange three different types of messages [9]:

- HELLO messages, exchanged between neighbor nodes to accommodate for link sensing, neighborhood detection, and MPR selection signaling. Periodically, these messages are generated containing information about the links between the network interfaces.

- TC (topology control) messages, generated by MPRs to indicate which other nodes have selected it as their MPR. This information is stored in the *topology information base* of each network node which is used for routing table calculations. Such messages are forwarded to the other nodes through the entire network.

- MID (multiple interface declaration) messages, that are sent by the nodes to report information about their network interfaces employed to participate in the network. Such information is needed since the nodes may have multiple interfaces with distinct addresses participating in the communications.

The OLSR processes are regulated by a set of parameters predefined in the OLSR RFC 3626 [9] (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 an 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.

Table 1: Main OLSR Parameters and OLSR RFC 3626 specified values.

Parameter	Standard value	Range
HELLO_INTERVAL	2.0 s	$\mathbb{R} \in [2.0, 15.0]$
REFRESH_INTERVAL	2.0 s	$\mathbb{R} \in [2.0, 15.0]$
TC_INTERVAL	5.0 s	$\mathbb{R} \in [4.0, 35.0]$
WILLINGNESS	3	$\mathbb{Z} \in [0, 7]$
NEIGHB_HOLD_TIME	3× HELLO_INTERVAL	$\mathbb{R} \in [5.5, 45.0]$
TOP_HOLD_TIME	3× TC_INTERVAL	$\mathbb{R} \in [10.5, 90.0]$
MID_HOLD_TIME	3× TC_INTERVAL	$\mathbb{R} \in [10.5, 90.0]$
DUP_HOLD_TIME	30.0 s	$\mathbb{R} \in [10.5, 90.0]$

3.2 Energy Efficient OLSR Tuning

The main drawback of OLSR is the significant routing data workload generated by the continuous protocol information exchange. This generates network congestion and excessive energy consumption problems over large and dense networks (with high activity) [21]. This high power consumption could limit the use of network devices that are fed by limited energy sources in VANET communications.

In this work, we define an optimization problem to find the best configuration enabling green communications in VANETs. The OLSR configuration parameters are suggested with unclear values in the OLSR RFC 3626. Therefore, the range of values each parameter can take, shown in Table 1, has been inferred by following OLSR restrictions with the aim of avoiding pointless configurations. Taking into account this information, we can define an optimization problem in order to fine-tune OLSR by using DE for obtaining power-aware configurations for VANETs.

An important issue is that an excessive reduction of the power consumption of the protocol can cause malfunction. Thus, we have applied a QoS restriction to the optimization process in order to avoid this problem. In this sense, the *packet delivery ratio* (PDR) quality metric has been analyzed to guarantee a minimum level of QoS in the communications. PDR is the fraction of data packets originated by an application that a routing protocol delivers [15]. PDR can not degrade by more than 15% over the one obtained by the standard OLSR. This restriction is taken into account in the evaluation of the *quality* or *fitness* of the different OLSR settings (tentative solutions). Therefore, the energy-efficient parameter tuning problem searches for the *best* configuration that provides the higher energy savings while maintaining PDR within margins of good performance.

4. POWER CONSUMPTION MODEL

The communications in a VANET are carried out by different types of devices, such on-board units, sensors, smartphones, etc. The amount of energy that they dedicate to communications depends on the operating modes of their network interfaces. There are four operation modes: *sleep*, *idle*, *transmit*, and *receive*. In *sleep*, the radio device is turned off and the node is not capable of detecting any signal. *Idle* mode is the default state of wireless interfaces in ad hoc networks. In this state, nodes keep listening and the interface can change to start transmitting or receiving packets. Finally, *transmit* and *receive* modes are for sending and receiving packets, respectively.

Here, we deal with the power consumption in data and control packets exchange. Therefore, we analyze the operational states that act during packets exchange (transmit and receive states) by evaluating *per-packet power consumption* modeled by Cano et al. [6].

Thus, the energy is calculated according to the power requirements in transmit and receive modes, P_{send} and P_{recv} respectively, and the time needed to exchange the packets (t). These values are obtained by using the network interface card characteristics of electric current (I_{send} and I_{recv}) and power supply (V_{send} and V_{recv}), the size of the packets, and the used bandwidth. The following equations compute the energy consumed when the packets are transmitted (E_{send}) and when the packets are received (E_{recv}).

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

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

According to the specification of the Unex DCMA-86P2 network interface used in our simulations, the energy consumption is 440 mA in transmitting mode and 260 mA in receiving mode; and it is fed with 5.0 V. This device offers 6 Mbps bandwidth implementation of IEEE 802.11p. 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 or not they are 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. OPTIMIZATION METHODOLOGY

The search procedure for energy-efficient OLSR configurations is carried out by an off-line optimization method composed by two main components: the DE algorithm and a VANET simulation process (see Figure 1). DE is used to find new tentative configurations in the continuous search space. The evaluation of the new solutions is carried out by the simulation part, ns-2 is invoked by DE to simulate a VANET scenario configuring OLSR with the new generated parameter setting (see Figure 1). After this simulation, ns-2

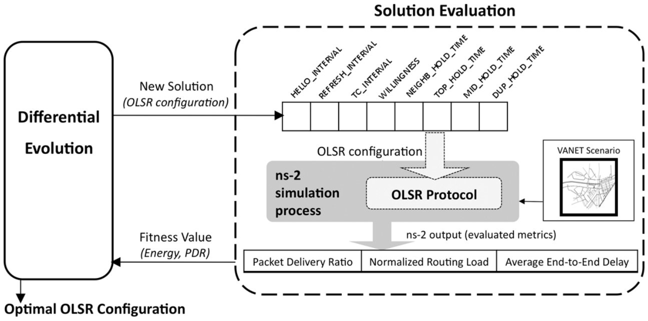

Figure 1: Optimization methodology.

output is analyzed to obtain energy consumption and PDR used to compute the fitness value to guide the algorithms search. The following sections present the used algorithm (DE), problem encoding, and fitness function.

5.1 Differential Evolution (DE)

Differential Evolution [20] is a stochastic population based algorithm designed to solve optimization problems in continuous (real) domains (real parameters, real valued functions). The population consists of a set of individuals (vectors) which simultaneously evolve through the search space of the problem. The task of generating new individuals is performed by differential operators such as the *differential-mutation* and *differential-crossover*. A *mutant individual* w^i_{g+1} is generated by the following equation (6):

$$w^i_{g+1} \leftarrow v^{r1}_g + \mu \cdot (v^{r2}_g - v^{r3}_g) \qquad (6)$$

where $r1, r2, r3 \in \{1, 2, \dots, i-1, i+1, \dots, N\}$ are mutually different random integers, and also different from the index i. The mutation constant $\mu > 0$ stands for the amplification of the difference between the individuals v^{r2}_g and v^{r3}_g, and it avoids the stagnation of the search process.

In order to increase even further the diversity in the population, each mutated individual undergoes a crossover operation with the *target individual* v^i_g, by means of which a *trial individual* u^i_{g+1} is generated. A randomly chosen vector component is taken from the mutant individual to prevent that the trial individual replicates the target individual.

$$u^i_{g+1}(j) \leftarrow \begin{cases} w^i_{g+1}(j) & \text{if } r(j) \le C \text{ or } j = j_r, \\ v^i_g(j) & \text{otherwise.} \end{cases} \qquad (7)$$

As shown in Equation 7, for each component j of the trial individual u^i_{g+1}, the crossover operator chooses both, a random integer value j_r and a random real number $r(j) \in (0, 1)$, uniformly distributed. Then, the crossover probability C and $r(j)$ are compared just like j and j_r. If r is less than or equal to C or j is equal to j_r, then we select the j^{th} element of the mutant individual to be allocated in the j^{th} element of the trial individual u^i_{g+1}. Otherwise, the j^{th} element of the target individual v^i_g becomes the j^{th} element of the trial individual. Finally, a selection operator decides whether to accept the trial individual for the next generation if and only if it yields a reduction (assuming minimization) in the value of the evaluation function (also called *fitness* function f), as shown by the following Equation (8):

$$v^i_{g+1} \leftarrow \begin{cases} u^i_{g+1} & \text{if } f(u^i_{g+1}) \le f(v^i_g), \\ v^i_g(j) & \text{otherwise.} \end{cases} \qquad (8)$$

Algorithm 1 shows the pseudocode of DE. After initializing the population, the individuals evolve during a number of generations (maxGenerations) and while the stop condition is not reached. Each individual is then mutated (Line 5) and recombined (Line 6). The new individual is selected (or not) following the operation of Equation 8 (Lines 7 and 8).

Algorithm 1 Pseudocode of DE

```
91: initializePopulation()
92: while !stopCondition() or g < maxGenerations do
93:     for each individual v_g^i do
94:         choose mutually different(r1, r2, r3)
95:         w_{g+1}^i ← mutation(v_g^{r1}, v_g^{r2}, v_g^{r3}, μ)    ▷ Equation 6
96:         u_{g+1}^i ← crossover(v_g^i, w_{g+1}^i, C)              ▷ Equation 7
97:         evaluate(u_{g+1}^i)
98:         v_{g+1}^i ← selection(v_g^i, u_{g+1}^i)                 ▷ Equation 8
99:     end for
910:    g++
911: end while
```

5.2 Problem Encoding

As Figure 2 shows, the solutions are encoded as vectors with eight components, since the OLSR protocol is governed by eight different configuration parameters (see Table 1).

The three first components represent the timeout timers to broadcast control messages (HELLO_INTERVAL, REFRESH_INTERVAL, and TC_INTERVAL, respectively) and the last four denote the timeout hold timers of OLSR (NEIGHB_HOLD_TIME, MID_HOLD_TIME, TOP_HOLD_TIME, and DUP_HOLD_TIME). These seven components are real values and their ranges were defined in Table 1. Finally, the forth component encodes the WILLINGNESS parameter, and therefore, it takes an integer value from zero to seven.

Figure 2: Solution encoding for the energy-efficient OLSR tuning problem.

5.3 Fitness Function

The fitness function is decisive for the DE optimization procedure, as it guides the population during the search process. The optimization problem proposed here concerns power-aware communications. Therefore, the energy consumed by the VANET nodes when they use a given OLSR configuration is the main component of the fitness function. In turn, we have included PDR metric in order to bias the search for solutions with acceptable QoS, avoiding OLSR malfunction due to an excessive power reduction. Both metrics, energy and PDR, are obtained by simulating a realistic VANET with a given OLSR configuration (see Section 6.1).

The fitness function to minimize is given by the expression in Equation 9, where $E(s)$ and $PDR(s)$ are the energy consumption and the PDR for a given OLSR configuration s, respectively. E_{RFC} and PDR_{RFC} are the reference values for the energy consumption and the PDR when using the standard configuration in RFC 3626, respectively. PDR_{MAX}

is the theoretical maximum PDR, that is, 100%. Finally, $\omega_1 = 0.9$ and $\omega_2 = -0.1$ are the weights for the energy and PDR contributions, respectively, and Δ=0.1 is a normalizing offset to keep the fitness value in the interval $[0, 1]$.

$$F(s) = \Delta + \left(\omega_1 \times \frac{E(s)}{E_{RFC}} + \omega_2 \times \frac{PDR(s)}{PDR_{MAX}}\right) \quad (9)$$

The previous equation is valid for solutions (configurations) that provide PDR with a degradation lower than 15% of the OLSR RFC obtained PDR value, since we considered as acceptable a degradation lower than 15% of PDR. In order to keep genetic information of solutions with worse PDR value, we applied the penalization model presented in Equation 10. The penalized fitness $F_P(s)$ takes into account the differences between the current PDR ($PDR(s)$) and the worst PDR admitted ($PDR_{85\%RFC}$), and the difference between the energies.

$$F_P(s) = F(s) + \left((PDR_{85\%RFC} - PDR(s)) \times \frac{E(s)}{E_{RFC}}\right) \quad (10)$$

6. EXPERIMENTAL ANALYSIS

As we have stated before, the experimentation carried out in this work comprises two main components: the DE algorithm and the VANET simulation. The DE algorithm has been implemented in C++ using MALLBA [3] optimization framework. The VANET simulation is employed to evaluate tentative solutions, but also in the final validation. It is carried out by using ns-2.34 extended by UM-OLSR. The experiments have been done by running 30 independent runs of DE in a Gigabit Ethernet cluster of Pentium IV 2.4 GHz cores, 1 GB RAM, and O.S. Linux Fedora core 6.

This section introduces the set of VANET scenarios, the experiments to obtain energy-effcient OLSR settings, and the experimental validation.

6.1 VANET Scenarios

The experimental evaluation of OLSR configurations was performed over several urban VANET scenarios covering real areas of the downtown of Málaga in Spain. Our testbed is composed of 54 urban VANET scenarios by taking into account different vehicular environments (geographical areas and road traffic densities) and network workloads. Tables 2 and 3 summarize the main features of the scenarios used in our experimentation.

The vehicular environment was generated by using the SUMO [17] traffic simulator. Three different geographical areas named U1, U2, and U3 from real areas of downtown of Málaga (Spain) have been taken into account in the scenarios definition (see Figure 3). Thus, we study whether our energy efficient OLSR suffers from a high underperformance when the network size increases because of its overloading as the standard version [21]. In these areas, there are different number of vehicles moving through the roads following real traffic rules during three minutes (see Table 2). Additionally, we have generated different traffic densities (number of vehicles moving through the roads) named L (low), M (medium), and H (high). Thus, we analyze how do various mobility situations affect the routing performance.

In each scenario, there is a number of data exchanges between pairs of vehicles. The data is generated by a constant bit rate (CBR) generator for 30 seconds. The number of

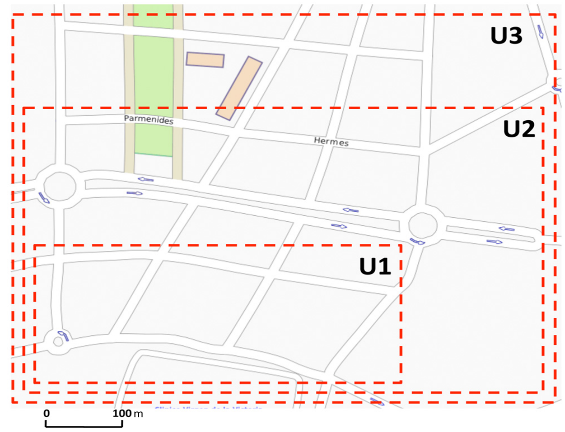

Figure 3: Málaga urban areas taken into account in each VANET scenario.

Table 2: VANET scenarios details.

scenario	area size	vehicles	CBR sources
U1	120,000 m^2	10	5
		15	8
		20	10
U2	240,000 m^2	20	10
		30	15
		40	20
U3	360,000 m^2	30	15
		45	23
		60	30

vehicles that generate the information (CBR sources) to be sent to the other nodes depends on the VANET scenario (see Table 2). In turn, we have defined different scenarios by using six different traffic data rates to experiment with several network workloads. They are grouped in *low-rates* (33, 66, and 100 kbps) and *high-rates* (333, 666, and 1000 kbps). Thus, we can analyze the capacity of our routing approaches with different data traffic loads. The vehicles network devices employ one of the evaluated OLSR parameterizations to compute the routing paths among the VANET nodes. Table 3 summarizes the main features of the network used in our VANETs simulations.

Table 3: VANET communications specification.

parameter	value/protocol
Propagation model	Nakagami
Carrier Frequency	5.89 GHz
Channel bandwidth	6 Mbps
PHY/MAC Layer	IEEE 802.11p
Routing Layer	OLSR
Transport Layer	UDP
CBR Packet Size	512 bytes
CBR Data Rate	33/66/100 333/666/1000 kbps
CBR Time	60 s

Ns-2 simulator has been used to evaluate the VANET communications. In order to reflect the network interactions in a trustworthy manner, the nodes are configured by using the real specifications of Unex DCMA-86P2, a real WiFi transceiver designed specifically to support IEEE 802.11p. In addition, we have included in the simulations the fading **Nakagami** radio propagation model representing the WAVE radio propagation in urban scenarios [29].

In order to perform the fitness evaluations, during the optimization process we have used the U2 VANET scenario involving 20 vehicles generating 66 kbps CBR. The values for energy and PDR for this scenario when using standard OLSR are $E_{RFC} = 9104.19$ J and $PDR_{RFC} = 87.12\%$.

6.2 Optimization Performance

This section presents the quality of results and the computational efficiency of the optimization process. In this work, DE performed 30 independent runs and it was configured with eight individuals completing 125 generational steps (1000 fitness function evaluations), with a crossover probability $Cr = 0.9$ and a mutation factor $\mu = 0.125$.

Table 4 summarizes the experimental results. It shows the *best* (minimum), the median, and the *worst* (maximum) fitness values obtained in the 30 independent runs. In turn, this table presents the final energy and PDR values obtained for the final solutions in the scenario used during the optimization process.

Table 4: Optimization experimental results.

Solution	Fitness	Energy (J)	PDR
Best (Minimum)	**0.6831**	**6684.708**	77.76%
Median	0.7157	7026.932	78.92%
Worst (Maximum)	0.7382	7256.192	79.08%
OLSR RFC 3626	n/a	9104.19	**87.12%**

The results presented in Table 4 demonstrate that significant improvements in the energy consumption can be made when optimized configurations are used. The best solution reduced by 26% the energy consumption with respect to the standard OLSR configuration, while the PDR degradation remained below 10%.

In terms of the performance of DE for solving the energy-efficient OLSR configuration problem, Figure 4 shows the graphs of the best solution through the best, median, and worst in the 30 independent runs. In this figure, we can see that the median and worst executions perform improvements even in the last steps of the generational steps. In contrast, the best execution converges very quickly to the best fitness value before the 35^{th} generation.

Finally, in terms of the computational effort required to automatically find power-aware OLSR settings, we have measured the run time. The mean time in which the best solution was found is 1.0037E+4 seconds (2.8 hours) and the global mean run time is 1.6525E+4 seconds (4.6 hours). This relative low effort in the protocol design is completely justified by the subsequent benefits obtained in the energy consumed by the nodes once the VANET is physically deployed, as we show in the following analysis.

6.3 Experimental Validation

In order to confirm the efficiency of the optimized configuration, a set of validation experiments are used to compare the performance of the best found configuration by DE (DE/EE-OLSR), the standard configuration (RFC), and the QoS optimized version of OLSR (DE-OLSR) [30]. These

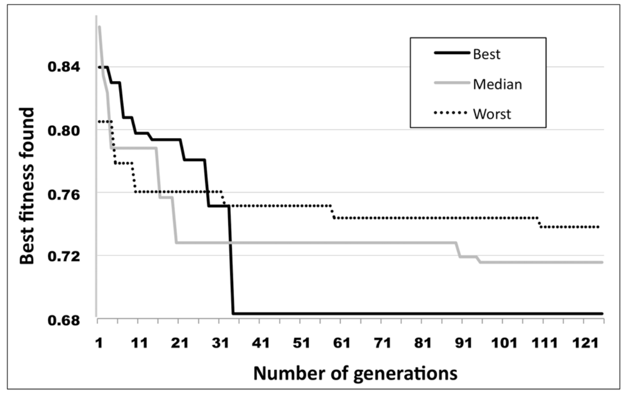

Figure 4: Best fitness evolution.

experiments involve simulations of the 54 VANET scenarios presented in Section 6.1 for the three parameterizations.

The experimental validation will evaluate the power consumption in transmitting (E_{send}) and receiving (E_{recv}) packets, the percentage of power consumed by the routing protocol (E_{OLSR}), and the average total power required by each vehicle ($E_{tot \times v}$). In turn, we will consider the PDR metric to analyze the QoS of the VANET communications. The average results are showed in Table 5 grouped by scenario size.

Table 5: Results of the validation experiments grouped by scenario size.

Config.	energy metrics				PDR
	E_{sent}	E_{recv}	E_{OLSR}	$E_{tot \times v}$	
urban U1 scenario					
DE/EE-OLSR	**7156.60**	**3163.72**	**1.42%**	**703.21**	66.11%
DE-OLSR	8680.03	3608.83	4.53%	853.47	69.57%
RFC	9404.27	3586.67	7.17%	892.59	**71.71%**
urban U2 scenario					
DE/EE-OLSR	**12203.31**	**5319.49**	**3.22%**	**598.21**	62.04%
DE-OLSR	15350.54	6736.58%	8.26	760.33	66.30%
RFC	17569.69	7956.95	13.74%	865.08	**71.78%**
urban U3 scenario					
DE/EE-OLSR	**15270.64**	**7239.09**	**6.22%**	**516.38**	56.62%
DE-OLSR	18429.02	11150.40	15.69%	678.07	**67.70%**
RFC	21574.81	16247.10	25.10%	877.75	64.00%
average					
DE/EE-OLSR	**11543.52**	**5240.77**	**3.60%**	**605.93**	61.59%
DE-OLSR	14153.20	7165.27	9.39%	763.96	67.86%
RFC	16182.92	9263.57	15.51%	878.47	**69.16%**

For all studied scenarios, the experimental results presented in Table 5 indicate that the smallest percentage of power consumed by OLSR (E_{OLSR}) is carried out by our new DE/EE-OLSR configuration. This configuration requires less energy in transmitting and in receiving packets. On average, VANET nodes save by 35% on the standard configuration and by 21% on DE-OLSR when they use the energy-effcient version of OLSR proposed here.

As all optimized configurations (DE/EE-OLSR and DE-OLSR) improve the RFC in terms of energy-efficiency, we decided to analyze the percentage of energy saving by using said configurations comparing them to the standard one.

Table 6 presents the average energy savings grouped by scenario size, traffic density, and network workload. According to these results, the energy savings increase with the scenario size. Thus, our approach improves the scalability problem that OLSR presents [21]. In terms of traffic density and network workload, the energy improvements are

Table 6: Average energy savings over RFC (%).

Config.	scenario size			traffic density			workload	
	U1	*U2*	*U3*	*low*	*med.*	*high*	*low*	*high*
DE/EE-OLSR	20.6	31.4	40.5	36.9	31.5	34.2	36.1	33.9
DE-OLSR	5.4	13.5	21.8	17.4	12.2	18.8	21.2	15.2

kept in similar quantities. DE/EE-OLSR saves more than 30% of the power in all cases. In this case, DE/EE-OLSR performs better than the existing DE-OLSR, because DE-OLSR was optimized without taken into account power consumption. According to these results, we can observe that DE/EE-OLSR is much more energy-efficient than OLSR in all VANET scenarios.

With the aim of providing the energy comparisons with statistical confidence, we have applied the Friedman Rank statistical test [26] to the energy consumption results of the all simulated scenarios. We have used this non-parametric test since the resulting distributions violated the conditions of equality of variances several times. The confidence level was set to 95% (p-value=0.05). Confirming the previous observations, the results of the Friedman test ranked DE/EE-OLSR as the configuration with the lowest power consumption (p-value<<0.05) followed by DE-OLSR and the standard configuration, respectively.

In order to corroborate that the automatic obtained configurations do not cause a malfunction of the OLSR protocol, we also studied the PDR. For all scenario sizes, the three analyzed configurations delivered correctly more than 55% of the packets. As expected, the PDR metric decreases as the scenario size gets larger. The RFC and the DE-OLSR configurations offer the best PDR. However, the average PDR of DE/EE-OLSR is only reduced by less than 9% regarding the RFC, which is well bellow the threshold we set in the definition of the problem as an acceptable value (15%). According to this, we can confirm that automatic energy-efficient OLSR configuration offers green communications without leading to a malfunction of the protocol.

7. CONCLUSIONS AND FUTURE WORK

In this paper we have studied the optimization problem of finding green configurations for the OLSR protocol in VANETs. The design of energy-efficient communications is an important issue in this research area, and few previous authors have tackled the OLSR configuration problem from an energy-oriented point of view. The main contribution of this work is the proposal of an automatic methodology for computing energy-efficient configurations for the OLSR protocol in VANETs by coupling DE and ns-2 simulator, that can be directly applicable to other protocols. In turn, we have validated the optimized configuration found by comparing it against the standard one in RFC 3626 and DE-OLSR, studying their performance in terms of energy and PDR in 54 VANET scenarios. In the light of the experimental results we can conclude that:

- The methodology presented in this work obtained automatically a set of energy-efficient OLSR parameter settings requiring a mean time of 4.6 hours (for each independent run).
- On average, the best obtained power-aware configuration (DE/EE-OLSR) saved up to 30% of energy, with significant improvements up to 40% in large networks.
- This important reduction in energy consumption was obtained while keeping the degradation of PDR below 9%.

The optimization methodology used in this work (coupling DE and a simulation process analysis) offers the possibility of automatically and efficiently customizing any VANET protocol, not just OLSR. Moreover, this approach can be used to improve other existing energy-efficient strategies applied over OLSR that appear in the literature. This is an added value of this line of research.

As a matter of future work, we are applying other metaheuristic algorithms to solve this optimization problem. In turn, we will analyze new fitness functions considering new power-aware and QoS metrics. Finally, in the view that OLSR energy savings vary in inverse proportion with QoS, the use of multi-objective optimization techniques to solve this problem is a promising idea.

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