Using Number of Retransmissions to Improve Routing in Ad-hoc NETworks

Tiguiane Yélémou
Polytechnic University of Bobo Dioulasso,
School of Computer Science, Burkina Faso
Email: tyelemou@gmail.com

Philippe Meseure and Anne-Marie Poussard
University of Poitiers, XLIM CNRS Lab, France
Email: (Philippe.Meseure, anne.marie.poussard)@univ-poitiers.fr

***Abstract*—In this paper, we analyze the effectiveness of usual metrics and Quality of Service (QoS) methods used to improve routing in wireless networks, when considering the erroneous nature of radio links. We first analyze an additive metric based on Bit Error Rate (BER) and we propose a new metric similar to hop-count metric where retransmissions are accurately taken into account. With this number of retransmissions-based metric, the distance between two adjacent nodes will not be 1, but 1 plus the cost of retransmissions required on the link. Our approach is a light and immediate way to evaluate link quality. It does not imply additional network overhead and costly computation. To test the efficiency of this new metric, we have implemented it into the well-known Optimized Link State Routing protocol. Realistic simulation results show that this metric outperforms traditional metrics like the ones based on delay, BER or Expected Transmission Count.**

Keywords*—*Wireless networks; QoS metrics; Routing protocols; OLSR protocol; cross layer approach.

I. Introduction and Motivations

Routing in wireless networks is still an issue. It remains hazardous to guarantee any quality of service (QoS) for such networks. Most algorithms compute paths by relying on a selected metric. This allows them to compare computed paths and find the best. However, most of the used metrics do not take into account all specific characteristics of ad hoc wireless networks such as erroneous links, interference, etc. In this context, a node may need several attempts to transmit data successfully. Unfortunately, retransmissions imply additional delays, decrease throughput and increase communication overhead in the network. In critical cases, communications fail after several attempts.

In order to guarantee a certain level of QoS, routing protocols should be smart enough to pick a stable and good quality communication route in order to avoid retransmission and packets loss. In recent years, many QoS approaches have been proposed that take into account link quality in the choice of routes. Nevertheless, these methods arise many issues. Indeed, some approaches rely on link estimation that are hard to measure in practice (for instance, the bit error rate). Others require costly analysis of the network and imply a substantial communication overhead. Finally, some approaches choose routes that maximize packet delivery ratio, but at the cost of a high number of intermediate nodes and/or delay.

To make protocols more reliable, an effective and simple estimation of link quality must be proposed, as well as a link quality-aware computation of shortest paths . In this paper, we focus on metrics related to the packet loss rate criterion. First, the Bit Error Rate (BER) as QoS link criterion is analyzed and a BER-based metric as an additive metric is designed. Second, to evaluate link quality, a light, efficient and immediate solution is proposed and a new metric based on the number of retransmissions at Medium Access Control (MAC) level is proposed. With this metric, the shortest path is expressed not exactly in terms of number of hops but rather in terms of number of transmissions. In a realistic environment taking into account obstacles in the propagation medium, these two metrics (the BER-based and number of transmissions count-based ones) are tested and compared with those based on number of hops, delay and Expected Transmission Count (ETX).

The remainder of this paper is organized as follows. In Section II, related work is presented and shortcomings of commonly used metrics are highlighted. In Section III, a thorough study of BER-based metric is drawn. In Section IV, our new metric is described. In Section V, performance results of the well known Optimized Link State Routing (OLSR) protocol enhanced with this new metric is presented and compared with delay, ETX and BER based ones. We conclude and present some perspectives in Section VI.

II. Related work

Wireless networks offer a lower QoS than wired ones. To address the QoS requirements of multimedia applications, several metrics have been proposed and incorporated into routing protocols for a judicious choice of data transmission routes. The provided performances have been mixed. In this section, critical overview of the most commonly encountered metrics is made. The costs (in terms of routing load and additional time) generated by measure and use of these metrics in routing protocols are analyzed. Here, the speech focuses on Packet Delivery Ratio (PDR)-based metrics. BER-based metric is analyzed in Section III.

Packet loss in Mobile Ad hoc NETwork (MANET) is due to many factors. Among them, buffer overflows, transmission loss and link breakages are the most dominant [1]. In addition, a received packet whose delay is over the tolerable delay threshold is also considered as a lost packet. Loss caused by over-threshold delay can only be monitored at the receiver, requiring a feedback message be sent to the source for QoS purpose. Packet loss caused by buffer overflow and maximum

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retransmissions exceeding, are the only information that can be obtained from intermediate nodes. Successful design of a metric that takes into account all of these components is very delicate.

Many approaches measure the packet loss rate by injecting probing packets into the network. A large number of sample packets are required to accurately estimate a highly variable link. Shi et al. [2] evaluate the number of probing packets needed to get an accurate result as follows: $N = \frac{1-p}{m^2 p}$ where p is the packet loss probability and m the coefficient of variation. According to this formula, we see that this active measurement scheme is not suitable for MANETs. For example, for a link with 10% mean packet loss rate ($p = 0.1$), 900 samples must be sent on that link to get a measurement result where standard deviation is within 10% of the loss probability (i.e., $m = 0.1$). When each node should send probe packets, these can cause a large overhead in MANETs, thus skewing the obtained results. Furthermore, it takes some time for measurements. For example, if one sample packet is sent every 1 second, 15 minutes are needed to send 900 samples. This shows that the active measurement scheme is obviously not suitable for a wireless network particularly in mobility context. In order to overcome this dilemma (amount overhead), Link Quality Ranking (LQR) [3] uses the following trade-off. Instead of estimating a link-layer metric for each link, LQR performs a pairwise comparison of the physical-layer metrics and selects the best link. One problem faced when broadcasting probe-based estimators, is that they decouple link estimation from data traffic. If a link goes bad and packets are lost, the link estimate will not reflect this change until the next routing beacon is dropped [4].

The average rates of the link packet loss are commonly used. Link quality of a route is evaluated by summing the metric values of every link on the route [5][6]. This way of using this metric is questionable. The average or the sum of link quality measurements along one route may hide the worst link. Indeed, if the quality of a link among one route is rather bad, the packets can not be delivered successfully although the average or sum value is rather good.

The PDR metric is often used as a multiplicative metric [7]. A blind multiplication applied to this metric strongly favors long paths. In such a case, inter-hop interference may be significant. Indeed, the intermediate node can not simultaneously receive a packet from a neighbor upstream and send another to a downstream neighbor. Additional delay due to intra-communication interference is often not taken into account. It has an impact on throughput but not necessarily on packet delivery ratio.

ETX routing metric [6] is one of the most popular among this class of metrics. It is developed to improve the performance of routing in static wireless mesh networks where hop count is not suitable. The ETX of a link is calculated using the forward and reverse delivery ratios of the link. These delivery ratios are measured using probe packets. For two adjacent nodes X and Y, X measures probe delivering rate by determining the ratio between the number of probes received from Y and the number of expected ones. When X sends a probe, it includes the calculated ratio in the message. Y does the same. Hence, each node knows the ratio in both directions of a link (one is calculated, the other is provided by the neighbor). The metric is then obtained by:

$$ETX = \frac{1}{PDR_{X \to Y} \times PDR_{Y \to X}} \quad (1)$$

It can be noted that, although ETX distinguishes two PDR values for respectively upstream and downstream direction, the obtained link metric is the same for both directions. ETX is therefore symmetric. We consider this point as a drawback of the approach. Indeed, if a link is asymmetric, we think that this link should be used but only for traffic in the reliable direction. Only ACK messages should be sent in the unreliable direction, since these messages are small and then are more likely to be transmitted correctly. Besides, this metric is independent on network load. A detailed analysis of OLSR [8] with the original hysteresis [9] and ETX routing metric revealed that the original hysteresis performs better than ETX-based protocols in a large dense mesh network. An analysis was then carried out on the ETX protocols. It revealed that in realistic networks, using the ETX algorithm, the predicted losses are twice the actual losses that are experienced even in ideal lab conditions for 802.11 [8]. Shi et al. [10] present the design and selection of appropriate routing metrics as the principal issue to guarantee efficient routing in self-organizing networks. They attempt to analyze, compare and summarize traffic-based routing metrics in the Expected Number of Transmissions (ETX) family. Several studies [11][12][13] have been proposed to improve the metric, but its fundamental limits remain.

Delay based-metrics are also questionable. Delay at each node is composed of input queuing delay, processing delay, output queuing delay, transmission delay, propagation delay, and retransmission delay. Most of QoS-based delay metric focus only on transmission delay at MAC layer [14][15], while the other components of delay take a significant portion of the total hop-to-hop delay. Li et al. [16] consider queuing delay at network layer, but their estimation method is complex. In practice, it is not easy to obtain the number of packets waiting in network-layer buffer.

Delay is closely related to packet loss rate. A packet loss that induces retransmissions grows delay and also network congestion significantly. These network performance measures depend on the quality of used links and ambient flow. Delay and link loss ratios are often subject to high variation. End-to-end delay changes with network load as interface queue lengths vary. This can cause routes to oscillate away from a good path once the path is used. Delay must be calculated easily to avoid additional delay due to complex process.

In addition to the sensitivity of the link quality criterion measurement, many authors have questioned the use of these QoS values. In [2][17][18][19][20], the authors highlight the complexity and exorbitant cost (overhead and computing time) of route-discovery approach with admission control processes.

III. BER-BASED METRIC

The BER criterion characterizes the network at the lowest level of the transmission chain (physical layer). Measuring the error rate at this level provides a more refined estimation of quality of radio links. It allows the study of physical

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TABLE I. EXPECTED NUMBER OF TRANSMISSIONS DEPENDING ON BER.

ber	$nb_{transmissions}$
10^{-5}	1.05
10^{-4}	1.51
2.10^{-4}	2.27
3.10^{-4}	3.42
4.10^{-4}	5.15
5.10^{-4}	7.76

phenomena that influence the quality of communication. This link quality criterion has a direct impact on packet delivery rate and average communications delay.

Delahaye [21][22] uses a ray-tracer propagation model called CRT for a better estimate of the radio channel in Network Simulator (NS). The BER used in [23][24] is the result of simulation of this realistic channel model. The use of this metric in the MANET routing protocols (OLSR, Ad hoc On-demand Distance Vector, Zone Routing Protocols) has significantly improved PDR and delay. However, this metric has many drawbacks in actual implementation. The BER metric is quite hard to measure in practice. A first method consists in injecting probe packets in the network. Knowing every binary elements that a packet should contain, the receiver is able to evaluate the bit error rate by counting how many bits are erroneous. Nevertheless, the packet should be large enough to allow a precise measure of BER but its size is in practice limited to the maximal transfer unit of the network. Note that control packets are too small and cannot be used to evaluate BER. So, this method generates an additional load for the network [25]. Another approach consists in sending impulses and measuring the impulse response associated with a transmission. The main drawback is that this method requires an adapted physical layer. These disadvantages are presented in [2].

Moreover, using BER as an additive metric induces long end-to-end transmission path [24]. These long paths with an overall good BER value would potentially permit a better packet delivery ratio, but they generate a long delay and induce a poor throughput. First, long paths increase intra-communication interference. Second, they also increase the vulnerability of established routes, particularly in mobility or dense networks and multi-communication contexts. For all these reasons, the BER-based metrics remain theoretical.

Against these BER metric limits, we invested a new metric based on the number of retransmissions required to make a data transmission over a link successful. We can note that the number of packet retransmissions is highly related to the bit error rate ber. If we suppose a multimedia stream with constant packet size of n bits, the packet error rate is $per = 1 - (1 - ber)^n$. Furthermore, the expected number of transmissions to get a successful packet can be computed as the mathematical expectation of the stochastic variable per. It equals $1/(1-per)$. Therefore, the expected number of transmissions is equal:

$$nb_{transmissions} = \frac{1}{(1 - ber)^n} \tag{2}$$

Table I shows how the expected number of transmissions depends on BER, for 512-byte-long packets ($n = 4096$).

We see that when BER equals $4e^{-4}$ or more, the expected number of transmissions is beyond the number of attempts that a default MAC layer allows to successfully deliver a packet. If possible, these links should not be used.

We therefore propose a new metric based on the number of transmissions and more precisely the number of retransmissions (that appear when the first attempt is not successful). As shown in Table I, this metric is highly related to BER, but, it does not require to be measured. It appears as a low-level but effective measure of the quality of links. This metric only requires that each MAC layer computes a mean value of the number of transmissions required to send packets to each neighbor, including the large ones. It is therefore not a costly measure. The next section is devoted to this metric.

IV. RETRANSMISSION-BASED METRIC

In this section, first, the choice of route when intra communication interference (different transmissions for the same communication) is taken into account is discussed. In a second step, the design of our number of retransmissions-based metric is presented. In a third step, this metric is compared with the ETX metric.

In this new metric, the estimated cost of retransmission, compared to the cost of the first attempt, must be evaluated, and delay seems a convenient way to evaluate it.

Let us evaluate the transmission time between a source S and its neighbor D. Let's consider a given constant time $t1$ corresponding to a successful first transmission. If transmission fails, the additional time for each retransmission is $t2$. For more details on different timing at MAC level see [26][17]. To simplify, $t1$ is supposed to include processing time to pass from routing level to MAC level, Request To Send / Clear To sent (RTS/CTS) mechanism [27] time and propagation time, and $t2$ includes additional ACKnowledge (ACK) packet waiting timeout, RTS/CTS mechanism time and propagation time (hence t2>t1).

Thereby, the delay is:

$$t = t1 + (n - 1) \times t2$$

where n is the total number of transmissions. We normalize this equation to get our new metric (called PR for Packet Retransmission) as follows:

$$PR = \frac{t}{t1} = 1 + (n - 1) \times a. \tag{3}$$

with $a = \frac{t2}{t1}$

Note that this metric appears as the number of hops penalized by a weighted number of retransmissions $a \times (n-1)$. It equals 1 if no retransmission is needed, but it can have a greater value if retransmissions occur. This value can be seen as an equivalent (but not integer) number of intermediate hops. PR is therefore an additive metric, since equivalent number of hops can be cumulated. In a sense, it is an alternative to the simple number of hops metric: this new metric is based on the number of intermediate nodes to access a recipient, but unlike the standard number of hops, it takes into account the quality of links.

To evaluate this metric, the number of packet transmissions must be determined. This information is available at the MAC level (it is a part of the communication statistics at the MAC layer) and, by a cross layer approach, is operated at routing level. There is no need to use special probes contrary to what is required in most metrics. When the used packet size is small (such as hello packet), the number of transmissions is almost always 1 (no retransmission) when the used link exists. On the contrary, large packets allow a better estimate of the quality of a link with this metric. In our protocols, all packets are taken into account.

Note that a is a mean value that represents retransmission cost. To calibrate the value of a, we use a statistical approach. A realistic propagation model taking into account the obstacles, with data packets in a multi-communication context, allowed us to find the value 1.65 for a with 0.1 as standard deviation. In-depth study could better refine the value of a. This parameter may vary depending on the nature (dense or less dense) and congestion level of the studied network.

To test the effectiveness of this new metric, it has been incorporated in OLSR as the metric used for path selection. At each node, the metric is calculated from the number of retransmissions required to make data transmissions successful over a given link. The obtained information is recorded as a new field in the record of neighbors and is disseminated through the network thanks to Topology Control (TC) messages. As it is an additive metric, a path length is computed as the sum of the metric of each of its links.

V. Performance evaluation

In this section, we briefly present the five different protocols implementing the metrics we analyze. Then, we present our experimental setup and simulation conditions. We conclude the section with an analysis of simulation results.

A. Routing protocols

We compare the performance of five routing protocols, the standard one OLSR-3626 and four modified ones, OLSR-delay, OLSR-ETX, OLSR-BER and OLSR-PR.

OLSR-3626 refers to the standard OLSR described in RFC-3626 [9]. Route selection criterion used in this protocol is the minimum number of hops needed to reach destination.

The four other protocols are based on standard OLSR. Basically, they consider another metric than the number of hops. These metrics are additive: the distances of a route is the sum of the distance of all elementary links on the route. A node computes the shortest path, in term of the considered metric, toward each destination and records it in its routing table.

OLSR-delay chooses delay as metric. Link delay measures are based on Hello messages. Considering OLSR-ETX, ETX metric is implemented like in [28]. The delivery ratio is based on Hello messages. OLSR with BER consideration (OLSR-BER) consists in selecting the path with the lowest global BER described in Section III. OLSR-PR is based on PR metric as described in Section IV.

TABLE II. Simulation parameters.

Parameters	Values
Network simulator	NS 2
Simulation time	100s
Simulation area	1000m*1000m
Maximum number of transmissions	4
Transmission power	0.1W
Data types	CBR
Data packet size	512 bytes
MAC layer	IEEE 802.11a

B. Experimental setup

To show the effectiveness of new QoS approaches for protocol enhancements, t work, evaluations often rely on simulation. Most of the time, experiments do not take into account any environment parameters when modeling the propagation channel. They often consider only the direct ray between transmitter and receiver assuming that no obstacle disturbs transmissions. Furthermore, other effects such as multiple paths induced by the environment are not taken into account although they highly influence the quality of the received signal [29][30][31]. If the environment is not considered, the obtained results are biased and rather optimistic. The influence of bad links is thus highly underestimated. To compute more convincing simulations, we must use a realistic model of wave propagation taking into account the environment characteristics. Therefore, we enhanced NS2 [32] with a communication ray-tracer (CRT) simulator that has been developed at the XLIM-SIC laboratory [21]. Our BER-based protocol directly relies on BER values computed by this CRT software. The global parameters for the simulations are given in Table 2.

C. Simulation results

We simulate OLSR protocol based on our new metric and compare results with standard and the most common enhanced ones. Communication concerns simultaneous transmissions between ten source-destination couples during 100s. The number of hops between transmitters and receivers varies from 2 to 6. To compare the obtained results, we consider two criteria: packet delivery ratio (PDR) and average end-to-end delay. Our metric considers both quality of links in terms of transmission error and some kind of delay estimation to select shortest paths. It is important to note that, for these results, BER estimation time for all links is not taken into account. The BER measurement is supposed completed before the packet transmission begins. Different protocols are analyzed in fixed-nodes context.

In this set of simulation scenarios, the number of nodes increases from 10 to 50. We study the protocols'performance under the influence of path breakages in low densities, routing overhead and new paths in high densities (high network connectivity).

Fig. 1 shows that all these enhanced OLSR outperform the standard one (OLSR-3626) in delay. This means that the shortest path based on the number of hops metric is not suitable for communications in realistic environment (Couto et. al have produced the same result [28]). These results show that our approach (OLSR-PR) always finds best paths in term of end-to-end delay than other protocols. Considering the PDR criterion, OLSR-BER and OLSR-PR outperform the others (Fig. 2). Very often, OLSR-BER is slightly better than OLSR-PR. The

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difference does not exceed 10 points. An analysis of simulation trace files (statistical results) shows that the paths found by OLSR-3626 is shorter (in terms of number of hops), followed by OLSR-PR. The average length of the paths used by OLSR-BER and OLSR-ETX are the longest.

The best performance of OLSR-PR against OLSR-BER and OLSR-ETX is due to the intra-communication interference effect and additionnal processing time at the intermediate nodes that are larger for the latter. Our new approach allows to better optimize the number of hops. But the poorer performance of OLSR-3626 is due to the fact that some of the used links have a very poor quality, resulting in too many retransmissions.

Regarding PDR parameter as shown in Fig. 2, although OLSR-PR often seems less efficient than OLSR-BER, a thorough analysis shows that it has delivered more packets (it provides the best throughput). This has an impact on the end-to-end delay since additionnal packets delivered by OLSR-PR and not by OLSR-BER require longer delays, so the average delay is degrated.

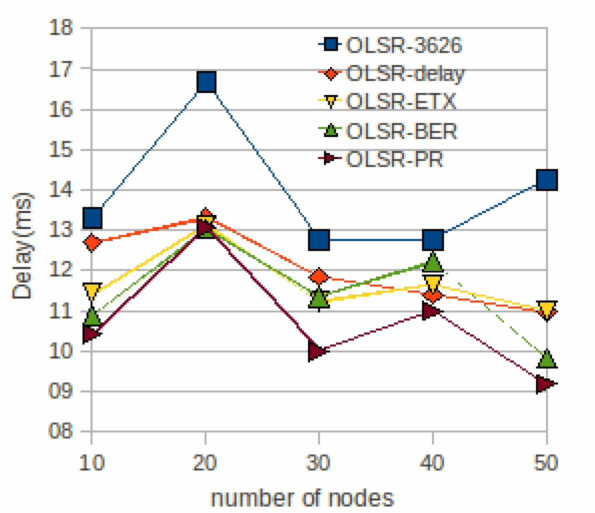

Fig. 1. Delay evolution with number of nodes.

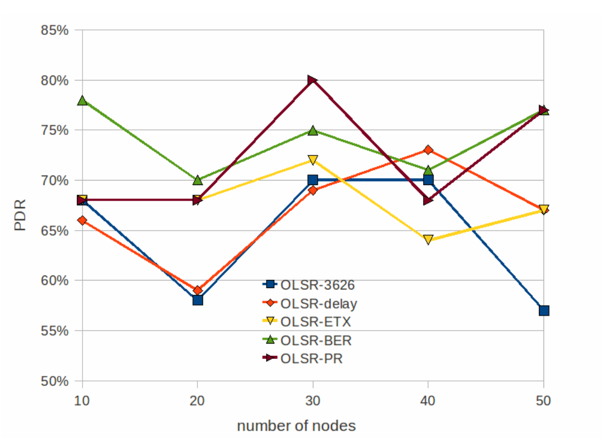

Fig. 2. PDR evolution with number of nodes.

VI. Conclusion and Prospects

We conducted a critical analysis of existing metrics used in QoS routing, then we proposed a metric based on the number of retransmissions required to manage data transmission over a link. With our QoS approach, the distance between a node and its neighbor will not be 1 but $1 + a * (n - 1)$ where n represents the average number of transmissions required to make transmissions successful and a is a parameter to weight retransmission cost. We chosed to base a on expected transmission delay, that is, the ratio between the average delay required for a retransmission over the delay necessary for an initial successful transmission. This metric indirectly relates to BER since the latter affects the number of retransmissions. In addition, it takes into account the real time network load. Its estimation does not induce additional routing load or a large computation time. Without considering the complexity of the BER measurement, this number of retransmision-based metric is a compromise between the number of hops metric that does not take into account the quality of links and metrics based on packet delivery ratio that induce too long paths.

We integrated this new metric in OLSR. Paths that require less retransmission are preferred in routing table calculation process. Simulation results in fixed-nodes context show that this approach improves the average transmission delay and is better than traditional metrics. For delay-sensitive applications, it is better to use a retransmission-based metric to quantify links.

For better PDR and delay performance, neighbor links and MPR node selection should be reconsidered. In future work, we intend to evaluate performances of our new metric in mobility nodes context.

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