Throughput Analysis of Next-Hop Forwarding Method for Non-linear Vehicular Ad Hoc Networks

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Abstract. Position based routing plays a significant role in multi-hop Vehicular Ad hoc Networks (VANETs), due to high mobility of nodes. Selection of next-hop node is crucial to improve the performance of routing. In this paper, we have proposed a method for selecting next-hop forwarding node based on the distance between the source and next-hop node and link quality. Next-hop node is selected based on Expected Progress Distance (EPD) criteria. The EPD is estimated in terms of expected distance between the source and next-hop node. The expected delay (E_D) and throughput (T_h) are also estimated for the proposed method. The mathematical model derived for calculating EPD, delay, and throughput are simulated in MATLAB and evaluated the performance of the proposed method.

Keywords: VANET, MANET, Next-Hop Forwarding, Position Based Routing, Greedy Forwarding, EPD, Delay, Throughput.

1 Introduction

Current advances in wireless communication systems are enabling a new vehicular communication system to improve and protect road transportation. Vehicular Ad Hoc Network (VANET) [1] is the budding and challenging subclass of Mobile Ad Hoc Networks (MANETs) [2]. VANET is composed of a large number of vehicles providing connectivity to each other. We assume that vehicles move in any direction with high mobility. Neighboring vehicles that are within a transmission range directly communicate over a wireless links. End-to-end connectivity between source and destination vehicle in VANET requires multi-hop packet forwarding by intermediate vehicles. VANET supports vehicles that are equipped with computing device, short range wireless interface and GPS receiver [3].

Position based routing can be defined as a next-hop forwarding method in which a node uses the position information of both itself and the destination node to determine a route. Therefore, position based routing protocols does not require any information about the global topology of the network. Unlike traditional routing protocols, position based routing protocols can address the challenges present by interesting properties of VANETs [4].

The dynamic topology of VANET reduces the throughput and efficiency of the routing protocols. Therefore, various approaches have been recommended to improve the throughput and the efficiency of position based next-hop forwarding [5], [6], [7] for linear and non-linear topology network. In this paper, we propose a forwarding method for non-linear network to select the next-hop node using next-hop forwarding method. We also use a link metric that is Expected Progress Distance (EPD) to evaluate the performance of forwarding method.

The rest of this paper is organized as follows. We discuss the related work in section 2. In section 3, the design of proposed method is introduced. Section 4 presents the mathematical analysis of the proposed method. Results and performance evaluation is presented in section 5. Finally, we conclude this paper in section 6.

2   Related Work

Takagi and Kleinrock [8] proposed the first position based routing protocol that is MFR routing protocol which is based on the notion of progress. MFR is a well-known loop-free method for finding a route in a network by utilizing position information of nodes [9]. The neighbor with the greatest progress on the straight line joining the source and destination is chosen as next-hop node for sending packets further. Therefore MFR forwards the packet to the node that is closest to the destination node in an attempt to minimize the number of hops [10].

Kranakis [11] proposed the DIR (referred as the Compass Routing) is based on the greedy forwarding method in which the source node uses the position information of the destination node to calculate its direction. Then the message is forwarded to the nearest neighbor having direction closest to the line drawn between source and destination. Therefore, a message is forwarded to the neighboring node minimizing the angle between itself, the previous node, and the destination. A GEDIR [9] is a loop free location based routing algorithm. It is the variant of greedy routing. In GEDIR, a source node forwards packets to its neighbor nodes that are closest to the destination node.

Hiraku, Akira, and Kenichi [12] proposed the next-hop forwarding method by limiting the forwarding distance for linear vehicular ad hoc networks. This is position based routing method based on the greedy forwarding method. In some cases, performance (packet delivery ratio and throughput) of the network may degrade due to longer forwarding distance because longer forwarding distance can cause transmission errors in the wireless network. When the maximum forwarding distance increases, the propagation loss increases and the transmission quality of the wireless link, such as packet delivery ratio degrades. To stop degradation in the network, next-hop forwarding by limiting the forwarding distance method is useful. In this method the author calculated the Expected Progress Distance (EPD) to select the next-hop node by choosing among neighbor nodes that are within a predefined maximum forwarding distance (see Fig. 1). This method improves both the forwarding distance and the transmission quality of the wireless link.
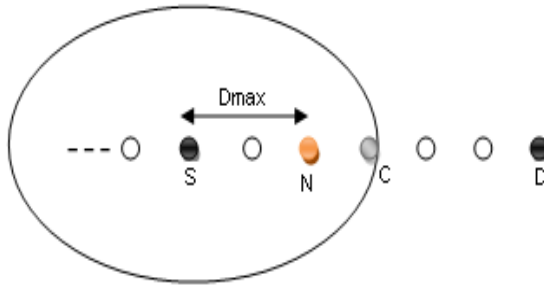
Fig. 1. Greedy forwarding by limiting the forwarding distance method (linear case)

3   Proposed Work

In this section, we propose a next-hop forwarding method by limiting the forwarding distance for non-linear network. In a dense non-linear network such as city traffic network, nodes are distributed randomly and move in any direction. In such traffic network, numbers of moving and stopped vehicles are very large, spacing between vehicles is small, and fixed road side infrastructure is available. However position-based routing in city scenarios faces a lot of challenges due to potentially more irregular distribution of vehicle nodes, forced mobility, and difficult signal reception. City vehicular ad-hoc network defined as dense and large network where source nodes have many alternative paths to destination nodes. The shortest-path position-based routing protocols frequently select paths that have the minimum number of hops rather than the maximum expected capacity.

3.1   Next-Hop Forwarding Method by Limiting the Forwarding Distance for Non-linear Network

This method considers both forwarding distance and transmission quality to selects a next-hop node. In this method, forwarding node selects a neighbor node as the next-hop node by choosing among neighboring nodes that are within a predefined maximum forwarding distance. The next-hop node is selected using the EPD link metric. This method gives better performance in terms of transmission quality considering Expected Transmission Time (ETT).

In Fig.2, S and D are source and destination nodes. N is the next-hop node and C is the closest to destination node. D_{max} is the maximum forwarding distance between forwarding node (source node) and next-hop node. As greedy forwarding method decides the next-hop node by exchanging Hello packets and selects the neighbor node that is closest to the destination node as the next-hop node. In this method, a neighbor node with good reception environment and the closest to the destination is selected as next-hop node. As shown in the Fig.2, source node S selects node N (not node C) as the next-hop node for further transmission.
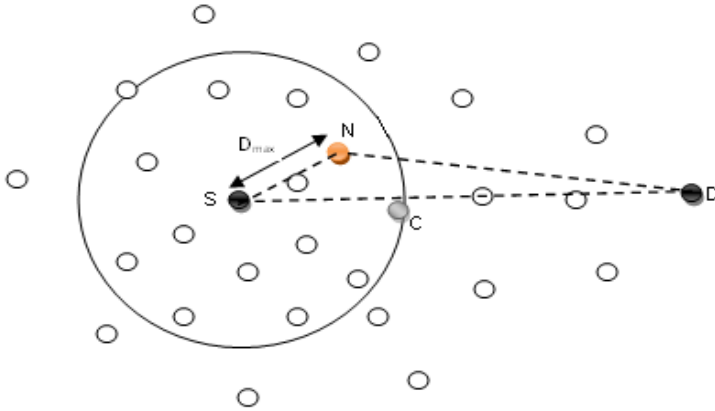
Fig. 2. Greedy forwarding by limiting the forwarding distance method (non-linear case)

3.2   Next-Hop Node Selection

The progress distance is obtained through position information of forwarding node, neighbor nodes, and destination node. Using the neighbor information table, forwarding node find the next-hop node whose *EPD* is maximum among all neighboring nodes. As shown in the Fig.2, neighbor node *N* is selected as the next-hop node. In the greedy forwarding method, neighbor node *C* is selected as the next-hop node because it is the closest neighbor to the destination node within the transmission range. When we consider *ETT*, the node nearest to the forwarding node (source node) is selected as the next-hop node because smallest *ETT* gives the best transmission quality of the wireless link in the ad hoc networks.

4   Mathematical Analysis

In this work, we consider the non-linear network where vehicles move on the road in every direction. The distance between nodes is assumed to be a random variable with Poisson distribution. The path loss depends on the forwarding distance between forwarding node and next-hop node. To select next-hop node with good transmission quality, limiting the maximum forwarding distance is more effective. In this section, we study the expected distance to next-hop node $E(D_{max})$, *ETT*, and *EPD* to select a next-hop node with good transmission quality.

4.1   Expected Distance to Next-Hop Node

One of the metrics used in any vehicular network is end-to-to-end delay that depends on the criteria used to select the next-hop node for forwarding the packets. Selecting next-hop node at the maximum distance from the source or close to the destination is to reduce the number of hops occurring in a route. Here it is assumed that the minimum number of hops in a route results in minimum end-to-end delay. Since we

have considered a non-linear network of randomly distributed nodes, it is difficult to determine the exact value of maximum distance between a source and next-hop node. Therefore, this distance can be considered as a random variable and its expected value can be determined. Let assumed that a source node S has n neighbors in the direction of destination node. Let N is the next-hop node of source node S (see Fig. 2). Let d_1, d_2, d_3..., d_n denotes the distances between source node S and its neighbors [13]. D_{max} is the maximum distance between the source node S and its one-hop nodes, i.e.

$$D_{max} = Max_{i=1}^{n} d_i \tag{1}$$

We can calculate the expected value of distance D_{max} between the source node and its neighbors as follows:

Let $F(D_{max})$ and $f(D_{max})$ be the *CDF* and *PDF* of D_{max}. Then,

$$F(D_{max}) = P[d_1 \le D_{max}, d_2 \le D_{max},, \dots, d_n \le D_{max}]$$

$$= \prod_{i=1}^{n} P[d_i \le D_{max}] = \left(\frac{D_{max}}{R}\right)^n \tag{2}$$

Similarly,

$$f(D_{max}) = \frac{d}{d_{D_{max}}} F(D_{max}) = \frac{n}{R}\left(\frac{D_{max}}{R}\right)^{n-1} \tag{3}$$

The expected value of D_{max} is,

$$E(D_{max}) = \int_0^R D_{max} \cdot f(D_{max}) \, dD_{max}$$

$$= \int_0^R D_{max} \cdot \frac{n}{R}\left(\frac{D_{max}}{R}\right)^{n-1} dD_{max}$$

$$= \frac{n}{R^n}\left[\frac{D_{max}^{n+1}}{n+1}\right]_0^R = \frac{nR}{n+1} \tag{4}$$

4.2   Expected Progress Distance (EPD)

The expected maximum distance between a source and its next-hop node computed in (4) can be used in determining the shortest path between an original source and final destination. Number of hops (hop counts) can be calculated to divide the distance between original source and final destination by the maximum distance obtained by (4). Hop counts is one of the most common routing metric used in most MANET protocols such as AODV, DSR, DSDV, GSR, OLSR and GPSR. But, this is a simple metric to find shortest route between a source and destination.

Hop counts are one equal unit and independent from the quality or other characteristics of the links. Therefore, hop counts though, minimizes the number of hops in the multi-hop network, but it may not minimize end-to-end delay. To take quality of link into account we have also considered transmission time along with the maximum distance between source and next-hop node. Transmission time varies from

link to link and thus its exact value cannot be determined. Therefore, we have considered it as a random variable and determined its expected value.

The *ETT* (Expected Transmission Time) routing metric [14] is an isotonic metric and it is used to maximize the throughput of the path by measuring the link capacities and would increase the overall performance of the network. *ETT* may be defined in two ways. Firstly, it is defined in terms of Expected number of Transmission (*ETX*) as follows:

$$ETT = ETX \cdot \frac{S}{L} \qquad (5)$$

Where *S* is the size of a packet and *L* is the bandwidth of the link. *ETX* [15] is a path metric that is used to maximize the network throughput by measuring loop-free paths and link quality in the wireless network. It is simply the sum of the *ETX* value of each link along the path. When the *ETX* metric is lesser for a link, the wireless link is better. In position based greedy forwarding method, *ETX* is measured by using periodically broadcast control messages which are sent very frequently.   Let *p* is the probability to deliver a packet successfully and *q = 1-p* is the probability of failure to deliver a packet. *ETX* to successfully deliver a packet to the next-hop [16] can be estimated as:

$$ETX = \sum_{n=1}^{\infty} x \cdot p^x (1-p)^{x-1}$$

$$= \frac{1}{(1-p)} \qquad (6)$$

The relationship between the *ETT* of a link and *ETX* can be defined as:

$$ETT = ETX \cdot \frac{S}{L} = \frac{S}{L \cdot (1-p)} \qquad (7)$$

To improve the performance network expected distance $E\,(D_{max})$ calculated in (4) is combined with *ETT* to compute a new *EPD* metric for a link. This new metric is used to select a next-hop node to transmit a packet from source to destination. Therefore, link metric, *EPD* is calculated as expected distance to next-hop node $E\,(D_{max})$ divided by the expected one-hop transmission time *ETT* [12] as follows:

$$EPD = \frac{Expected\ Distance\ to\ Next\ Hop\ Node}{Expected\ one\ hop\ Transmission\ Time} = \frac{E(D_{max})}{ETT}$$

$$= \frac{nR}{ETT \cdot (n+1)} \qquad (8)$$

4.3   Expected Delay and Throughput

It is common in VANETs that the nodes move within a certain transmission range. Therefore, network performance directly depends on the number of hops with average delay in a VANET. Delay is one of the key parameter to be considered for vehicular network traffic [17]. It is defined as the time taken for a packet to be transmitted across a network from source to destination. Throughput of the network is universally proportional to the average delay between source and destination [18]. Throughput of the network can be estimated as follows:

$$Delay\ (E_D) = \frac{Expected\ Progress\ Distance\ (EPD)}{Bandwidth\ of\ the\ Link\ (L)} = \frac{n\,R}{ETT\cdot(n+1)} \cdot \frac{1}{L} \tag{9}$$

$$Throughput(T_h) = \frac{ETT\cdot(n+1)\cdot L}{nR} \tag{10}$$

5 Results and Performance Analysis

The mathematical model proposed here has been simulated using MATLAB. In the simulation, we have deployed the nodes randomly. The transmission range of nodes has been fixed at 250m. The network area is a squared region of 2000m. This model has been used to calculate the *EPD*. We have evaluated the impact of network size (i.e., number of nodes in the network) and *ETT* on Expected Progress Distance. In the simulations, results have been computed in terms of expected progress distance between source and next-hop node.

5.1 Expected Progress Distance (EPD)

Fig. 3 shows the corresponding result for expected progress distance. From the Fig. 3 we can observe that as the number of nodes increases, the expected progress distance between forwarding node and next-hop node is also increases. We have computed the results of *EPD* for varying network size for different transmission range since it impacts the *EPD*. The results have been computed by fixing transmission range at different values of *R, i.e.* 250m, 265m and 280m respectively. As shown in the figure, *EPD* is better for $R = 280$m than $R = 265$m since higher transmission range provides better value of *EPD*. Further, *EPD* increases as the node density increases because nodes fall closer and link quality is better between closer nodes.
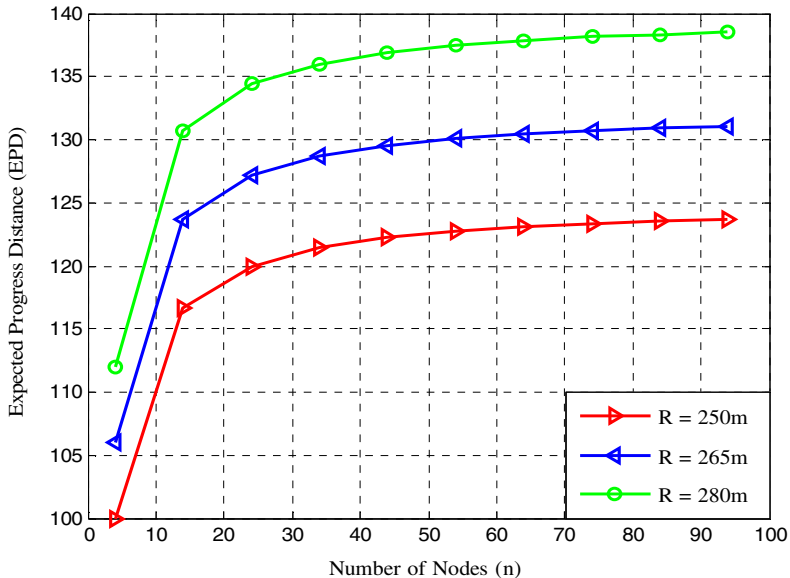

Fig. 3. Expected progress distance (*EPD*)

5.2   Delay (E_D) and Throughput (T_h)

Delay and throughput are most important parameter to be considered for vehicular traffic. Fig. 4 shows the variation in average delay as the number of nodes increases. We can observe that as the number of nodes increases, the average delay between forwarding node and next-hop node is decreases. Delay is always higher for higher *ETT* (*ETT* = 14) compared to lower *ETT* (*ETT* = 10).
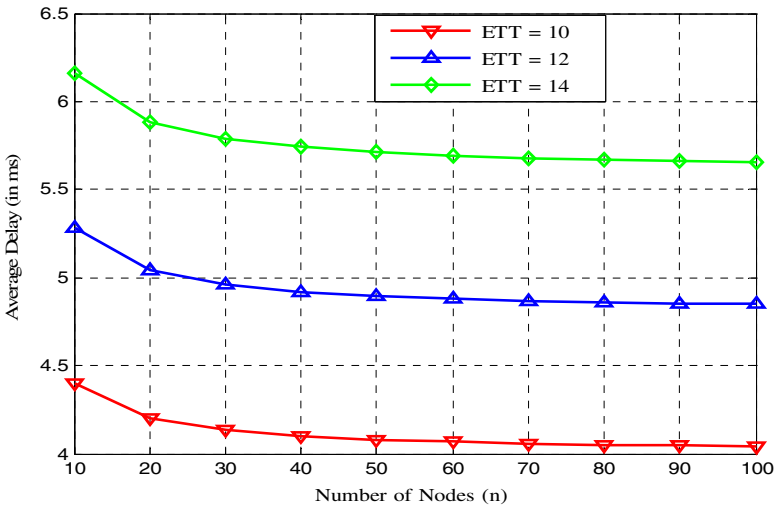

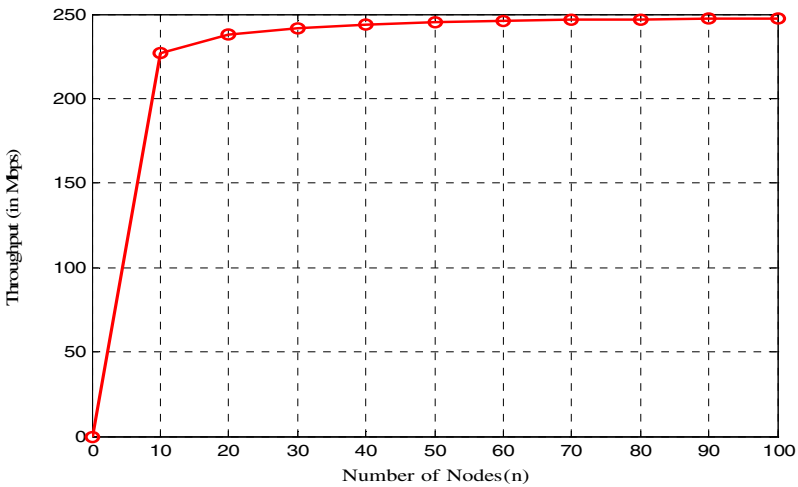**Fig. 4.** Average delay as a function of *n*

Fig. 5. Throughput (T_h, in Mbps)

Fig. 5 shows that number of nodes directly affects the throughput of VANETs communications. From the numerical analysis, we can see that initially throughput increases faster as number of nodes increases and network becomes saturated at 85 nodes and get maximum throughput for the maximum number of nodes for a fixed transmission range.

6   Conclusion

In this paper, we have proposed a method for selecting next-hop forwarding node based on the distance between the source and next-hop node and link quality. In this method, the neighbor node that has the maximum *EPD* is selected as the next-hop node among neighboring nodes. Nodes in the network have higher *EPD* when the network size is large and small *ETT*. Delay and throughput are estimated for selected next-hop node. Network performance in terms of throughput will be maximized for the maximum number of nodes for a fixed transmission range. Therefore, this method by limiting the forwarding distance is an effective position-based routing method to forward packets from source to destination with good transmission quality of wireless link.

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