Practical Link Reliability for Ad hoc Routing Protocol

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***Abstract*—Due to the unreliability characteristics of wireless communications, and nodes mobility, mobile ad hoc networks demand robust protocol design. Hence, routing protocol choosing the most reliable route between two terminals have been proposed in order to minimize the path failure occurrence. The interest of this approach has been shown, in research literature, mainly by simulation in terms of delay or packet delivery ratio. Meanwhile, there is a problem to put in practice the route reliability paradigm. The route reliability depends on links reliability. The motivation of this paper is to determine a measure of the link reliability. In this paper, we study the link reliability formulation in order to propose a realistic wireless link parameters modeling. The modeling takes into account the mobility, the transmission quality, and the communication load. Reliability can be computed without extra signaling by each node.**

***Index Terms*—link reliability, route reliability, mobile ad-hoc network, routing protocol.**

I. Introduction

The network objective is to ensure efficient transmission of data between a source and a destination. Consequently, the routing protocol in charge of the routes establishment, maintenance and recovery in ad-hoc networks should maximize the packet delivery ratio. To achieve this goal, during the establishment phase, routing protocols must choose the best route based on one or more criteria. Standard unipath ad hoc routing protocols such as AODV [1], DSR [2] and DYMO [3] use the minimum number of hops criterion as basic and default routing metric. However, this criterion is not very suitable in a mobile ad hoc network because, wireless links do not have the same failure probability. Indeed, when the number of nodes is reduced in a given area, distance between them is increased. It may consequently decrease the link quality in terms of bandwidth and increase the failure probability of routes. Hence, standard protocols are not efficient in to dynamic environments [4].

To reduce the routes failure rate, a solution is to use as route selection criteria: the route reliability. The route with the highest reliability is selected. It may improve the used links quality and ensure better network resources utilization (by reducing the routing cost) [5]. The knowledge of route reliability or/and availability improves network performance in terms of network lifetime, end-to-end latency, delivery ratio and throughput, as shown in [4], [6], and [7].

This paper focuses on the route reliability computation. As route reliability depends on link reliability, the main motivation is to find a practical way to compute the link reliability so that reliable routing protocols can efficiently be implemented. We are going to present a reliability modeling of the link. This model includes the link disruption, due to the effects of the mobility, of the wireless transmission quality and of the load due to collisions (in the basic IEEE 802.11, access to the medium is collision based and, above a given number of consecutive collisions, the transmission is abandoned).

We have introduced this paper with the presentation of reliability importance to improve the performance of mobile ad hoc networks. In the next section, we present the related works on methods (measurements and analytical models) that are proposed to determine links reliability between two adjacent nodes. In the section III, we propose a new efficient analytical method to determine the links parameters. As in [8], we assume that mobile nodes move according to the Semi-Markov Smooth (SMS) mobility model proposed in [9]. This mobility model overcomes most existing mobility models (such as Random Way Point Mobility (RWP), Random Walk Mobility (RWM)) limitations such as speed decay and sharp turn. In order to reflect the realistic mobile wireless communication, our method improves the link parameters, proposed in [8], by taking into account different factors: collisions, interferences and fading. Section IV compares the results that are obtained by our analytical model and by simulations. It shows the relevance of the model to predict link parameters in shadow fading environment whatever relative speed of nodes pair and network conditions.

II. Related works on link parameters

The link quality is basically obtained from the awareness of the signal strength and of the lost rate. The signal strength reveals the channel state and more precisely its stability, it can be computed either from an analytical modeling based on a predictable node movement, or from real measures (SSA [10], ABR [11], ASBM [12]). In [6] authors propose another link reliability-aware route maintenance (LRRM) which modifies DSR maintenance mechanism based on link reliability. Link reliability is actively related to the physical conditions (such as current speeds and positions) of the two nodes, the total number of received and forwarded packets. The authors show by simulation that the proposed local recovery protocol improves the performance in terms of network lifetime, end-to-end latency, delivery ratio and throughput. When using real measures (signal strength or number of received and forwarded packets) to determine the stability, the protocols assume that the current stable links will remain so in the future. Thus, they use the history of the link connection (resp. statistics of exchanged packets) to determine the stability (resp. reliability) of links. This presents an important limitation because history does not reflect all possible changes of links state in the future.

Another way to determine the link reliability is to measure the link duration, and then to define the most reliable link as a function of an average value. In literature, the most reliable link may be the one with either the smallest or longest duration [13]. In the fact, the choice depends on the node movement. In practice, the node has to monitor the link duration and to correlate it to the failure occurrence in order to determine the link reliability. In [14], the authors propose a routing protocol which initiates a new route discovery before the moment when a link break occurs on the used route. The mechanism is based on an analytical method which tries to predict link duration. The future position of each node i can be deduced according to its current position (x_i, y_i), speed v_i and direction θ_i. Thus, based on nodes transmission range r, link expiration time (LET) is computed. However, this analytical method is applicable only in a context where nodes speed and direction remain constant during the communication, which is not realistic in mobile ad hoc networks. Another drawback of this measurement method is that the obtained value is difficult to translate in a reliability value that could be usable at routing level.

Studies on link reliability and availability, based on different *macrocopic* random mobility model, are presented in [5], [7] [15]–[18]. Another prediction model of link reliability where nodes move according to RWM is proposed in [18]. Authors formulate link unreliability as the probability that the node $(i+1)$ is outside of the transmission range r of the node i at the time $t+\Delta t$ ($d_{i,(i+1)}(t+\Delta t) > r$), knowing that node $(i+1)$ is in the range of the node i at time t; where r is the range of node i. This link reliability $R_L(t, t+T)$ in $[t, t+T]$ is an average value based on the transmission range which does not take into account the initial distance between the pair of nodes. Thus, in this method, all links of the network have the same reliability. This assumption is not valid. As, we can see in figure 1(a) and 1(b), link reliability decreases according to the initial distance between the nodes. Details on these results will be given in section IV. Moreover, the interference, collision and fading are neglected in this link reliability model. Authors in [5] propose an interesting approach to compute different link parameters in networks where nodes move according to RWM Model. It takes into account the initial distance between the pair of nodes and transmission range. Unfortunately, the derived links reliability and availability equations contain integral which is not closed-form solution. The link availability estimation in network where mobility epoch lengths are exponentially distributed with mean λ^{-1} is proposed in [7]. Note that, an epoch is a random length interval during which a node moves in a constant direction at a constant speed. However, it is shown that this algorithm cannot accurately calculate the link availability, it can just reflect the general tendency [7]. The previous analytical related works present another limitation: they do not take into account fading, interference and collision as link breaking causes.

In this paper, we propose a new way to compute the link reliability. Our link parameter model is based on different physical factors and particularly on the initial distance between the pair of nodes. In order to get computable analytical results, we based our equation on a given mobility model: the Semi-Markov Smooth Mobility (SMS) Model proposed in [9].

The SMS mobility is a *microscopic* mobility which integrates a variety of nice properties of existing mobility models and overcomes theirs limitations such as speed decay and sharp turn. According to physical law of smooth motion, SMS mobility is flexible to mimic nodes movement in the realistic mobile networks. In each SMS movement, a node will randomly select a target direction ϕ_α and target speed v_α as expected direction and speed of the movement. Each SMS movement contains three consecutive phases: (1) Speed Up (α-) phase for even speed acceleration from 0 m/s to v_α (2) Middle Smooth (β-) phase for maintaining stable velocities which respectively fluctuate around v_α and Slow Down (γ-) phase for even speed deceleration to 0 m/s. Link parameters using smooth mobility have been studied in [19], but as the previous related works, it is assumed that a link between a pair of nodes is always active if the distance between them is less than the transmission range. In the next section, we present our analytical link model, improving the model presented in [19], by taking into account the realistic factors: fading, interference and collision.

III. Proposition: Analytical Model for link Paramaters in Mobile Ad hoc

We propose an analytical model of link reliability for mobile ad hoc networks in which nodes move according to smooth mobility model. The link reliability is modelized as a function of various parameters like transmission range, initial distance between pair of nodes, relative node movement. Contrarily to previous models, our proposed method models the reality of wireless communication by taking into account the influence of the interference, collisions and fading as causes of link breaking.

A Markov chain model is used to describe the distance evolution between nodes in an ad hoc network, moving according to memoryless smooth mobility model. Node *w* moves into reference node *u*'s transmission range r which is divided into n equivalent length bins of width ε meters. Hence, $r = n \cdot \varepsilon$ assuming n states in node *u*'s transmission range; $E = \{e_1, e_2, \ldots, e_i, \ldots, e_n\}$. Communication time T is partitioned into small intervals of fixed length time, termed epoch. In each epoch, the link $L_{i,j}$ between the nodes i and j is active, if three required conditions are satisfied: (1) the distance $d_{i,j}$ between a pair of given nodes is less than the transmission range r, (2) from a given distance $d_{i,j}$, transmitted packets between pair of nodes are not lost due to channel errors, and (3) packets that are transmitted through this link $L_{i,j}$ are not dropped due to collision between them and other packets of the network after a given number of successive retransmissions.

A. Link Reliability Modeling

Links reliability is defined as the probability that a link exists at a certain time in the future given that it exists right now. Thus, link reliability is defined as the product of (1) no packet drop probability $\bar{p}_{drop}$, and (2) the sum of probabilities that two nodes communicate without channel error from the state e_1 to the state e_n at the epoch k. In a given state e_i ($0 \le i \le n$), the probability that two nodes communicate without channel error after k epochs is the product of (2.a) the probability $rv_i(k)$ that the distance between the pair of nodes after k epoch is equal to i *meters*, and (2.b) the probability $\bar{p_e}(i)$ that the packet, that is sent on the distance of i *meters*, is not lost due to channel errors.

Given an active link at epoch 0 between two nodes, its reliability $R_L(k)$ after k epoch is defined as the probability that the link will continuously be available until at least the epoch k. The link reliability based on the reliability distance probability vector $RV(k)$ is:

$$R_L(k) = \bar{p}_{drop} \times \sum_{i=1}^{n} (rv_i(k) \times \bar{p_e}(i)) \quad (1)$$

where $rv_i(k)$ are the elements of the reliability distance probability vector.

B. Reliability Parameters Computation

1) Node distance probability modeling with Smooth Mobility: The probability vector $RV(k)$ after the epoch k is a vector (with $(n+1)$ elements):

$$RV(k) = P(0)P_R^k \quad (2)$$

Where P_R^k is the reliability matrix of transition probability after k epoch; $P(0)$ is the initial probability vector which denotes the probability of initial distance between a pair of nodes at the epoch 0.

$$P(0) = [p_1(0), p_2(0), p_3(0), \cdots, p_n(0), \cdots] \quad (3)$$

The $P(0)$ depends on the objective [5]:

- If the objective is to compute parameters for a given link, $P(0) = [p_1(0) = 0, \cdots, p_i(0) = 1, \cdots, p_n(0) = 0, \cdots]$; where i corresponds to the initial distance on the link.
- If the objective is to compute an average value for the parameters of the network, $P(0) = [p_1(0) = \frac{1}{n}, p_2(0) = \frac{1}{n}, \cdots, p_n(0) = \frac{1}{n}, \cdots]$; where all the elements are equiprobable in our study.

In general case, it is necessary to determine the mobile node distribution over a network area according to the mobility model.

The transition matrix of reliability P_R is the transition matrix probability with an absorbing state e_{n+1} (modeling, any nodes pair with a distance greater than r). The communication link is considered to be broken, if the distance between the pair of nodes reaches the absorbing state. There are $(n+1)$ possible states, thus, P_R is a $(n+1)\times(n+1)$ size matrix. Each element of P_R, $p_{i,j}$ corresponds to the probability of transition from state e_i to state e_j in a given epoch. Note that for all i,j, $p_{i,j} \ge 0$ and $\sum_i p_{i,j} = 1$. This probability is formulated as follows for smooth mobility model [8]:

$$p_{i,j} = Pr(e_i \to e_j) \approx \frac{0.2}{v_\alpha} \times \sqrt{\frac{2j-1}{2i-1}} \times \ln\left[\frac{|4(v_\alpha+\delta_v)^2 - \varepsilon^2(j-1)|(i+j-1)^2}{|\varepsilon^2(i+j-1)^2 - 4(v_\alpha+\delta_v)^2|(j-1)^2}\right] \quad (4)$$

Where v_α represents the stable speed of nodes in the smooth model, δ_v is the maximum speed variation of v_α in one time step (empirical value is 2m/s [9]). The relative speed range according to v_α is $[0, 2(v_\alpha + \delta_v)]$.

2) SNR-based channel error modeling: Assuming the physical layer wireless channel is modeled by a log-normal shadow fading, the signal attenuation between wireless nodes includes two components: (1) a deterministic geometric component with path-loss exponent α, and (2) a stochastic component defined as a random variable with a mean equal to zero and variance equal to σ^2. Hence, the probability $\bar{p_e}(d)$ that a packet is not lost due to channel errors, in a log-normal shadow fading environment, is given in [20]:

$$\bar{p_e}(d) = 1 - \frac{1}{2} + \frac{1}{2} erf\left(\frac{\beta_{th} - \alpha \times 10\log_{10}(d)}{\sqrt(2)\sigma}\right) \quad (5)$$

Where erf(.) is the standard error function, d is the distance between two nodes; β_{th} is the lowest threshold which is required to deliver a packet between the nodes. β_{th} depends on the receiver threshold power $p_{r,th}$ denoted as receiver sensitivity and transmitter power p_t. The value of the variance σ^2 is chosen according to the simulation environment.

3) Packet drop probability: We assume that nodes use CSMA/CA based MAC layer and every node in the network has always a packet to send. Data packet is dropped after m consecutive unsuccessful retransmissions. The probability that the packet is not dropped given in [21] as a function of the probability of collisions p_c, is:

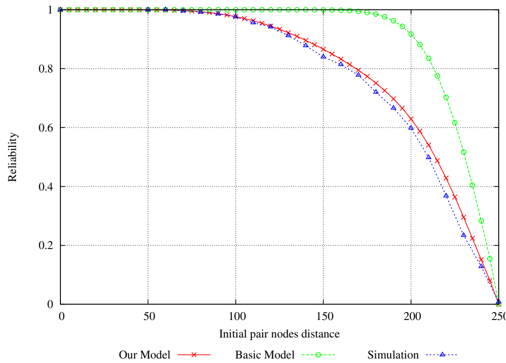
$$\bar{p}_{drop} = \left(1 - p_c^{m+1}\right) \quad (6)$$

$$p_c = 1 - \bar{p_c} = 1 - \left(1 - \frac{1}{CW}\right)^{d_{avg}-1} \quad (7)$$

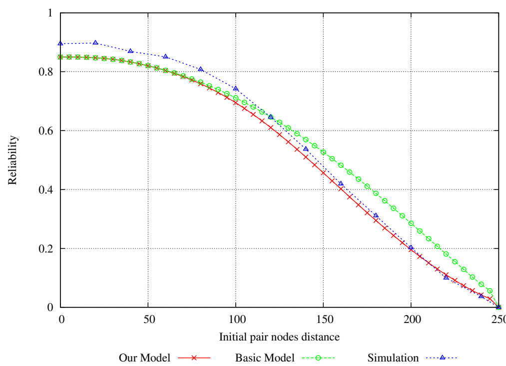
Where m is the number of retransmissions (6 retransmissions are defined in 802.11); CW is the contention windows and d_{avg} is the average degree of network nodes (which is given as in [22]).

$$d_{avg} = \frac{n * (\frac{3\sqrt{3}}{4})r^2}{|A|} \quad (8)$$

Where n is the total number of nodes, r is the transmission range and $|A|$ is the size of the network area.

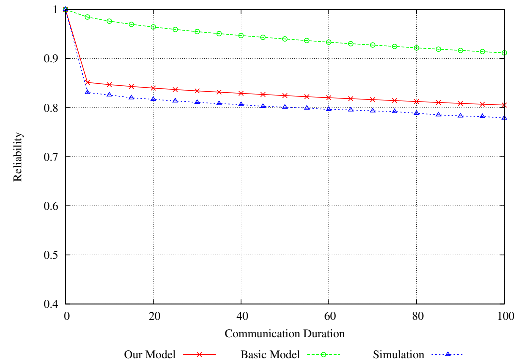


(a) $v_r = 4m/s$

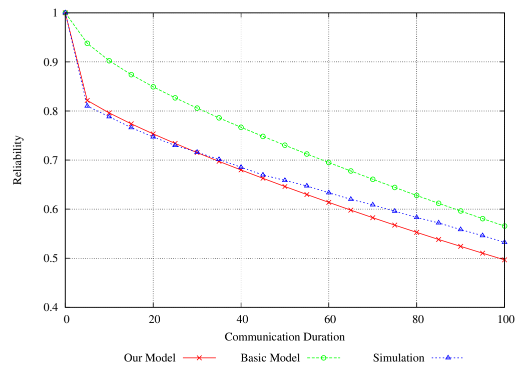


(b) $v_r = 17m/s$

Fig. 1. 2 Nodes Scenario: Reliability vs Initial Nodes Distance *(communication Duration=100 s)*



(a) $v_r = 4m/s$



(b) $v_r = 17m/s$

Fig. 2. 2 Nodes Scenario: Reliability vs Communication Duration

IV. Results Analysis

We focus on the validation of our formulation of the link reliability (1). We used OMNeT++ simulator [23]. Link reliability is simulated in different contexts and compared to value derived from our link reliability equation as well as those given by the basic link reliability proposed in [8]. The simulation area is specified by a $1401m \times 1401m$ square region as in [8]. We select IEEE 802.11 link layer and radio shadow fading propagation. The theoretical radio coverage region of each mobile is assumed to be a circular area with a radius equal to 250m. The shadow fading environment parameters are path loss $\alpha = 4$, and $\sigma = 8$. During simulation, link failure between adjacent nodes is detected through ping send and response. Link reliability value is obtained after 3000 runs, by average.

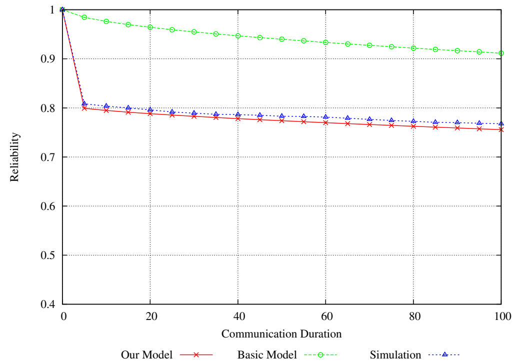
A. Two nodes in the simulation area

In this section, we are interested to determine link reliability in absence of interference and collision. For that, we place only two nodes in simulation area, hence link reliability between the pair of nodes is only impacted by node movements, and fading.

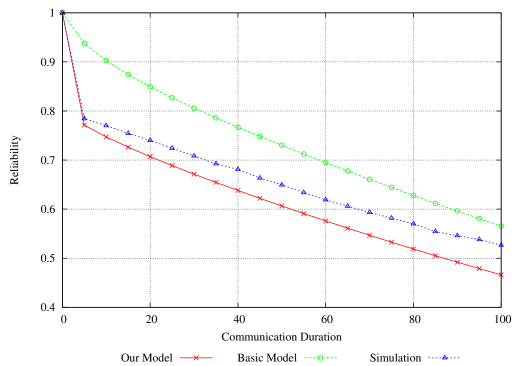
Figure 1(a) and 1(b) present the impact of the initial distance between the pair of nodes on link reliability value. We compare the simulation results to the link reliability given by our proposition and by the basic model. In the two figures, we observe that the obtained link reliability decreases when the initial distance increases. With small and medium relative speed values, our link reliability computing method accurately approximates the link reliability obtained by simulation. The link reliability value for a pair of nodes moving with a small relative speed $v_r = 4m/s$ is not influenced by an initial distance less than $100m$. While for high relative speed $v_r = 17m/s$, initial distance highly impacts the link reliability value. Link reliability, is presented in figure 2(a) and 2(b), in function of communication duration, for different relative speeds. Assuming that the link exists at the beginning, the second node is uniformly placed in the range of the reference node (from $0m$ to $250m$). We observe that our proposition is more accurate than the basic model for small relative speeds whatever communication duration. For high relative speeds, our approximation method is not so good but it is always more accurate than the basic model.

B. Fifty nodes in the simulation area

In order to study the collision and interference impacts on link reliability, 50 nodes are placed randomly inside the simulation area, and we compare the three methods. We assume that at the beginning, the link exits between the two given nodes. Other nodes try to send packets to the reference node, leading to interference and collision. Hence, compared to the previous two nodes scenario, link reliability decreases. Note that, basic model gives the same value whatever the number



(a) $v_r = 4m/s$



(b) $v_r = 17m/s$

Fig. 3. 50 Nodes Scenario: Reliability vs Communication Duration

of nodes in the simulation area. As shown in figures 3(a) and 3(b), our proposition improves basic model approximation.

V. Conclusion

In this paper, we have proposed a practical link reliability computing model. This model considers the SMS mobility model without losing the initial nodes distance. As shown by our simulation results, the initial distance strongly influences the link reliability. Moreover, we integrate the transmission quality and also an expression of collision occurrence in our formulation. Our proposal leads to a more accurate calculation. This proposition could be used by reliable routing protocols to select the best reliable routes. Meanwhile, the computation is more suitable for low movement than for fast movement such as vehicular. However, when the mobility is too high the reliability becomes too low and there is no interest to use a reliable routing protocol. This analytical model is being integrated to a multipath routing protocol in order to enhance the reliability.

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