SPIVC: A SmartPhone-based Inter-Vehicle Communication System

Wen-Long Jin[1], Candy Kwan, Zhe Sun, Hao Yang, Qijian Gan

Civil and Environmental Engineering
Institute of Transportation Studies
University of California, Irvine
Irvine, CA 92697-3600
Email: wjin@uci.edu

Word Count: 3500+250×12=6500

November 15, 2011

SUBMITTED TO 2012 TRB ANNUAL MEETING

---

[1] Author for correspondence

Abstract

Inter-vehicle communications (IVC) could potentially improve safety, mobility, and fuel efficiency of a transportation system. However, traditional decentralized approaches based on Dedicated Short Range Communications could take a long time to reach a meaningful market penetration rate. In this study, we attempt to take advantage of ubiquitous smartphones and develop an IVC system based on smartphones, called SPIVC. In this system, smartphones on vehicles communicate with a central server and share traffic information with each other. Field tests are carried out on both WiFi and 3G networks to determine the accuracy of GPS devices and communication delays between vehicles. A communication model is developed to explain communication delays. It is found that location errors are about 4 meters after warm-up, and communication delays are in the order of seconds and depend on the frequency of location updates in GPS devices. The SPIVC system, which can be centralized or decentralized, holds great promises for an array of multimodal transportation applications that are not very sensitive to GPS accuracy and communication delay.

Key words: Inter-vehicle communication, smartphones, SPIVC, WiFi, 3G, GPS accuracy, communication delay

1. Introduction

In 1999, the Federal Communication Commission (FCC) allocated the spectrum from 5.850GHz to 5.925GHz for dedicated short range communications (DSRC) *(1)*. A corresponding communication protocol, IEEE 802.11p, is being developed to enable wireless access in the vehicular environment (WAVE). In 2004, the U.S. Department of Transportation initiated efforts in developing Vehicle Infrastructure Integration (VII) systems *(2,3)*, in which information can be shared among vehicles, traffic management centers, various elements of road infrastructure that include traffic signals, message signs, bus stops, and other safety hardware. In recent years, there have been extensive interests in developing Intelligent Transportation Systems (ITS) based on inter-vehicle communications (IVC), including vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications.

1.1 Overview of IVC Systems

As early as in the 1990s, IVC has been used to help drivers respond more promptly to emergencies on a road *(4,5,6)*. In 2002, the CarTalk project in Europe studied Advanced Driver Assistance Systems based on IVC *(7,8)*. These safety-related applications utilize localized information and have acted as important driving forces for the development of IVC technologies. Since the introduction of Carnet *(9)* and Fleetnet *(10)* in 2000, IVC networks have been studied as a special form of mobile ad hoc network (MANET) *(11)*, in which vehicles form a vehicular ad hoc network (VANET). Such a decentralized advanced traveler information system can have many potential applications in alleviating traffic congestion *(12)*. In *(13)*, the so-called Autonet system was proposed as an "autonomous, self-organizing, transportation management, information, and control system".

Figure 1 illustrates an IVC system on the top of a transportation network, where road-side stations, traffic signals, police cars, ambulances, fire trucks, and personal cars can be equipped with IVC devices and can collect, relay, or disseminate messages that are relevant to themselves or others. That is, the overall IVC system is a coupled transportation and communication system.

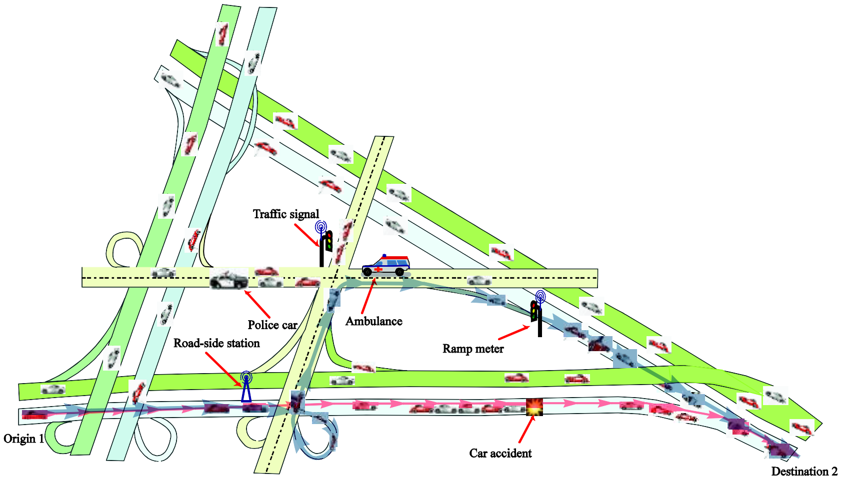


Figure 1. An IVC system: A coupled transportation and communication system

In an example shown in Figure 1, immediately after the occurrence of an incident, a warning message is automatically initiated by a car involved in the incident and relayed through IVC. Minutes later, a region with a radius of miles around the incident spot would be informed about the incident, and IVC-equipped vehicles would change their departure times or routes accordingly. For example, some vehicles on the thinner route from Origin 1 to Destination 2 in Figure 1 would choose the alternative wider route. Decisions on route choices and speed limits can be guided by traffic signals or collectively determined by vehicles. We can see that, in this incident scenario, IVC could potentially improve safety, mobility, energy consumption efficiency, and environmental effects in a transportation network.

1.2 Overview of Smartphones

During the past few decades, the world has witnessed rapid developments in various frontiers of telecommunication and information technologies. Powerful and portable computation and communication devices, such as cellular phones and 802.11a/b/g (Wi-Fi) units, have become ubiquitous and virtually indispensable in daily lives. Compared with the DSRC technologies, whose applications in transportation systems are still in its initial stage of development, cellular networks, especially 3G networks, have been well developed and applied for both collection and dissemination of traffic information since the 1990s. For examples, in *(14)*, vehicle locations are automatically detected through cellular triangulation; cellular networks have also been applied to establish vehicle-to-vehicle communications *(15)*, but such an IVC unit is usually embedded in cars.

Since the introduction of iPhones, smartphones have pervaded the market in an unprecedented pace. According to a survey in May, 2011 (http://blog.nielsen.com/nielsenwire/consumer/android-leads-u-s-in-smartphone-market-share-and-data-usage/), 37% of mobile consumes in the U.S. use smartphones. In addition to powerful processing capabilities and user-friendly interfaces, many smartphones are equipped with GPS, accelerometer, camera, microphone, gyroscope, and other sensors that enable the collection of different types of information. In *(16)*, traffic data were collected through smartphones. In the future, it is probable that DSRC modules be integrated into smartphone. Thus smartphones can be an excellent platform for implementing IVC systems. In *(17)*, smartphones were used to build a sensor network. However, there have been no systematic studies on how smartphones would perform in IVC systems.

In this study, we present an implementation of smartphone based IVC system, called the SPIVC system. With the help of a central server, V2V and V2I communications can be enabled through either WiFi or cellular networks. With field tests, we attempt to determine optimal configurations of smartphones, accuracy of GPS devices, and communication delays. Before the market penetration rate of DSRC devices reaches a meaningful level, the SPIVC system could be readily applied to tackle many transportation problems. Since it is possible that DSRC technologies could be integrated into smartphones in the future, lessons and insights obtained through such efforts could be useful for implementations of DSRC-based IVC. In addition, the SPIVC system is intrinsically multimodal due to the exceptional portability of smartphones. Compared to VANETs, the central server can simplify tasks in communication routing and data management. In addition, it can help to collect data for the purpose of research.

The rest of the paper is organized as follows. In Section 2, we introduce the architecture, implementation, and field tests of the SPIVC system. In Section 3, we discuss GPS accuracy when devices are either static or dynamic. In Section 4, we present a communication model of the system and analyze communication delays between two vehicles. In Section 5, we conclude our study and discuss future directions.

2. Architecture, Implementation, and Field tests

In this study, we attempt to develop a SPIVC system for enhancing the safety of bike riders. In the system, bikes can broadcast their real-time location information to all surrounding cars through WiFi or 3G networks. With this information obtained by surrounding cars, drivers can be alerted as a bike appears within to a certain distance, SPIVC is enabled through a central server: periodically, bikes send their location information to a central server, and cars retrieve nearby bikes' location information from the server. Note that the frequency for a bike to send its location information can be controlled by the bike rider. Compared with a distributed VANET, a centralized SPIVC system can gather both cars and bikes' information without disturbing the client side or slowing down the communication process, and it is easier to address communication security issues since any illegal requests or updates can be filtered out by the central server.

2.1 Architecture

The architecture of the system is shown in Figure 2. On the client side, there are two apps: the bike app installed on the bike phone, and the car app installed on the car phone. The bike app communicates with an Apache Web Server to send its location to a MySQL Database, and the car app sends its request to the Apache Web Server to retrieve nearby bikes' locations from the database.

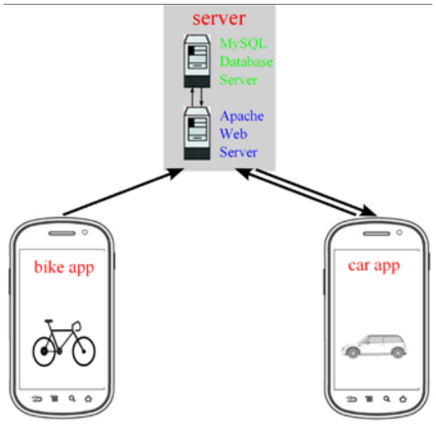


Figure 2. The architecture of the SPIVC system for bike safety applications

Different from the decentralized VANET, this system can be easily implemented on regular smartphones, on which DSRC chips are not yet available. Here IVC is intentionally restricted to be unidirectional from bikes to cars, but communication from cars to bikes can be readily implemented. The simple system architecture helps us to better understand detailed properties of the SPIVC system.

2.2 Implementation

The bike and car apps are developed on the Google Android platform for smartphones (http://developer.android.com/index.html). The program flow-chart is shown in Figure 3. Locations of bikes and cars are obtained from GPS devices through the standard LocationListener service provided by Android. The updating frequency is determined by two threshold parameters, minimum time and minimum distance, in the requestLocationUpdate method of the LocationManager class, where these parameters can be set in the preference options of both apps. In a bike app, the bike's locations and time stamps are stored on both a SD card and the database in a central server, uploaded through http request. In a car app, nearby bikes' locations and time stamps are downloaded from a central server again using http request and then are stored on a SD card along with car's locations and time stamps. Real-time locations of bikes and cars are also shown on Google Maps on the respective phones to help bikers and drivers to understand the surrounding environment. In both apps, we calculate the times for communicating with the central server. In the car app, we also calculate the distance between a bike and a car and the communication delay for a location-time pair, a record containing both location and time stamp information of the bike, from the bike app to the car app.

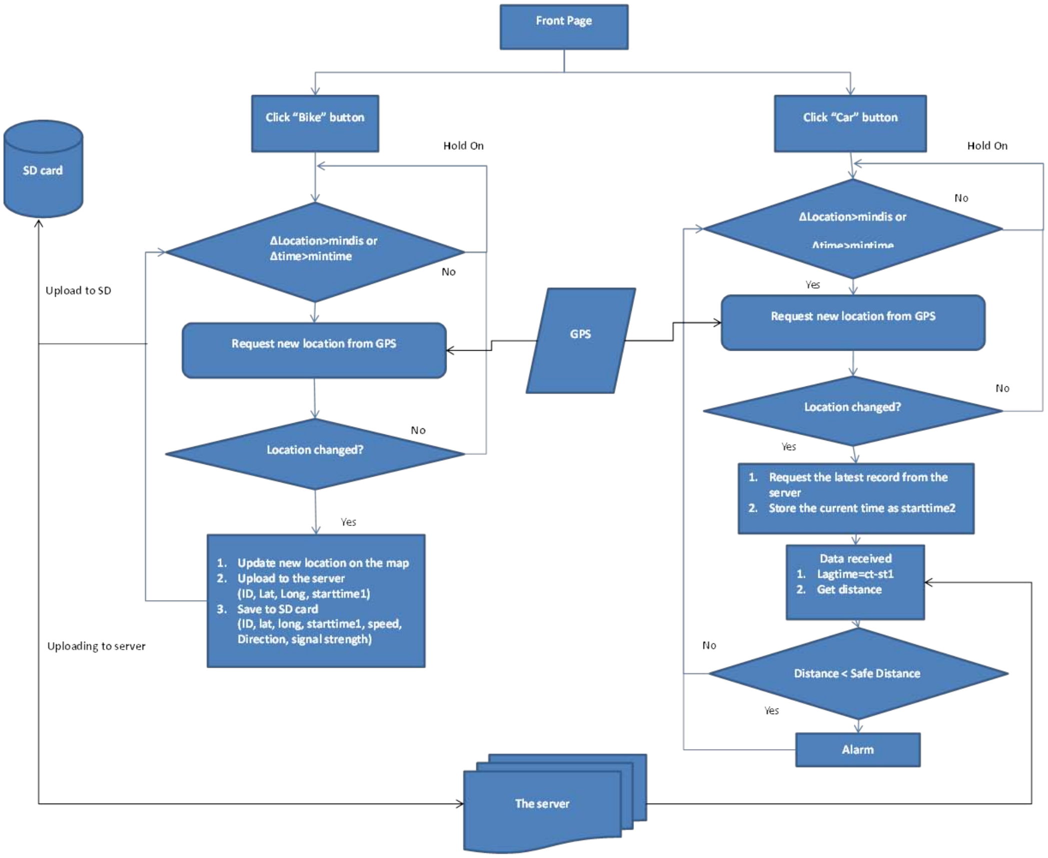


Figure 3. The program flow-chart of the SPIVC system

The central server comprises an Apache Web Server and a MySQL server. PHP scripts on the Apache Web Server handles http requests from both bike and car apps and communicates with a MySQL database, which is used to store bikes' locations and time stamps and corresponding smartphones' IDs.

Scenario	Bike Phone	Car Phone	mindis	mintime
1	Moto/WiFi	HTC/WiFi	0	0
2	Moto/WiFi	HTC/WiFi	0.5	0
3	Moto/WiFi	HTC/WiFi	1	0
4	Moto/WiFi	HTC/3G	0	0
5	Moto/WiFi	HTC/3G	0.5	0
6	Moto/WiFi	HTC/3G	1	0
7	HTC/3G	Moto/WiFi	0	0
8	HTC/3G	Moto/WiFi	0.5	0
9	HTC/3G	Moto/WiFi	1	0

Table 1: Summary of field tests

2.3 Field Tests

With the SPIVC system, we developed test protocols and carried out field tests summarized in Table 1. Two phones, HTC Incredible and Motorola Droid, run the bike and car apps, respectively, and either WiFi or 3G networks are enabled for different scenarios. On both phones, we set different values of mindis (minimum distance: meter) and mintime (minimum time: second) in the requestLocationUpdate method. For each of the nine scenarios, we perform three tests. With data stored on the phones and the server, we compare all the records to make sure that they are consistent.

3. GPS Accuracy

One attractive feature of smartphones is that the embedded GPS devices can provide us real-time location information. However, the accuracy of GPS devices highly determines their applicability in transportation systems. To test the accuracy of GPS, we let a smartphone run the bike app at one static location, and then record its locations over a period of two minutes. Since we cannot obtain the phone's exact location, errors in locations are calculated as the distances between individual locations and the mean location in both longitude and latitude. The distance between two points, $(\mathrm{long}_1, \mathrm{lat}_1), (\mathrm{long}_2, \mathrm{lat}_2)$, is calculated as follows: $\mathrm{d} = \mathrm{R} \cdot \mathrm{c} = 2\mathrm{R} \cdot \mathrm{atan2}(\sqrt{\mathrm{a}}, \sqrt{1-\mathrm{a}})$, where R=6271 km is the earth radius, $\Delta\mathrm{lat} = \mathrm{lat}_1 - \mathrm{lat}_2, \Delta\mathrm{long} = \mathrm{long}_1 - \mathrm{long}_2$, and $\mathrm{a} = \sin^2(\frac{\Delta lat}{2}) + \cos(lat_1)\cos(lat_2)\sin^2(\frac{\Delta long}{2})$.

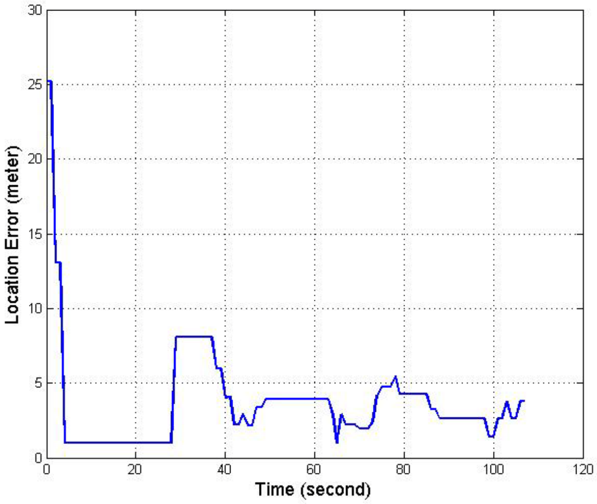


Figure 4. Location errors in one static location

In Figure 4, the bike app at a fixed location is turned on at time 0, and location errors are calculated at different times. From the figure, we can see that the initial location error can be as large as 25 meters. But after about 5 seconds, the location errors decrease to around 5 meters. This suggests that the GPS device on the smartphone has a warm-up time of about 5 seconds.

To further test the GPS accuracy and warm-up times, we first start the bike app and collect its location data at one location, and then move the smartphone to another location and repeat the test. The respective location errors are shown in Figure 5. From the figure, we can see that, if the GPS device is turned on, no further warm-up times are needed when the smartphone moves from one location to another location.

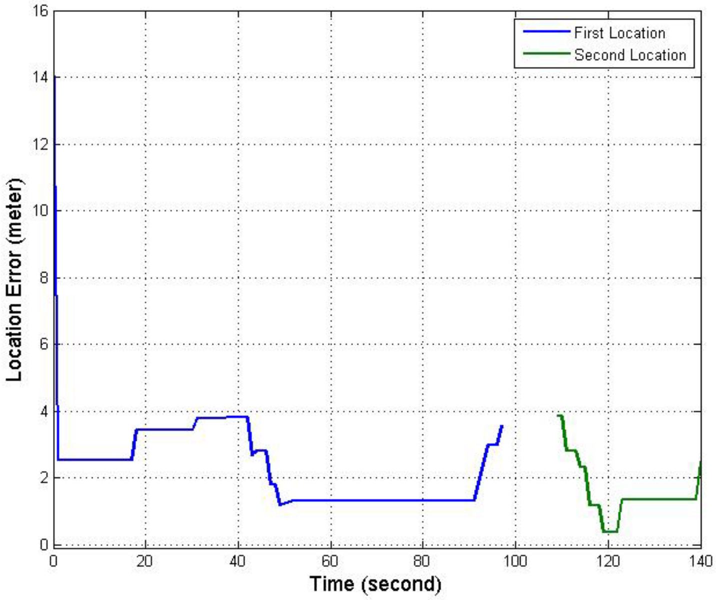


Figure 5. Location errors at two static locations

From both tests, we can conclude that the accuracy of GPS devices on regular smartphones is in the range of 4 meters after they are warmed up, and the impact of mobility on GPS accuracy is inconsequential. However, we should pay attention to GPS devices' warm-up times, since the accuracy could be very low and unsafe for some applications.

4. Communication Delay

Another important feature of the SPIVC system is the communication delay between two connected vehicles. We present a simple model for communications in the SPIVC system in Figure 6. In the figure, d_1 is the time for the bike app to send a location-time pair to the server, d_2 is the time for the car app to send a request to the server, and $\mathrm{d}_2^{'}$ is the time for the server to deliver the latest records of bike location-time pairs to the car app. Suppose that t_1 is the time that the bike phone updates its latest location from its GPS device, and t_2 is the time that the car phone updates its latest location from its GPS device. When $\mathrm{t}_1 + \mathrm{d}_1 \leq \mathrm{t}_2 + \mathrm{d}_2$, the server will send bike's latest location information at t_1 to the car phone. That is, the latest bike's record that the car can obtain at t_2 is at t_1. Thus, when the car app calculates the distance between the bike and the car, there is a communication delay of $\mathrm{D} = \mathrm{t}_2 - \mathrm{t}_1$. In the model, t_1 is determined by the GPS location updating frequency on the bike app, and t_2 by the location updating frequency on the car app as well as the three transmission times, d_1, d_2, and $d_2^{'}$.

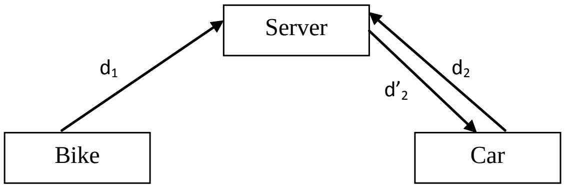
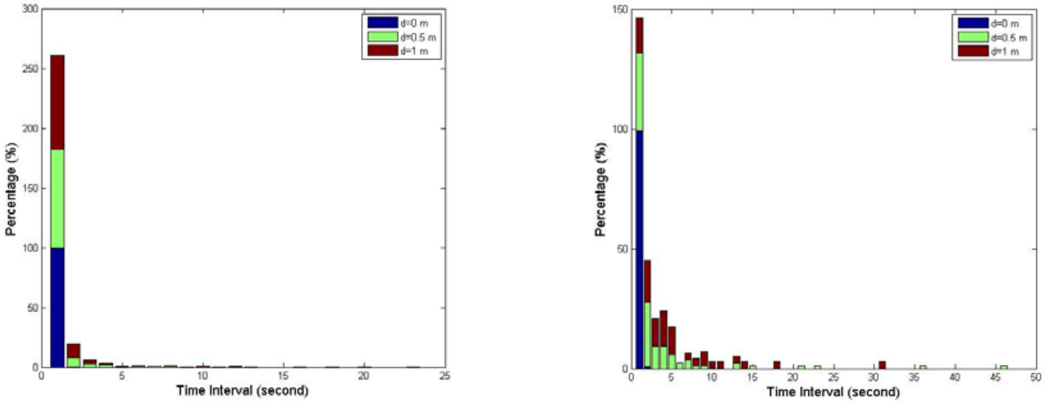


Figure 6. A communication model of the SPIVC system

The location updating frequencies of both bike and car apps are shown in Table 2 for the nine test scenarios. In our tests, the car phone is always static, and the bike phone moves at a speed of about 1 m/s. From the table we can see that the location updating frequency is not affected by communication modes, but is smaller under the situation of larger mindis and lower speed. More detailed distributions of time intervals between two consecutive location updates are given in Figure 7, from which we can see that the minimum interval is always 1 second, and the distributions are more dispersed with larger minimum distance threshold. Therefore, in order to achieve a higher location updating frequency, one wants to set smaller mindis at a lower speed. Theoretically, the minimum distance threshold should be in the order of the speed of the smartphone times the desired location updating frequency.

Scenario	Bike Phone	Car Phone	mindis	mintime	Bike Phone (Hz)	Car Phone (Hz)
1	Moto/WiFi	HTC/WiFi	0	0	1.00	1.00
2	Moto/WiFi	HTC/WiFi	0.5	0	0.60	0.34
3	Moto/WiFi	HTC/WiFi	1	0	0.51	0.22
4	Moto/WiFi	HTC/3G	0	0	0.99	1.00
5	Moto/WiFi	HTC/3G	0.5	0	0.55	0.25
6	Moto/WiFi	HTC/3G	1	0	0.57	0.23
7	HTC/3G	Moto/WiFi	0	0	1.00	0.97
8	HTC/3G	Moto/WiFi	0.5	0	0.76	0.21
9	HTC/3G	Moto/WiFi	1	0	0.65	0.15

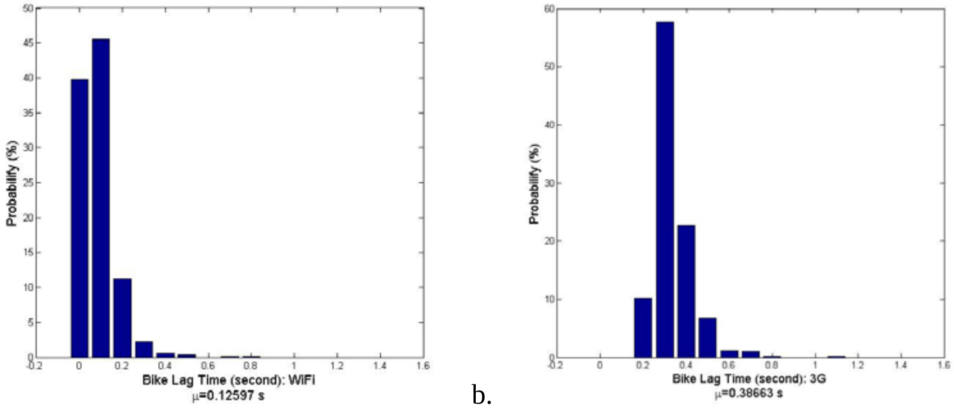
Table 2: Location updating frequencies of different tests



(a) (b)

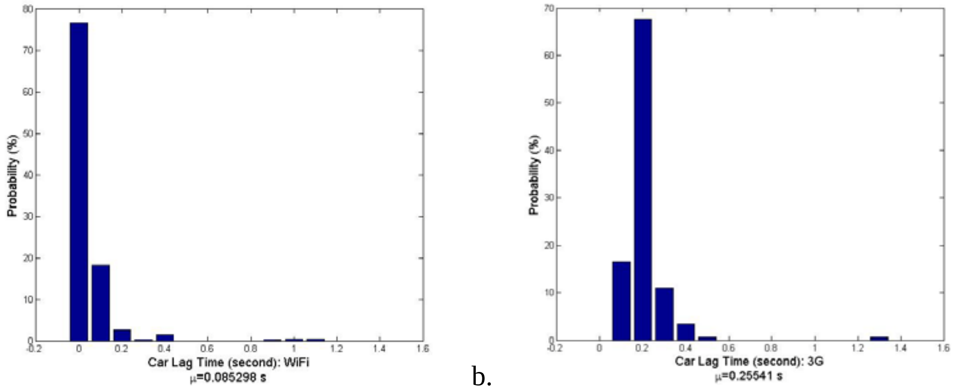
Fig.7. Distribution of time interval of two consecutive location updates: a. bike; b. car

Distributions of communication times, d_1, d_2, d_2', are given in Figures 8 and 9, from which we can see that the average communication times are about 0.1 s on WiFi networks and about 0.2-0.3 s on 3G networks. It is expected that 3G networks are slower than WiFi networks. Thus the total communication time on both apps is about 0.3-0.4 s.



a. b.

Figure 8. Distribution of Communication Time $\mathbf{d_1}$: a. WiFi, b. 3G



a. b.

Figure 9. Distribution of Communication Time $\mathbf{d_2 + d_2'}$: a. WiFi, b. 3G

Finally, Table 3 shows the average delays from a bike to a car for different minimum distances. From Tables 2 and 3, we can see that the average communication delay is approximately the sum of the location updating intervals and the communication times, but is actually dominated by the former. Compared with about 0.1 s of communication delay in VANET, the communication delay in the SPIVC system is significantly longer. This is as expected, since the location information is not directly pushed from the bike app to the car app. Rather, the communication delay is highly determined by the location updating frequencies of both the car and bike apps. In transportation systems, this delay would significantly increase human drivers' reaction time (about 1-2 seconds), and therefore the SPIVC system in its current form cannot be applied in safety-related applications.

Minimum Distance (meter)	Mean Communication Delay (second)	Sample Size
0	1.31	461
0.5	2.53	95
1	3.74	43

Table 3: Delay under different minimum distances

5. Conclusion and Future Work

In this study, a simple smartphone-based inter-vehicle communication (SPIVC) system is implemented and evaluated with field tests. Different from vehicular ad hoc networks, the system follows the traditional server-client model. From the field tests, we have the following conclusions in order: (i) GPS devices on smartphones have warm-up times of about 5 seconds, during which location errors are as large as 25 meters; but after warm-up, location errors decrease to about 4 meters; (ii) Communication times are larger on 3G networks than on WiFi networks, and they are in the order of 0.1-0.2 seconds; (iii) But the V2V communication delay in the centralized SPIVC system, increasing with and dominated by the location updating intervals of GPS devices, is in the order of seconds; and (iv) Smaller minimum distance thresholds in the Android apps and faster moving speeds of vehicles can help to increase location updating frequency.

The relatively long vehicle-to-vehicle communication delays and large GPS location errors would obviate many safety applications of such a centralized system in its current form. Due to its simplicity in implementations and the ubiquitous smartphones, the SPIVC system in its current form can already be used to develop route guidance, green driving, and other ITS strategies, which are not very sensitive to location accuracy and communication delay. In particular, the SPIVC system is suitable for user-oriented multimodal transportation applications. In the future, we will be interested in implementing vehicle-to-vehicle communications through ad hoc WiFi communications, which will directly push a message from the sender to the receiver and could bypass the process of GPS location updating. That is, it is possible to develop a decentralized SPIVC system. It is suspected that decentralized IVC could offer much shorter communication delay than a centralized system. Thus it is still important to further study properties of VANETs and develop corresponding route protocols. In addition, it is possible to integrate more advanced positioning technologies, e.g., the real-time kinematic GPS, to improve the accuracy of location information.

In this simple implementation of the SPIVC system, only location information is collected and disseminated. With smartphones, it is possible to collect speeds, acceleration rates, turning directions, and other information from GPS, accelerometer, and other sensors. We will be interested in studying the accuracy of such information as well to further understand the behavior and properties in smartphones for possible safety applications in the future.

With more devices sharing information with each other, technical challenges include database management, communication routing, and information security for both centralized and decentralized SPIVC systems. This and proposed studies would shed light on potential benefits of IVC in the transportation system.

References

1. FCC. FCC allocates spectrum in 5.9 ghz range for Intelligent Transportation Systems uses, 1999. http://www.fcc.gov/Bureaus/Engineering_Technology/News_Releases/1999/nret9006.html. Accessed September 26, 2007.

2. USDOT. USDOT’S ITS Program - Major Initiatives — 2004, 2004. http://www.its.dot.gov/press/Initiatives4.htm. Accessed January 30, 2007.

3. X. Dong, K. Li, J. Misener, P. Varayia, and W. Zhang. Expediting Vehicle Infrastructure Integration (EVII). Technical report, CALIFORNIA PATH PROGRAM, 2006. UCB-ITS-PRR-2006-20.

4. J.K. Hedrick, M. Tomizuka, and P. Varaiya. Control issues in automated highway systems. IEEE Control Systems Magazine, 14(6):21–32, 1994.

5. M. Aoki and H. Fujii. Inter-vehicle communication: technical issues on vehicle control application. Communications Magazine, IEEE, 34(10):90–93, 1996.

6. F.H. Eskafi, K.F. Petty, and P.P. Varaiya. Dynamic channel allocation for vehicle-to-vehicle communications in automated highway systems. Intelligent Transportation System, 1997. ITSC 97. IEEE Conference on, pages 58–63, 1997.

7. Safe and comfortable driving based upon inter-vehicle communication. http://www.cartalk2000.net/. Accessed November 11, 2003.

8. D. Reichardt, M. Miglietta, L. Moretti, P. Morsink, and W. Schulz. CarTALK 2000: safe and comfortable driving based upon inter-vehicle-communication. Intelligent Vehicle Symposium, 2002. IEEE, 2, 2002.

9. R. Morris, J. Jannotti, F. Kaashoek, J. Li, and D. Decouto. CarNet: a scalable ad hoc wireless network system. Proceedings of the 9th workshop on ACM SIGOPS European workshop: beyond the PC: new challenges for the operating system, pages 61–65, 2000.

10. Internet on the road. URL http://www.fleetnet.de/. Accessed November 11, 2003.

11. Mobile Ad-hoc Networks (manet) Charter. URL http://www.ietf.org/html.charters/manet-charter.html Accessed July 1, 2008.

12. A.K. Ziliaskopoulos and J. Zhang. A zero public infrastructure vehicle based traffic information system. In TRB 2003 Annual Meeting CD-ROM, Washington, D.C., 2003.

13. W. W. Recker, W.-L. Jin, X. Yang, and J. Marca. Autonet: Inter-vehicle communication and network vehicular traffic. International Journal of Vehicle Information and Communication Systems, 1(3/4):306–319, 2008.

14. H. Song and H. Siemens. Automatic vehicle location in cellular communications systems. IEEE Transactions on Vehicular Technology 43 (4), 902-908, 1994.

15. U. Dietz. Cellular Vehicle Communications: Preliminary results from the CoCar project, 2009.

16. J.C. Herrera, D.B. Work, R. Herring, X.J., Ban, Q. Jacobson, and A.M. Bayen. Evaluation of traffic data obtained via GPS-enabled mobile phones: The Mobile Century field experiment. Transportation Research Part C, 18(4): 568-583, 2010.

17. J. Ahnn, U. Lee, H. Moon, and M. Gerlag. Senster: scalable smartphone based vehicular sensor networking systems, 2010.