Link Reliability Model for Vehicle Ad Hoc Networks

Zeyun Niu, Wenbing.Yao, Qiang Ni, and Yonghua Song
Brunel University

Abstract: In this paper, we develop a novel link reliability model for vehicle ad hoc networks, which consist of vehicular wireless mobile terminals. In order to accurately present the vehicular mobility of the node, classic traffic theory is applied that discards the dependence on different vehicular mobility scenarios. Road density and terminal relative speed are introduced in our model. We demonstrate the ability of our model to present stable link with a high probability in vehicular wireless environment.

1. Introduction

Vehicle ad hoc networks refer to wireless vehicular ad hoc networks in which vehicles are equipped with wireless communication interface. There has been growing interest in using vehicle ad hoc networks for inter-vehicle or roadside-vehicle communications. Among the challenges of vehicle ad hoc networks, dynamic topology brings hardness to routing protocol design since terminal mobility may cause frequent link breakages. When any link of a path is broken, the path needs to be either repaired through routing maintenance process or replaced by a new found path. Selecting reliable route is crucial for establishing reliable route between two connecting vehicles as rerouting may be costly.

Link reliability is given by a probability that persist for a certain time interval to describe the future status of a link. Previous work [1, 2, 5, 6] focus on link reliability can be generally classified into two types; one is link lifetime estimation based algorithms that use link lifetime distribution of each link to give out path link lifetime estimation as a routing metric; the other kind is prediction-based link reliability estimation algorithms that explore a probabilistic link reliability model for routing discovery process. Both of these two methods depend on the mobility model that defines the movement scenario of the network. However, no link reliability model specifically for vehicle ad hoc networks has been developed so far.

In this paper, we develop a novel link reliability model for vehicle ad hoc networks. To give out a macroscopic description of node movement pattern, we apply road density, average speed and traffic flow, only three classic traffic metrics to denote terminal mobility pattern. Therefore, a specific link reliability model is given based on this vehicular mobility model. Rather than considering link residual time from the link available moment to infinite, we use relative speed to narrow down the link residual time that is available only when the two nodes are within radio range of each other. As a result, network resource can be efficiently estimated and utilized.

2. Mobility Issues in Vehicle Ad Hoc Networks

Connectivity characteristics of links between pairs of vehicles have been discussed in [3, 7]. As the two nodes belonging one connection, they must be within each other's radio range to form this link. However, this relevant distance is not the only condition that provides the availability of this connection. Movement pattern of the terminals can seriously effects connectivity: the more relatively stable the two nodes, the more connection availability can be achieved. In another word, topology stability is a key factor that affects the link availability. Different from general mobile ad hoc networks, the topology in vehicular ad hoc networks can be certainly predictable by using traffic flow characters and geographic situations or maps.

Many mobility models have been introduced, e.g., Random Waypoint Model, Gaussian Markov Model. They usually represent a system consists of a group of nodes in which each node has an independent movement with respect to its neighbors in the system. These microscopic models usually give out network topology description when estimation works are focus on certain routing protocols. Each model may only present a specific scenario of a wireless network. Although, some of them can be implemented for vehicular scenario in ad hoc networks, no general vehicular model can be provided by using only one of these models.

Rather than any microscopic mobility models, classic traffic theory can provide a macroscopic definition of the network vehicular topology. In classic traffic theory, vehicle road density λ [veh/km], terminal average speed v_m [km/h], and traffic flow q [veh/h] are three elementary metrics to denote node mobility pattern. Statistic probability can be obtained to give out probability distribution of these metrics. Therefore, not only individual vehicle behavior but also general status information can be represented by these traffic metrics.

Instead of describing individual vehicular behavior during the connection, we utilize relative speed of the two nodes on an active link to modeling link reliability. The relative information, presented by relative speed, relative distance, et al., in the vehicular environment is sometimes crucial for a traffic model. This is caused by the time and space concentration character of the vehicular traffic. Based on the above analysis, we further give out the link reliability model for vehicle ad hoc networks.

3. Link Reliability Model for Vehicle Ad Hoc Networks

A link reliability model is a probabilistic function that can predict the future status of a wireless link. A most popular method to give out such a model is by firstly capture the probability density function of link lifetime, or link duration, for certain mobility model and then estimating the link reliability through adaptive integration or discrete sum. As designed for general ad hoc networks, the affection of these link reliability models are most depending on the mobility model they are considering. In this paper, we use traditional traffic flow theory to describe the vehicular environment that will be more accurate for our link reliability estimation.

Applying classical vehicular traffic theory, we use traffic density λ in [veh/km], relative speed Δv in [km/h] to describe link lifetime t_{ll}. The connection distance is usually the largest one among all the node pairs. We assume that each hop has the connection distance equal to the maximum communication radio range, D_r. As the value of relative velocity is assumed as normal distributed: $\Delta v \sim N(\mu_{\Delta v}, \sigma_{\Delta v}{}^2)$, and vehicles are assumed to have Poisson distributed arrivals. We obtain the probability distribution function (pdf) for link lifetime as:

$$p_t(t) = \frac{4 \cdot D_r}{\sigma_{\Delta v} \cdot \sqrt{2\pi}} \cdot \frac{1}{t^2} \cdot e^{-\frac{\left(\frac{2 \cdot D_r}{t} - \mu_{\Delta v}\right)^2}{2 \cdot \sigma_{\Delta v}^2}} \quad (1)$$

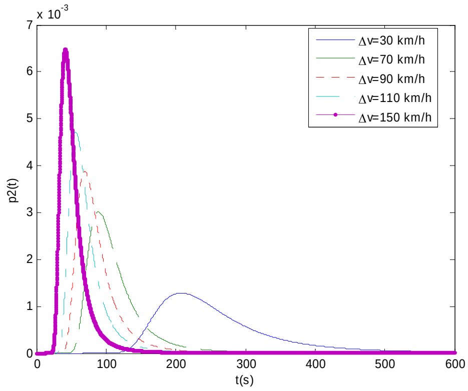

Fig 1. The pdf function of link lifetime

Applying the above pdf function of link lifetime, we accordingly develop our link reliability model by introducing road density and relative speed. Our approaches are based on following considerations.

- Road density, defined as the number of on-board vehicles within a length unit, can critically influence traffic flow factors such as road capacity, node velocity. Vehicle velocity can reach its maximum speed if the road density is under a critical density λ_c. Meanwhile, traffic flow can linearly increase that vehicle can travel freely without influence each other. However, once the density exceeds λ_c, vehicle velocity will correspondingly decrease and the distance between two neighbor vehicles tends to be steady.
- Relative speed can directly reflect the mobility situation of two involved vehicles. Two neighbor vehicles can have a very small relative speed even though they are both traveling with a high speed. This is highly distinguished from MANETs.
- When the road density exceeds λ_c, relative speed and distance may be stable as the road may be blocked seriously. Vehicle velocity under such situation will have a relative stability that vehicle mobility may have little influence on the decision of link reliability.
- In vehicular environment, link reliability should not rely on the residual time that is observed from next second to infinite as defined for MANETs. Two neighbor vehicles can easily exceed the communication radio range of each other. Their relative speed and current road density should be involved in their judgment of link residual time.

According to above analysis, we introduce a link reliability model as given below:

$$\rho_{sd}(T_{sd}, \lambda) = \begin{cases} \frac{\delta \cdot \lambda}{\lambda_c} \int_{t_0}^{t_0 + T_{sd}} T_{sd}\, p(t)\,dt, & \text{iff } \delta \cdot \lambda < \lambda_c \\ \int_{t_0}^{t_0 + T_{sd}} T_{sd}\, p(t)\,dt, & \text{otherwise} \end{cases} \quad (2)$$

where t_0 is the connection start time, T_{sd} is the link active time during which the two mobile nodes are within the direct radio connection range, $p(t)$ is the empirical probabilities in terms of the link life time t we give above, and ρ_{sd} is the link reliability, i.e. the probability that the connection between s and *d* will last duration T_{sd}, which can be calculated from the range between the two active nodes L_{RA}, and the relative moving speed of the two vehicles V_{RA} using

$$T_{sd} = \frac{L_{RA}}{V_{RS}} = \frac{\sqrt{(y_1 - y_2)^2 + (x_1 - x_2)^2}}{\vec{v}_1 - \vec{v}_2}. \qquad (3)$$

The onboard vehicle navigation system, such as GPS, can provide the vehicle location information (x_1, y_1) (x_2, y_2) and moving speed $\vec{v}_1, \vec{v}_2$ for the calculation of L_{RA} and V_{RA}. δ is a revise factor that correct the influence of road density. Road density can be broadcasted by infrastructure device, e.g., RSU, the road-side union provided by IEEE802.11p.

5. Future Work

Future work will concentrate on refining the link reliability model as a routing or QoS metric. In the highly dynamic vehicle ad hoc networks, shortest path routing algorithm is no longer suitable as the fluctuant terminal mobility can cause flooding in route discovery and reroute process. Link reliability should be considered as a path rating metric that value the route capacity and reliability. This part of work should be consisted of the following issues:

- What's the mechanism to broadcast or multicast the link reliability as a link status information;
- How to implement link reliability into routing protocol as a route metric, which need to obtain link reliability along certain discovered route;
- How to optimize route selection algorithm that can deal with the tradeoff between minimum hops and largest link reliability.
- How to manage link reliability as a QoS metric that is required by certain vehicular applications.

Extension work based on this paper also includes evaluation work on some common ad hoc routing protocols with the implementation of our link reliability model.

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