A Cross-layer Stability-based On-Demand Routing Protocol for Mobile Ad-hoc Networks

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Abstract

It is widely known that having neighborhood information can help on optimizing the operations of several protocols including routing and medium access protocols. This work presents a new stability-based routing protocol for mobile ad hoc protocols that effectively determine and use this information.

Unlike existing similar protocols, our proposal has two main specific features. First, it is designed for on-demand routing protocols like AODV protocol and second, and most importantly, it uses the cross-layer paradigm to gather some useful measurement from the MAC layer. Hence, we develop adaptive stability metrics to identify stable links in a mobile wireless networking environment based on the analysis of routing protocol periodic messages. Our metrics then only rely on on-line statistical evaluation of observed link durations. Neither do they require information on signal strength, nodes speeds, nodes directions, radio conditions, or spacing of the mobile devices, nor do they depend on the availability of additional hardware such as GPS receivers or a synchronization of the devices.

We demonstrate the ability of the metrics to select stable links with a high probability in a wide range of scenarios using ns-2 simulations.

Keyworks: mobile ad hoc networks, on-demand routing protocols, link stability, cross-layer, quality of service, entropy function.

1 Introduction

An ad hoc wireless network consists of a group of mobile nodes and all communication is carried out through wireless links in a distributed fashion without a centralized controller. It has different properties when operating in different nodal movement patterns, performing different tasks and carrying varieties of patterns of traffic. The topology of an ad hoc network varies as a result of the mobility of its mobile hosts and the links break down and set up more frequently. A number of factors such as limited transmission range and power limitations, force long-distance communication in ad hoc networks to go through multi hops and each intermediate node is not responsible for the traffic it relays. Routing in ad hoc networks has to adapt to the unexpected link breakage and topology changes. To discover and maintain the routes in ad hoc networks requires more control traffic, which makes the task of performing ad hoc network routing more complex and less efficient. Indeed, due to the random movement of nodes, the bandwidth and power limitations, and the lack of fixed infrastructure, the development of efficient protocols to support the various networking operations in mobile ad hoc networks (e.g., routing, resource allocation, quality of service (QoS) support, etc.) presents many issues and challenges.

One of the key factors, which make it difficult to develop QoS routing in ad hoc networks, is the link breakage as a result of the mobility of its mobile hosts. Hence, every self-organizing system capable of change has certain variable features that can take different values. For example, a node can have different positions, move with different speeds, and have different directions. All these variable features can determine the characteristics of the system. However, even it is very useful that a node has these knowledges of its neighbors, it is very difficult and costly to collect all these informations. Indeed, it requires a complex computations and so consumes many resources that have a bad impact on mobile ad hoc network performance. Thus, instead of selecting those weak links which will break soon and introduce more maintenance overhead, we can select stable links, i.e. having longer expected lifetime, at the beginning. By taking into consideration of link stability in routing protocols, the routing overhead can be significantly reduced. Moreover, the QoS performance can be improved a lot.

Published research works that addressed the stability-based routing problem usualy require a lot of equipements to measure stability. However, our proposal described in his paper does not require a GPS-like system and positions information exchange. We describe a stability-aware routing protocol that uses the cross-layer paradigm by making the MAC and routing layers interacting to efficiently estimating the link stability. The basics of the proposed scheme is that each node estimate, at MAC layer, the average load of all its neighbors by observing received packets even the received node is not the destination. Hence, a *load vector* is computed. At routing layer, observing the rate of received Hello messages of neighbor nodes for each update period, a *stability vector* is computed. The destination has to send a Route REPly (RREP) message for each received route request message during a defined timeout. A *stability information* field is added to the route reply and route request messages to carry an information about the stability of traversed links. Each node which receives the RREP packet forward it to the next hop after updating the stability information based on the content of its stability vector. This message goes through the intermediate nodes till reaching the source which selects the most stable route using one of two possible approaches: path-stability-based and neighborhood stability-based.

The simulation results demonstrate that our proposed protocol is able to overcome transient network characteristics due to mobility, and extend the longevity of established routes.

The remainder of this paper is organized as follows. In Section 2, we give the most important works that have addressed the stability issue in mobile ad hoc networks. The description of the proposed cross-layer routing protocol is given in Section 3. Simulation methodology and performance evaluation of our proposal are detailed in Section 4. Section 5 concludes the paper by summarizing results and outlining future works.

2 Related works

Many works have investigated the stability issue in mobile ad-networks. Hereafter, we review the most related works close to our mechanism and that address the use of the stability information in the routing protocols.

The stability of a link is given by its probability to persist for a certain time span, which is not necessarily linked with its probability to reach a very high age. One of the earliest works in the context of link stability is the development of Associativity Based Routing (ABR) [9]. The idea behind this ad hoc routing protocol is to prefer stable links over transient links. A link is considered to be stable if it exists for a time of at least $A_{thresh} = 2rtx/v$, where rtx is the transmission range and v denotes the relative speed of two devices. It is left open how to determine the relative speed v among the mobiles which in turn determines A_{thresh}. ABR measures the lifetime of a link periodically. The motivation behind this approach has been found in assuming an implicit grouping for links that reach a certain age. After a time of A_{thresh}, it is assumed that the nodes move with a similar speed in a similar direction and thus are likely to stay together for a relatively long period of time. However, this assumption is justified only intuitively for dynamic scenarios.

In a dynamic environment, we may combine another metric, path longevity, with the metrics above to avoid frequent route switching and to reduce routing overhead. After data transmission starts, some decision will be made when the metric drops to a predefined threshold. There already exists some research on selecting stable routes. [10, 2] provide some metrics to find stable paths. [11] defines a parameter called the stability of the route r, which is: $Stability(r) = (Associativity(r)/RelayingLoad(r))$, The term Associativity is the same as defined in the Associativity Based Routing (ABR) protocol [9]; the RelayingLoad is the number of routing entries in the routing table of that node. On the other hand, due to the node mobility, some links may finally break during the transmission even considering the route stability at the route discovery process. Link breakage will cause packet delay and more overhead to find a new route. One possible way is to predict the link status and switch to a new route before the link breaks. Some work is required to decide which parameter should be chosen to better predict the link failure and with low overhead before we can apply the prediction algorithm. Ideally, after predicting the link failure, a node has alternative routes to the destination to avoid packet drop and delay. For some routing protocols, such as DSR, nodes store alternative routes in their route caches. These cached routes should be maintained to follow the topology changes.

Signal Stability-Based Adaptive Routing protocol (SSR) presented in [12] is an on-demand routing protocol that selects routes based on the signal strength between nodes and a node's location stability. This route selection criterion has the effect of choosing routes that have "stronger" connectivity. It distinguishes strongly connected from weakly connected. However, this concept is considered only as a supplement to SSA signal strength based approach and has been found to perform poorly in [12]. links where a link is considered to be strongly connected, if it has been active for a certain predefined amount of time. SSR comprises of two co-operative protocols: the Dynamic Routing Protocol (DRP) and the Static Routing Protocol (SRP). Also based on signal strength measurements is the Routelifetime Assessment Based Routing (RABR) [13]. It tries to predict the time when the received signal strength falls below a critical threshold using a measured value of average change in received signal strength. Another prediction method for link durations is presented in [15]. The method is based on distance measurements between mobile devices. A refinement in [7] takes possible changes in speed or direction of motions into account. The distance between connection peers may be acquired with the help of GPS receivers or signal strength measurements. Apart from the shortcomings of these two methods, the problem with this approach is that the distance of a receiver is only a very vague hint on link availability. In realistic environments the coverage area of a radio transmission hardly ever has a circular shape and is subject to strong fluctuations. A further approach based on the availability of GPS measurements has been suggested in [14]. The Flow Oriented Routing Protocol (FORP) follows a similar approach of calculating a link s residual lifetime from a mobile s own speed and the speed and distance of the connected party. However, this method strongly depends on the assumption of a free space propagation model and on having GPS equipment available for distance measurements and time synchronization. These requirements can hardly be presumed in a realistic environment.

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The co-operation between layers to enable performance enhancement is very important and useful in wireless ad-hoc networks. Numerous works have been presented in the open literature that introduce several coupling ways and solutions between different communication layers [4]. The global objective of such co-operation is to achieve a reliable communication-on-the-move in highly dynamic environments as well as QoS provisioning. Hereafter, we propose a layer cooperation protocol called CSRP that aims to maintain a route stability during application life session as possible as long. The main features of our proposal is that considers accurate parameters that are shared between deferent layers to maintain topology stability for routing packets. The stability process is simple and efficient and can be easily applied to real world scenarios. Results provide an enhancement in term of delay, bandwidth, and energy, for applications.

3 Proposal description

A neighbor is considered stable with regard to a given node when they are stable or they are moving to the same direction. However, this cannot be known without monitoring frames sent by each node's neighbor in absence of GPS-based localization system. In this section details about the operation of our proposal as well as how the needed information is gathered are given.

3.1 Preliminaries and assumptions

The format of the route request (RREQ) and route reply (RREP) packets in the extended AODV described in this paper is slightly different from those used in the basic AODV. Indeed, in addition to the hop count, there will be another field, which represents a `stability information` of all traversed links from a node to another one either for RREQ or RREP message. In the following sub-sections, we will detail how the content of this field is computed for each kind of message.

In addition of the new field added in the routing messages, a node has to add a new field, called `stability rate` in each routing entry it maintains. This field gives an idea about the stability of the path to the corresponding destination. More information on how to compute this field will given later.

3.2 A short overview

Before embarking into the proposal details, let's give a short overview of its operations. We assume that a stability vector which measures the stability of neighbors is maintained and updated each given period by each node in the mobile ad hoc network. When a node i receives a route request from its neighbors j, it updates its next hop to the source according to the stability rate link (i, j) in order to use the most stable next hop for the reverse path. On the other hand, when a node receives a route reply, it updates the stability information field by taking into account the stability rate of the node from which it received this message. At MAC layer, the node computes the average load of all the neighbors by observing received packets even the received node is not the destination. Hence, a field in a `load rate vector` is maintained for each neighbor. This load ratio will be applied as a weigh to select two routes that have the same `stability rate.`

The source selects the best path when it receives more than one route reply. Two methods are proposed for the path selection by the source either basing the selection only on the stability of the path or taken into account the stability of the neighborhood of nodes belonging the path. The former method is adequate for networks with heterogeneous movement patterns where the latter is interesting for networks with homogeneous movement patters. These methods as well as the motivations behind them will be detailed later in the paper.

3.3 Computing the stability vector

Each node monitors the control packets received from its neighbors. These control packets include not only routing period packets but also each frame that the MAC layer receives.

A stability vector is maintained by each node which is indexed by the neighbors link layer 2 identity. Hereafter, we detail how this vector is computed and updated and explain their effects on route lifetime and so on the end-to-end QoS guarantees in mobile ad hoc networks.

Let's first define some useful parameters. Denote by $\triangle_{up}$ the update period after which the stability vector V_i at node i will be updated and let $n_i$be the number of neighbors of node i.

Assume $n_{ij}(\triangle_{up})$ be the number of Hello messages received from node j at node i during $\triangle_{up}$. Note that $n_{ij}(\triangle_{up}) \leq n^{max}_{HELLO}$, where n^{max}_{HELLO} is the expected maximum number of Hello messages that can be sent during $\triangle_{up}$. Indeed, as Hello messages are broadcasted periodically, we can know the maximum number of these messages that could be sent by any node in the network in a given period.

Given the parameters defined above, the stability rate of node j at node i is then $V_i(j) = s_{ij} = \frac{n_{ij}(\triangle_{up})}{n^{max}_{HELLO}}$, $0 \leq s_{ij} \leq 1$. Note that, because of the risk of collisions, node i might not receive an expected Hello message sent by node j at an expected time especially because there are sent in broadcast manner. In order to overcome this problem and to have increase the stability estimation accuracy, we also count any received frame from neighbors if an expected Hello message does not arrive at the expected time. So, if from expected time to receive that message until current time the node i receives another control packet or a data packet from j, it increments $n_{ij}(\triangle_{up})$.

3.4 Selecting the stable reverse path by intermediate nodes

First of all recall that in the basic AODV, when a node receives a RREQ send by a source, it has to create a reverse path to that source in order to be able to send back eventually received RREP messages. This path is known as the *reverse path.*

As we have mentioned above, associated with each routing entry to node s at node i, a stability rate that we denote $SR(s, i)$. Before forwarding a RREQ message, a node has to include in the `stability information` field of RREQ, its stability rate to the source. When a node i receives a route request message `RREQ(s,d)` from a neighbor j. It computes a new stability rate for the source as follows:

$$SR_{new}(s, i) = \min\left(SR(s, j), s_{ij}\right)$$

If the node has already a routing entry to the source node s through its neighbors k ($k \neq j$), it has to consider the one that has the **maximum stability rate** and to update the routing table according to the obtained result. If the next hop to the source s has been modified, the node i has to broadcast the RREQ packet to its neighbors.

The operations described above are done at each intermediate node, until the route request reaches the destination d.

3.5 Selecting the stable path by the source

When the routing protocol at the source node receives the first packet of an user application to send to a destination node, it checks whether it has a valid route to the destination or not. If not, it broadcasts a route request in order to compute a valid path. Each intermediate node sets up a reverse path to the source node and if it has a valid route to the destination, it sends back a route reply message otherwise it broadcasts the request to its neighbors as described above. When the destination receives a route request, it sends back to the source a route reply.

Before sending/forwarding a route reply message, each node has to update the stability information contained in the message header by taking into account the stability of the link from which it receives this message. The node generating this message sets this field to 0 if it is the destination, otherwise it sets this field to the stability information it has in its routing entry to reach the destination.

After a period of time after sending its route request (RREQ), a source receives shall a first route reply (RREP) which includes the stability information about the path to the destination. Because the source node cannot know in advance how many route reply messages it will receive, it starts using the first received path. If it receives a new route reply (RREP) form another neighbor that has a stability information better than that of the current selected path, it switches to the new path otherwise, it continues using the previous selected path.

The way how the compute the stability information depends on the method that the source wants to adopt to select the best path. Hereafter, we explore two methods to select the best route by the source: path stability-based selection and neighborhood stability-based selection and we describe how the scalability information field is computed for each method.

3.5.1 Path stability-based selection

The stability information field in this case is updated as follows. Assume that a node i receives a RREP(m,s) (generated by node m) message to forward from a node j where the stability information field is set to s_{RREP}. Node i has to set the stability information field to $min(s_{i,j}, s_{RREP})$, so that the source s retrieves in each received route reply the stability rate of the corresponding path.

This method ensures that the chosen path remains stable for the long possible time as the links it contains are the most stable among the possible links to reach the destination. In other words, it has the longest lifetime.

The motivation behind this method is that there are some network configuration where the shortest path is not always the most stable one. Using this method avoids having unstable paths especially in mobile networks where some nodes are moving very fast while some others are more less fixed or are moving together (group moving).

3.5.2 Neighborhood stability-based selection

We believe that the path stability-based selection is not adequate when the nodes have similar movement patterns which means that the values in the stability vector is quite similar in all nodes. That's why we propose a second approach based of the neighborhood stability which reflects how stable the neighbors of each node. To measure the neighborhood stability, we use an entropy-based technique.

Entropy [8, 7] presents the uncertainty and a measure of the disorder in a system. There are some common characteristics among self-organization, entropy, and the location uncertainty in mobile ad hoc wireless networks. These common characteristics have motivated our work in developing an analytical modeling framework using entropy concepts and utilizing mobility information as the corresponding variable features. In our context, we define the entropy at node i as $H_i(\triangle_{up}) = \frac{-\sum p_{ij} \log p_{ij}}{\log n_i}$, where $p_{ij} = \frac{sij}{\sum s_{ij}}$, where j belongs to the neighbors set of node i. Hence, the stability information in the route requests will contain the minimum of entropy function values of traversed links. So, when node i receives a route reply from its neighbor node j, it compares its neighborhood stability $H_i(\triangle_{up})$ with the stability information s_{RREP}. It then sets this value to $\min(H_i(\triangle_{up}), s_{RREP})$ and forward the route request to the next hop toward the source.

4 Performance evaluation

We have implemented our proposal in ns-2 network simulator [3]. We have extended the AODV [5] protocol and DCF [18] scheme to support our cross-layer algorithm. We report in this section the results of simulations we have done for various network scenarios. We also provide a performance analysis of our proposal based on the obtained simulation results.

4.1 Scenario description

The simulated scenarios consists of 50 nodes located in a uniform distribution within an area of 1500x300 forming a multihop network. These scenarios are generated by the enhanced random waypoint mobility model described in [17].

In this mobility model each node moves toward a random destination and pauses for a certain time after reaching the destination before moving again. In our simulations, the nodes move at an average speed of 15m/sec. The pause times are varied to simulate different degrees of mobility. The traffic sources start at random times after the beginning of the simulation and stay active during the remaining simualtion time. The sources are CBR (Constant Bit Rate) and generate UDP packets at 4 packets/sec, each packet being 512 bytes. Each simulation is run for 900 seconds simulated time. Each point in the plotted results represents an **average of ten simulation** runs with **different random mobility scenarios**. Note that the number of source nodes is 30 sources. The radio model is very similar to the first generation WaveLAN radios with nominal radio range of 250m. The nominal bit rate is 2 Mbps.

4.2 Simulation metrics

We analyze several QoS metrics to evaluate the performance of our approach and we compare results with the AODV basic mechanism protocol. The following metrics are defined:

- **Packet delivery fraction**: The delivery fraction is measured as the ratio of the number of data packets delivered to the destination and the number of data packets sent by the source.
- **Route bytes**: It is the routing overhead which is measured as the total number of Bytes of transmitted routing packets.
- **Mean delay**: It is the average delay of all the flows. The average delay is used to evaluate how well the schemes can accommodate real-time flows.

In order to show the gain on energy and the effect on the connectivity of the network and thus the useful lifetime, we evaluate the following metrics:

- **Gain on remaining energy**: This metric stands for the gain (in %) on the total remain energy at the end of simulations of our new mechanism (CSRP), compared with the basic mechanism.

4.3 Simulations results and analysis

We present in this subsection the performance of the basic **AODV protocol** and **CSRP** for the various metrics presented above.

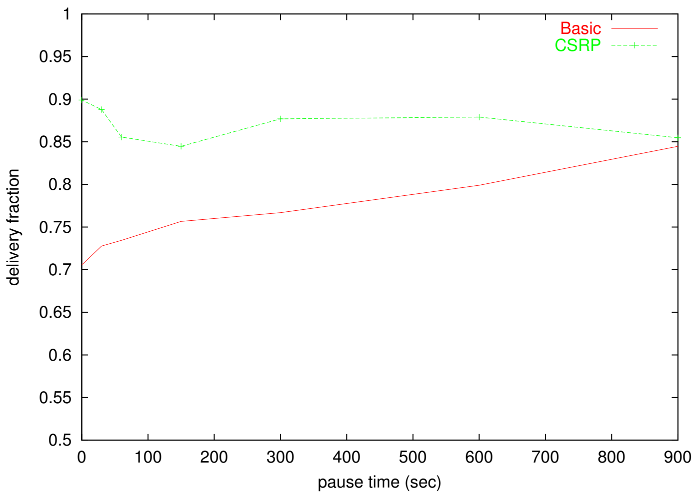

Figure 1: Total packet delivery fraction

In Figures 3, we plot the mean delay of our new mechanism and the basic AODV routing protocol. It's obvious from the curvus that the mean delay is improved well using CSRP. Indeed, in such scenarios, our algorithm allows re-routing and refresh routes including new nodes that have better quality than in the old routes which improves the end to end delay. Note that we mean by a good quality node, the node that is more stable and less busy regarding the other nodes in the some other alternative route possibilities. More specifically, high stability rate informs that the node does not change frequently its neighbors. Moreover, differentiate between nodes that participate heavily in communications including sending, receiving, and forwarding packets, and other nodes helps to avoid **at the same time selecting unstable and high congested nodes.** Indeed, this lets packets follow routes that generate a high cost and so are less congested which yielding to lower delay comparing to the obtained delay with routing based on minimum hops count (Figure3). This later, does not take into account node stability regarding to its neighbors during the simulation time and so it ignores links with lowest stability rate and furthermore busy nodes. Furthermore, we remark that the improvement on delay increases with high network mobility. The basic AODV change routes frequently which increases routing overhead consumed to re-establish broken routes (see Figure2). However, our proposal can select stable route even with mobile nodes but they follow the same movement direction. By this way, route failures are more avoided than in the basic AODV protocol and so the routing packet broadcasts decrease. Indeed, in such scenarios, our algorithm allows re-routing and refresh routes including new nodes that have better quality than in the old routes which improves application performance. Hence, the improvement on packet delivery ratio attempts more than 16 % for high mobile network as shown in Figure 1. However, no significant improvement for stable network (pause time = 900). These results are proved by the fact that routing overhead is low with our new mechanism as shown in Figures 2.

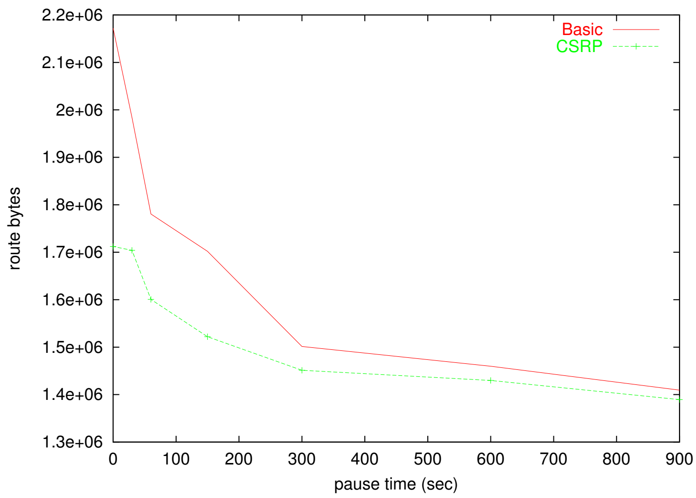

Figure 2: Routing overhead

To demonstrate the efficiency of our scheme regarding to the energy consumption, we plot in Figure 4 the gain in the total remaining energy that is obtained at the end of simulation. Our algorithm presents an improvement for more

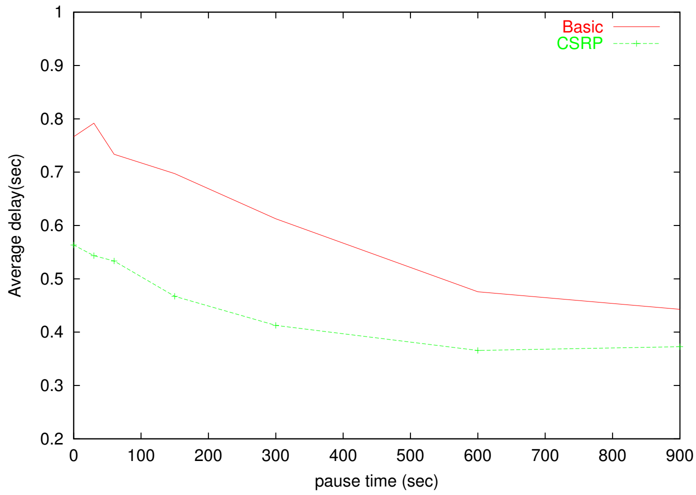

Figure 3: Average delay

than **18%** with comparing to the basic AODV. We constate that the gain on energy increases with mobility. This show that our protocol gives more benefits when mobility increase. Moreover, this metric demonstrates how network longevity can be extended using our proposal.

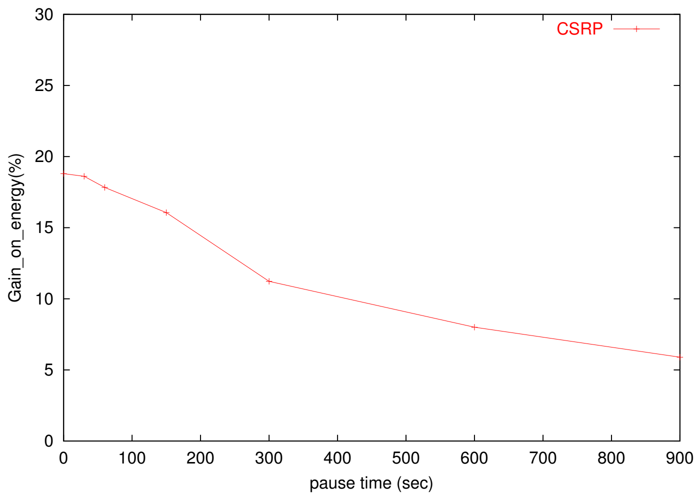

Figure 4: Gain on the remaining energy at the end of each simulation

5 Conclusion and future works

In this paper we introduce a cross-layer stability-based routing in mobile ad hoc networks. We propose new routing algorithm based on accurate stability parameters in dynamic network characteristics. At the MAC layer, each received frame is processed even if the received node is not the final destination. Information about the neighbor sending this frame is recorded and used by the routing protocol to increase the accuracy of the estimation of the stability vector which contains the stability rate of each link with the neighbors. This stability vector is then used by the routing protocol to select the best next-hop to a given destination.

Performance evaluation using ns-2 simulator show the importance of considering the stability information in route selection process. Overall, we conclude that our mechanism demonstrates significant benefits at high and unstable traffic scenarios. Even though we implemented the model in AODV, the technique used is very generic and can be used with any on-demand protocol such as DSR. Furthermore, this proposal can be applied to single channel and multi-channel based medium access protocols, and there is no need for synchronization.

One of the important future work is to evaluate the performance of this proposal considering service differentiation issue and incorporating other parameters like the end-end delay tolerate by audio applications.

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