Simulation and Testbed Evaluation for Optimizing Energy Consumption in Ad Hoc Networks based on OLSR Protocol

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Abstract: This paper presents a proposal to optimize energy consumption in ad hoc networks based on the OLSR protocol. This approach focuses on the set up of routes with less congestion level and higher energy capacity. Therefore, in addition to the remaining energy of nodes, a new metric is introduced, the strategic value, which reports the importance of a specific node in the network based on the numbers of neighbors it has. In order to obtain valuable results, the evaluation was performed in a simulation environment (NS3) and on a real testbed. In that sense, an actual ad hoc network was implemented using embedded devices (Raspberry Pi). Results show a decrease in energy consumption, especially in zones with the highest device density, as well as an increase of the time of operation for nodes with higher amount of neighbors. Additionally, the performed evaluation shows a positive effect in the quality of traffic flows, avoiding route breakages and packet losses.

1 INTRODUCTION

Ad hoc networks represent an alternative in order to implement new schemes of communication, for example the concept of opportunistic communication (Giordano 2014). In particular, such approach stands out the possibility to take advantage of the high density of mobile devices in order to set up wireless links through a collaborative mechanism, as described in (Tehrani et al. 2014) and (Do et al. 2012).

Also, ad hoc networks present a real potential for the implementation of services focused on smart cityes, especially for the capture and fast dissemination of data in urban zones (Bellavista et al. 2013).

In spite of the advantages described, there are a set of challenges attached to an ad hoc scenario.

Mainly, energy limitation in mobile devices due to the use of batteries is a significant factor for the design and implementation in real enviroments.

In that sense, the transmission of multimedia traffic as well as the increase in the data rate achieved using recent standards, such as IEEE 802.11n/ac, result in a higher traffic load and, therefore, higher demand of energy consumption on devices.

Moreover, wireless medium is another factor that deserves to be analized in regard to energy consumption, due to the operation of a radio interface. A wireless card analyzes the power level of detected signals in order to change to receiving mode, or starts a transmission process if the medium is available and there are packets to transmit. Such mode of operation causes that a node located in an interference zone changes to a receiving state due to the detection of signals with a power level higher than the threshold, even if it is not the target of data.

This effect is named overhearing and contributes to the increase of energy consumption.

In this paper, we have focused on mechanisms at routing level in order to optimize the energy expenditure, specifically in Ad hoc networks based on the OLSR protocol. In particular, OLSR implements a mechanism to disseminate the routing information over special nodes named MPR (Multi Point Relay). These nodes are selected in a process which consitently analyzes the availability to carry out the MPR function (willingness), the number of nodes within its connectivity area (reachability), and the simmetry of the links with neighbour nodes (Clausen and P. Jacquet 2003). However, the original standard does not consider energy limitations.

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In this sense, this paper presents a new approach in order to optimize the enegy consumption by means of analyzing energy capacity as well as the distribution of the nodes in the network. Thus, energy expenditure in zones with higher device density is reduced while the lifetime of strategic nodes (i.e. nodes with higher connectivity, with higher number of neighbours) is increased. The presented proposal is called, therefore, Strategic OLSR (S-OLSR).

The evaluation was performed, on the one hand, in a simulation environment (NS3) (Ns3-project 2014) and, on the other hand, over a real testbed formed by a set of ten ad hoc nodes. The testbed was implemented using Raspberry Pi. The results prove that the proposed scheme contributes to reduce the energy expenditure and, additionally, causes a positive impact on the quality of transmitted traffic.

The paper is organized as follows. Section 2 presents related work. Section 3 describes the mechanism of optimization proposed. The evaluation and results in the simulation environment is presented in Section 4. Section 5 describes the testbed implementation as well as the experiments performed and results. Finally, Section 6 presents conclusions and future lines of work.

2 RELATED WORK

This section presents a classification of related work regarding energy optimizations implemented over the OLSR protocol.

2.1 EMPR-OLSR

A first set of solutions propose to include the residual energy level as metric in order to select MPR nodes. In this paper, this methodology is referred as Energy MPR - OLSR (EMPR-OLSR).

As an example, (Wardi et al. 2011) presents a proposal that uses this approach based on a minimun energy threshold as a condition to consider a node for being part of the set of MPR candidates.

A modification is proposed in (Fatima Lakrami and Najib Elkamoun 2012), in which the willingness parameter is defined as a function of the residual energy and, consequently, the normal process of selection described in the standard is used.

However, these mechanisms cause an increment in the number of nodes selected as MPR to reach the nodes at more than one hop. Therefore, it generates a flooding increase of Topology Control (TC) messages. An analysis of this effect is described in (Mahfoudh and Minet 2008).

2.2 ER-OLSR

The second related methodology takes into account the energy capacity of nodes for routing computation. Consequently, these mechanisms have been called Energy Routing – OLSR (ER-OLSR). In this sense, (Toh 2001) proposes a cost function in order to evaluate the energy expenditure related to a route between transmitter and receiver nodes, and then select the path with less cost. The main disadvantage of such strategy is that the evaluation is performed globally on a route and, therefore, intermediate nodes with critical energy levels may not be taken into account.

In order to avoid such effect, (Adoni and Joshi 2012) proposes to set the value corresponding to the node with less residual energy in a path as the route cost. Additionally, (Rango et al. 2008) and (De Rango and Fotino 2009) describe schemes conceptually similar to (Adoni and Joshi 2012), in this case introducing a metric called MDR (Minimum Drain Rate) that provides an estimation about the lifetime of a node.

Nevertheless, the main drawback of these proposals is the liability to increase the number of hops due to an evaluation focused on a single node.

In that sense, an analysis in each node along the route represents a better indicator about the real energy conditions in the network.

2.3 EA-OLSR

Finally, the third mechanism described in previous works proposes the application of the metric of residual energy for both MPR nodes selection and route computation, simultaneously. These proposals have been called Energy Aware – OLSR (EA-OLSR) in this paper.

Regarding this mechanism, (Kunz 2008) uses the residual energy in order to select MPR nodes and additionally, a weigth is assigned in each link accordign to the energy capacity in the node that forwards the traffic.

A variation of this approach is presented in (Machado et al. 2013), which introduces the usage of the ETX (Expected Transmission Count) metric for route computation. Such a metric allows to evaluate the reliability of a link and, consequently, an indirect management of the energy capacity can be performed.

3 STRATEGIC OLSR (S-OLSR)

In this paper, we introduce a new metric called Strategic Value (SV). This metric consists in an indicator about the number of neighbor nodes within an interference zone. Consequently, the strategic value is related to the relative location of a node and, therefore, provides information about the distribution of nodes in the network.

The SV is obtained from the information collected during the exchange of hello messages (OLSR protocol) and, therefore, it is updated according to the configured hello interval. Then, the SV is used in routing computation using information from every hop, in order to find intermediate nodes with less strategic value. Additionally, this process is complemented with an energy analysis. The proposed scheme selects the nodes with an energy capacity equal or greater than 90% compared with the residual energy available in a competitor node.

This is performed in order to set up routes with less overhearing effect and suitable energy capacity.

Moreover, the tolerance configured guarantees the priority for the routes selected. The presented approach based on OLSR protocol, that takes into account both energy capacity and strategic value of nodes, is called Strategic OLSR (S-OLSR).

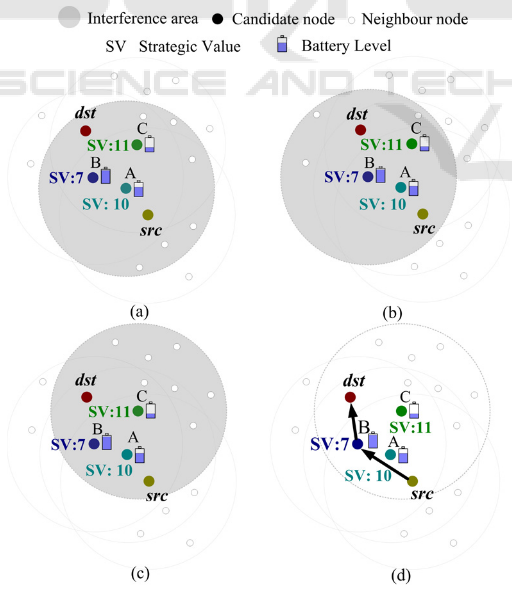

Figure 1: Descriptive diagram of S-OLSR operation and interference zones for nodes: (a) Node A, (b) Node B, (c) Node C, (d) Route analysis.

Figure 1 describes a diagram showing how the proposal works. The routing protocol is going to set up a route between nodes src and dst. Thus, the coverage areas depicted in Figures 1(a), (b) and (c) indicate that nodes A, B and C, respectively, are candidates to be forwarder nodes in order to find the shorter route to the target. The residual energy, as well as the SV metric for these candidate nodes are also depicted in the diagram. Additionally, there are a set of neighbor nodes inside the interference zone of each candidate node. Examples of SV and remaining energy values were defined in order to describe the operation of the proposal.

Then, according to the scenario, node B, which has the lower strategic value and more residual energy, becomes the best option to forward packets towards the destination node (dst), as can be seen in Figure 1(d). Especially, it can be observed that the overhearing effect is lower (7 nodes within the interference area) when using node B as forwarder node than when using node A or C (10 nodes and 11 nodes within the interference area, respectively).

In order to carry out the assessment, the proposal was implemented using the NS3 simulator, performing the required modifications to the standard protocol (OLSR RFC3626). Mainly, the strategic value and the residual energy information were included inside the header of hello messages.

Regarding the residual energy, this information is provided by the physical layer in a cross-layer operation. Finally, the metrics are evaluated for routing computation as described above. The pseudo-code for the routing modification is presented in Table I. Moreover, next section describes the methodology used for the evaluation of the proposal in the simulation environment.

Table 1: Algorithm S-OLSR: Operation on each node n for routing computation.

```
Required: TargetNode (tn), Neighbor-Set Nodes (N), StrategicValue (SV), Residual Energy (Er), HopNumber (h), Address (add), EnergyTolerance (α).
Initialize:(add_table, SV_table, Er_table = null; h = 2; α=0.9)
Begin RoutingTableComputation
 while (RoutingFinished = false )
  for (n = 0 ; n < N ; n++)
   if (add_n=NextHopToadd_tn&(add_table=null||(SV_n < SV_table & Er_n ≥ α*(Er_table)))) then
          add_table = add_n ;
          SV_table = SV_n;
          Er_table = Er_n;
   endif
  endfor
  if  add_table = add_tn   then
          RoutingFinished = true;
  else
          h++;
  endif
 endwhile
end
```

4 SIMULATION EVALUATION

4.1 Methodology

Figure 2 presents a diagram of the process for the evaluation in the simulation environment.

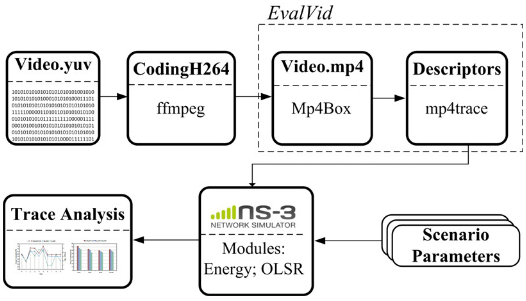

Figure 2: Evaluation methodology for the proposal in the simulation environment.

First, it is worth mentioning that a video sequence has been used as traffic flow, mainly due to the significant load of traffic that this kind of data involves but also because of the increasing demand of multimedia contents among mobile users nowadays. As can be seen in Figure 2, the process starts from a raw file (.yuv), and it is encoded (H264) and packaged afterwards (MP4). Finally, the trace file containing information about size and timestamp of video packets is obtained. This process is performed by means of FFmpeg (FFmpeg.org 2016) and Evalvid (Klaue et al. 2003). This descriptor file, as well as the parameters specified in the Table 2, are used to set up the simulation in the NS3 environment. Furthermore, Figure 3 presents the scenario of evaluation. As can be seen, the node 0 is the source of the traffic and node 1 is the receiver. This scenario was designed in order to compare the pattern of energy consumption for the mechanism ER-OLSR and the standard (RFC3626) versus the proposed scheme (S-OLSR).

Table 2: Simulation Parameters.

Parameter	Value
Mac Protocol	802.11g
Rate	54 Mbps
Rx Sensitivity	-76 dBm
Tx Power Level	0 dBm
Interference Range	30m
Intensity Consumption (mA) (Intel7260 802.11a/b/g/n)	Tx:606; Rx:485; Idle:75
Traffic Video	300s; 100 repetitions
Video Bitrate (Average)	300 kbps
Initial Node Energy	10000 J

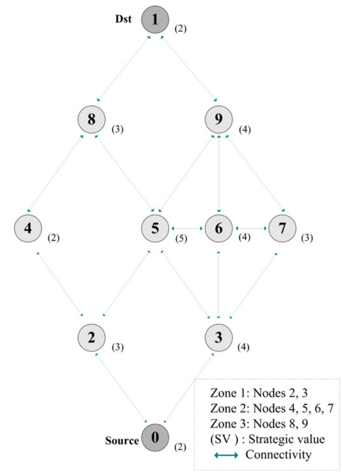

Figure 3: Scenario designed for the evaluation of S-OLSR.

4.2 Results

Results are shown in Figure 4. Energy expenditure works as a clear indicator of which nodes belong to the routes used for data transmission. As can be seen, the standard OLSR protocol causes higher energy consumption on node 5, which is the node with the highest strategic value in the scenario.

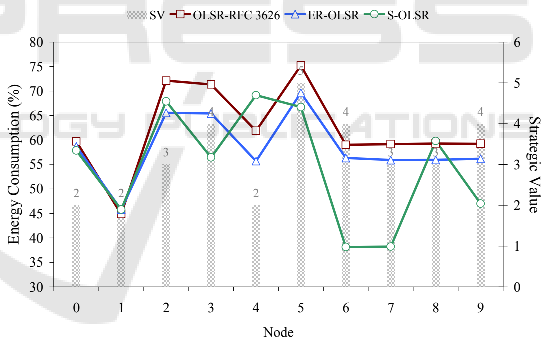

Figure 4: Comparison of energy consumption pattern and the strategic value of the nodes.

This high strategic value entails that a greater number of nodes are affected by the overhearing effect, specifically, nodes 2, 3, 6, 8 and 9, which are located inside the interference area of node 5. This behavior is due to the use of the number of hops as the single metric for the routing computation.

Consequently, the probability of selecting nodes with a greater number of links is higher. Regarding ER-OLSR, results show a reduction of the energy expenditure on each node. However, the pattern of consumption is similar to the original protocol. Such behavior is mainly due to the lack of analysis about the distribution of the nodes in the scenario. In regard to S-OLSR, the routing computation analyzes the residual energy and, additionally, the number of nodes inside the interference area by means of the SV metric. Consequently, this mechanism assigns priority to routes with less overhearing effect.

Therefore, results describe a significant modification in the pattern of energy consumption.

Specifically, Figure 4 shows an increase in the energy expenditure on the nodes 2 and 4 (with less strategic value), compared with the competitors, nodes 3 and 5. Regarding node 5, the difference achieved is not remarkable due to the critical location of this node in the scenario, i.e. it is inside the interference area of all potential routes toward the destination node. Nevertheless, the priority in the selection of nodes with less strategic value has lead to a significant decrease of the energy consumption in nodes 3, 6, 7 and 9. Furthermore, Figure 5 shows an analysis of the distribution of the energy consumption on the scenario. As can be seen, S-OLSR reduces the energy expenditure for all zones defined on the scenario (Figure 3). In particular, zone 2, which is characterized by the highest density of nodes, presents the most significant difference, 53% (S-OLSR) compared with 59% (ER-OLSR) and 64% (standard OLSR). The advantage achieved is observed even globally, (including src and dst nodes). In this case, results are 54% (S-OLSR), 58% (ER-OLSR) y 62% (standard OLSR).

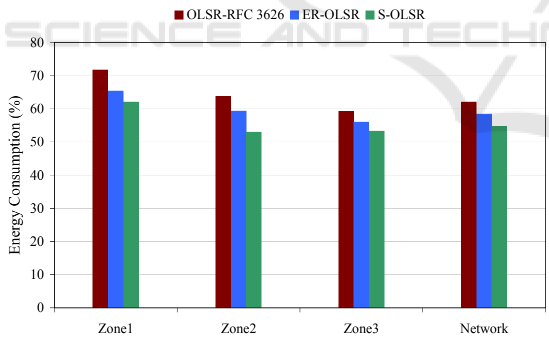

Figure 5: Comparison of average energy consumption for defined zones and for the whole network.

5 TESTBED EVALUATION

5.1 Ad Hoc Node Implementation

For the testbed evaluation, we implemented a set of 10 ad hoc nodes over embedded devices with Linux (Raspberry Pi B+) (Ada 2015). The functional diagram of a node is presented in Figure 6.

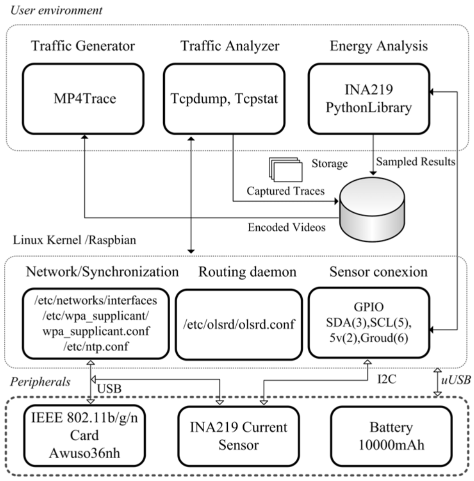

Figure 6: Functional diagram of an ad hoc node implemented over a Raspberry Pi B+.

Ad hoc network configuration is performed in the block Network/Synchronization. Additionally, we installed the OLSR protocol (olsrd daemon) as well as a NTP client to synchronize the nodes during startup. The selection of the wireless card was carried out taking into account the prior experimentation with several models. The main constraints were the compatibility of drivers with the development platform and the operation of the card in a real ad hoc communication mode. Taking into account the results of the tests, Awuso36nh card (linux driver rt2800 /chipset RT3070) (AlfaNetwork 2015) was selected. Finally, the nodes are powered using a power bank of 10000mAh. At user level several free distribution tools have been installed, such as the mp4trace tool for video transmission, available in the Evalvid package, tcpdump (Tcpdum.org 2016) and tcpstat for capture and analysis of traffic. The transmitter node stores the set of videos which will be used in the test.

Additionally, the current sensor INA219 (Adafruit 2015) has been incorporated in each node, in order to assess the level of average power consumption demanded by the wireless card. The sensor is handled by a set of Python libraries developed by Adafruit. The communication is carried out is via the I2C bus (Inter - Integrated Circuit) in the GPIO pins (General Purpose Input / Output). Figure 7 shows the physical ad hoc node implemented and the components. The main goal of the testbed is to help configure the scenario from the Figure 3 for the evaluation of S-OLSR.

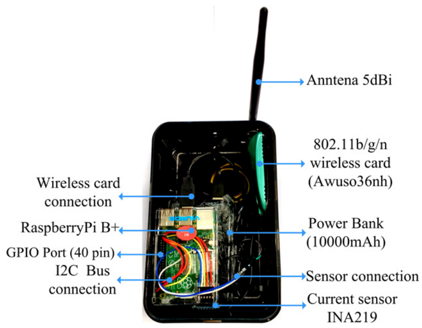

Figure 7: Description of Ad hoc node components.

5.2 S-OLSR Implementation

Beyond the simulations, S-OLSR was implemented on real ad hoc nodes. Figure 8 shows the functional diagram for the performed development.

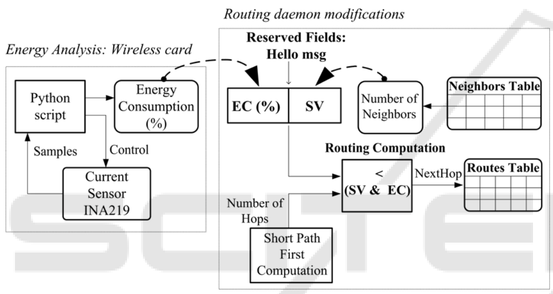

Figure 8: Functional diagram for S-OLSR implementation.

As can be seen, the first step is to measure the energy consumption (EC) demanded by the wireless card. For this purpose, the current sensor is controlled by a Python script, which captures current samples from the wireless card during a time interval and later processes the samples in order to compute the percentage of energy consumption.

Finally, this energy value is stored and updated at the same rate as the hello interval does (2s) within the OLSR protocol. In regard to modifications on the routing protocol, we used the routing daemon olsrd-0.9.0.2 (Olsr.org 2016) as starting point. In order to include new metrics (SV and EC), the reserved fields in the header of the hello message was used so that modifications to the original protocol have kept to a minimum. As aforementioned, the value of energy consumption is introduced from the information provided by the current sensor. The SV metric is deducted from the number of nodes at one hop observed in the neighbor table and also included inside the hello message. Therefore, this slight modification of the hello message allows the exchange of the new metrics without altering the original fields and thus, maintaining backward compatibility. Moreover, routing computation has been modified in order to take into account these new metrics. The routes, previously determined by the SPF process (Short Path First), give now higher priority to the nodes with less strategic value and less energy consumption to be selected as next hop and included in the routing tables. Also, it is worth clarifying that the energy metric used was the energy consumption, instead of the residual energy, due to the fact that obtaining the samples of current from the wireless card using the sensor was simpler than inferring the remaining battery.

5.3 Results

Figure 9 presents the set up for the experiment in the laboratory environment. The scenario depicted in Figure 3 was implemented. In order to replicate node connectivity, layer-2 filters in each node have been configured, providing connectivity only among nodes according the scheme in Figure 3. The main parameters used for the testbed are described in Table 3.

Figure 9: Testbed evaluation in the laboratory environment.

Table 3: Testbed parameters.

Parameter	Value
Mac Protocol	802.11g
Rate	54 Mbps
Rx Sensitivity	-76 dBm
Anntena Gain	5dBi
Tx Power Level	0 dBm
Hello and TC Interval	2s ; 5s
Intensity Consumption (mA)	Tx:409; Rx:204;offline:100mA
Video Traffic	60s -10 repetitions
Video Bitrate (Average)	300kbps
Node Energy (mA)	4.17mAh

An initial energy capacity has been defined (4.17mAh) for every node in the network, excluding N5, which is the node with the highest strategic value. Intentionally, the initial energy capacity of node 5 was set to 50% (2.08mAh) in order to evaluate the case when node 5 consumes all the remaining energy before the experiment ends.

Additionally, the Python script will disable the wireless card (switch to offline state) when the energy consumption increases to 90% of the capacity, which equates to 10% of residual energy, and emulates the power-saving state. The traffic used corresponds to 1min of the "Big Buck Bunny" video sequence. The evaluation consists in the comparison of S-OLSR with the standard protocol.

First, an analysis about the routes selected by each mechanism was performed. Figure 10 shows results about the throughput in each node. As can be seen, the OLSR protocol (standard) leads the traffic through routes defined by node 3, either nodes 5 or 6, and finally node 9. On the other hand, S-OLSR estimates the better route through nodes 2, 4 and 8.

This is the operation expected for the proposal, due to the less strategic value of such nodes.

Therefore, in this case the traffic flow avoids node 5 (N5) because it is the node with the highest energy restriction in the configured scenario.

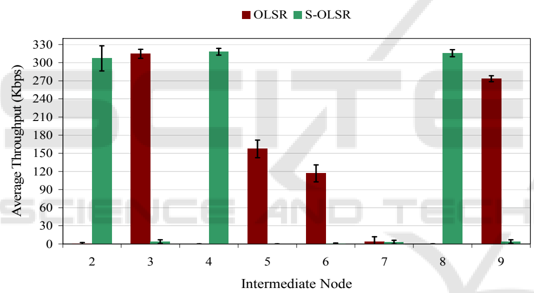

Figure 10: Throughput at each intermediate node.

Additionally, Figure 11 shows the throughput measured on the receiver node (N1).

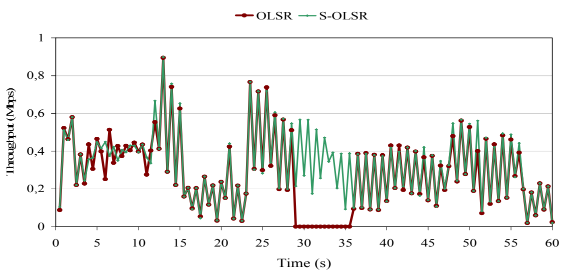

Figure 11: Throughput at the receiver node (N1).

As can be observed, the behavior of the standard protocol causes the interruption of the traffic (from 28s to 35s), due to the full depletion of energy in node 5, while the new route is recovered through node 6, as can be inferred from Figure 10. In regard to S-OLSR, the traffic flow is continuous during the whole experiment. As can be seen in Figure 12, S-OLSR presents higher reception rate (97%) compared with the standard OLSR (82%). In this sense, Figure 13 shows higher average PSNR (38dB) versus the original OLSR (34dB).

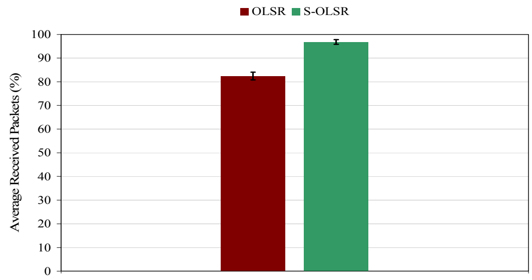

Figure 12: Comparison of average packet reception rate: Standard OLSR and S-OLSR.

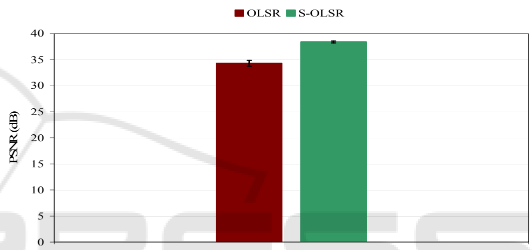

Figure 13: Comparison of average PSNR: Standard OLSR and S-OLSR.

Finally, another experiment was carried out in order to characterize the energy depletion profile on node 5. In this case, in addition to the video traffic from N0 toward N1, a background flow (400Kbps) from N3 to N9 was configured. This background traffic tries to emulate ongoing connections from other nodes in the network that, while not being routed through node 5, interfere severely on energy consumption due to the overhearing effect. The initial energy capacity for node 5 was set up to 80%.

Again, the critical threshold of residual energy is set up to 10% in order to disable the wireless card and emulate a power-saving state. Results are shown in Figure 14. As can be observed, the energy depletion is most remarkable with the standard protocol. In particular, the critical energy level takes place approximately at 43s. The change in the slope next to the critical value is due to lower consumption demanded by the wireless card when is disabled (100mA, Table 3). On the other hand, S-OLSR presents a slower decrease of the residual energy on node 5. Thus, the time of operation is extended to 55 seconds, corresponding to an increase of 20% in the interval defined for evaluation (60 seconds).

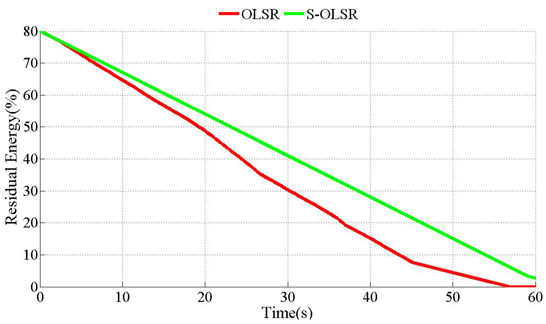

Figure 14: Comparison of energy depletion on the node with highest strategic value in the scenario (N5).

6 CONCLUSIONS

In this paper we performed a thorough analysis regarding energy optimization in ad hoc networks and propose a new routing approach based on the OLSR protocol. Specifically, our proposal (S-OLSR), in addition to the energy metric, includes the analysis of node distribution in order to set up routes characterized by a less level of congestion.

Also, this approach aims at decreasing the power consumption on nodes with higher amount of neighbors, since they are likely to be the most strategic nodes to maintain the whole network connectivity. The evaluation performed on the simulation environment shows clear changes in the pattern of energy expenditure using S-OLSR. The most significant difference is achieved on the zone with higher node density. Specifically, results show a reduction in the energy consumption of 6% and 11% in comparison with the ER-OLSR mechanism and the standard OLSR protocol, respectively.

Moreover, results from the real testbed show the expected behavior of the proposal. The routes are set up through nodes with less strategic value, which contribute to extend the lifetime of the node with the highest number of links (N5), even when the traffic load is increased in the network.

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