Short-range Wireless Communication System for V2I Communication

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ABSTRACT: Vehicle to Infrastructure (V2I) and Vehicle to Vehicle (V2V) communications realize the wireless exchange of critical safety information between vehicles and infrastructures so as to avoid or at least mitigate the vehicle to vehicle, and/or vehicle to person collisions, which has brought in outstanding attentions from public and private sectors. For example, the United States Department of Transportation (USDOT) has launched a national program to enhance vehicle transportation through the applications of communication technologies known as IntelliDriveSM (succeeding the USDOT's VII, for Vehicle-Infrastructure Integration, program). This system considers safety, mobility, and environmental improvements through a combination of vehicle to vehicle and vehicle to infrastructure communications. On the other hand, the fast developing wireless communication technologies provide cutting edge innovative technologies that have the potential to improve the communications among vehicles, infrastructures, and human beings. This paper intends to review the available devices/techniques that can be used for such applications. Possible candidates for dedicated short range communication (DSRC) include Bluetooth, Wi-Fi, Radio Frequency Identification (RFID), and ZigBee. Typical techniques are those that are related to object positioning. One conceptual application in work zone is introduced and it is recommended testing the applications of these devices and techniques in both simulation and on-site environments.

TYPICAL WIRELESS COMMUNICATION DEVICES AND TECHNIQUES

Typical wireless communication systems or devices include Bluetooth, RFID, and ZigBee. Wi-Fi is not a wireless communication, but it can be of great assistance to the transmission of wireless information through combined usages. In V2I, V2V, and even V2P communication systems, it is always a need to identify the position of a vehicle, a roadway infrastructure, or a person (a worker, or a pedestrian). Therefore, it is important to know the various position techniques, including the wireless position techniques and GPS based positioning techniques. All these will be reviewed in the following sections.

Bluetooth

Bluetooth was invented by the Swedish company Ericsson, and 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 that allows electronic devices to communicate without wires. It was designed for low power consumptions and is based on low-cost transceiver microchips. Bluetooth communicates using radio waves with frequencies between 2.402 GHz and 2.480 GHz which is within the 2.4GHz ISM frequency band, a frequency band that has been set aside 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) (Chen et al., 2011).

The first version of Bluetooth provided 1Mbps speed, which is certainly enough for some applications, although the 3 Mbps provided by the second version are beneficial when more devices are connected and when the data requirements are higher, such as when connecting a printer or Smartphone being used as a wide area network modem. Bluetooth is divided into three classes, class 1, class 2 and class 3, which range located from 100M, 10M and 5M. In order to avoid interference, Bluetooth uses spread-spectrum frequency hopping technology which makes it unlikely that two devices will transmit the same frequency and therefore minimizes the risk of interference.

RFID

Radio frequency identification (RFID) is also a short range wireless communication device, but is more oriented towards the identification of a nearby object (including animals and people) via its negative tag. Factors such as attenuation, cross paths of signals, and interference from other RFID tags, RFID readers and RF devices, may affect the communication between the tag and RFID readers. Though there is some overlap at the higher level of RFID devices, the technology generally assumes that an RFID tag will be brought within a few centimeters of a reader in order to scan its specific and unique ID and possibly to obtain a small amount of additional information. By contrast, the general definition of short range wireless devices assumes that devices communicate from a static location or anywhere within a certain radius of other short range wireless devices and can communicate whenever the device decides that it needs to. Although RFID could be called "Ultra Short Range", it is really the nature of the application that is different (Lee et al., 2012). The extreme shortness of range is just a reflection of the need to bring an object near to a reader before communications can occur.

RFID is most applicable when an object can easily be brought to a particular location to be scanned, such as an automated checkout counter at a supermarket, or a gate through which trucks enter and exit a port with tagged containers. The development of an RFID-based Real-Time Locating System (RTLS) has three aspects essential to a robust and accurate RTLS: localization methods, wireless networking technologies, and an Assistant Tag (AT) (Ham and Hargrove, 2011). The localization method minimizes localization errors and retains high accuracy in localization against obstacles, whereas the wireless networking technology deals with data on a real-time basis and has a strong signal-transfer capability that could minimize information loss during signal transfer. In addition, the AT is a virtual reader that aims to maintain signal availability when many obstacles that hamper signal transfer are present. This section will discuss details about these three aspects and will be followed with a discussion on how the system has been developed (Ting et al., 2011).

ZigBee

ZigBee is a short range wireless technology. Compared with other similar technologies, ZigBee has advantages like being low cost and having enough data rate to transfer information between car and hurdle. What's more, ZigBee devices can work for years without worrying about replacing
batteries, which makes it an excellent choice to be used in areas where power is a major concern. However, Iqbal and Yukimatsu (2011) found that there is a problem while communicating between ZigBee Host and Sensor if there are hurdles like trees or buildings. ZigBee relays could be a solution to increase the communication range. Figure 1 is an illustration of ZigBee’s sample applications in ITS.

Figure 1. An Intelligent Transportation System Using ZigBee as a Communication Medium (Source: Iqbal and Yukimatsu, 2011).

ZigBee (IEEE 802.15.4) and Bluetooth (IEEE 802.15.1) are designed for wireless personal area networks (WPANs) with smaller coverage area and lower power consumption. ZigBee operates at the frequency spectrum of 902 to 928 MHz and 2.4 GHz, whereas Bluetooth operates at 2.4 GHz. The transmission range of ZigBee is 100 m, while that of Bluetooth is only 10 m. On the other hand, the data rate of ZigBee is only 20 to 250 kbps, while that of Bluetooth is 1 Mbps. Because of their low data rates and transmission range, these protocols are not considered for vehicle networks.

Wi-Fi

Wi-Fi is typically used for general purpose wireless LAN and always relies on a base station. From this end, Wi-Fi cannot be called as a short-range wireless system. Short range wireless systems have carved out niches beneath Wi-Fi, compensating for a lower bandwidth with significantly lower power consumption and smaller form factors, and also with niches above Wi-Fi’s providing higher speed for specific applications. The IEEE 802.11 family is the king of the wireless LAN, and it does not seem like to reduce in rank from its current position as the protocol best suited to the moderate fast interconnection of a huge number of computers and shared devices, such as internet routers, printers and cloud servicer. Wi-Fi positioning systems (WPS) were established that rely on wireless access points for location coordinates. For the proper functioning of a wireless architecture, IEEE project 802 defined a standard which assigns a Media Access Control (MAC) address to local area network devices. In a WPS, the MAC address for a Wi-Fi access point becomes an index for a geo-location reference point. The Service Set Identifier (SSID) is an
additional identifier for Wi-Fi access points. Collecting and locating Wi-Fi access points for a WPS database is the major method using Wi-Fi to locate (Cavoukian and Cameron, 2011).

**Methods to Track Object Positions**

Typical methods to track object include: (a) Received Signal Strength Indication (RSSI), (b) Time Difference of Arrival (TDOA), (c) Angle of Arrival (AOA), (d) Time of Flight (TOF), and (c) Time of Arrival (TOA) (Lee et al., 2012). The TOA method estimates the distance between reader and tag using RF signaling speed and turnaround time of signaling between the two. This information is used to calculate the tag’s location using a trilateration technique. The benefits of the TOA method are that its accuracy is not much affected by distance and that it is less influenced by a multipath effect. Also, the TOA method performs well in a Non-Line-Of-Sight (NLOS) environment and outdoors. As a result, it can have higher accuracy in tracking object positions with large coverage area without being much affected by obstacles. The TOA method is proved to be very efficient in tracking object positions (Chon et al., 2004).

**Wireless Positioning**

Recently wireless positioning can be categorized and outdoor and indoor technologies. Outdoor positioning mainly uses satellites technology such as the well-known GPS (Global Positioning System) system to navigating (Razi and Kenichi, 2011). However, satellite based positioning system needs the tracking device to be able to receive line-of-sight signals from satellites so that cannot be used indoors since buildings are always blocking signals, also not performance accuracy. As following, this paper is introducing some popular methods of indoor wireless positioning systems which were proposed using different techniques.

This first method is called as “Angle of Arrival (AOA)” which is a geographic positioning method, also called the triangulation method. This system includes receiver and sender. Major method of this is that the receiver uses a directional antenna or antenna array to measure the signal which received from sender. Two such AOA measurements will be able to locate the target’s location (shown in Figure 1). For example the received arrival orientation of signal determines the location of mobile devices shows in Figure 2.

![Figure 2. AOA Geographic Positioning Technology.](image)
The major problem of this system is about the accuracy of position which is depended on the sender relative to the receiver’s position. Another situation is that if the sender is precisely in a straight line between the two receivers, the AOA measurement cannot detect the target’s location. Thus, usually more than two receivers, at least three of them, will ensure more accuracy position. In indoor environment, because the signal path will be blocked by buildings and other around objects, AOA technology is not applicable to indoor positioning system. Additionally, since AOA needs expensive antenna array at receivers to strong signal arrival orientation, therefore, it is not a good way for low-cost indoor applications at all.

The second method is called instanced based triangulation. As showing in the Figure 3, the distance between sender (Mobile device) and the receiver can be estimated by RSS (Received Signal Strength), TOA (time of arrival), received signal phases and other techniques. In order to estimate the accuracy location of mobile device in two-dimensional space, we at least need three measurements. If the estimated distance value between receiver and mobile device is $d$, mobile device can be positioned to a circle and the receiver as the centered, $d$ as the radius of the circle. The second measure reduces the ambiguity of positioning, and the mobile device positioned in two crossing circular arc. The third measure locks the position of mobile device (Wang et al., 2010).

![Figure 3. Magnetization as a Function of Applied Field.](image)

Recently a new indoor positioning technology comes out namely the signal fingerprint technology. For each specific location, the multipath channel structure is different with others while the same radio frequency signal is launched from that very location, also this multipath characteristic can be considered as the fingerprint of positioning or characteristic signature. Each received signal is dependent to its terrain and transmission obstacles. Since this technology is not a mature and approved from solid applications, we are going to do some more research on it in the future, even though it already is used for indoor positioning applications.

**GPS Based Positioning Methods**

In terms of GPS based relative positioning methods, the localizing problem of interest herein is to determine the vehicle separation by estimating the 2-D inter-vehicle vectors, as shown in Figure 4. The interest of the study has been limited to the 2-D positioning performance analysis although the system is capable of solving 3-D problem. Availability, accuracy and reliability are three most important criteria for the positioning performance in the present context. The work has been focused on whether and how GPS can meet these requirements. GPS can be operated in single point or relative mode. In addition, two measurements are used for GPS positioning, namely code
(or pseudo-ranges) and carrier phase. Code measurements are obtained through delay lock loops and are precise in sub-meter level but are prone to be affected by signal reflection, also called multipath. In contrast, carrier phase measurements are obtained through phase lock loops and are accurate in millimeter level and are much less influenced by multipath; however, carrier phase are ambiguous and the ambiguity resolution can hardly successfully achieved unless under certain conditions (Williams et al, 2012).

![Inter-Vehicle Vector (IVV) Defined as that from Left-Bottom Vehicle to Right-Top Vehicle (Source: Williams et al. 2012).](image)

Figure 4. Inter-Vehicle Vector (IVV) Defined as that from Left-Bottom Vehicle to Right-Top Vehicle (Source: Williams et al. 2012).

In single point mode, a single receiver is used to provide positions and the accuracy of these positions is controlled by numerous factors, such as satellite availability and geometry, receiver and antenna specifications, satellite errors, atmospheric effects and the multipath environment, just to name a few. Under favorable conditions in which line-of-sight signals are available down to a few degrees above the horizon, the accuracy can be achieved better than 5 m. With the use of the Wide Area Augmentation System (WAAS), which provides additional signals and corrections to GPS satellites from geostationary satellites covering North America, its accuracy can reach 1–2 m with the appropriate receiver. Code measurements are adopted in these instantaneous position solutions.

V2V applications require relative positioning between two vehicles. There are three methods used to determine relative positions of two vehicles. The single point position between the two vehicles is exchanged and the difference between the positions is used to calculate the relative positions. This method is referred to as the difference in position (DPOS). The DPOS position accuracies depend on many factors like the magnitude of the atmospheric errors and multipath errors. However, the most important factor influencing the position accuracy is the number of uncommon satellites used in each of the solutions (Maitipe and Ibrahim, 2011). The typical DPOS position accuracy is 1–3 m.

As to the Differential GPS (DGPS) method, the code measurements are exchanged between the receivers and used to calculate the relative position, which has the significant advantage over the DPOS method by assuring that only common satellites are used in the calculation of the position solution. DPOS resembles DGPS when common satellites are used. If uncommon satellites are used, DPOS will function much worse than the case when only common satellites are used because the significant measurement errors from one satellite will impact both receivers similarly and bias.
the solution in the same way. However, this will not affect the relative position error.

The third method, called RTK, is similar to DGPS except it uses the carrier phase measurements in addition to the code measurements. The carrier phase measurements can provide much more accurate relative positions than the code measurements. The disadvantage of RTK method is that both code and carrier phase measurements must be exchanged between the vehicles resulting in much more data than those required for the DPOS method. It also takes time to determining the carrier phase ambiguities, which can be difficult if the vehicles are separated by long distance, for example, a few tens of kilometers. When carrier phase ambiguities are known, typical error positions can be as low as 0.01 m, compared with 0.2–1 m when the carrier phase ambiguities cannot be determined (Petty and Mahoney, 2007). Both DGPS and RTK require the OTA sharing of additional GPS data using RTCM format messages (RTCMv3) which contains actual GPS carrier and code measurements.

ONE CONCEPTUAL APPLICATION IN WORK ZONE

Qiao and Qiao (2012) proposed a conceptual wireless communication system aiming to enhance the safety of workers in work zone. Figure 5 illustrates a coordinated wireless communications system for worker safety enhancement. The yellow dots are construction barrels, while the green dots are receivers for P2I communications and transmitters for I2V communications. The red dots are the workers wearing a special type of transmitter.

Figure 5. Coordinated Traffic WORK ZONE wireless communication system to enhance worker’s safety (Source: Qiao and Qiao, 2012).

A signal emitter will be placed on worker’s body (e.g. attached to worker’s cloths). A set of receivers are placed on barrels of work zone, each communicates with the emitter frequently. This is the so-called Person-to-Infrastructure (P2I) communication. With the suitable position locating algorithm, the location of the workers can be easily identified.

If the location of workers is in a dangerous area, the roadside devices (Bluetooth, RFID, or ZigBee) will communicate with upcoming vehicles with preset warning message provided to drivers. This will reduce the risk of vehicle to worker, or even vehicle to vehicle collisions.
CONCLUSIONS

In this paper, several different communication devices are scanned including: Bluetooth, Wi-Fi, Radio Frequency Identification (RFID) and ZigBee. Positioning techniques (wiles positioning, methods to track object position, and GPS based positioning methods) are also reviewed. These new technologies are all of great values in synthesizing the V2V, V2I, and even V2P (vehicle to person) communication systems so as to enhance the safety of transportation system while maintaining lower environmental impacts. It is recommended further evaluating the usages of these devices and techniques in various transportation environments through both in-house simulation tests and on-site pilot tests.

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