An Intersection Collision Warning System using Wi-Fi Smartphones in VANET

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Abstract—Intersection collision warning system has been widely studied with the progress in wireless communication technology and positioning devices, which are now increasingly available on smart phones. In this paper, we present an Intersection Collision Warning (ICW) system using Wi-Fi smart phones with built-in GPS receivers for vehicular ad-hoc networks. In the system, smart phones first retrieve safety-related information, i.e., location, moving direction and velocity, via onboard GPS receivers and then periodically exchange the information using standard wireless communication between vehicles to compute the probability of potential collision and issue warnings when necessary. Simulation results show that our ICW system can significantly reduce the probability of collisions.

I. INTRODUCTION

A Vehicular Ad-Hoc Network (VANET) is a form of mobile ad-hoc network (MANET). It integrates a variety of wireless technologies, including Wi-Fi IEEE 802.11 b/g, WiMAX IEEE 802.16, and Bluetooth, to facilitate communications between vehicles in the vicinity.

Various types of applications using VANET have been devised, including collision avoidance [1], emergency management [2], traffic management [3], and infotainment [4]. Safety applications such as intersection crash warnings, blind spot warnings, and road sign alarms have been studied intensively.

Intersection Collision Warning (ICW) is an important class of safety applications. It alerts drivers of the traffic situations at critical spots (e.g., at the intersection) by providing reliable and timely warnings that vehicles are approaching the intersection and therefore prevent intersection collisions. Early results have shown that collision warning systems could significantly reduce crash fatality and property damage [5].

We note that when multiple vehicles are approaching an intersection at about the same time, it could help avoid potential collisions if the drivers know the information of all the vehicles in the vicinity, including location, velocity, and moving direction. Fig 1 depicts a simple but common scenario. Vehicle 1 is a small vehicle which is on its way from west to east and Vehicle 2 is also a small vehicle which makes a left-turn from east to south. Vehicle 3 is of large size, causing a blind spot for the driver of Vehicle 2. Vehicle 2 turns to left without noticing Vehicle 1 is coming across the intersection and a collision would occur. If an ICW was applied as extra eyes for driver’s blind spot, the driver of Vehicle 2 could have been warned of the potential hazards ahead and made appropriate actions to avoid the collision.

A vehicle receiving such messages from its neighbors before approaching the intersection may be able to predict a potential collision with vehicles entering the intersection from other intersection lags. While such information may be collected via onboard sensing devices, e.g. radars, LIDAR, and vision sensors [6], which may be transmitted between vehicles using wireless communication devices installed on vehicles [7], [8], [9], [10], we note that installing these ranging sensors and wireless devices may carry a high price tag, and thus may not be practical for most vehicles.

We present an alternative solution using smart phones. Typical smart phones are equipped with GPS, camera, audio, video, and other types of sensors. They support various communication protocols such as 2/3G, Wi-Fi, and Bluetooth. Moreover, a fast increasing number of drivers are carrying smart phones. According to ComScore’s study, in 2010 over 45.5 million people in the United States owned smart phones. Taking advantage of the sensing, computation and communication functionalities of smart phones, we devise an innovative and affordable intersection collision warning system. It uses a dynamic ad hoc wireless network formed by smart phones for information exchanging. Based on the location, moving direction and velocity in the information, the system estimates
the time for a potential collision and appropriately warns the drivers to avoid the collision. We carry out extensive performance evaluation of the system.

The rest of the paper is organized as follows. Section II describes related work. Section III presents the design of our intersection collision warning (ICW) system using Wi-Fi on smart phones. The performance of ICW is analyzed in Section IV. We conclude the paper in Section V.

II. RELATED WORK

A number of collision warning systems over vehicular ad hoc networks have been proposed in recent years. Most of the systems are designed for forward collision warning [1], [11], [12], [13], [14]. The most relevant to our research are [15], [16], [17], [18].

In [16], the vehicles cooperatively share their locations, speeds, and travelling directions for collision prediction so that drivers are warned if their vehicles’ estimated time-to-collision to an intersection is close to time-to-avoidance and they have not taken any appropriate action before the warning. The authors stated that the wireless communication range, network delay, vehicle velocity, driver response time and the accuracy of location and velocity data had critical effects on the design of a collision warning system, but they did not provide convincible evaluation on these factors.

In [15], an inter-vehicle communication (IVC) simulator was developed to evaluate an ICW system. Vehicles use GPS receivers and digital maps to locate the position of intersections and then begin to broadcast similar information at a certain distance from the intersection. The authors claimed that under their pre-fixed broadcast mechanism and traffic load, where 20 vehicles broadcast 64-byte packets 50 meters away from the intersection, packets were unlikely to collide. They also conducted detailed simulation in [17], where transmission interval, traffic flow, and traffic signal effects on collision percentage and collision speed were studied.

Our work differs from the previous studies in three aspects: (1) We use two important QoS metrics of packet delivery ratio and end-to-end delay to evaluate the proposed ICW system performance. (2) We study the tradeoffs between transmission interval, vehicle velocity, traffic flow, and network throughput. (3) We retrieve all the necessary information among vehicles through wireless transmission via smart phones at no extra cost to users. As in most other collision warning systems, we use onboard sensing devices and wireless communication devices. We also use roadside infrastructures whenever possible, even though we do not require them.

Previous study has used smart phones for communication in VANET. For example, the authors in [18] developed a collision avoidance support system using Wi-Fi smart phones with built-in GPS receivers to compensate the drawback of vision corner for optical-based collision systems. However, their system requires a HotSPot created by an AP with a high gain antenna, which may not be available for certain application environments. Utilization of AP is also subject to the AP flooding problem. In our system, we use smart phones to form an ad-hoc network and share information among vehicles.

Auto manufacturers are also making efforts to connect vehicles to drivers’ smart phones. Most of the designs intend to use smart phones as remote control of the car. Mercedes-Benz, for example, announced recently a new telematics platform that improves its navigation system with traffic and weather information and lets drivers lock or unlock their cars using an iPhone or BlackBerry. Smart phone applications are also developed so that drivers can proactively track their cars’ maintenance schedule and vehicle-related information, such as fuel expense and mileage. Recently, Chrysler has announced a smart phone application for the 2011 Jeep Grand Cherokee. The application is capable of downloading vehicle information such as warning lights, maintenance schedules, warranties, and roadside assistance.

To the best of our knowledge, our system is the first to utilize Wi-Fi smart phones with built-in GPS receivers for intersection collision warning. We have conducted extensive simulation study to evaluate the system performance and the results show that our system can significantly reduce collisions at intersections.

III. INTERSECTION COLLISION WARNING SYSTEM

We assume that each driver in the ICW system carries a Wi-Fi GPS smart phone. With the built-in GPS receiver and digital map, the smart phone is able to locate the positions of intersections. When a vehicle enters the intersection area, the smart phone carried by its driver will broadcast periodically its current location, moving direction, and velocity to smart phones on all neighboring vehicles in its transmission range. The smart phones on the neighboring vehicles that receive these messages will calculate the probability of route contention for the host vehicle and its neighboring vehicles. Based on the estimated degree of danger, a smart phone will issue a warning message to the driver.

Our intersection collision warning system is based on the following two steps: potential collision detection and warning.

A. Potential Collision Detection

Detecting potential collision can avoid dangerous situations before they occur. Assume that two vehicles A and B at \((x_1, y_1)\) and \((x_2, y_2)\) are moving with the velocity vectors \((u_1, v_1)\) and \((u_2, v_2)\), respectively, and the coordinates for intersection is \((x_0, y_0)\), as depicted in Fig 2.
When we look at a particular vehicle, we will refer it to as a host vehicle. By route contention it means the possibility of collision if the host vehicle and its neighboring vehicles arrive at the intersection at the same time [16]. For each vehicle, based on the vehicle-related status message received from all its neighboring vehicles, the ICW first computes the relative location of the transmitting vehicle to intersection. Then the expected time-to-intersection (TTX) for each vehicle is determined. For example, vehicle A and vehicle B are expected to arrive at intersection at TTX_1 and TTX_2, respectively, where

\[ TTX_i = \sqrt{\frac{(y_i - y_0)^2 + (x_i - x_0)^2}{v_i^2 + u_i^2}}, \quad i = 1, 2 \]  

(1)

If TTX_1 = TTX_2, then vehicle A and B are expected to arrive at the intersection at the same time, and a route contention occurs.

Given that the vehicles have sizes and the intersection is actually a four-lane four-way area, we may use the following rule to detect route contention,

\[ |TTX_1 - TTX_2| < c \]  

(2)

where c is a parameter for comparison. A smaller value of c will yield a higher accuracy.

Route contention is computed between a host vehicle and all of its neighboring vehicles. To reduce the computation, moving directions are used to filter messages that will not generate route contentions. For instance, if an adjacent vehicle is moving in the same direction as the host vehicle, the message from that vehicle is ignored as long as it does not change direction at the intersection. In addition, once a vehicle passes through the intersection, it stops sending messages, indicating no contention for the route.

B. Warning

Once a route contention is detected, a warning is issued based on the threat level. The driver should only be alarmed for the potential collision if he/she is unaware of. If the driver has already reacted to the potential hazards, the warning should be discarded. A simple way to issue a warning is as long as there is enough time for the driver to take appropriate action to avoid the collision.

Assuming a full stop is taken as the avoidance method, then the expected time-to-avoidance (TTA) for each vehicle is determined as:

\[ TTA = RT + \frac{v}{\mu g} \]  

(3)

where \( v \) is the current speed, \( \mu \) is the friction coefficient, \( g \) is the gravitational acceleration, and RT is the driver’s Response Time.

A warning is issued if \( TTX < TTA \). In some cases, the drivers can avoid a collision by reducing certain amount of the speed rather than a full stop. Therefore, we add a positive parameter \( \alpha \) to give a better conservative warning:

\[ TTX < TTA + \alpha \]  

(4)

Our simulation results are detailed in next section.

IV. PERFORMANCE EVALUATION

In this section, we outline the simulation environment and performance metrics used for our performance evaluation and then provide the simulation results.

A. Simulation Environment

Among many possible intersection scenarios, we focus on a simple four-way four-lane crossing that each intersection has two lanes, as shown in Fig 1. For some specific scenario, a traffic signal may exist in the middle of the intersection to regulate the traffic. In this paper, we mainly focus on the scenario without traffic signals, where all vehicles must stop at the intersection before proceeding. Simulation parameters and environment properties are discussed below.

1) Intersection area: This value specifies the distance from the intersection at which smart phones will perform data transmission. The area covers the rectangle centering at the intersection as depicted the bold dotted rectangle in Fig 1. A vehicle starts to broadcast messages once it enters the area and stops communication after it moves out of the area. Similarly, safety-related message are analyzed only when the vehicle is in this area. We define the intersection area in our simulation as from 80m by 80m to 320m by 320m.

2) Vehicle Speeds: There are various vehicle types on the road: cars, buses, motocycles, and trucks, and the driver behaviors can also be different. We assume that vehicles on the same lane and across lanes on the moving side of the intersection have different speeds. The instantaneous speeds of vehicles on each lane are randomly drawn from 10m/s to 30m/s.

3) Intersection traffic flow: This value defines the average number of vehicles that enter and leave the intersection area in one simulation. An appropriate set of traffic flow values is important to the performance evaluation simulating different traffic conditions. Based on the traffic density and the level of service (LOS) [19] of the intersection and for scenarios without traffic signals, the traffic flow is simulated at different values: 1200, 2400, 3600, 4800, 6000 and 7200 vehicles/hour.

4) Number of vehicles: This value defines the total number of vehicles crossing the intersection in a single run. We fix the simulation time at 60 seconds. Therefore, six values are used based on the different traffic flow scenarios in the study: 20, 40, 60, 80, 100 and 120.

5) Transmission interval: Transmission intervals play an important role in collisions reduction. Safety-related messages are broadcasted periodically based on this transmission interval value. While smaller transmission interval can increase the information accuracy with frequent updates, the number of messages is also increased which may lead to a high probability of message collision. This parameter depends on traffic flow, vehicle speeds, and driver’s behavior, among other things.
Table I

| Parameter                        | Value                                      |
|----------------------------------|--------------------------------------------|
| Intersection area ($m^2$)        | $80 \times 80$, $120 \times 120$, $160 \times 160$, $200 \times 200$ |
| Vehicle speed (m/s)              | $10 \sim 30$                               |
| Traffic flow (vehicle/hour)      | $1200$, $2400$, $3600$, $4800$, $6000$, $7200$ |
| Number of vehicles               | $20$, $40$, $60$, $80$, $100$, $120$       |
| Transmission interval (ms)       | $10$, $20$, $50$, $100$, $200$, $400$, $500$ |
| Propagation model                | Two-ray-ground                             |
| Traffic type                     | UDP                                        |
| Message size (byte)              | 100                                        |
| Simulation time (s)              | 60                                         |

The transmission intervals in our simulation vary from run to run among 10, 20, 50, 100, 200, 400 and 500 msec.

In summary, simulation parameters are shown in Table 1. We conducted 20 simulation runs to achieve results with a high level of confidence.

B. Performance Metrics

We adapt two classical metrics of packet delivery ratio and end-to-end delay to evaluate the performance of our ICW system.

1) Packet delivery ratio (PDR): This metric is critical for evaluating the transmission reliability. For a given packet, it is defined as the percentage of vehicles which have successfully received a packet among all vehicles within transmission range. Low delivery ratio may cause the drivers to miss important information and result in accidental events.

2) Transmission delay: It is defined as the average time taken for a safety message to be successfully transmitted across networks from a transmitting vehicle to the receiving vehicles. This metric is also very important for safety applications. Messages not delivered on time could be useless, for the driver may not have sufficient time to react to the imminent collision. Therefore, low delay is preferred for safety applications.

C. Simulation Results

We first investigate the influence of transmission interval on packet delivery ratio and transmission delay. Fig 3 shows the results for a typical intersection area (200m by 200m) with 120 vehicles in different scenarios. Transmission interval varies from 10 ms to 500 ms and vehicle speeds vary at three different ranges: $1 \sim 10$m/s, $11 \sim 20$m/s and $21 \sim 30$m/s. Our results show that lower transmission intervals lead to higher delivery ratios. However, further decreasing transmission interval does not improve the delivery ratio, as excessive messages can cause the medium to be saturated. On the other side, the delivery ratios decrease quickly by increasing the transmission interval, especially for transmission intervals greater than 400ms. The reason is that larger transmission interval implies a smaller number of messages which are prone to be lost due to physical layer errors.

Fig 4 uses the same simulation settings as in Fig 3. The result shows that lower transmission intervals lead to higher transmission delay as the same reason in Fig 3. When the transmission interval increases, the number of packets decreases and the transmission delay gets smaller. Another important observation is that vehicle speed has little impact on transmission delay. This is also verified in Fig 6 and Fig 8.

Based on the results in Fig 3 and Fig 4, we can see that 200ms transmission interval provides relatively high delivery ratio but low transmission delay. Therefore, for the rest simulations, we fix the transmission interval at 200ms to achieve better results.

Fig 5 and Fig 6 have the same simulation settings as in Fig 3 except that the transmission interval is fixed at 200ms and the number of vehicles varies from 20 to 120 based on different traffic flows. As can be seen, delivery ratio decreases as the number of vehicles increases. The reason is obvious, as more vehicles involved in the transmission indicate more messages to be sent and the channel is more likely to be congested. As
This full text paper was peer reviewed at the direction of IEEE Communications Society subject matter experts for publication in the IEEE Globecom 2011 proceedings.

from 80m by 80m to 320m by 320m. We conduct simulations for seven different intersection areas, as the driver may not have enough time to avoid the collision. On the other hand, a late notification of collision warning may be useless, early warning message may distract the drivers. On the other far away from the intersection may not be accurate and a too

Communication starts when the number of vehicles increases.

for the transmission delay, it increases for the same reason when the number of vehicles increases.

Fig 7 and Fig 8 show the results of distance to intersection on delivery ratio and transmission delay. Communication starts far away from the intersection may not be accurate and a too early warning message may distract the drivers. On the other hand, a late notification of collision warning may be useless, as the driver may not have enough time to avoid the collision. We conduct simulations for seven different intersection areas, from 80m by 80m to 320m by 320m.

V. CONCLUSION

We devise in this paper an intersection collision warning system and evaluate its performance using simulation. The proposed system uses Wi-Fi smart phones with built-in GPS receivers to collect and analyze safety-related messages for preventing potential collisions. Our results demonstrate that the proposed ICW approach can have a significant impact on assisting drivers to avoid potential collisions.

ACKNOWLEDGEMENT

This work was supported in part by the NSF under grants CCF-0830314, CNS-1018422 and CNS-0953620.

REFERENCES

[1] J. A. Misener, R. Sengupta, and H. Krishnan, “Cooperative collision warning: Enabling crash avoidance with wireless technology,” in Proc. 12th World Congress on ITS, November 2005.

[2] M. Rocci, M. Gerla, C. E. Palazzi, S. Ferretti, and G. Pau, “First responders’ crystal ball: How to sry the emergency from a remote vehicle,” in Proc. the 1st IEEE International Workshop on Research Challenges in Next Generation Networks for First Responders and Critical Infrastructures (NetCRI 07). IEEE Computer Society, 2007.

[3] Y. Jungkeun, N. Brian, and L. Mingyan, “Surface street traffic estimation,” in MobiSys ’07: Proceedings of the 5th international conference on Mobile systems, applications and services. New York, NY, USA: ACM, 2007, pp. 220–232.

[4] L. Suk-Bok, P. Gabriel, P. Joon-Sang, G. Mario, and L. Songwu, “Secure incentives for commercial ad dissemination in vehicular networks,” in MobiHoc ’07: Proceedings of the 8th ACM international symposium on Mobile ad hoc networking and computing. New York, NY, USA: ACM, 2007, pp. 150–159.

[5] P. Zador, S. Krawchuk, and R. Vocas, “Final report-automotive collision avoidance (acas) program. technical report dot hs 809 080,” August 2000.

[6] NHTSA and I. J. P. Office, “Report to congress on the national highway traffic safety administration its program, program progress during 1992-1996 and strategic plan for 1997-2002,” January 1997.

[7] E. Schoch, F. Kargl, T. Leinemüller, and M. Weber, “Communication patterns in vanets,” IEEE Communications Magazine, vol. 46, no. 11, pp. 119–125, November 2008.

[8] Q. B. Mussabbir, W. Yao, Z. Niu, and X. Fu, “Optimized fmipv6 using ieee 802.21 mh services in vehicular networks,” Vehicular Technology, IEEE Transactions, vol. 56, no. 6, pp. 3397 –3407, November 2007.

[9] C. Sommer and P. Dressler, “Progressing toward realistic mobility models in vanet simulations,” Communications Magazine, IEEE, vol. 46, no. 11, pp. 132 –137, November 2008.

[10] T. Taleb, E. Sakhaee, A. Jamalipour, K. Hashimoto, N. Kato, and Y. Nemoto, “A stable routing protocol to support its services in vanet networks,” Vehicular Technology, IEEE Transactions, vol. 56, no. 6, pp. 3337 –3347, November 2007.

[11] T. Elbatt, S. K. Goel, G. Holl, H. Krishnan, and J. Parikh, “Cooperative collision warning using dedicated short range wireless communications,” in V ANET. ACM Press, 2006, pp. 1–9.

[12] X. Yang, J. Liu, N. H. Vaidya, and F. Zhao, “A vehicle-to-vehicle communication protocol for cooperative collision warning,” in Mobile and Ubiquitous Systems: Networking and Services. MOBIQUITOUS 2004., 22-26 2004, pp. 114 – 123.

[13] S. E. Shladover and S.-K. Tan, “Analysis of vehicle positioning accuracy requirements for communication-based cooperative collision warning,” 2006.

[14] T. Elbatt, S. K. Goel, V. Kukshya, G. Holland, H. Krishnan, and J. Parikh, “Communications performance evaluation of cooperative collision warning applications,” July 2005.

[15] A. Dogan, G. Korkmaz, Y. Liu, F. Özgüner, U. Özgüner, K. Redmill, O. Takeshita, and K. Tokuda, “Evaluation of intersection collision warning system using an inter-vehicle communication simulator,” in Intelligent Transportation Systems, 2004. Proceedings. The 7th International IEEE Conference, 3-6 2004, pp. 1103 – 1108.

[16] R. Miller and Q. Huang, “An adaptive peer-to-peer collision warning system,” in Vehicular Technology Conference, 2002. VTC Spring 2002. IEEE 55th, vol. 1, 2002, pp. 317 – 321 vol.1.

[17] Y. Liu, U. Özgüner, and E. Ekici, “Performance evaluation of intersection warning system using a vehicle traffic and wireless simulator,” in Intelligent Vehicles Symposium, 2005. Proceedings. IEEE, 6-8 2005, pp. 171 – 176.

[18] Y.-J. Chen, C.-C. Chen, S.-N. Wang, H.-E. Lin, and R. C. Hsu, “Gpsensecar -a collision avoidance support system using real-time gps data in a mobile vehicular network,” in ICNC ’06: Proceedings of the International Conference on Systems and Networks Communication. Washington, DC, USA: IEEE Computer Society, 2006, p. 71.

[19] N. J. Garber and L. A. Hoel, “Traffic and highway engineering,” 1999.