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One Dimensional Vehicular Ad-hoc Network Connectivity Analysis Under Fading Conditions

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Abstract

Inter vehicle headway distance and channel fading are the two important highly random factors affecting the connectivity of vehicular ad-hoc networks (VANET). In this paper we investigate the combined effect of vehicle headway distance and channel fading on network connectivity. We develop a mathematical model for connectivity based on inter arrival time and channel parameters. The effect of channel fading is incorporated in to the analysis by using stochastic geometric method. We investigate on the Inter arrival time based power distribution which primarily determines connectivity probability and mean number of connected nodes in the network.

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Keywords: vanet; connectivity; fading; counting measure; path probability.

1. Introduction

Vehicular ad-hoc network (VANET), a subset of mobile ad-hoc network (MANET) envisions establishment of communication between vehicles moving at high speeds in highways. The resultant distributed self-organizing wireless networks do not require infrastructure like base station and access points. The communication among the vehicles (nodes) takes place in a co-operative manner. These infrastructure-less networks form an important part of intelligent transportation systems(ITS) and delivers innovative road safety related information such as collision warning, road condition, lane changing information, etc. Though MANET and VANET both share the properties of node movement and topology changes, VANET is characterized by high speed node mobility and high randomness in the wireless channel conditions. Due to highly random nature of inter vehicle headway distance, vehicle speed, driver behavior and wireless channel properties, connectivity becomes an important performance measure in VANET. Hence, reliable and fast communication between the transmitting and receiving nodes becomes an exciting research challenge.

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Two nodes are said to be connected if they can establish a reliable communication between each other through a single hop or multiple hops. Several studies discussing the connectivity properties of VANET [1, 10, 12] are available. Connectivity is primarily dependent on the inter vehicle time head way which is defined as the time interval between the rear bumper of successive vehicles in the highway.

Vehicular headway depends on vehicle speed, traffic flow, driver behavior, etc. Normal traffic flow in the highway is classified into three types - free flow, synchronized flow and wide moving jam [20]. In the free flow state, traffic density is low, vehicles can move with maximum speed and no vehicle queue is formed in the highway. In synchronized state, traffic flow becomes maximum and the vehicles in different lanes travel with a synchronized speed where some bunching of vehicles may occur. Synchronized and wide moving jam come under congested flow [19]. There exists a correlation between traffic flow and traffic density in free flow condition up to the critical density. After that, the traffic is said to be in the congested state. Under congested traffic the headway is very less and network will surely be in the connected state. Network undergoes intermittent changes in free flow traffic. Hence we analyze the connectivity properties of the vehicular network in free flow condition only. In addition to the random nature of the headway, the connectivity depends on the channel fading due to multi path and scattering. It is assumed that the medium access control of the system handles interferences from other devices so that it can be ignored in the analysis.

In this work, we model the vehicle arrival process in the highway using Poisson point process and inter arrival time which is converted in to headway distance is taken as the random variable representing transmitter receiver distance. The effect of channel fading is modeled as Rayleigh random variable. The combined effect of fading part and distance part which determines the signal to noise ratio (SNR) at the receiver end is modeled using stochastic geometry. The connectivity between the transmitter and receiver depend purely on the SNR. The connectivity probability and the average connected distance are derived based on the channel parameters such as path loss exponent, transmitter - receiver distance and channel path gain. The relation between Poisson process and random division of an interval is interpreted by applying Laplace transform and vehicle time headway distribution is derived. The density of the Poisson point process with fading is calculated on the basis of stochastic geometry and the network path probability under fading condition is derived. Again the probability that the longest interval of a random division of an interval less than a threshold value is used for deriving the network connectivity probability and average number of connected nodes in terms of mobility parameters such as vehicle density, traffic flow, static transmission range, etc.

2. Related Work

Extensive studies have been reported on the connectivity problems of mobile ad-hoc networks in different perspectives [3-6]. Connectivity of mobile ad-hoc networks primarily depend on the mobility pattern as well as the channel conditions. Most of the studies based on ad-hoc networks were conducted with predefined node placement statistics and static transmission range. Connectivity is then analyzed based on the node density, transmission range, etc. In [4] the connectivity probability of one dimensional network is analyzed with uniform node distribution and is extended to two dimensions to find the bounds for connectivity. The authors in [6] derived critical range of nodes for connectivity with probability one as infinity. These types of node distribution are not applicable to vehicular network due to high dynamic nature of the node movement. Vehicular type movements of nodes are considered in [1, 2, 9]. In [1], authors rely on some road statistics and numerical solution for the connectivity distance, platoon size, etc. derived based on queuing theoretical perspective. In [2] real road scenario is created using a simulator and determined the minimum transmission range to get full network connectivity and the effect of vehicle density on the transmission range analyzed. Authors of paper [3], Poisson type node distribution is assumed and used GI/D/∞ queue to analyze the network connectivity. In [9] M/G/∞ queue is used for the connectivity analysis. Connectivity distance, platoon, etc. are analyzed under various channel models such as Rayleigh, Rice, Nagakami, Weibul, etc. Simulation studies were also done based on road statistics. In the above studies vehicle traffic dynamics is not considered in the connectivity studies.

In [11], percolation theory is applied to evaluate the network connectivity. Authors of [18] proposed the enhancement of connectivity by considering both direct connectivity from a source node as well as the indirect connectivity through multi hop forwarding, termed as available connectivity. Link duration is analyzed in papers [16, 17]. Authors of [16]