DEVELOPING WIRELESS WARNING SYSTEM TO ENHANCE THE WORKERS SAFETY IN WORK ZONE AREA

Fengxiang Qiao, Ph.D. Associate Professor, Texas Southern University, qiao_fg@tsu.edu, Corresponding Author

Yijun Qiao, Graduate Research Assistant, Rice University, markqiao@gmail.com

Xiaobing Wang, Graduate Research Assistant, Texas Southern University, xiaobingwang2010@gmail.com

Lei Yu, Ph.D., PE. Professor of Texas Southern University, yu_lx@tsu.edu

ABSTRACT

Work zone safety is always an issue in traffic operation and management. Due to the lack of short range communications between workers and vehicles, the vehicle to worker collision becomes one of the important types of crashes within work zone area. In this research, the framework of wireless warning system is identified that can provide warning message to drivers through the smart probing of workers' geo-locations. Possible short range communication devices such as Bluetooth, Radio Frequency Identification (RFID), ZigBee, Smartphone, etc. are scanned and their potential usages to enhance the work zone safety are discussed. Recommendations are proposed on how to use these systems to enhance the person to vehicle (P2V) communication, especially on how to enhance the workers' safety in work zones. Barrels or steps to use these devices are further discussed.

Keywords: Intelligent Transportation System, Wireless Warning System, V2I Communication,

INTRODUCTION

Background of Research

Work Zone Safety Issue

According to a NHTSA (2010), 32,885 people died in motor vehicle traffic crashes in the United States in 2010 with about 2.24 million people injured. Work zone is one of the areas that traffic conflicts could happen. Table 1 lists the fatalities in motor vehicle traffic crashes by state and work zone in 2010. For example in Texas, 96 workers died in motor vehicle traffic crashes in 2010, the highest among all states.

Table 1: Fatalities in Motor Vehicle Traffic Crashes by State and Work Zone (2010)

State	Not in Work Zone	In Work Zone	UnKnown	Total
Alabama	853	9	0	862
Alaska	56	0	0	56
Arizona	748	14	0	762
Arkansas	551	11	1	563
California	2,671	41	3	2,715
Colorado	437	11	0	448
Connecticut	317	2	0	319
Delaware	101	0	0	101
District of Columbia	23	1	0	24
Florida	2,398	43	4	2,445
Georgia	1,187	57	0	1,244
Hawaii	113	0	0	113
Idaho	208	1	0	209
Illinois	895	32	0	927
Indiana	741	13	0	754
Iowa	377	13	0	390
Kansas	427	4	0	431
Kentucky	755	5	0	760
Louisiana	695	15	0	710
Maine	160	1	0	161
Maryland	487	6	0	493
Massachusetts	308	4	2	314
Michigan	930	12	0	942
Minnesota	390	14	7	411
Mississippi	637	4	0	641
Missouri	805	14	0	819
Montana	186	3	0	189
Nebraska	185	5	0	190
Nevada	252	5	0	257
New Hampshire	128	0	0	128
New Jersey	550	6	0	556
New Mexico	344	2	0	346
New York	1,195	5	0	1,200
North Carolina	1,310	7	2	1,319
North Dakota	105	0	0	105
Ohio	1,069	11	0	1,080
Oklahoma	647	19	2	668
Oregon	308	9	0	317
Pennsylvania	1,301	23	0	1,324
Rhode Island	64	2	0	66

South Carolina	809	1	0	810
South Dakota	134	6	0	140
Tennessee	1,024	7	0	1,031
Texas	2,902	96	0	2,998
Utah	228	8	0	236
Vermont	69	2	0	71
Virginia	732	8	0	740
Washington	457	1	0	458
West Virginia	313	2	0	315
Wisconsin	557	14	1	572
Wyoming	148	7	0	155
Total	32,287	576	22	32,885
Puerto Rico	340	0	0	340

Source: Fatality Analysis Reporting System (FARS) 2010 ARF, NHTSA, and The National Work Zone Safety Information Clearing House

http://www.workzonesafety.org/crash_data/workzone_fatalities/2010

Traditional ways to enhance workers safety in work zone include the placement of suitable traffic signs and signals, physical barrels, flag guidance from safety guard, etc. However, drivers may normally not wish to follow these guidance and signals. Traditional improper driving behaviours include: lane change in the last minutes; speeding even though there are sped limit sign; little awareness of workers' crossings; etc. These unsafe behaviours and worker fatalities call for the employment of a more advanced in-vehicle warning system to alert drivers before and during work zones.

Actually there are two systems here: one is for the positioning of workers' location, another is for relaying the warnings to the drivers. The technology for these two systems should be different. The relay portion should use a longer-ranged technology for early warning, especially for vehicles travelling at a high speed. This paper focuses on short-range wireless communication systems to provide a cost-effective and accurate positioning system. The workers' movement information and guidance to drivers may be transmitted to drivers through the proper use of short range wireless communication system. The information relay will not be a focus of this paper.

V2P Wireless Communication System to Enhance the Safety of Workers

Qiao and Qiao (2012) proposed a coordinated P2V wireless communication system to enhance work zone safety as illustrated in Figure 1. The work space is surrounded by a chain of physical barrels preventing traffic to enter in. The yellow dots are construction barrels, and the green dots are receivers for P2I (Person to Infrastructure) communications, which is directly connected to the I2V (Infrastructure to Vehicle) communications. The red dots are the workers carrying with transmitters.

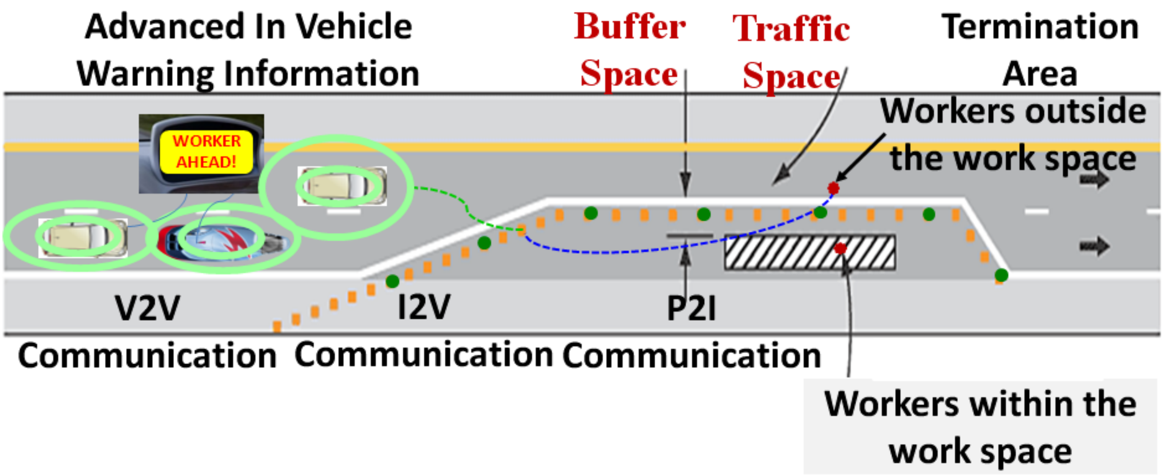

Figure 1 - Coordinated Traffic WORK ZONE wireless communication system to enhance worker's safety (source: Qiao and Qiao, 2012)

In Figure 1, when workers step outside the designated work space, or even beyond the entire work zone area, there is a high risk of potential conflicts between motor vehicles and workers. If there are good wireless communications with suitable sensors and transmissions equipped, drivers may be warned in an earlier location and thus have sufficient time to avoid the collisions with workers. These programmable warnings can be divided into several levels of severity depending on the workers' locations. Further, incoming vehicles can send a reverse-warning back to the workers so that the workers, too, can prepare for incoming danger.

Research Objective

The objective of this paper is to review the widely used short range wireless communication devices, and identify if they can be used in the P2V wireless communication system as illustrated in Figure 1.

SHORT RANGE WIRELESS COMMUNICATION SYSTEM

A limited number of short-range radio applications such as the garage door opener, were in use in the 1970s. It suffered from frequency drift and susceptibility to interference at that age (Bensky, 2000). Similar systems are still in use today, although radio technology has advanced tremendously. In 1994 Bluetooth was invented, which initiated the recent attentions of developing short range wireless communication devices for multiple usages. Other similar devices may include: RFID, Wi-Fi, ZigBee, XBee, Smarphone, etc. So far, there are very limited tests and use of short range wires communication devices for workers safety enhancements. In the rest part of this paper, the features of these devices and their possible applications in work zone will be further discussed.

Bluetooth

Features of Bluetooth

Bluetooth was named after Harald Bluetooth, a legendary Nordic king of the late 1900s that all Swedes are taught about in grade school. Bluetooth is a technology to communicate wirelessly, which is designed for low power consumptions and based on low-cost transceiver microchips. Bluetooth communicates within the 2.4GHz ISM frequency band (between 2.402 GHz and 2.480 GHz), which is a frequency band for industrial, scientific and medical devices by international agreement. The Bluetooth specification was conceived in 1994 and is now managed by the Bluetooth Special Interest Group (SIG).

The first version of Bluetooth provided 1Mbps speed, and the second version provides 3 Mbps speed, which is beneficial if more devices are connected with higher data requirements (e.g. connecting a printer or smartphone as a wide area network modem). Bluetooth uses spread-spectrum frequency hopping technology so that two devices will transmit the same frequency with minimized risk of interference. There are three classes of Bluetooth: class 1 (100M), class 2 (10M) and class 3 (5M).

Many engineering applications can be found on the use of Bluetooth. For example, Bekkelien (2012) added the package "Bluetooth" to a Global Positioning Module (GPM) provider for indoor positioning purposes (Figure 2). The class Bluetooth has the main responsibility of starting the Bluetooth inquiry and estimating a position based on the outcome from the inquiry as demonstrated by the sequence diagram shown in Figure 3.

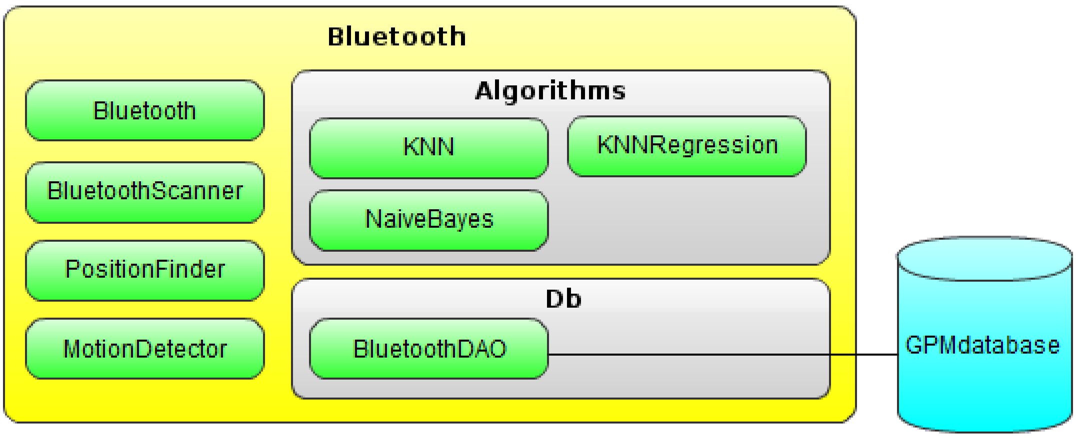

Figure 2 - Bluetooth provider architecture (Source: Bekkelien, 2012)

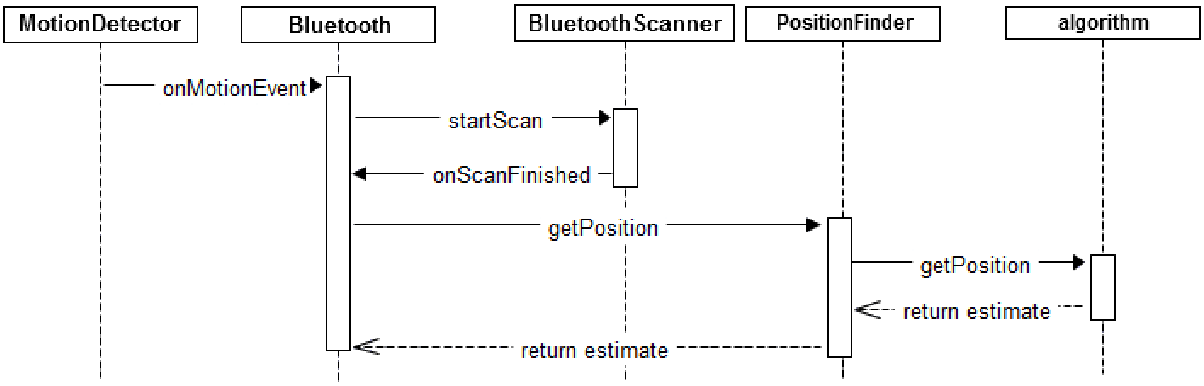

Figure 3 - Sequence diagram for position estimation using the Bluetooth provider

Possible Applications in Work Zone

Since Bluetooth can be used for positioning purposes, it is possible that Bluetooth can be used in the P2V communications. Bluetooth might be able to provide the "best" accuracy by current short range communication technologies. When it is selected for use in work zone for safety enhancement, special attentions might be on the spacing between a pair of Bluetooth device. For examples, do we need to place Bluetooth for all traffic cones, or every other cone? What is the possible interface and how to overcome it? How to power the devices? What is the cost? There should be a specific study on this issue.

RFID System

Features of RFID

The RFID technology has been utilized in many areas such as logistics, inventory management, vehicle tracking, agriculture, etc. (Qiao et al, 2009; Qiao et al., 2012a; Qiao et al., 2012b). A typical RFID system has several components including tag, reader and processing computers as is illustrated in Figure 4.

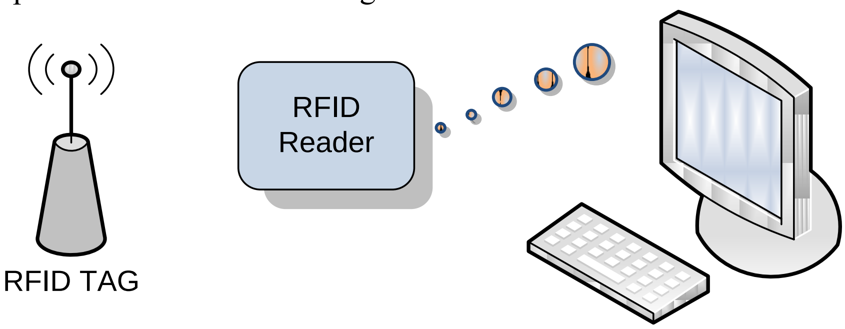

Figure 4 – Components of RFID System (Source: Qiao, et al., 2009)

RFID is an attractive technology due to its low cost and high accuracy in the context of worker positioning. For example, Nakamori, et. al. (2012) designed a RFID indoor positioning system to track and guide continuously moving robots using both short-range and long-range modes. The RFID technology has been utilized in a variety of areas such as logistics, inventory management, vehicle tracking, agriculture, etc. (Want, 2006). The range of a RFID tag could be very long (more than 1 mile for some active tags with power supplies), or very short (several inches for some passive tags with no power supplies).

RFID signals in indoor environments are generally harshly impaired and tags have very limited capabilities which pose many challenges for positioning them. Technologies and applications of RFID on positioning have been in development now (Bouet and Santos, 2010, Nakamori, et. al., 2012). They developed an obvious and interesting method to obtain these two types of data, which is to localize RFID tags attached to devices or objects or carried by people. Qiao et al. also proposed a RFID based smart guide signing system, and have tested the working range of RFID tags (Qiao, etc., 2012b).

Kotchasarn (2009) reported an RFID-based in-vehicle alert system to alert vehicle drivers about road signs at an optimum distance before encountering them. It enables transmission of important data to vehicles within an effective non-line-of-sight (NLOS) distance. However this research did not conduct any on-road test.

Possible Applications in Work Zone

Based on the above literature, it is possible that the RFID is used to identify the position and in-vehicle alert system. Thus, RFID can be used for the P2V work zone safety enhancement. For example, the RFID tags can be placed on traffic cones or other places. Each tag may only cover a certain degrees (the detailed placement should be tested in real situations). Also, the minimum and maximum density of RFID tags should be considered as well as the possible interferences.

ZigBee

Features

ZigBEE is a specification of communication protocols based on IEEE 802 standard for personal area networks. It is suitable for low data rate, long battery life, and secure networking. As Gislason (2010) described: "ZigBee chips do not currently fit onto the back of a Bee, but they do come in 5 × 5 mm packages, and consume so little power they can last longer than the lifetime of a bee on a couple of AAA batteries." Figure 5 is a picture of a ZigBee.

Figure 5 - A ZigBee (Source: Wikimedia Commons).

The origin of ZigBee came from the peculiar behaviour of bees, first noted in the 1960s by Nobel Prize-winner Karl von Frisch. Bees, after zigging and zagging around in the fields, return to the hive, and perform what some call the Waggle Dance to communicate the distance, direction and type of food to others in the hive. After receiving a WAGGLE-DANCE indication, bees fly off directly to the source of food (Gislason, 2010).

ZigBee can be used as communications transceivers for highly accurate position estimation. Schwarzer, et. al. found that due to the coherent synthesis of a sequence of measurements from all available frequency channels it is possible to mitigate perturbations from multipath propagation effectively. They developed some techniques to easily adapt to many other communications standards. It is favourable where low-cost and precise localization of commercial communications transponders is desired.

Possible Applications in Work Zone

Since ZigBee can be used for positioning, it is a good candidate for the P2V application in work zone. Similar to the discussions for Blue and RFID, spacing and interferences should be carefully considered. Besides, the use of ZigBee is also highly related to the positioning algorithms. Qiao and Qiao (2012) identified a Geolocation based person to infrastructure (P2I) positioning algorithm, which can possibly use the ZigBee for further roadside tests.

Smartphone

Features

A Smartphone is a phone with more advanced computing capabilities and connectivity. Its operating system varies a lot, but they all have the function to detect the geolocation of the phone and are installed with Bluetooth. With such good functions, the Smartphones are already not only ordinary phones: they are detection and connection devices. However, the cellular assisted GPS may not be accurate enough for some applications and tests (Zandbergen, 2009).

Possible Applications in Work Zone

With the use of proper algorithms and other devices, the Smartphone can be used as one of the devices in the system to communicate with other Smartphone and/or other Bluetooth devices. This can realize the function of positioning if proper geolocation algorithms are preset. At least, the location of the workers and whether the workers have entered dangerous regions can be easily detected.

DISCUSSION ON THE USE OF SHORT RANGE WIRELESS COMMUNICATION DEVICES

Even though there are several types of devices as discussed above that have the potential to be used for work zone safety enhancement, there are some barrels or steps to go before they can be of direct use.

- Test the accuracy of the positioning systems in the presence of wireless multipath due to the metal equipments used by the workers. It will be great if you can go to some real construction zone to test these systems.
- Interference is also a potential issue (two workers next to each other). This can be tested as well.
- It will be better if building up a second system using a different technology and conduct the same tests in the same locations. Then the performance can be compared.
- Next build a system that relays the warnings to a real vehicle. Here vehicle manufacturers can be approached for joint tests. The relay system not only relays warnings from a work zone, but also warnings on dangerous road conditions (from road signs, warnings, etc.)

Traffic engineering field tests are necessary if sufficient simulation tests (e.g. the in-house simulator test) have been proven successful. It is necessary to evaluate how "early" warning affects driver behaviour. Field test should be in both night and day conditions.

Recently outdoor wireless positioning mainly uses satellites technology like GPS to navigate. However, satellite based positioning system needs the tracking device to be able to receive line-of-sight signals from satellites. The error band of a civil-use GPS device could provide is mostly even equivalent to the width of a lane. The GPS is too inaccurate to be directly used as a sensor to enhance the work zone safety. However since it is widely used in almost all vehicles, it is a good supplemental device that can work with other devices.

Another issue to be discussed is Wi-Fi. Wi-Fi does not really fit in the classification of short-range wireless system, since its application is only as a general purpose wireless LAN and it always relies on a base station. However with the environment of Wi-Fi, the workers' location and even vehicles' location can be directly transmitted to the website through suitable short range wireless communications. Such information will be further processed in Transportation Management Center (TMC), and then broadcasted back to road users, workers and management team. In other words, Wi-Fi can set up a bridge to link the short range wireless communication with the existing powerful wire communication and TMCs. It will enhance and amplify the function of short range wireless communication systems.

CONCLUSIONS

In this paper, the various short range wireless communication devices that can possibly be used in P2V systems are discussions. Focuses are placed on whether these devices can be used in positioning. Another issue in the P2V communication is how to relay the signal from worker to work zone, to roadside infrastructures, to upcoming vehicles, and to more vehicles. This will be further studied in next step of research.

ACKNOWLEDGEMENT

This paper is prepared in partial supports by the U.S. National Tier 1 University Transportation Center (UTC) TranLIVE, the U.S. National Science Foundation (NSF) CREST #1137732, and Texas Southern University Seed Grant.

REFERENCES

Bekkelien, http://cui.unige.ch/~deriazm/masters/bekkelien/Bekkelien_Master_Thesis.pdf

Bensky, A. (2000). Short-range wireless communication, LLH Technology Publishing, 2000, ISBN 1-878707-76-0 (LLH eBook)

Bouet and Santos (2013). RFID Tags: Positioning Principles and Localization Techniques.

Choi, E.–H. (2010). Crash Factors in Intersection-Related Crashes: An On-Scene Perspective. DOT HS 811 366. 12.

Gislason, D. (2010). "ZigBee Wireless Networking", (via EETimes). http://www.eetimes.com/design/embedded-internet-design/4201087/ZigBee-applications--Part-1-Sending-and-receiving-data/

Kotchasarn, C. (2009), RFID Assisted Vehicular Communication Systems. 2009 First International Conference on Computational Intelligence, Communication Systems and Networks.

Nakamori, E.; Tsukuda, D.; Fujimoto, M.; Oda, Y.; Wada, T.; Okada, H.; Mutsuura, K., "A new indoor position estimation method of RFID tags for continuous moving navigation systems," *Indoor Positioning and Indoor Navigation (IPIN), 2012 International Conference on* , vol., no., pp.1,8, 13-15 Nov. 2012

NHTSA, (2010). Fatality Analysis Reporting System (FARS) 2010 ARF, NHTSA, http://www-nrd.nhtsa.dot.gov/Pubs/811552.pdf

Qiao, F. X, L. Yu, R. Fatholahzadeh and X. Yuan (2012a). Smart Guide Signing System Using RFID as an Intelligent Sensor. Proceedings of the 13th ASCE Aerospace Division Conference on Engineering, Construction, and Operations in Challenging Environments and the 5th NASA/ASCE Workshop on Granular Materials in Space Exploration.

Qiao, F., L. Yu, R. Zhang, Z. Chen, and R. Fatholahzadeh (2009), RFID Applications in Transportation Operation and Intelligent Transportation Systems (ITS), Texas Southern University, Research Report for the Southwest Region University Transportation Center (SWUTC), Report number: SWUTC/09/476660-00044-1, June 2009, (57 pages). http://swutc.tamu.edu/publications/technicalreports/476660-00044-1.pdf. Date accessed: July 31, 2012.

Qiao, F., J. Wang, X. Wang, J. Jia, , and L. Yu (2012b). A RFID Based e-STOP Sign and Its Impacts to Vehicle Emissions. Presented and published in the proceedings of the 15th International IEEE Conference on Intelligent Transportation Systems (ITSC), Anchorage, AK, USA, September 16-19, 2012.

Salama, S. (2010). Blinding sun caused 22 car crashes in eight months. Gulf News.

Schultz, G. G. and E. S. Talbot (2009). Advance Warning Signals. Transportation Research Record: Journal of the Transportation Research Board, 27-35.

Schwarzer, Vossiek, Pichler, and Stelzer (2013). Precise Distance Measurement with IEEE 802.15.4 (ZigBee) Devices. Website: http://140.116.82.38/members/html/ms07/ytchen/paper/%5BY2008%5D%5BRWS%5DPrecise%20Distance%20Measurement%20with%20IEEE%20802.15.4%20%28ZigBee%29%20Devices.pdf

Sercombe, C. (2012). A blinding sun may be cause for traffic fatality. Hamtramck Review.

Singh, H., K. Kumar and H. Kaur (2012). Intelligent Traffic Lights Based on RFID. International Journal of Computing & Business Research.

Want, R., "An introduction to RFID technology," *Pervasive Computing, IEEE* , vol.5, no.1, pp.25,33, Jan.-March 2006

Wu, G. Y., K. Boriboonsomsin, W. B. Zhang, M. Li, and M. Barth (2010). Energy and Emission Benefit Comparison of Stationary and In-Vehicle Advanced Driving Alert System. Transportation Research Record: Journal of the Transportation Research Board, 98-106.

Zandbergen, P. A. (2009). Accuracy of iPhone Locations: A Comparison of Assisted GPS, WiFi and Cellular Positioning. http://onlinelibrary.wiley.com/doi/10.1111/j.1467-9671.2009.01152.x/full.