# Ad Hoc Routing Based on the Stability of Routes

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## ABSTRACT

Some reactive ad hoc protocols allow the discovery and/or storage of multiple paths to the same destination node. The selection of the path to utilize is commonly based on the criterion of the minimum number of hops. However, some other strategies could be appropriate to improve the network performance. In this paper, we intend to minimize the load in the network by choosing the most stable path, i.e. the path which is expected to have the longest lifetime. With this purpose, we estimate the stability of the path by means of the received signal strength. The simulations show that important improvements associated to the network performance are achieved by the use of this cross-layer information.

## Categories and Subject Descriptors

C.2.2 [Network Protocols]: Routing Protocols

## General Terms

Design, Algorithms, Experimentation, Performance

## Keywords

MANET, Route stability, DSR, Ad Hoc Routing

## 1. INTRODUCTION

The development of wireless technologies in conjunction with the production of light-weighted and advanced computing devices is easing the ubiquitous computing. Under this new paradigm, mobile ad hoc networks (MANET) facilitate the connection of users whenever and wherever without the demand of any pre-installed telecommunication infrastructure. The absence of infrastructure in mobile ad hoc networks requires the collaboration of the devices that form the network in order to ensure the communication among those terminals that are not directly connected. By this cooperation, packets in the MANET may be forwarded from the source to the destination host through multiple hops or nodes. The sequence of the nodes that allows the communication of distant nodes determines a path.

The discovery of the potential paths as well as the detection of their breakages could be accomplished by diverse methodologies that differentiate the already developed routing protocols. In a simplified classification, ad hoc routing protocols could be characterized as reactive, proactive or hybrid. In proactive protocols, nodes know the network topology (partially or completely) by the reception of periodic messages. With this information, a path is immediately available when the devices have need of it. On the other hand, reactive strategies are based on the demand of a route that nodes perform exclusively when they are going to initiate a communication. Once the path is discovered, the node could utilize it until it becomes inoperative due to node mobility, channel interferences or disconnections of the devices. The hybrid strategy combines the proactive scheme used in a determined area around the source with the reactive procedures for those nodes that are out of the defined zone.

Some of the reactive routing protocols allow the discovery of multiple paths to the same destination node [1] [2]. The selection of the path to utilize is commonly based on the criterion of the minimum number of hops. However, some other strategies could be applied in order to minimize the principal disadvantages of this type of protocols. These disadvantages are mainly associated to the deterioration that the network suffers when mobile nodes must proceed to a route discovery. Usually, this process is initiated by the emission of a broadcast message called Route Request. This message is received by all the nodes in the network, which will reply to the source with a unicast message in case of knowing the demanded route to the destination. Meanwhile, the packets must be stored in internal queues and, as a consequence, their delay increase. If traffic presents a significant rate, the storage space could become insufficient and losses will take place. Additionally, the route discovery is associated to the flooding of control packets in the network. This operation causes the consumption of the limited battery in nodes as well as potential interferences with some other packets. Therefore, the reduction of the number of performed route discovery is expected to improve the network performance.

As a first step towards the diminution of the number of route discoveries, the conditions that trigger this procedure should be analyzed. Firstly, the route discovery procedures are employed when mobile nodes do not have any route to their destinations. With the aim of minimizing this effect, some protocols propose that a node learns the maximum number of routes from the received packets [3]. On the other hand, it is also necessary to discover a route when the previous one is not available as the movements of the nodes that formed it have provoked its break. These circumstances could be mitigated by the selection of more stable paths, i.e. those that are expected to have a longer lifetime. In this paper, authors propose the utilization of the stability of routes as the criterion for selecting a route to employ among the multiple discovered paths. In this sense, the received signal strength is considered an indirect measurement of a route lifetime.


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The remainder of this paper is organized as follows. In Section 2, the related work about ad hoc routing based on the route stability is presented. The proposed technique for route selection is described in Section 3. Section 4 includes the simulation results that show the comparison of conventional minimum number of hops criterion to the criterion based on route stability. Finally, Section 5 draws the main conclusions of the paper.

## 2. RELATED WORK

ABR (Associativity Based Routing) is one of the first proposals to define routes basing on the path stability. It prioritizes the routes comprised of stable links [4]. A link is considered stable when its lifetime has overcome a specific threshold that depends on the relative speed of the mobile devices. One of its main disadvantages is the requirement of periodic emission of 'hello' messages in order to estimate the expected link lifetime.

On the other hand, SSA (Signal Stability Adaptive Routing) classifies the links into strong and weak depending on the received signal strength measured when packets are forwarded through them [5]. When a mobile node receives a Route Request as an initial operation in the route discoveries, it will process the message only if it is received by a strong link, so that packets received by weak links will be dropped. In the same way, a node will only send information through strong links. Among the multiple responses that a node receives after initiating the route discovery, it will select the first one.

Some other strategies intend to support their selection algorithm on the distances between the terminals [6]. In this case, the mobile devices should include a GPS terminal whose presence is not always guaranteed in any ad hoc application due to its cost. This restriction is overcome in the proposal of [7]. Under this scheme, the fragility of a route is computed as the difference of the received signal strengths of consecutive packets flowing from the same origin in order to detect if nodes are getting closer or apart. As a clear inconvenience, this technique needs the storage of the learnt information. As a simplification of this technique, we propose the estimation of the expected residual lifetime of a path by the analysis of the minimum signal strength with which a packet is received through the complete route.

## 3. ROUTING AND PATH STABILITY

One of the main techniques to reduce the number of route discoveries could be based on the selection of more stable paths, i.e. those paths that are expected to present a longest lifetime. Although there exist several techniques to estimate the residual lifetime of a path, the authors of this contribution propose the indirect measurement of the distance between nodes as this parameter could represent the fragility of the route. If two consecutive nodes in a path are separated by a distance similar to the transmission range, the link is expected to be broken shortly due to the high sensibility of the link to the movements of the nodes. This behavior is referenced as the edge effect [8].

Since a route becomes unavailable as soon as one of its links is broken, the fragility of a route is strongly dependent on the more unstable link. Formally, Route Lifetime (*RL*) is expressed as:

$$RL = \min_{i=1}^{N}\left(L_i\right) \tag{1}$$

where a Route is composed of $N$ links and $L_i$ represents the lifetime of link $i$.

As an indirect measurement of the distance between nodes, the received signal strength is employed. For a first approach, authors consider a free-space propagation model. However, some other propagation models could also be considered applying the difference of the received signal strengths as exposed in [7]. With this parameter, Equation 1 could be summarized as:

$$RL \propto \min_{i=1}^{N} \frac{1}{D_i} \propto \min_{i=1}^{N} S_i \tag{2}$$

where $D_i$ represents the distance for the Link $i$ and $S_i$ is the received signal strength of the last packet through link $i$.

Taking into account Equation 2, the analysis of the minimum signal strength with which a packet is received through the multiple hops in the route is introduced in the route discovery procedure of a reactive protocol. Initially, a node intending to discover a route to a destination will broadcast a Route Request message in the MANET. This message will include an extra field containing the minimum signal strength with which this packet has been received. On the other hand, the node that knows the route to the destination generates a Route Reply where this extra field is set to the same value that this field contained in the corresponding Route Request. On the way back to the source, the field is updated in each hop if the received signal is lower than the stored value.

If multiple replies are allowed in the protocol, the source may receive diverse Route Replies to reach the desired destination. Each Route Reply informs about the minimum signal strength associated to the route that it is offering. Based on this information, the source could select the path to utilize applying different criteria. In this paper, authors propose two criteria:

- Maximum/Minimum Signal Strength (MMSS). Source selects the path linked to a maximum value in the field of minimum Signal Strength. So, if source receives $R$ Route Replies, the selected path (*SP*) is chosen by:

$$SP = \left\{ P_i \middle/ mss\,(P_i) = \max_{i=1}^{R} (mss\,(P_i)) \right\} \tag{3}$$

  where $P_i$ represents the paths learnt from all the Route Reply messages and *mss* is the value of the minimum signal strength contained in the corresponding Route Reply.

- Minimum number of Hops and Maximum/Minimum Signal Strength (MHMMSS). By this criterion, the source first selects the paths with a lower number of hops. Among them, the route to employ is the one associated to a maximum value in the minimum Signal Strength field. Formally, this criterion is represented as:

$$H = \left\{ P_i \middle/ hops\,(P_i) = \min_{i=1}^{R} (hops\,(P_i)) \right\} \tag{4}$$

$$SP = \left\{ H_i \middle/ mss(H_i) = \max_{i=1}^{L} (mss(H_i)) \right\} \quad (5)$$

Firstly, a new set *H* (of *L* elements with *L*≤*R*) is formed by the paths with the minimum number of hops obtained with the *hops* function. The selected path is chosen among the *L* elements of the set *H* by analyzing the minimum signal strength extracted from the *mss* function.

## 4. RESULTS

Due to the difficulty of implementing real tests, extensive simulations have been performed to analyze the different behavior of the network when the criteria shown in Section 3 are employed. For this purpose, authors have chosen the simulation tool Network Simulator ns-2.1.9.b [9] where the corresponding changes in the routing module of this tool were performed in order to include the physical information. In this analysis, DSR has been selected as the ad hoc routing protocol due to its capabilities of multi-pathing that allows the discovery and storage of multiple routes to the same destination node. Table 1 summarizes the parameters utilized in the simulations.

The performance of the proposed criteria has been numerically evaluated by the estimation of the following parameters:

- Percentage of Lost Packets. It is defined as the ratio between the lost data packets and the data packets generated by the sources in the MANET.
- End-To-End Delay. It represents the average value of the time that the received data packets take to reach the destination from their origin. This parameter includes the time the nodes stay in the internal queues, the retransmissions at the MAC level, and the forwarding through multiple intermediate nodes.
- Normalized Overhead. It corresponds to the ratio between the total control packets and the received data packets. Each hop of the control packets is computed as a new control packet.

Table 1. Parameters of the simulations.

| | |
|---|---|
| Simulation Area | 1500 m x 300 m |
| Mobile nodes | 50 |
| Mobility pattern | Random WayPoint<br>Maximum speed: [1,10] m/s.<br>Minimum speed = 1 m/s<br>Pause Time : 0 seconds |
| Traffic pattern | 10 CBR sources<br>Rate = 10 packets/s<br>Packet size= 512 B |
| Simulation Time | 1000 s |
| Transmission Range | 250 m |
| Runs per point | 3 |
| Ad hoc protocol | DSR |
| Link Layer | 802.11 |
| Propagation model | Free-Space |

Figure 1, 2 and 3 represent the obtained results. For each mobility pattern, we have compared the performance of the network when conventional DSR is employed (based on the number of hops exclusively) to the behavior of the network when the route stability is utilized in the ad hoc protocol. In this case, the MMSS (Maximum/Minimum Signal Strength) and MHMMSS (Minimum Hops Maximum/Minimum Signal Strength) are applied. To facilitate the understanding and to show the general tendencies of the evaluated criteria, the results of the different simulations have been also adjusted through a linear regression, resulting in the straight lines of the figures.

Figure 1 shows the percentage of Lost Packets versus the maximum speed of the mobile nodes. It can be noticed that there exists a proportionality between these two parameters as an increment in the speed results in a higher amount of broken links, effect that can lead to losses. Additionally, the breakages of routes demands the temporal storage of packets in internal queues meanwhile the route discovery procedure is being performed. The storage is detected as an increment of the End-to-End Delay when the speed augments. On the other hand, the route discovery procedures are associated to flooding processes in the network and, therefore, the overhead is incremented as it is shown in Figure 3.

For the three considered parameters, the best performance is achieved when the criterion MHMMSS is applied into the selection algorithm of DSR. On the contrary, the exclusive utilization of the signal strength information without considering the number of hops does not guarantee any improvement on the network performance. This behavior is explained by two main factors. Firstly, the wireless medium is quite sensitive to the interferences produced by the neighbors. Therefore, if the number of hops that packets must utilize is reduced, the probability that a packet generates a collision is decreased. As shown in Figure 3, DSR MMSS reduces the number of route discoveries on the network as it selects stable routes. However, the interferences increase and then, a bigger amount of packets is lost.

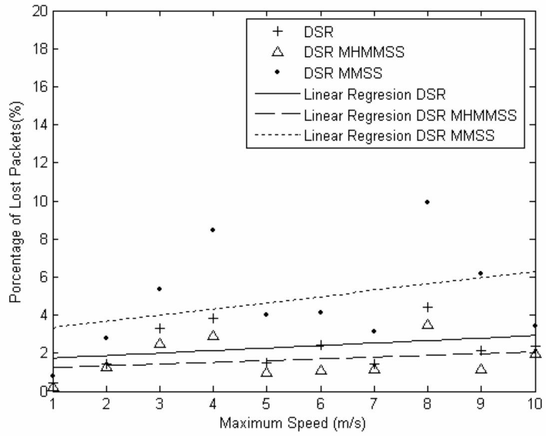


Figure 1. Percentage of Lost Packets as a function of the Maximum Speed.

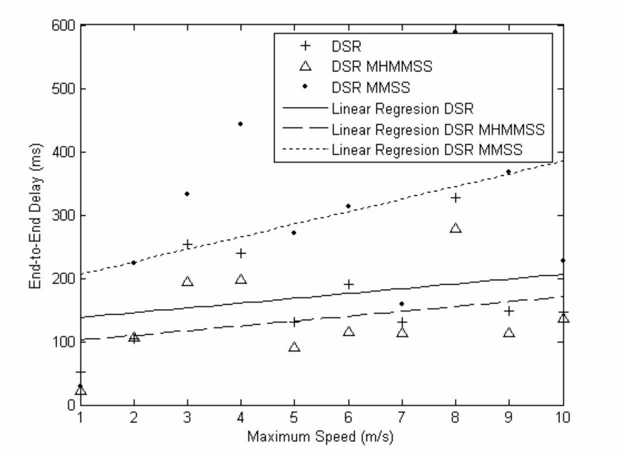


Figure 2. Packet Delay as a function of the Maximum Speed.

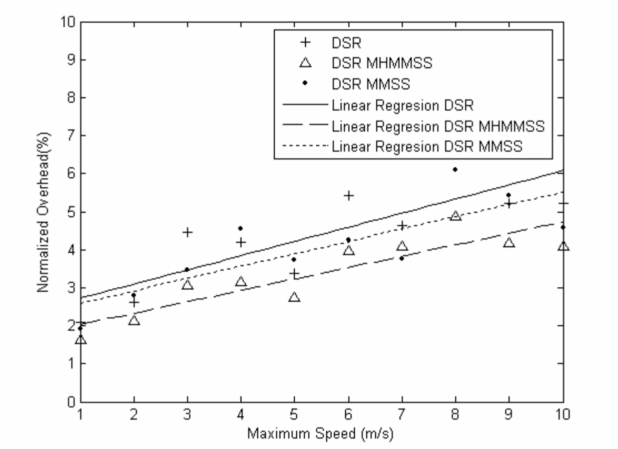


Figure 3. Normalized Overhead as a function of the Maximum Speed.

Another explanation for the degradation of DSR MMSS is due to the route lifetime. The potential paths in the ad hoc networks possess a lifetime which is strongly dependent on the number of hops that it is composed of [10]. Actually, routes with few hops are characterized by a higher lifetime compared to paths composed of a great number of hops. As the aim of this work is the reduction of the number of route discoveries, the number of hops should also been considered for the selection policy.

# 5. CONCLUSIONS

The ad hoc routing protocols commonly utilize the number of hops of the routes as the exclusive parameter to consider in the selection of the path to employ in order to forward the packets. In this work, we show that the estimation of the residual route lifetime could benefit in the performance of the network if this information is considered in the selection policy. However, simulation results expose that the criterion of the number of hops should be included in this technique and it should also have a significant weight on the selection procedure.

# 6. ACKNOWLEDGMENTS

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# 7. REFERENCES

[1] M. K. Marina and S. R. Das, "Ad hoc On-demand Multipath Distance Vector Routing", Technical Report, Computer Science Department, Stony Brook University, April 2003.

[2] D.J. Johnson, D. Maltz y Y. C. Hu, "The Dynamic Source Routing Protocol for Mobile Ad Hoc Networks (DSR)", IETF Internet Draft, July 2004.

[3] S. Gwalani, E. Belding-Royer y C. E. Perkins, "AODV-PA: AODV with Path Accumulation", in Proc. of *Next Generation Internet Symposium*, in conjunction with ICC, Anchorage (USA), May 2003.

[4] C.K.Toh, "Associativity Based Routing For Ad Hoc Mobile Networks", *Wireless Personal Communications Journal*, Special Issue on Mobile Networking and Computing Systems, 4 (2), pp. 103-139, March 1997.

[5] R. Dube, C.D. Rais, K.Y.Wang y S.K. Tipathi, "Signal Stability based Adaptive Routing (SSA) for Ad-Hoc Mobile Networks", *IEEE Personal Communication*, February 1997.

[6] S. Jiang, D. He y J. Rao, "A Prediction-based Link Availability Estimation for Mobile Ad Hoc Networks", in Proc. of *International Workshop on Wireless Networks and Mobile Computing*, Taiwan, April 2000.

[7] O. Tickoo, S.Raghunath y S. Kalyanaraman, "Route Fragility: A Novel Metric for Route Selection in Mobile Ad Hoc Networks", in Proc. of *IEEE ICON*, Sidney 2003.

[8] K. Fall y K. Varadhan, "ns Notes and Documentation", The VINT Project, http://www.isi.edu/nsnam/ns

[9] J. Yoon, M. Liu y B. Noble, "Random Waypoint Considered Harmful", in Proc. of *INFOCOM'03*, pp. 1312-1321. San Francisco, April 2003.

[10] F. Bai, N. Sadagopan, B. Krishnamachari, A. Helmy, "Modelling Path Duration Distributions in MANETS and Their Impact on Reactive Routing Protocols", *IEEE Journal on Selected Areas in Communications*, vol. 22, no. 7, September 2004.