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Speed and Pause Time Impact on Position Based Routing Protocols Under Different Mobility Models

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Abstract. **Position based routing protocols use geographical position information to route data packets between mobile nodes (MNs), which make them popular in mobile ad hoc networks (MANETs). The issue of routing and maintaining packets between MNs in MANETs has always been a challenge due to the dynamic changes in the network layout. The aim of this paper is to investigate the fundamental factors speed, pause time and minimum node degree which have a major impact on the performance of position based routing protocols under different mobility models. A comparative study of major position based routing protocols and mobility models are presented here. Both Independent Entity and Dependent Group Mobility Models have been selected. The effect of speed and pause time on the performance of protocols under each of the chosen mobility models are analysed. Deriving an analytical theorem for the required transmission range in connected ad hoc networks. Meaningful metrics for assessing the performance of MANET protocols are identified and defined. OPNET simulator was used to design and build a unified simulation environment; to evaluate the performance of the different protocols proposed in the Internet Engineering Task Force (IETF), in different scenarios.**

Keywords*: Mobility models, Mobile Ad hoc network, Position based routing protocols, Mobility Impacts, minimum node degree, analytical method, OPNET.*

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1. Introduction

The needs of efficient routing mechanism over wireless communication have been increasing drastically over the last decade to address the rapid growth and demand in data-hungry applications and payloads. MANET is one of the potential technologies that can support advanced packet services and real-time applications, which also become one of the most innovative and challenging area of wireless networking. A MANET is made up of MNs, equipped with wireless communications devices, which form a network without a fixed infrastructure and topology. This type of network is useful for a diverse range of applications, such as: emergency, military, Sensors, personal networks, environmental monitoring and border security. In MANETs, each node operates as a router and an end-system to forward packets.

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The nodes are able to move about, change location frequently and organize themselves into a network. Because of this, MANETs can offer a larger degree of freedom at a considerably lower cost than other networking solutions. MANETs can be used alone or as a hybrid together with other networks such as internet. Different MANET applications have different needs, and therefore the various MANET routing protocols can often be suitable in many different areas.
Special routing algorithms are often needed to accommodate changing topology. In comparatively small networks, flat routing protocols may be sufficient. In larger networks, either geographic or hierarchical routing protocols are required [3, 8, 12, 24, 25]. In order to evaluate routing protocol performance in MANET, the protocol should be tested under realistic conditions (real time) 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).

The main characteristics of MANETs, specifically lack of a fixed infrastructure, very limited bandwidth and mobility of all the nodes; has posed additional challenges in the design and implementation of protocols to support these networks. The potential for a rapidly changing topology imposes new requirements for routing protocols to maintain routes through the network without degrading the overall performance by excessively flooding the network with link state advertisements or routing table updates. To satisfy these requirements, the research community has devoted a tremendous effort, resulting in the development of several routing protocols during the last few years [1, 6, 17, 18, 19, 24]. However, in the implementation of MANET routing protocols, the design process has to be accompanied by performance evaluation and testing of the new routing Strategies.

Simulation plays a key role in developing and testing new MANET routing protocols. Different theoretical MMs have been developed to represent the mobility patterns of nodes under different circumstances. However, in some cases the simulation tools only support a very limited number of these models. For scenarios important to applications such as future combat systems (FCS), these methods may not accurately reflect how the network will be used.

It is important to evaluate and compare the performance of different MANET routing protocols applied to FCS scenarios and incorporating more advanced MMs. It is necessary to choose the appropriate MMs for each scenario, and to recognise the impact of the model on the performance of the routing protocol by relating the results to key performance parameters, as defined by [33].

2. Related Works

Location information is popularly used for forwarding data packet in connectionless algorithms. Mobility model 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 [3, 4, 7, 8, 15, 22, 30]. Much of the initial research was based on using random waypoint "RWpM" as the underlying mobility model and Constant Bit Rate as the traffic pattern. Routing protocols like AODV, LAR, DSR, GPSR, DSDV, AODV and TORA [10, 12,16, 17,18, 24, 29] were mainly evaluated based on the following metrics: packet delivery ratio (ratio of the number of packets received to the number of packets sent) and routing overhead (number of routing control packets sent). The outcomes were: on-demand protocols such as DSR and AODV performed better than table driven ones such as DSDV at high mobility rates, while DSDV performed quite well at low mobility rates [4,12].

Other researchers have performed comparison studies of the two on-demand routing protocols: DSR and AODV, using the performance metrics of packet delivery ratio and end to end delay [11, 22, 30]. A Study by Coroson et al. [1] examined the routing protocol performance issues and evaluation considerations. Santi et al. [5], analysed the radio range assignment problem for MNs.

Paper [12] evaluated the MANET routing protocol DSR and DSDV under different MMs. A study

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survey carried out be Camp et al. [2] also uses the framework [25] to analyse the impact of the mobility model by building a real-test bed. But they only discuss different MMs that have a different impact on performance of the protocol; they did not analyse exactly how a parameter has an impact the performance.

Comprehensive mobility survey was carried out by Hong et al. [13]. [19] Appel and Russo, preformed an analytical study of the asymptotic minim node degree of graph uniform.

DAS et al. [25] proposed a framework to analyse these influences by four reference MMs, (RWpM, RWP, Freeway, Manhattan model). Bettstetter et al. [30] examined the the spatial node distribution of the random waypoint mobility model. Philips et al.[35] explained how the expected number of neighbours of MN should propagate with the system area to maintain connectivity. Paper by Malarkodi et al. [38] 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.

Previous research has been extended in this paper, by assessing the performance of position based routing protocols under different MMs (Dependent and Independent). Our previous work “Local Area Dynamic routing algorithm” [18, 22] has been improved to incorporate Physical layer and link layer statistics. New criteria have been added to the routing decisions based on the received signal, which the information extracts from locomotion components message.

A comprehensive analysis has been carried out on the impact of speed and pause time on the protocol`s performance. Correct adjustment of the MN radio transmission range in connected MANETs has been investigated.

This research is significant in practice for the simulation study of MANET routing protocols and the design and improvement of MMs. This research is organized as follows. In section 3, the three position based routing protocols in our performance evaluation are presented. In section 4, the MMs in our performance comparison are described. In section 5, the required transmission range in connected MANETs is mathematically analysed. Section 6 deeply examines how the main parameters of the mobility model speed and pause time impacts on the performance of routing protocols according to the OPNET simulation and the simulation results are given. In section 7 the conclusion and future works are discussed.

3. Position Based Routing Protocol

Position based algorithms (connectionless algorithm) overcomes the problem related to the maintenance of the routing table in connection oriented algorithms [2, 5, 6, 8, 11, 26], where the performance degrades quickly when there is an increase in the number of MNs or the speed (dynamic changing). Although a connectionless algorithm has no route manipulation for data transmission, it still encounters three problems; Broadcast storm under high node density, Local maximum problem under low node density, and the geographically constrained broadcast of a service discovery message.

Position based routing algorithms eliminate some of the limitations of topology based routing by using geographical information about the mobile nodes to make decision about routing packets. This position information is obtained by position service and location service.

Global Positioning Service (GPS) is an example of position services, which provides information about the position of the source node. Grid Location Service (GLS) is an example of a location service, which provides information about the position of the destination node. 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. Some existing major position based routing algorithms are Greedy Perimeter Stateless Routing (GPSR) and

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Geographical routing protocol (GRP).

3.1 Greedy Perimeter Stateless Routing

GPSR proposed by Karp and Kung is a position based routing algorithm. 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 node which is closest 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 [1,4,8,19]. 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 [4, 8, 17, 18, 19, 25].

3.2 Geographical Routing Protocol

GRP is a position based routing protocol [6, 11, 18, 23, 27]. Routing in GRP is based on the shortest geographical distance between source and destination. Each node within a geographical area uses GPS to identify its own position. GRP uses quadrants (neighbourhoods) to optimise flooding, it initiates network wide flooding to identify all nodes in the network [6, 12]. The disadvantage is heavy control overhead when there are RREP [6, 11, 23, 27].

3.3 Local Area Dynamic Routing Protocol

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) 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. Therefore, the differences LANDY Fig. 1 has to other Protocols: It uses the locomotion prediction technique to estimate the future node position. It uses the locomotion instead of the current position to find the MNs locomotion trajectory to predict the future position of MN, which reduces the impact of the inaccuracy of neighbour's positions on the routing performance.

It avoids routing loop or routing failure, using the back track process and the recovery process. It uses local locomotion to determine packets' next hop, and this increases the scalability of routing protocol. Recovery with LANDY is much faster than with other location protocols which use mainly greedy algorithms such as GPSR. No signalling or configuration of the intermediate node is required after failure.

It allows sharing of the locomotion and velocity information among the nodes through locomotion table (LT). It uses backtrack process to the previous node up to three node, for alternative paths before

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it switches to the recovery process.

3.1.1 Network Initialization and Process Analysis

It is assumed that the routing area is a two dimensional plane. The entire network is divided into several non-overlapping triangular cells, and each cell has CCID (Cell Code Identifier). LANDY`s algorithm allows each MN to determine the cell where it resides during the life of the network, based on the information provided by LT and the GPS device equipped with each node.

Let n is the number of MNs in the region and Ni is the scale of the MN, Sj number of neighbour MNs to the source node S, where Ni < n(CCID).

k is the existing number of MNs in the request region (CCID) at time t0 and k' (=k+Δk) is the number of MNs in that region at time t1, where k<=n(CCID), Δk can be either positive or negative. uv is the number of edges in the given network RNG (Relative Neighbour Graph), uv' (<=uv) is the number of edges in the request region, bp is the number of backtrack packets received by the node S and l is the length of the path (in hops) from the source node S to the destination node D. The network layer interacts with the MAC layer to estimate the bandwidth and taking consideration of the activities of neighbouring nodes, which makes LANDY more practical.

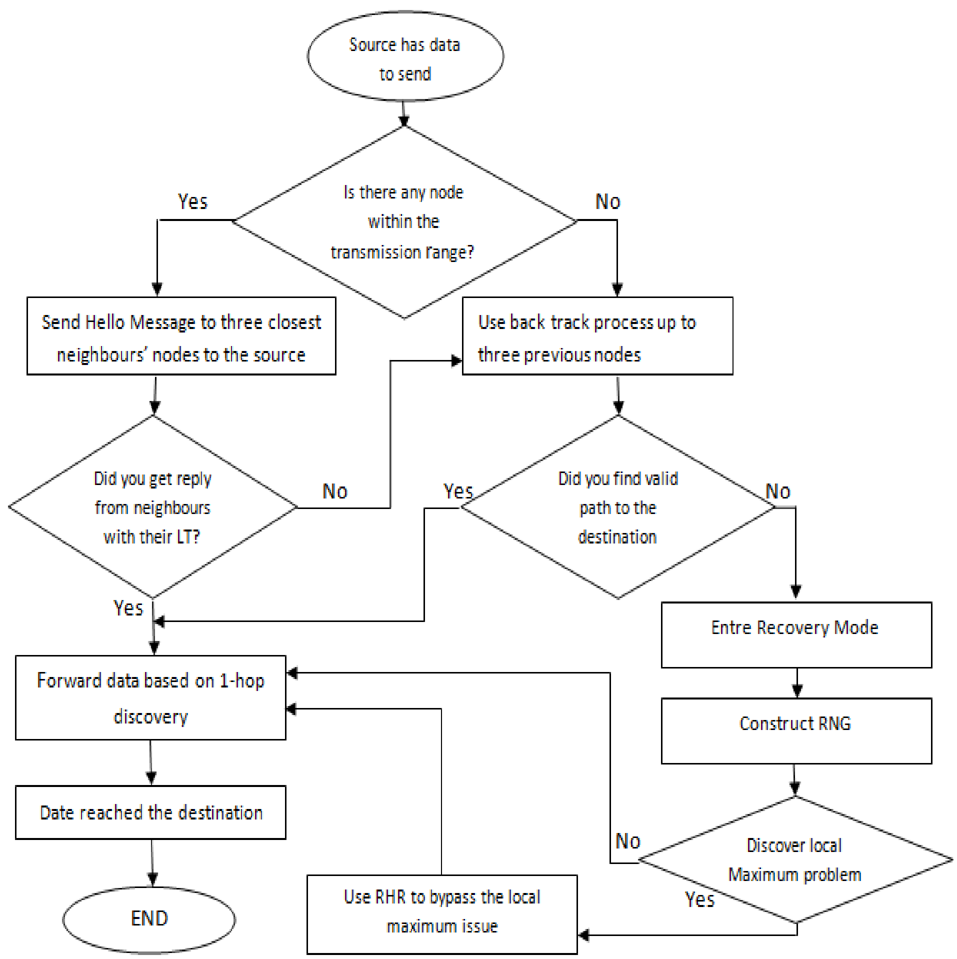

Fig. 1 LANDY algorithm

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3.1.1 Mobile Nodes Distribution and Neighbours Discovery

LANDY localizes 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 Ni query packets. The number of neighbour MNs (Ni) 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.

In LANDY, the MN updates its locomotion components (LC) through position service (e.g. GPS) periodically. The MN broadcasts its mobile code Identifier (MCID), 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 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. Since the inter-arrival time of HELLO message t_i is jittered with a uniform distribution, each node has a different inter-arrival time of HELLO message. At time $t+t_i$, node a broadcasts a new HELLO message with updated LC.

The MN receive the new HELLO message and updates the LT. Upon not receiving a HELLO message from a neighbour for a long time (t2), the MN assumes that the link to the neighbour is broken and removes the neighbour form 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 t2 is calculated using (1).

$$M = \frac{1}{(t2 - t1)} \sqrt{(x1 - x0)^2 + (y1 - y0)^2} \qquad (1)$$

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.

Various MMs have been proposed so far, but the most common ones are Random walk Model, Random Waypoint Model, Probabilistic Version of the Random Walk Model, Manhattan, Reference Point Group Model, and Gauss-Markov [12, 24, 27, 31]. A new routing protocol for an ad hoc network should be thoroughly simulated, so it is essential to use a mobility model that accurately represents the MNs that will eventually utilize the given protocol. This will determine whether the proposed protocol

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will be useful when implemented. A mobility model should attempt to replicate the movements of real MNs. Changes in speed, direction must occur, and they must occur in reasonable time slots. MMs can be classified into Independent Entity (EMMs) and Dependent Group (GMMs), which are described below;

4.1 Independent - Entity Mobility Models

In EMMs a node's movement does not control in anyway, other nodes' movements. Nodes move independently from each other, randomly. i.e. Random Waypoint Model (RWpM) , Random Walk Model (RWM), Random Direction Model (RDM), Gauss-Markov model (GMM), City- section mobility model (CsMM), Manhattan Mobility Model (MMM), Probabilistic Version of the Random Walk Mobility Model (PVRWM). RWpM was chosen from the EMMs in our study.

4.1.1 Random Waypoint Model

It is a model that includes pause times between changes in destination and speed. RWpM is a basic model, which describes the movement pattern of nodes where MNs randomly designate a destination in the simulation plane. RWpM became a 'benchmark' mobility model to evaluate the MANET routing protocols, because of its simplicity and wide availability. MMs are used for simulation purposes when new network protocols are evaluated.

Each MN goes to nominated destination with a constant velocity which each MN chooses randomly. Every node is independent, when the node arrives at the destination, it waits for a designated time and if the pause time is equal to zero then, this means that the node has a continuous mobility.

The two important parameters of RWpM are velocity and pause time of each node.

These parameters affect the performance of the evaluated protocol. If the simulation of velocity is small and pause time is long, a stable topology is formed. Otherwise, a dynamic topology can be formed. Various topologies can be obtained by varying these parameters [20, 35]. Pros: Simple to implement and Easy theoretical analysis. Cons: Average speed decay problem, Long journeys at low speeds, and solution – use non-zero min speed [16, 21, 31, 33, 34].

4.2 Dependent - Group Mobility Models

MMs Represent MNs whose movements are dependent. 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 (RPGM), Nomadic Community Model (NCMM), Column Mobility Model (CMM), Pursue Mobility Model (PMM). Under the GMMs, RPGM was selected for our study.

4.2.1 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 below[33];

$$|\vec{V}_{member}(t)| = |\vec{V}_{member}(t)| + SDR * max\,speed \qquad (2)$$

$$\theta_{member}(t) = \theta_{leader}(t) + ADR * max\,angle \qquad (3)$$

Where $0 \le$ SDR, ADR ≤ 1. SDR is the speed deviation ratio and ADR is the angle deviation ratio.

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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 members (MNs). The movement of the group leader determines the mobility behaviour of the entire group.

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5 Communication Process Between Two Active Mobile Nodes and Minimum Node Degree

A graph is connected, if a path exist between two MNs, otherwise, it is disconnected [35]. 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. Additionally, a k-connected theory graph exists, when at least two MNs can communicate via k path. Also, if no (k-1) node exist that would not disconnect the graph if removed, then a graph is k-connected [21, 36]. A k-edge connected graph exists, where at least k-edge multi-paths between pairs of MNs are disjointed. A k-connected graph is also k-edge connected. However, the reverse does not always apply.

The edge connectivity λ(G) is mathematically described as MN connectivity κ(G). For every graph with at least two MNs, we have $\kappa(G) \leq \lambda(G) \leq dmin(G)$ [30, 37].

The MN at the route request stage will send at least query packets, but the backtrack packets 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 for LANDY algorithm is presented in (4).

$$Q(uv' + n(CCID) + bp) = Q(uv' + bp) \tag{4}$$

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. The distance between two nodes(x1, y1) and (x0, y0) can be derived from (5).

$$\sqrt{(x1 - x0)^2 + (y1 - y0)^2} \tag{5}$$

In MANET, it is important to know when the link is disconnected with surrounding nodes, this might cause unacceptable message delivery delay.

To explore this issue, the following scenario will be considered. A set of MNs, with a transmission range r0, randomly placed in a large region $A \gg r_0^2\pi$ and probability p (node density ρ = n/A). What is

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the minimum requirement for transmission range r0 between MNs to avoid isolated network (each MN has minimum 1-hop neighbour).

To answer the above, the following method "nearest neighbour" has been used [14]. Nearest neighbour distance (ξ) is defined as the distance between MN and its closest neighbour.

The probability density function of nearest neighbour distance in two dimensions homogenous network, is represented in (6), (7), [36]

$$f(\xi) = 2\pi\rho\xi \,.\, e^{-\rho\pi\xi^2} \tag{6}$$

$$E(\xi) = \int_0^{\infty} \xi p(\xi)\, d\xi = \frac{1}{\sqrt[2]{\rho}} \tag{7}$$

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 ≤ r. If r = r0, then it is likely that MN u has at least one neighbour. This is represented in (8) (9), otherwise, MN has no neighbours (disconnected) and this is represented in (10).

$$P(\xi \le r0) = \int_{\xi=0}^{r} f(\xi) = 1 - e^{-\rho\pi r^2} .\ \mathrm{Q(uv' + bp)} \tag{8}$$

$$P(d(u) > 0) = P(\xi \le r0) .\ \mathrm{Q(uv' + bp)} \tag{9}$$

$$P(d(u) = 0) = P(\xi \le r0) = 1 - P(\xi \le r0) = e^{-\rho\pi r_0^2} .\, \mathrm{Q(uv' + n(CCID) + bp)} \tag{10}$$

The goal is to create a connected network "graph G", where there is no disconnection between MNs. d (u) > 0, ∀u ∈ G ⇔ dmin(G) > 0. The probability of this scenario, with statistical independence assumed, is represented in (11). To ensure, with at least P probability, that no MN is isolated in the network, radio range can be set for all MNs using (12) [36].

$$P(d_{min} > 0) = \binom{n}{n} P(d > 0)^n\ P(d = 0)^0 = (1 - e^{-\rho\pi r_0^2})^n .\mathrm{Q(uv' + bp)} \tag{11}$$

$$r_0 \ \ge \sqrt{\frac{-\ln\left(1 - p^{\frac{1}{n}}\right)}{\rho\pi}} \tag{12}$$

For calculating node mobility. Each node can find its location information using GPS, so that it can calculate the node mobility using (13) and (14). Equation (15) represent node mobility with transmission range r0.

$$x1 = x0 + (\, v \times (\cos\theta\,))\,.\ M \tag{13}$$

$$y1 = y0 + (\, v \times (\,\sin\theta\,))\,.\ M \tag{14}$$

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$$M(d_{min} > 0) = r_0 \geq \sqrt{\frac{-\ln\left(1 - p^{\frac{1}{n}}\right)}{\rho\pi}} \tag{15}$$

A node`s velocity is in “s. unit”, and its next location can be calculated. For calculating the next location, it uses current location p0(x0, y0), Velocity v, Direction Value θ, and circular functions formula to derive the next location p1(x1, y1). After calculating the next location; its current location, next location and transmission range are added into LT and delivered to the surrounding nodes.

The minimum node degree of connected network (graph G) is represented in (16), and the average node degree of G is represented in (17) [12], where the degree of a node u is denoted as d(u) and if d=0, then it is isolated.

$$d_{min}(G) = min_{\forall u \ni G}\{d(u)\} \tag{16}$$

$$d_{mean}(G) = \frac{1}{n}\sum_{u=1}^{n} d(u) \tag{17}$$

To avoid the above isolation, MNs need to have neighbours, which is denoted as n0. Also, the formed network graph should have a minimum degree “dmin(Gr) ≥ n0 ⇔ min∀u∈G d(u) ≥ n0”. The higher MN degree, the fewer resulting failure of links and neighbours.

In some ad hoc network types, optimal throughput can be achieved by having a certain number of neighbours [35]. In subsections “one and two dimensions scenarios”, an analytical theorem for the required transmission range in connected ad hoc networks to obtain a certain dmin(G) for given n is derived and demonstrated . Also, the critical number of MN n for a given r0, can be established.

5.1 One–dimensional scenario;

A number of n MNs are randomly placed in an interval [0,xmax] (18). To find out the probable n nodes that are located in the interval [x1,x2], where 0 ≤ x1 ≤ x2 ≤ xmax. Within the given interval, the number of MNs is represented by d∗ (19). This is compared with [35], Section (3.4).

$$p = \frac{x_2 - x_1}{x_{max}} \;.\; M \tag{18}$$

$$P(d^* = n_0) = \binom{n}{n_0} p^{n_0} (1-p)^{n-n_0} \tag{19}$$

The probability that n0 of n nodes are positioned in the interval [x1,x2] is represented in (20)

$$P(d^* = n_0) = \frac{(np)^{n_0}}{n_0!} \cdot e^{-np} \;.\; M \;.\; \mathrm{Q}(\mathrm{uv}' + \mathrm{bp}) \tag{20}$$

Assuming we have large n and large xmax, but ratio n/xmax is constant. MNs per unit length is the density ρ = n/xmax. For given density ρ we can calculate the probability that n0 nodes are in an interval of length x0 = x2 − x1 as represented in (21).

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$$P(d^* = n_0) = \frac{(px_0)^{n_0}}{n_0!} \cdot e^{-px_0} . M . \mathrm{Q}(\mathrm{uv}' + \mathrm{bp}) \quad (21)$$

The interval [x1,x2] could be a symmetric interval covering a randomly selected location on the line (22).

$$[x_1, x_2] = [\, x_p - \frac{x_0}{2}, x_p + \frac{x_0}{2} \,] \quad (22)$$

xp does not always represent the position of a MN on the line. But, (n − 1) nodes are still uniformly distributed on the line in large n scenarios. Also, if the radio range is set to r0 = x0/2, there is a high probability MN has n0 neighbours. Where, MN is isolated it is represented in [23].

$$P(d = n_0) = \frac{(\rho 2r_0)^{n_0}}{n_0!} \cdot e^{-\rho 2r_0} . M \quad (23)$$

Where;

$$P(d = 0) = e^{-\rho 2r_0}$$

5.2 Two–dimensional scenario;

To find out the probable n nodes that are located in certain area A0 in the system plane A. Replacing the system interval [0,xmax] and sub-interval x0 with system area A and subarea A0. Then, expected MNs number per region is ρ = An. As in [12], the distribution of n0 nodes in an area A0 is represented in (24);

$$P(d^* = n_0) = \frac{(\frac{A_0}{A} n)^{n_0}}{n_0!} \cdot e^{-\frac{A_0}{A} n} = \frac{(\rho A_0)^{n_0}}{n_0!} \cdot e^{-\rho A_0} \quad (24)$$

A radio range r0 covers an area $A_0 = \pi r_0^2$ for large n and large A, where MNs is randomly chosen n0 neighbours. This can be represented in (25)

$$P(d^* = n_0) = \frac{(\rho \pi r_0^2)^{n_0}}{n_0!} \cdot e^{-\rho \pi r_0^2} . M . \mathrm{Q}(\mathrm{uv}' + \mathrm{bp}) \quad (25)$$

Otherwise it is isolated with a probability of P(d = 0) = $e^{-\rho \pi r_0^2}$ [35]. The expected number of neighbours of a MNs is represented in (26) (27), which is the average node degree dmin of the resulting graph.

$$E(d) = \rho \pi r_0^2 . M . \mathrm{Q}(\mathrm{uv}' + \mathrm{bp}) \quad (26)$$

$$P(d = 0) = e^{-\rho \pi r_0^2} . M . \mathrm{Q}(\mathrm{uv}' + \mathrm{bp}) \quad (27)$$

The network has a minimum node degree dmin ≥ n0, is given by (28), where each MN has at least n0 neighbours (29).

$$P(d_{min} \geq n_0) = (1 - \sum_{N=0}^{n_0 - 1} \frac{(\rho \pi r_0^2)^N}{N!} \cdot e^{-\rho \pi r_0^2})^n . M . \mathrm{Q}(\mathrm{uv}' + \mathrm{bp}) \quad (28)$$

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$$E(d) = \int_{r=0}^{r_0} \int_{\phi=0}^{2\pi} \rho(r, \phi) r \, dr \, d\phi \; . \; M \; . \; Q(uv' + bp) \qquad (29)$$

6 Simulation Setup, Performance Metrics and Result Analysis

Different mobility patterns have been selected to represent real movement scenarios related to FCS. The MANET network simulations are implemented using OPNET Modeller simulation tool. 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 scenarios simulate the MANET nodes moving in a 2-D mobility region, and in this implementation the height dimension is omitted. The MMs are used to govern the movement of the nodes.

Each scenario performs ten simulation runs with different random seeds and the mean of the metrics are compared. The common parameter setting of the simulation is shown in table 1. The traffic destination is a random node. The traffic application is a traffic generator. This traffic generator starts at 10s during simulation. The packet inter-arrival time is exponentially distributed with mean value of 10s.

For analysing how variation speed impact on the performance, two models have been set with various pause time (10 - 60 sec), and every model has the mean speed changing from 10m/s to 60m/s. In all this patterns, 70 nodes move in an area of 1000m × 1000m for a period of 1200s, to avoid the effect of initializing and ending, the data was gathered between 200s – 1000s. Scenario files were generated with varying node speeds. The following performance metrics were obtained from the two MMs (RWpM, and RPGM): Throughput, and average end-to-end delay. These metrics are suggested by the MANET working group for routing protocol evaluation [14, 22, 24, 27].

TABLE 1. SIMULATION PARAMETERS

Parameters	**Description**
Simulator	OPNET v14.5
Simulation Area	1000 x 1000 sq. units
Mobility Models Used	RWpM, RPGM
Number of Nodes	70
Mobility Speed	10,20,30,40,50, 60 m/s
Traffic model	CBR
Routing Protocols	LANDY, GPSR, GRP
Pause time	10,20,30,40,50, 60 sec
MAC layer	IEEE 801.11

6.1 Performance Metrics

The performance evaluation, as well as the design and development of routing protocols for MANETs, requires additional parameters. According to the IETF RFC 2701, the following metrics

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were collected during the simulation in order to evaluate the performance of the different protocols: When evaluating the performance of routing protocols in MANET, it is important to check against certain parameters for their performance.

6.1.1 Average end to end delay

The average end-to-end delay of a packet is the time of generation of a packet by the source node up to the destination node. So this is the time that a packet takes to go across the network. This time is expressed in seconds. Therefore, all the delays in the network are called packet end-to-end delay, like buffer queues and transmission time. The File transfer protocol (FTP) is tolerant to a certain level of delays. There are different kinds of activities, which increase network delay. Packet end-to-end delay is a measure of how well a routing protocol adapts to the various constraints in the network, to give reliability.

6.1.2 Throughput

Throughput is defined as; the ratio of total data that reaches destination node from the source node. The time it takes the destination node to receive the last message, is called throughput [11]. Throughput is expressed as bytes or bits per sec (byte/sec or bit/sec). Some factors impact the throughput: if there are many topological changes in the network layout, unreliable communication between MNs , limited bandwidth availability and limited energy [11].

6.2 Simulation Results

In our simulation, three position based MANET routing protocols (LANDY, GPSR and GRP) were evaluated under two different MMs.

6.2.1 Throughput

The results for throughput are shown in Fig. 2, and Fig. 4. The rate of packet throughput increases gradually according to the increasing number of nodes in all protocols (GRP, GPSR and LANDY). The error bars indicate 95% confidence intervals. As shown in Fig. 2, there are a few differences between LANDY and GPSR in section of speed between 10 – 30 m/s , but differences increase in section 30-70 m/s. LANDY successfully increased the rate of packet throughput as high as 24%. The reason why it is not a large performance improvement, is that the numbers of alternative routes are limited in the network which comprises of a few nodes. Because the numbers of nodes are small and nodes are of wide distribution, the numbers of routes are limited though a node searches for multiple routes.

When pause time is varied from 0 to 20, the Throughput values for LANDY, GRP and GPSR is stable. In overall, LANDY delivers the highest Throughput and GPSR shows the lowest Throughput. When maximum speed is varied, LANDY delivers the highest Throughput and GPSR gives the lowest throughput.

Also, the performance decrease is not large, but the performance decrease makes a distinct appearance when the speed is more than 30 m/s. The more a node moves, the more nodes that consist of a link are changed, and link error can be generated frequently. Therefore, LANDY packet processing ratio improves upon GRP and GPSR, in setting the shortest path. By observing the packet throughput, Fig. 3, Fig 5. The more a node moves, the more nodes that consist of a link are changed, and link error can be generated frequently. Therefore, LANDY packet processing ratio improves upon GRP and GPSR, in setting the shortest path. GRP packet ratio is lower due to link errors increasing as a result of faster node movement. But in LANDY, packet throughput is decreased little, when the maximum velocity of nodes is 60 m/sec. The efficiency is 5%. This is logical, because large packet drops will of course produce lower throughput.

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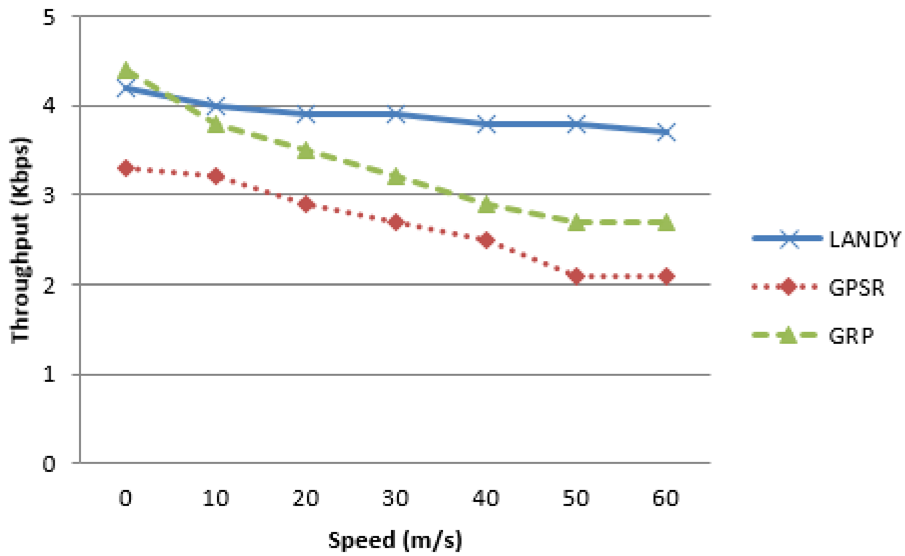

Fig. 2 Throughput Vs Speed – RWpM

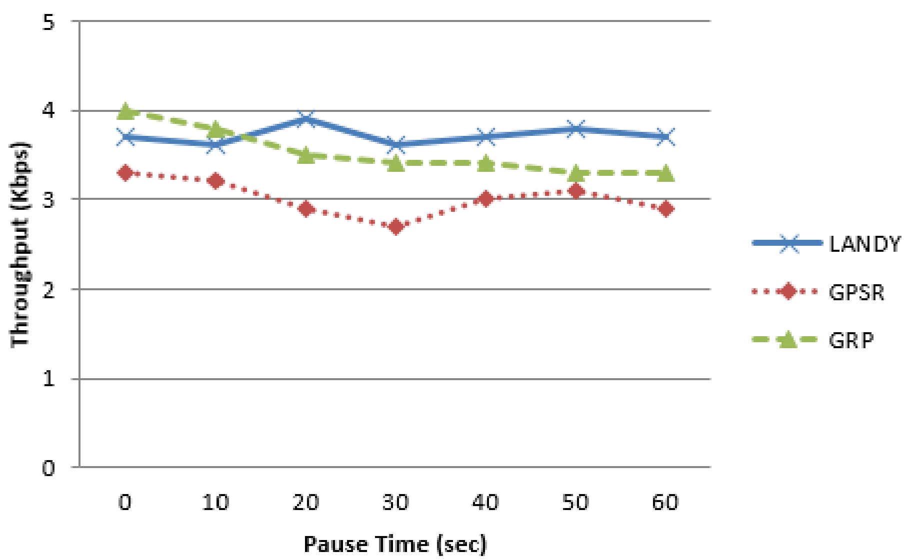

Fig. 3 Throughput Vs Pause Time – RWpM

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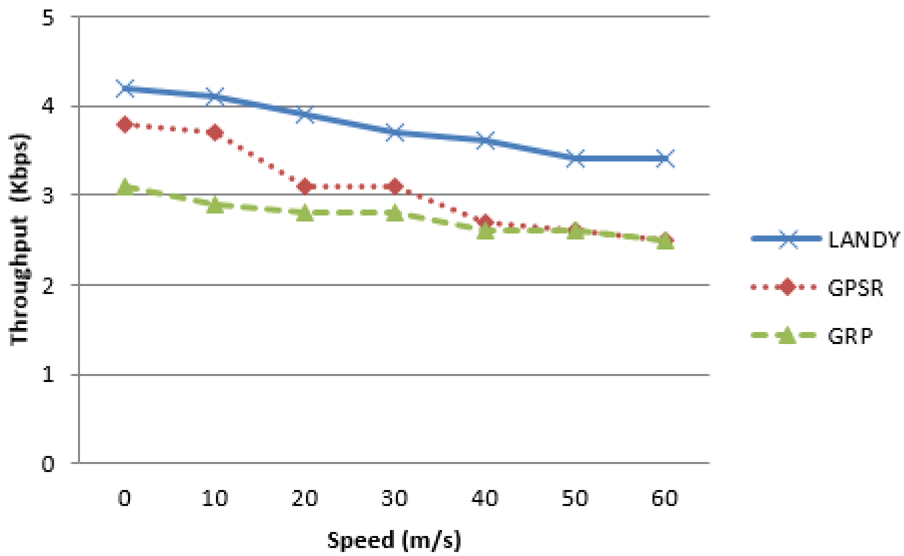

Fig. 4 Throughput Vs Speed – RPGM

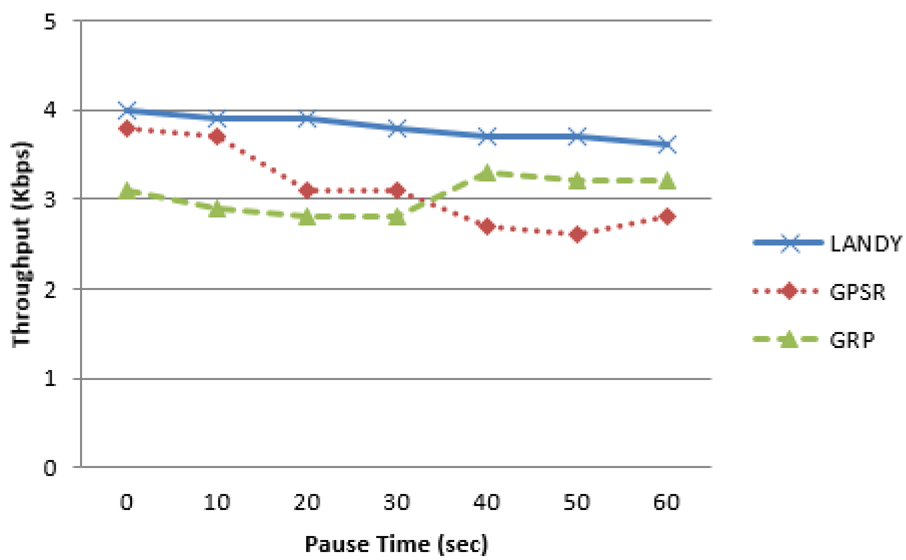

Fig. 5 Throughput Vs Puse Time – RPGM

6.2.2 Average end to end delay

In end-to-end delay scenario, it should exhibit a lower performance when the number of nodes are under 70, because alternative longer routes might be selected instead of the shortest path. The end-to-end delay is lower in the case where more than two alternative routes can be selected or many alternative routes Fig. 6 and Fig. 8 show the average end-to-end delay of LANDY, GRP and GPSR. The error bars indicate 95% confidence intervals. Since LANDY searches the mobile node's future

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position instead of current position, it searches the path from the source to the destination faster than GPSR. Thus, the average end-to-end delay of LANDY is lower than GPSR.
When number of nodes are between 10 and 30, GPSR has the highest average end-to-end delay, and it decreases for GRP and LANDY. With increasing the number of nodes, the value of average end-to-end delay for GPSR will be highest among the three protocols and it is the lowest for LANDY.

When the pause time is 0, GRP has the highest average end-to-end delay. When the pause time is increased to 30, the slope for GRP decreases and it almost remain the same for GPSR and LANDY. When the pause time is increased to 60, the value of the end-to-end delay increases for GRP, LANDY and GPSR. In overall, GPSR has the highest average end-to-end delay and LANDY has the lowest reading.

The end-to-end delay time is massively affected when network speed is at a slow rate. As a result of little or no mobility of nodes, error occurs in the entire path and so there is a greater chance that it searches paths consisting of the same nodes. In this case, it cannot be effective even if it selects a path taking mobility in to consideration. Moreover, LANDY is most likely to have a larger number of nodes between source and destination node than GPSR. Therefore, more nodes can participate in communication.

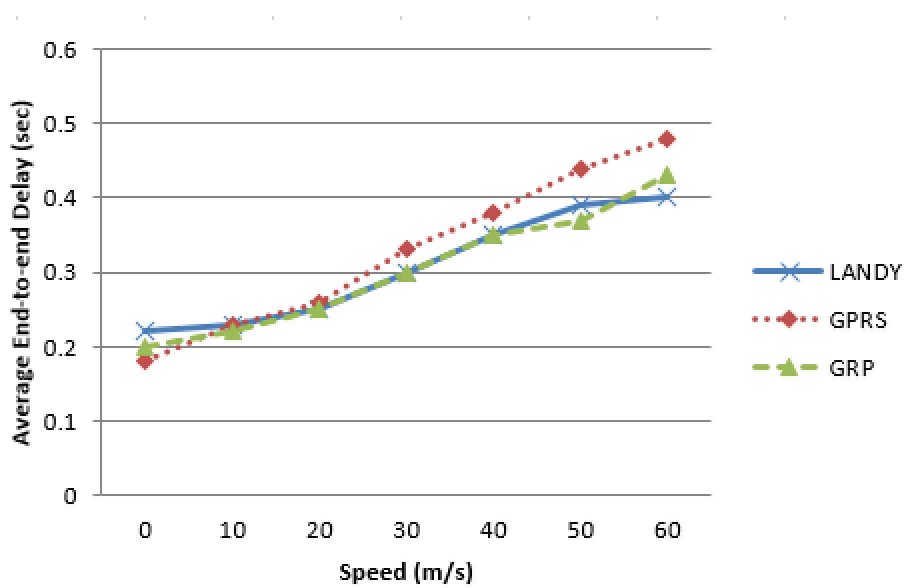

Fig. 6 Average end-to-end delay Vs Speed – RWpM

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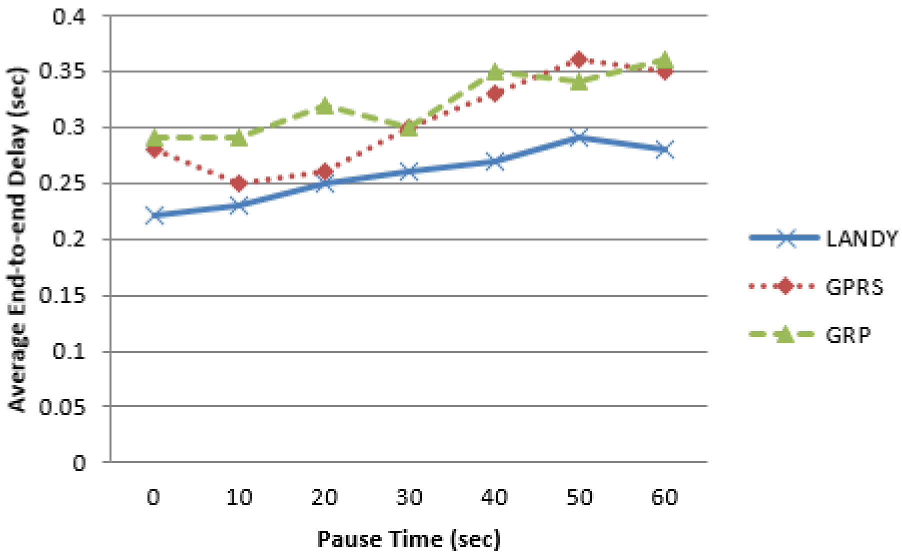

Fig.7 Average end-to-end delay Vs Pause Time - RWpM

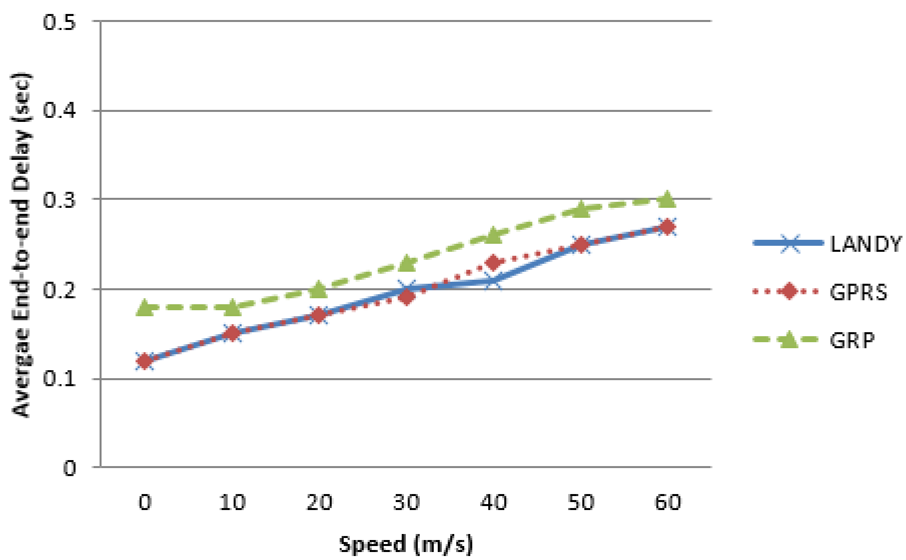

Fig. 8 Average end-to-end delay Vs Speed – RPGM

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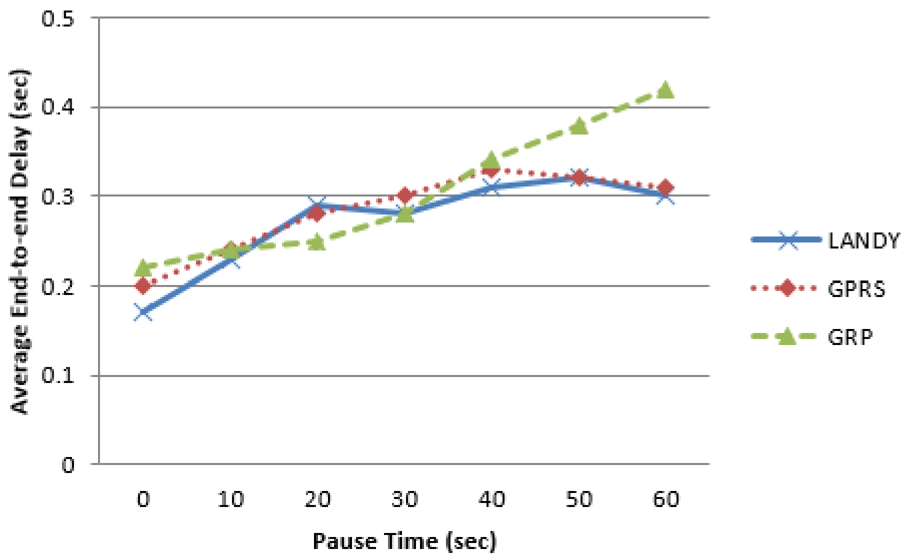

Fig. 9 Average end-to-end delay Vs Pause Time - RPGM

6.3 Mobility Models Performance Analysis

As Fig. 10, and Fig. 12 show, with increased speed, each metrics is deteriorating in some means. The RWpM model has the highest delivery ratio, lowest end-to-end delay, and shortest average hop count. The RPGM model is the reverse. These results exist since the nodes in RWpM 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 RPGM model than in that of RWpM. 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.

When the pause time is 0, RPGM has the highest throughput and lowest Average end-to-end delay. When the pause time is increased to 30, the throughput slope for RPGM decreases and it increases for end to end delay, also it will remain the same for RWpM. When the pause time is increased to 60, the throughput for RPGM and RWpM decreases and the average end to end delay increases.

As the Fig. 11, and Fig. 13 show, with the speed increasing, each metric is getting worse in some way. These results exist since the topology of the network is more stable 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 RWpM model is better than that of RPGM model.

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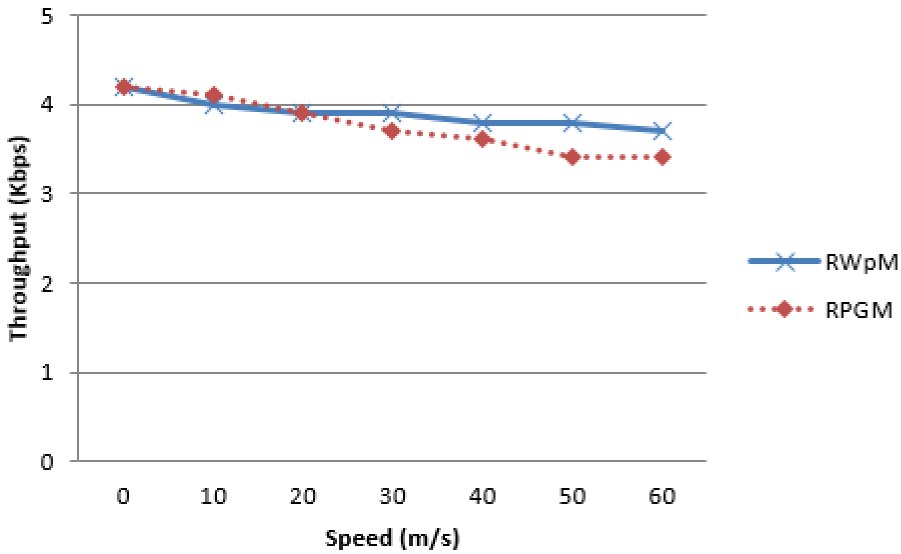

Fig. 10 Throughput Vs Speed – LANDY

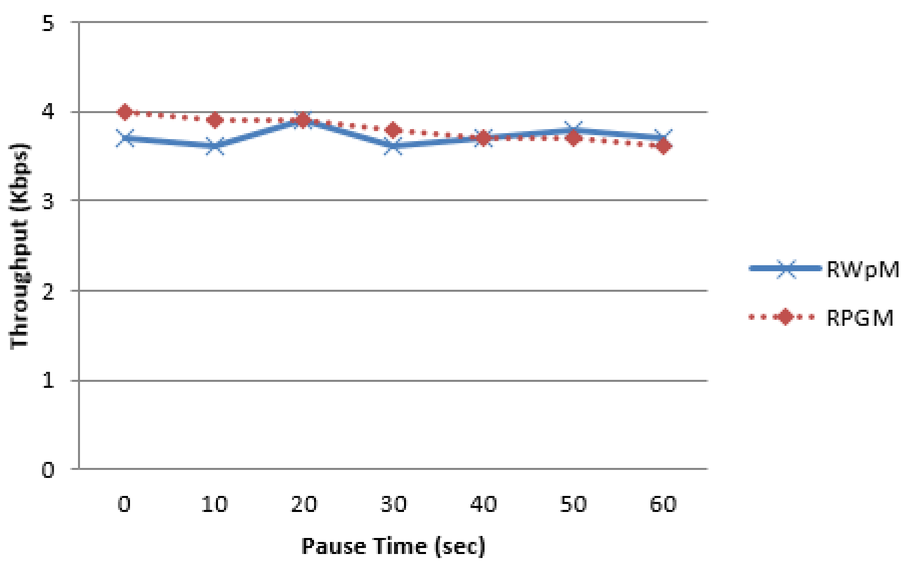

Fig. 11 Throughput Vs Pause time – LANDY

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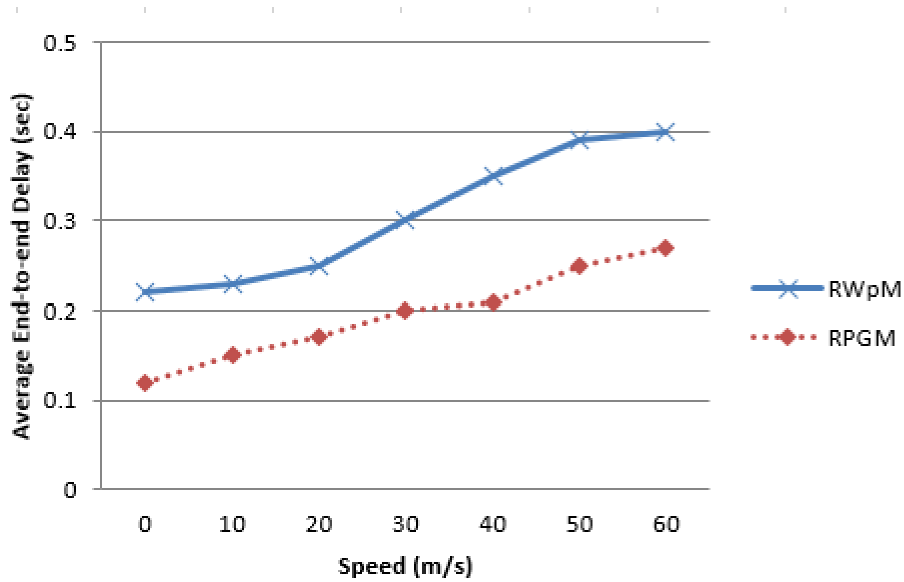

Fig. 12 Average end-to-end delay Vs Speed – LANDY

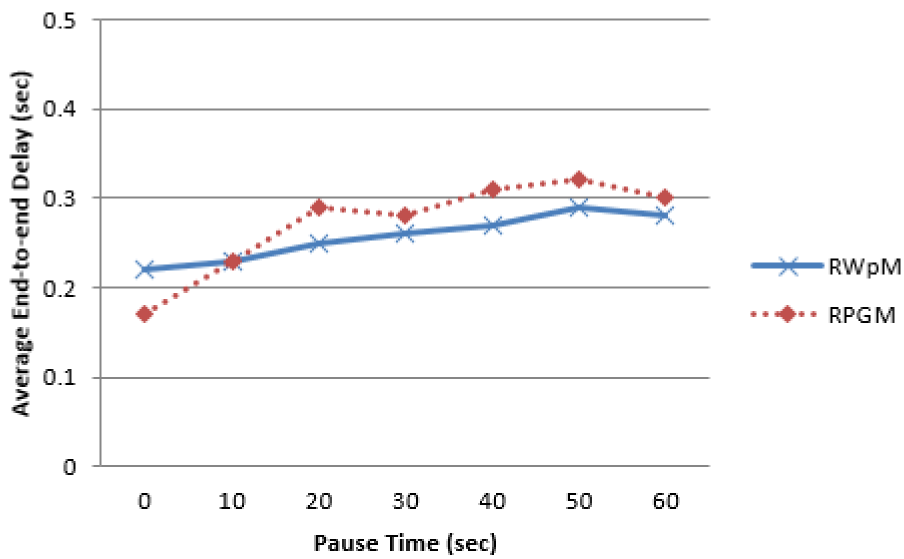

Fig. 13 Average end-to-end delay Vs Pause time – LANDY

7 Conclusion

We have analyzed the performance comparison of the routing protocols LANDY, GRP and GPSR using OPNET Simulator. Results indicate that performance of the routing protocol varies over different

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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.

Based on a summarization of MMs, effects of the speed and pause time on the performance metric of MANET routing protocols are analysed. The result of simulation indicates 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 for it is very important for protocol evaluation. Protocols that have link layer support for link breakage detection, are much more stable.

The percentage of packets received using LANDY is almost constant at 82% even when mobility increases. This result indicates that these kinds of protocols will be desired for high mobility networks. GPR and GPSR are dependent on periodic broadcast which show a rather poor result, only 55 % of the packets are received when mobility is increased.

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. Congestion occurs and packets are dropped. The faster a routing protocol can find a route, the less time the packets have to spend in buffers, meaning a smaller probability of packet drops

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 FCS applications, and have to be included in a comprehensive simulation. It is important to investigate the application scenarios, to evaluate performance of MANET routing protocol. Also it is important to examine the movements of MNs in the real world, to develop a new model that combines the best characteristics of major MANET MMs, which can be used for performance evaluation of routing protocols in MANET.

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