The Effects of Wireless Transmission Range on Path Lifetime in Vehicle-Formed Mobile Ad Hoc Networks on Highways

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Abstract—An information network built on top of vehicles using inter-vehicle communication (IVC) can be viewed as a type of mobile ad hoc networks (MANET). The lifetime of the unicast routing paths existing in an IVC network can be affected by several factors such as vehicle moving speed, wireless radio transmission range, traffic density, etc. This paper uses more realistic vehicle mobility traces to study the effects of wireless transmission range on path lifetime in an IVC network. The results presented in this paper can help IVC researchers choose an appropriate wireless transmission range for IVC networks.

I. INTRODUCTION

In recent years, Intelligent Transportation Systems (ITS) is becoming popular and an important research topic. ITS aims to provide drivers with safer, more efficient, and more comfortable trips. For example, ITS wants to provide drivers with timely traffic congestion and road condition information so that drivers can avoid congested or dangerous areas. In addition, ITS wants to provide drivers with networking services so that they can exchange information, send/receive emails, browse web pages from the Internet, etc. To achieve these goals, timely and efficient distribution and acquisition of useful information among vehicles is necessary.

In the ITS research community, inter-vehicle communications (IVC) has attracted the interests of many automobile manufactures and researchers. In such a scheme, no infrastructure is required for communications between vehicles, and each vehicle is equipped with a wireless radio by which it can send and receive its own messages and forward messages for other vehicles. The vehicles on the roads dynamically form an ad hoc network at any time. Information is distributed, acquired, or exchanged on top of this network. Such an information network can be viewed as a type of MANET. In the rest of this paper, for brevity, we will simply call such a vehicle-formed MANET an IVC network.

Although many studies about MANET have been conducted in the past, their results may not be applicable to an IVC network. In such a network, vehicles can move at a high speed such as 120 Km/hr. In past studies, however, mobile nodes are generally assumed to move at a much lower speed.

In addition, vehicles generally move on paved roads with acceleration/deceleration, lane-changing, and car-following behaviors. However, mobile nodes in past studies are generally assumed to move freely in a random-waypoints fashion, which has recently been found to lead to unreliable results [1]. Due to these differences, the results obtained from past studies about MANET require re-inspection for their suitability for IVC networks.

In ITS, timely and efficient information distribution, acquisition, and exchange among vehicles is important. However, due to several reasons, it is not easy to achieve these goals. First, an IVC network can easily get partitioned. This situation can easily happen when traffic density is low (e.g., at midnight), when the wireless transmission range is short, when few vehicles are equipped with wireless radios, etc. Second, in an IVC network the unicast routing path between a pair of vehicles can easily break. This situation can easily happen when the source and destination vehicles are moving in opposite directions. This is because in this situation lane-changing is very likely to occur.

Because network topology can change so frequently in an IVC network, an established unicast routing path in such a network is not expected to last for a long period of time. As such, a routing protocol designed for IVC networks should have a good path-finding and path-repair designs to extend the lifetime of an established path. These designs should be able to find reliable paths between vehicles while incurring minimum control packet bandwidth overhead. Otherwise, the networking performance of application programs run on an IVC network will be bad and the goodput of an IVC network will be low.

Although application performance and the goodput of an IVC network can be improved somewhat by using a better routing protocol, they are still fundamentally determined by the lifetime of the routing paths existing in an IVC network. This is because if the lifetime of most routing paths in such a network are very short (say, only 2 seconds), a unicast routing protocol will constantly need to repair broken paths. This will...
not only incur much control packet bandwidth overhead, but also cause excessive disruptions to application programs. For this reason, in this paper we focus on the lifetime and several other properties of routing paths in a simulated IVC network.

The lifetime of routing paths in an IVC network can be affected by several factors such as vehicle moving speed, vehicle mobility pattern (e.g., car-following and lane-changing behaviors), wireless radio transmission range, traffic density, etc. In this paper, we study the effects of wireless transmission range on path lifetime. Although it is natural to envision that as wireless transmission range increases, the expected lifetime of a path in an IVC network would increase, in the past there is no performance data to support this conjecture. This paper provides many quantitative performance data showing the effects of wireless transmission range on path lifetime. These results can provide a reference for the DSRC (Dedicated Short Range Communications) standard body to choose an appropriate wireless transmission range for IVC networks.

This paper makes several contributions. First, we use more realistic vehicle mobility traces to study IVC-related problems. In contrast, past studies about MANET mostly used the unrealistic random-waypoints mobility pattern. Second, we use these traces to study the effects of wireless transmission range on path lifetime. This topic has not been addressed in the past. Lastly, our other results (e.g., the relationship between the initial hop count of paths and their expected lifetime) can be used by routing protocols to predict the lifetime of a path and thus better utilize the resources of an IVC network.

The rest of this paper is organized as follows. Section II surveys related work. Section III describes the simulation environment and settings. Section IV explains the performance metrics used in this study. In section V, we present the simulation results. Finally, we conclude the paper in Section VII.

II. RELATED WORK

In the literature, several papers have discussed and studied the applications of MANET to IVC networks. To meet the paper length limitation, they are listed below [5], [6], [7], [8], [9], [10], [11], [12], [13], [14], [15], [16] for the reader’s references.

III. SIMULATION SETTINGS

A. Traffic Simulator

The microscopic traffic simulator that we used to generate mobility traces of vehicles is VISSIM 3.60 [17], which is a commercial software developed by PTV Planung Transport Verkehr AG company, located in Germany. VISSIM uses the psycho-physical driver behavior models developed by Wiedemann [18], [19] to model vehicles moving on the highways. This includes acceleration/deceleration, car-following, lane-changing, and other driver behaviors. Stochastic distributions of speed and spacing thresholds can be set for individual driver behavior.

![Fig. 1. The topology of the highway used in this study. The highway is a rectangular closed system with 3 lanes in each direction. Its length and width are 8 Km and 5 Km, respectively.](image)

B. Highways System

The topology of the highway used in this study is a rectangular closed system with 4 circular corners. It has 3 lanes in each direction, and its length and width are 8 Km and 5 Km, respectively. There are no entrances and exits on this highway system.

Vehicles are injected into this system in both directions at the top-left corner. The injection rate is 1,000 vehicles per hour in each direction. After all vehicles have entered the system, they move freely in the highway system according to their respective desired speeds, vehicles characteristics, and driving behavior.

The vehicle mobility traces are taken after all vehicles have entered the highway system and have been moving for at least one hour. Many traces are taken and each one lasts for 300 seconds. In this paper, the reported performance results are derived from one of these traces. We have also processed other traces and found that their results are all close to each other. Note that in this highway system, vehicles in different directions do not interact with each other. This is because in this topology a vehicle cannot leave the highway in one direction and then enter the highway in the opposite direction.

C. Vehicle Traffic

In this study, the total number of vehicles moving in the highway system is set to be 2,000 and a half of them are moving in each direction. The average distance between a vehicle and the vehicle immediately following it on the same lane can be calculated. It is (26 Km/lane * 3 lanes/direction)/(1,000 vehicles/direction) = 78 meters, where 26 Km is the perimeter of the simulated highway.

The desired speeds chosen for these vehicles determine the absolute speeds of these vehicles and the relative speeds among them. The distribution of these desired speeds is [20%: 100 - 110 Km/hr, 40%: 90 - 100 Km/hr, 20%: 80 - 90 Km/hr, 20%: 70 - 80 Km/hr], which means that 20% of
the vehicles are moving at their desired speeds uniformly distributed between 100 Km/hr and 110 Km/hr, 40% of the vehicles are moving at their desired speeds between 90 Km/hr and 100 Km/hr, etc.

\[ \text{D. Wireless Radio} \]

The transmission range of the wireless radios used in these vehicles is varied from 100 to 150 meters with an increment of 10 meters. This range is a reasonable setting for the DSRC standard proposed for ITS applications.

IV. STUDIED PERFORMANCE METRICS

The studied performance metrics are described in this section. For each metric, we analyze and show its performances in 12 different cases, which are the combination of the studied path population and the used wireless transmission range.

We classify all unicast paths in the highway system into two path populations and report their performances separately. We decide not to report the performances of the aggregation of these two populations because we found that some of their performances differ significantly and it is better not to mix them.

The first population (SameDir) consists of all of the paths whose source and destination vehicles are moving in the same direction in the highway system. The second population (DiffDir), on the other hand, consists of all of the paths whose source and destination vehicles are moving in different directions in the highway system. It is clear that the aggregation of these two populations represents all of the paths in the highway system.

The tested wireless transmission range are 100, 110, 120, 130, 140, and 150 meters, respectively. Since each of these six ranges is applied to each of the two path populations, we have 12 different cases in total. In the rest of the paper, they are named SameDirWRrange100m, SameDirWRrange110m, ... SameDirWRrange150m, and DiffDirWRrange100m, DiffDirWRrange110m, DiffDirWRrange150m, respectively.

A. Lifetime Percentage Distribution

The first performance metric is the lifetime percentage distribution of all of the paths in a particular case. We define the lifetime of a repairable unicast path between two vehicles as the duration in which there exists one path between them. That is, during this period these two vehicles can find a path to exchange their messages, even though this path may no longer exist. If the path does not break in this second, we repeat this connectivity test in the next second.

Suppose that a path is found to be broken in M'th second, we will try to find the shortest backup path between the source and destination vehicles. If no such backup path can be found, the lifetime of this repairable unicast path is now determined and it is (M+1) - N. If such a path can be found, the old path is replaced with this new path and its connectivity will be tested in each subsequent second as before.

The lifetime percentage distribution is useful. It gives us a sense of how long generally an established path can last. We can also use this distribution to compute the expected lifetime of a path in a particular case. Clearly, we prefer to see long lifetime rather than short lifetime for these paths. Otherwise, many useful unicast-based applications such as email, ftp, http, and telnet are unlikely to be useful on an IVC network.

B. Path Repair Time Interval v.s. Lifetime

This metric is the relationship between the lifetime of paths and their corresponding path repair time interval. The path repair time interval of a path is defined as follows. Suppose that a path starts at T0 and during its lifetime it experiences N successful path repairs at T1, T2, T3, ..., TN, respectively. Then the path repair time interval of this path during its lifetime is defined to be \((T_1 - T_0) + (T_2 - T_1) + \ldots + (T_N - T_{N-1}) \)/N. After the path repair time intervals of all paths are calculated, for each specific lifetime, we then calculate the average of the path repair time intervals of all paths whose lifetime is the same as that specified.

This performance metric shows how frequently a routing protocol needs to use its path repair design to extend a path’s lifetime. Clearly, we prefer to see a long path repair time interval, otherwise constantly triggering the path repair design will incur much control packet bandwidth overhead and hurt TCP performance greatly.

V. SIMULATION RESULTS

A. Lifetime Percentage Distribution

Figure 2 shows the percentage distributions of the lifetime of SameDir paths under six different wireless transmission ranges. Figure 3 instead shows the distributions of the lifetime of DiffDir paths. The Y axis shows the fraction of the paths whose lifetime is exactly a specific value in the 300-second trace. The X axis shows the range between 1 and 50 seconds rather than the whole range between 1 and 300 seconds. This is because for these cases, over 63% of all paths in the trace have a lifetime less than 50 seconds. As such, we focus only on this range to see the details.

The percentage distributions of these cases give us several insights. First, as wireless transmission range increases, more
paths have a longer lifetime. On the other hand, as wireless transmission range decreases, more paths have a shorter lifetime. This phenomenon is reasonable as when wireless transmission range is large, it is easier to find a neighboring vehicle to repair a broken path and extend its lifetime. Second, surprisingly, the distributions for the SameDir and the DiffDir suites are almost identical. This means that, given the same wireless transmission range, if a path can be set up between two vehicles, no matter whether it is in the SameDir or DiffDir path population, its expected lifetime would be about the same.

**B. Path Setup Probability**

Figure 4 shows the path-setup probability under different wireless transmission ranges. The probability is calculated by dividing the total number of paths in a case by the theoretically maximum number of paths in a case, which is 300 * (2000 *(2000 - 1))/2 = 599,700,000 and means that in each second of the 300-second trace period, a path can be set up between every pair of the 2,000 vehicles.

First, we see that as expected, when wireless transmission range increases, the probability that a path can be set up between a pair of vehicles increases as well. Second, we see that for this traffic density (2,000 vehicles in the simulated highway system), using a wireless transmission range of 150 meters can already increase the path-setup probability to about 90%. Lastly, we see that since these curves get flattened when the transmission range is close to 150 meters, using a wireless transmission range larger than 150 meters will not further increase the path-setup probability significantly.

**C. Path Repair Time Interval v.s. Lifetime**

Figure 5 and Figure 6 show the relationship between the path repair time interval of SameDir/DiffDir paths and their corresponding lifetime, respectively. First, from the absolute performance numbers of these curves, we see that, regardless of the used wireless transmission range, the path repair time interval for all lifetimes is very short and is only between 1 and 1.2 seconds. This is a bad news as the path repair design of a routing protocol will need to be triggered very frequently and thus cause much control packet bandwidth overhead.

Second, we see that using a longer wireless transmission range only increases the path repair time interval minimally, which is against our first thought that using a longer range would be able to increase the path repair time interval. We found that this phenomenon can be explained and it is caused by using the shortest path between a pair of vehicles. When we increase the wireless transmission range, due to the property of the shortest-path algorithm used in a routing protocol, the neighboring vehicles on a found path will be separated as far as possible. This results in each vehicle on the path almost standing on the boundary of the wireless transmission ranges of its neighboring vehicles. As such, using a longer transmission range will not increase the path repair time interval much unless a non-shortest-path algorithm is used.

Third, we see that the SameDir and DiffDir path populations exhibit the same path repair time interval v.s. lifetime.
relationship. This suggests that when setting up a path, we do not need to care about whether the source vehicle is moving in the same direction with the destination vehicle, because the frequency of triggering the path repair design will be about the same.

VI. FUTURE WORK

In the future, we plan to use the NCTUns 2.0 network simulator [20] to study how real-world protocols would perform on IVC networks. NCTUns 2.0 can take VISSIM’s vehicle mobility trace output as its input and uses real-world TCP/IP protocol stack and applications to generate high-fidelity simulation results. This makes it a suitable tool for studying IVC-related problems.

VII. CONCLUSIONS

In this paper, we study the effects of wireless transmission range on the lifetime of routing paths in an IVC network. Our results show that using a longer wireless transmission range can increase the expected lifetime of a repairable path in an IVC network. Also, the path-setup probability in an IVC network at any time can be increased as well. However, our results show that if a routing protocol seeks to find and use the shortest path between a pair of nodes, using a longer wireless transmission range will not significantly increase the expected path repair time interval.

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