INTEGRATING INTER-VEHICLE COMMUNICATION WITH ROADSIDE WIRELESS ACCESS POINTS TO PROVIDE A LOWER-COST MESSAGE BROADCASTING SERVICE ON HIGHWAYS

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ABSTRACT

Intelligent Transportation Systems (ITS) is an important research topic. One important function of ITS is to broadcast emergent traffic information to vehicles so that they can avoid a dangerous or congested zone in time. This paper investigates the use of inter-vehicle communication to assist roadside wireless access points to provide a lower-cost message broadcasting service on highways.

I. INTRODUCTION

Intelligent Transportation Systems (ITS) is an important research topic. ITS aims to provide drivers with safer, more efficient, and more comfortable trips. For example, ITS aims to provide drivers with timely traffic congestion and road condition information so that drivers can avoid congested or dangerous areas. Message broadcasting for vehicles can be done by using wide-area wireless technologies such as GPRS or 3G cellular networks [1]. Due to the wide-area property of these networks (e.g., the radio range of a GPRS base station can be up to 35 kilometers), only a few base stations are needed to provide broadcasting services for vehicles on highways.

Although using wide-area wireless networks to provide broadcasting services for vehicles is feasible, it has the following drawbacks. First, its cost is high. The cost of GPRS and 3G base stations and their client-side network interface cards are very high. For example, without the subsidy provided by telephone companies, the price of a mobile phone with a 3G interface is still very high. Second, the bandwidth provided by these networks for a user is very low. For example, the popular 3+1 (time slots) GPRS package offers a user only 36 Kbps/12 Kbps bandwidth for his (her) downlink/uplink, respectively. Third, because of the long range of the radio, the spatial reuse of wireless channels is poor. As such, the total capacity of such a wireless network is small. Fourth, due to the large coverage of such networks, a message cannot be targeted to the vehicles in a certain zone to provide location-specific information services.

An alternative is to deploy a large number of IEEE 802.11(a/b/g) wireless access points along the highway to provide a message broadcasting service. An IEEE 802.11(a/b/g) access point provides a much higher bandwidth than GPRS and 3G network. For example, IEEE 802.11(b) provides 11 Mbps while IEEE 802.11(a/g) provides 54 Mbps. This allows a long message to be transmitted in a much shorter time, allowing drivers to respond to an emergent event more quickly. The effective radio range of such an access point is about 100 meters. This allows it to have good spatial reuse of wireless channels and thus increase the total capacity of the wireless network. In addition, this enables it to provide localized message broadcasting services for vehicles in a certain zone. Nowadays an IEEE 802.11(a/b/g) access point costs much less than a GPRS or 3G base station. As such, it is feasible to deploy many of them along the highway to provide a high-bandwidth message broadcasting service for vehicles.

Recently, in the ITS research community, inter-vehicle communications (IVC) has attracted the interests of many automobile manufactures and researchers. In such a scheme, each vehicle is equipped with a wireless radio. A vehicle can use the radio to send its messages, receive messages from other vehicles, or forwards messages of other vehicles. The vehicles on the roads dynamically form a mobile ad hoc network (MANET) at any time. Information can distributed, acquired, or exchanged on top of this network. Such an information network is a type of MANET. In the following of this paper, for brevity, we will simply call such a vehicle-formed MANET an IVC network.

Since IVC can be used to distribute messages among vehicles, it can help roadside IEEE 802.11(a/b/g) wireless access points to “broadcast” messages to vehicles. “Broadcast” here actually means “distribute.” This is because when a message is broadcast by an access point, it may be received by only a few vehicles around the access point due to the short radio range. These vehicles then rebroadcast the received message, causing more vehicles to receive this message. This re-broadcast process can repeat until all desired vehicles have received this message. Many techniques have been proposed in the literature (e.g., [2]) to reduce the number of rebroadcast messages while keeping the message delivery ratio high.

This paper investigates the effectiveness of IVC on reducing the number of wireless access points that need to be deployed along the highway. The study is focused on whether IVC can allow us to increase the distance between two neighboring access points without reducing the message delivery ratio too much. If this is feasible, the cost for purchasing many access points can be saved. Otherwise, due to the 100-meter short radio range, many access points will be needed. In addition to the purchasing cost, a lot of cost incurred in providing power to access points, connecting them to fixed Internet, maintaining and fixing them, etc. can be avoided.

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In this paper, we use a more realistic vehicle mobility trace generated by the VISSIM [3] microscopic traffic generator to conduct simulation studies. Our simulation results show that using IVC can reduce the number of required wireless access points at the cost of decreased message delivery ratio. As for the decreased amount, it depends on the combination of AP distance and radio penetration rate (i.e., the percentage of vehicles having a radio).

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 and presents the results. Finally, we conclude the paper in Section V.

II. RELATED WORK

In the literature, several papers have discussed and studied the applications of MANET to IVC networks. Due to the paper length limit, we can only briefly describe them here.

In [4], the authors showed that messages can be delivered more successfully, provided that messages can be stored temporarily at moving vehicles while waiting for opportunities to be forwarded further. In [5, 6], the authors studied how effectively a vehicle accident notification message can be distributed to vehicles inside a relevant zone. In [7], the authors focused on how to establish a direct transmission link between two neighboring vehicles. In [8], the authors studied the lifetime of routes in ad hoc networks assuming that node mobility can be described by a simple mathematic model.

In [9], the authors compared the packet delivery ratio of a location-based routing protocol with that of a topology-based routing protocol on a simulated highway IVC network. In [10], the authors proposed a position-based routing protocol for IVC networks in city environments. In [11], the author studied the effectiveness of distributing information on an IVC network. The authors in [12] proposed a practical routing protocol for vehicles moving on the roads. The author in [13] studied the effects of wireless transmission range on path lifetime in an IVC network.

Most of the work focuses on setting up and maintaining a routing path between two vehicles in an IVC network. In contrast, this paper differs from these works in that it focuses on the message broadcasting service for informing vehicles with important events or conditions. Since messages are mostly short and they are distributed in an IVC network by a rebroadcasting scheme, how to easily set up and maintain routing paths in an IVC network and how path lifetime is distributed are not the focuses of this paper.

Recently, in [14], the authors studied the strategy used to deploy wireless access points for outdoor wireless local area networks. Although they also studied the effects of AP distance on the performance of an outdoor wireless local area network, there are some important differences between the two papers. First, the approach taken in their paper (analytical) is different from that taken in this paper (trace-based simulation). Second, the performance metrics studied in their paper (throughput, link utilization) are also different from those studied in this paper (message delivery ratio and message hop count distribution).

III. SIMULATION SETTINGS

A. Traffic Simulator

The microscopic traffic simulator that we used to generate mobility traces of vehicles is VISSIM 3.60, which is a commercial software developed by PTV Planung Transport Verkehr AG company, located in Germany. VISSIM uses the psychophysical driver behavior models developed by Wiedemann [15, 16] 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. According to the user manual, the models have been calibrated through multiple field measurements at the Technical University of Karlsruhe, Germany. In addition, field measurements are periodically performed to make sure that updates of model parameters reflect recent driver behavior and vehicle improvements.

B. Highways System

The topology of the highway is a rectangular closed system with 4 circular corners and has 3 lanes in each direction. 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 simulated hour in each direction. After all vehicles have entered the system, they move freely in the highway system according to their respective desired speeds, vehicle characteristics, and driving behavior.

Since vehicles are assigned different desired speeds and different thresholds for changing lanes for achieving their desired speeds, a vehicle may thus (1) move at its desired speed when there is no slower vehicle ahead of it, (2) follow the lead vehicle patiently, which may happen when the lead vehicle is slower but the difference between the lead vehicle’s speed and its own desired speed is still tolerable, or (3) decide to change lanes to pass the lead vehicle if the speed difference is intolerable.

The vehicle mobility traces are taken after all vehicles have entered the highway system and have been moving for at least one simulated hour. Ten traces are taken and each one lasts for 300 seconds. In this paper, the reported performance results are averaged results from these traces. We have also computed the standard deviation of a performance metric from these traces. These standard deviations usually are less than 5% of their corresponding averages. To make performance curves easy to read rather than being cluttered up with standard deviation points, in the presented performance plots, only average points are plotted and standard deviation points are omitted.

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. Wireless Radio

The transmission range of the wireless radios used in both vehicles and roadside wireless access points is chosen to be 100 meters. It is a reasonable setting for the DSRC (Dedicated Short Range Communication) standards proposed for ITS applications.

Since this paper focuses only on the connectivity among vehicles rather than the achievable data transfer throughput among vehicles, this paper does not consider the bandwidth vehicles rather than the achievable data transfer throughput.

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D. Roadside Wireless Access Points

Along the highway, roadside wireless access points are deployed at the center of the six lanes of the highway (see Figure 1). Because the radio range is 100 meters, if the distance between two neighboring access points is less than 200 meters (2 * radio range), every vehicle will be able to connect to an access point at any time, resulting in 100% message delivery ratio. Because the result is intuitive, the distances studied in this paper are all greater than 200 meters and they are 500, 1000, 1500, and 2000 meters, respectively.

E. 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. This car-following distance is typical of a highway in which many vehicles use the highway but they move smoothly without congestion.

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 set to be [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. We think that this distribution is typical of a highway in which various types of vehicles exist.

F. Radio Penetration Rate

Radio penetration rate means the percentage of vehicles that are equipped with a wireless radio and participate in the IVC network. Because it is unrealistic to expect that all vehicles on the roads are equipped with a wireless radio to participate in the IVC network, we varied this parameter to see its effect. Eight different values are tested and they are 30%, 40%, 50%, 60%, 70%, 80%, 90%, and 100%, respectively.

For each specific penetration rate, a certain number of vehicles are randomly chosen to participate in the IVC network. For example, if the total number of vehicles in the highway system is 2,000 and the penetration rate is 50%, we will randomly choose 1,000 vehicles to participate in the IVC network.

IV. PERFORMANCE METRICS AND RESULTS

A. Message Delivery Ratio

In this study, the traffic monitoring and management center (TMMC) broadcasts a message to all vehicles on the highway in every second of the trace. To do this task, it sends the message to all roadside wireless access points and asks each of them to broadcast the message once. As presented previously, vehicles receiving this message will use IVC to re-distribute the message until all reachable vehicles have received it. Those vehicles that cannot be reached by either wireless access points or IVC will not receive the message. The message delivery ratio is defined to be the number of vehicles receiving the message divided by the number of vehicles that are equipped with a radio on the highway. For reliability concerns, this ratio should be as high as possible.

Figure 1 shows the message delivery ratios under different radio penetration rates and AP distances. We see that when the radio penetration rate is high (say, 100%), the message delivery ratios under different AP distances remain about the same and all are close to 100%. This is a good news as it indicates that the number of roadside wireless access points can be greatly reduced. For example, we see that the message delivery ratio when the AP distance is 2000 meters is close to 100%. Compared to a fully-deployed configuration where the AP distance is less than 200 meters, about 90% of the total access points can be avoided while achieving the same level of message delivery ratio.

We also see that as the radio penetration rate decreases, the message delivery ratio decreases as well, and this trend is clear when the AP distance is large. This phenomenon is expected as IVC will become less effective to distribute messages when fewer vehicles participate in the IVC network. To overcome this reliability problem, the TMMC can “broadcast” the message multiple times at slightly different times. According to the probability theory, the probability of eventually receiving a message will be greatly increased. For example, although the message delivery ratio when the radio penetration rate is 30% and AP distance is 2000 meters is only about 0.43, if the TMMC broadcasts the same message five times, the message delivery ratio will be increased to 1 − (1 − 0.43)^5, which is 0.94. This suggests that when the traffic density is low (e.g., at midnight), when the radio penetration rate is low, or when the AP distance is large, the TMMC should rebroadcast the same message multiple times to achieve a higher level of reliability.

B. Average Message Hop Count

This performance metric concerns the average number of hops that a message needs to traverse on the IVC network to reach a
vehicle. If on average a message needs to traverse a large number of hops to reach a vehicle, it may cause several problems. First, the message will be delayed by a large amount of time and this is bad for emergent notification messages. Second, the message will need to be rebroadcast many times on the IVC network and this will waste bandwidth. For these reasons, the average message hop count should be as small as possible.

The hop count of a message to a vehicle is defined to be the minimum number of hops that a message needs to traverse to reach that vehicle. It is the length of the shortest path from any roadside wireless access point to that vehicle. Since the TMMC broadcasts a message in every second, we record the hop counts of the message to all reachable vehicles in every second of the trace. Finally, these recorded hop counts are averaged to generate the average message hop count of a case.

Figure 2 shows the average message hop counts under different radio penetration rates and AP distances. We see that when the AP distance is not large, the average message hop count remains about the same under different radio penetration rates. For example, the average message hop count remains about 3 for the AP distance = 500 meters case. We also see that the average hop counts of such cases match what are expected quite closely. For example, when the AP distance is 1000 meters, because very likely a vehicle can reach its nearest access point within 1000/2 = 500 meters, the required number of hops to reach an access point is about 500/100 = 5 hops, where 100 is the radio transmission range in meters. On the other hand, when the AP distance is 1000 meters, the radio penetration rate begins to play an important role. For example, when the AP distance is 2000 meters, the average message hop count decreases as the radio penetration rate decreases. This phenomenon can be explained as follows. When fewer and fewer vehicles participate in the IVC network, the chance that a message can be continuously relayed over multiple hops becomes smaller and smaller. As such, the average message hop count decreases with the radio penetration rate when AP distance is large.

C. Message Hop Count Distribution in Percentage

Figure 3 shows the percentage distribution of the message hop counts under different AP distances when the radio penetration rate is 100%. This figure clearly confirms our explanation above that the average message hop count under a specific AP distance is roughly equal to \((\text{AP distance}/2)/100\), where 100 is the radio range in meters. For example, for the AP distance = 1500 meters case, we see that most vehicles can use less than 8 hops to reach its nearest access point to receive a message. This trend is evidenced by the fact that the percentages of hop counts higher than 8 diminish very rapidly. One interesting finding is that the percentages of hop counts below this “threshold” are about the same. This means that below this “threshold,” the chance of using a certain number of hops to reach an access point is about the same for different number of hops. We note that the chance of a vehicle using a hop count larger than this threshold still exists, although it is small. This phenomenon is evidenced by the non-zero percentages of message hop counts that are higher than the “threshold” in Figure 3. It is possible that a vehicle, although physically closer to an access point than to another access point, has no path to connect itself to the former access point but instead has a long path to connect itself to the latter access point.

V. CONCLUSIONS

In this paper, we investigate the effects of using IVC on reducing the required roadside wireless access points. The goal is to provide the same level of message delivery ratio for vehicles on highways. We used a more realistic vehicle mobility trace generated by the VISSIM microscopic traffic simulator to conduct simulation studies. The system parameters studied include the radio penetration rate and the distance between neighboring wireless access points.

Our results show that using IVC to reduce the required roadside wireless access points but at the same time maintain the message delivery ratio is possible when the AP distance is not too large or the radio penetration rate is not too small. For the
situation when the AP distance is large and the radio penetration rate is small, the message delivery ratio may decrease to a small value such as 43%. To overcome this problem, it is suggested that the traffic monitoring and management center broadcasts the same message multiple times at slightly different times. From the probability theory, this approach can increase the message delivery ratio to any desired high value at the cost of wasted bandwidth and increased message latency.

REFERENCES


