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Model for Path Duration in Vehicular Ad Hoc Networks under Greedy Forwarding Strategy

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Abstract

In this paper, we present an analytical model to find the probability density function (PDF) of link and path duration in vehicular ad hoc networks (VANETs), assuming the distance headway to have lognormal distribution. We then analyze the impact of vehicle mobility and transmission range on the link duration PDF and mean path duration in VANETs. We consider the greedy forwarding strategy to forward message from one hop to the next. Our analytical and simulation results suggest that, the link duration PDF can be approximated as lognormal with appropriate parameterization. We present the Kolmogorov-Smirnov goodness-of-fit test results to justify this claim.

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1. Introduction

Vehicular Ad Hoc Networks (VANETs), which allow vehicles equipped with wireless communications devices to form a self-organized network without the requirement of permanent infrastructures, are highly mobile wireless ad hoc networks envisioned to provide support for both safety and non-safety applications by enabling vehicle-to-vehicle (V2V) and vehicle-to infrastructure (V2I) communications [1][2]. The link duration or link life time is the period of time during which two vehicles in the network stay within the transmission range of each other. The link duration has significant influence on the route lifetime, which, in turn, determines the packet delivery ratio and the per connection throughput for a given source-to-destination pair in the network. The lifetime of a multi-hop route is determined by the lifetime of its weakest link, i.e., the link with the lowest life time among all the links constituting the multi-hop route.

The importance of link and path duration on the performance of MANETs has been extensively studied in the literature [3][4][5]. In the case of VANETs, simulation results in [6] confirm that, for both highway and urban environments, both the

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single hop as well as the multi-hop connection life time is an important quality of service (QoS) metric for unicast routing that highly depends on the vehicle density, the channel conditions and the relative speed of vehicles.

Several papers have appeared that deal with the analysis and evaluation of communication link (single hop as well as multi-hop) life time in MANETs [4][7][8][9]. Based on experiments with dynamic source routing, Bai *et al*. [4] propose an approximate PDF for the path duration in MANETs. Pascoe-Chalke *et al*. [7] derive the time duration of an n node path in a MANET. Yueh-Ting Wu *et al*. [8] develop an analytical framework for link duration in multi-hop mobile networks. They show that the link duration for two nodes is determined by the relative speed between the two nodes and the distance during which the link is connected. Wu *et al*. [9] present statistical models to accurately evaluate the distribution of the lifetime of wireless links in a MANET in which nodes move randomly within constrained areas.

In [10], Sun *et al.* propose an analytical model for the probability density function (PDF) of link lifetime under the following assumptions :(i) equally spaced nodes; and (ii) normally distributed vehicle speed. However, their first assumption is not reasonable since, as widely known, inter-vehicle distance is a random variable. Yan *et al.* [11] investigate the probability distribution of the lifetime of individual links in a VANET assuming (i) the PDF of inter-vehicle headway distance to be log-normal, and (ii) the vehicle speed to be deterministic. Empirical studies have shown that, Poisson distribution provides an excellent model for vehicle arrival process and the vehicle speed is a random variable that follows Uniform distribution [12][13]. Liu *et al.* [14] propose expected path duration maximized routing algorithm for cognitive-radio enabled VANETs (CR-VANETs). Barghi *et al.* [15] introduce a new protocol which uses the characteristics of vehicle movements to predict the vehicle behavior and select a route with the longest life time for connecting vehicles to the Internet.

In this paper, we present an analytical model to find the PDF of the link as well as the path duration in one-dimensional VANETs. We assume a position based routing protocol such as greedy perimeter stateless routing (GPSR) [16] that use a greedy strategy for packet forwarding. Position-based routing relies on the knowledge of the geographical position of the nodes to select the best path to forward data to a destination. Thus, when using position-based routing each node must be able to determine its own location and a source node must be aware of the location of the destination node. Under greedy forwarding, the sender forwards the packet to the neighbor that is closer to the destination. The forwarding is continued till the packet reaches the destination. If greedy forwarding fails, GPSR use perimeter forwarding strategy [16]. An analytical model for the link and path duration would be useful for estimation the average link and path duration and for anticipating disruption of the routing path. The model would also be useful towards the design of stable position based routing protocols that maintain reliable routing paths to improve the network performance. Remainder of this paper is organized as follows: The system model, which includes models for the inter vehicle distance and the vehicle mobility, is presented in Section 2. In section 3, we present the analysis of link and path life time under the greedy forwarding approach. The analytical and the simulation results are presented in Section 4. The paper is concluded in Section 5.

2. System Model

In this section, we describe the models for the head way distance and vehicle mobility employed in this paper. Consider the one dimensional VANET formed a single lane highway where all the vehicles move in the same direction. For the analysis of link life time, we assume the probability distribution of the headway distance, to be lognormal [17]. The basis for the lognormal headway model is that a vehicle maintains a safe distance while following its leading vehicle closely at variable speeds. The lognormal headway model has been validated by real traffic measurements [18][19][20][21]. Real world traffic data collected by S. Yin *et al.* [22] shows that the log-normal distribution model is a better choice when fitting headway data when the traffic is in forced flow status. Further, we assume that vehicles on the highway have the same mean velocities, but they are permitted to move with variable instantaneous velocities that are limited to a range of values. This means that each vehicle selects a speed from the range according to a probability distribution. Suppose a vehicle selects a speed independently and uniformly in the range $[v_{min}, v_{max}]$ the PDF of V is given by

$$f_V(v) = \frac{1}{V_{max} - V_{min}} \quad ; \quad v_{min} \le v < v_{max} \tag{1}$$

3. Analysis of Link and Path Life Time

In this section, we present analytical model for the probability distribution of link life time. We assume a fixed transmission range (R meters) and a fixed transmission power for all the vehicles. We do not consider the variability of transmission range arising out of channel randomness or other issues. Consider the one dimensional VANET formed a single lane highway where all the vehicles move in the same direction. As mentioned before, our analysis of link life time is based on a position based routing protocol such as GPSR [16] that use a greedy packet forwarding strategy. An example of greedy forwarding is shown in Fig 1. Here, source vehicle has a packet destined for destination vehicle. Source vehicle's radio range is denoted by the circle about source vehicle. Source vehicle forwards the packet to vehicle B, as the distance between B and destination vehicle is less than that between destination vehicle and any other vehicle within the communication range of source vehicle. This greedy forwarding process repeats, until the packet reaches destination vehicle.