ENERGY EFFICIENT OLSR PERFORMANCE EVALUATION UNDER ENERGY AWARE METRICS

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ABSTRACT

Mobile ad-hoc networks are one of the most active research areas in the wireless communications field. These networks do not need any fixed infrastructure or configuration, easily adapting to difficult scenarios and types of use. Since mobile nodes are often powered by limited batteries, energy is an important issue in MANETs since the lack of a node can lead to the partitioning of the network.

Recently, many different strategies have been proposed in order to optimize the energy consumption and prolong the mobile network lifetime, especially at the routing layer. These policies use energy-aware metrics, instead of minimum-hop routing, to achieve this goal. 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.

In this paper, we analize the behavior of different energy-aware routing metrics applied to OLSR protocol, in order to verify their effectiveness in reducing energy consumption and prolonging network lifetime in combination with such a proactive routing protocol. We find that MDR routing strategy is the better way to calculate paths between nodes in a network according to energy-saving needs, although this metric can have some drawback in the total amount of energy consumed in the network. We already tested as an hybrid approach (like CMDR) can mitigate this drawback.

Index Terms - energy, OLSR, MANET, routing

1. 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 focuses on Mobile Ad-hoc Networks, also known as MANETs [1]. A MANET is a network without a fixed infrastructure, in which every node can act as a router; this is required when the two end-points interchanging data are not directly within their radio range. This kind of network, self-organizing and self-reconfiguring, is very useful when it is not economically practical or physically possible to provide a wired networking infrastructure (battlefield scenarios, natural disasters, etc.).

Performance of a mobile ad hoc network depends heavily on the selected routing scheme, and the traditional Internet 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) [7]. 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, trying to satisfy various properties, like: distributed implementation, efficient bandwidth utilization, throughput optimization, fast route convergence and freedom from loops.

Since mobile hosts today are powered by battery, efficient utilization of battery energy is a key factor. When a node exhausts its available energy, it ceases to function and the lack of mobile hosts can result in partitioning of the network, thereby affecting the overall communication performance.

In this work we measure and compare the energy consumption behaviour of the Optimized Link State Routing (OLSR) protocol [4], which uses a proactive approach. OLSR is an interesting issue, as it is one of the routing proposals for MANETs arrived to the RFC status. We want to check whether or not, using OLSR protocol under the IEEE 802.11 technology, some of the power aware routing proposals in the literature could be efficiently utilized to extend the lifetime of nodes and connections. In fact, we believe that, because of the overhearing and idle activity of a network interface card based on the current IEEE 802.11 technology, a majority of the proposed schemes not only are quite tricky to be implemented, but also could not achieve their assumed benefits. The simulation results presented in this paper were obtained using the ns-2 simulator [2], which is a discrete event, object oriented, simulator developed by the VINT project research group at the University of California at Berkeley.

The rest of this paper is organized as follows: in section 2 the mechanisms behind OLSR routing protocol are explained, in section 3 the main energy-aware routing metrics are presented, section 4 depicts some improvements in energy-aware metrics and mechanisms that can be adopted in OLSR protocol, in section 5 the results of simulations of different scenarios are shown. Finally, some conclusions are drawn.

2. OLSR (OPTIMIZED LINK STATE ROUTING) PROTOCOL

The Optimized Link State Routing (OLSR) protocol is an optimization of the classical link state algorithm, adapted to the requirements of a MANET ([4]). 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, Fig.1). 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.

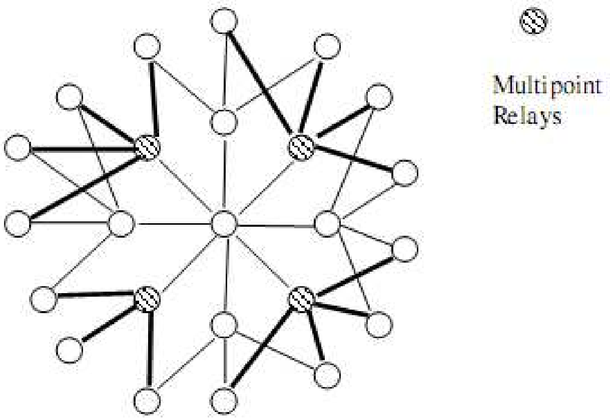

Figure 1. MPR election in OLSR protocol.

3. RELATED WORKS: ENERGY-AWARE ROUTING METRICS

In recent years a number of power-aware mechanisms have been proposed at the network layer (like [5, 6, 8, 11-13]), particularly for DSR (Dynamic Source Routing [9]) protocol. Here a brief description of the most relevant energy-aware routing metrics proposed is given.

The MTPR (Minimum Total Transmission Power Routing, [7]) 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 (Minimum Battery Cost Routing, [7]).

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 (Min-Max Battery Cost Routing, [7]), 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 (Conditional MMBCR, [7]) 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.

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) [10] 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.

4. ENERGY-AWARE IMPROVEMENTS FOR OLSR PROTOCOL

MDR suffers from the same problem as MMBCR, ignoring the total transmission power consumed by a single path: this way, it could even lead to a higher overall energy consumption in the network. To prevent this issue, MDR can be introduced in a hybrid way, as a Conditional MDR (CMDR): as far as all nodes in a route have sufficient remaining lifetime (over a threshold), a simple MTPR approach is used. In this work, the advantages and the drawbacks of using conditional approach in MDR metric will be shown.

Another energy-aware improvement can be led to OLSR protocol by the introduction of a more accurate way of calculating the willingness of nodes. In OLSR, this parameter is defined as the willingness of a node to be selected as a MPR by its neighbors. In the default implementation of OLSR protocol, every node declares to its neighbors the same willingness (a value named WILL_DEFAULT): this way each node has the same probability to be selected as a MPR by its neighbors, and the selection is performed only according to the position of nodes. An energy-aware selection of willingness can introduce an improvement in MPR selection, allowing the nodes to declare a willingness value of WILL_HIGH (meaning an high willingness to act as a MPR for its neighbors) or WILL_LOW (to signal a low willingness to forward neighbor's data). This way, a node can change its probability to be selected by its neighbors as a MPR according to its own energy status. In this work, an heuristic for the Energy-Aware Willingness Selection (EA-Willingness) is adopted, according to the following pseudo-code:

EA-Willingness heuristic

```
double battery=ACTUAL_ENERGY/INITIAL_ENERGY;
double lifetime=65535;
if(drain_rate()!=0.0)
       lifetime=ACTUAL_ENERGY/drain_rate();
willingness()=WILL_DEFAULT;
if(lifetime<10.0)
       willingness()=WILL_LOW;
else{
       if(battery<0.1 && lifetime<100.0)
              willingness()=WILL_LOW;
       else if(battery>0.1 && lifetime>100.0)
              willingness()=WILL_HIGH;
}
```

5. SIMULATIONS

In this section the energy consumption model adopted, the simulation parameters applied and simulation results are illustrated.

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 [3], 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 neighbouring 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

We evaluated OLSR protocol energy behavior in two different scenarios, using the ns-2 network simulator.

The first scenario is a fixed network composed of 21, equi-spaced nodes (Fig.2). In this network, there is only a CBR/UDP connection, between nodes 7 and 13. This way we could simulate a case in which a routing protocol has to choose between a shortest path (containing nodes that will experience the heaviest traffic load) and some alternative paths (longer, but with better energy profile). Energy-aware routing could split the consumption between nodes, preserving the central ones from an early shut-down.

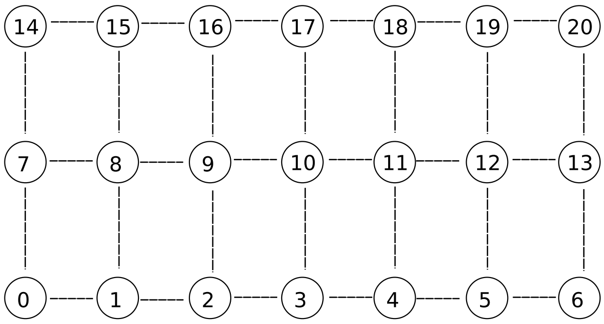

Figure 2. Fixed network.

Then, we simulated a dense wireless network, with 50 static nodes randomly positioned in a 870x870 m area (with a density of about 66 nodes/km^2). Between mobile hosts there are 12 CBR/UDP sources generating 20 packets/second (with a packet size of 512 bytes). The duration of each simulation is 380 seconds (with a setup time at the beginning, without traffic).

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, detailed information about energy consumption during simulation could be obtained. These data were used to evaluate the protocol from the energetic point of view: different parameters were adopted to compare the energy performance of various solutions (in terms of metrics and mechanisms). These parameters are explained in the following:

Number of Alive Nodes vs Time: this parameter shows the lifetime of nodes, plotting the expiration time of each one;

Connections Duration: this parameter illustrates the lifetimes of the connections in the network;

Average Nodes Residual Energy vs Time: this parameter shows the behavior of average energy consumption over time in the network (total residual energy [J]/number of nodes);

Average Number of MPRs per Node vs Time: this parameter represents the average number of MPRs per node in the network, over the time;

Spatial Distribution of Nodes Residual Energy: this plot illustrates graphically how the residual energy is distributed among the nodes in the network at the end of the simulation.

All used simulation parameters are listed in Tab.1 below:

Table 1. Simulations parameters.

Modulation	QPSK
Area	870m x 870m
Nodes	50
Nodes speed	0 m/s
Simulation Time	380 s
Traffic Sources	12
Traffic Type	CBR/UDP
Packet Size	512 bytes
Start of Traffic	30 s
End of Traffic	350 s
Transmission Power	1.4 W
Reception Power	1.0 W
Idle Power	0.0 W

C. Simulation Results

In the following subsections, the results of our simulations are presented.

Idle power and overhearing influence

In this work, the energy spent by the nodes in the idle state (when a node is neither transmitting nor receiving data) and in overhearing (when a node is in the radio range of another one transmitting unicast data to a third node, see [3]) are neglected. The rationale for this was that these types of energy consumption are substantially independent from the routing protocol used. Moreover, as was demonstrated in [14-15], these two types of consumption are very relevant. In order to consider the energy impact of the metrics analysed, we decided to ignore idle and overhearing energy consumption in the subsequent simulations.

Fixed scenario

The simulations of the fixed scenario showed the effectiveness of energy-aware metrics in selecting paths across the nodes in the network that are not experimenting heavy traffic load. This behaviour produces better results in terms of nodes lifetime, especially if used in association with the EA-Willingness mechanism, as shown in Fig. 3.

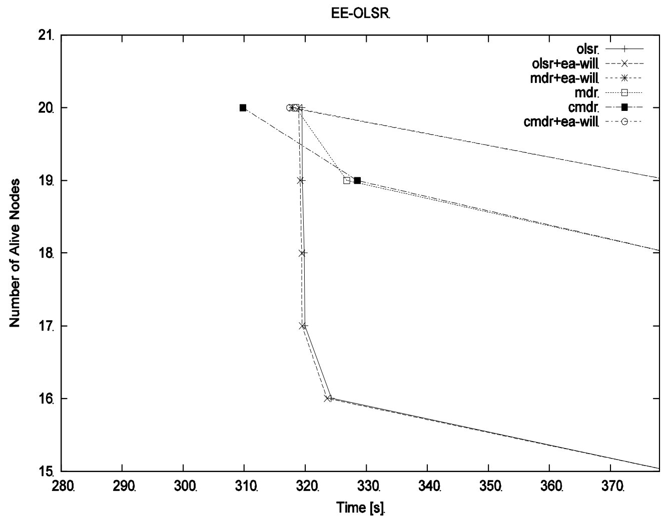

Figure 3 – Number of alive Nodes vs Time, with fixed scenario

On the other hand, if we consider the average residual energy of the network over time (Fig. 4), we can notice how the energy-aware metrics lead to an higher average consumption than MTPR. We can also notice how the conditional metric, that uses an hybrid approach (CMDR uses MTPR metric as far as the network is energetically good), can mitigate this effect.

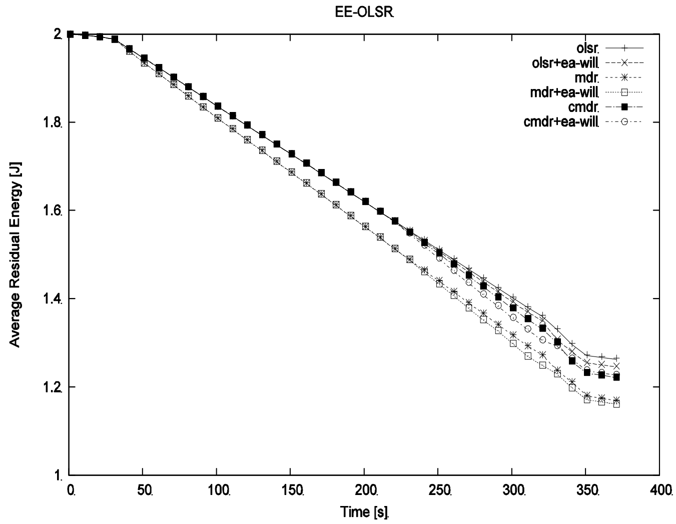

Figure 4 – Average nodes Energy (in Joules) vs Time, with fixed scenario

Figures 5 and 6 show the distribution of energy consumption in the space for the opposite metrics: MTPR, that prefers shortest paths, and MDR, that selects paths considering the energy drain rate of nodes. The residual energy of the nodes in the network is represented by their colour: the darkest ones have less energy (the values in the right-side legend are in Joules).

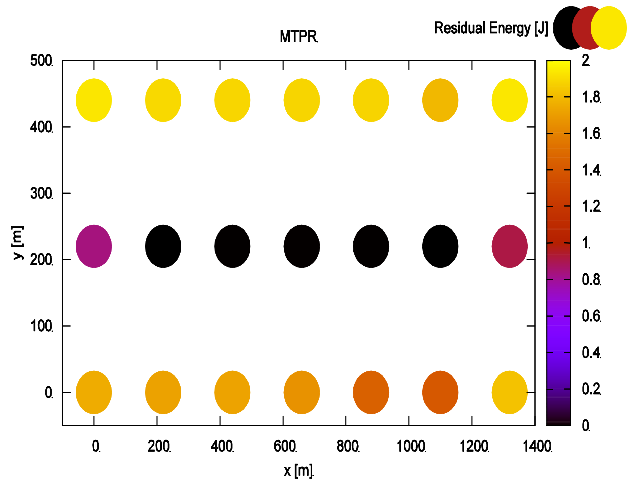

Figure 5 – Spatial distribution of energy consumption, with fixed scenario and MTPR metric.

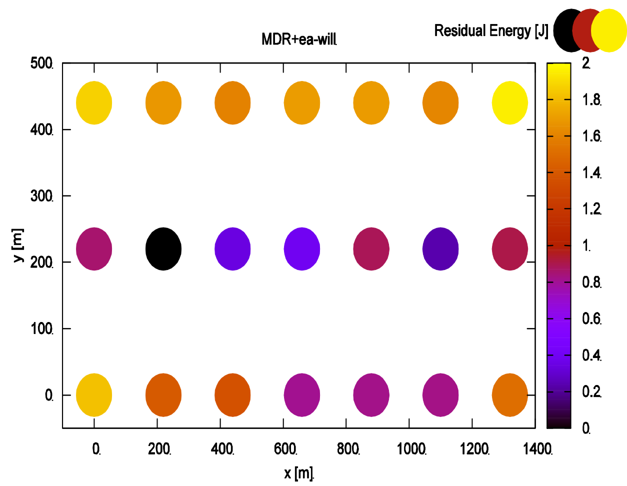

Figure 6 – Spatial distribution of energy consumption, with fixed scenario and MDR metric.

From these figures, we can see how MTPR metric ignores the nodes that are not in a shortest path to the destination, while MDR can distribute the packets also among some of these nodes.

Fig. 7 shows the previous data with histograms: this way we can illustrate the ability of energy-aware metrics of distributing the consumption among a larger number of nodes in the network.

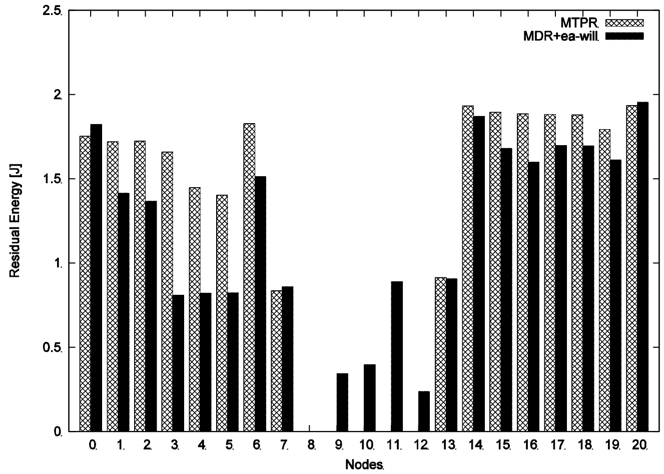

Figure 7 – Distribution of energy consumption, with fixed scenario, depicted by means of histograms.

Table 2 shows a performance comparison of different metrics in this scenario.

Table 2. Performance comparison,with fixed scenario.

	OLSR	MDR + EA-Will	CMDR + EA-Will
Average E2E Delay [ms]	1.60	1.90	1.66
Normalized Control Protocol Overhead [% bytes]	30.64	33.16	34.63
Data Packet Delivery Ratio [%]	95.86	97.27	97.91
Average node lifetime [s]	365.86	377.04	377.02
Average final energy [J]	1.26	1.16	1.25

Random scenario

The simulations of a random dense scenario, with a larger number of connections between nodes, confirms the effectiveness of energy aware metrics, at the cost of a larger average energy consumption. As shown in Fig. 8, in facts, MDR leads to a lower average energy consumption at the end of simulation, with respect to classical OLSR metric, but using a conditional approach (and the EA-Willingness selection) good results can be easily obtained.

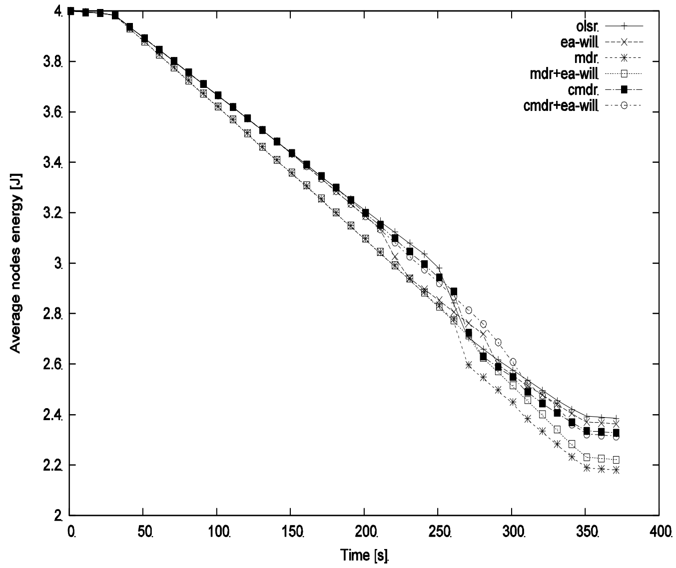

Figure 8 – Average node energy (in Joules), with random scenario.

In Fig. 9, on the other hand, we can notice how MDR and CMDR can improve the performance of OLSR classical metric only if used in association with the EA-Willingness.

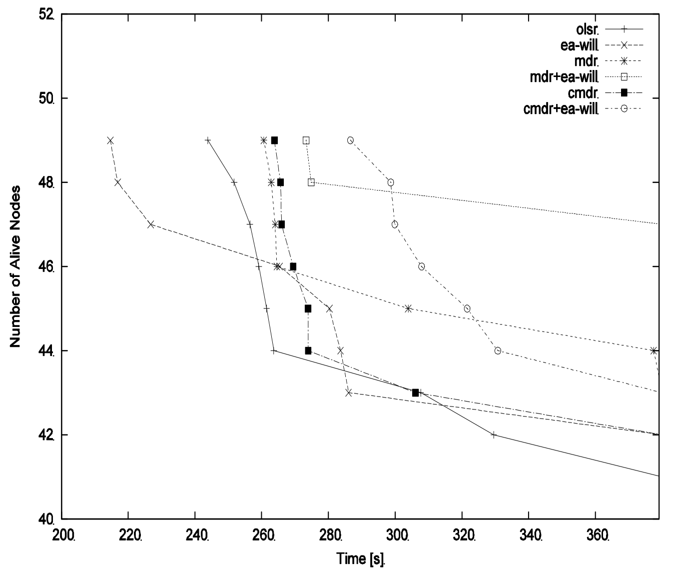

Figure 9 – Number of alive nodes vs Time, with random scenario.

Fig. 10 represents the number of MPRs per node, during the simulation, with different routing metrics: it shows how energy-aware metrics maintain higher the number of MPRs during the simulation, letting the protocol to select paths among a larger number of nodes.

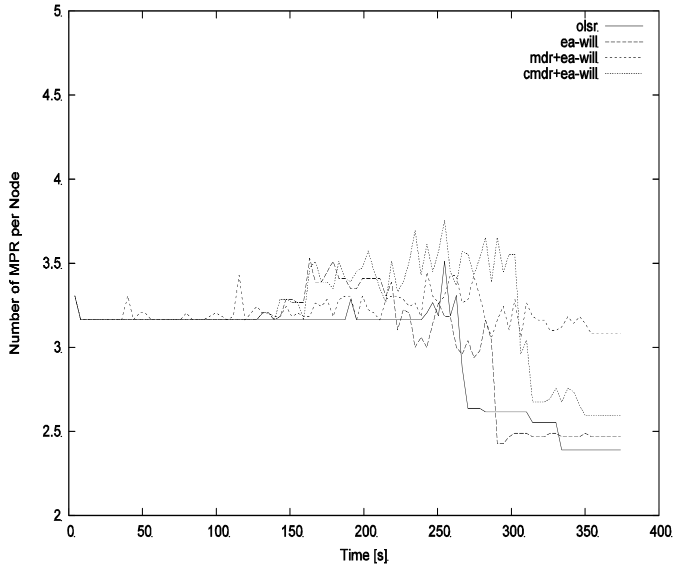

Figure 10 – Number of MPR per node, with random scenario.

Table 3 collects some statistic about the performance of the different metrics, and shows how the use of energy-aware routing metrics can lead to a better distribution of energy consumption in a mobile network, without affecting the performance of such a proactive protocol.

Table 3. Performance comparison, with random scenario.

	MTPR	MDR	CMDR
Data Packet Delivery Ratio [%]	92.65	99.51	96.32
E2E Delay [ms]	3.47	4.12	3.90
Normalized Control Protocol Overhead [% bytes]	7.69	8.24	8.22
Average connection duration [s]	287.65	313.54	305.24
Average node lifetime [s]	362.66	375.76	371.31
Average final energy [J]	2.38	2.21	2.31

6. CONCLUSIONS

In this paper, we tested the main energy-aware metrics over the OLSR routing protocol for MANETs. We demonstrated that selecting paths between nodes according to nodes energy can improve effectively the behavior of the network, in terms of nodes and connections lifetime, without affecting the classical performance parameters (like end-to-end delay or routing overhead). We also showed as these metric have a drawback: splitting the consumption among a larger number of nodes, they can lead to an higher overall energy consumption. This side-effect can be reduced using a conditional approach, that maintains shortest-path routes as long as no nodes in the network have low battery conditions. Moreover, we demonstrated the benefits of the association of an energy-aware mechanisms, such as the EA-Willingness setting, to the energy aware-metrics. This solution leads to a clear improvement of the energy behavior in a mobile network, without affecting the other performance parameters.

In future works, the benefits of the energy-aware metrics and mechanisms could be tested over a larger set of scenarios, in order to validate their effectiveness and to optimize the tuning of their parameters in every possible scenario.

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