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Research Article

A Probabilistic Analysis of Path Duration Using Routing Protocol in VANETs

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In recent years, various routing metrics such as throughput, end-to-end delay, packet delivery ratio, path duration, and so forth have been used to evaluate the performance of routing protocols in VANETs. Among these routing metrics, path duration is one of the most influential metrics. Highly mobile vehicles cause frequent topology change in vehicular network environment that ultimately affects the path duration. In this paper, we have derived a mathematical model to estimate path duration using border node-based most forward progress within radius (B-MFR), a position based routing protocol. The mathematical model for estimation of path duration consists of probability of finding next-hop node in forwarding region, estimation of expected number of hops, probability distribution of velocity of nodes, and link duration between each intermediate pair of nodes. The analytical results for the path duration estimation model have been obtained using MATLAB. The model for path duration estimation has been simulated in NS2. Each of the analytical results has been verified through respective simulation results. The result analysis clearly reveals that path duration increases with the increase in transmission range and node density and decreases with the increase in the number of hops in the path and velocity of the nodes.

1. Introduction

The intelligent transport system (ITS) has been working to make the road safer and efficient to cope up with increasing number of on-road vehicles day by day. The number of accidents on the roads is continuously increasing due to high growth in on-road vehicle population. The increasing number of accidents has become an issue of concern worldwide. It has made the roads vulnerable and threatening as every year millions of people are dying in accidents throughout the world. A modern network concept, VANETs, has become the hope for providing safer and well-organized transportation in near future [1].

In VANETs, routing is the process of finding optimal path for information forwarding between source and destination node. Position-based routing protocols have become one of the most investigated choices among researches due to geographic region sharing of on-road vehicles [2–7]. In position-based routing, forwarding of information is performed either through direct communication or through intermediate nodes between source and destination node. The intermediate nodes are high speed moving vehicles in VANETs that act as router during forwarding of information from source to destination. Due to ad hoc network architecture, no fixed infrastructure is considered during information forwarding in VANETs [8]. The mobility of nodes is one of the most critical factors in design, analysis, and performance evaluation of information forwarding techniques in VANETs. High mobility of nodes causes dynamic changes in the network topology that ultimately results in infrequent path failure. The communication between source and destination node is frequently interrupted due to path failure. Once a path failure occurs, a new path has to be set up for further communication. The frequent path failures degrade the performance of routing protocol and add overhead in terms of establishing a new path [9].

In VANETs, any routing path is made up of one or more links between pair of intermediate nodes. Therefore, lifetime of a link is one of the most important contributors in path duration. Path duration can be defined as the duration of time till every link of the route is active. In VANETs, 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. The links between intermediate nodes frequently break due to the high mobile nodes moving out of each other's transmission range. Therefore, estimation of path duration between source and destination decreases the chances of path breakage. The effective use of knowledge of path duration improves the performance and efficiency of routing protocols in VANETs [10].

In this paper, our main contribution is in terms of probabilistic and mathematical analysis of path duration using border-node based most forward progress within radius (B-MFR) routing protocol. For this analysis, a mathematical model to estimate path duration has been developed. B-MFR is a position-based routing protocol which selects next-hop node from the nodes belonging to the border area of the transmission range. The mathematical model for path duration estimation consists of the following modules. (1) The probability of finding at least one node in the considered forwarding region has been mathematically derived. (2) Average number of hops between source and destination has been estimated. (3) The probability distribution function for relative velocity between any two nodes has been derived. (4) Link duration between any two nodes has been obtained. Analytical results for the path duration estimation model have been obtained using MATLAB. The model for path duration estimation has been simulated in NS2 also. Each of the analytical results has been verified through respective simulation results.

The rest of the paper is organized as follows. In Section 2, the two communication modes in VANETs have been described. Section 3 presents related works in detail. In Section 4, all the mathematical formulations for the proposed path duration estimation have been presented. In Section 5, the simulation results and analysis have been discussed. Finally, we concluded the work presented in the paper in Section 6.

2. Communication Modes in VANETs

Vehicular communications in on-road traffic environments have been realized through VANETs. In this network, vehicles termed as nodes share information through wireless communication. Dedicated short range communications (DSRC) [11] technology is used for wireless communication. DSRC is an enhanced version of Wi-Fi technology specially designed for VANETs environment and this is known as wireless access in vehicular environment (WAVE). During the communication, when a sender node does not find any neighboring nodes, it forwards the information using road side units (RSUs) available along the road. However, the availability of RSUs is not strictly considered in VANETs. Thus, the communications in VANETs can be categorized in the following two modes: (1) vehicle-to-vehicle (V2V) communication and (2) vehicle-to-roadside (V2R) communication [12].

2.1. V2V Communication. V2V communication is the basic and primary aim in VANETs. It is pure ad hoc communication between two vehicles [13]. V2V communication can be through direct link or through multihop links (see Figure 1). If the destination node is present within the transmission range of the source node then the direct link is established for communication and this type of communication is known as single-hop communication. If the destination node is present outside the transmission range of the source node then the intermediate nodes are used to deliver the message up to the destination and this type of communication is known as multihop communications. V2V communication is mainly used for the safety applications such as road blockade alarm, electronic brake warning, incoming traffic warning, vehicle stability warning, lane change warning, and collision warning. This type of communication is also used for the different types of the protocol operations. To set up RSUs such as fixed infrastructure access points, internet gateways, and base station on the road side is expensive. Therefore, VANETs should use V2V communication as much as possible for communication purpose.

2.2. V2R Communication. V2R communication is the combination of ad hoc network and fixed infrastructure networks [14]. This mode of communication (as shown in Figure 1) involves on-road vehicles as well as RSUs. Only single-hop communication between a vehicle and RSU is used in V2R communication. Further, vehicle sends the message to the road side unit which broadcasts the message to all the vehicles in the neighborhood. Generally, RSUs use links of higher bandwidth for communication and broadcasting. RSUs may be placed at every one kilometer or less to enable and maintain high data rate in highly dense traffic environment.

3. Related Work

In spite of the fundamental importance of estimating the path duration of communication links in VANET, there have been some mathematical and experimental studies in MANETs. The estimation of path duration in MANETs is proposed using several theoretical and analytical models. Many research work and models are also proposed for the implementation and improvement of the VANET. Some of the related research works about the path duration have been carried out in the recent past decade.

The path duration is an important design parameter for the better performance and routing decision in VANETs. Authors in [15] show the analysis of path duration and provide different parameters related 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 with the help of exponential distribution. The path duration depends on

Figure 1: VANETs and its communication modes.

different parameters like relative speed of the moving nodes, transmission range, and number of hops. This result helps to enhance the performance of the reactive routing protocols used in 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, link duration of that path must be maximum. If there is any link breaks in the route, it means whole route will be expired. The link stability and route lifetime are directly proportional to each other. In [16], link stability and route lifetime are analyzed for the ad hoc networks. "Edge Effect" phenomenon occurring 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 border node or node cover maximum distance towards the destination. In dense network, nodes are easily available at border of the transmission range and are 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 lie 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 VANETs. 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 be avoided over the longer average link duration of nodes. In [17], a scheme is proposed using ad hoc on demand distance vector (AODV) routing protocol to maximize the path duration and also provide a local path recovery in case of path failure with the help of the cached alternative path computing. In this schema, 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 then on the basis of the IPD values. If two paths tie 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 [17], 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 MANETs or VANETs, 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 [18], show 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, the 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 protocols using the position information of the node in the networks are known as the position-based routing protocols. 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) [19] and edge-node based directional routing (E-DIR) [20] have been proposed for VANET to select the best node for further transmission. These routing

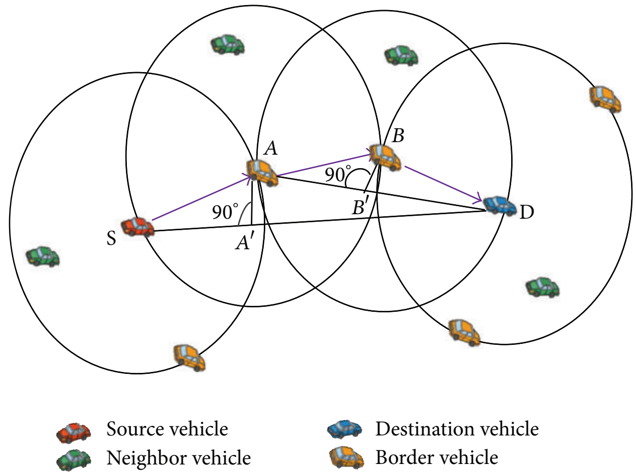

Figure 2: B-MFR forwarding method.

protocols can be used in estimation of path duration for VANET. We are introducing B-MFR for our proposed work.

B-MFR is a modified version of MFR (most forward progress within radius) routing protocol. It avoids using the interior nodes within the transmission range for packet forwarding. Therefore, in B-MFR, a packet is sent to the next-hop node, which is positioned nearer to border or on the border of the transmission range towards the destination (see Figure 2). It means the border node with the greatest progress on the line joining source and destination is chosen as a next-hop node. Thus, in B-MFR, only the border nodes present nearer to border or on the border of the sender's transmission range are selected as the next-hop nodes for further packet transmission.

In contrast, B-MFR exploits the dynamics of VANETs by choosing the node farthest from the source node to make the multihop forwarding more efficient. This routing protocol is especially important in VANETs when the node density is high 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 forward the data. Therefore, the border-node based protocol helps to reduce the number of hops between source and destination. Moreover, B-MFR is a very useful routing concept to estimate expected distance and expected number of hops between source and destination node mathematically. These mathematical expressions can be used in estimation of path duration in VANETs.

The main drawback of the B-MFR is that the node farthest from the source cannot be sufficient selection criteria in a network with frequent topological changes. Further, B-MFR is not more suitable for sparse VANETs where smaller number of vehicles moving on the road and no or fewer road side units are present along the road. In such networks, it is important to guarantee high packet delivery rate with minimum delay and, therefore, robustness of the routing protocol is of main concern. To achieve this, we need to find the path duration by taking into consideration both the direction and speed of the vehicular nodes.

4. Proposed Work

The randomness in vehicular traffic environment motivates the need for a suitable stochastic model to determine the ability of a routing protocol in terms of successful packet delivery and to analyze the network performance. Poisson distribution has been used in the model to realize dynamic traffic environment in VANETs. We followed Poisson distribution since we are interested in finding number of nodes present in specified forwarding area given the mean density of nodes in the network area. Further, the arrival of each node is independent. We assume that the nodes in the network area are deployed in a two-dimensional space according to a spatial Poisson process. The mathematical model attempts to estimate the average path duration using a position-based routing concept. Once path duration of a path is estimated well before the path breakage then the performance of a routing protocol can be enhanced significantly.

4.1. The Routing Protocol Used. The role of routing protocol is very important in the estimation of the path duration in VANETs where the network topology frequently changes. For the proposed model, the B-MFR position-based routing protocol is used which we have explained in Section 3. B-MFR is based on greedy routing approach and typically used for long distance multihop communications. It minimizes the number of hops that the message has to travel in between source and destination. In greedy routing approach, sender node first finds the position information of its direct neighbors and then selects 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.

4.2. Mathematical Models. Since we are interested in the path duration, therefore the main goal of this section is to derive a mathematical expression for path duration between two vehicles by deriving other useful mathematical expressions

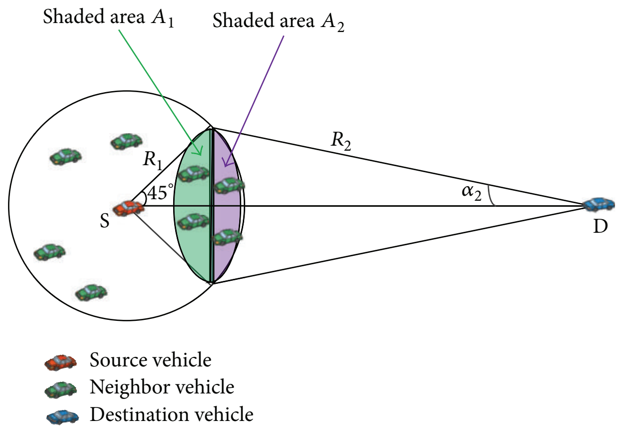

Figure 3: Area of shaded region ($A_s = A_1 + A_2$).

such as average number of hops and link duration. In this work, we use traditional traffic flow principle to describe the vehicular environment which will be more accurate for our path duration estimation. Vehicles are assumed to follow Poisson distributed arrivals for obtaining the probability distribution function (*pdf*).

4.2.1. Modeling Assumptions. In our proposed model, some assumptions are made which are given as follows.

(1) Nodes are equipped with GPS receiver, digital map, and sensors.

(2) No other fixed infrastructure for communication is present.

(3) Transmission range for every node is same.

(4) Average speed of the nodes in the network is constant.

(5) Link duration for the nodes moving away from the source node.

4.2.2. Mathematical Notations. The notations are used in our analysis. See Notations section.

4.2.3. Area of Border Region for Finding the Next-Hop Node. Since the node closer to the border or on the border line covers maximum distance, 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. Therefore, we have considered a region around the extreme end of the transmission range towards the destination. That region is shown by shaded area in Figure 3.

In Figure 3, 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 parts showing areas A_1 and A_2. Border nodes can be chosen from the shaded area A_2, because area A_2 lies closest to border line of the sender's transmission range. Greedy routing is the appropriate method to select a next-hop node for the given shaded region.

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

$$A_s = A_1 + A_2, \tag{1}$$

where

$$A_1 = R_1^2 \cdot \alpha_1 - \frac{R_1^2 \cdot \sin(2\alpha_1)}{2}, \qquad A_2 = R_2^2 \cdot \alpha_2 - \frac{R_2^2 \cdot \sin(2\alpha_2)}{2}. \tag{2}$$

As we can see in Figure 3, the line from source to destination (SD) is the bisector of the angle 90° ($\alpha_1 = 45°$); therefore, area of shaded region, A_s, is

$$A_s = R_1^2\left[\frac{\pi - 2}{4}\right] + R_2^2\left[\alpha_2 - \frac{\sin(2\alpha_2)}{2}\right]. \tag{3}$$

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

4.2.4. Probability of Finding Nodes in the Shaded Region. 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 present in selected region can be calculated as

$$\text{Number of nodes} = \omega \times \text{Area of the region}. \tag{4}$$

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

$$P(X = x) = \frac{(\omega A)^x \cdot e^{-\omega A}}{x!}, \quad x = 0, 1, 2, 3, \ldots. \tag{5}$$

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

$$P(Y = n) = \binom{x}{n}(p)^n(1-p)^{x-n}. \tag{6}$$

If a node is present in the selected region, only two possibilities are there: one is selecting the node, p_s, and the other is not selecting the node, q ($= 1 - p_s$).Therefore, probability of both the cases occurring is equal; that is, $p_s = q = 1/2$. Now, probability of selecting exactly n nodes in the given shaded region is [21]

$$P(n) = \sum_{x=n}^{\infty}\binom{x}{n}(p_s)^n(1-p_s)^{x-n} \cdot \frac{(\omega A_s)^x}{x!} \cdot e^{-\omega A_s} = \frac{(p_s \omega A_s)^n}{n!} \cdot e^{-p_s \omega A_s}. \tag{7}$$

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

$$P(n) = \left(\frac{\omega}{2}\left\{R_1^2\left[\frac{\pi-2}{4}\right]+R_2^2\left[\alpha_2-\frac{\sin(2\alpha_2)}{2}\right]\right\}\right)^n \times (n!)^{-1} \cdot e^{-(\omega/2)\{R_1^2[(\pi-2)/4]+R_2^2[\alpha_2-(\sin(2\alpha_2)/2)]\}}. \quad (8)$$

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

$$P_n = 1 - \sum_{i=0}^{n-1}\left(\frac{\omega}{2}\left\{R_1^2\left[\frac{\pi-2}{4}\right]+R_2^2\left[\alpha_2-\frac{\sin(2\alpha_2)}{2}\right]\right\}\right)^i \times (i!)^{-1} \cdot e^{-(\omega/2)\{R_1^2[(\pi-2)/4]+R_2^2[\alpha_2-(\sin(2\alpha_2)/2)]\}}. \quad (9)$$

From (9), we can easily obtain the probability, P, of having at least one node within the border region as

$$\begin{aligned} P &= 1 - P(X=0) \\ &= 1 - e^{-(\omega/2)\{R_1^2[(\pi-2)/4]+R_2^2[\alpha_2-(\sin(2\alpha_2)/2)]\}}. \end{aligned} \quad (10)$$

4.2.5. 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 [10].

To determine the average number of hop counts, nodes within the transmission range R follow the Poisson distributed model. If destination node is present in the sender's transmission range then the probability of finding destination node is the same as the probability of finding next-hop node. We assume that Z_1 is the distance between the source and next-hop node. The probability density function (*pdf*) of the link distance, Z_1, between source and next-hop node is defined as [22]

$$f(Z_1) = 2\pi\omega Z_1 \cdot e^{-\pi\omega Z_1^2}. \quad (11)$$

Distance between two nodes which provide a link to a route can be defined as the link distance. Link distance can be increased by increasing the distance between source node and next-hop node towards border line within the transmission range [23]. The probability of one-hop count can be calculated as

$$P(1) = \int_0^{R_1} f(Z_1)\,dZ_1 = 1 - e^{-\pi\omega R_1^2}. \quad (12)$$

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

$$\begin{aligned} P(2) &= \int_{R_1}^{2R_1} 2\pi\omega Z_1 \cdot e^{-\pi\omega Z_1^2} dZ_1 \times \left[1 - e^{-(\omega/2)\cdot A_s}\right], \\ P(2) &= \left[e^{-\pi\omega R_1^2} - e^{-4\pi\omega R_1^2}\right] \times \left[1 - e^{-(\omega/2)\cdot A_s}\right]. \end{aligned} \quad (13)$$

Similarly, the probability for three-hop count is

$$P(3) = \left[e^{-4\pi\omega R_1^2} - e^{-9\pi\omega R_1^2}\right] \times \left[1 - e^{-(\omega/2)\cdot A_s}\right]^2. \quad (14)$$

Consequently, the k-hop counts probability can be defined as

$$P(k) = \left[e^{-(k-1)^2\pi\omega R_1^2} - e^{-k^2\pi\omega R_1^2}\right] \times \left[1 - e^{-(\omega/2)\cdot A_s}\right]^{k-1}. \quad (15)$$

Now, by using (12), (13), (14), and (15), we can calculate the expected number of hops, E_H, between source and destination as follows:

$$\begin{aligned} E_H &= \sum_{H=1}^{k} HP(H) = P(1) + 2P(2) + 3P(3) + \cdots + kP(k), \\ E_H &= \sum_{H=1}^{k} H\left[e^{-(H-1)^2\pi\omega T^2} - e^{-H^2\pi\omega T^2}\right] \\ &\quad \times \left[1 - e^{-(\omega/2)\{R_1^2[(\pi-2)/4]+R_2^2[\alpha_2-(\sin(2\alpha_2)/2)]\}}\right]^{H-1}. \end{aligned} \quad (16)$$

4.2.6. Velocity of Nodes. Direction of movement and speed of a node are very essential parameters for the calculation of the path duration in case of VANETs. Link duration 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

$$V_R = \sqrt{V_1^2 + V_2^2 - 2 \cdot V_1 \cdot V_2 \cos\theta}. \quad (17)$$

In this work, we assume that all the nodes move with constant velocity in the network; that is

$$V = V_1 = V_2. \quad (18)$$

Therefore, relative velocity is

$$V_R = V \cdot \sqrt{2(1-\cos\theta)}. \quad (19)$$

In the above equation, θ can vary from 0 to $\pi/2$ 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 within

$(0, \pi/2)$, and *pdf* of $f_\theta(\theta)$ is $2/\pi$. Then the *pdf* of V_R, $f_{V_R}(V_R)$ can be expressed as

$$f_{V_R}(V_R) = \frac{1}{\sqrt{1-\sin^2(\theta/2)}} \cdot \frac{2}{\pi} = \sqrt{\frac{4V^2 - V_r}{V}} \cdot \frac{2}{\pi}. \tag{20}$$

4.2.7. Link Duration. Link duration is the 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 be 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 will be the next-hop node for each hop between the source and destination. Since the velocity of each node in the network is constant, it means that the links between source and next-hop node will always be maintained. As we have assumed Z_1 to be the distance between source and next-hop node within radius R_1, then the expected value of Z_1 [24] can be computed as

$$E_{Z_1} = \frac{nR_1}{(n+1)}. \tag{21}$$

Therefore, link duration T can be expressed as

$$T = \frac{E_{Z_1}}{V_R} = \frac{nR_1}{V_R(n+1)}. \tag{22}$$

The *pdf* of T, $f_T(T)$ is given by

$$\begin{aligned} f_T(T) &= \int_0^V V_R \cdot f_{d_{V_R}}(V_R T, V)\, dv \\ &= \int_0^V \left[E_{Z_1}\right] \cdot \left[\frac{2}{\sqrt{4V^2 - V_R^2}} \cdot \frac{1}{\pi}\right] dV_r. \end{aligned} \tag{23}$$

4.2.8. Path Duration. The path duration is one of the key parameters which could be useful to improve the performance and throughput of a highly dynamic network such as VANET. The path duration will be helpful in the process of path selection during the transmission of packet from source to destination [25, 26]. Path duration can be derived from the *pdf* of the link duration. Let $T_1, T_2, T_3, \ldots, T_{E_H}$ denote the link duration of $1, 2, 3, \ldots, E_H$ hops, respectively. E_H is the average number of hops required to reach the destination as estimated in (16). Therefore, the path duration can be expressed as

$$T_{\text{path}} = \text{MIN}\left(T_1, T_2, T_3, \ldots, T_{E_H}\right). \tag{24}$$

By using Bayes' theorem [21], the *pdf* of T_{path} is

$$f\left(T_{\text{path}}\right) = E_H \cdot E_Z \cdot C_T^{E_H - 1}. \tag{25}$$

Here, T represents the link duration and $C_T = 1 - F_T$ is the complementary cumulative density function (cdf) of T. Therefore,

$$f\left(T_{\text{path}}\right) = E_H \cdot f_T(T) \cdot \left[1 - \int_{T=0}^{\infty} f_T(T)\, dT\right]^{E_H - 1}. \tag{26}$$

Finally, the average path duration can be estimated as

$$\begin{aligned} E_{T_{\text{path}}} &= \int_0^\theta T_{\text{path}} \cdot f\left(T_{\text{path}}\right) \cdot dT_{\text{path}} \\ E_{T_{\text{path}}} &= \int_0^\theta T_{\text{path}} \cdot E_H \cdot f_T(T) \\ &\quad \cdot \left[1 - \int_{T=0}^{\infty} f_T(T)\, dT\right]^{E_H - 1} \cdot dT_{\text{path}}. \end{aligned} \tag{27}$$

5. Simulations and Results Analysis

In this section, extensive simulations have been performed to analyze the mathematical model for estimation of path duration presented in Section 4. The impact of four parameters, namely, transmission range, number of hops, velocity of nodes, and density of nodes on path duration, have been analyzed. The simulation results of the model have been compared with analytical results obtained for the mathematical formulation of path duration estimation.

5.1. Simulation Environment. The mathematical estimation of path duration has been simulated using network simulator (NS-2.34). MOVE (mobility model generator for vehicular networks) [27] has been used to generate realistic vehicular traffic environment along with open-source microtraffic simulator, SUMO (simulation of urban mobility). The vehicular traffic scenario consists of roads, traffic lanes on roads, junctions, traffic lights at junctions, vehicles speed, probability of turning left or right of a vehicle at junctions, and so forth has been set up using road map editor and movement editor of MOVE. The trace file used in ns2 is produced following the setup procedure of MOVE.

A set of five horizontal and five vertical roads crossing each other and thus making twenty five junctions is used as simulation area. The lane width used is 5 m. The velocity range 0–60 Km/h is used for node movement and transmission range varies from 100 m to 600 m. The other basic parameters used for the simulation are packet size of 512 bytes, traffic type as CBR, wireless channel, omnidirectional antenna, 802.11p as MAC wireless standard, and 300 s simulation time. The position-based routing protocol used for the simulation is B-MFR. After setting the network and traffic flow with above discussed parameters, we conducted the simulation. The average of ten different simulation runs is taken for data record where different source and different destination are selected. MATLAB is used to obtain analytical results for the mathematical formulation of the model.

5.2. Result Analysis. The results obtained for the model have been analyzed in the following subsections. In each subsection, impact of a specific parameter on path duration has been analyzed. In each analysis, the simulation and analytical results have been discussed comparatively.

5.2.1. The Impact of Transmission Range. Figure 4 shows the impact of transmission range on path duration. Path duration

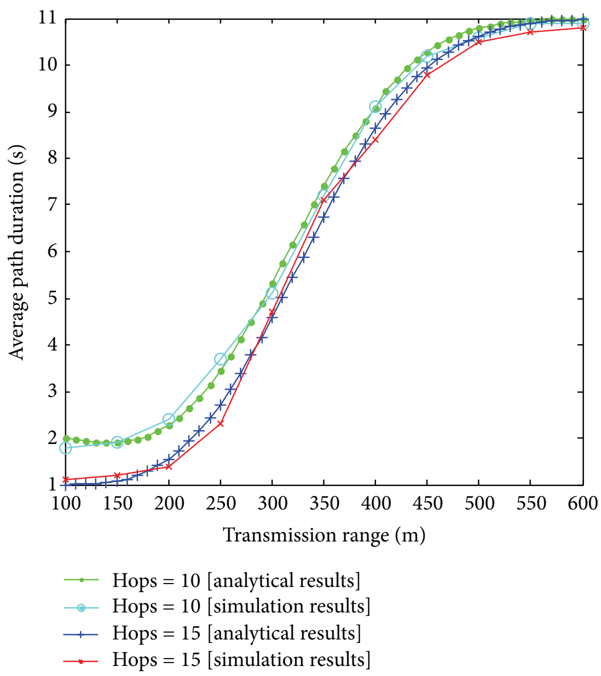

Figure 4: Average path duration versus transmission range.

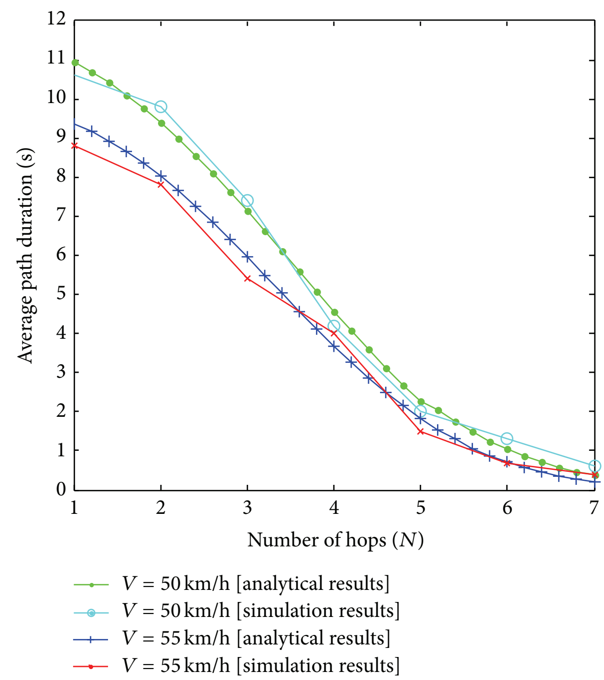

Figure 5: Average path duration versus number of hops.

of the routes is dependent on the transmission range of the nodes in the network. It can be clearly observed that the average path duration increases with the increase in transmission range. This can be attributed to the fact that the larger transmission range increases the probability of finding next-hop node in the border area of sender's transmission range. It means selection of border node gives better result as compared to interior node within the transmission range. Additionally, increasing the number of hops in the considered path decreases the average path duration. The simulation results are close to the analytical results that validate the model.

5.2.2. The Impact of Number of Hops. The plots in Figure 5 show the impact of number of hops on average path duration which depends on each hop of the route and it varies with number of hops for fixed transmission range. It clearly reveals that increasing the number of hops in the path decreases average path duration. The reason behind this is that increasing the number of hops in the path also increases the probability of link failure. Figure 5 also shows that the high velocity of nodes (e.g., $V = 55$ m/s) has a relatively reduced average path duration as compared to low velocity of nodes (e.g., $V = 50$ m/s). This is due to the increasing probability of link failure with higher velocity of nodes. The simulation results are close to the analytical results that verify the model.

5.2.3. The Impact of Node Density. The node density is also a critical factor for the path duration as the possibility of finding suitable next-hop node is increased with the increased number of nodes. The results depicted in Figure 6 show the impact of node density on average path duration. It clearly conveys that increasing the node density in a given area increases path duration. This is due to the increasing probability of availability of suitable next-hop node with increasing node density in the network. Moreover, the results also confirm that, for a given node density, increasing the number of hops in the path decreases average path duration. The closeness between analytical and simulation results for hops = 15 is smaller as compared to hops = 10 due to the increment in the network dynamics with increasing number of hops.

5.2.4. The Impact of Velocity of Nodes. VANETs are known for their mobility. The high velocity of nodes makes vehicles in and out from the transmission range of the source node, which causes most of the link or path breakage in the network. The results in Figure 7 show the impact of velocity of nodes on average path duration. It can be observed that increasing the velocity of nodes decreases the path duration. This can be attributed to the fact that increasing the velocity of nodes in the network increases the probability of link failure which ultimately decreases average path duration. Moreover, it also reveals that increasing the number of hops for a given velocity decreases average path duration due to the increment in the number of links in the path that again increases the probability of link failure. In the figure, simulation results are very close to the analytical results.

6. Conclusion

In this paper, we have derived a mathematical model for estimation of path duration between source and destination nodes using position-based routing concept. This model has

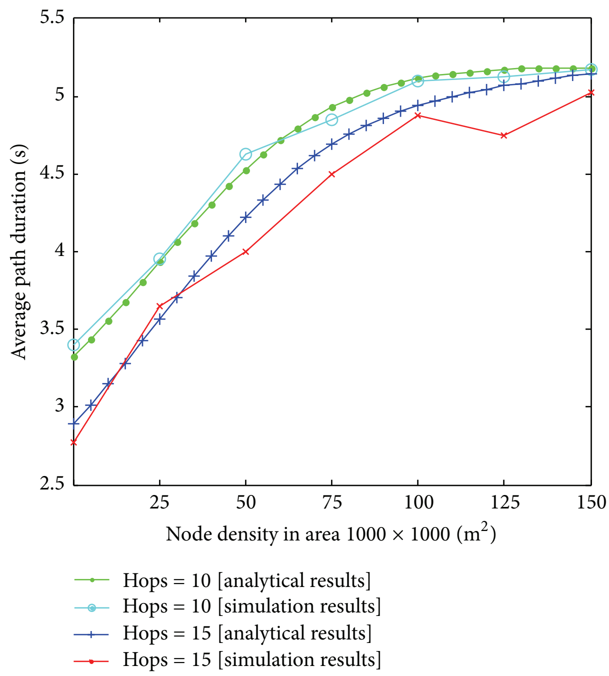

Figure 6: Average path duration versus node density.

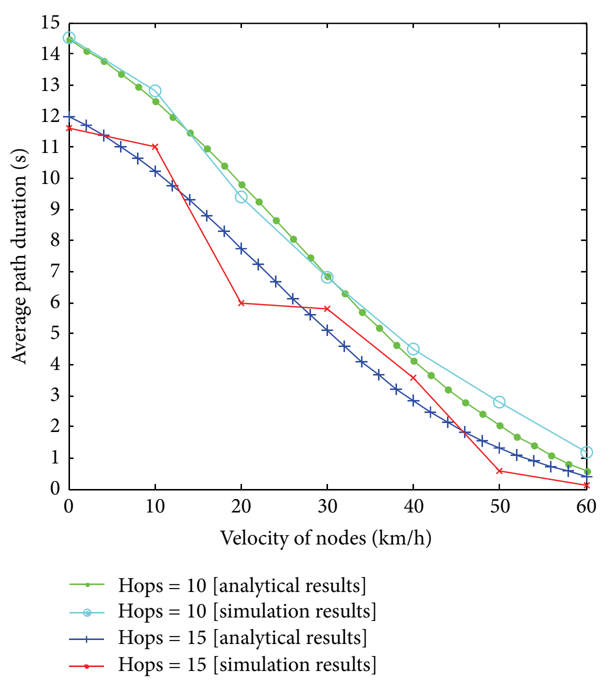

Figure 7: Average path durations versus velocity of nodes.

been verified by means of simulations and analytical results. Both the results are well approximated by the mathematical model. The mathematical model that we present is able to describe the effects of various road traffic parameters including the transmission range, number of hops, node density, and velocity of nodes on path duration. The use of the B-MFR routing protocol in this work is to find the routing path with maximum path duration. It demonstrates the selection of next-hop nodes positioned in a region around the extreme end of the transmission range towards the destination.

The mathematical analysis and simulation results reveal that high transmission range and smaller number of hops increase the path duration, but it decreases as the velocity of the nodes increases. From the above observations, it may appear that, in highly dynamic networks such as in VANET, it is very necessary to maintain the path duration between source and destination nodes. Therefore, message can be forwarded timely to reduce the large number of accidents on the road. Thus, we can say that the work in this paper helps us to improve the routing performance and decrease the number of path failures generally occurring in VANETs.

Notations and Their Descriptions

R_1: Transmission range of nodes (omnidirectional)
A: Region covered by transmission range
A_s: Selected region of the transmission range
ω: Node density
x: Number of nodes in the shaded region
n: Number of nodes selected out of x nodes
P_s: Probability of successfully selecting a node
q: Probability of not selecting a node
P_n: Probability for selecting at least n nodes in the shaded region
E_H: Expected number of hops between source and destination nodes
R_2: Distance between next-hop node and destination node
Z_1: Distance between source and next-hop node
V_R: Relative velocity between source node and next-hop node
α_1: Angle between R_1 and SD
α_2: Angle between R_2 and SD
θ: Relative angle between source and next-hop node.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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