QoS Routing Using OLSR Protocol

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Abstract: - This paper proposes a new routing approach that combines the residual bandwidth, energy and mobility of the network nodes. Metrics are designed to cope with high mobility and poor residual energy resources in order to find optimal paths that guarantee QoS constraints. A maximizable routing metric theory has been used to find a metric that selects, during the routing process, routes that are more stable (less mobile), that offer a maximum throughput and that live for a long time. The OLSR (Optimized Link State Routing) protocol, which is an optimization of link state protocols designed for MANETs (Mobile Ad hoc Networks) is used as a test bed in this work. We prove that our proposed composite metrics selects a more stable MPR set than the QOLSR algorithm which is a well known QoS OLSR extension. By mathematical analysis and simulations, we have shown the efficiency of this new approach in terms of routing load, packet delivery fraction, delay and prolonging the network lifetime.

Key-Words: - Mobile Ad hoc networks, quality of service, routing protocol, routing metric, mobility, residual energy

1 Introduction

A MANET is a collection of mobile nodes working on a dynamic autonomous network. Since there is no existing communication infrastructure, adhoc networks cannot rely on specialized routers for path discovery and routing. Therefore, nodes in such a network are expected to act cooperatively to establish routes instantly. Such a network is also expected to route the traffic, possibly over multiple hops, in a distributed manner, and to adapt itself to the highly dynamic changes of its links and the residual energy of its constituent nodes.

Providing QoS in MANETs [1] is a tedious task. It's known that combining multiple criteria in the routing process is a hard problem (NP-Complete). The goal of QoS routing protocols is to obtain feasible paths that satisfy end-system performance requirements. Most QoS routing algorithms are mainly extension of existing classic best effort routing algorithms.

In this paper, we propose a new composite metric to find the optimal path respecting QoS constraints. The objective of the composite metric is to find an optimal stable path with a maximum available bandwidth and a maximum network life time.

Using the OLSR Protocol, we show that our proposed metric selects a stable MPR Set rather than the QOLSR algorithm which is a well known as a QoS algorithm.

2 Optimized Link State Routing Protocol

OLSR (Optimized Link State Routing) protocol [2-3] is a proactive table driven routing protocol for mobile ad hoc networks and it is fully described on RFC 3626 (Thomas Clausen & Philippe Jacquet, (October 2003)). OLSR optimizes the topology information flooding mechanism, by reducing the amount of links that are advertised and by reducing the number of nodes forwarding each topology message to the set of MPRs only. Information topology is called Topology Control (TC) messages are only originated by nodes selected as Multipoint Relays (MPRs) by some other node in the network. MPRs are selected in such a way that a minimum amount of MPRs, located one-hop away from the node doing the selection (called MPR Selector), are enough to reach every single neighbour located at two-hops of the MPR selector [14]. TC messages will only advertise the links between the MPRs and their electors. These forwarding constrains considerably decrease the amount of flooding retransmissions.

The computation of the MPR set with minimal size is a NP-complet problem [10-12]. The standard MPR selection algorithm currently used in the OLSR protocol is as follows:

For a node x, let N(x) be the neighborhood of x. N(x) is the set of nodes which are in the range of x and share with x a bidirectional link. We denote by N2(x) the two-neighborhood of x, i.e, the set of nodes which are neighbors of at least one node of N(x) but that do not belong to N(x) .

Based on the above notations, the standard algorithm for MPR selection is defined as follows (figure 1):

1. $U \leftarrow N^2(x)$
2. $MPR(x) \leftarrow \varnothing$
3. $while\ \exists v:\ v \in U \wedge \exists! w \in N(x): v \in N(w)\ do$
   - (a) $U \leftarrow U - N(w)$
   - (b) $MPR(x) \leftarrow MPR(x) \cup \{w\}$
4. $while(U \neq \varnothing)\ do$
   - (a) $choose\ w \in N(x)\ such\ as: CRITERIA(w) =$ $|N(w) \cap U| = \max(|w' \cap U| : w' \in N(x))$
   - (b) $U \leftarrow U - N(w)$
   - (c) $MPR(x) \leftarrow MPR(x) \cup \{w\}$
5. $return\ MPR(x)$

Figure 1 MPR Selection Algorithm

OLSR uses hop count to compute the shortest path to an arbitrary destination using the topology map consisting of all its neighbours and of MPRs of all other nodes. The number of hop criterion is not suitable for QoS support.

3 QoS Routing Problems

One of the key issues in providing end-to-end QoS in a given network is how to find a feasible path that satisfies the QoS constraints. The problem of finding a feasible path is NP-Complete if the number of constraints is more than two. It cannot eventually be solved in a polynomial time dealing with heuristics and approximations. The network layer has a critical role to play in the QoS provision process. The approaches used by the QoS routing algorithms follow a trade-off between the optimality of paths and the complexity of algorithms especially in computing multi-constrained path. A survey on such solutions can be found in [10].

The computational complexity is primarily determined by the manner of composing metrics [12]. The three basic composition rules are: additive (such as delay, delay jitter, logarithm of successful transmission, hop count and cost), multiplicative (like reliability and probability of successful transmission) and concave/min-max (e.g. bandwidth). The additive or multiplicative metric of a given path is the sum or multiplication of the metric of all the links of the path. The concave metric of a path is the maximum or the minimum of the metric over all the links in the path.

If $M_{i;j}$ is the metric for link $\{i,j\}$ and P is the path between (i, j, k,..1,m) nodes, the QoS metric M(P) is defined as [10-11]:

Additive : M(P) = $M_{i,j} + M_{j,k} + \ldots + M_{l,m}$

Multiplicative : M(P) = $M_{i,j} \text{ x } M_{j,k} \text{ x} \ldots \text{x } M_{l,m}$ (1)

Concave : M(P) = $\min\{M_{i,j}, M_{j,k}, \ldots, M_{l,m}\}$

The proof of NP-Completeness relies heavily on the correlation of the link weight metrics. QoS Routing is NP-Complete when the QoS metrics are independent, real numbers or unbounded integers.

In general, QoS routing focuses on how to find feasible and optimal paths that satisfy QoS requirements of various voice, video and data applications. However, based on maximizable routing metrics theory [12], it is shown that two or more routing metrics can be combined to form a composite metric if the original metrics are bounded and monotonic.

Mathematical proof is based on the maximizable routing metric theory and is available in [18]. this paper is focused on the energy component and prolonging the network lifetime.

4 Our Improvement

4.1 Overview of our solution

Bandwidth is one of the most important factors required and requested by customer's applications. Mobility and energy are crucial problem in MANETs, and up to now, the majority of routing protocols have shown some weaknesses to face a high mobility and poor energy resources in the network.

Our objective consists in positively manage the network bandwidth taking into account the constraints of energy and mobility, in order to adapt and improve the performance of adhoc routing protocols and the network life time.

Initially, we start by giving some results of comparing our approach based on the mobility parameter. Thus, we evaluate the modified OLSR (Mob-OLSR) that it is based on our proposed mobility metric [4]. Mob-OLSR is then compared to the standard version of the OLSR protocol (without QoS extension) and QOLSR [8](the well known QoS extension for OLSR).

Simulations results conduct us to think to use mobility as a parameter to fulfill QoS requirements. So, we have focused after on combing the mobility with the bandwidth. In this regard, two metrics were proposed. The first is based on the sum criteria and the second is based on the product criteria.

We have first tested our idea on the OLSR protocol developing two OLSR variants: SUM-OLSR and PRD-OLSR protocols. The SUM-OLSR protocol is related to the sum criteria, and the PRD-OLSR protocol is related to the product criteria. We have eliminated the SUM-OLSR version for its hard cost in terms of PDR. However, it is important to mention that the SUM-OLSR performs better than the QOLSR protocol.

In a second step, and in order to maximize bandwidth while taking into account the constraints of energy, a new generalized metric was presented.

The proposed metric (ENOLSR) will be compared to different proposed metrics so called PRD-OLSR and Mob-OLSR and QOLSR. This work is amongst the first efforts to consider nodes with mobility and energy constraints in MANETs.

4.2 The Proposed metric

Our goal is to select the metric that maximizes network throughput taking into account the key constraints of MANETs environment (mobility, energy). The idea behind the composite metric is that the cost function is computed locally at each node during the topology information dissemination during the flooding process.

Once the network converges, each node runs the shortest path algorithm based on the calculated composite metric to find the optimal route to the destination. Bandwidth, mobility and remaining energy information's are available and could simply be gathered from lower layers. This paper is mainly focused on solving the routing issues based on the assumption that an underlying mechanism is there to gather the necessary information about the individual metrics.

Some solutions already proposed in [7] can be used to measure bandwidth. The Mobility will be calculated based on our lightweight proposed approach cited [4-6]. Energy information can be derived from the energy model used in NS2 simulator at the MAC Layer [4].

Individual metrics must be combined according to the following rules:

- Nodes with no energy must be rejected in the process of route discovery and maintenance.
- Nodes with high mobility should be avoided in the process of routes construction.
- Tolerate a slight decrease in throughput in order to maximize other performance parameters (delay, collisions, NRL)
- Nodes start with a maximum energy resource that decreases over time depending on node's states (transmitting/receiving, in idle/transition mode, etc.).

Based on these rules, we proposed to combine individual metrics as given below:

$$\textbf{Sum-metric} = [K0 * BW(w') + K2 * (1 - M(w'))] \quad (2)$$

$$\textbf{Prd-metric} = K0 + \frac{BW(w')}{M(w')} \quad (3)$$

Generalized metric=

$$\left[\left(K0 + \frac{K1}{M(w')}\right) * BW(w') + K2 * (1 - M(w'))\right] [K3 * E(w')] \quad (4)$$

Where

BW : Available Bandwidth in kilobits per second

E : residual energy of node (number in range 0 to 5; 0 refers no energy for node to perform)

Constants K0, K1 and K2 will be set by the administrator based on the nature of the network. For example, in a very dynamic environment, and to give more importance to the mobility of nodes, we can fix K0 to 0, K1 to 1 and K2 to 1.

An important value of K3 will indicate the importance of energy in the routing process.

The bandwidth metric can be based on:

This bandwidth metric reflects a real dynamic environment where nodes have limited energy resources, and bandwidth constraints are crucial (streaming application).

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4.3 Proprieties of the proposed metrics

The bandwidth metric represents the available bandwidth at the link. A simple technique proposed in [13], which computes available bandwidth based on throughput can be used to measure the bandwidth on any given node (respect. *link L(i,j)*).

Let $B_{av}(i,j)$ represent the available bandwidth of the link (i,j):

$$B_{av}(i,\mathrm{j}) = \min\{B_{av}(i); B_{av}(j)\} \quad (5)$$

Where $B_{av}(i,j)$ is the available bandwidth of the node *i*

Also, let *Wi,j* be the weight on the link *L(i,j)*. Wi,j can be estimated from the following relationship given below.

$$W_{i,j} = \frac{1}{B_{av}(i,j)} \quad (6)$$

The condition of *boundness* implies that along any path starting from root, the metric is non-increasing. The metric relation is given by: *met {m,W(i,j)}*.

Given m is the metric of the root. It is evident that this meets the *boundedness* and that *monotonicity* conditions hold for the selected metric. The available bandwidth is always positive, hence for any node located at distance "d" from the root *W(i,j)* would always be less than or equal to the metric value at the root. Since the bandwidth is always positive and greater than zero hence it satisfies the *boundedness and monotonicity* conditions.

The mobility metric represents the r ate of changes in the neighboring of a given node at time t compared to the previous state at time $t-\Delta t$. We suggest our proposed mobility measure presented in [14]. Mobility of a node i at a time t is given by the following formula:

$$M_i^{\lambda}(t) = \lambda \frac{NodesOut(t)}{Nodes(t-\Delta t)} + (1-\lambda)\frac{NodesIn(t)}{Nodes(t)} \quad (7)$$

Where:

$NodesIn(t)$: The number of nodes that joined the communication range of i during the interval $[t-\Delta t, t]$.

$NodesOut(t)$: The number of nodes that left the communication range of i during the interval $[t-\Delta t, t]$.

$Nodes(t)$: The number of nodes in the communication range of i at time t.

λ: The mobility coefficient between 0 and 1 is defined in advance. For example, in an environment where the

number of in is higher than the number of out nodes, we can take $\lambda = 0.25$.
Many simulations have been done for different values of λ (λ=0; 0.25; 0.5; 0.75; 1). Simulation result [4] shows that for λ=0.75 the network performs well (in term of delay, Packet delivery fraction and throughput). For this reason, we consider this value (λ=0.75) in the rest of this work.
Let $W_{i,j} = M_{L(i,j)}$ be the edge weight on the link *L(i,j)*.
The link mobility between two nodes A and B is defined as the average mobility of the involved nodes (figure 2), as showed in following equation:

$$M^{\lambda}_{L(A,B)} = \frac{M^{\lambda}_{A}(t) + M^{\lambda}_{B}(t)}{2} \qquad (8)$$

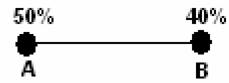

Figure2 Link mobility estimation example: $M_{L(A;B)} = 45\%$

As node's mobility reflects how likely it is to either corrupt or drop data. It could be considered as reliability metrics [11]. Because the reliability metric is bounded and strictly monotonic, it may be sequenced with the partial metric while preserving *boundedness and monotonicity*.
Moreover, residual energy function is monotonic and bounded its value decreases in time (depending on the state of the node: *transmission/reception*, *transition/sleep* mode, etc.). It also reflects how likely it is either to corrupt or drop data. Consequently, it can be sequenced with the partial metric while preserving *boundedness and monotonicity*.

Energy consumption parameters are derived from the energy model defined in NS2 [15] as follow:
Pt_consume= 1.320 (~ 3.2W drained for packet transmission); *Pr_consume= 0.8 (2.4W drained for reception); P_idle=0.07, P_sleep =06; P_transition=0.5*

The edge weight E_{ij} for the *link L(i,j)* can be estimated from the following relationship: $E_{ij} = \text{Min}(E_i, E_j)$.
Where E_i: the remaining energy for the node *i* and E_i=0 means that the node i have drained out its energy. Thus, the routing protocol should omit such node in the process of routes construction.
To validate the robustness and efficiency of the proposed Metrics, we have used four mobility models: *bandwidth model, mobility model, sum_bandwidth-mobility model, prd_bandwidth-mobility model, and bandwidth-energy-mobility model.*

Metrics serves as Cost-to-Forward function. In OLSR, metrics will be used as a criterion in the MPR selection algorithm. By exchanging Hello messages, every node is aware of its neighbor nodes and can simply compute its Cost-to-Forward value (i.e. to forward packet).
The Cost-to-Forward function *(F(i))* for each of the four models can be defined as shown in figure 3.

Bandwidth model: $F(i) = BW_i$

Mobility model: $F(i) = M_i$

Sum_bandwidth-mobility Model:
$F(i)$= *Default metric1* $= [K0 * BWi + K2 * (1 - Mi)]$

Prd_bandwidth-mobility model
$F(i)$=*Default metric2* $= K0 + \frac{BWi}{Mi}$

Bandwidth-energy-mobility model.

$F(i)$= **Comp_Met**
$= \left[\left(K0 + \frac{K1}{Mi}\right) * BWi + K2 * (1 - Mi)\right] [K3 * Ei]$

Figure 3 Cost-to-Forward functions

5 Simulations and results

In this section, we present some simulations to compare the performance of the original *OLSR* protocol based on the *MPR* selection standard algorithm, with the two modified *OLSR* protocols related to different proposed model: : bandwidth model *(QOLSR),* mobility model *(MobOLSR),* sum_bandwidth-mobility Model (Sum-OLSR), prd_bandwidth-mobility model *(Prd-OLSR)* and bandwidth-energy-mobility model *(EN-OLSR).* For the comparison process, we have used the most important metrics for evaluating performance of *MANETs* routing protocols during simulation (*Normalized Routing Overhead (NRL)*, *Packet Delivery Fraction (PDF), Average End-to-End delay and Avg_throughput).*

5.1 Simulation environment

For simulating the original OLSR protocol and the modified OLSR protocols related to our proposed criterions, we have used the OLSR protocol implementation which runs in version 2.33 of Network Simulator NS2 [15-5].
Simulations are considered in the same MANET environment as illustrated in the Table 1.

Table 1 Simulation parameters

For each presented sample point, 40 random mobility scenarios are generated. The simulation results are thereafter statistically presented by the mean of the performance metrics. This reduces the chances that the observations are dominated by a certain scenario which favors one protocol over another. As we are interested in the case of high mobility, we have reduced the HELLO interval and TC interval at 0.5s and 3s, respectively, for quick updates of the neighbors and topology databases.

5.2 Results and discussion

To show how the modified versions of the *OLSR* protocol are more adapted to the link status and topology changes comparing to the original *OLSR* protocol, we have made several performance comparison based on the five performance metrics discussed in Section 5-A. We have run simulations in different mobility levels by varying maximum speed of nodes between 0km/h (no mobility) to 140km/h (very high mobility) in steps of 10km/h. To maximize performances we have chosen the mobility coefficient equal to $\lambda = 0.75$.

We have defined several *OLSR* variants to study performance impacts of individual and combined QoS parameters.

Mob-OLSR is the OLSR variant that only uses mobility as QoS parameter [4] in the process of selecting MPRs (figure 1).

QOLSR is the well known *OLSR* QoS extension [8]. *QOSLR* tries to maximize bandwidth without worrying about the network dynamicity (mobility).

Prd-OLSR is the *OLSR* variant designed to cope with high mobility to find optimal paths that maximize bandwidth. *Prd-OLSR* uses the combined criteria (equation 2) based on the product function when selecting MPRs.

Parameters	Values
Number of Nodes	50
Transmission range	250m
Trafic type	Constant Bit Rate (CBR)
Number of connexions	10
Packet size	512bytes
Simulation time	100s
Mobility model	RWP

ENOLSR is the proposed variant of *OLSR* designed to cope with high mobility and poor residual energy resources to find optimal paths that maximize bandwidth. *Prd-OLSR* uses the generalized criteria represented by equation 3 based on product function) in the process of selecting *MPRs.*

In figures (4 to 8), we notice that the proposed *ENOLSR* finds a compromise between bandwidth, energy and mobility. Our proposed protocol selects stable routes providing an optimum bandwidth while prolonging the lifetime of the network.

OLSR provides the worst delay when compared to the proposed protocols. Precisely, the *QOLSR* and *ENOLSR* protocols delay is around 1.65 seconds (enhancement by 0.3sec comparing to the original *OLSR*) with higher mobility rate (maximum speed equal to 140km/h) and decreases to almost 1.25 seconds (enhancement by 0.1sec comparing to the original OLSR) within static topology conditions. This allows us to conclude that *ENOLSR* and *QOLSR* protocols ensure in the whole the same delay.

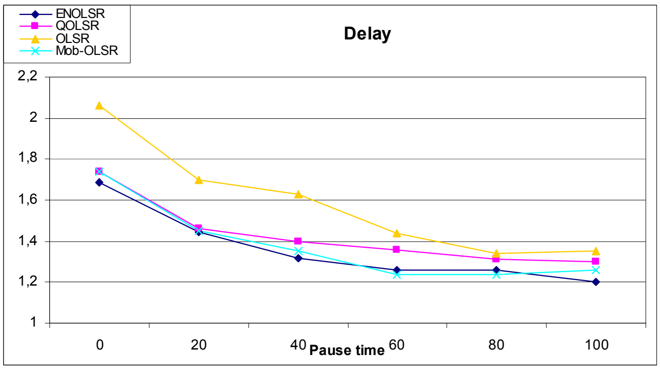

Figure 4 Delay comparison of the proposed versions of OLSR

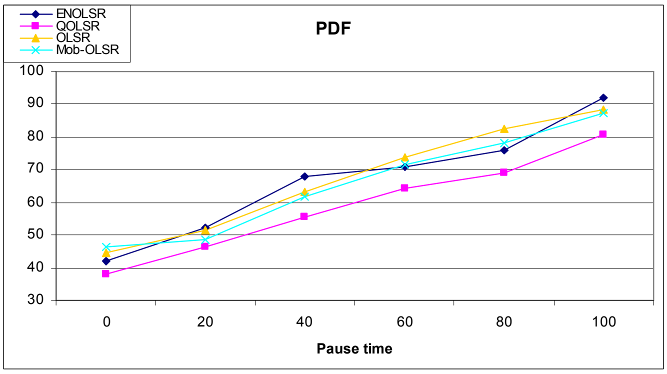

Figure 5 PDF comparison of the proposed versions of OLSR protocol.

A tolerable degradation in throughput is shown for our proposed protocol compared to the *QOLSR* protocol. This is justified by the enhancement seen in the *PDF* parameter. Indeed, during the process of learning routes, our protocol avoids nodes with high mobility and poor residual energy even if they offer a high bandwidth. *QOLSR* protocol provides the worst amount of NRL when compared to the others protocols. *ENOLSR* ensures an optimal NRL. It exceeds the NRL induced by *OLSR* and performs better than *QOLSR.*

In the worst case (at the maximum speed value equal to 40m/s), the NRL increases to 2.1% for QOLSR protocol, 1.3% for the original OLSR and 1.6% for ENOLSR. In addition, QOLSR ensures the worst PDF when compared to our proposed protocols. An enhancement of 10% (resp. 65%) than the Original OLSR protocol is shown.

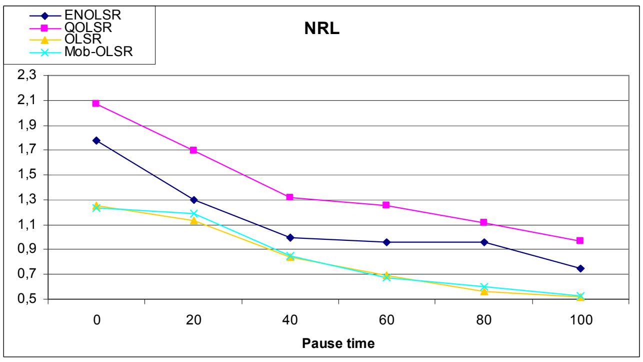

Figure 6 NRL comparison of the proposed versions of OLSR

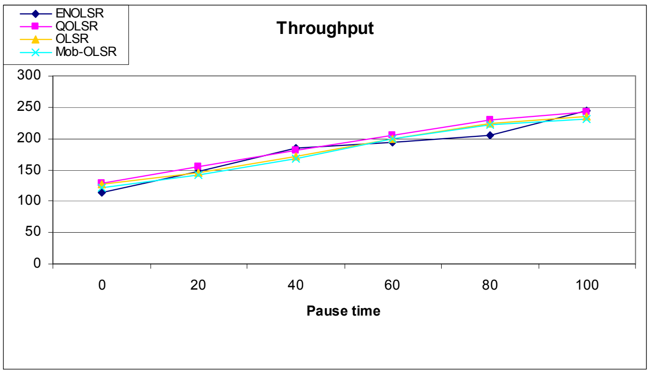

Figure 7 Throughput comparison of the proposed versions

5.3 Prolonging network life time

Selfish nodes can have a major impact on the performance of solutions presented in Section VI. In some extreme cases, these malicious nodes can cause serious denials of service. The main problem comes from the fact that *MPRs* and optimal network paths are selected based on some private information revealed by the network nodes. Selfish nodes can misbehave and reveal false information if this behavior can save their energy and mobility degree. Moreover, one of the main drawbacks of the classical OLSR is the malicious use of the broadcast TC messages A malicious compromised node can flood the network with fake TC messages.

In order to reduce the energy consumption and increase the network lifetime, different approaches propose to use the node residual energy as a metric for the routing protocol.

First, the MPR selection algorithm has to be based on the node residual energy rather than the node mobility. The selection can rely on a simple metric based on the residual energy levels of the nodes or on a more complex weighted metric based on the residual energy levels of the nodes and their mobility degree [18]. The choice of this criterion depends on the physical model of energy consumption of the nodes.

Second, the route computation has to be adapted to consider the energy costs of the network paths. Some solutions simply assign very high costs to links coming out of nodes with very low residual energy levels and use the Dijkstra's algorithm to compute the lowest total cost paths (e.g., [17] and [16]). However, other criteria can be defined. A local criterion could be used and a path minimizing the maximum energy used by any single node of the path should be preferred .

To this end, in order to increase the network lifetime, ENOLSR protocol uses the node residual energy for the routing process (equation 1).

In the following sub-sections, simulations run for 70 sec. Nodes are nodes moves randomly according to the Random Waypoint (RWP) mobility model [5]. Nodes velocity can reach 40m/s and the pause time is equal to 10sec. We choose the energy model defined in NS to model nodes energy consumption with *(Pt_consume= 3; Pr_consume= 2; P_idle=0.07; P_sleep =0.6; P_transition=0.5)*. Nodes initial energy is fixed to 160. For comparison, we measure the average energy for nodes in *MPRSet* for both *OLSR* and *ENOLSR* protocols.

As expected, our energy-based model prolong the network lifetime (see Fig. 8).

For static nodes, the purely standard model (standard version of *OLSR*) seem very inefficient. In such cases, the same MPR nodes would always be selected over and over again and their energy would drain out very rapidly.

In summary, the *EN-OLSR* model is able to consider the tradeoff between network lifetime and delay. Compared to the connectivity and the OLSR models, EN-OLSR is able to perform better in terms of network lifetime since a set of optimal MPR nodes is selected.

Thus, our contribution appears more in an environment where the nodes are intelligent and therefore does not revel true information during the process of MPR selection for fear they lose their energy. So, the generalized criterion is designed to cope with selfish nodes.

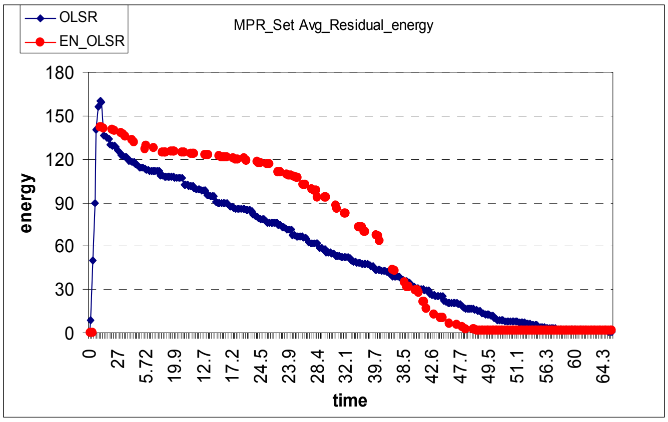

Figure 8 MPRSet average residual energy for OLSR & ENOLSR

4 Conclusion

Satisfying QoS requirements in MANETs are the key functions for multimedia applications. In this paper we have discussed different approaches used to provide QoS enhancements in OLSR. Our proposed combined metric attempts to make use of available resources to find the most optimal path based on mobility, bandwidth and energy parameters.

The proposed metric is expected to efficiently support real-time multimedia traffic with different QoS requirements. Simulation results show that the proposed OLSR variants perform well than the QOLSR protocol which is a well known OLSR QoS extension.

The next step is to apply our proposed approach to other adhoc routing protocols and also to adapt our developed algorithms to Wireless Sensor Network routing protocols

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