EE-OLSR: ENERGY EFFICIENT OLSR ROUTING PROTOCOL FOR MOBILE AD-HOC NETWORKS

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ABSTRACT

This paper presents two novel mechanisms for the OLSR routing protocol, aiming to improve its energy performance in Mobile ah-hoc Networks. Routing protocols over MANET are an important issue and many proposals have been addressed to efficiently manage topology information, to offer network scalability and to prolong network lifetime. However, few papers consider a proactive protocol (like OLSR) to better manage the energy consumption. OLSR presents the advantage of finding a route between two nodes in the network in a very short time, thanks to its proactive scheme, but it can expend a lot of resources selecting the MultiPoint Relays (MPRs) and exchanging Topology Control information. We propose a modification in the MPR selection mechanism of OLSR protocol, based on the Willingness concept, in order to prolong the network lifetime without losses of performance (in terms of throughput, end-to-end delay or overhead). Additionally, we prove that the exclusion of the energy consumption due to the overhearing can extend the lifetime of the nodes without compromising the OLSR functioning at all. A comparison of an Energy-Efficient OLSR (EE-OLSR) and the classical OLSR protocol is performed, testing some different well-known energy aware metrics such as MTPR, CMMBCR and MDR. We notice how EE-OLSR outperforms classical OLSR, and MDR confirms to be the most performing metric to save battery energy in a dense mobile network with high traffic loads.

INTRODUCTION

In the last few years, thanks to the proliferation of wireless devices, the use of mobile networks is growing very fast. In particular, a very large number of recent studies focused on Mobile Ad-hoc Networks (MANETs) [1]. The performance of a mobile ad hoc network depends on the routing scheme employed, and the traditional routing protocols do not work efficiently in a MANET. This kind of network, in fact, has a dynamic topology (every node can move randomly and the radio propagation conditions change rapidly over the time) and a limited bandwidth (so that the control traffic overhead must be reduced to the minimum) [2]. Developing routing protocols for MANETs has been an extensive research area in recent years, and many proactive and reactive protocols have been proposed from a variety of perspectives ([3]-[7]). These protocols try to satisfy various properties, like: distributed implementation, efficient utilization of bandwidth and battery capacity, optimization of metrics (like throughput and end-to-end delay), fast route convergence and freedom from loops. In this work, we will try to analyze the performance of a MANET from the energy point of view. Since mobile hosts today are powered by battery, efficient utilization of battery energy is very important. Battery life, therefore, can also affect the overall network communication performance: when a node exhausts its available energy, it ceases to function and the lack of mobile hosts can result in network partitioning. For that reason, reducing power consumption is an important issue in ad hoc wireless networks. However, the majority of the routing proposals to date have not focused on the power constraints of unethered nodes: traditional routing protocols tend to use shortest path algorithms (minimum hop count) without any consideration of energy consumption, often resulting in rapid energy exhaustion for the small subset of nodes in the network that experience heavy traffic loads. In recent years a number of power-aware metrics have been proposed (like [11]-[14]). The majority of these metrics has been applied to DSR routing protocol, so we decided to perform an energetic evaluation of another protocol, i.e. the proactive protocol OLSR, arrived to the RFC status. In particular the energy behavior of OLSR protocol has been evaluated and a novel energy aware MultiPoint Relay selection mechanism has been proposed. We want to investigate the effects of applying energy-aware routing to the OLSR protocol in a MANET, to evaluate the influence of overhearing and idle activity on the energy consumption in a network using the IEEE 802.11 technology and to check if these considerations could affect the performance of a protocol that ensures a good QoS in terms of end-to-end delay.

This paper is organized as follows: section II presents a short summary on some related works about energy-aware metrics for routing protocols; OLSR is briefly introduced in section III; our mechanisms to improve energy consumption in OLSR (with energy-aware selection and overhearing exclusion) is explained in section IV; finally, performance evaluation of different energy metrics and conclusions are summarized in the last two sections.

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RELATED WORKS

The routing protocols for mobile networks can be classified into four broad categories: proactive, reactive, hybrid, and cluster-based. These protocols try to satisfy various properties to reach the best compromise in term of scalability, mobility support, and energy consumption. The need of energy efficiency is a problem concerning with the constraints imposed by battery capacity and heat dissipation which are opposed by the desire of miniaturization and portability. In a wireless network, we have different opportunities to increase energy efficiency. One of them is the possibility of dynamically offloading computation from the local terminal to remote, energy-rich nodes (e.g., fixed servers). Another chance comes from making various network protocols, such as link, MAC routing and transport protocols, energy-aware. In recent years a number of power-aware metrics have been proposed at the network layer (like [2]-[3], [6]-[7],[11]-[14],[16],[17]). Here we present a brief description of the most relevant power-aware routing metrics proposed recently.

A. MTPR (Minimum Total Transmission Power Routing) and MBCR (Minimum Battery Cost Routing)

The MTPR [2] mechanism uses a simple energy metric, represented by the total energy consumed to forward the information along the route. This way, MTPR reduces the overall transmission power consumed per packet, but it does not affect directly the lifetime of each node (because it does not take account of the available energy of network nodes). Notice that, in a fixed transmission power context, this metric corresponds to a Shortest Path routing.

Let $c_i(t)$ be the battery capacity of node n_i at time *t*. We define $f_i(t)$ as a battery cost function of node n_i. The less capacity a node has, the more reluctant it is to forward packets; the proposed value is $f_i(t) = 1/c_i(t)$. The metric that minimizes this function to forward a packet is called MBCR.

B. MMBCR (Min-Max Battery Cost Routing) and CMMBCR (Conditional MMBCR)

If only the summation of battery costs on a route is considered, a route containing nodes with little remaining battery capacity may still be selected. MMBCR ([2]), defines the route cost as: $R(r_j) = \max_{\forall n_i \in r_j} f_i(t)$. The desired route r_O is obtained so that $R(r_O) = \min_{\forall r_j \in r_*} R(r_j)$, where r_* is the set of all possible routes. Because MMBCR considers the weakest and crucial node over the path, a route with the best condition among paths impacted by each crucial node over each path is selected.

CMMBCR metric ([2]) attempts to perform a hybrid approach between MTPR and MMBCR, using the former as long as all nodes in a route have sufficient remaining energy (over a threshold) and the latter when all routes to destination have at least a node with less energy than the threshold.

C. MDR (Minimum Drain Rate)

Power saving mechanisms based only on the remaining power cannot be used to establish the best route between source and destination nodes. If a node is willing to accept all route requests only because it currently has enough residual battery capacity, too much traffic load will be injected through that node. In this sense, the actual drain rate of power consumption of the node will tend to be high, resulting in an unfair sharp reduction of battery power. To address the above problem, the Minimum Drain Rate (MDR) [11] mechanism can be utilized with a cost function that takes into account the drain rate index (DR) and the residual battery power (RBP) to measure the energy dissipation rate in a given node. In this mechanism, the ratio RBP_i/DR_i, at node n_i, indicates when the remaining battery of node n_i will be exhausted, i.e., how long node n_i can keep up with routing operations with current traffic conditions. The corresponding cost function can be defined as: $C_i = RBP_i/DR_i$. Therefore, the maximum lifetime of a given path r_p is determined by the minimum value of C_i over the path. Finally, the MDR mechanism is based on selecting the route r_M, contained in the set of all possible routes r_* between the source and the destination , having the highest maximum lifetime value.

OPTIMIZED LINK-STATE ROUTING (OLSR)

The Optimized Link State Routing (OLSR) protocol is an optimization of the classical link state algorithm, adapted to the requirements of a MANET ([10]). Because of their quick convergence, link state algorithms are somewhat less prone to routing loops than distance vector algorithms, but they require more CPU power and memory. They can be more expensive to implement and support and are generally more scalable. OLSR operates in a hierarchical way (minimizing the organization and supporting high traffic rates). The key concept used in OLSR is that of multipoint relays (MPRs). MPRs are selected nodes which forward broadcast messages during the flooding process. This technique substantially reduces the message overhead as compared to a classical flooding mechanism (where every node retransmits each message received). This way a mobile host can reduce battery consumption. In OLSR, link state information is generated only by nodes elected as MPRs. An MPR node may choose to report only links between itself and its MPR selectors. Hence, contrarily to the classical link state algorithm, partial link state information is distributed in the network. This information is then used for route calculation. OLSR provides optimal routes (in terms of number of hops). The protocol is particularly suitable for large and dense networks as the technique of MPRs works well in this context.

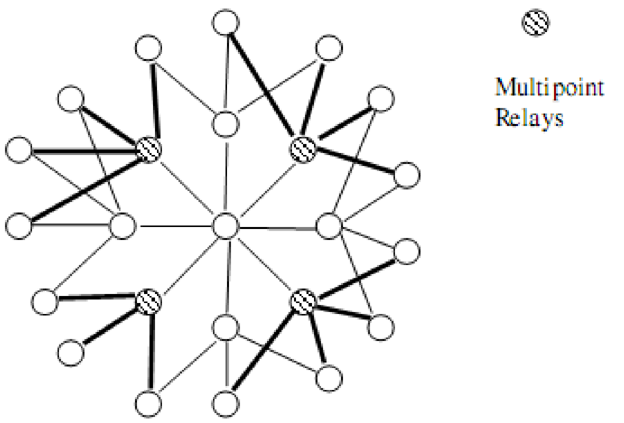

Figure 1. MPR election in OLSR protocol.

ENERGY EFFICIENT OLSR (EE-OLSR)

With EE-OLSR (Energy-Efficient OLSR) we denote a routing protocol obtained modifying OLSR in order to improve its energy behavior, without loss of performance. In addition to the energy-aware metrics presented in the last section, we studied two ad-hoc mechanisms that will be shown in this section: the EA-Willingness Setting and the Overhearing Exclusion.

A. EA-Willingness Setting mechanism

The Energy Aware Willingness Setting is a mechanism to involve energetic considerations in MPR selection. The OLSR specification has a variable, the "willingness" of a node, representing the availability of that node to act as a MPR for its neighbors. By default, each node declares a default willingness value.

In EE-OLSR, each node, calculating its own energetic status, can declare an appropriate willingness. We decided to base the willingness selection on both metrics: the battery capacity and the predicted lifetime (based on the energy-drain rate) of a node. The heuristic used to associate a willingness ("*default*", "*low*" or "*high*") to a pair *(battery, lifetime)* is shown in Fig. 2 and in Tab. 1. For example, in condition of high battery value, if the predicted lifetime is short a node declares a W_DEFAULT willingness. On the other hand, if a longer node lifetime is predicted (because the node is experimenting low traffic), the node can declare a W_HIGH willingness. In the same way, if the battery charge is low a node is less available to become MPR and declares a W_LOW willingness value (whatever lifetime it predicts). This permits a better load balancing to be obtained and node with lower residual energy are not stressed. All willingness states are listed in table below.

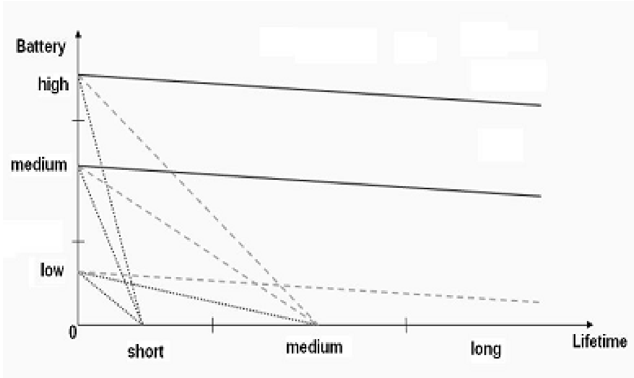

Figure 2. Simulation trace scansion and states sequences individuation.

Fig. 2. The EA-Willingness Setting heuristic

Table 1. Energy-based Willingness Selection.

Battery → Lifetime	Low	Medium	High
Short	W_LOW	W_LOW	W_LOW
Medium	W_LOW	W_DEFAULT	W_DEFAULT
Long	W_DEFAULT	W_HIGH	W_HIGH

The implementation of EA-Willingness Setting heuristic was obtained implementing the following pseudo-code in the OLSR protocol:

ENERGY AWARE WILLINGNESS

```
double battery = ENERGY/INIT_ENERGY;
double lifetime = 65535;
if (drain_rate() != 0.0)
   lifetime = ENERGY/drain_rate();
willingness() = OLSR_WILL_DEFAULT;
if (lifetime < 10.0)
   willingness() = OLSR_WILL_LOW;
else {
   if (battery < 0.1 && lifetime < 100.0)
      willingness() = OLSR_WILL_LOW;
   else if (battery > 0.1 && lifetime > 100.0)
      willingness() = OLSR_WILL_HIGH;
}
```

In our implementation, we decided to use the ratio between actual and initial energy of a node to measure its battery capacity (with values between 0.0 and 1.0) and to measure the predicted lifetime of a node in seconds (considering 65535 as infinity, for representation reasons). We chose to consider less than 10% of residual capacity as low battery values, and we stated that less of 10 seconds predicted are a short lifetime, while more than 100 second are a long lifetime.

B. Overhearing Exclusion

Another mechanism that allows energy saving in OLSR protocol (without changing its behavior) is the Overhearing Exclusion. Turning off the device when a unicast message exchange happens in our neighborhood, can save a large amount of energy. This can be achieved using the signalling mechanisms of the lower layers (i.e. the RTS/CTS exchange performed by IEEE 802.11 to avoid collisions), and do not affect the protocol performance. In facts, OLSR does not takes any advantage from unicast network information directed to other nodes (while other protocols such as DSR have a mechanism to do so). We will be able to show, via simulation, the amount of energy saved with this mechanism.

C. Energy-aware Packet Forwarding

After the MPR election it is important to select the next hop for data packet forwarding (among the MPR neighbors set). For this purpose we decided to consider some energy aware metrics such as explained in section II. These different metrics present some advantages and drawbacks, as explained in [2] . This approach permitted us to decouple the MPR election process from route selection mechanism. MPTR, MMBCR and MDR have been considered, as shown in the following section.

PERFORMANCE EVALUATION

In this section we illustrate the energy consumption model adopted, the simulation parameters applied and simulation results.

A. Energy Consumption Model

We assume all mobile nodes to be equipped with IEEE 802.11g network interface card, with data rates of 54 Mbps. The energy needed to transmit a packet p from node n_i is: $E_{tx}(p, n_i) = i \cdot v \cdot t_p$ Joules, where i is the current (in Ampere), v the voltage (in Volt), and t_p the time taken to transmit the packet p (in seconds). In our simulations, the voltage v is chosen as 5 V and we assume that the packet transmission time t_p is calculated by $(p_h/(6 \cdot 10^6) + p_d/(54 \cdot 10^6))$ seconds, where p_h is the packet header size in bits and p_d the payload size. As shown in [8], we assume the energy consumption caused by overhearing a packet is the same as the energy consumed by actually receiving the packet. The energy $E(p, n_a)$ consumed to transmit a packet from node n_a to node n_b is given by:

$$E(p, n_a) = E_{tx}(p, n_a) + E_{rx}(p, n_b) + (N-1) \cdot E_O(p, n_i) \quad (1)$$

where E_{tx}, E_{rx}, and E_O denote the amount of energy spent to transmit the packet from node n_a, to receive the packet at node n_b and to overhear the packet, respectively. N represents the average number of neighboring nodes affected by a transmission from node n_a. Equation 1 implies that when the network is denser, packet overhearing causes more energy consumption.

B. Simulation Parameters

To evaluate EE-OLSR protocol, we used the ns-2 network simulator. We simulated a dense wireless network, with 50 nodes moving in a 870 × 870 m area (with a density of about 66 nodes/km^2). Each node moves randomly in this area, with a speed of 3 m/s and no pause time. Between mobile hosts there are 12 CBR/UDP sources generating 20 packets/s (with a packet size of 512 bytes). The duration of each simulation is 400 seconds (with a setup time at the beginning, without traffic). To extract average values, we simulated each scenario 5 times. NS-2 simulator allows to extract from a simulation many interesting parameters, like throughput, data packet delivery ratio, end-to-end delay and overhead. To have detailed energy-related information over a simulation, we modified the ns-2 code to obtain the amount of energy consumed over time by type (energy spent in transmitting, receiving, overhearing or in idle state). This way, we obtained accurate information about energy at every simulation time. We used these data to evaluate the protocols from the energetic point of view: we will see the impact of each protocol on different new parameters, like the number of nodes alive over time (to check the lifetime of nodes), the expiration time of connections (to see the network lifetime), and the energy usage divided by type (receiving, transmitting, overhearing). All used simulation parameters are listed in Tab. 2 below:

Table 2. Simulation parameters.

Modulation	QPSK
Area	870m x 870m
Nodes	50
Nodes speed	3 m/s
Simulation Time	400 s
Traffic Sources	12
Traffic Type	CBR
Packet Size	512 bytes
Start of Traffic	30 s
End of Traffic	380
Transmission Power	1.4 W
Reception Power	1.0 W
Idle Power	0.0 W

C. Simulation Results

Many simulations have been assessed in order to test the energy consumption by type, the energy-aware willingness mechanism and the impact of different energy-aware metrics on the protocol performance. Let EE-OLSR with energy-aware metrics for packet forwarding be EE-OLSR-MPTR, EE-OLSR-MMBCR and EE-OLSR-MDR for, respectively, the MPTR, MMBCR and MDR metrics. The standard version of OLSR with minimum hop count metric is indicated simply with OLSR term.

1) Influence of Idle Power consumption

Fig. 3 shows the amount, in a log-scaled percentage, of energy consumption in a simulation, by type. This figure illustrates that the larger part of energy is spent in idle state (when the node is not using its network device): this state absorbs about 90% of the energy consumption of mobile devices. To clean results from this value (dominant as well as almost protocol independent), we will ignore the idle power consumption in following simulations.

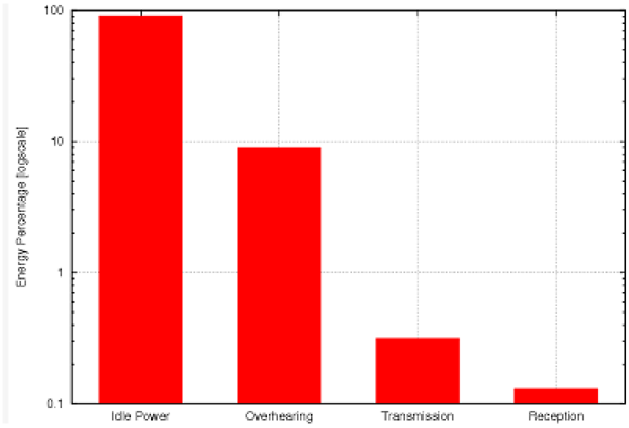

Figure 3. Energy consumption by type, in percentage (log scale).

2) EA-Willingness Setting

To show how the EA-Willingness Setting mechanism improves the performance of a MANET using OLSR, we plotted the expiration time of connections and the network aggregate throughput, in figures 4 and 5.

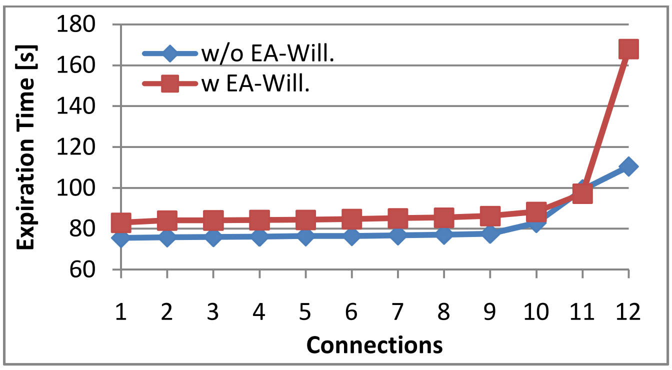

Figure 4. Expiration Time of Connections, with and without EA-Willingness Setting.

We can see how the use of an energy-aware willingness selection can extend the lifetime of network nodes (and, thus, of connections) of several seconds. Most connections last about 10 seconds more, and the last connection to expire dies about 60 second later.

The prolonged lifetime of nodes and connections positively affects the throughput: while the classical OLSR begins to lose data because of the lack of nodes, the use of EA-Willingness Setting can improve the network performance.

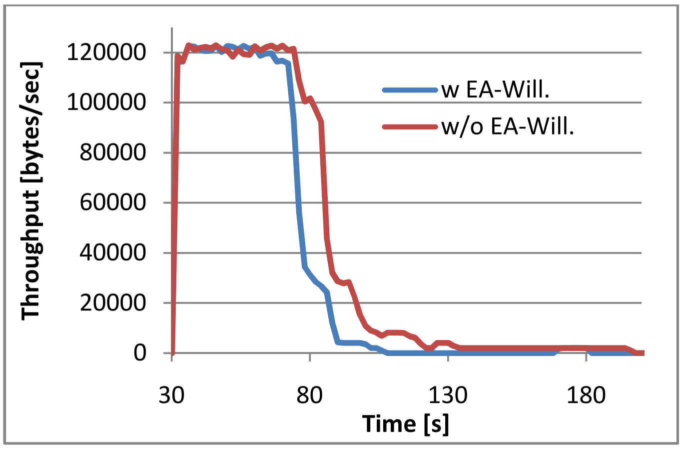

Figure 5. Network Throughput, with and without EA-Willingness Setting.

3) Overhearing Exclusion

In Fig. 3 we could note how overhearing consumes nodes' energy more than useful types of consumption (transmission and reception power). Fig. 6 shows clearly how much the use of a mechanism of Overhearing Exclusion can improve the energetical performance of a mobile network.

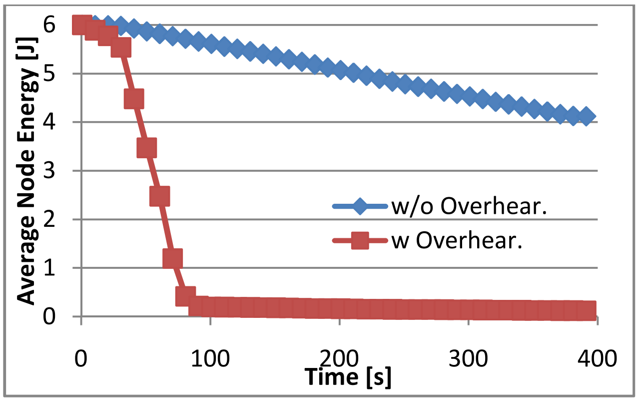

Figure 6. Average Node Energy by Time, with and without Overhearing Exclusion.

In facts, without overhearing energy consumption, the energy in the network is consumed very slowly, allowing the nodes to send and receive packets for a longer time.

4) EE-OLSR under different metrics versus OLSR

The following simulations will compare classical OLSR protocol with EE-OLSR (using both EA-Willingness and Overhearing Exclusion mechanisms), with some of the different energy-aware metrics proposed in literature.

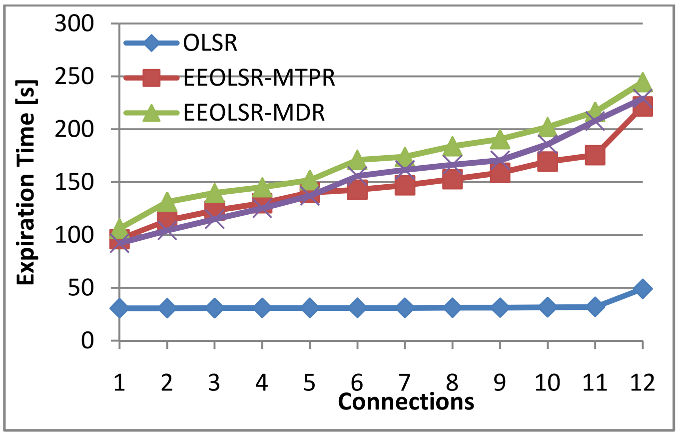

Figure 7. Expiration Time of Connections, with classic OLSR and different energy-aware metrics applied to EEOLSR.

The Fig. 7 shows the expiration time of connections. With every metric applied, EE-OLSR outperforms classical OLSR, especially using the MDR metric.
As shown in Fig. 8, EE-OLSR also guarantees a longer lifetime for every node in the network. While with classical OLSR all nodes tend to exhaust their energy almost at the same time, EE-OLSR extends their lifetime up to the end of the simulations: in particular, using MDR metrics, about 20 nodes can survive over 400 seconds.

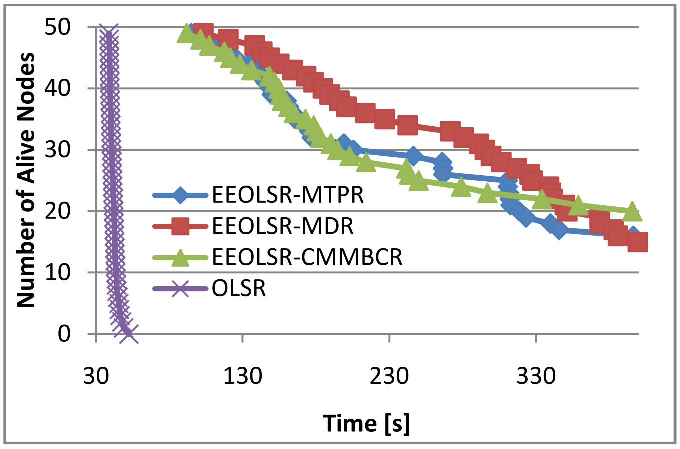

Figure 8. Expiration Time of Nodes, with classic OLSR and different energy-aware metrics applied to EEOLSR.

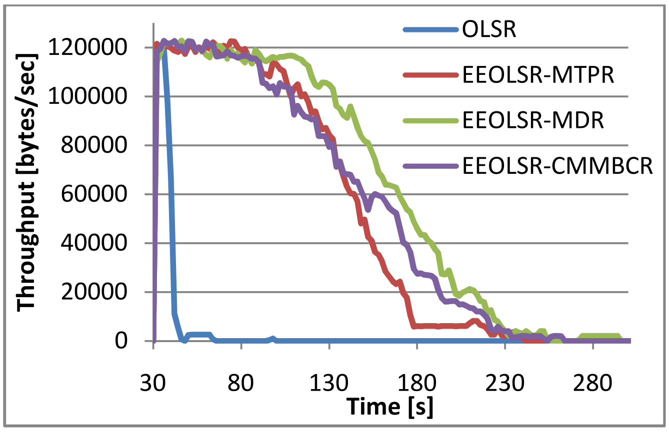

Figure 9. Network Throughput, with classic OLSR and different energy-aware metrics applied to EEOLSR.

In Fig. 9 we plotted the network throughput over the time: while OLSR throughput falls down after about 50 seconds; EE-OLSR delivers packets until the end of simulations (whatever metric. is used) We can note the particularly good performance of MDR metric.
Finally, Tab. 3 shows an overview of the performance of different simulated protocols: EE-OLSR outperforms classical OLSR (especially in association with MDR metric), delivering more packets to destination, and extending the lifetime of nodes and connections. Moreover, the use of mechanisms and metrics of EE-OLSR does not lead to any loss of performance in terms of end-to-end delay, protocol overhead or path length. It is possible to observe the increase in the delivered packets and this is due to the longer nodes lifetime that permits to support more traffic. Moreover, according with Fig.9, the throughput increases producing a lower end-to-end data packet delay.

Table 3. Performance comparison of classic OLSR and different energy-aware metrics applied to EE-OLSR.

	OLSR	EEOLSR MTPR	EEOLSR CMMBCR	EEOLSR MDR
Packets Delivered	11811	26458	28453	32672
E2E Delay (msec)	4.1940	4.0971	4.1800	3.8974
Normalized Overhead	0.1526	0.1655	0.1558	0.1551
Average Hop Count	2.27	2.21	2.28	2.25
Node Average Lifetime (s)	149.79	274.46	276.23	302.56
Mean Connection Expiration Lifetime (s)	81.69	147.41	154.03	171.24

CONCLUSIONS

A novel energy aware MPR election policy has been proposed. This novel features allows energy node to be preserved for longer time. A traffic load balancing between MPR nodes has been achieved and performance improvement of OLSR in comparison with OLSR based on minimum-hop count has been obtained. More energy-aware metrics have been evaluated and the MDR resulted the best choice in the MPR election and route selection between source and destination. EE-OLSR outperforms OLSR in terms of throughput, average nodes lifetime, connection expiration time, nodes lifetime, preserving the normalized control overhead. In future works EE-OLSR will be compared with MDR based DSR in order to evaluate the energy behaviour of two different topology management strategies.

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