Analysis of MPR Selection in the OLSR Protocol*

Dang Nguyen and Pascale Minet
HIPERCOM project
INRIA Rocquencourt, France
{dang-quan.nguyen, pascale.minet}@inria.fr

Abstract

Mobile ad hoc networks have very attractive intrinsic qualities. However they will be adopted only if they are able to support applications with QoS requirements. They should provide a route providing the QoS requested by a flow. The OLSR routing protocol can be extended for that purpose. OLSR relies on multipoint relay (MPR) selection that has an important effect on the routing protocol's performances. Indeed, the overhead generated by the OLSR protocol and more particularly the flooding efficiency depend on MPR selection. Moreover, MPRs are used as intermediate nodes in the routes. The analysis of MPR selection presented in this paper, gives quantitative results and also takes QoS support into account. Simulations on large and dense networks show that our analysis is highly accurate.

1. Introduction

Mobile ad hoc networks have shown to be increasingly interesting due to their intrinsic qualities such as user mobility, environment adaptability,... Because of the limited radio range, they are generally multihop. Therefore, routing protocol is required in order to achieve communications between users in ad hoc networks.

The OLSR routing protocol [1] has been standardized at IETF. OLSR is based on the MPR (Multipoint Relay) concept to offer an efficient flooding technique and to build shortest routes. However, ad hoc networks should support application with QoS requirements such as multicast applications, VoIP,... The MPR selection according to native OLSR is unable to build routes satisfying a given QoS request, because it only allows to build the shortest routes which do not take into account any other route metrics like available bandwidth, delay,...). That is why, the MPR selection should be modified to provide QoS support as done in [3]. Whereas there are already existing analysis of MPR selection, in this paper, we extend the MPR selection analysis to take into account QoS support. We then present quantitative results obtained by simulations and compare them with our analytical results.

The paper is organized as follows. In section 2, we recall the main principles of the OLSR protocol, detailing the MPR selection. We also present analytical results concerning MPR selection in related works. In section 3, we first define the QoS MPR selection algorithm. We then establish new analytical results for this QoS MPR selection and compare them with the MPR selection. These results are validated by simulations on large and dense networks. In section 4, we focus on the flooding optimization using MPR retransmissions and compare it with a flooding technique based on QoS MPR retranmissions. We compare the number of retransmissions of a flooded message using both techniques. We notice that MPR flooding offers a better optimization than QoS MPR. Finally, we conclude this paper in section 5.

2. Related work

In this section, we present the context of our work. First, we describe the OLSR routing protocol in ad hoc networks. The main part of this protocol is a flooding mechanism based on *Multipoint Relay* (MPR) retransmissions. We then present some existing works on MPR performance analysis in term of flooding efficiency and overhead consideration.

2.1. The OLSR protocol

OLSR (Optimized Link State Routing) [1] is an optimization of a pure link state routing protocol. It is based on the concept of *multipoint relays* (*MPRs*). First, using *multipoint relays* reduces the size of the control messages: rather than declaring all its links to all nodes in the network, a node declares only the set of links with its neighbors that have selected it as "*multipoint relay*". The use of *MPRs* also minimizes flooding of control traffic. Indeed only *multipoint relays* forward control messages. This technique sig-

---

*This study is funded by DGA/CELAR (French Ministry of Defence) in MANET project. Technical point of contact: thierry.plesse@dga.defense.gouv.fr

21st International Conference on
Advanced Information Networking and Applications Workshops (AINAW'07)
0-7695-2847-3/07 $20.00 © 2007 IEEE

nificantly reduces the number of retransmissions of broadcast control messages [2]. The two main OLSR functionalities, Neighbor Discovery and Topology Dissemination, are now detailed.

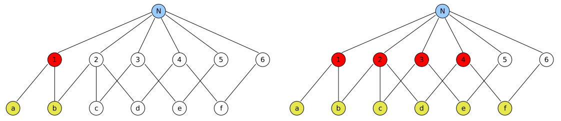
2.2. OLSR main functionalities

2.2.1 Neighborhood discovery

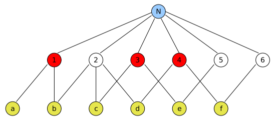
To detect its neighbors with which it has a direct link, each node periodically broadcasts *Hello* messages, containing the list of neighbors known to the node and their link status (*symmetric, asymmetric, multipoint relay or lost*). The *Hello* messages are received by all one-hop neighbors, but are not forwarded. They are broadcast once per refreshing period "*Hello_interval*". Thus, *Hello* messages enable each node to discover its one-hop neighbors, as well as its two-hop neighbors. On the basis of this information, each node independently selects its own set of *multipoint relays* (MPR) among its one-hop neighbors such that the *multipoint relays* cover (in terms of radio range) all two-hop neighbors.

- **MPR selection algorithm:** It proceeds in three steps:

1. A node N_i first selects as MPRs all its neighbors that are the only neighbors of a two-hop node from N_i.
2. It then selects as MPR a neighbor that has the largest count of uncovered two-hop nodes. This step is repeated until all two-hop nodes are covered.
3. Finally, any MPR node N_j such that the MPR set excluding N_j covers all two-hop nodes is discarded.



(a) Step 1. (b) Step 2.



(c) Step 3.

Figure 1. Selection of MPRs by node N

Figure 1 illustrates the different steps of the MPR selection algorithm run by node N. In the first step, node N selects node 1 as its MPR, because it is the only neighbor able to reach node a. In step 2, node N successively selects node 2 because it covers two uncovered nodes and has the highest degree, then node 3 to cover node e and finally node 4 to cover node f. In step 3, node N removes node 2. Its MPRs are nodes 1, 3 and 4.

The *MPR* set is computed whenever a change in the one-hop or two-hop neighborhood is detected. In addition, each node M maintains its "*MPR selector set*". This set contains the nodes that have selected M as an *MPR*.

2.2.2 Topology dissemination

Each node of the network maintains topological information about the network obtained by means of *TC (Topology Control)* messages. Each node M selected as a *multipoint relay* broadcasts a *TC* message at least every "*TC_interval*". The *TC* message originated from node M declares the set of nodes having selected M as MPR. The *TC* messages are flooded to all nodes in the network and take advantage of *MPRs* to reduce the number of retransmissions. To optimize flooding, the OLSR forwarding rule is used:

- **OLSR Forwarding rule**: *Any node N_i forwards a broadcast message only if it is received for the first time from a node having selected N_i as MPR.*

Thus, a node is reachable either directly or via its *MPRs*. The neighbor information and the topology information are refreshed periodically, and they enable each node to compute the routes to all known destinations. These routes are computed with Dijkstra's shortest path algorithm. Hence, they are optimal as concerns the number of hops.

2.3. MPR analysis

Several existing analysis have been done on MPR selection and MPR flooding performances. In [8], the authors have shown that the number of MPR selected per node is in $\mathcal{O}(n^{\frac{1}{3}})$ in a 2-dimension network domain, with n the network density (or average number of neighbors per node). They also show that the number of retransmissions of a flooded message using MPR flooding technique is in $\mathcal{O}(T \times n^{-\frac{2}{3}})$, with T the total number of nodes in the network. In [9], the authors have provided a lower and super bounds of the number of MPR selected per node in function of the network density. They also gave analytical results on the performance of MPR flooding in term of reliability. However, at this time we are not aware of any analytical work on MPR selection with consideration to quality of service issue. This paper aims to give an analytical results on MPR selection based on a specific metric for a QoS purpose such as bandwidth, delay,.... We name it *QoS MPR selection*. These results are then validated by simulations on large and dense networks and are compared with MPR selection.

3. MPR selection analysis

In this section, we present our analysis of MPR selection. First, we consider a particular MPR type called QoS MPR that are nodes selected as MPR for quality of service purpose (i.e. selection based on bandwidth, delay or other criterion). Then, we consider flooding performance in term of overhead for routing protocols that use MPR flooding technique such as OLSR, OSPF-MPR [4].

3.1. QoS MPR selection

In order to compute routes that satisfy a specific QoS demand, each node must have a knowledge of the partial QoS topology of the network (i.e. partial topology enhanced with QoS information on the nodes). This QoS topology is required by QoS routing protocols designed for ad hoc networks such as QOLSR [6] and [7]. In these routing protocols, each node must then compute its QoS MPR set and must flood them to the entire network. The idea of QoS MPR selection is to extract from the one-hop neighbor set a subset of nodes that have the best QoS metric. The condition is that each two-hop neighbor must be covered by at least one selected one-hop neighbor having the best QoS metric. The QoS MPR selection algorithm is presented in [5] and can be described as follows.

- **QoS MPR selection algorithm:**

1. Sort all one-hop neighbors in decreasing order of QoS metric (ex.: available bandwidth, inverse of delay,...).
2. Consider each one-hop neighbor in that order: this neighbor is selected as QoS MPR iff it covers at least one two-hop neighbor that has not yet been covered by all the previous QoS MPRs.
3. Mark all neighbors of the selected node as covered. Repeat step 2 until all two-hop neighbors are covered.

3.2. QoS MPR modeling

We can state the following properties for the QoS MPR selection algorithm.

Property 1 *For a 1-dimension network domain, the average number of neighbors selected as QoS MPR is in* $\mathcal{O}(\log(n))$*, with* n *the average network density.*

Proof: We prove this property based on the following remark. The QoS MPR selection process can be seen as the arrival process of pre-sorted nodes. Let be $\{N_1, N_2, \ldots, N_n\}$ the set of N's one-hop neighbors sorted by decreasing order of QoS value. In the i^{th} step, node N_i is selected as QoS MPR iff its distance to node N is greater than this of any previous node N_j with $j < i$; so that N_i can cover more nodes in the two-hop area. Therefore, the probability of a new node to be selected as QoS MPR by node N is 2^{-m} where m is the number of nodes already selected as QoS MPR. If $\mathrm{d}n$ is the infinitesimal quantity of node arriving in N's one-hop neighborhood in the sorted order, and $\mathrm{d}m$ is the number of nodes among those neighbors that will be selected as QoS MPR, we have: $\mathrm{d}m = \frac{1}{2^m}\mathrm{d}n$.

Thus, the total number of nodes selected as QoS MPR is $m = \mathcal{O}(\log(n))$ where n is the average number of one-hop neighbors. ■

Property 2 *For a 2-dimension network domain, the average number of neighbors selected as QoS MPR is in* $\mathcal{O}(n^{1/3}\log(n))$*, with* n *the average network density.*

Proof: Let us consider a node N selecting its QoS MPR set. We proceed in two steps:

- First, we focus on the minimal set of QoS MPRs (denoted $\mathcal{S}_1$) that must cover all two-hop neighbors. Thus, they are located on the circle centered on N with radius equal to N's coverage range. We deduce that the number of nodes in this set is in the order of $\mathcal{O}(n^{1/3})$ as shown in [8].
- Secondly, we are now interested in other neighbors selected as QoS MPRs strictly inside this border (denoted $\mathcal{S}_2$). The selection process of these nodes is done according to the decreasing order of their QoS values. In other words, a new node is selected as QoS MPR (it joins $\mathcal{S}_2$) iff it has the best QoS value among neighbors not yet chosen as QoS MPR and it must cover one or more two-hop neighbors still uncovered by $\mathcal{S}_2$.

In order to compute $\mathcal{S}_2$'s size, we consider the sector formed by two segments NN_i and NN_{i+1} on the disk of N (centered on N and having as radius N's coverage range). Nodes N_i and N_{i+1} are in $\mathcal{S}_1$ (i.e. on the border) and immediately next to each other. The angle (NN_i, NN_{i+1}) is denoted α. We have $\alpha = \mathcal{O}(n^{-1/3})$ becoming small when n increases.

The process of QoS MPR selection in the sector can be seen as the arrival process of neighbors within this sector, following the decreasing order of QoS value of neighbors. In this order, a new node is selected as QoS MPR iff it covers one or more two-hop neighbors still uncovered by the previously arrived nodes. As all nodes are assumed to have the same coverage range, this new node covers more two-hop neighbors if its distance to node N is greater than all the distances from the previously arrived nodes to N. When the α angle becomes small enough, we can apply the property 1 to this sector and deduce the number of

QoS MPR selected in this sector to be $\mathcal{O}(\log(n))$. With $\mathcal{O}(n^{1/3})$ the number of sectors in the disk of N, we obtain the desired result. ■

Property 3 *For any network configuration with average density n, if the average number of MPR (resp. QoS MPR) selected per node is in $\mathcal{O}(f(n))$ and $\lim_{n\to\infty}\frac{f(n)}{n} = 0$, the following properties can be stated:*

1. *The total number of nodes chosen as MPR (resp. QoS MPR) (by at least one neighbor) is $T \times (1 - \mathrm{e}^{-\mathrm{c}f(n)})$, with T the total number of nodes in the network and c a constant. We denote this quantity M (resp. M_{QoS}) for total number of MPR (resp. QoS MPR) in the network.*
2. *The average number of MPR selectors (resp. QoS MPR selectors) per MPR (resp. QoS MPR) is also in $\mathcal{O}(f(n))$.*

Proof: We proceed in two steps. In the first step, let $\mathcal{O}(f(n)) = \mathrm{c}f(n)$ be the average number of QoS MPR selected by a given node. Therefore, the probability that a node is chosen as QoS MPR by a given neighbor is $\frac{\mathrm{c}f(n)}{n}$. Given the fact that each node selects its QoS MPR set independently of other nodes, we deduce that the probability that a node is not chosen as QoS MPR by any node of its neighbors is $\left(1 - \frac{\mathrm{c}f(n)}{n}\right)^n = \left(\left(1 - \frac{\mathrm{c}f(n)}{n}\right)^{\frac{n}{\mathrm{c}f(n)}}\right)^{\mathrm{c}f(n)} = \mathrm{e}^{-\mathrm{c}f(n)}$, with $\lim_{x\to 0}(1-x)^{\frac{1}{x}} = \frac{1}{\mathrm{e}}$. Thus, the total number of nodes in the network that are chosen as QoS MPR by at least one neighbor node is $T \times (1 - \mathrm{e}^{-\mathrm{c}f(n)})$.

In the second step, let I_{MS} the number of QoS MPR selector instances in the network (i.e. the sum of the size of QoS MPR selector set at each node). Let I_M the number of QoS MPR instances in the network (i.e. the sum of the size of the QoS MPR set at each node). We have $I_{MS} = I_M$ because everytime a node selects a neighbor as QoS MPR, it automatically becomes a QoS MPR selector of this node. Having $\frac{I_M}{T} = \mathrm{c}f(n)$, we deduce that the average number of QoS MPR selectors per QoS MPR is: $\frac{I_{MS}}{T\times(1-\mathrm{e}^{-\mathrm{c}f(n)})} = \frac{I_M}{T} \times (1 - \mathrm{e}^{-\mathrm{c}f(n)})^{-1} \approx \mathrm{c}f(n)(1 + \mathrm{e}^{-\mathrm{c}f(n)}) \approx \mathrm{c}f(n)$, with $\lim_{\mathrm{n}\to+\infty}\frac{\mathrm{f(n)}}{\mathrm{e}^{\mathrm{f(n)}}} = 0$. ■

Lemma 1 *From the above property, the average number of QoS MPR selectors per QoS MPR is in $\mathcal{O}(n^{1/3}\log(n))$.*

3.3. Model validation

We now validate our analytical results by simulations on large and dense networks. For each simulation, the network is made of nodes randomly located with a uniform distribution on a 2-dimension area. The QoS metric at each node is also attributed randomly and with a uniform distribution. The simulations are repeated for different densities of the network (different average numbers of neighbors per node). No MAC layer is used, and the network suffers no control packet loss. Therefore, all nodes instantaneously and accurately acquire neighborhood information. Each node in the network computes its QoS-MPR set based on the QoS-MPR selection algorithm provided earlier in this paper. We compute the average values (size of QoS MPR set, size of QoS MPR selector set,…) on all nodes in the network. For a network-wide broadcast message, we assume that there is no transmission collision, thus no packet loss. All nodes in the neighborhood of a transmitter receive a copy of the message. These nodes will then decide to retransmit or not that message according to the QoS-MPR retransmission rule. We count the number of retransmissions in the whole network. The simulator code is available at [10].

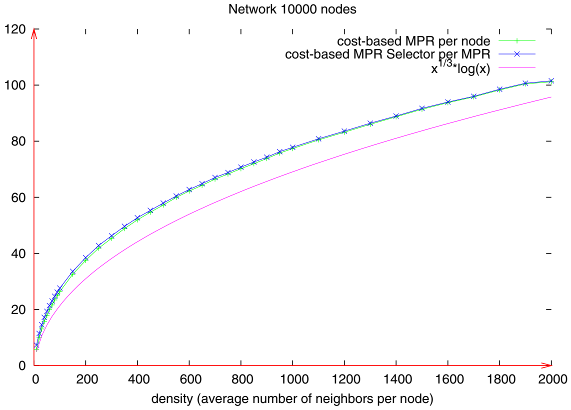


Figure 2. Average number of QoS MPR, QoS MPR selectors

Figure 2 shows the average number of QoS MPR selectors and MPR selectors for different networks densities in a network of 10000 nodes. This figure shows that for a large and dense network, the number of QoS MPR selected per node is almost the same as the number of QoS MPR selectors per QoS MPR. The trend of these curves is also shown to be $\mathcal{O}(n^{1/3}\log(n))$.

Figure 3 shows the total number of QoS MPRs in the network, comparing simulation results and analytical results (with the constant $\mathrm{c} = 0.15$). The network is made of 10000 nodes and the density varies from 10 to 2000 neighbors per node. We see that the simulations confirm the trend obtained by analysis of the number of QoS MPRs in the whole network.

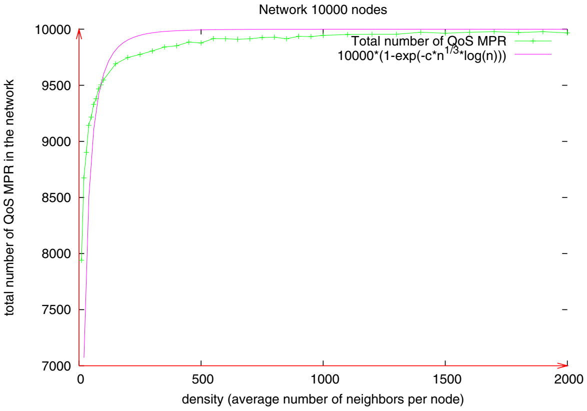


Figure 3. Total number of QoS MPRs in the network

4. MPR flooding analysis

In this section, we compare the techniques of MPR flooding and QoS MPR flooding in term of overhead. In other words, we compute the number of retransmissions per flooded message with both techniques.

4.1. MPR flooding vs QoS MPR flooding

We first describe the QoS MPR forwarding rule that is used by the QoS MPR flooding technique. We then analyze the flooding performance of QoS MPR flooding with regard to the MPR flooding technique used by OLSR.

- **QoS MPR forwarding rule:** For each flooded message received by a QoS MPR node, the message is forwarded (broadcast) iff it has been received for the first time from a QoS MPR selector of this QoS MPR node.

We can notice that the QoS MPR forwarding rule is the same as the MPR forwarding rule when the QoS MPRs are substituted by MPRs.

Property 4 *In a network made of T nodes and of density n, the number of retransmissions of a flooded message using the QoS MPR flooding technique is lower bounded by* $\mathcal{O}(T \times n^{-2/3} \text{log} n)$.

Proof: Each transmission of a flooded message covers all nodes in a disk of radius equal to the radio range. The flooded message will be retransmitted by the QoS MPR nodes of the sender if it is received for the first time from an QoS MPR selector. In order to cover all the network area, we need at least $\frac{T}{n}$ disks. For each disk, there are $\mathcal{O}(n^{1/3} \text{log}(n))$ QoS MPRs that receive the message for the first time. Then they will retransmit it. Thus, the number of retransmissions of a flooded message by means of QoS MPRs is higher than $\mathcal{O}(T \times n^{-2/3} \text{log} n)$. ■

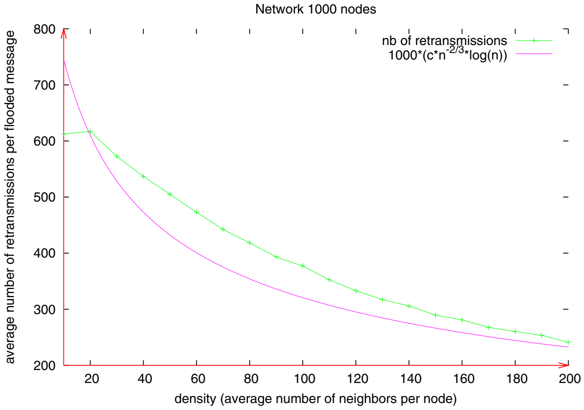


Figure 4. Number of retransmissions per flooded message

Figure 4 shows the average number of retransmissions per flooded message using QoS MPR flooding technique. We run the simulations on a network made of 1000 nodes with density varying from 10 to 200 neigbors per node. The simulations confirm the results obtained by analytical model for highly dense networks (more than 100 neighbors per node).

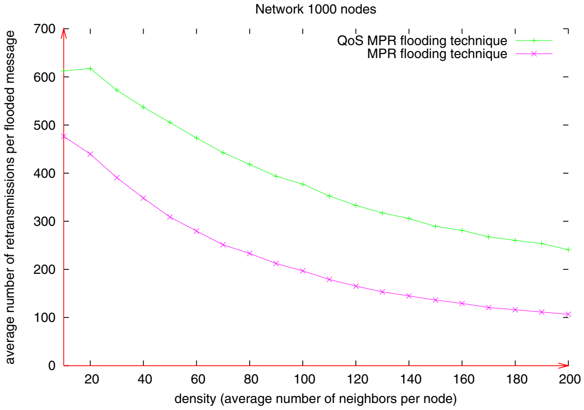


Figure 5. Number of retransmissions per flooded message: QoS MPR flooding vs. MPR flooding

In [8], the authors indicate that when using MPR flooding technique, a flooded message is retransmitted $\mathcal{O}(T \times n^{-2/3})$ times in the whole network, with T the total number of nodes and n the network density. Figure 5 compares, by simulations, the number of retransmissions per flooded message using QoS MPR flooding and MPR flooding techniques. The network is made of 1000 nodes with density varrying from 10 to 200 neigbors per node. The simulation shows that QoS MPR flooding generates more retransmissions per flooded message than MPR flooding (by a factor of $\log n$).

The flooding performances highlight the benefits brought by MPR flooding instead of QoS MPR flooding. This conclusion implies that the network will need both MPRs and QoS MPRs in order to support QoS and to offer optimized flooding.

4.2. Topology dissemination modeling

We are now interested in the topology dissemination locally perceived by each node of the network, i.e. the number of TC messages each node must retransmit according to the MPR (or QoS MPR) flooding technique.

Property 5 *With the MPR (resp. QoS MPR) flooding technique, the number of retranmissions of TC messages per node is equal to the number of retransmissions of each TC message in the whole network.*

Proof: Let us consider a TC message flooded in the network. This TC message is retransmitted r times with $r = \mathcal{O}(T \times n^{-2/3}\log n)$ in case of QoS MPRs and $r = \mathcal{O}(T \times n^{-2/3})$ in case of MPR. During each TC period, each MPR (resp. QoS MPR) generates a TC message. Thus, there are $r \times M$ (resp. $r \times M_{QoS}$) TC messages in the whole network. As each MPR (resp. QoS MPR) retransmits only once a TC message if it is received for the first time, the number of TC messages retransmitted by an MPR (resp. QoS MPR) is $(r \times M)/M$ (resp. $(r \times M_{QoS})/M_{QoS}$). ∎

This result implies that if a node in the network locally monitors the number of TC messages it retransmits during a TC interval; it can then deduce how far (in term of number of retransmissions) each single TC message is forwarded. The node can deduce the diameter of its network using this local information.

5. Conclusion

In this paper, we have computed the complexity of the selection of QoS MPRs, i.e., multipoint relays selected according to a QoS metric as for instance the available bandwidth, the delay, the loss rate, the residual energy. We have shown that the average number of neighbors selected as QoS MPRs is in $\mathcal{O}(n^{1/3}\log n)$, with n the average number of neighbors per node. This result is corroborated by simulations in very large and dense networks (up to 10 000 nodes with densities up to 2000).

It has been shown in [8] that the average number of neighbors selected as MPRs is in $\mathcal{O}(n^{1/3})$. Our result shows that the number of QoS MPRs is higher than the number of MPRs by a factor of $\log n$. Hence, we recommend to use:

- MPRs to optimize network flooding and,
- QoS MPRs to build routes meeting QoS constraints.

This has been done in the QoS support [3] we have designed and implemented on a real platform. This QoS support conciliates an optimized network flooding and an interference aware QoS routing.

References

[1] C. Adjih, T. Clausen, P. Jacquet, A. Laouiti, P. Minet, P. Muhlethaler, A. Qayyum, L. Viennot: *Optimized Link State Routing Protocol*, RFC 3626, IETF, October 2003.

[2] A. Qayyum, L. Viennot, A. Laouiti: *Multipoint relaying: An efficient technique for flooding in mobile wireless networks*, INRIA research report N° 3898, March 2000, INRIA Rocquencourt, France. http://www.inria.fr/rrrt/rr-3898.html

[3] D-Q. Nguyen, P. Minet: *QoS Support and OLSR Routing in a Mobile Ad Hoc Network*, IEEE int. Conference on Networking ICN'06, Mauritius, April 2006.

[4] E. Baccelli, T. Clausen, P. Jacquet: *OSPF MPR Extension for Ad Hoc Networks*, IETF draft, November 2006.

[5] Y. Ge, T. Kunz, L. Lamont: *Quality of Service Routing in Ad Hoc Networks using OLSR*, the 36^{th} Hawaii Int. Conference on System Sciences, HICSS-36, Hawaii, USA, January 2003.

[6] H. Badis, K. Al Agha: *QOLSR, QoS Routing for Ad Hoc Wireless Networks Using OLSR*, European Transactions on Telecommunications, Vol. 15, No. 4, 2005.

[7] L. Moraru, D. Simplot-Ryl: *QoS Preserving Topology Advertising Reduction for OLSR Routing Protocol for Mobile Ad Hoc Networks*, in Proc. 3rd conf. on Wireless On demand Network Systems and Services (WONS 2006), Les Mnuires, France, 2006.

[8] P. Jacquet, A. Laouiti, P. Minet, L. Viennot: *Performance analysis of OLSR Multipoint Relay flooding in two ad-hoc wireless network models*, INRIA research report, N° 4260, September 2001, http://www.inria.fr/rrrt/rr-4260.html

[9] A. Busson, N. Mitton, E. Fleury: *Analysis of the Multi-Point Relay Selection in OLSR and Implications*, In the 4th Mediterranean Ad Hoc Networking Workshop, MED-HOC-NET 05, Porquerolles, France, June 2005.

[10] D-Q. Nguyen: *Simulator code*, http://ndquan.free.fr/QoS-MPR-Computation.tar.bz2