



Impact of the Mobility Models, Route and Link connectivity on the performance of Position based routing protocols

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ABSTRACT

This paper investigate the fundamental factors “mobility models, route and link connectivity” in Mobile Ad hoc networks (MANET) which have a major impact on the performance of position based routing protocols. In addition, a new measurement method called probability of communication process is proposed. The method is used to measure the success rate of established path by a MANET routing protocol, which allow to stress test and inspect the stability, scalability and adaptability of MANET routing protocols. We analysed the effect of “route and link connectivity” on the performance of protocols under two different mobility models. Results show the evaluation and performance of the proposed protocol under a unified simulation environment for different scenarios.

1 Introduction

The dynamic topology of a MANET poses a real challenge in routing and maintaining packets between mobile nodes in MANET. In MANETs, mobile nodes operate as routers and end-system connecting points in order to forward packets while moving about, change location frequently and also organize themselves into a temporary ‘ad-hoc’ network. Because of this, MANETs can offer a larger degree of freedom at a considerably lower cost than other networking solutions. Special routing algorithms are often needed to accommodate changing topology. So far, method for determining the efficient routing paths and delivering messages in an ad hoc environment where the network topology changes has yet to receive much attention.

New prototypes are needed to describe the mobile ad hoc feature of wireless networks; and new algorithms are required to effectively and efficiently route data packets to mobile destination in order to support many of multimedia applications. In order to evaluate

routing protocol performance in MANET, the protocol should be tested under realistic conditions on real time basis such as arbitrary obstacles, a sensible transmission range, limited buffer space for the storage of messages, representative data traffic models, and realistic movements of the MNs (i.e. a mobility model)[CAMP, T. *et al.*, 2002], [XIANG, X. *et al.*, 2007], [ASENOV, H. *et al.*, 2009], [KELLERER, W. *et al.*, 2001].

Different theoretical mobility models have been developed to represent the mobility patterns of nodes under different circumstances for our simulation models. However, in some cases, relying on the simulation tools can be inadequate since it only supports a very limited number of these models. It is desirable for a MANET routing protocol to include the following characteristics:

- **Distributed:** MANET routing protocol requires to execute its process in a distributed manner, due to the decentralized nature of its network.
- **On demand operation:** It is important to utilise the resources more efficiently (power and bandwidth), because traffic distribution



cannot be assumed. Therefore, the algorithm should adapt to the traffic on demand.

- Loop-free: Loop free routing, will ensure efficient network operation and better message delivery.
- Security and Reliability: As well as the usual vulnerabilities of wireless connection, an ad hoc network has its specific security problems issues due to the broadcast nature of wireless transmission.
- Bidirectional/Unidirectional links: Routing protocol should support multi directionality, due to the dynamic nature of MANET.

We have designed and improved our proposed routing protocols [MACINTOSH, A. *et al.*, 2012a] to include the above characteristics.

2 Related Work

Mobility Models (MMs) is the foundation of simulation study on various protocols in MANET. Extensive research has been done in modelling mobility for MANETs and many MMs have been proposed in the literature [LAL, C. *et al.*, 2012], [XU, M. *et al.*, 2009], [KARP, B. *et al.*, 2000], [PERKINS, C. *et al.*, 2003], [BAI, R. *et al.*, 2006].

Comprehensive MMs survey was carried out by Su *et al.* [AKYILDIZ, F. *et al.*, 2002]. A Study by Coroson *et al.* [CORSON, S. *et al.*, 1999] examined the Routing Protocol Performance Issues and Evaluation Considerations. In this paper, the advantages and limitations of the protocols were examined and expressed as qualitative and quantitative attributes. Paper [PERKINS, C. *et al.*, 2003] evaluated the MANET routing protocol AODV under different MMs. In this paper only topology based routing protocols were considered. Paper by [MALARKODI, B. *et al.*, 2009] gives a more detailed classification in four categories: temporal dependency, spatial dependency, geographic restriction and hybrid characteristic. In this paper, it emphasises that the results of simulative performance evaluation strongly depends on the models used. Bettstetter *et al.* [BETTSTETTER, C. *et al.*, 2002] examined the spatial node distribution of the random waypoint mobility model. The goal was to define MMs based on motion matrices class and

the impact of these metrics on routing performance.

Stepanov *et al.* [STEPANOV, I. *et al.*, 2008] present the significant impact of realistic MMs on MANET simulation results. The research work has shown that a realistic MMs could substantially affect the output of simulation experiment. [APPEL, M. *et al.*, 1997], performed an analytical study of the asymptotic minimum node degree of graph uniform. Logical grids distances between nodes are used to form the graph. Paper [BETTSTETTER, C., 2002] present a comprehensive analysis of link connectivity based on undirected graph. In the paper, a fundamental characteristic of MANET is investigated, which is the minimum node degree essential for multi-hop communication. Transmission range were derived and set to

$r_0 \geq \sqrt{\frac{-\ln(1-p_n^2)}{p\pi}}$, in connected network.

[GRUPTA, P. *et al.*, 2006] examined link connectivity, they obtained a necessary and a sufficient condition on r_0 “radio transmission range” for connectivity. They also have shown that if the r_0 of n nodes in a disc of unit area is

set to $r = \sqrt{\frac{\log n + c(n)}{n\pi^2}}$, the resulting wireless

multihop network is asymptotically connected with probability one if and only if $c(n) \rightarrow \infty$. Philips *et al* [PHILIPS, T. K. *et al.*, 1998] explained how the expected number of neighbours of MNs should propagate with the system area to maintain connectivity.

In this research, we extended other researches in similar areas by assessing the performance of position based routing protocols under different MMs (Dependent and Independent). The impact of MMs, route, and link on position based routing protocols in MANETs have not been considered before. We have investigated these factors analytically and mathematically. We employed proximity graphs theory to find the link between MNs in connected network topology. One of our contributions is investigating the correct adjustment of the MN radio transmission range in order to achieve connected MANETs. Moreover, previous research considered only connectivity between MNs; none of them investigated “connectivity, path and routing overhead”, which has been investigated in depth in this paper. We propose



and introduce a new performance metric measurement called the probability of communication process connectivity to compute the success rate of established path and the result is compared to [BETTSTETTER, C., 2002]. This research also provides practical significance for the simulation study of MANET routing protocols and the design and improvement of MMs.

This research is organized as follows. In section 3, a brief description about the positions based routing protocols in our performance evaluation. In section 4, we present the MMs in our performance comparison. In section 5, we analyse mathematically the required transmission range in connected MANETs. Section 6 deeply analyses how the main parameter of the MMs, route, and link impacts on the performance of routing protocols, and introducing the new measurement method. In section 7 details of the simulation and results are given. In section 8 the conclusion and future works are discussed

3 Position Based Routing Protocol

Position based algorithms overcome the problem related to the maintenance of the routing table in connection oriented algorithms [BETTSTETTER, C., 2001], [LENDERS, V. *et al.*, 2006], [BLAZEVIC, L. *et al.*, 2005], where the performance degrades quickly when there is an increase in the number of MNs or the speed. Position based routing algorithms eliminate some of the limitations of topology based routing by using geographical information about the MNs to make decision about routing packets. This position information is obtained by position service and location service. If a MN wants to send data to a destination node, it will make routing decision based on the destination and the positions of the source one-hop neighbours. Consequently, position based routing protocols do not require route establishment or maintenance. Position information only needs to be distributed in the local area.

3.1 Greedy Perimeter Stateless Routing

Greedy Perimeter Stateless Routing (GPSR) proposed by Karp and Kung is a position based routing algorithm [KARP, B. *et al.*, 2000]. GPSR makes greedy forwarding decisions using only information about the position of immediate neighbours in the network topology. Packets are forwarded to the next-hop node which moves the packet to a nodes which most close to the position of the destination.

By keeping only local topology information, GPSR scales better than topology based routing as the number of network destinations increases. If the packet reaches a region where greedy forwarding is impossible, the algorithm enters into recovery mode by routing around the perimeter of the region [CORSON, S. *et al.*, 1999, LAL, C. *et al.*, 2012], [KARP, B. *et al.*, 2000], [JUN, T. *et al.*, 2008]. The GPSR protocol is a routing protocol that is often used to establish routes in MANET or sensor networks. However, for it to operate effectively, it is a requirement that all MNs assist each other. However, such a process would be unlikely to perform efficiently in MANET. The disadvantages of GPSR are the control overhead and slow recovery process [LAL, C. *et al.*, 2012], [KARP, B. *et al.*, 2000], [ASENOV, H. *et al.*, 2009], [PHILIPS, T. K. *et al.*, 1998].

3.2 Local Area Dynamic Routing protocol

3.2.1 Overview

The position based routing algorithm has two advantages over the topology based routing algorithm; first, the routing algorithm does not require route establishment or maintenance. Second, the geographical information is distributed only in the local region. While the position based routing protocols (e.g. GPSR) eliminate some of the limitations of the topology based routing protocols by using geographical information to make decisions about routing packets, they don't take into account the locomotion of the nodes.

Local Area Dynamic Routing protocol (LANDY) [MACINTOSH, A. *et al.*, 2012a]



uses locomotion information and the velocity of MNs, to route packets. It is assumed that nodes will have access to a position service. Obtaining location information from the position service, LANDY will employ a forwarding strategy to route packets between MNs. If routing problems occur with the forwarding strategy, the algorithm will include a recovery mode which will operate when the protocol recognizes that this problem has occurred. In the recovery mode, the protocol navigates the planar graph to the desired destination.

3.2.2 Algorithm process

In the previous work, LANDY [MACINTOSH, A. *et al.*, 2012a], [MACINTOSH, A. *et al.*, 2012b] localises routing information distribution in the one-hop range. Thus LANDY will reduce the control overhead, simplify routing computation and save memory storage. Each MN in the network needs to maintain the local status of its MNs neighbours only. For each connection, a MN gets order of query packets (N_i). The number of neighbour MNs (N_i) may increase or decrease based on the movement of MNs within the local region. Therefore the distribution of the MNs within a region for the network state is $S(n)$ in the worst case scenario.

The MN updates its locomotion components (LC) through position service (e.g. GPS) periodically in LANDY. The MN broadcasts its Mobile code identifier (MCID), Cell code identifier (CCID) and LC in a HELLO message periodically. Data packets are marked with the LC of the sender and the destination, so that the receiving nodes are able to update the neighbour's locomotion information upon receiving the data packet.

The MN does not flood the HELLO message. Thus, the LANDY routing protocol reduces the control overhead and simplifies the routing computation. The HELLO message broadcasting mechanism makes all nodes aware of their neighbours' locomotion information. Each MN periodically broadcasts a HELLO message to its one-hop neighbours, with its MCID, CCID and LC. The HELLO message inter-arrival time is jittered with a uniform distribution to avoid synchronization of neighbours' HELLO messages that could result in conflict. Each MN updates its

locomotion table (LT) of neighbours when it receives a HELLO message.

The LT associates an expiration value with each entry. If the node does not receive a HELLO message from a neighbour within the expiration time, it removes the neighbour from the table. Based on the LT, the source is able to estimate the future position of its neighbours. At time t , the MN a broadcasts a HELLO message, encapsulating the LC in the message. Upon receiving the HELLO message from neighbouring node, the receiving node updates LT of neighbour's locomotion information. Since the inter-arrival time of HELLO message t_{\square} is jittered with a uniform distribution, each node has a different inter-arrival time of HELLO message. At time $t+t_{\square}$, node a broadcasts a new HELLO message with updated LC.

The Source MN(S), receive the new HELLO message and updates the LT. Upon not receiving a HELLO message from a neighbour for a long time (t_2), the MN assumes that the link to the neighbour is broken and removes the neighbour from the LT. Besides the one-hop HELLO message broadcasting, the MNs will send out the LC in the data packets. The data packet LC transmission provides an alternative to the locomotion distribution. It is helpful in a dense mobile network with heavy traffic load. The mobility of the node at time t_2 is calculated using (1).

$$M = \frac{1}{(t_2 - t_1)} \sqrt{(x_1 - x_0)^2 + (y_1 - y_0)^2} \quad (1)$$

Where; M is the mobility of the MNs, (x_n, y_n) are the X and Y coordinates of the MNs positions.

4 Mobility Models in MANET

MMs designed to represent the motion of MNs, and how their location, velocity, acceleration changes over time. MMs used to evaluate the performance of ad hoc network protocols. Since the performance of protocol depends on the mobility model, it is important to choose a suitable model for the evaluated protocol. Generally, there are two types of MMs used in the simulation of wireless networks; Independent - Entity Mobility Models (IEMMs)



and Dependent - Group Mobility Models (DGMMs). In IEMMs a node's movement does not control in anyway, other nodes' movements. Nodes move independently from each other, randomly. i.e. Random Waypoint Model, Random Walk Model, Random Direction Model, Gauss-Markov model, Manhattan Mobility Model.

DGMMs Represent MNs whose movements are mutually dependent on the group movement. DGMMs used when MNs cooperate with each other to accomplish a common goal. Typical situations do exist in military environments (soldiers move together), i.e. Reference Point Group Model, Nomadic Community Model, Column Mobility Model, Pursue Mobility Model.

4.1 Gauss-Markov Model

Gauss-Markov model (GMM) is a model that uses one tuning parameter to vary the degree of randomness in the mobility pattern. GMM was designed to adapt to different levels of randomness via tuning parameters [CAMP, T. *et al.*, 2002], [PERKINS, C. *et al.*, 2003]. GMM is a different model from Random Waypoint in terms of velocity management. In this model, the velocity of MN is correlated over time and GMM random process. GMM random process satisfies the requirements for both Gaussian processes and Markov processes. The velocity of MN at time slot t is dependent on the velocity at time $(t - 1)$.

Therefore, GMM is a dependent mobility model where the dependency is determined by the parameter which affects the randomness of GMM process. By tuning this parameter, different mobility model can be created [BETTSTETTER, C. *et al.*, 2002], [RANGARAJAN, H. *et al.*, 2004]. GMM creates movements, which are dependent on node's current speed and direction. The idea is to eliminate the sharp and sudden turns present in the Random Waypoint even by keeping a certain degree of randomness. Initially each MNs is assigned a speed and direction. At fixed intervals of time n , movement occurs by updating the speed and direction of each MN. The value of speed and direction at the n instance is calculated based upon the value of

speed and direction at the $n-1$ instance and random variable using (2), and (3).

$$s_n = \alpha s_{n-1} + (1 - \alpha)s + \sqrt{(1 - \alpha^2)}sx_{n-1} \quad (2)$$

$$d_n = \alpha d_{n-1} + (1 - \alpha)d + \sqrt{(1 - \alpha^2)}dx_{n-1} \quad (3)$$

where; s_n and d_n Are, the new speed and direction of the MN at interval n . α is the tuning parameters to vary the randomness, where $(0 \leq \alpha \leq 1)$. s and d are constants representing the mean value of speed and direction. As $n \rightarrow \infty$ and sx_{n-1} and dx_{n-1} are random variables from a Gaussian distribution. At each time interval the next current location is calculated based on the current location, speed and direction. MN location can be calculated using (4), and (5).

$$x_n = x_{n-1} + s_{n-1} \cos d_{n-1} \quad (4)$$

$$y_n = y_{n-1} + s_{n-1} \sin d_{n-1} \quad (5)$$

Where; (x_n, y_n) and (x_{n-1}, y_{n-1}) are the X and Y coordinates of the MNs positions.

4.2 Reference Point Group Model

Reference Point Group Model (RPGM) represents the random movement of a group of MNs as well as the random movement of each individual MN within the group. RPGM is a group mobility model where group movements are based after the path travelled by a logical centre. RPGM used to calculate group motion via a group motion vector, group mobility. The movement of the group centre completely describes the movement of this corresponding group of MNs. Including their direction and speed. Individual MNs randomly move about their own predefined reference points whose movements depend on the group movement, RPGM can be represent mathematically in (6), and (7) [GRUPTA, P. *et al.*, 2006].

$$|V_{member}^{\rightarrow}(t)| = |V_{member}^{\rightarrow}(t)| + SDR.max\ speed \quad (6)$$

$$\theta_{member}(t) = \theta_{leader}(t) + ADR.max\ angle \quad (7)$$

Where; $0 \leq SDR, ADR \leq 1$. SDR is the speed deviation ratio and ADR is the angle deviation ratio. ADR and SDR are used to control the deviation of the velocity of the group members

from that of the leader. In the RPGM, each group has a centre, which is either a logical centre or a group leader node. The assumption is that the centre acts as the group leader. Thus, each group is continuing one leader and a number of MNs. The movement of the group leader determines the mobility behaviour of the entire group.

5 Probability of Link Connectivity between Active Mobile Nodes

A graph is made of number of vertices and edges, where an edge is a link between two vertices. If individual edge of a graph is linked with some unique value, then graph is weighted. The number of edges linked with the vertex is identified as degree of any vertex v is denoted by $d(v)$. The minimum degree of a graph is the least degree of a vertex of a graph denoted by $\delta(G)$ and the maximum degree of a graph is the maximum degree of any vertex of a graph denoted by $\Delta(G)$. A graph G is consistent if $\Delta(G) = \delta(G)$. A graph is connected, if a path exist between two MNs, otherwise, it is disconnected [BETTSTETTER, C., 2002].

In connected networks, MNs can communicate with each other via gateway MN or multi links. In disconnected networks, there are several isolated sub-networks, forming a sub-graph of connected MNs, which cannot communicate to other sub-networks.

Extensive Link connectivity analysis is carried out by [BETTSTETTER, C., 2002], which is based on undirected graph theory. However, the paper did not consider the route overhead. Based on the work therein, we expand and make improvement to include the route overhead in our analysis and simulation.

Minimum node degree (d) is a major factor for multi-hop communication. It represent the relation between the node and its neighbour's MNs. If " $d = 1$ " then the network is connected, which mean the node is able communicate to its neighbour, otherwise it is disconnected (isolated) when " $d = 0$ ". Equation (8) represent the probability of link connectivity for active MNs, and the minimum node degree of

connected network (graph G) is represented in (9) [BETTSTETTER, C., 2002].

$$\begin{aligned} Prob_{(lc > 0)} &= (1 - e^{-\rho\pi r^2})^n & (8) \\ d_{\min(G)} &= \min_{u \in G} \{d(u)\} & (9) \end{aligned}$$

where; $Prob_{lc}$ is the probability of link connectivity, ρ is node density, r is node transmission range, and n is the number of nodes in the network, $d_{\min(G)}$, is minimum node degree of connected graph, u is the degree of a node, denoted as $d(u)$, is the number of neighbors of node u .

Additionally, a k -connected theory graph exists, when at least two MNs can communicate via k path. The MN at the route request stage will send at least query packets, but the backtrack packets (bp) process might have an impact which result in sending more than Q number of query packets. Therefore the communication packet overhead for the searching stage is $Q(uv'+bp)$. This query number depends on the locomotion of MNs. The route reply stage will send acknowledgements with the chosen path of length l . Therefore in normal circumstances, i.e. if there is no dynamic transformation in the network layout between route request and reply stages, the packet overhead for the reply stage is $Q(l)$ or $Q(n)$. Therefore, the packet overhead is presented in (10).

$$Q(uv' + n(CCID) + bp) = Q(uv' + bp) \quad (10)$$

Where; Q is the number of query packets, uv' is communication packet overhead for the searching stage, bp backtrack packet, $CCID$ is the cell code identifier.

In order to accomplish a connected ad hoc network, "no isolated nodes" or MNs can reach each other via multi path. Based on this, we need to find out; what is the minimum radio transmission range? In our simulation, a random MN of ad hoc network is represented as a random point. Therefore, it is probable that the distance between MNs and their closest neighbours is $\leq r$. If $r = r_0$, then it is likely that MN u has at least one neighbour. This is represented in (11), and (12), otherwise, MN has no neighbours (disconnected) and this is represented in (13).

$$P(\xi \leq r_0) = \int_{\xi=0}^{r_0} 1 - e^{-\rho\pi\xi^2} \cdot Q(uv' + bp) \quad (11)$$

$$P(d(u) > 0) = P(\xi \leq r_0) \cdot Q(uv' + bp) \quad (12)$$



$$P(d(u) = 0) = P(\xi \leq r_0) = 1 - P(\xi > r_0) = e^{-\rho\pi r_0^2} Q(uv' + n(CCID) + bp) \quad (13)$$

The goal is to create a connected network "Graph G", where there is no disconnection between MNs. $d(u) > 0, \forall u \in G \Leftrightarrow d_{min}(G) > 0$. To achieve a fully connected ad hoc networks, there must be a multi-path from and to each MN. The probability of this scenario, with marginal independence assumed, is represented in (14). To ensure, with at least P probability, that no MN is isolated in the network, radio range can be set for all MNs using (15) [BETTSTETTER, C., 2002].

$$P(d_{min} > 0) = \binom{n}{n} P(d > 0)^n P(d = 0)^0 = (1 - e^{-\rho\pi r_0^2})^n \cdot Q(uv' + bp) \quad (14)$$

$$r_0 \geq \sqrt{\frac{-\ln\left(1 - \frac{1}{p\bar{n}}\right)}{\rho\pi}} \quad (15)$$

A high node degree makes an MN resilient against failures of neighbors MNs and links. For calculating node mobility (M). Each node can find its location information using GPS, so that it can calculate the node mobility using (16) and (17). Equation (18) represent node mobility with transmission range r_0 with at least one neighbour.

$$x1 = x0 + (v \times (\cos \theta)) \cdot M \quad (16)$$

$$y1 = y0 + (v \times (\sin \theta)) \cdot M \quad (17)$$

$$M(d_{min} > 0) = r_0 \geq \sqrt{\frac{-\ln\left(1 - \frac{1}{p\bar{n}}\right)}{\rho\pi}} \quad (18)$$

6 Novel Probability of Communication Process between Active Mobile Nodes

Simulation experiments are widely used to evaluate MANET routing protocols. Similar to simulations of traditional wired networks, these experiments must model the network topology, network traffic, and the routing and other

network protocols. In addition, the wireless and mobile nature of MANETs necessitate consideration of node mobility, physical layer issues, including the radio frequency channel, terrain, and antenna properties, and, perhaps, energy and battery characteristics. Node mobility, joined with physical layer characteristics, determines the status of link connections and, therefore, the network's dynamic topology. Link connectivity between MNs is the most important factor, affecting the relative performance of MANET routing protocols. The connectivity depends on the radio transmission range and number of MN density. Each MN contributes to the connectivity of the entire network. Communication between two active nodes can be initiated as follows:

A) Two MNs moving in their particular self-directed modes come within the range of each other and start communication.

B) A MN becomes active at any given time at a random place and it happens to be in the range of communication of another MN. These initial conditions of active communication will have an impact on the calculation of the link/path metrics of the MANET. The key factor in the mobility model that was inherent for each MN of the MANET, plays the key role in controlling the performance metrics including link/path metrics. Two nodes are neighbours if their intermediate distance is less or equal to their transmission range.

A new metric for measuring routing performance called probability of communication process between active MNs is presented. The measurement based on the assembled paths over randomised dynamic network topologies. The topology of the network can be represented as undirected weighted graph (19).

Where; V is a set of active MNs and A is a set of active wireless links. In MANET, it is important to know when the link is disconnected with surrounding nodes, this might cause unacceptable message delivery delay. Although, an active path can be established between MNs when there is valid links connectivity; it is unlikely analytically to capture and measure the performance due to the dynamic changes of the



network topology over time. Therefore, we use the following method ‘‘Sobol sequences’’ to capture and measure the routing performance over many repeated network simulation scenarios. At any time t , the undirected weighted graph can be represented in (20).

$$G_t = (V, A_t) \cdot M(d_{min} > 0) \quad (20)$$

Where; G_t is subset of G , A_t is a set of active wireless links at any time t , and V is a set of active MNs during the simulation experiments, due to the dynamic changes in the routing paths between the active MNs. The number of established paths will have to be computed and averaged over many scenarios. Simulation scenarios were equally run for 500 times ($n=500$) within 1000s. The established active paths between the nodes throughout the simulation were measured 500 times. The value of n can be any real number. With variant the value of n by increasing it, the accuracy of the result may increase. The average successful established paths can be present in (21).

$$A_t = A_0 + A_1 + \dots + A_{n-1} \quad (21)$$

Equation (22) is derived to measure the probability of the path connectivity for one set of simulation scenario. And (23) is used to measure the probability of the path connectivity over many set of simulation scenarios.

$$\text{Probep} = \frac{\sum_{j=0}^{(Ts-1)} A_j}{Ts} \cdot M(d_{min} > 0) \quad (22)$$

$$\begin{aligned} \text{Probep} &= \frac{\sum_{j=0}^{(Ts-1)} \sum_{k=0}^{(n-1)} A_{jk}}{Ts} \cdot M(d_{min} > 0) = \frac{\sum_{j=0}^{(Ts-1)} \sum_{k=0}^{(n-1)} A_{jk}}{Ts} \cdot r_0 \\ &\geq \sqrt{\frac{-\ln\left(1 - p^{\frac{1}{n}}\right)}{\rho\pi}} \quad (23) \end{aligned}$$

Where; Probep is successful probability of established path, T_s is the total number of scenarios, n is a real number for each time the simulation run, M is the node mobility. The simulation result presented in the following subsection will consider only the minimum node connectivity (i.e., $d=1$).

7 Analysis on Impact of Route, Link and Mobility Models

In order to explain how the route, link, and MMs impact on the performance of the MANET routing protocols, various predominance metrics used and performance discrepancies analysed in this section.

7.1 Simulation Setup and Results: Mobility Models

We have chosen LANDY [MACINTOSH, A. *et al.*, 2012a], and GPSR [KARP, B. *et al.*, 2000] position based MANET routing protocols for performance investigation under different MMs. Both protocols were evaluated under GMM and RPGM using OPNET v14.5 simulation tools. The MMs are computed using C-code programs, whose results are imported into OPNET simulation models. Each node is then assigned a particular trajectory. The LANDY protocol is implemented in the OPNET as a process model in wireless MNs. The LANDY process model can be represented in a State Transition Diagram (STD). MN models were constructed that included OPNET standard IEEE 802.11 physical and MAC layers, as well as custom build process models to implement the LANDY protocol.

The traffic application is a traffic generator. This traffic generator starts at 10s during simulation. Every model has the mean speed changing from 10m/s to 30m/s with zero pause time. In all this patterns, 500 nodes move in an area of 1000m \times 1000m for a period of 1200s, to avoid the effect of initializing and ending, we only gather the data between 100s – 1100s. The error bars indicate 95% confidence intervals in all the scenarios.

Six sets of source and destination pairs were selected randomly from a group of 500 MNs. Constant bit rate (CRB), used to set the rate of the transmitted data packet, which is set to 8 packets /s, and the size of user datagram packet (UDP) is fixed to 512 bytes. The accurate adjustment of the MNs radio transmission power is key factor in the simulation. It allows the controlling of the network topology in MANET [BAI, F. *et al.*, 2003],

[BETTSTETTER, C., 2002]. If we increase the transmission power of a MN, this will result in higher range and consequently reach more MNs via a direct link. Otherwise if we set the power low, this might result in isolation without any link to other MNs. We have configured the six sets with two different power levels Table 1. Each set will cover various volume of unidirectional links. For example, set 0.1 represents 10% MN with low transmission range and 90% with high transmission range. This method will aid the performance investigation for scenarios with various volume of unidirectional links.

Set No.	Set 0	Set 0.1	Set 0.2	Set 0.3	Set 0.4	Set 0.5
No. of MNs	0	100	200	300	400	500

Table 1. Ratio set for unidirectional links

The high level is assigned to MN with transmission range 300 m, and the low level is assigned to MN with 125 m transmission range. Due to the dynamic topology of the MNs, it is not possible to determine the exact number of links, which results in route repeatedly being assembled and breaks. The MAC radio propagation bit rate is set to 11 Mb/s with frequency operating at 2.422 GHz. Table 2. represent the setting for MMs on both protocols.

Parameter	GMM	RPGM
No. of Mobile Nodes	500	500
Speed update frequency	2.5 s	NA
Angle std deviation	450	NA
Speed std deviation	1.5 m/s	NA
Group deviation	NA	2
Pause time	NA	0 s
No. of groups	NA	50 groups

Table 2. Configuration parameters of mobility models

The unidirectional links results are shown in Fig. 1, Fig. 2, Fig. 3 and Fig. 4 for LANDY, GPSR as a function of radio range in the 500-node scenarios, respectively. The result indicates that at higher speed, the probability of unidirectional links occurrences is higher. Routes between the MN become unstable at higher speed, due to the dynamic topology and possibly break, leading to unidirectional links. The results shows that GMM generate more unidirectional links compared to RPGM on both

protocols. At speed of 0 m/s crossing set 0 Fig.1, Fig.2, Fig.3and Fig.4, on both protocols, we have noticed a small number of unidirectional links generated. Due to the interfering by neighbour MNs which result in packet dropping. Also, with increasing the speed of the MNs, this will lead to link breaks frequently and resulting to interpretation as unidirectional links by both routing protocols.

When the number of unidirectional links fluctuate at high rate mobility rate, the slight drop is due to the fact that the number of RREQ “Route Request” packet sent by the source node decreases, and it indicates that either the routing paths has been successfully constructed, or there exists more bidirectional links in the network than the unidirectional links. Also, low transmission range does not always provide an increase in number of unidirectional link, due to the impact of other factors such as the behavior of mobility model and speed MNs.

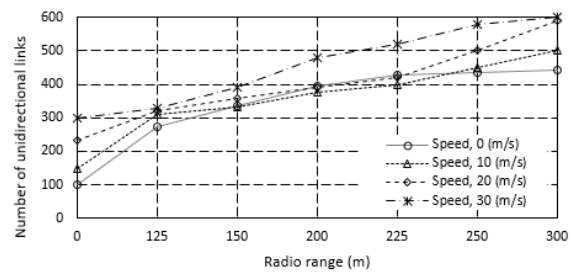


Fig. 1 GMM unidirectional links vs Radio range – LANDY

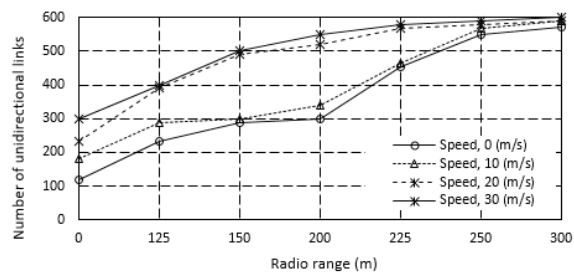


Fig. 2 RPGM unidirectional links vs Radio range – LANDY



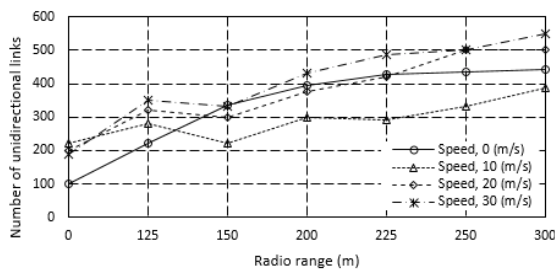


Fig. 3 GMM unidirectional links vs Radio range – GPSR

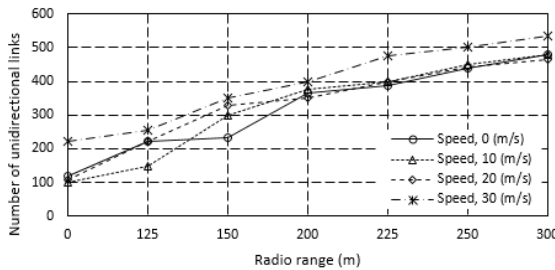


Fig. 4 RPGM unidirectional links vs Radio range – GPSR

The results of the average RREQ packet sent by each source MNs are shown in Fig. 5, Fig. 6, Fig. 7 and Fig. 8 for LANDY, GPSR as a function of radio range in the 500-node scenarios, respectively. The source MNs send RREQ at route discovery and recovery process of route failure on both routing protocols. Results indicates that, the higher mobility of MNs result in increasing the production of RREQ in the network. Which causes routing overhead. With speed increasing more overhead is generating in both protocols. But LANDY have less overhead than GPSR. Also, by observing more simulation experiments, shows that more than 80% of routing packets in the network is created by the RREQ packet of MNs.

In general, the performance of GPSR drops with increasing number of nodes set with low transmission range, but LANDY perform well comparing to GPSR. Results also shows that, the impact of RPGM on routing performance is minimal, compared with GMM. Such performance is due to MNs closeness, which restricts movement to within a small area around the reference point. As a result, link connectivity increases, leading to less unidirectional links occurrences. On the other hand, MNs in GMM are uniformly distributed.

Consequently, nodes are more vulnerable to form unidirectional link.

In addition, result shows with the speed increasing, each metrics is getting worse in some way. These results exist since the topology of the network is more unstable with the speed increasing. As a result of the RPGM model only has pause time in simulation boundary and the MNs need to keep moving in the same direction until they reach the border of the simulation area. The metric in RPGM model is better than that of GMM model.

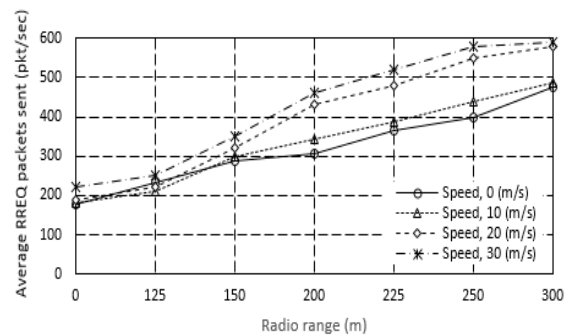


Fig. 5 GMM Average RREQ packet sent vs Radio range – LANDY

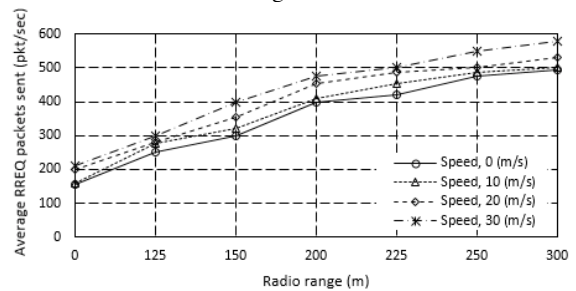


Fig. 6 RPGM Average RREQ packet sent vs Radio range – LANDY

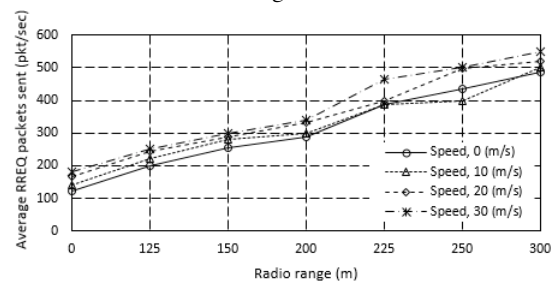


Fig. 7 GMM Average RREQ packet sent vs Radio range – GPSR



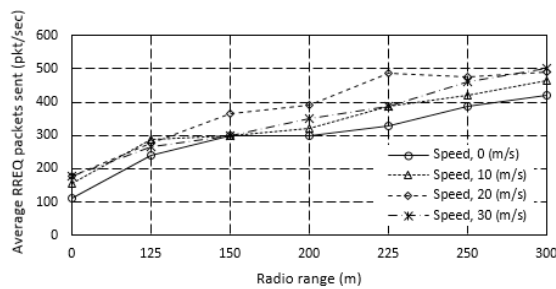


Fig. 8 RPGM Average RREQ packet sent vs Radio range – GPSR

7.2 Simulation setup and Results: Link and Route

In order to investigate the probability of link connectivity and the probability of communication process/ path between active MNs. We have configured the setting in Table 3 for our simulation scenarios. Each simulation is repeated using 500 different scenarios generated from random seeds.

Parameters	Description
Simulation Area	1000 x 1000 sq. units
Mobility Models Used	GMM, RPGM
Number of Nodes	500
Mobility Speed	0, 10, 20, 30m/s
Antenna type	Omnidirectional
Traffic model	CBR, UDP
Data traffic size	512 bytes
Data packet rate	8 packets/s

Table 3: Configuration parameters

The results of the link connectivity probability shown in Fig. 9, Fig. 10, Fig. 11 and Fig. 12 for LANDY, GPSR as a function of transmission range in the 500-node scenarios, respectively. The link connectivity probability varies for each routing protocol under different mobility model. The highest percentage of link connectivity probability is presented by GMM (%93) for set 0.5 compared with RPGM (%81). LANDY overcome GPSR in both cases. We compare our result to [BETTSTETTER, C., 2002] section 4.3. In [BETTSTETTER, C., 2002], simulation study considered only nodes in the “inner zone”.

The disadvantage of this method, with increasing r_0 , the number of nodes decrease (mobile nodes which contribute to the statics of the simulation). In our simulation study, we considered both scenarios the center and the borders.

We go one step further and ask the question; what is the minimum radio range for the above scenarios in connected MANET? The condition $M (d_{min} > 0)$ is important and essential for a graph to be connected. Equation (18) can be used to calculate transmission range r_0 for lower bound in order to achieve connected network. When increasing the number of MNs with low transmission range, all the MMs shows dramatically decrease in the link connectivity probability especially in set 0.1 and 0.3. This behavior as result of the presence of unidirectional links, which impact and reduce the communication process between the MNs and its neighbors.

It is apparent between set 0 and set 0.3 on both MMs, the link connectivity probability fluctuate as much as %62. In addition, the outcome of observing the results intensely suggests that occurrence of all bidirectional links between the neighbouring MNs may not guarantee least fully connected mobile network.

With continuing the increase in the MNs with low power transmission P_{trans} (set 0.5), the link connectivity probability continue fluctuating. In order to reach a value alike link connectivity probability of set 0, the P_{trans} has to be marginally increased. This can be seen on Fig. 9, Fig. 10, Fig. 11, and Fig. 12, by increasing the P_{trans} in set 0.5, we can achieve similar performance to set 0. Also, result shows that the probability of k-connected network changes dramatically with the increase of r_0 . In addition result shows equation [MACINTOSH, A. *et al.*, 2012b] is valid in simulation area restricted with border effects. Which is necessary for finding accurate range or density that create connect network.

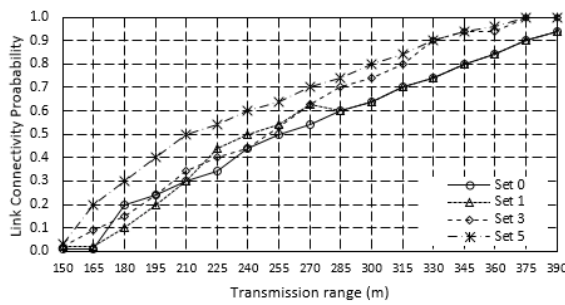


Fig. 9 GMM Link connectivity probability vs Transmission range – LANDY

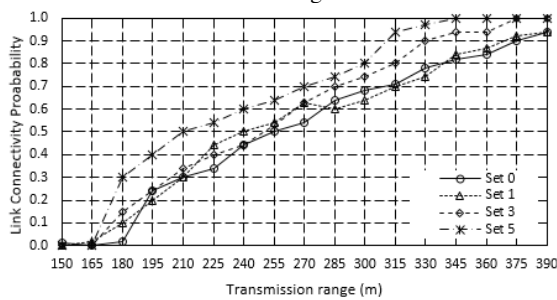


Fig. 10 RPGM Link connectivity probability vs Transmission range – LANDY

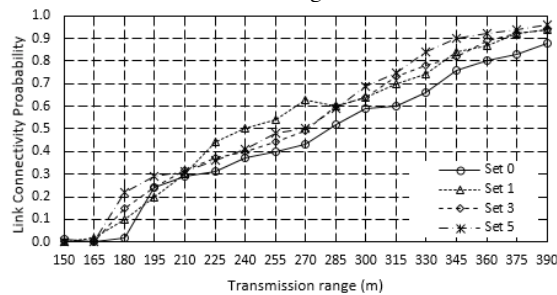


Fig. 11 GMM Link connectivity probability vs Transmission range – GPSR

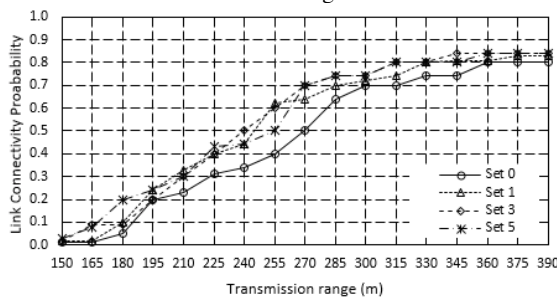


Fig. 12 RPGM Link connectivity probability vs Transmission range – GPSR

Also, results indicates that RPGM perform better than GMM with regards offering lower connectivity on both protocols. Furthermore, results shows that impacts of the unidirectional

links on the performance of the routing protocols when Ptrans is nominal (i.e., 250) which is commonly implemented in commercial outdoor radio interface. By increasing Ptrans beyond the nominal value will lead to increase in the channel load, and this effect is not desirable. Also, it will lead to increase in the routing overhead.

The results of the Path connectivity probability shown in Fig. 13, Fig. 14, Fig. 15 and Fig. 16 for LANDY, GPSR as a function of transmission range in the 500-node scenarios, respectively. We measure the path connectivity probability, by measuring the number successful RREP “route reply” received at the source MNs. The process of receiving RREP from the destination by the sources MNs indicates that the target MNs received the RREQ packet (i.e., creating forward route) and reply by sending a RREP packet (i.e., creating reverse packet).

The process of successful bidirectional communication leads to successful established route between the MNs. Fig. 13, Fig. 14, Fig. 15, and Fig. 16, shows Path connectivity probability for both protocols under GMM and RPGM. These scenarios were repeated 500 times with different setting for MNs Ptrans various between 150 to 400m. The results shows accurate details about the unidirectional link impact on the performance of the routing protocols comparing to the link connectivity probability in Fig. 9, Fig 10, Fig. 11, and Fig. 12. Results indicates that the path connectivity probability for set 0 MNs shows better performance compared to set 0.1, and set 0.3. When Ptrans set to 250 m, results shows that route between MNs in the network established successfully during the simulation run between 400 and 500. This indicates guaranteed route establishment at this setting. The path connectivity probability in GMM is greater than RPGM at Ptrans > 250 m. Generally LANDY perform better than GPSR in relation to established path “path connectivity probability”. The performance of GPSR fluctuate significantly for set 0.3 and 0.5 across both MMs. The Path connectivity probability fluctuate as much as %65 between set 0 and 0.5, as result of the high number of unidirectional links in between the MNs in the network. GPSR has no unidirectional link detection



mechanism, as result of that path between the MNs will be unstable will breaks frequently. Remarkable observation is in accordance with the termed “phase transition” [BETTSTETTER, C., 2002] section 5.2. We can get similar result to [BETTSTETTER, C., 2002] by increasing node density ρ for a given transmission range r_0 . This solution is valid in area without border effect, in order to achieve higher connectivity in MANET.

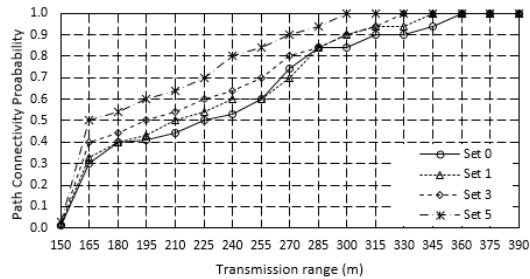


Fig. 13 GMM Path connectivity probability vs Transmission range – LANDY

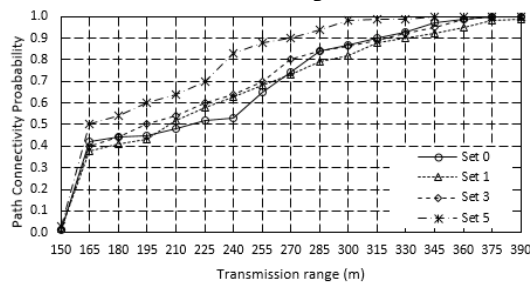


Fig. 14 RPGM Path connectivity probability vs Transmission range – LANDY

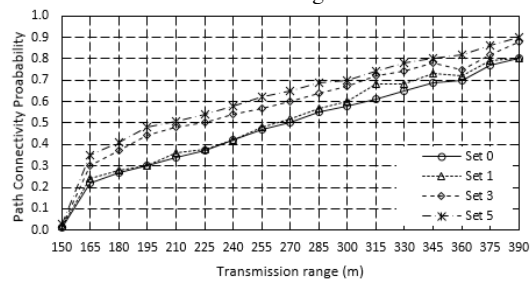


Fig. 15 GMM Path connectivity probability vs Transmission range – GPSR

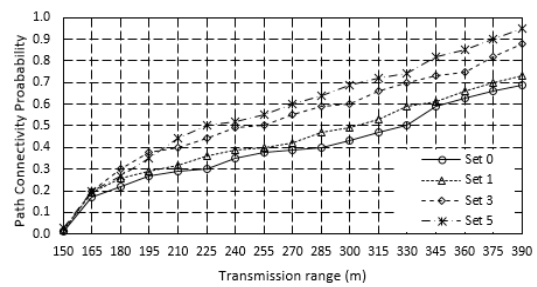


Fig. 16 RPGM Path connectivity probability vs Transmission range – GPSR

7.3 Simulation setup and Results: Routing overhead

The routing overhead can be defined by the ratio of total number of routing packets to the total number of data packets transmitted. It measures the efficiency of a routing protocol, the degree to which it will function in congested or low bandwidth environment. Due to the broadcast nature of the control message delivery, the packets are measured by summing up the size of all the control packets received by each MN during the whole simulation period. We compare our result to the result in [XU, M. *et al.*, 2009]. Furthermore, we increased the number of MNs to 1000, and increased the speed to 60 (m/s) to stress test the protocols.

Results indicate that performance of the routing protocol varies over different MMs. In addition, more coordinated movements of the nodes reduces the number of control packets required to be distributed over the network and reduces the routing overhead.

The Result of the routing overhead are shown in Fig.17 and Fig. 18, in the 1000- node scenarios, respectively. Routing overhead can be determined by quantifying the effect per packet and number of path searches. Because LANDY and GPSR, broadcast routing protocol packets proactively in a nearly constant interval. Results show, that LANDY has a smaller overhead than GPSR and the proposed protocol in [XU, M. *et al.*, 2009] as the number of link searches are small, because LANDY broadcast routing protocol packets proactively in a nearly constant interval. The routing overheads of LANDY are nearly constant. GPSR have large number of routing control messages due to the topology



changes. It is important to note that the location service will increase the routing control overhead.

In contrast, LANDY has less overhead than GPSR among both MMs. The routing overhead increases with the speed of the MNs. RPGM model gives minimum overhead as it supports the group movement and hence ensures more reachability. In addition, with increased speed, each metrics is deteriorating in some means. The GMM model has the highest routing overhead, and shortest average hop count. The RPGM model is the reverse.

These results exist since the nodes in GMM model are often travelling near the centre of the simulation area, but the nodes in RPGM model only can change the direction until it reaches the border of the simulation area. Therefore, the topology of the network can more easily be partitioned in GMM model than in that of RPGM. Moreover, the RPGM model through the probability of moving; a MN can go a longer distance before changing direction. It alleviates the sharp turnings and sudden stops; by changing the setting of MN. The probability of the MN continuing to follow the same direction is higher than the probability of the node changing directions.

The percentage of packets received using LANDY is high even when mobility increases. This result indicates that these kinds of protocols will be desired for high mobility networks. GPSR is dependent on periodic broadcast which show a rather poor result. In-addition, a large byte overhead would mean a larger wasted bandwidth. Many small control information packets would mean that the radio medium on which packets are sent, is acquired more frequently. This would impact massively on the performance, power and network utilization.

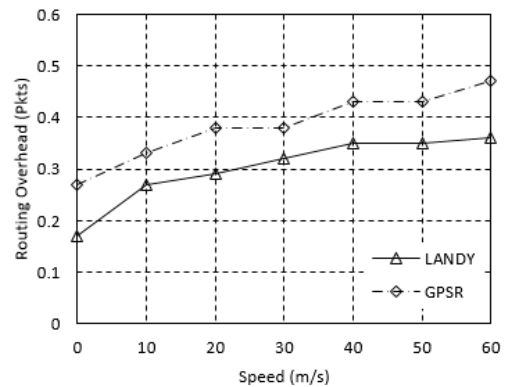


Fig. 17 Routing Overhead Vs Speed - GMM

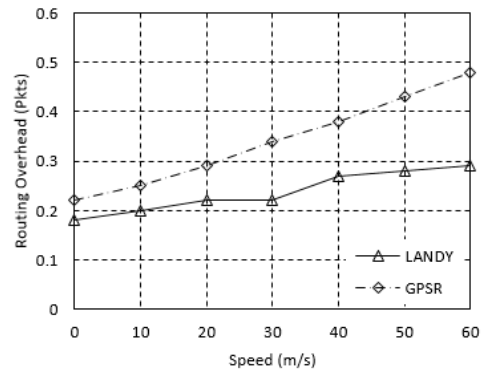


Fig. 18 Routing Overhead Vs Speed - RPGM

8 Conclusions and Future Work

The effects of the route, link, and MMs on the performance metric of MANET routing protocols have been analysed. The simulation results indicate that even setting the same parameters, different MMs have a different impact on the performance evaluation of protocols. Therefore, choosing an appropriate mobility model as well as setting appropriate parameters serve as the key role for protocol evaluation. It is found that Protocols that have link layer support for link breakage detection, are much more stable.

The performance of the protocols differs slightly during different network loads. The most apparent difference is the byte overhead. While LANDY has a rather unaffected overhead, it increases for GPSR during high loads. A higher sending rate causes the protocol

to detect broken links faster, thus reacting faster; this leads to a slight increase in control packets, which affects the byte overhead. The increased send rate also sets demands on the send buffer of the routing protocol.

Whenever congestion occurs, packets are dropped. The faster a routing protocol can find an alternative route, the less time the packets have to spend in buffers, meaning a smaller probability of packet drops. From a network layer perspective, changes in link connectivity trigger routing events such as routing failures and routing updates. These events affect the performance of a routing protocol, for example,

by increasing packet delivery time or decreasing the fraction of delivered packets, and lead to routing overhead, e.g., for route update messages. Therefore, for given physical layer assumptions about link connectivity, are critical to the significance of simulation results for MANET routing protocols.

A tremendous amount of research remains to be done in the area of MMs in ad hoc networks. Group Pursuit Models are of special interest for future compact systems “FCS” applications, and have to be included in a comprehensive simulation.

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