Impact of Range of Simulation Time and Network Shape on the Hop Count and Stability of Routes in Mobile Ad hoc Networks

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Abstract— **Routing protocols for mobile ad hoc networks (MANETs) have been extensively studied in the literature. The most common mobility model used in these studies is the Random waypoint mobility model. Simulations are generally conducted under the first 1000 seconds of node movement under the Random waypoint mobility model. In this paper, we show that the performance of MANET routing strategies, namely minimum hop and stability-based strategies, varies with the range of the simulation time considered. Based on an extensive set of simulation studies conducted in this paper, we observe that routes incurred in the first 1000 seconds of node movement are bound to be unstable and have larger hop count when compared to routes computed in simulations with starting time greater than 1000 seconds of node movement. Similarly, we observe that routes incurred in nearly single-dimensional rectangular topologies are bound to be unstable and have larger hop count when compared with the routes incurred in square network topologies of the same area. We also observe that for a fixed network shape and node mobility, as the network density increases, the stability of routes increases. We run all of our simulations under diverse conditions of node mobility and network density.**

Index Terms— **Routing, Stability, Mobile Ad Hoc Networks, Simulation.**

I. INTRODUCTION

Wireless networks provide ubiquitous communication capability and location-independent information access to mobile users. A mobile ad hoc network (MANET) is a dynamically reconfigurable self-organizing wireless network with no fixed infrastructure or a centralized administration. MANETs function in a "peer-to-peer" mode of operation. Routes in MANETs are often "multi-hop" due to the limited radio propagation range of wireless devices. Each mobile node in MANET also functions as a router to establish end-to-end connections between any two nodes. MANET routing protocols primarily belong to one of the two categories [1][2]: (1) Minimum-hop based routing and (2) Stability-based routing. Given a sequence of network topologies depicting the changes in the locations of nodes over time, we can obtain a sequence of minimum hop routes (called the minimum hop mobile path) over the network sequence by applying the minimum-hop Dijkstra algorithm [3] on the network topologies. Similarly, we can apply the algorithm *OptPathTrans* proposed in [4] to determine a sequence of stable routes (called the stable mobile path).

MANET routing protocols and algorithms are often evaluated with simulations. The node mobility model used to simulate the mobility of nodes plays a significant role in the performance of the routing protocols and algorithms. The Random waypoint mobility model [5] is one of the most commonly used mobility model in MANET studies. The movement of nodes is independent of their peers. Each node starts moving from an arbitrary location (also called waypoint) to a randomly selected destination with a randomly chosen velocity. Once the destination is reached, the node stays at that waypoint for a certain time called the pause time. After the pause time, the node selects another destination and then continues to move with a different velocity. The simulations are mostly carried out within the first 1000 seconds of the movements [6][7]. This is because of the overhead involved in letting the nodes move for a long time and storing their mobility profiles in memory with common simulators like Ns-2 [8].

We believe the stochastic properties of the Random waypoint mobility model will play a significant role over a wide range of simulation time and expect to see a difference in the performance of the routing algorithms. We developed our own code to simulate the Random waypoint mobility model to generate mobility trace files offline. Using these mobility traces, it is possible to locate the position of a node for any simulation time, be it at 1000 seconds or at 5000 seconds. We are now in a position to evaluate the performance of the minimum-hop path and stable path routing algorithms when simulations are run for the first 1000 seconds of node movement, from 1000 to 2000 seconds of node movement, in general, for any range of simulation time. This will be the first attempt in this research area to explore the impact of random waypoint simulation time period on the performance of routing algorithms. Throughout this paper, we use the terms 'path' and 'route' interchangeably. They mean the same.

We conduct a series of simulations to determine whether the performance of the minimum-hop and stable path routing algorithms remains the same irrespective of the time period of random waypoint movements that the simulation is exposed to. We study the performance of the stable mobile path and the minimum hop mobile path when generated under different simulation time periods. Specifically, we evaluate the number of route transitions and the average hop count when the minimum hop mobile path and stable mobile path are generated over simulation time periods of 1 to 1000 seconds, 1001 to 2000 seconds, 2001 to 3000 seconds, 3001 to 4000 seconds, 4001 to 5000 seconds.

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In addition, we are also interested in determining the impact of network shapes on the performance of the routing algorithms. We select two topologies – one square and another rectangular – both of the same area, run the algorithms for the stable mobile path and minimum hop mobile path and study their performance. Even though the total number of nodes and the network area remain the same, the actual shape of the network topology influences the distribution of the nodes. The number of neighbors per node is not the same for all nodes. For example, with rectangular topologies, nodes in the periphery have very few neighbors compared to nodes in the center of the network. Uneven distribution of nodes is bound to affect the performance of the routing algorithms and protocols. Thus, the performance obtained for a routing protocol/ algorithm in a rectangular network topology may not be the same performance obtained for the same routing protocol/ algorithm operated in a square network topology of the same area.

The rest of the paper is organized as follows: In Section 2, we briefly describe the background work available in the literature to compute the stable mobile path and the minimum hop mobile path. Section 3 describes the approach adopted to determine the location of a node at any time instant of the simulation and the use of this approach to determine a snapshot of the network topology at that time instant. In Section 4, we describe our simulation environment, illustrate the results and describe our interpretation. The simulation results were obtained for diverse conditions of network shape, node mobility, node density and simulation time range. Section 5 concludes the paper.

II. STABLE MOBILE PATH AND MINIMUM HOP MOBILE PATH

Farago and Syrotiuk [9] proposed the notion of mobile graph and mobile path to record the sequence of network topology changes over a given time span. A *mobile graph* is defined as the sequence $G_M = G_1G_2 \ldots G_T$ of static graphs that represents the network topology changes over some time scale T. In the simplest case, the mobile graph $G_M = G_1G_2 \ldots G_T$ can be extended by a new instantaneous graph G_{T+1} to a longer sequence $G_M = G_1G_2 \ldots G_T\, G_{T+1}$, where G_{T+1} captures a link change (either a link comes up or goes down). But such an approach has very poor scalability. In this research work, we sample the network topology periodically for every one second, which could, in reality, be the instants of data packet origination at the source. For simplicity, we assume that all graphs in G_M have the same vertex set (i.e., no node failures).

A *mobile path*, defined for a source-destination (*s-d*) pair, in a mobile graph is the sequence of paths $P_M = P_1P_2 \ldots P_T$, where P_i is a static path between the same *s-d* pair in $G_i = (V_i, E_i)$. That is, each static path P_i can be represented as the sequence of vertices $v_0v_1 \ldots v_l$, such that $v_0 = s$ and $v_l = d$ and $(v_{j-1},v_j) \in E_i$ for $j = 1,2, \ldots, l$. The timescale of T normally corresponds to the duration of a session between s and d. Let $w_i(P_i)$ denote the weight of a static path P_i in G_i. For additive path metrics, such as hop count and end-to-end delay, $w_i(P_i)$ is simply the sum of the link weights along the path. Thus, for a given *s-d* pair, if $P_i = v_0v_1 \ldots v_l$ such that $v_0 = s$ and $v_l = d$,

$$w_i(P_i) = \sum_{j=1}^{l} w_i(v_{j-1}, v_j) \qquad (1)$$

For a given mobile graph $G_M = G_1G_2 \ldots G_T$ and *s-d* pair, the weight of a mobile path $P_M = P_1P_2 \ldots P_T$ is

$$w(P_M) = \sum_{i=1}^{T} w_i(P_i) + \sum_{i=1}^{T-1} C_{trans}(P_i, P_{i+1}) \qquad (2)$$

where $C_{trans}(P_i, P_{i+1})$ is the transition cost incurred to change from path P_i in G_i to path P_{i+1} in G_{i+1}. Note the transition cost $C_{trans}(P_i, P_{i+1})$ has to be represented in the same unit as that of the path metric used to compute $w_i(P_i)$.

The stable mobile path for a given mobile graph and *s-d* pair is the sequence of static paths such that the number of route transitions is the theoretical minimum possible. In other words, we optimize $\sum_{i=1}^{T-1} C_{trans}(P_i, P_{i+1})$ in equation (2) irrespective of the cost of the other term $\sum_{i=1}^{T} w_i(P_i)$. For the minimum hop mobile path, we assume the link weights are unity and optimize the term $\sum_{i=1}^{T} w_i(P_i)$, irrespective of the cost of transition.

In [4], we proposed an algorithm called *OptPathTrans* to determine the stable mobile path and hence the minimum number of route transitions. Given a mobile graph G_M spanning over time period T and a source-destination (*s-d*) pair, algorithm *OptPathTrans* works based on a simple greedy heuristic: Whenever, an *s-d* path is required at time t, choose the longest living *s-d* path since time t. The above strategy is repeated over the duration of the *s-d* session. The sequence of stable paths generated as a result of this process is called the stable mobile path. To generate a minimum-hop mobile path, one could follow the above approach except that whenever an *s-d* path is required, choose the *s-d* path that has the minimum hop count (determined using Dijkstra algorithm [3]) and stay with that path until it exists.

III. CONSTRUCTION OF THE MOBILE GRAPH

A mobile graph over a time period is a sequence of static graphs periodically collected at time instants evenly spread throughout the time period. The sequence of time instants is selected in such a way that there is no appreciable loss of knowledge about link formation or failure. A static graph is merely a snapshot of the network at a particular time instant and is basically constructible once the location of every node in the network is determined. Below, we describe the procedure adopted to determine the location of a node at a particular time instant, assuming the node mobility model used is the Random waypoint mobility model.

Consider a two-dimensional network field of size X_{max} x Y_{max}. The network dimensions are specified in meters. Let N be the set of nodes in your network. Let the total simulation time be *SIM-TIME*. The velocity of the nodes is given in m/s. Initially, the nodes are distributed randomly by generating a sequence of random X and Y co-ordinates, each in the range 0 to X_{max} and 0 to Y_{max}.

Let (x_i^1, y_i^1) be the initial co-ordinates (location 1) of node i at time t_i^1. (For each node i, the value of t_i^1 is 0 sec as it is the instant at which the simulation begins). Node i chooses a random destination location (x_i^2, y_i^2) such that x_i^2, y_i^2 are uniformly randomly selected in the range [0… X_{max}] and [0… Y_{max}] respectively. A velocity v_i^{1-2} uniformly distributed in the range [v_{min}, …, v_{max}] is selected. The node then moves from (x_i^1, y_i^1) to (x_i^2, y_i^2) with velocity v_i^{1-2}. The distance covered by node i during this movement is $d_i^{1-2} = \sqrt{(x_i^1 - x_i^2)^2 + (y_i^1 - y_i^2)^2}$. The time instant at which node i will reach (x_i^2, y_i^2) is $t_i^2 = t_i^1 + \frac{d_i^{1-2}}{v_i^{1-2}}$. After reaching (x_i^2, y_i^2), node i chooses a random destination location (x_i^3, y_i^3) and a velocity v_i^{2-3} uniformly distributed in the range [v_{min}, …,v_{max}]. The node then moves from (x_i^2, y_i^2) to (x_i^3, y_i^3) with velocity v_i^{2-3}. The distance covered by node i during this movement is $d_i^{2-3} = \sqrt{(x_i^2 - x_i^3)^2 + (y_i^2 - y_i^3)^2}$. The time instant at which node i will reach (x_i^3, y_i^3) is $t_i^3 = t_i^2 + \frac{d_i^{2-3}}{v_i^{2-3}}$. Node i continues to move similarly to locations (x_i^4, y_i^4), (x_i^5, y_i^5), …, (x_i^{s-1}, y_i^{s-1}), (x_i^s, y_i^s) at time instants $t_i^4, t_i^5, t_i^6, \ldots, t_i^{s-1}, t_i^s$ respectively such that t_i^{s-1} < *SIM-TIME* and t_i^s >= *SIM-TIME*.

We now compute the X and Y co-ordinates of a node i at time instant t ($t_i^j \le t \le t_i^k$), when the locations of the node at time t_i^j and t_i^k are (x_i^j, y_i^j) and (x_i^k, y_i^k) respectively, as follows:

Let $f = \frac{t - t_i^j}{t_i^k - t_i^j}$.

Then, the location of node i at time t is given by (x_i^t, y_i^t), where

$$x_i^t = f * x_i^k + (1 - f) * x_i^j$$
$$y_i^t = f * y_i^k + (1 - f) * y_i^j$$

Using the above procedure, one can determine the location of every node $i \in$N, at any given time instant t. Once the locations of the nodes are determined, we construct the static graph at time instant t, by determining the set of edges that form the graph. An edge exists between two nodes in the graph at time t, if the distance between the two nodes at time t is less than or equal to the transmission range of the nodes.

IV. SIMULATIONS

A. Mobility Model

We use the Random waypoint mobility model [5], one of the most widely used mobility model for MANET simulations. According to this model, each node starts moving from an arbitrarily location to a randomly selected destination with a randomly chosen speed in the range [v_{min},…, v_{max}]. Once the destination is reached, the node stays there for a pause time and then continues to move to another randomly selected destination with a different speed. We use v_{min} = 0 and the pause time of a node is 0. The values of v_{max} used are 10 m/s (representing low mobility scenario), 20 and 30 m/s (representing moderate mobility scenarios), 40 and 50 m/s (representing high mobility scenarios).

B. Network Shape

The dimensions of the networks simulated in this paper are: 1500m x 300m (rectangular topology) and 670 x 670m (square topology). Both the topologies have the same area but the perimeter of the square network is smaller than that of the rectangular network. With a square network, the nodes are evenly distributed and the number of neighbors per node is anticipated to be close enough. On the other hand, with a rectangular network like the one used in our simulations, the number of neighbors per node will not be the same due to the relatively more loss of neighbors for nodes in the periphery of the network.

C. Network Density

The network density for both the square and rectangular networks is varied by simulating these networks with 25 and 50 nodes. The average number of neighbors per node is given by $N\pi R^2/A$, where R is the transmission range of the nodes, N is the number of nodes and A is the area of the network. The transmission range of the nodes is fixed at 250m. The area of both the networks used in our simulation is 450,000m^2. Hence, the average number of neighbors per node in a network of 25 nodes is close to 10 (referred to as low-density network) and that in a network of 50 nodes is close to 20 (referred to as high-density network).

D. Performance Metrics

The performance metrics measured in our simulations are the number of route transitions and the average hop count per path. The number of route transitions is the number of times we need to change from one static path to another static path in a mobile path. The stability of routes is inversely related to the number of path transitions. The larger the number of path transitions incurred through a routing algorithm, the lower the stability of the routes yielded by the routing algorithm. The average hop count per path is the time-averaged hop count of a mobile path, computed basically as the sum of the hop counts of the static paths for every time instant divided by the total number of time instants.

For each combination of node mobility, density and network shape, we run five sets of simulations: simulation time ranging from 1 to 1000 seconds, 1001 to 2000 seconds, 2001 to 3000 seconds, 3001 to 4000 seconds and 4001 to 5000 seconds. The performance results in Figures 1 through 5 are the averages obtained after running the simulations with 15 source-destination pairs for each of the above different conditions and ranges of simulation time.

E. Hop Count per Path

We observe that for a given network shape, the hop count of the minimum hop mobile routes is not much affected by the range of simulation time and the node mobility. On the other hand, the hop count of minimum hop mobile routes incurred with rectangular topologies is more than that incurred with square topologies by a factor of 30 – 40%. For a given network shape, the hop count of minimum hop mobile routes

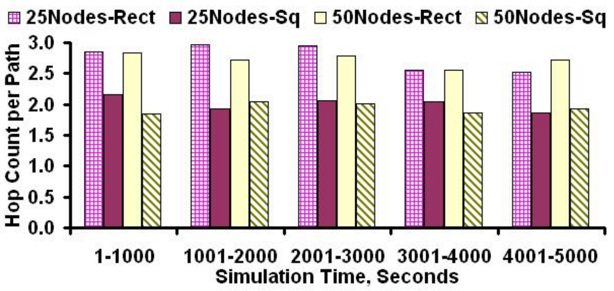

Figure 1.1. Hop Count of Minimum Hop Mobile Path

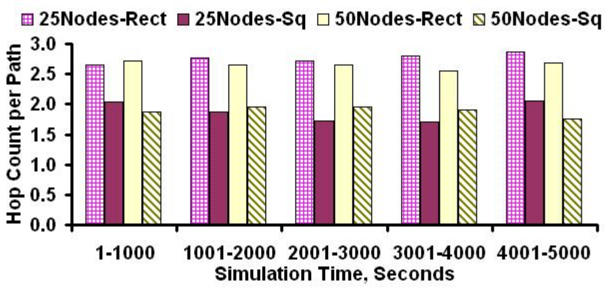

Figure 2.1. Hop Count of Minimum Hop Mobile Path

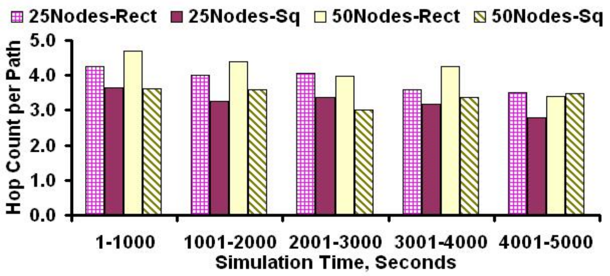

Figure 1.2. Hop Count of Stable Mobile Path

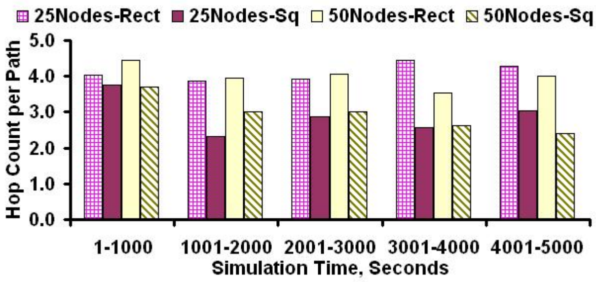

Figure 2.2. Hop Count of Stable Mobile Path

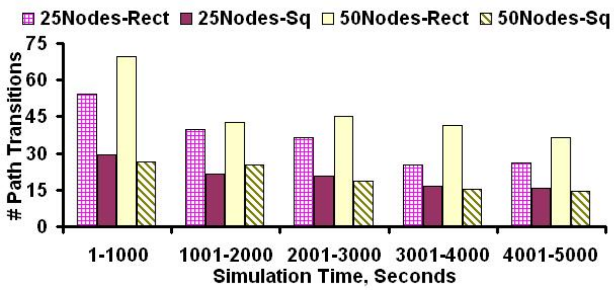

Figure 1.3.Number of Path Transitions for Minimum Hop Mobile Path

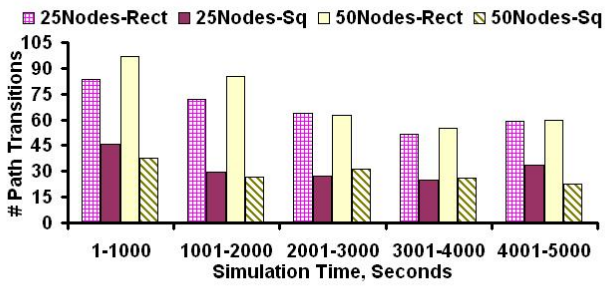

Figure 2.3. Number of Path Transitions for Minimum Hop Mobile Path

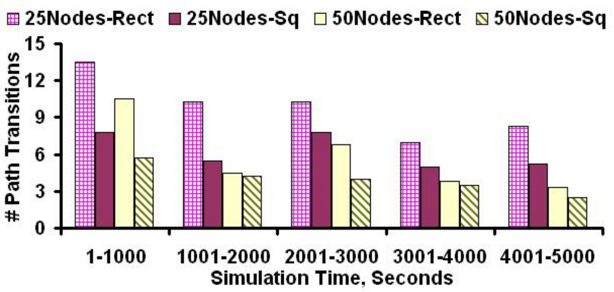

Figure 1.4. Number of Path Transitions for Stable Mobile Path

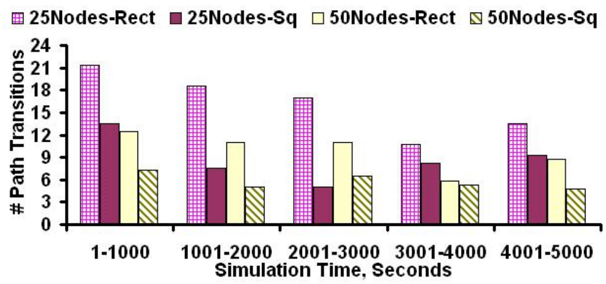

Figure 2.4. Number of Path Transitions for Stable Mobile Path

Figure 1. Performance at v_{max} = 10 m/s

Figure 2. Performance at v_{max} = 20 m/s

is sometimes more for a low-density network compared to that in a high-density network. This could be attributed to the availability of relatively more alternate routes in a high-density network.

We observe that the hop count of stable mobile routes decreases significantly as we conduct simulations beyond 1000 seconds. This illustrates that as the nodes continue to move in the Random waypoint model, they come closer to one another and it is possible to find more stable routes with a reduced hop count. The decrease is more for rectangular topologies. For a given network density, the decrease in the hop count of stable mobile routes is more dominant in rectangular topologies (15 to 40%) compared to that incurred in square topologies (10 to 25%). For a given network density, network shape and range of simulation time, the hop of stable mobile routes is not much affected by node mobility.

F. Number of Path Transitions

With respect to the minimum hop mobile routes, we observe that the number of path transitions incurred during the simulation range of 1-1000 seconds is the highest. The number of path transitions incurred beyond 1000 seconds is relatively very low. This could be attributed to the nodes coming closer to one another as the simulation time progresses. The minimum hop paths are increasingly formed using nodes that do not move away from each other. The decrease in the number of path transitions is more for the

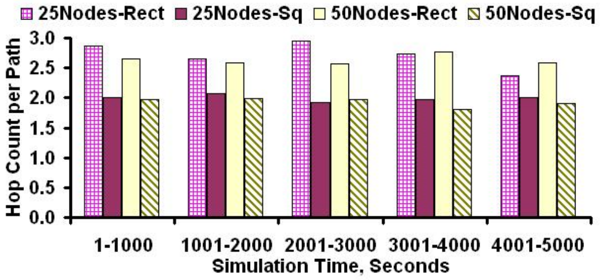

Figure 3.1. Hop Count of Minimum Hop Mobile Path

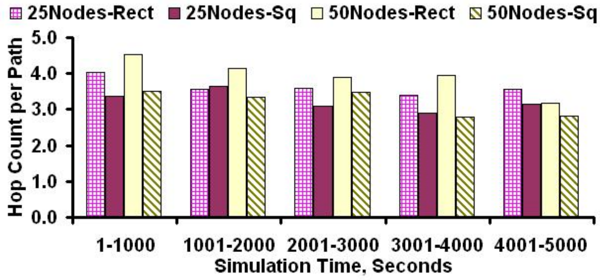

Figure 3.2. Hop Count of Stable Mobile Path

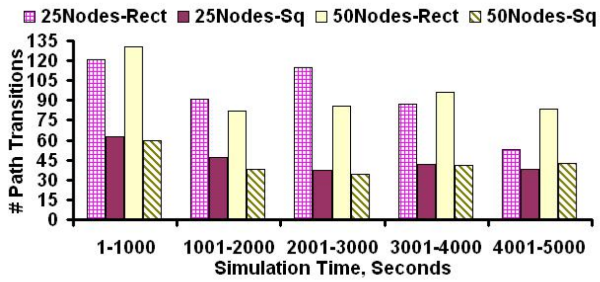

Figure 3.3.Number of Path Transitions for Minimum Hop Mobile Path

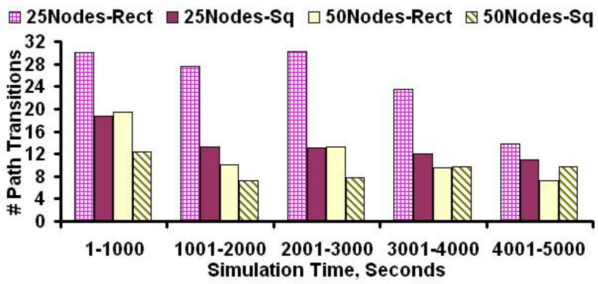

Figure 3.4. Number of Path Transitions for Stable Mobile Path

Figure 3. Performance at v_{max} = 10 m/s

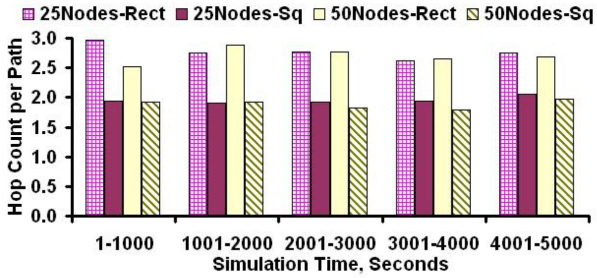

Figure 4.1. Hop Count of Minimum Hop Mobile Path

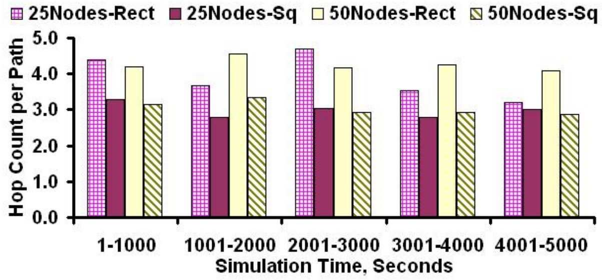

Figure 4.2. Hop Count of Stable Mobile Path

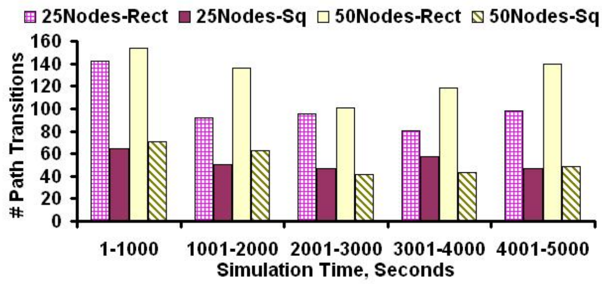

Figure 4.3. Number of Path Transitions for Minimum Hop Mobile Path

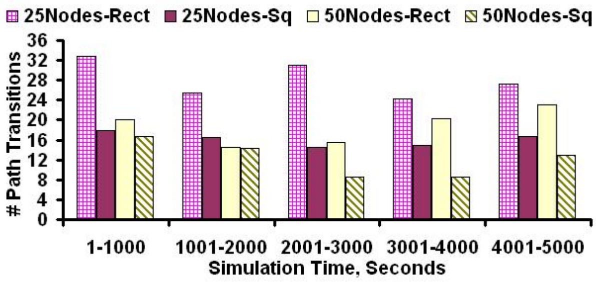

Figure 4.4. Number of Path Transitions for Stable Mobile Path

Figure 4. Performance at v_{max} = 20 m/s

rectangular networks (could be as large as by a factor of 2.5) when compared to the square networks (could be as large as by a factor of 1.85). This is due to the fact that in rectangular networks, nodes are initially very unevenly distributed and as node movement progresses beyond 1000 seconds, the nodes move closer to each other. For a given network shape and range of simulation time, the number of path transitions incurred with high-density networks is sometimes more than that incurred in low-density networks. This is due to the fact that the physical distance of a hop is more for high-density networks, with the pursuit to lower the hop count. But, with increase in the range of simulation time, the nodes start moving towards the center, yielding stable routes.

With respect to the stable mobile routes, we also observe that the number of path transitions incurred during the simulation range of 1-1000 seconds is the highest. The number of path transitions incurred beyond 1000 seconds is low for both rectangular and square topologies. The number of path transitions incurred with rectangular topologies is mostly higher due to the uneven distribution of nodes and larger hop count. But, as the range of simulation time used is beyond 1000 seconds, the nodes continue to move closer towards each other and form stable routes with a relatively lower hop count. We also observe that as the node mobility increases, the decrease in the number of path transitions is not that significant with the range of simulation time. We observe that the decrease in the number of path transitions is at most by a factor of 1.6 in networks with high node mobility, where as in networks with low and moderate mobility, the decrease in the number of path transitions could be as large as by a factor of 2.7.

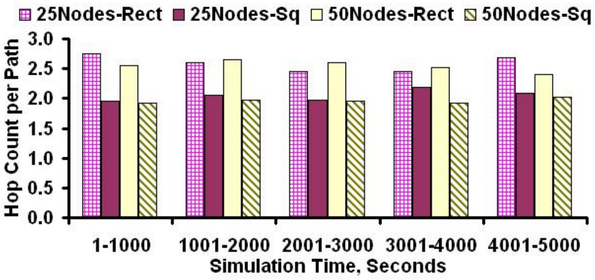

Figure 5.1. Hop Count of Minimum Hop Mobile Path

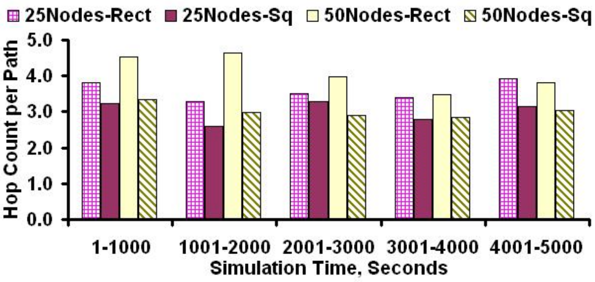

Figure 5.2. Hop Count of Stable Mobile Path

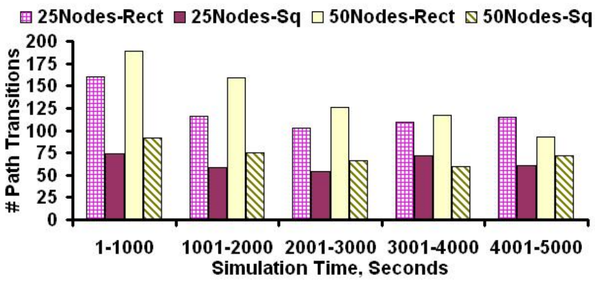

Figure 5.3. Number of Path Transitions for Minimum Hop Mobile Path

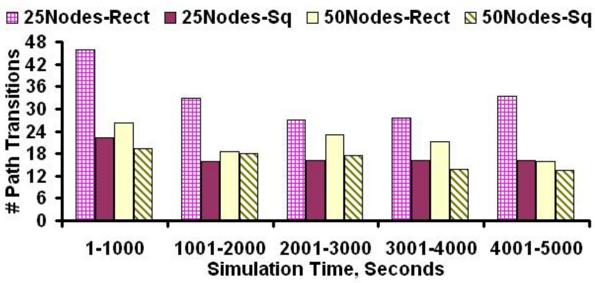

Figure 5.4. Number of Path Transitions for Stable Mobile Path

Figure 5. Performance at v_{max} = 50 m/s

Another important observation is that for a fixed range of simulation time and network shape, the number of path transitions incurred with stable mobile routes decreases with increase in the network density. This comes at a slight increase in the hop count of the stable mobile routes at high network density. In networks of high density, there exist several choices for algorithm *OptPathTrans*, to choose the sequence of nodes that will exist for a longer time. Further analysis of the individual edges that form part of the static stable paths of the stable mobile route, reveals that the individual physical distance is only close to one-half of the transmission range of the nodes. As a result, it takes more time for the constituent nodes of an edge to drift away, leading to the discovery of more stable routes. Nevertheless, shorter the physical distance of the individual links, the more the hop count. We should also note that the hop count of the stable routes chosen by algorithm *OptPathTrans* does not become substantially high. Because, even though the probability of failure of an individual link is low, the more the number of links, the probability of failure of a path becomes high.

V. CONCLUSIONS

The hop count and the number of path transitions of stable mobile routes are very much influenced by the range of simulation times considered. The range of simulation time also affects the number of path transitions incurred by minimum hop mobile routes; even though it does not much affect the hop count of minimum hop mobile routes. As the nodes continue to move under the Random waypoint mobility model, they tend to approach each other and form clusters at the center of the network, thus reducing the hop count and improving the stability considerably. We also observed that the number of path transitions incurred by the stable mobile routes decreases with increase in the network density; where as the number of path transitions incurred by the minimum hop mobile routes sometimes increases with increase in the network density. Also, for a given network density, shape and range of simulation time, the hop count of the routes is not much affected by node mobility. For a given network density, node mobility and range of simulation time, the hop count of routes in a rectangular topology is generally more than that incurred in a square topology of the same area. The more one-dimensional the rectangular topology, the more will be the hop count of the routes and lower the stability. We also observe that as we move the simulation time to beyond 1000 seconds of node movement, the number of path transitions and hop count of the routes get reduced significantly in a rectangular topology when compared to a square topology of the same area. Future work will involve extending this study for the multicast routing protocols and exploring the tradeoffs between link efficiency, hop count per source-receiver path and tree stability with respect to the range of simulation times and network shape.

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