QoS for Ad hoc Networking Based on Multiple Metrics: Bandwidth and Delay

Hakim Badis[1,2] , Anelise Munaretto [3], Khaldoun Al Agha[1,2] and Guy Pujolle[3]
[1]LRI Laboratory, University of Paris XI, Orsay, France {badis, alagha}@lri.fr
[2]INRIA Laboratory, Rocquencourt, France
[3]LIP6 Laboratory, University of Paris VI, Paris, France {anelise.munaretto, guy.pujolle}@lip6.fr

Abstract: A link state routing approach makes available detailed information about the connectivity and the condition found in the network. OLSR protocol is an optimization over the classical link state protocol, tailored for mobile ad hoc networks. In this article, we design a QoS routing scheme over OLSR protocol, called QOLSR. In our proposal, we introduce more appropriate metrics than the hop distance used in OLSR. In order to improve quality requirements in routing information, delay and bandwidth measurements are applied. The implications of routing metrics on path computation are examined and the relational behind the selection of bandwidth and delay metrics are discussed. We first consider algorithms for single-metric approach, and then present a distributed algorithm for multiple metrics approach. We also present a scalable simulation model close to real operations in Ad Hoc Networks. The performance of our protocol are extensively investigated by simulation. Our results indicate that the attained gain by our proposal represent an important improvement in such mobile wireless networks.

I. INTRODUCTION

The problem of QoS routing for mobile Ad hoc networks is studied. Most routing protocols for the mobile Ad hoc networks (MANETs) [1], such as OLSR [2], AODV [3], DSR [4], are designed without explicitly considering QoS of the routes they generate. The number of hops is the most common criterion adopted by such proposed routing protocols. It is becoming increasingly clear that such routing protocols are inadequate for multimedia application, such as video conferencing, which often require guaranteed QoS. QoS routing requires not only finding a route from a source to a destination, but a route that satisfies the end-to-end QoS requirement, often given in terms of bandwidth or delay. QoS is more difficult to guarantee in Ad hoc networks than in most other type of networks, because the wireless bandwidth is shared among adjacent nodes and the network topology changes as the nodes move [5].

The link state routing approach makes available detailed information about the connectivity and the topology found in the network. Moreover, it increases the chances that a node will be able to generate a route that meets a specified set of requirement constraints. OLSR protocol is an optimization over the classical link state protocol for the mobile Ad hoc networks. It performs hop by hop routing, i.e. each node uses its most recent information to route a packet. This paper aims at specifying a QoS-enhanced OLSR [2] routing in Mobile Ad Hoc Networks, the QOLSR. We propose to implement QoS functionality to deal with limited available resources in a dynamic environment.

This paper is organized as follows. Section II depicts the metrics measurements proposed by the QOLSR protocol. The routing table calculation of QOLSR is presented in Section III. Therefore, we validate the proposal by means of performance evaluation (Section IV). Finally, we present our conclusions (Section V).

II. METRICS MEASUREMENTS

The delay and bandwidth metrics are taking into account as QoS constraints for the proposed QOLSR protocol. Such metrics are included on each routing table entry corresponding to each destination. We use the IEEE 802.11b as the medium access control to achieve the bandwidth measurement.

A. Delay Metric

Each node includes in the *Hello* message, during the neighbor discovery performed by the QOLSR, the creation time of this message. When a neighbor node receives this message, it calculates the difference between such a time and the current time, which represents the $\mathrm{measured\_delay}$. Such one-way $\mathrm{measured\_delay}$ includes the queuing time, the transmission time, the collision avoidance time and the control overhead time. Otherwise, the measurement of the one-way delay avoids the increase of traffic load at adding acknowledgment messages to the QOLSR protocol. Therefore, we suppose a synchronized network in our works.

Due to the characteristics of sparse ad hoc networks, classical clock synchronization algorithms are not applicable. Meanwhile, the aim of this paper is not to solve the synchronization issue. Time synchronization in Ad Hoc Networks is a wide subject of research, e.g. the work presented in [6].

The proposed QOLSR calculates the average delay with one of the two proposed methods: AV, RTT.

In a first work [7], we use Average delay and Variance method (AV) during the routing calculation, as show in Figure 3.

In this paper, we propose a new approach, the RTT method. The average delay is calculated through the following formula: $\mathrm{Average\_delay} = \alpha \times \mathrm{Average\_delay} + (1 - \alpha) \times \mathrm{measured\_delay}$. Then, the first results of such implementation. Figure 4 depicts the best performance achieved using $\alpha = 0.4$.

B. Bandwidth Metric

A remarkable work is presented in [8], considering the acknowledgement time from the data packets. For our approach, the bandwidth will be calculated between a node and its neighbors having direct and symmetric link. We consider for our analysis data packets and signaling traffic that also use the available bandwidth and then must be taken into account.

Let be a node i and j its neighbor, then we define our available bandwidth for i to j through the following formula:

$\mathrm{Bw}_{(i,j)} = (1-u) \times \mathrm{Throughput}_{(i,j)}$, where u is the link utilization.

The throughput seen by one packet of S bits can be calculated as:

$$\mathrm{Throughput}_{packet} = \frac{S}{t_q + (t_S + t_{CA} + t_{Overhead}) \times R + \sum_{r=1}^{R} B_T}$$

where: t_q is the Mac queuing time, t_S the Transmission on time of S bits, t_{CA} the Collision Avoidance phase time, $t_{Overhead}$ the Control Overhead time (e.g. RTS, CTS, etc), R the Number of necessary transmissions, B_T the Backoff time for retransmission r. This formula reveals some undesirable characteristics such as packet size dependence and high variance due to random per packet effects. To increase statistical robustness of the measurements, a packet window of 16 or 32 samples (packets) is adequate.

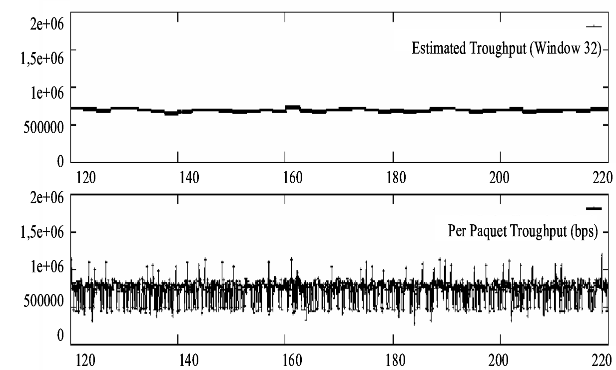

Fig. 1. Window operation

To illustrate, Figure 1 shows where the high variance per packets measurements is aggregated on a window of 32 packets.

The idle time and window duration are calculated to produce the link utilization factor and the permissible throughput measurement as:

$$\frac{\mathrm{idle\_time\_in\_window}}{\mathrm{window\_duration}} \times \mathrm{Throughput\_measured}$$

III. Routing table calculation

Let $G = (V, E)$ be the network with $|V|$ nodes and $|E|$ arcs and $p = (i, j, k, ..., q, r)$ a directed path.

The first approach presented uses one single metric in route decisions such as hop count or delay or available bandwidth.

For delay metric, each arc (i, j) in the path p is assigned a real number del_{ij}. When the arc (i, j) is inexistent or j is not a MPR of i (Referring to the OLSR routing mechanism), then $\mathrm{del}_{ij} = \infty$. Let $\mathrm{del}(p) = \mathrm{del}_{ij} + \mathrm{del}_{jk} + ... + \mathrm{del}_{qr}$. The routing problem is to find a path $p*$ between i and r so that $\mathrm{del}(p*)$ is the minimum. In such a case, we use the well-known Dijkstra routing algorithm.

For bandwidth metric, each arc (i, j) in the path is assigned a real number Bw_{ij}. When the arc (i, j) is inexistent or j is not a MPR of i, $\mathrm{Bw}_{ij} = 0$. Let $\mathrm{Bw}(p) = \min\{\mathrm{Bw}_{ij}, \mathrm{Bw}_{jk}, ..., \mathrm{Bw}_{qr}\}$. The routing problem is to find a path $p*$ between i and r that maximizes $\mathrm{Bw}(p*)$. In order to implement such a metric, we propose a variant-Dijkstra algorithm.

The second approach treats each metric individually. Such approach is not feasible due to the algorithm complexity. The problem of finding a path with n additive and m multiplicative metrics is *NP-complete* if $n + m \geq 2$ [9]. Including a single metric, the best path can be easily defined. Otherwise including multiple metrics, the best path with all parameters at their optimal values may not exist. For example, a path with both maximum bandwidth and minimum delay may not necessarily exist. Thus, we must define precedence between bandwidth and delay. Queuing delay is more dynamic, thus bandwidth is probably often considered as more important. If the bandwidth requirement cannot be met, the chance is that queuing delay will also be high. Our strategy is to find a path with maximum bandwidth (a widest path), and when there is more than one widest path, we choose the one with the shortest delay. We refer to such a path as the shortest-widest path. In our proposed work, we will introduce an algorithm of shortest-widest path. The widest path problem is to find a path $p*$ between i and r that maximizes $\mathrm{Bw}(p*)$. The widest path problem can be solved with similar technique used in shortest path algorithms such as Dijkstra's routing algorithm or Bellman-Ford algorithm.

IV. Performance evaluation

In this section, we evaluate the performance of QOLSR applying multiple metrics. We have carried out simulations to analyze OLSR and QOLSR in different configurations and scenarios. We use the OPNET simulator for our evaluation.

A. Simulation Model

The simulation model introduced in [10] aims the flexibility and hence it implements several parameters:

- The network parameters: number of nodes, region, inter-arrival, etc;
- The OLSR parameters: $Hello\ interval$, $TC\ interval$, use of MPRs (on/off), etc;
- The QoS parameters: variation threshold, RTT (on/off), routing calculation technique, etc;
- The CSMA/CA parameters: radio range, noise ratio, RTS/CTS, signal decay, etc;
- The mobility parameters: speed-min, speed-max, length mobility intervals, etc.

The simulation model is very close to a real Ad-Hoc network operations. At each time, we can detect the position of mobiles by our mobility model. Each node is represented by a subqueue and placed in the region by randomly selecting its x and y co-ordinates. With our method, the simulation model is very optimized that enables to reduce the CPU time and consequently to increase the time of simulation.

The random mobility model proposed is a continuous-time stochastic process. Each node's movement consists of a sequence of random length intervals, during which a node moves in a constant direction at a constant speed. A detailed description can be found in [10].

B. Implemented Algorithm

In order to achieve the performance evaluation including delay and bandwidth metrics in the QOLSR proposed protocol, we implement the algorithm as represented in Figure 2.

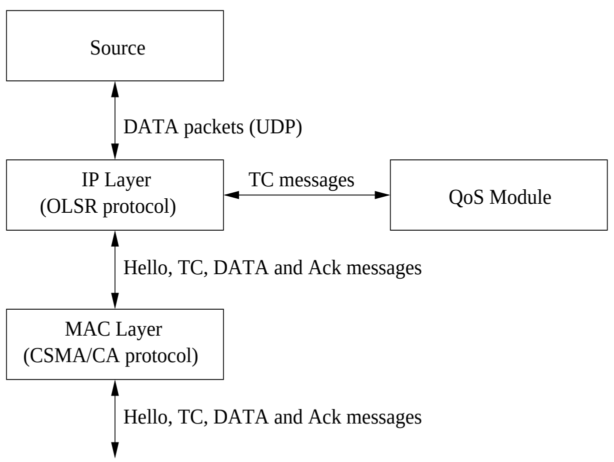

Fig. 2. The generic QOLSR scheme

The source layer sends a DATA packet (for instance, an UDP packet) to the OLSR layer with a specified $interarrival$ time. Such DATA packet contains the address of the node, which has originally generated this message. This field should not be confused with the source address from the UDP header, which is changed each time to the address of the intermediate node witch is retransmitting such message. It contains also the destination address and the packet length.

The OLSR layer includes the next hop in DATA packet. The next hop router is identified by the entry of the destination in the host routing table. The OLSR layer sends Hello messages each $Hello\_interval$, TC messages each $TC\_interval$ and DATA messages to the MAC layer. The QoS module maintains for each neighbor a window of 32 packets. It calculates the idle time and window duration to produce the link utilization factor. Before that when OLSR layer sends a TC message, QoS module includes for each MPR selectors, the permissible throughput measurement and the average delay.

The MAC layer transmits the packet using CSMA/CA protocol to its neighbors and forwards such packet to the OLSR layer. Such layer uses an acknowledgment for a point to point packet, as Data packet. However, broadcast packets, as TC messages are not acknowledged.

C. Simulations

The configured parameters in the simulated scenarios are: threshold variance is fixed in 10%, the range transmission is 60 meters, the threshold of the reception is 0,00027 watts and the interarrival time is 60s.

In the first scenario, we perform the evaluation analyzing the average transmission time with AV method, varying the number of mobiles in a region of $100^2 m^2$. We suppose the bandwidth equal to 10kb/s. The results found in such a scenario are shown in the following Figure:

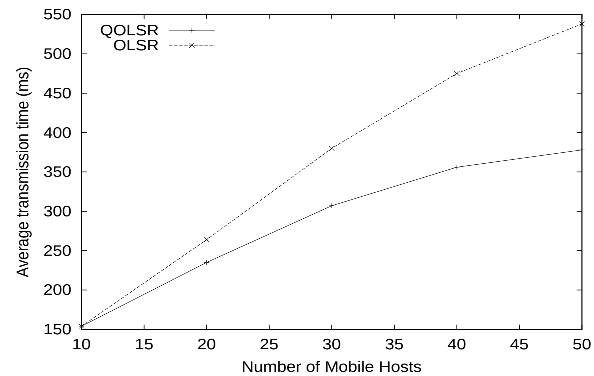

Fig. 3. Average transmission time with AV method

Figures 3 depicts an improvement comparing with the standard OLSR protocol to the average transmission time, i.e., the complete time to a data packet leaves the sender node and arrives in the destination node. As expected, the obtained gain increases (can reach 17.9%) with increasing number of mobiles. The presented results are very interesting, because of in a real wireless network, usually we have an important number of the collision due to the interferences of the radio transmission, and then, the obtained gain can improve the transmission time of such wireless networks.

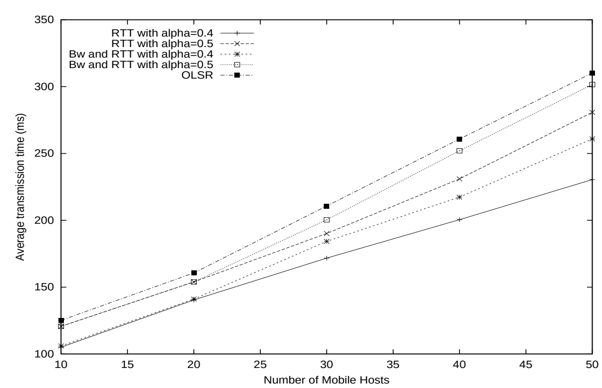

Fig. 4. Average transmission time with RTT method

Figure 4 depicts the average transmission time versus number of mobile nodes comparing four different routing table calculation with the standard OLSR protocol in a $200^2 m^2$ area network and 1Mb/s of bandwidth. The results plotted are:

- RTT with $\alpha = 0.4$: QOLSR with the RTT method, where $\alpha = 0.4$ using the delay as a single metric approach.
- RTT with $\alpha = 0.5$: QOLSR with the RTT method, where $\alpha = 0.5$ using the delay as a single metric approach.
- Bw and RTT with $\alpha = 0.4$: QOLSR with multiple metrics (bandwidth and delay), where $\alpha = 0.4$.
- Bw and RTT with $\alpha = 0.5$: QOLSR with multiple metrics (bandwidth and delay), where $\alpha = 0.5$.

The best performance is achieved using $\alpha = 0.4$. RTT with $\alpha = 0.4$ has the less average time because the routes are chosen with delay which is an additive metric. In this case ($\alpha = 0.4$), we increase the dominance of the last $\mathrm{measured\_delay}$ in the formula: $\mathrm{Average\_delay} = \alpha \times \mathrm{Average\_delay} + (1 - \alpha) \times \mathrm{measured\_delay}$ because of the node's movement. So, we take with more importance the actual topology. However, with $\alpha = 0.5$, the $\mathrm{Average\_delay}$ is the classical average. Bw and RTT with $\alpha = 0.4$ ($\alpha = 0.5$) has less performance than RTT with $\alpha = 0.4$ ($\alpha = 0.5$), because the routes are chosen first with bandwidth and second with delay metric. The bandwidth metric follows the concave composition rule. Then, the distance between the source and destination is not taken into account. Consequently, the end-to-end delay is more important.

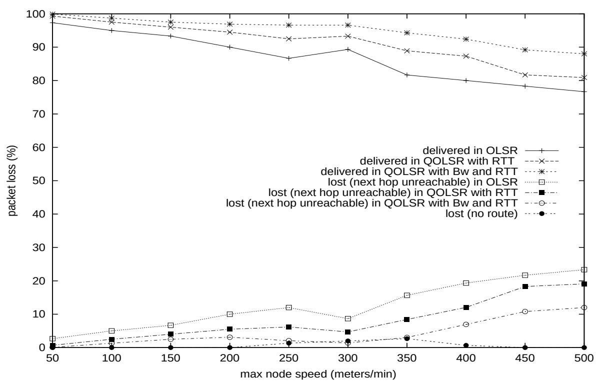

Fig. 5. Data transmitted in varying node speeds

Figure 5 shows the results of our simulation in which the data packets sent and successfully delivered are plotted against the increasing speed. The speed is increased from $50 meters/minute$ ($3Km/hr$) up to $500 meters/minute$ ($30Km/hr$). In this simulation, 50 nodes constitute the network in a region of $1000^2 m^2$, and all the 50 nodes are packet-generating sources. We also keep the movement probability as 0.3, i.e., only 20% of nodes are mobile and the rest are stationary. Each mobile node selects its speed and direction which remains valid for next 60 seconds. We can see that when the mobility (or speed) increases, the number of packets delivered to the destinations decreases. This can be explained by the fact that when a node moves, it goes out of the neighborhood of a node which may be sending it the data packets. There are about 99.92% of packets delivered for QOLSR with Bandwidth (Bw) and delay (del) as metrics at a mobility of 2 meters/minute (99.3% for QOLSR with del and 97.3% for OLSR). At a mobility of 500 meters/minute, 88% of packets delivered for QOLSR with Bw and del as metrics (80.9 % for QOLSR with del and 76.6 % for OLSR). QOLSR with Bw and del as metrics has the highest packets delivered because the routes are chosen with minimal interferences and the next-hops are valid about more than window of 32 packets. The data packets are lost because the next-hop node is unreachable. A node keeps an entry about its neighbor in its neighbor table for about 6 seconds. If a neighbor moves which is the next-hop node in a route, the node continues to forward it the data packets considering it as a neighbor. Also, the next-hop is unreachable if there are interferences. Few of packets are also lost because of unavailability of route and it is the same for OLSR with or without QoS. This happens when a node movement causes the node to be disconnected from the network temporarily, until it re-joins the network again.

V. CONCLUSIONS

This paper presented a Link state QoS routing protocol for Ad hoc networks. In order to improve quality requirements in routing information, delay and bandwidth measurements are applied. The implications of routing metrics on path computation are examined and the rationales behind the selection of bandwidth and delay metrics are discussed. In our simulations, the QOLSR protocol produces better performance comparing with the best effort OLSR protocol.

REFERENCES

[1] "http://www.ietf.org/html.charters/manet-charter.html."

[2] T. Clausen and P. Jacquet, "Optimized Link State Routing Protocol," *In IETF Internet Draft, draft-ietf-manet-olsr-11.txt*, July 2003.

[3] C. Perkins, E. M. Royer and S. R. Das, "Ad Hoc On-Demand Distance Vector routing," *In IETF Internet Draft, draft-ietf-manet-AODV-12.txt*, November 2002.

[4] D. Johnson and Al, "Dynamic Source Routing in Ad Hoc Wireless Networks," *In IETF Internet Draft, draft-ietf-manet-DSR-8.txt*, march 2003.

[5] S. Chakrabarti and A. Mishra, "QoS Issues in Ad Hoc Wireless Networks," *IEEE Communications Magazine*, Febrary 2001.

[6] Kay Römer, "Time Synchronization in Ad Hoc Networks," *In Proceedings of ACM MobiHoc 2001*, October 2001.

[7] A. Munaretto, H. Badis, K. Al Agha and G. Pujolle, "A Link-state QoS Routing Protocol for Ad Hoc Networks," *In the proceedings of IEEE MWCN2002, Stockholm, Sweden*, September 2002.

[8] Kazantzidis and M. Gerla, "End-to-end versus Explicit Feedback Measurement in 802.11 Networks," *In Seventh IEEE Symposium on Computers and Communications*, 2002.

[9] F. Kuipers, P. Van Mieghem, T. Korkmaz and M. Krunz, "An Overview of Constraint-Based Path Selection Algorithms for QoS Routing," *IEEE Communications Magazine*, vol. Vol.40, No.12, December 2002.

[10] H. Badis and K. Al Agha, " Scalable model for the simulation of OLSR and Fast-OLSR protocols ," *Med-hoc-Net*, June 2003.