Metric Anticipation in Mobile Ad-Hoc Networks

Sabrina Naimi, Anthony Busson, Véronique Vèque, Larbi Ben Hadj Slama, Ridha Bouallegue

Metric Anticipation in Mobile Ad-Hoc Networks

Sabrine Naimi
Laboratory of Signals and Systems
Université Paris Sud - Supélec - CNRS

Anthony Busson
Université Claude Bernard Lyon 1
LIP (ENS Lyon - INRIA - CNRS - UCBL)

Veronique Veque
Laboratory of Signals and Systems
Université Paris Sud - Supélec - CNRS

Larbi Ben Hadj Slama
Innov'COM Laboratory
Higher School of Communication - Tunisia

Ridha Bouallegue
Innov'COM Laboratory
Higher School of Communication - Tunisia

***Abstract*—In this paper, we propose a new method for metric calculations in order to improve mobility management in wireless networks. The idea consists in anticipating metric values in order to compensate the delay generated by the measure of the link quality and the routing protocols. As an example, we consider the popular ETX (Expected Transmission Count) metric. We focus on ad-hoc networks, even if our approach could be used in other contexts. We show by simulations that our approach, when well parametrized, allows a Packet Delivery Ratio (*PDR*) close to 100% when nodes are moving.**

I. Introduction

With the success of wireless communications, it becomes possible to access the network everywhere at anytime without the need to plug the communicating devices to an infrastructure. Nodes (laptop, smart-phone, etc.) may scan the different radio channels, and associate with an available wireless network (Base Station, Access Point, etc.). An undeniable benefit of these wireless technologies is the possibility to be mobile while staying connected. But mobility management is not a simple task. It must be performed at different layers to ensure that mobility keeps transparent for applications. Efficient mechanisms exist at the physical and MAC layers, allowing a wireless card of a given technology to switch from one infrastructure network to another: from one Access Point (*AP*) to another in case of Wi-Fi, or from one Base Station (*BS*) to another in case of cellular networks. These mechanisms are not sufficient and have to be completed with algorithms at the network layer. For instance, when the new *AP* does not belong to the same network, the IP address change has to be managed properly. Protocol such as Mobile IP protocol [1] can offer this service.

But, multi-interfaces nodes or nodes of multi-hop ad-hoc networks have different properties. For these nodes, different mechanisms are required to manage mobility efficiently. In an ad-hoc network, where nodes use a wireless technology of the 802.11 family, mobility management at the layer 2 is generally not available, and classical IP sub-netting does not hold. Nodes use $/32$ addresses. Therefore, the mobility has to be managed at the layer 3 by the routing protocol itself. When a node moves, routing table entries for this node/destination are updated accordingly. Also, when nodes are equipped with several interfaces of different technologies, for example a smart-phone equipped with Wi-Fi and 3G interfaces, mechanisms at the upper layers have to decide which technology is the most efficient at each time and must switch transparently from one technology to another as function of the available wireless networks and the radio environment (vertical handover [2]).

We think that these situations may be managed efficiently through metrics. A metric is a numerical value associated to each wireless link. It may reflect the presence of a link (Hop Count), the link quality (received signal strength, loss rate, etc.), bandwidth, etc. When the metric is high, the link quality is poor and inversely. These metrics can be used in the multi-interfaces context to help a node to choose the best technology at a given time. In ad-hoc networks, these metrics are used by routing protocols to select the best routes to the destinations. In case of additive metrics, the route is computed in such a way that the sum of the metrics on the path is minimized. As the quality of a link recedes when two nodes move away from each other, the metric associated to the link increases. Routing protocols then modify their routes for links with lower metrics (better quality), and thus adapt to mobility.

Unfortunately, it is difficult to take into account link qualities with metrics in real time. Calculation is often performed at the network layer using HELLO packets leading to an imprecise estimate of the link quality. Moreover, a new value for a metric associated to a link cannot be instantaneously considered by the routing protocol. Indeed, new values must be disseminated in the network before being taken into account in route calculations.

In this paper, we propose a new method for metric calculations. The idea consists in anticipating metric values in order to compensate the delay generated by the measure of the link quality and the routing protocols. As an example, we consider the popular ETX (Expected Transmission Count) metric [3]. We focus on ad-hoc networks, even if our approach could be used in other contexts, as the multi-interfaces case. We show by simulations that our approach, when well parametrized, allows a Packet Delivery Ratio (*PDR*) close to 100% when nodes are moving.

The paper is organized as follows. First, we present the main routing metrics used in wireless networks in Section II. In Section III, we present the basic idea of our algorithm and a more precise example with the anticipation of the ETX metric.

In Section IV, we propose rules to set the parameters of our algorithm. Simulation scenarios and results are described in Section V. We conclude in Section VI.

II. Contributions and related works

Ad-hoc routing protocols defined by the Internet Engineering Task Force (IETF) use by the default, the Hop Count metric to determine the shortest path. This metric is inappropriate in the context of wireless ad-hoc networks because it does not take the quality of the radio link into account (throughput, loss rates, signal strength, etc.). Recent works on routing protocols [4] have been carried out to take into account richer or better metrics in the calculation of routes.

In this section, we present some existing metrics used in routing ad-hoc networks and the associated method for calculating routes. The considered metrics are Hop Count, ETX [3], ETT [5], and LinkDuration [6]. We focus on these four metrics because they are the most popular, or have been shown the most efficient [7] [4].

The most commonly used metric in ad-hoc networks is the Hop Count metric [8]. This metric provides information on the existence of a link between two nodes without taking into account the quality of these links. It si equal to 1 is the link exists and 0 otherwise. Hop Count metric will privilege links with long distance, that may present high loss rates and reduced signal strengths. Moreover, long links are particularly sensitive to mobility as nodes may be at the edge of the radio range.

Complex metrics such as ETX [3] have been designed to select paths with high transmission rates. ETX is calculated using the ratio of forward and reverse delivery ratio of the link. The forward delivery ratio, **df**, is the probability that a data packet successfully reaches the recipient. The reverse delivery ratio, **dr** is the probability that the packet is successfully received. The expected probability that a transmission is successfully received is defined by **df * dr**. ETX is defined as follows:

$$ETX = \frac{1}{df * dr} \quad (1)$$

Therefore, ETX estimates the average number of transmissions (including retransmissions) required for the success reception of a packet. The use of this metric to calculate path, promotes the closest functional links and links with high capacity.

ETX does not distinguish between links with different capacities. To remedy these problems, the metric ETT (Expected Transmission Time) [5] was proposed. ETT improves the ETX metric taking into account the transmission rate of the link and the packets' length:

$$ETT = ETX * \frac{L}{B} \quad (2)$$

In the formula above, L is the packet' length and B is the transmission rate of the link. ETT can be seen as the time expected to transmit a packet of length L. It multiplies the number of attempts (the ETX metric) to send the packet by the time to transmit the packet on the link ($\frac{L}{B}$).

The Link Duration (LD) [7] metric measures the duration of the link between two nodes. For each existing link, it gives the time from the detection of the link. In [9], the authors show that LD may be a useful tool to manage mobility. They consider the duration of a path as criteria to select routes. The path duration is simply the minimum of the link durations LD of the different links forming this path. The authors argue that more the path duration is long, more the path is stable leading to less link breakages in case of mobility. We will show that, for our scenarios, it is wrong.

As we have explained Hop Count and Link Duration metrics are unable to manage mobility. Moreover, classical metrics measuring link qualities such as ETX or ETT, do not reflect link qualities in real time leading to poor performances in presence of mobility. They are generally computed at the network layer, and are based on the reception/no reception of some specific control packets. It introduces a delay between the instantaneous value of the link property, i.e. the *Frame Error Rate* (FER) for ETX and ETT metrics, and the one estimated through the control packets. Moreover, even if it was possible to measure in real time the FER or another quantity reflecting the link quality, these metrics have to be announced by the routing protocols involving an incompressible delay.

A cross layer approach using information from the MAC or the physical layer can help to estimate more precisely and instantaneously the quality of the link. Also, to counter balance the delay introduced by the routing protocol to disseminate metrics and compute routes, we propose to anticipate the value of the metrics through a cross layer mechanism. If this algorithm is accurately parametrized, metrics used by the routing protocol will reflect the states of the link in real time. Receding links will not be used anymore and routes will be adapted in real time with regard to link conditions and thus to mobility.

III. Anticipated ETX and ETT

The purpose of this paper is to propose metrics sensitive to mobility and which reflects the quality of the link at the same time. Basically, the idea may be summarized as follows. ETX and ETT metrics have been shown efficient to find paths that optimize the network throughput, so they give pertinent values on link qualities. Unfortunately, they are not efficient to manage mobility because there is a delay between their real/instantaneous values and the ones taken into account in the routing process. Consequently, we try to anticipate the values of these metrics some seconds in advance. In this Section, we present the computation of the anticipated ETX metric denoted ETX_ANT in the rest of this paper. Extension to ETT is straightforward.

Each node computes the anticipated metric for each neighbor/link. We assume that nodes have a table linking the link quality measured at the physical layer and the FER. This quantity can be the Signal-to-Noise Ratio (SNR), the Received Signal Strength Indicator (RSSI) often available for 802.11 and

```
IF ( LINK_QUALITY > THRESHOLD_QUALITY )
        ETX_ANT=UPDATE(ETX)
ELSE
        index = SEARCH_INDEX(SNR_HELLO)
        ETX_ANT=ETX_ANT_ARRAY[index]
ENDIF
```

TABLE I
MANAGEMENT MOBILITY ALGORITHM

3G/LTE cards, or any other quantity reflecting link quality. It can be provided by the card itself or estimated by the nodes when it is not available. The basic idea of the algorithm is to use the classical ETX computation when the link quality is good, and to increase artificially and gradually the metric when the link quality degrades.

The algorithm is summarized in the table Algorithm I. When the node receives a packet (a HELLO message, or a data packet according to the implementation) from a neighbor, it updates the metric associated to this link. We use a threshold on the link quality denoted THRESHOLD_QUALITY. If the LINK_QUALITY measured for this packet is greater than THRESHOLD_QUALITY, the link has a sufficient quality and there is no need to anticipate the ETX metric. The metric associated to this link is then the classical ETX metric that is updated with the classical method denoted by *UPDATE(ETX)* in our algorithm. If LINK_QUALITY is lower than THRESHOLD_QUALITY, we anticipate the value of the ETX metric. We use a precomputed array ETX_ANT_ARRAY[.] associating LINK_QUALITY and the anticipated ETX values. First, we compute the index corresponding to the value of LINK_QUALITY. Then, we associate to the link the corresponding value of the anticipated ETX.

Obviously, values of the threshold and the ETX_ANT array will significantly impact the performance. In the next Section, we describe the method that we have implemented to parameterize these quantities.

IV. SETTING

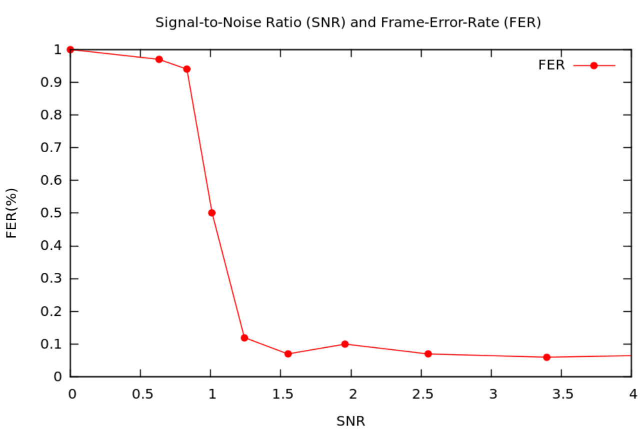

Fig. 1. FER with SNR

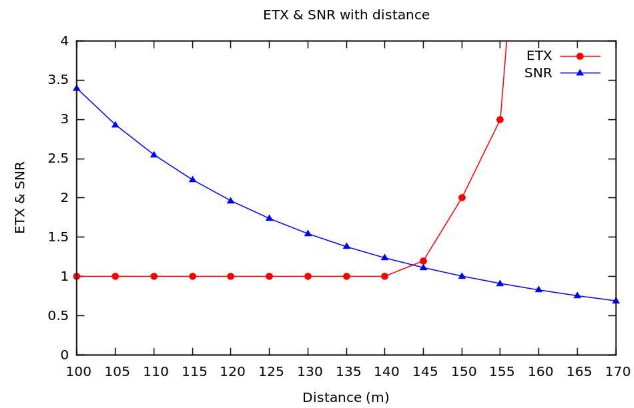

Fig. 2. SNR as function of the distance.

In this section, we present the design rules of our metric. More precisely, we present the method used to compute THRESHOLD_QUALITY and the ETX_ANT array. We assume that we know the relationship between LINK_QUALITY and the FER. In our implementation, the LINK_QUALITY is the SNR and it is easy (through measures for example, or arrays provided by cards' manufacturers) to approximate values of the FER with regard to the SNR. In Figure 1, we plotted this function. It has been performed with the simulator NS-3. The parameters are described in Section V and Table II. We observe that when the SNR becomes less than 1.11, the FER suddenly increases from approximately 10% to 100%. It means that if the link degrades due to the mobility of the nodes, the FER will increase very sharply. The classical ETX metric will not be updated sufficiently quickly to consider this as a lossy link by the routing protocol, and packets will be lost. We assume that the time to take into account a new metric by the routing protocol is given by the variable $TIME$. Therefore, SNR lower than 1.11 must be anticipated $TIME$ seconds in advance.

In our scenario, we assume that we have evaluated the SNR with regard to the distance. It can be done on the deployment site of the ad-hoc network. It is plotted in Figure 2. Given the relative speed of two nodes V_{rel}, the distance between the two nodes increases of $TIME \times V_{rel}$ in $TIME$ seconds. For instance, for $V_{rel} = 30km/h$ and $TIME$=2 seconds, we should anticipated the metric 16.6 meters in advance. The critical SNR equals 1.11 is thus anticipated 16.6 meters before, i.e. when SNR=1.73 (at $140 - 16.6 = 123.4$ meters). The THRESHOLD_QUALITY is thus set with a value of 1.73.

Then, we use the curve shown in Figure 1, that links the SNR and the FER. It allows us to compute the theoretical ETX for SNR lower than 1.11 and fill the ETX_ANT_ARRAY[.] array. At the same time, the SEARCH_INDEX(.) function is set in order to return the index of the array corresponding to a given SNR/LINK_QUALITY. In our algorithm, we use this array when LINK_QUALITY (the SNR) is lower than 1.73 to give the value of ETX_ANT. In Figure 3, we plotted the expected behavior of the ETX and anticipated ETX with regard to the length of the link. We can observe that when we are above the THRESHOLD_QUALITY, that corresponds to distances less than 123.4 meters in the figure, we do not anticipate the value of ETX. But when the SNR passes the threshold (at 123.4 meters), there is a shift in the ETX value, corresponding to 16.6 meters or equivalently $TIME$ seconds.

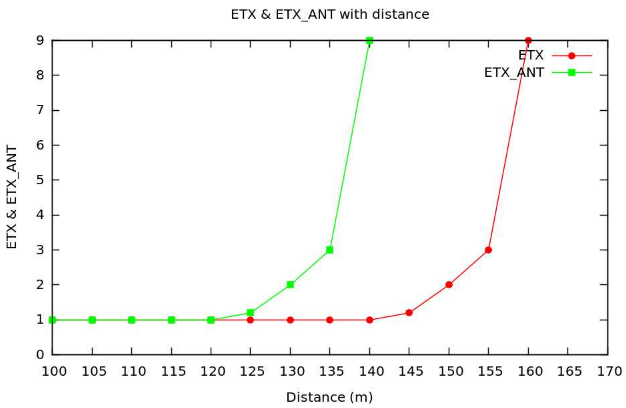

Fig. 3. ETX and ETX_ANT with regard to the distance.

V. Simulations

A. Simulators and parameters

For the implementation of our algorithm, we used the Optimized Link State Routing (OLSR) protocol [10]. We chose OLSR because it is a link state protocol. Therefore, link states information (called Topology Control in OLSR) are exchanged periodically. It is thus easy to use these TC messages to propagate our metrics. The other changes we apply to OLSR is the algorithm used to compute routing tables. We changed the OLSR default algorithm by the Dijsktra algorithm. As our metric is additive, the Dijsktra algorithm will find paths that minimizes the sum of the metrics (on the path) rather than the Hop Count. Also, we integrate computation of the metrics to the OLSR daemon. ETX and anticipated ETX metrics are updated each time a new HELLO message is received. LD is set according to the lifetime of the link: difference between the last time the link has been set as symmetric and the current time. We did not change link managements in OLSR, so only symmetric links (as defined by OLSR) are considered in the routing process.

We used the network simulator NS-3 [11] to perform simulations. The parameters used for the simulations are given in table II. We consider two scenarios: a chain of nodes and a more classical ad-hoc topology.

B. Simulation results

The first topology we considered is a chain of nodes. Nodes of this chain are fixed, but we move a mobile node along this chain. This first topology is a trivial case that allowed us to test the efficiency of our algorithm, and where results are easy to interpret. The source is the mobile node. It transmits data packets at regular interval (CBR traffic). The destination is the first node in the chain (as shown in Fig 4). When the source moves away from the destination, OLSR updates its

Parameters	Numerical Values
Simulation time	62 [sec]
Window size (Chain scenario)	1200×500 [m^2]
Window size (Ad hoc scenario)	500×500 [m^2]
Number of nodes (Ad hoc scenario)	25
Propagation model	Random Propagation Loss Model
Wireless technology	IEEE 802.11a
Traffic type	Constant Bit Rate (CBR)
THRESHOLD_QUALITY	1.11

TABLE II
Simulation Parameters

paths according to the ETX_ANT metric. The topology is a 1200×200 rectangle with 11 fixed nodes. The fixed nodes are located at a distance of 100 meters of each others. The speed of the mobile node varies from 10 km/h to 70 km/h. The source moves and the application starts after a few seconds to let the time to OLSR to fill the routing tables. The simulation stops when the mobile node is arrived at the end of the chain.

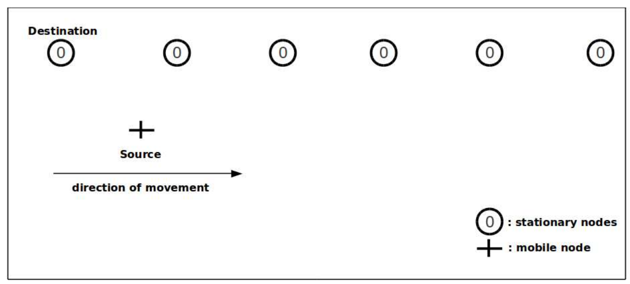

Fig. 4. Scenario 1: a mobile node passes along a fixed chain of nodes at a constant speed. There are 12 nodes: 11 stationary nodes, each placed at a distance of 100 meters forming a chain, and a mobile node.

The *Packet Delivery Ratio* (PDR) is used as a measure of performance. PDR is the ratio between the number of packets received by the destination over the number of packets sent by the source. In Figure 5, we plotted the PDR for the different metrics (Hop Count, ETX, ETX_ANT, and LD) when varying the speed of the mobile node. Results show that ETX_ANT presents the best performance. It is 100% for speed less than 30 km/h as it corresponds to the speed for which the metric has been dimensioned. For higher speed, performance of ETX_ANT decreases, but are greater than 80% and outperforms the other metrics. LD is the worst metric because it chooses paths with the longest duration. Indeed, in this scenario, the metric LD is not pertinent as new links should be privileged rather than old ones.

In the second scenario, we considered 25 mobile nodes in a window with size 500×500 m^2. Mobility of nodes follow the Random Way point model (RWP) [12].

Results of this scenario are shown in Figure 6. It clearly appears that anticipated ETX metric still outperforms the other metrics. We note that the PDR with ETX_ANT does not drop below 70%. It is not 100% because relative speeds of the mobile nodes vary and may be greater than 30 km/h. Performances for the LD metric are the worst: the PDR drops to 10%.

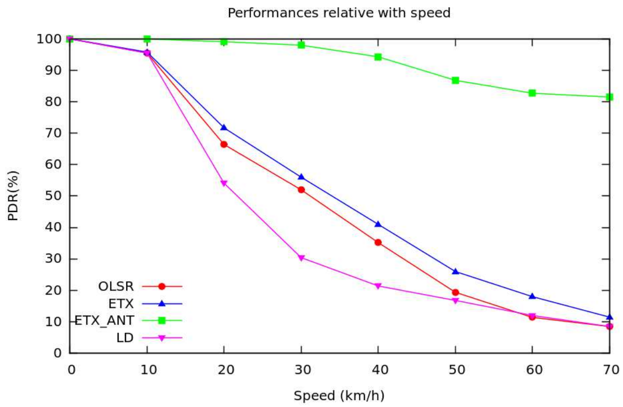

Fig. 5. PDR in the chain scenario.

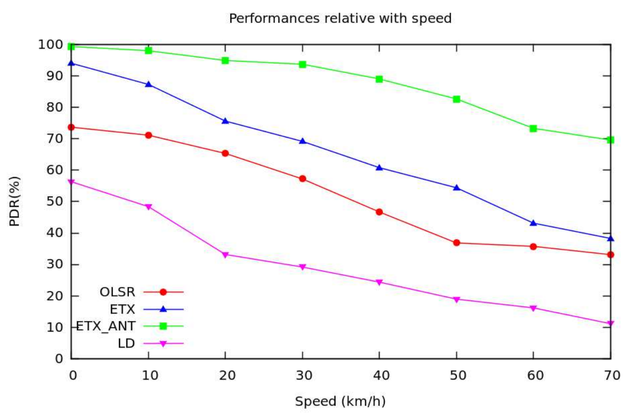

Fig. 6. PDR in the mobile ad-hoc scenario.

VI. Conclusion

In this paper we have presented a simple algorithm to anticipate the value of routing metrics. This technique is based on a cross-layer approach. The signal strength is measured at the physical layer to estimate and anticipate the value of the metric. This anticipation allows the routing protocol to compensate the delay due to the computation and dissemination of the metrics. For the ETX metric, we have shown through simulations, that this approach shows very good performances in terms of Packet Delivery Ratio. When this algorithm is accurately dimensioned, it leads to a PDR of 100% and the routing protocol is thus transparent to mobility. In our scenario, we considered a simple radio environment, but it is obvious that our algorithm must be improved in order to take into account more elaborated radio environment, including fading for instance.

References

[1] C.Perkins. Ip mobility support. *RFC 2002*, Oct. 1996.
[2] S. Fernandes and A. Karmouch. Vertical mobility management architectures in wireless networks: A comprehensive survey and future directions. *IEEE Communications Surveys and Tutorials*, 2010.
[3] John Bicket Robert Morris Douglas S. J. De Couto, Daniel Aguayo. A High-Throughput Path Metric for Multi-Hop Wireless Routing. *MobiCom'03*, 2003.
[4] Draves Richard, Padhye Jitendra, Zill Brian. Comparison of routing metrics for static multi-hop wireless networks. In *Proceedings of the 2004 conference on Applications, technologies, architectures, and protocols for computer communications*, SIGCOMM '04, pages 133–144, New York, NY, USA, 2004. ACM.
[5] Igor M. Moraes Luis Henrique M. K. Costa Otto Carlos M. B. Duarte Marcelo G. Rubinstein Pedro Miguel Esposito, Miguel Elias M. Campista. Implementing the Expected Transmission Time Metric for OLSR Wireless Mesh Networks. *Wireless Days, 2008. WD '08. 1st IFIP*, 24-27 Nov. 2008.
[6] Bhaskar Krishnamachari Ahmed Helmy Narayanan Sadagopan, Fan Bai. Paths: analysis of path duration statistics and their impact on reactive manet routing protocols. In *Proceedings of the 4th ACM Interational Symposium on Mobile Ad Hoc Networking and Computing, MobiHoc 2003, Annapolis, Maryland, USA, June 1-3, 2003*, pages 245–256. ACM, 2003.
[7] Gerharz, M. and de Waal, C. and Frank, M. and Martini, P. Link stability in mobile wireless ad hoc networks. In *Proceedings of the 27th Annual IEEE Conference on Local Computer Networks*, LCN '02, pages 0030–, Washington, DC, USA, 2002. IEEE Computer Society.
[8] B. A. Chambers R. Morris D. S. J. De Couto, D. Aguayo. Performance of multihop wireless networks: Shortest path is not enough.
[9] Ahmed Helmy Fan Bai, Narayanan Sadagopan. Important: A framework to systematically analyze the impact of mobility on performance of routing protocols for adhoc networks. In *INFOCOM*, 2003.
[10] P. Jacquet T. Clausen. Optimized link state routing protocol (OLSR). *RFC 3626*, Oct. 2003.
[11] http://www.nsnam.org/.
[12] Hyytiä, Esa and Virtamo, Jorma. Random waypoint mobility model in cellular networks. *Wirel. Netw.*, 13(2):177–188, April 2007.