Link Stability in MANETs Routing Protocols

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***Abstract*—Mobile ad hoc networks (MANETs) is a promising communication paradigm for the emerging collaborative environments, which do not need an underlying stable, centralized routing and management infrastructure. In this paper we propose a particular approach for the design of a mobile routing protocol focused on the stability (measured as the transmission intensity change rate) of network links instead of speed and path length, and simulate its adoption in a random network analyzing the corresponding communication graphs.**

***Keywords*-MANET, routing protocol, link stability.**

I. Introduction

Starting from the routing protocols developed in the seventies, valuable work has recently been done in the field of routing protocols for mobile ad hoc networks (consisting of interconnected mobile hosts with routing capabilities), especially since the advent of wireless networks based on UMTS/LTE and WiFi/WiMAX protocols [5] where it is possible to deal with a variable-speed link going from 1 to about 300 Mbps up to 120 Km/h. Because mobile networks can have very unstable links, stability of routes (instead of the only link speed/intensity and path length) becomes a main target in the development of a mobile routing protocol.

In the following section the state-of-the-art is examined, pointing out the fundamental routing protocol issues. Next, Section III introduces the link stability concept in high mobility networks. In Section IV we present the best-path analysis related to link stability, then stating our proposal of an algorithm for route discovery in Section V. A practical network simulation is illustrated in Section VI together with some relevant parameters. Finally, Section VII summarizes and provides some directions for future work in this area.

II. Background and Related Work

In mobile (and hence wireless) ad hoc networks, instead of wireline networks, every node acts both as a router and a host, so the classical "wired" routing protocols are not applicable at all to MANETs.

Existing routing protocols may be classified based on:

- the logical organization through which the protocol "describes" the network. From this point of view they may be divided in *uniform* (all nodes have the same function) and *non uniform* (the way nodes generate and/or answer path control messages may be different for different group of nodes) routing protocols;
- the way routing information is obtained. From this point of view, protocols may be divided in "Proactive", or Table-Driven (such as DSDV Destination-Sequenced Distance-Vector [10] and WRP Wireless Routing Protocol [11]), "Reactive", or On-Demand (such as AODV Ad hoc On-Demand Distance Vector [10], DSR Dynamic Source Routing [11], and TORA Temporally Ordered Routing Algorithm [11]), and "Hybrid" (such as ZRP Zone Routing Protocol [12]);
- how the routing path is created.

There can be a considerable network overhead and computing resource use in a MANET in order to keep track of frequent changes in topology. Protocols of reactive type were designed for these environments, with the aim of not keeping track of network topology [9]. If a node needs to reach a destination, it starts a discovery process [8] to find the path by transmitting broadcast messages of Route Request (RREQ) type, with TTL set to 1 [13]. Each message has a sequence number, so that only the first message is considered, while its subsequent copies are discarded. When a node receives the first copy of a RREQ from a source node, it stores the address, thereby establishing a return path (reverse route). When the first RREQ reaches the destination, a reply message of type Route Reply (RREP) is sent to the source through the return path. This type of protocol is generally efficient for a single rate network; in a multi-rate network, however, what counts is not to minimize the number of jumps to reach a destination, but the total throughput on a given routing.

An existing technique taking into account, instead of the number of hops, the throughput is the MTM (Medium Time Metric) [1]. In this technique a cost inversely proportional to the speed of the link is established; hence, the minimum cost link is chosen. Instead of considering only the cost of the link, its stability should also be considered [4].

A simple model for computing link stability and route stability based on received signal strengths is proposed in [7]. A comparison of various proposed link stability models is made in [8], stressing *route lifetime*. A different approach is carried out by [4], where *signal stability* is used to define link's connection strength. In [2] a mobility metric (*link duration*) is defined, attempting to quantify the effect of node movement in order to develop an adaptive ad hoc network protocol. This last idea is in part also adopted in the

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present paper, going further towards the more comprehensive concept of *link stability*, taking into account transmission intensity rate change, too.

III. Routing Instability in Mobile Networks

Although existing routing techniques are of indisputable validity, as a result of lengthy trials conducted in wired networks, a problem causing the performance loss in wireless ad hoc networks (and impacting on the route discovery processes) is the same routing instability, given that we are dealing with high mobility networks. What is "routing instability"? Let us consider a node represented by a mobile phone transmitting while in movement and think how variable is the signal received from a surrounding node as the issuer node moves in a closed or open environment. The level of the received signal, changing constantly, causes a continuously variable ratio of Signal-to-Noise (S/N), altering the bit-rate and consequently the "cost" of the link. This variability would lead to a continuous instability of routing, causing a continuous search of the "best path". This implies an increase in transmission overhead, impacting greatly on the entire network performance and throughput. A technique that keeps track of link stability is now presented, so as to avoid too unstable links in the route discovery process.

A. Keeping track of routing stability

Keeping memory of stability means understanding how stable are connections between nodes; the idea is to have a table maintaining information associated with each link on its state transitions. With the word "transition" you can consider the link's moving from one transmission intensity (measured in dBm and equal to the signal/noise ratio) to another. Table I illustrates each link associated with its number of transitions.

Table I
LINK TRANSITIONS

Link #	No. of transitions
L_1	n_1
L_2	n_2
L_3	n_3
...	...

B. Stability index and thresholds

Let us now analyze what causes the increase in the number of transitions associated with the link. In order to record link's stability, omit all transitions lying within a defined tolerance (those without a significant loss in link performance). The key idea is to record a transition whenever the link's transmission intensity "oscillates too much", i.e., the difference between the new I_i and the previous I_{i-1} sampled transmission intensity relative to I_{i-1} (in absolute value) falls outside a predefined threshold τ. So you keep track of a transition when

$$\left|\frac{I_i - I_{i-1}}{I_{i-1}}\right| > \tau$$

In order to correctly keep track of transition frequency, it is advisable to sum the number of transitions of a link compared to an observation period. For example, if C is the number of transitions in the time interval ΔT, the frequency F will be

$$F = \frac{C}{\Delta T}$$

C. Observation's time interval

To establish a statistical time interval ΔT is not simple. You can guess it to be inversely proportional to the mobility rate of nodes and directly proportional to the number of nodes. Thus, given a network of N nodes, with average nodes' mobility rate μ, you can say that

$$\Delta T = k \cdot \frac{N}{\mu}$$

After this interval the various counters (column "No. of transitions" in Table I) are zeroed.

At the end, a maximum threshold $C_{\max}$ for the number of transitions in the time interval remains to be defined. Consider, for example, a time interval $\Delta T = 300$ milliseconds and a possible maximum value $F_{\max}$ for the transition frequency F of one transition every 60 milliseconds. From that, you may establish for example $C_{\max} = 3 < \Delta T \cdot F_{\max} = 5$. In a nutshell, if there are more than three transitions within an observation period of 300 milliseconds (i.e., $C > C_{\max}$) you will say that the network link is unstable.

In order to practice an effective implementation of the mechanisms given above, one can follow two approaches. The first is to monitor the stability of the link, the second provides for the updating of the link stability table only after a route discovery request. Given the high overhead required by the first approach, it seems preferable to implement the second as better detailed later.

IV. Best Path Choice in Route Discovery

When deciding on the best path, two alternative approaches called "Link Stability" and "Link Rate" are considered and described below in detail.

A. Link Stability

This technique – as the term shows – prefers link stability, and then in the choice of the route to be built it excludes a priori all links having a transition frequency F above a certain threshold. Returning to our example, if $F_{\max} = \frac{1}{60}$ is the threshold corresponding to a transition every 60 milliseconds, all links having $F > \frac{1}{60}$ will be excluded from the choice. Note that, albeit being true that the stablest link has to be chosen, a stable link could also be one with a zero (i.e., not working) signal intensity. Therefore a minimum

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threshold I_{min} should be set for the link intensity, below which the choice cannot be done even if the link is very stable. So, considering threshold values F_{max} and I_{min}, a network link is stable when $I_i \geq I_{\text{min}}$ (for all $i = 1 \ldots n$, being $n = \Delta T \cdot F_{\text{max}}$ the total number of samples) and $F \leq F_{\text{max}}$.

B. Link Rate

In this technique, stability becomes of secondary importance: link speed is in any case to be preferred. So, when choosing routes for the construction of the best path, the stablest link will be chosen only within those of equal cost (at an equal speed). But what does *equal speed* mean? First, it should be noted that from a practical point of view having two links of the same speed may not correspond to reality, if not for a purely random case. Therefore, two links are of equal speed if the difference in speed between them is no more than 20%. E.g., if the link L_1 has a bit rate $V_1 = 100$ Mbps you can say that a second link L_2 has the same speed V_2 if 80 Mbps $\leq V_2 \leq$ 120 Mbps.

Coming back to the above sketched technique the algorithm, among two links of equal speed, will choose (only under such conditions) the stablest one. To define this stability the same considerations outlined in the previous technique can be done.

V. Our Proposal

From what said, the focus is here on the approach called *link stability*, where the characteristic parameters for network monitoring are highlighted, i.e., the transition frequency of the received signal intensity (dBm) and the signal intensity itself. In the protocol design and implementation a crucial role is played by the link stability table. To optimize efficiency, the table will be updated at the beginning of every route discovery process, and used in the same process to identify the route.

A. The routing process

Each node manages a routing-path table keeping track of all incoming and outgoing connections. The table contains, with respect to a classic routing table, not the mere next hop off an interface but the entire route (that is, all node addresses belonging to the route to destination) and a time-stamp field used to delete the obsolete routes not used for more than a threshold time limit, as shown below.

Observing Figure 1, the application layer sends a route request to the network layer. The routing protocol (interior protocol) checks if the destination address already exists in the device routing-path table. If it does not, the route discovery process is activated in order to enter the destination node address and its path in the routing-path table. If the destination address exists in the device routing-path table, the relative path (included in the routing-path table) will be used and updated by the real time-stamp value of the sender. In MANETs, the paths included in the routing-path table cannot be static since the network topology changes very frequently; the responsibility of route availability is demanded to the upper layer (because there may be an expired timeout waiting for an acknowledgment). The upper layer must still decide whether to delete a route from the table, even if its time limit has not expired: this means that it will request a route discovery every time a packet nondelivery happens.

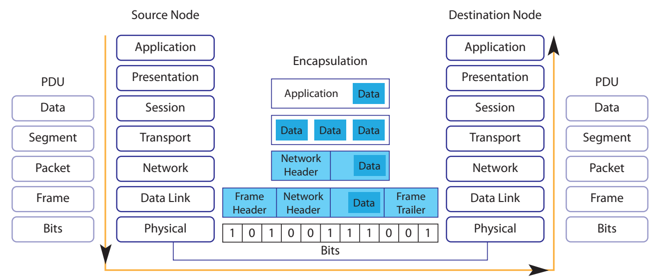

Figure 1. Encapsulation process in communication between nodes

B. Identification of stablest links

To define the stablest links during the route discovery process, a node must collect n transmission intensity values I_i (expressed in dBm) during a statistical time interval ΔT. During this interval, the minimum value I_S of the sampled data I_i will be stored, and the transition counter C will be updated every time the absolute value of the relative difference between the two last observed values is outside the predefined percentage threshold τ.

These values, at the end of ΔT, will be used to check that the received signal intensities I_i are all greater than or equal to a minimum acceptable threshold I_{min} and if they overcome the percentage threshold τ not too often (i.e., $C \leq C_{\text{max}}$).

If the link is declared stable, a better indicator could be given by a "stability index" $0 < s \leq 1$ given by 1 minus the ratio between the transition counter C with respect to the total number of samples n

$$s = 1 - \frac{C}{n}$$

where $s = 1$ means "highly stable" ($s > 0$ being $C < n$). If the link is unstable, put $s = 0$.

In the example of Table II we assume a maximum transition frequency $F_{\text{max}} = \frac{1}{60}$ and an observation period $\Delta T = 300$ milliseconds. Five intensity signal measurements in dBm are sampled over ΔT (being $\Delta T \cdot F_{\text{max}} = 300 \cdot \frac{1}{60} = 5$) and checked against a predefined minimum acceptable intensity $I_{\text{min}} = -85$ dBm and a relative transition percentage threshold $\tau = 20\%$. A maximum acceptable transition counter $C_{\text{max}} = 3 < 5$ is also established. The transition counter C is increased every time the absolute value of the

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relative transition percentage (determined by the last two transmission intensities) overcomes the threshold τ.

Note that the minimum intensity I_{min} is never violated (i.e., $I_S = -80 > I_{\text{min}} = -85$). So, the link is stable because the transition counter $C = 3$ does not exceed the maximum C_{max} too, and its stability index is $s = 1 - \frac{3}{5} = 0.4$.

Should the transmission intensity I_i of the current sample fall under the predefined minimum acceptable intensity I_{min}, then no more samples are collected and the link can be declared "unstable", as shown in Table III.

Table II
LINK STABILITY TABLE – A STABLE LINK

S#	Link transmission intensity I_i (dBm)	Minimum intensity I_S (dBm)	Relative transition % $\left\lvert \frac{I_i - I_{i-1}}{I_{i-1}} \right\rvert$	Transition counter C
1	-50	-50	–	0
2	-70	-70	40.00%	1
3	-80	-80	14.29%	1
4	-40	-80	50.00%	2
5	-70	-80	75.00%	3

$I_{\text{min}} = -85$ dBm, $\tau = 20\%$, $C_{\text{max}} = 3$, $s = 0.4$

Table III
LINK STABILITY TABLE – AN UNSTABLE LINK

S#	Link transmission intensity I_i (dBm)	Minimum intensity I_S (dBm)	Relative transition % $\left\lvert \frac{I_i - I_{i-1}}{I_{i-1}} \right\rvert$	Transition counter C
1	-50	-50	–	0
2	-70	-70	40.00%	1
3	-90	-90	21.43%	2

$I_{\text{min}} = -85$ dBm, $\tau = 20\%$, $C_{\text{max}} = 3$, $s = 0$

C. Route Discovery packet fields

The Route Discovery packet contains the following fields:

- destination node address;
- sender node address;
- sender node time-stamp;
- hop-count (number of links, or nodes, passed through);
- number of stable links;
- pointer to a stack containing addresses of nodes traversed from the sender (bottom) to the recipient (top).

D. Route Discovery algorithm

The Route Discovery process can be summarized as follows.

1) Every node initiating a transmission activates a route discovery process.
2) The transmitter node sends a packet including the destination address and the above mentioned fields.
3) Every node receiving the packet checks if the destination address matches itself.

Matching. The receiving node stores the return path, and the percentage of stable links over all links traversed. Later, after receiving the first packet, it waits for any other route discovery packet related to the pair sender-timestamp for a specified time ΔT_B. If in this time another route discovery packet arrives, the node compares the percentage of stable links over all links passed through with the previous stored percentage. If it is higher, the new relative path and new percentage will be stored, otherwise the packet will be ignored. All other arriving route discovery packets will be treated the same manner until ΔT_B expires. The recipient, after selecting the best route among all considered in the above said interval:

a) sends an ACK using the final reverse route. This acknowledgment will be uniquely associated with the route discovery packet transmitted by sender with its time-stamp included;
b) inserts the reverse route (the winning route) in its routing-path table, binding it to a local time-stamp.

Reverse-route will be used as long as the routing is valid, i.e., while the recipient is reachable.
We can consider an improvement in despite of two paths with same percentage value of stable links. In fact, the best path can be better chosen based on the sum of the costs of the links of every path (column *"Cost" of path* of Table VI). The link's cost is the stability index s previously defined and showed in column *Weight* of Table IV. We remember that a link is unstable if $s = 0$. So, the best path will be chosen based on the maximum value of all path costs considered. For this solution, besides the percentage of stable links, the node will store the sum of costs for every path too, and the Route Discovery packet will have a further field reserved for the path cost.

No Matching. The receiving node checks whether its address is in the stack of traversed nodes:

a) if yes, it drops the packet, since it is a broadcast route discovery packet previously handled by itself, so the broadcast storm effect will be excluded;
b) if not, it sends a broadcast route discovery packet to the same destination address adding the node address from which the packet is coming, plus a stable link counter increased

by 1 (in case the receiving node has detected a stable link) and a counter storing all links traversed.

4) Return to Step 3.

VI. Network Simulation

In order to test the assumptions made in our proposed mobile routing protocol we adopted a software network simulator, CNET [3], implementing in the internal layer the route discovery behavior (see Figure 2). CNET employs a simple free-space-loss (FSL) model of signal propagation, with the signal's propagation loss determined by the transmission frequency and the distance between nodes as shown by the formula

$$\mathrm{FSL} = 20\log(f) + 20\log(d) + 92.467$$

where f is the transmission frequency (in GHz) and d is the distance (in km).

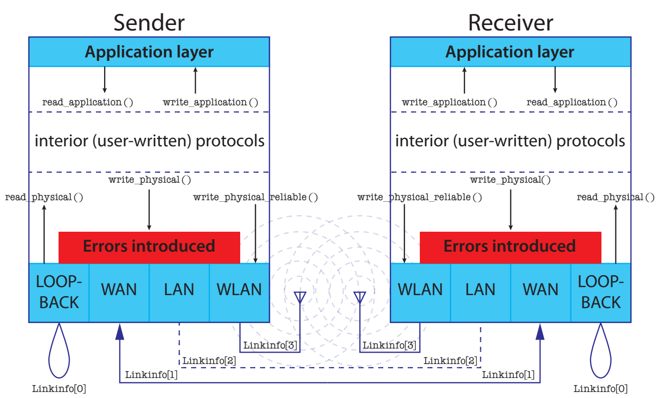

Figure 2. CNET simulation model

We carried out a simulation of a mobile ad hoc network with 18 links and 20 nodes transmitting at 2.45 GHz, with a Tx power of 14.771 dBm and a receiver signal-to-noise ratio of 16.0 dBm. After the simulation, we obtained a set of routes as the result of the *route discovery* processes randomly generated by the hosts of the mobile network. These routes are represented in the undirected weighted graph shown in Figure 3, where edge weight (obtained through a simulation of the transition counter depending on the FSL and Rx values) corresponds to link's stability index as shown in Table IV. The simulated network's properties have been analyzed with the graph utilities available in Mathematica (http://www.wolfram.com/products/mathematica/) and NetworkX (http://networkx.lanl.gov/), according to the indicators introduced by Hanneman [6] and are illustrated in Tables V and VI (note that node M16 has been excluded in the connectivity analysis of the graph). In Table VI, we show the list of paths (routes) for a specific node (M11) along with the "cost" of path, i.e., the sum of edge (link) weights, where an higher value means a better (more stable) path.

In Table V, the parameter *average shortest path length* summarizes the "stability" behavior of the entire network. The average shortest path length is the sum of path lengths $d(u, v)$ between all pairs of nodes (assuming the length is zero if v is not reachable from u) normalized by $n \cdot (n-1)$, where n is the number of graph nodes.

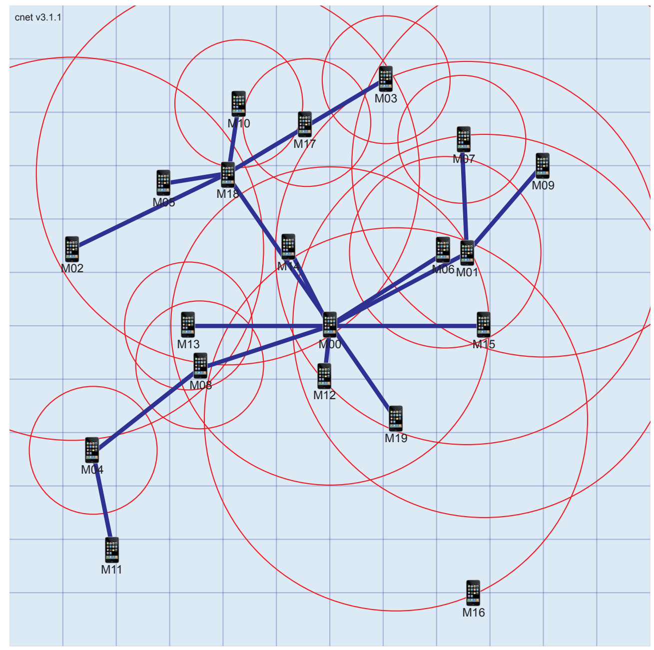

Figure 3. A route discovery simulation with CNET

Table IV
Simulated Network Links

Link	Distance (km)	FSL	Rx (dBm)	Weight (stability index)
{M00, M01}	0.146	83.561	-64.510	0.184
{M00, M06}	0.128	82.449	-63.398	0.259
{M00, M08}	0.126	82.281	-63.230	0.271
{M00, M12}	0.047	73.760	-54.709	0.848
{M00, M13}	0.132	82.668	-63.617	0.245
{M00, M14}	0.084	78.801	-59.750	0.506
{M00, M15}	0.145	83.484	-64.433	0.189
{M00, M18}	0.171	84.950	-65.899	0.090
{M00, M19}	0.107	80.880	-61.829	0.366
{M01, M07}	0.106	80.771	-61.720	0.373
{M01, M09}	0.108	80.964	-61.913	0.360
{M02, M18}	0.162	84.441	-65.390	0.125
{M03, M18}	0.172	85.001	-65.950	0.087
{M04, M08}	0.128	82.458	-63.407	0.259
{M04, M11}	0.095	79.878	-60.827	0.433
{M05, M18}	0.060	75.904	-56.853	0.702
{M10, M18}	0.066	76.753	-57.702	0.645
{M17, M18}	0.086	79.033	-59.982	0.491

VII. Conclusion

The simple techniques exposed here are suited to any type of mobile ad hoc network and any kind of speed,

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Table V
SIMULATED NETWORK'S GRAPH: NETWORK PARAMETERS

Network density	0.105
Network diameter	1.811
Network radius	0.963
Edge-connectivity	0.087
Degree histogram	0:0, 1:14, 2:2, 3:1, 4:0, 5:0, 6:1, 7:0, 8:0, 9:1
Neighbor connectivity	1:2.556, 2:0.389, 3:0.306, 6:0.389, 9:0.472
Average shortest path length	0.813
Center nodes	M00
Peripheral nodes	M11, M12
Articulation nodes	M00, M01, M04, M08, M18

Table VI
SIMULATED NETWORK'S GRAPH: PATHS FOR NODE M11

From	Path	To	"Cost" of path (sum of weights)
M11	M04, M08, M00	M19	1.329
M11	M04, M08, M00	M15	1.152
M11	M04, M08, M00, M01	M09	1.507
M11	M04, M08, M00, M01	M07	1.520
M11	M04, M08, M00	M06	1.222
M11	M04, M08, M00	M14	1.469
M11	M04, M08, M00, M18	M03	1.140
M11	M04, M08, M00, M18	M10	1.698
M11	M04, M08, M00, M18	M05	1.755
M11	M04, M08, M00, M18	M02	1.178
M11	M04, M08, M00	M13	1.208
M11	M04, M08, M00	M12	1.811

by the definition of the indicated parameters. Therefore, this methodology can probably be implemented in any type of network environment, even in networks with very high density of nodes, as wireless networks in delimited environments such as university campus, airports, shopping malls, etc.

It would be useful to conduct proper simulations to test the described algorithm and obtain significant values for the following parameters:

- the statistical time interval ΔT;
- the number n of samples considered in the time interval;
- the minimum acceptable signal intensity I_{min} in dBm;
- the percentage threshold τ of transmission intensity variation;
- the allowed frequency oscillatory limit F_{max} to define a stable link;
- the % of stable links over total traversed links for routing-path table;
- the sender node (waiting for acknowledgement) time-out to initiate a new route discovery;
- the time-out to declare an "old" route in the routing-path table;
- the recipient node wait-time ΔT_B to receive the route discovery.

It would also be useful to study how these techniques, when implemented, impact on the energy consumption of nodes (as a percentage of the generated network overhead).

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