Estimation and Analysis of Path Duration in Vehicular Ad Hoc Networks using Position-based Routing Protocol

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ABSTRACT

Vehicular Ad Hoc Network is one of the most emerging fields for researchers and industry communities. As the nodes are high speed moving vehicles on the road, cause frequent changes in network topology. Estimation of path duration between source and destination node is a challenging task in VANETs. Path duration is a key parameter to design a routing protocol as it is very useful to increase the throughput and performance of the VANETs. In this paper, we have proposed a mathematical model to estimate the path duration between source and destination node using position-based routing protocol in which a border node is selected as a next-hop node for further transmission. The mathematical model has been simulated using MATLAB. Further, the result also reveals that the path duration increases as the transmission range increases and decreases as the number of hops increases in VANET.

Keywords: VANET, MANET, Path Duration, Position-based Routing, Border Node, Shaded Region, Probability Distribution

1. INTRODUCTION

The Intelligent Transport System (ITS) has been working to make the road safer and more efficient since the number of vehicles on the roads are keep on increasing. As the number of vehicles keep increasing, the number of accidents has also been increased with vehicle related crimes. These accidents and crimes are an issue of concern worldwide; and makes the road more vulnerable and threatening as the millions of people die in road accidents all over the world every year. VANET is the technology, which will provide us a safer and well organized transportation and roads in near future.

In VANETs, transmission of data is possible by direct communication in two nodes within the transmission range or by intermediate node between source and destination node [1]. The intermediate nodes are high speed moving nodes (vehicles), which also act as a router to pass the information from source to destination. Since, VANET is an ad hoc network, therefore, there is no fixed infrastructures are presents between highly mobile nodes.

The mobility of nodes is a critical factor for design, analysis, and performance evaluation in VANETs. High mobility of nodes cause dynamic changes in the network topology and frequent path failures. Once a path failure occurs, the communication between source and destination will expire and a new path has to set up. The failure of the path degrades the routing performance of the VANETs and adds an overhead of creating a new path. The new path may be established in less time but frequent path failures affect the overall network performance certainly [2].

Routing is the process of finding optimal path between source and destination nodes and then, sending a message in a timely manner. Routes between source and destination node may contain multiple hops. Since the network topology is frequently changing, so finding and maintaining routes is very challenging task in VANET. In VANETs, position-based routing protocols are more suitable routing protocols and these can be used to improve the routing performance [3]. In position-based routing, the position of neighbouring nodes around the source node and position of the source node is known to every node. The knowledge of the position in VANET is the important data for the vehicles moving on the road.

In VANET or MANET the lifetime of a link is a random variable, whose probability distribution depends on mobility, node density, transmission range, different traffic scenarios, and various impairments of radio communications. Link between two nodes breaks frequently because nodes moving out of the transmission range of each other with high speed. If we estimate the path duration between source and destination node, it can help us to decrease the path breakage. Knowledge of path duration can improve the performance and efficiency of the VANETs protocols. Path duration can be defined as the amount of time every link of the route is active or amount of time till any of the link breaks in the route [4].

In this paper, our main contribution is a probabilistic and mathematical analysis of path duration in VANET, based on position-based routing concept. We derive the probability distribution as well as the expected path duration between source and destination in VANET. We assume that while vehicles have not reached the speed limit, or have not stopped, and have constant velocity. The rest of the paper is organized as follows. Section 2, present the related work of the path duration estimation in ad hoc networks. Section 3, presents the proposed work with mathematical analysis. Simulation results of the proposed work has been presented in section 4. Finally, section 5 will conclude this paper.

2. RELATED WORK

In spite of the fundamental importance of estimating the path duration of communication links in VANET, to the best of our knowledge, up to this point there have been some mathematical and experimental studies in MANETs. The estimation of path duration in MANETs is proposed in several theoretical and analytical models. Many research work and models proposed for the implementation and improvement of the VANET. Some of the related research work carried out in the recent past decade.

The path duration is an important design parameter for the better performance and efficient routing in VANETs. Authors in [5], shows the analysis of path duration and provide different parameters related to path duration and dependent on the path duration in MANETs. Authors also present the path duration impact on the reactive routing protocols. The result shows that the path duration Probability Density Function (*pdf*) for large number of hops can be estimated through exponential distribution. The exponential distribution is depends on the different parameters like relative speed of the mobility model, transmission range of nodes and number of hops. These parameters helps to enhance the performance of the reactive routing protocols used in the MANETs. It also shows that the inverse of the path duration is directly proportional to the throughput of the ad hoc networks for Dynamic Source Routing (DSR) protocol.

To maximize the path duration of the route, each link duration of that path must be maximum. If there is any link breaks in the route, it means whole route will expire. The link stability and route lifetime are directly proportional to each other. In [6], link stability and route lifetime are analysed for the ad hoc networks. "Edge Effect" phenomenon occurs in the highly dense networks is also discussed. "Edge Effect" phenomenon is an adverse effect on the network performance when the greedy routing approach is used in dense networks. In greedy routing approach sender node selects the nodes that covers the maximum distance towards the destination. In dense network, nodes are easily available at border of the transmission range and could be selected as the next-hop node for further transmission. Small movement of the border nodes outside the transmission range breaks the path and degrades the performance of the network. Therefore border node must lies within the transmission range or on the border line of the sender's transmission range to improve the routing as well as overall network performance.

Path selection is important to decide the path duration of the route in ad hoc networks. The shortest path is not always the best path in terms of the path duration. To maximize the path duration, the shorter average link duration of nodes should avoids over the longer average link duration of nodes. In [7], a schema is proposed using Ad hoc On demand Distance Vector (AODV) routing protocol to maximize the path duration and also provide an local path recovery, in case of path failure with the help of the cached alternative path computing. In this schema, each path information is recorded in a table with five fields: i). Destination Sequence number ii). Next-hop to the destination iii). Hop count iv). Inverse path duration (IPD) and v).Time stamp. The path for the transmission is chosen first on the basis of destination sequence number and IPD values. If two path ties on the basis of above two fields then the path will be selected on the basis of hop count. The path on first rank is selected as primary path and other paths are cached as backed recovery path.

In [7], result shows that expected link duration of the path is the parameter of the exponential distribution. This exponential distribution can be used to approximate the distribution, where hop count is large. In ad hoc networks, the greedy routing and Least Remaining Distance (LRD) approach are used. In LRD approach, the next-hop node is the node which attempts to minimize the remaining distance between source and destination in every hop. The average progress per hop towards destination also helps to find the number of hops from source-to-destination. Authors in [8], shows that the progress per hop and number of hops are related to the node density and distance of the path in greedy routing approach.

To estimate the path duration of the route in VANETs, use of the suitable routing protocol is also a critical factor. The position-based routing protocols may be the suitable routing protocols in VANETs. The routing protocol using the position information of the node in the network is known as position-based routing protocol. In these protocols, the next-hop node will be selected on the basis of maximum distance covered towards the destination within the sender's transmission range. Some position-based routing protocols such as Border-node based Most Forward progress within Radius routing (B-MFR) and Edge-node based Directional Routing (E-DIR) [9] [10] has been proposed for VANET to select the best node for further transmission. These protocols can be used in estimation of path duration for VANET. We are introducing B-MFR for our proposed work. In B-MFR routing protocol, only the nodes presents on the border of the sender's transmission range are selected as the next-hop nodes for further packet transmission. B-MFR help to decrease the number of hops between source and destination and gives better performance in the dense networks like city traffic scenario. In the dense network, nodes on the border of the transmission range are easily available to commute the data. The number of hops between source and destination are significantly decreased in the border node based protocol. These protocols are very much helpful in estimation of path duration as number of hops can be calculated and the link distance for every hop is approximately same, because in every hop the border node is chosen.

3. PROPOSED WORK

In our proposed work, first we find the region from where we can select a particular node using position-based routing concept to transmit a packet to the destination node. A mathematical model to estimate the path duration in VANETs is developed using the Poisson distribution method. This model attempts to estimate the average path duration based on reduced number of hops principle. Once the path duration of the routes in the network is estimated well before the path breakage then the performance and throughput of the VANETs can be enhanced significantly.

A. *Reachability Processes*

The role of routing protocol is very important in the estimation of the path duration in VANETs where the network topology changes very frequently. For our proposed model, we use B-MFR routing protocol based on greedy routing approach. The B-MFR utilizes the border-node to avoid using interior nodes within the transmission range for further transmitting the packet. This method selects the border-node as a next-hop node for forwarding packet from source to destination. In this method, a packet is sent to the border-node with the greatest progress as the distance between source and destination projected onto the line drawn from source to destination. In greedy routing approach, sender node first find the position information of its direct neighbours then select a node that is closest to the destination as a next-hop node for further transmission. The B-MFR method is useful to estimate the path duration as the number of hops can be decreased significantly by selecting the border node as a next-hop node.

B. *Mathematical Model*

Since we are interested in the path duration, therefore the main goal of this section is to derive mathematical expression for path duration between two vehicles by deriving other useful mathematical expressions such as average number of hops and link duration. In this work, we use traditional traffic flow principle to describe the vehicular environment that will be more accurate for the path duration estimation. Vehicles are assumed to have Poisson distributed arrivals to obtain the probability distribution function *(pdf).*

1) Modelling Assumptions: In our proposed model, some assumptions are made, which are given as follows:

- Nodes (vehicles) are equipped with GPS receiver, digital map and sensors.
- No other communication fixed infrastructure is present.
- Transmission range for every node is same.
- Speeds of the nodes in the network are same.
- Link duration of nodes moving away from the source node is considered only.

2) Mathematical Notations: The following notations are used in our analysis.

Table 1. Notations

Description	Notations
Transmission range of nodes (Omni directional)	R_1
Region covered by transmission range	A
Selected region of the transmission range	A_s
Node density	ω
Number of node in the transmission region	x
Number of nodes selected out of *x* nodes	n
Probability of successfully selecting a node	p_s
Probability of not selecting a node	$q=1-p_s$
probability for selecting at least *n* nodes in the shaded region	P_n
Expected no. of hops between source & destination	E_H
Distance between next-hop node & destination	R_2
Distance between source and next-hop node	Z_1
Relative velocity between source node and next hop node	V_R
Angle between R_1 and *SD*	α_1
Angle between R_2 and *SD*	α_2
Relative angle between source and next-hop node	θ

C. Calculation of Path Duration

1) Area of border region for finding the next hop node:

Since the node closer to the border or on the border line cover maximum distance towards destination, therefore it may reduce the number of hop counts between source and destination. It may not be possible to find even a single node at the extreme end of the sender's transmission range. So, we have considered a region around the extreme end of the transmission range toward the destination. That region is shown by shaded area in the figure 1.

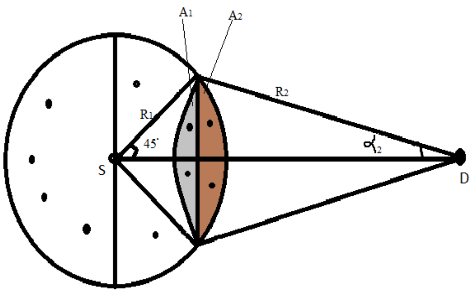


Fig. 1. Area of shaded region ($A_s = A_1 + A_2$)

In Fig. 1, circle shows the transmission range of source node *S*. Shaded region of the circle (A_1+A_2) can be used as the border region. Further, the shaded region can be divided into two part showing the area A_1 and A_2. Border nodes can be chosen from the shaded area A_1, because area A_1 lies closest to border line of the sender's transmission range. Greedy routing is the appropriate method to selects a next-hop node for the given shaded region.

Area of the shaded region can be also called as area of interaction of the two circles. One with the radius, R_1 and other with the radius, R_2. Area A_s of the shaded region can be calculated as

$$A_s = A_1 + A_2$$

Where,

$$A_1 = R_1^2.\alpha_1 - \frac{R_1^2.\ \sin(2\alpha_1)}{2},$$

$$A_2 = R_2^2.\alpha_2 - \frac{R_2^2.\ \sin(2\alpha_2)}{2}$$

As we can see in fig. 1, the line *SD* is the bisector of the angle 90°($\alpha_1 = 45°$), therefore, area of shaded region, A_s is

$$A_s = R_1^2\left[\frac{\pi-2}{4}\right] + R_2^2\left[\alpha_2 - \frac{sin(2\alpha_2)}{2}\right] \quad (1)$$

Thus, we can say that the shaded region is the combination of two arc, one with radius R_1 and other with radius R_2. The value of α_2 is depend on transmission range R_1 and distance between source and destination.

2) Probability of finding nodes in the selected area:

In this section, our aim is to find the probability of at least one node in the border region to improve the performance of the network. We assume that nodes are two-dimensionally Poisson distributed over the network with node density, ω. The number of nodes presents in selected region can be calculated as:

$$Number\ of\ nodes = \omega \times Area\ of\ the\ region$$

If *X* is the random variable representing the number of nodes in the shaded region A_s then the probability that number of nodes *x* located in the region A_s can be calculated as:

$$P(X = x) = \frac{(\omega A)^x .\ e^{-\omega A}}{x!}, x = 0, 1, 2, 3, ... \quad (2)$$

The probability of selecting *n* nodes out of *x* nodes is given by

$$P\ (Y = n) = \binom{x}{n} (p)^n (1-p)^{x-n} \quad (3)$$

If a node present in the selected region, only two possibilities are there: one is selecting the node, p_s and other is not selecting the node, $q\ (=1-p_s)$. Therefore, probability of occurring both the cases is equal i.e. $p_s = q = 1/2$. Now, probability of selecting exactly *n* nodes in the given border region is [11],[12],[13].

$$P(n) = \sum_{x=n}^{\infty} \binom{x}{n} (p_s)^n (1-p_s)^{x-n} .\ \frac{(\omega A_s)^x}{x!} . e^{-\omega A_s}$$

$$= \frac{(p_s \omega A_s)^n}{n!} .\ e^{-p_s \omega A_s} \quad (4)$$

Put the value of p_s = 1/2 and A_s in the above equation

$$P\ (n) = \frac{\left(\frac{\omega}{2}\left\{{R_1}^2\left[\frac{\pi-2}{4}\right] + {R_2}^2\left[\alpha_2 - \frac{\sin(2\alpha_2)}{2}\right]\right\}\right)^n}{n!} \times e^{-\frac{\omega}{2}\left\{{R_1}^2\left[\frac{\pi-2}{4}\right]+{R_2}^2\left[\alpha_2-\frac{\sin(2\alpha_2)}{2}\right]\right\}} \quad (5)$$

Now, the probability for selecting at least *n* nodes in the shaded region is

$$P_n = 1 - \sum_{i=0}^{n-1} \frac{\left(\frac{\omega}{2}\left\{{R_1}^2\left[\frac{\pi-2}{4}\right] + {R_2}^2\left[\alpha_2 - \frac{\sin(2\alpha_2)}{2}\right]\right\}\right)^i}{i!} \times e^{-\frac{\omega}{2}\left\{{R_1}^2\left[\frac{\pi-2}{4}\right]+{R_2}^2\left[\alpha_2-\frac{\sin(2\alpha_2)}{2}\right]\right\}} \quad (6)$$

From the equation (6), we can easily obtain the probability of having at least one node within the border region as

$$P = 1 - P(X = 0)$$

$$= 1 - e^{-\frac{\omega}{2}\left\{{R_1}^2\left[\frac{\pi-2}{4}\right]+{R_2}^2\left[\alpha_2-\frac{\sin(2\alpha_2)}{2}\right]\right\}} \quad (7)$$

3) *Average number of hops between source and destination node:*

Number of hops can be defined as the number of intermediate nodes in the route (source to destination). The main assumption is that each hop results in the same progress towards the destination, equal to the average distance covered by a node in one hop. Number of hops should be as low as possible. It will decrease the chances of link breakage and improve the path duration between nodes [14].

To determine the average number of hop counts, nodes within the transmission range *R* follow the Poisson distributed model. If destination node present in the sender's transmission range then the probability of finding destination node is same as the probability of finding next-hop node. Assume, Z_1 is the distance between the source and next-hop node. The probability density function of the link distance, Z_1 between source and next-hop node is defined as [15].

$$f(Z_1) = 2\pi\omega Z_1 . e^{-\pi\omega {Z_1}^2}$$

Distance between two nodes, which provide a link to a route can be defined as the link distance. Link distance can be increase by increasing the distance between source and next-hop node towards border line within the transmission range [16].

The probability of one-hop count can be calculated as follows:

$$P(1) = \int_0^{R_1} f(Z_1)\, dZ_1 = 1 - e^{-\pi\omega {R_1}^2} \quad (8)$$

However, the destination node can be far away from the source node that may be two, three or more hop count. If the destination node is out of transmission range, R_1 and under $2R_1$, then at least one intermediate node is required between source and destination to transmit the packet further in the network. The probability of a two-hop counts can be calculated as follows:

$$P(2) = \int_{R_1}^{2R_1} 2\pi\omega Z_1 . e^{-\pi\omega {Z_1}^2}\, dZ_1 \times \left[1 - e^{-\frac{\omega}{2} . A_s}\right]$$
$$= \left[e^{-\pi\omega {R_1}^2} - e^{-4\pi\omega {R_1}^2}\right] \times \left[1 - e^{-\frac{\omega}{2} . A_s}\right] \quad (9)$$

Similarly, for three-hop count is

$$P(3) = \left[e^{-4\pi\omega {R_1}^2} - e^{-9\pi\omega {R_1}^2}\right] \times \left[1 - e^{-\frac{\omega}{2} . A_s}\right]^2 \quad (10)$$

Therefore, consequently, the *k*-hop counts probability can be defined as

$$P(k) = \left[e^{-(k-1)^2\pi\omega {R_1}^2} - e^{-k^2\pi\omega {R_1}^2}\right] \times \left[1 - e^{-\frac{\omega}{2} . A_s}\right]^{k-1} \quad (11)$$

Now, by using equations (8), (9), (10) and (11), we can calculate the expected number of hops, E_H between source and destination node as follows:

$$E_H = \sum_{H=1}^{k} H\, P(H) = P(1) + 2\, P(2) + 3\, P(3) + \cdots + k\, P(k)$$
$$= \sum_{H=1}^{k} H\left[e^{-(H-1)^2\pi\omega T^2} - e^{-H^2\pi\omega T^2}\right] \times \left[1 - e^{-\frac{\omega}{2}\left\{{R_1}^2\left[\frac{\pi-2}{4}\right]+{R_2}^2\left[\alpha_2-\frac{\sin(2\alpha_2)}{2}\right]\right\}}\right]^{H-1} \quad (12)$$

4) *Velocity of Nodes:*

Direction of motion and speed of nodes are very essential parameters for the calculation of path duration in case of VANETs. Link duration is depends on the relative velocity of the nodes as it can increase the link distance between nodes. The relative velocity between nodes is inversely proportional to the link duration. The relative velocity of the source node and next-hop node should be known to determine the expected link duration. Let V_1 and V_2 be the velocity of source and next-hop nodes, then relative velocity V_R of the nodes can be calculated as

$$V_R = \sqrt{V_1^2 + V_2^2 - 2.V_1.V_2\cos\theta}$$

In this work, we assume that all the nodes moves with same velocity in the network that is

$$V = V_1 = V_2$$

Therefore, relative velocity is

$$V_R = V.\sqrt{2(1 - cos\,\theta)} \quad (14)$$

In above equation, θ can vary from *0* to $\frac{\pi}{2}$ as the next-hop node can move in the direction of destination only to maintain the communication link (link duration) between nodes. We assume that angle θ is uniformly distributed between (0, $\frac{\pi}{2}$), and *pdf* of $f_\theta(\theta)$ is $2/\pi$.

Then the *pdf* of V_R, $f_{V_R}(V_R)$ can be expressed as

$$f_{V_R}(V_R) = \frac{1}{\sqrt{1 - sin^2\frac{\theta}{2}}} . \frac{1}{\pi} = \sqrt{\frac{4V^2 - V_r}{V}} . \frac{2}{\pi} \quad (15)$$

5) *Link Duration:*

Link duration is the amount of time for which the direct link between two nodes within the transmission range is active and it is a part of the route. It is necessary that next-hop node must present within the transmission range of the source node to maintain the communication link between source and next-hop node. In this work, as we assumed, border node (node at maximum transmission range) will be the next-hop node for each hop between the source and destination [17]. Since the velocity of each node in the network is same, it means that the links between source and next-hop node (border node) will be maintain always. Let Z is the distance between source and next-hop node within radius R_1 (as shown in Fig. 1), then the expected value of Z [18][19] can be computed as

$$E_Z = \frac{nR_1}{(n+1)}$$

Therefore, link duration T can be expressed as

$$T = \frac{E_Z}{V_R} = \frac{nR_1}{V_R(n+1)}$$

The probability distribution function of T, $f_T(T)$ is given by,

$$f_T(T) = \int_0^V V_R . f_{d_{V_R}}(V_R T, V) dv$$

$$= \int_0^V [E_Z] . \left[\frac{2}{\sqrt{4V^2 - V_R^2}} . \frac{2}{\pi} \right] dV_r \qquad (16)$$

6) Path Duration:

The path duration is one of the key parameters which could be useful to improve the performance and throughput of the network. The path duration will be helpful in the process of path selection, during the transmission of packet from source to destination [20]. Path duration for a particular route in any type of network is very essential to choose a suitable path for the transmission.

Path duration can be derived from the *pdf* of the link duration. Let $T_1, T_{2,} T_3 \ldots T_{EH}$ denotes the link duration of *1, 2, 3,...*E_H hops respectively. E_H is the average number of hops required to reach the destination as estimated in equation (12), therefore, the path duration can be expressed as

$$T_{path} = \text{MIN}\left(T_1, T_{2,} T_3 \ldots T_{E_H}\right) \; (17)$$

By using Baye's theorem [21], the probability density function *(pdf)* of T_{path} is

$$f(T_{path}) = E_H . E_Z . C_T^{E_H - 1} \qquad (18)$$

Here, T represents the link duration and C_T = 1- F_T is the complementary *cdf* of *T*.

$$f(T_{path}) = E_H . f_T(T) . \left[1 - \int_{T=0}^{\infty} f_T(T)\, dT \right]^{E_H - 1} \qquad (19)$$

Therefore, the average path duration can be estimated as

$$E_{T_{path}} = \int_0^{\theta} T_{path} . f(T_{path}) . dT_{path}$$

$$= \int_0^{\theta} T_{path} . E_H . f_T(T) . \left[1 - \int_{T=0}^{\infty} f_T(T)\, dT \right]^{E_H - 1} . dT_{path} \; (20)$$

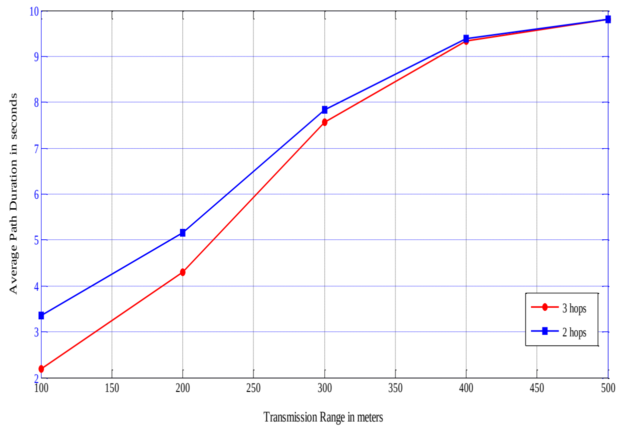
4. RESULTS ANALYSIS

In this section, the mathematical model presented in section 3 is analyzed. MATLAB is used to simulate the proposed mathematical model. To verify the correctness of the above mentioned analytical results, the results for average path duration is produced by varying input parameters like transmission range and number of hops.

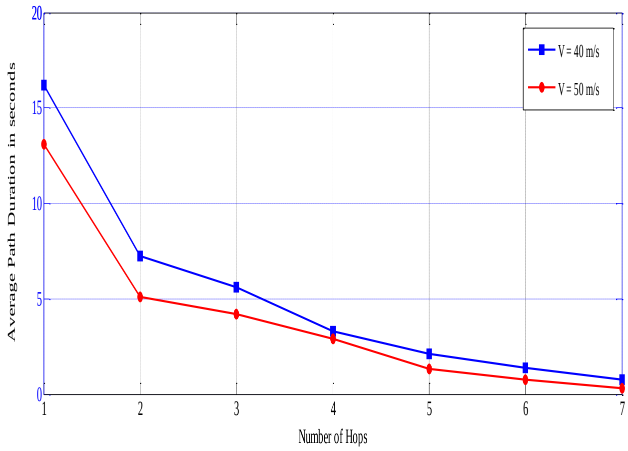
A. Average Path Duration

Fig. 2 (a) shows the plot between average path duration and transmission range. Path duration of the routes is depends on the transmission range of the nodes in the network. The figure shows clearly average path duration increases as the transmission range increases. If transmission range is maximum, it means the probability of next-hop node's location being well on the border of the sender's transmission range. It means that selection of border node gives better result as compared to interior node within the transmission range.

The average path duration is also depends on the each hop of the route. In Fig. 2 (b), the average path duration varies with number of hops for fixed transmission range. As the number of hops increase, the average path duration decreases for a fixed number of nodes and fixed area. Fig. 2 (b), also shows that with high velocity of nodes (e.g. V = 50m/s) has a relatively reduced average path duration as compared to low velocity of nodes (e.g. V = 40m/s).



(a)



(b)

Fig. 2. Average path duration vs (a) transmission range and (b) number of hops

5. CONCLUSION

In this paper, we have proposed an analytical model for estimation of path duration using position-based routing concept. This model has been verified by means of simulations. The simulation results are well approximated by the mathematical equations. In VANET, in order to maximize the communication link between nodes, it is very necessary to maintain the path duration. Therefore, message can be send timely to reduce the large number of accidents on the road. Analytical estimation of average path duration help us to improve the routing performance and decrease the number of path failures occurs in VANETs.

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