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Energy Consumption Balancing in OLSR Ad Hoc Wireless Routing Protocol

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Abstract: The Mobile computer science requires many processing. Besides the communication activities, the energy consumption is one of the most critical issues as far as the batteries mobile devices are concerned. Especially, in ad hoc networks where each node is responsible to transmit data packets for the neighbour nodes. Thus, a particular wariness must be taken not only to minimize all nodes appropriate energy consumption but also to balance the batteries individual levels. Any unbalanced energy usage can, however, cause a failure on one of the overloaded nodes and thus lead to partitioning and decreasing the network lifetime. In the present paper, we first introduce the state of art the ad hoc networks and then its energy consumption, followed by a detailled description of the standard Optimized Link State Routing (OLSR) protocol. Second, we insert the energy consumption criterion QoS. With such an objective, we bring an the improvement at the heuristics of the nodes selection at multipoint relays (MPR), which represents the strongest point of the OLSR routing. Finally, we suggest three algorithms for the MPR selection process according to the energy constraints.

Keywords: Mobiles ad hoc networks, ad hoc networks performance, energy consumption, optimized link state routing, wireless communication.

1 Introduction

The ad hoc networks domain is has constanty received an increasing attention in recent years. The specific nature of this network type is that no fixed installation is needed contrary to the other network types. One of the biggest challenges for this later type lies in the restricted autonomy by of the mobile stations comprising it. In fact, this autonomy is provided by a small battery powered device, representing a rare and finite ressource, hence, the energy management is a critical issue for the practical deployment of these networks. Each packet sent or received packet, as well as every mobile terminal use takes advantage from this resource. And for a better comfort, all features available to the users have been increasingly improved and appreciable. Reducing the energy consumption to a minimum is a major challenge in mobile networks. Such an objective has become more important for networks ad hoc, where the stations also have the routing function. Indeed, forward traffic on behalf of other nodes may exhaust the node's energy reserves.

The energy conservation has been treated for a long time at the physical layer.

Nevertheless, several studies have demonstrated that one of the major factors consuming the energy battery is the network card. So, the design of new communication network protocols should help to reduce this energy consumption. At present, the wireless routing protocols candidates for IETF (Internet Engineering Task Force) standardization as OLSR [5], AODV [13], DSR [6], FSR [2], do not offer performance guarantees and they are even less efficient at the energy level. Moreover, most routing protocols specifically developed to reduce energy consumption do not provide new routing algorithms ; however, they propose some improvements to those already existing. The basic idea of these protocols is to route packets according to the minimization criteria concerning energy consumption. This metric can be of two types : (i) the link cost, or (ii) the battery cost on each node.

In the literature, all the energy saving protocols have focused not only on the importance to minimize the energy consumption but also on the importance to increase the network lifetime by balancing this consumption through the network.

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This paper is organized as follows : In section II, we shortly provide some related work in the performance evaluation field, while in section III, we briefly describe the Optimized Link State Routing (OLSR). In section IV, we give the proposed heuristics for MPR selection. In section V we present the performance evaluation with simulation results of the proposed schemes. Finally, in section VI, we can find some concluding remarks.

2 Related work

Because the batteries power is a critical issue in MANET nodes, the routing protocols design limiting the energy consumption has become necessary.

Recently, several algorithms have been proposed with the purpose of building a power-aware and efficient-energy routing [1,8,9,10,11,14]. The energy metric used to estimate routes is a very important component in this sorte of protocol. According to the metric used, the protocol characteristics can change considerably. To reduce and balance the energy consumption two main metrics are defined as follows :

2.1 Link cost

This metric measures the power necessary by bit to transmit a source packet at the destination, [8,9,14]. In this case, the power depends on the packet size, and it is proportional to the distance which separates two nearby nodes. The objective is to determine the shortest route in terms of energy consumption. So, the paths with more hops having short transmission ranges are favored for the routing; those with fewer hops but having longer transmission ranges are abandonned.

This metric minimizes the global energy consumption in a network ; however, this is made to the detriment of the battery remaining capacity of nodes which are participating in the routing process. More exactly, the problem can be defined by the following mathematical equations :

$$\begin{cases} \min \sum_{i=0}^{d-1} E\left[n_i, n_{i+1}\right] \\ E\left[n_i, n_{i+1}\right] \propto (packet\_size, distance) \end{cases} \quad (1)$$

where :

- n_i : node belongs to path routing,
- n_{i+1} : source node,
- n_d : destination node,
- $E\left[n_i, n_{i+1}\right]$: energy consumed for transmitting a bit over link $\left[n_i, n_{i+1}\right]$.

2.2 Battery cost

This metric estimates the energy amount present in each node [9,10,14]. Contrary to the link cost metric, this one is more able to describe individually the node lifetime. The objective is to determine a path containing the stronger nodes with larger energy capacities, (i.e. the nodes with a lower cost). So, the mathematical equations can be of this shape :

$$\begin{cases} \min \sum_{i=0}^{d} \frac{1}{c_i(t)} = \max \sum_{i=0}^{d} c_i(t) \\ \frac{1}{c_i(t)} \geq \gamma \end{cases} \quad (2)$$

where :

- $c_i(t)$: remaining battery capacity of node i at time t,
- $\frac{1}{c_i(t)}$: battery cost of node i at time t,
- $c_o(t)$: remaining battery capacity of source node at time t,
- $c_d(t)$: remaining battery capacity of source node at time t,
- γ : fixed threshold.

Since the residual capacity metric of the battery allows to extend the node lifetime, our MPR selection heuristics proposed in the section IV are based on.

3 Optimized link state routing protocol

MANET IETF working group [5] has introduced the proactive routing protocol whose name is Optimized Link State Routing (OLSR) for mobile ad hoc networks which represents an optimization of the pure link state algorithm, [3,4,5,12]. The key concept used in this protocol is that of multipoint relays (MPR). Each node selects its multipoint relay among its one hop neighbours in such a manner that the set covers (in radio range terms) all the nodes that are two hops away. The idea is, then, summarized to select the number of necessary repeaters (one-hop neighbours) to reach all the second level nodes. This is set of selected neighbour nodes forms a covering tree called multipoint relay (MPR) of that node. The purpose of multipoint relays is to minimize the flooding of broadcast packets in the network by reducing useless duplicate retransmissions in the same region.

To maintain updated necessary informations for the multipoint relays selection and for the routing calculation, OLSR nodes employ periodic exchange of control messages. To get informed about the neighborhood, each node OLSR periodically broadcasts HELLO messages containing an information list about its neighbours and their link status. Such messages enable each one to select its multipoint relays set formed by a neighbour subset. The second type of message, essential to OLSR is the Topology Control message (TC message). It is sent periodically by each node in the network to declare its MPR selector set i.e neighbouring subsets by using the same mutipoints relays. Such informations establish a network card consisting of all the nodes an a partial link set sufficient enough for the routing table construction.

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Thus, TC messages are forwarded like usual broadcast messages in the entire network, but it takes advantages of MPR which enable a better scalability of intra-forwarding. The information diffused in the network by these TC messages help each node to build its topology table.

For route calculation, each node constantly calculates its routing table to reach all the known destinations present in the network by using the "shortest-path algorithm" in terms of hops based on the learning partial network topology.

MPR selection is the key point in OLSR. The smaller the MPR set is the less overload the protocol introduces. The proposed heuristic in [5] for the MPR selection searches iteratively select a 1-hop neighbour node which reaches the maximum number of uncovered 2-hop neighbours.

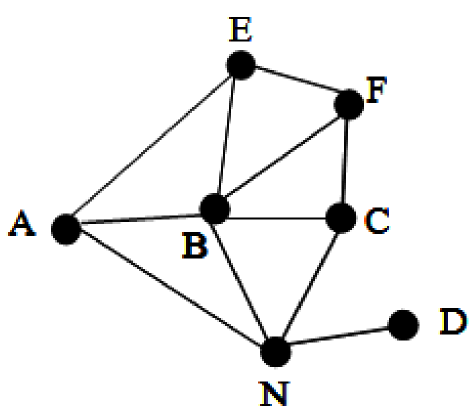

Fig. 1: Network example for MPR selection.

Table 1: MPR selection in standard OLSR.

Local node	one hop neighbour	2-hop neighbour	MPR
N	A, B, C, D	E, F	B

As far as the node N is concerned, nodes B and C cover the 2-hops neighborhood. However, B is selected as MPR because it has five direct neighbours whereas C has only four (B degree is higher than that of C).

The algorithm for the multipoint relays selection can be formalized as follows :

Let V1(x) be the set of one-hop neighbours of x. V2(x) the set of 2nd-hop neighbours of x and MPR(x) the set of multipoint relays of x.

- Start with an empty MPR set MPR(x) = Ø
- Select the nodes in V1(x) which are the only neighbours of some node in V2(x). Add these selected nodes of V1(x) in the multipoint relay set MPR(x) and remove all nodes from V2(x), which are now covered by nodes in MPR(x).
- While $V2(x) \neq Ø$ do

(a) - Calculate the degree for each node in V1(x).The degree for a node is the number of 2 hop neighbours in V2(x) covered by it.

(b) - Add that node of V1(x) in MPR(x) for which this number is maximum and remove all nodes from V2(x) which are now covered by this node in MPR(x).

OLSR is a routing protocol intended for a best-effort delivery. It emphasizes the way of reducing the network overload. So, in the MPR selection, the node chooses the direct neighbour that covers the maximum of neighbours that are two hops away. Introducing a QoS constraint based on minimizing energy consumption, nodes cannot use any more either the MPR choice principle or the shortest-path algorithm in term of hops proposed in standard OLSR. To minimize the energy consumption in OLSR, we suggest modifying the MPR selection. The following section begins with the metric energy definition allowing to estimate the optimal paths.

4 Description of proposed heuristics for MPR selection

The MPR selection is critically important for the determination of an optimal energy route in the network, on the basis of this idea, we propose three MPR selection algorithms.

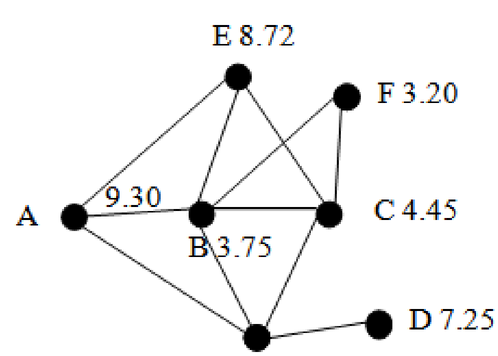

Fig. 2: Network example for illustrate the MPR selection.

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4.1 E_OLSR1

In E_OLSR1, the MPR selection is almost made in the same way as in the standard OLSR. However, if there are several one hop neighbours that cover the same number of 2-hop neighbours, the node with the best remaining capacity (Er) wins it, being so elected MPR node by the local node N.

So, using the same conventions as previously, the multipoint relays selection algorithm can be formalized as follows :

- MPR(x) = Ø;

- Select the nodes in V1(x) which are the only having a link with a neighbour of some node in V2(x). Add these selected nodes of V1(x) to the multipoint relay set MPR(x) and remove all nodes from V2(x) which are now covered by the nodes in MPR(x).

- While V2(x) $\neq$ Ø do;

(a) - Calculate the degree for each node in V1(x). The degree for a node is the number of 2 hop neighbours in V2(x) covered by this later.

(b) - Add the node of V1(x) with the maximum degree to the MPR(x) set. If several are available, select the node with the best residual energy capacity. Then, remove all nodes from V2(x) which are now covered by this node later in MPR(x).

Let us suppose that each node in the network in figure.2 knows its energy level. The node N would choose with E_OLSR1 the following MPR :

Table 2: MPR selection in E_OLSR1.

Local node	one hop neighbour	2-hop neighbour	MPR
N	A, B, C, D	E, F	C

Between B and C, it is the node C that is held as MPR because it haves the best residual energy.

4.2 E_OLSR2

Contrary to the standard OLSR, E_OLSR2 extension favors the energy metrics in the multipoint relays selection. E_OLSR2 opts for the remaining battery capacity as a main criterion in the MPR choice process. So E_OLSR2 will choose in each iteration the neighbour having the maximum remaining energy capacity until all the 2-hops neighbours are covered. If it is about a perfect equality, this algorithm could lean upon the other selection parameters like the calculation of their degree (maximum number of neighbours from the second level covered by these direct nodes equal in energy).

By using the same conventions as previously, the multipoint relays selection algorithm can be formalized as follows :

- MPR(x) = Ø;

- Select the nodes in V1(x) which are the only neighbour of some node in V2(x). Add these selected nodes of V1(x) in the multipoint relay set MPR(x) and remove all nodes from V2(x) which are now covered by the nodes in MPR(x).

- While V2(x) $\neq$ Ø do;

(a) - Select the node in V1(x) with better remaining energy capacity and that can achieve nodes in V2(x). If several ties exist, select the node which covers maximum number of nodes in V2(x);

(b) - Add this selected one-hop neighbour node in V1(x) to the multipoint relay set MPR(x) and remove all nodes from V2(x) which are now covered by nodes in MPR(x).

By applying this algorithm to the network in figure.2, the MPR of the node N would be :

Table 3: MPR selection in E_OLSR2.

Local node	one hop neighbour	2-hop neighbour	MPR
N	A, B, C, D	E, F	A, C

Among the direct neighbours of the node N are nodes A, B and C that have a connection with their 2-hop neighbours. The neighbour A is considered as the best in energy. So, A will be chosen as the first MPR of N to cover the node E in the second level. In a similar way, C is chosen as the next MPR to allow to cover F, so all the 2-hop neighbours are covered and the algorithm comes to an end.

4.3 E_OLSR3

This approach is hybrid combining E_OLSR1 and E_OLSR2, still applying a threshold of remaining battery energy at the nodes level. The basic idea is to start with applying E_OLSR1 for high energy nodes. If it turns out that the second level nodes are not yet all covered while

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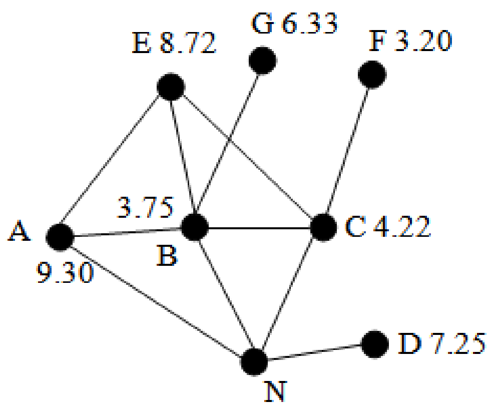

Fig. 3: Network example for illustrate the MPR selection.

there are only direct neighbours with a capacity Er $< \gamma$, then E_OLSR3 will switch to the E_OLSR2 application.

So, the MPR choice algorithm in E_OLSR3 is a loop. On each iteration, it looks for a node of the first level that meets at the same time the conditions to cover the maximum of neighbours of the second level and to possess a sufficient power threshold. The loop naturally stops when all the nodes of the second level are covered or when there is only MPR with insufficient energy. In that case, the rest of the algorithm uses E_OLSR2.

Still, with reference to the network in figure.3, the MPR nodes of the local node N should be selected through a threshold fixed at 4 Joules would be which is as follows (see Table. 4) :

Table 4: MPR selection in E_OLSR3, threshold 4 joules.

Local node	one hop neighbour	2-hop neighbour	MPR
N	A, B, C, D	E, F	A, C

Table 5: MPR selection in E_OLSR3, threshold 3 joules.

Local node	one hop neighbour	2-hop neighbour	MPR
N	A, B, C, D	E, F	C

At the 4 Joules threshold, the MPR selection process in E_OLSR3 is confused with E_OLSR2. In this way, the same nodes A and C is introduced in MPR set of the local node N.

In the case of a threshold of 3 Joules, the E_OLSR3 algorithm converges to E_OLSR1 algorithm. So, only the node C is chosen by the local node N (see Table. 5).

To illustrate clearly the E_OLSR3 principle, we examine the network in figure.3. The MPR choice of the local node N according to the threshold set at 4 Joules is as follows (see Table. 6) :

Table 6: MPR selection in E_OLSR3, threshold 4 joules.

Local node	one hop neighbour	2-hop neighbour	MPR
N	A, B, C, D	E, F	B, C

Among nodes A, B and C, the direct neighbours that have a connection with the second level nodes of the local node N, only A and C are above the threshold fixed at 4 Joules. At first, nodes A and C will be chosen favorable first candidates in the of MPR choice process. The node B will only be considered if nodes A or/and C are unable to cover the entire 2-hop neighborhood. At first by applying E_OLSR1, the node C will be chosen as MPR node because it has 2 neighbours (nodes F and E) at two hops away from the local node N whereas A has only one (node E). Given it stays a node G to be reached, E_OLSR3 would be forced to switch to the E_OLSR2 principle application. Although the node B is below the fixed threshold (4 Joules), it is included in the MPR set and the entire neighborhood at the second level is now covered.

5 Performance evaluation

We have used the event driven simulator NS-2 [18] for our simulations. We also used the wireless extensions provided by CMU [19].

NS-2 simulates a realistic physical layer that includes a radio propagation model, radio network interfaces, and the IEEE 802.11 Medium Access Control (MAC) protocol are using the Distributed Coordination Function (DCF). The radio network interface card (NIC) model includes collisions, propagation delay and signal attenuation with a 2Mbps data rate and a radio range of 250 meters.

We simulate an ad hoc network consisting of 36 nodes (wireless hosts) randomly placed (the distribution very close to reality) in a 800x800 m2 area. Reliable connections are established at random in the network. In the scenarios, we use the traffic source of constant bit rate (CBR) connections with 4 packets/second and a packet size of 1024 bytes. The start-up capacity of the battery for each node is fixed at 10 units. This initial battery energy is reduced gradually as one goes along by data transmission and reception. When it reaches zero, the corresponding node can no longer participate in the communication and is considered as 'dead'. In this paper, we are specifically interested in energy consumption and its balance across all mobile nodes. For each node, energy consumption is measured at the radio layer during the simulation.

According to the specification of IEEE 802.11-compliant WaveLAN-II [7] from Lucent, the

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power transmission varies from 0.045 Watts (9mA x 5 Volts) in sleep mode to 1.25˜1.50 Watts (230˜250mA x 5 Volts) in receiving and transmitting modes, respectively. The instantaneous power is multiplied by time transmission to obtain the energy consumed. For example, the data transmission of a 1024-byte packet consumes 6.14 x 10-3Joules (1.50 Watts x 1024 x 8 bits / 2000000 bps). Two energy-related assumptions are made for our simulation study as follows :

First, the energy consumption during idling was ignored. Since a node stays idle most of the time, a general idea to conserve energy is to put the node in sleep mode while idling and make the node consume negligible energy. Second, non-promiscuous receive mode [17] is assumed. Since a node does not know when others send packets to itself, it should be in promiscuous receive mode. However, emerging standards for wireless LANs such as IEEE 802.11 [16] and Bluetooth [20] provide a mechanism for each node to know when to wake up and receive packets and where to sleep the rest of the time. Thus, time delay due to data reception is similar to that due to data transmission for a relaying node. Without this assumption, energy consumption is dominated by data reception or overhearing [15] and the proposed algorithms may provide a limited benefit.

The key parameter of this study is the network lifetime. We vary the different parameters and study their effects on this metrics. The network lifetime can be defined in many ways :

- It is defined as the necessary time for K nodes in the network to die;

- It is the necessary time for the first node in the network to die;

- It can also be the necessary time for all nodes in the network to die.

For our present research, the first two definitions have been adopted. The network lifetime for the proposed algorithms is compared with the differents scenarios. This analysis is often made in relation with OLSR because these algorithms are derived from it.

We have tested both cases where : (i) where nodes are fixed with no mobility, and (ii) where nodes are mobile and move on the simulation area with different moving speeds.

5.1 Fixed nodes

Figure. 4 shows the moments to which a number of nodes dies because their batteries depletion when all the network nodes are fixed. We have chosen the value of the number of first dead nodes (K) between 1 and 7 for 8000 seconds of simulated time.

We have note that for OLSR, the first node dies approximately 1929 seconds earlier than in E_OLSR1,

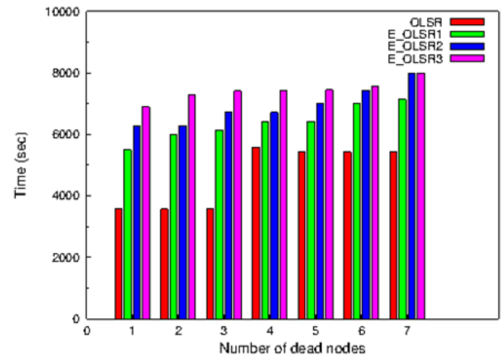

Fig. 4: Number of dead nodes/time.

2714 seconds earlier than in E_OLSR2, 3329 seconds earlier than in E_OLSR3. Similarly, this is true for 4 nodes, they die approximately 857 seconds earlier than in E_OLSR1, 1143 seconds earlier than in E_OLSR2, and 1848 earlier than in E_OLSR3.

We also note that E_OLSR3 gives better performances than E_OLSR2. Indeed, E_OLSR3 takes into account the battery residual capacity provides that this capacity is as a sufficient minimal amount. Now, the E_OLSR2 algorithm also uses as cost the battery residual capacity but without the threshold concept. Indeed, this difference at the cost function level allows E_OLSR3 to have a forecast on the remaining nodes lifetime. This can be a good indicator of the traffic routing through the node. If the node is low in energy (below the fixed threshold), this implies that this node is requested and that the routing through the same node may lead to network partition. In the case, where the neighbours at two hops away are not yet covered and where the candidates neighbours for MPR are below the fixed threshold, E_OLSR3 also tries to take advantage of the shortest-path routing. In this particular case, E_OLSR3 minimizes the number of nodes affected by the routing which allows it to dig the difference in energy reduction.

5.2 Mobile nodes

The mobility effect is presented in figure.5. We have compared the performances of three algorithms E_OLSR1, E_OLSR2 and E_OLSR3 with stadard OLSR. As we can see it, our algorithms are always better compared to OLSR in terms of the number of the dead nodes.

We have observed for OLSR and for a nodes speed equal to 4 meters/second that for example, the first node dies approximately 766 seconds earlier than in E_OLSR1, 1132 seconds earlier than in E_OLSR2, and 1150 seconds earlier than in E_OLSR3. This degradation in performance with in regard to the case where nodes are

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fixed is completely justifiable. As the nodes moving speed increases, the energy consumption rate in the network also increases. This is normal because a fast-moving node implies more route discoveries and consequently more energy is consumed in the network. Besides, as the nodes mobility increases, the difference between OLSR and our algorithms becomes less important. To find the best

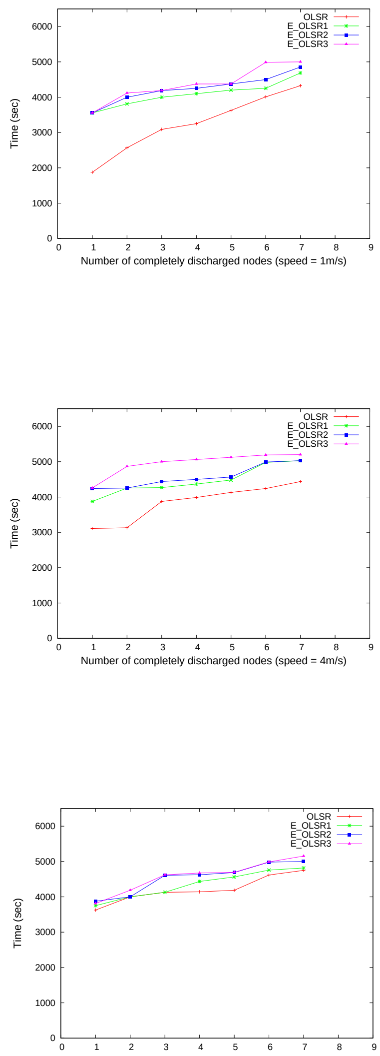

Fig. 5: Number of dead nodes/time with speed a) 1m/s (b) 4m/s (c) 8m/s and with a pause time of 4s..

available route, the algorithms which we have proposed during the route research process need to flood more control packets in the network. To measure this overload control, we have calculated the ratio of the number of control packets (in bytes) to the number of data packets (in bytes) transmitted within the network during 6000 seconds of simulated time. We can see, the values of the overload according to the nodes moving speed in the network in figure. 5. The difference between OLSR and our algorithms E_OLSR1, E_OLSR2 and E_OLSR3 grows with the nodes speed. This is due to the fact that in addition to the mechanisms introduced into our algorithms for the MPR selection, there is the fact that the routes do not become any more valid with higher moving speeds.

6 Conclusion

In this paper, we have proposed three routing algorithms based on the protocol OLSR. The proposed algorithms aim to extend the batteries lifetime of each node ; that is to say, the survival of an ad hoc network. It should be noted that the current standardized routing protocols by IETF, such as OLSR, is not interested in the routing impact on the energy consumption in the network. They are interested, on the other hand, to find the shortest path in terms of hops number.

We have compared in terms of energy performance the protocol OLSR with three proposed heuristics. In standard OLSR nodes die faster than in our proposed approaches. Although E_OLSR1 uses practically the same MPR selection algorithm as standard OLSR, it achieves a better performance. E_OLSR1 can not find the shortest path but the most optimal path in energy term.

The E_OLSR2 algorithm offers the best possible routes in terms of energy consumption to the detriment of the classic concept of the shortest path related to the end-to-end transmission time.

E_OLSR3 hybrid heuristic tries to find a compromise between the shortest path concept and the energy optimal path. This approach is based on the metric of nodes' remaining energy, a more precise metric for describing the nodes' lifetime. E_OLSR3 differs from E_OLSR2 by the application of a threshold which enables it to better control and especially to balance the energy consumption through the network.

The simulations results have proved that although the mechanisms added to the OLSR routing protocol have improved considerably its performances in term of the network survival. they have realized it with minimum overloads, and without having any effects on the other cross-layer. These heuristics are simple and easy to include in the OLSR routing protocol.

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