

THE IMPROVEMENT OF A VEHICLE TO INFRASTRUCTURE COMMUNICATION LINK FOR ITS/DSRC USING SDR AND MIMO TECHNOLOGY

Settawit Poochaya¹, Peerapong Uthansakul^{1*}, Monthippa Uthansakul¹, and Ozan Tonguz²

Received: June 02, 2014; Revised: June 20, 2014; Accepted: June 24, 2014

Abstract

The effect of multipath fading and the surroundings of the communication area cause errors in the V2I (Vehicle to Infrastructure) communication link. Traditional ITS/DSRC systems cannot read information when vehicles move at high speed. These reasons cause the unreliability of the conventional ITS/DSRC systems. Therefore, the authors propose using the MIMO technique and SDR technology to enhance the ITS/DSRC systems' performance. This article presents an implementation of the SDR technology for ITS/DSRC used with the MIMO technique. All experimentation has followed the IEEE 802.11p WAVE-DSRC standard. The USRP platform and GNU Radio software package have been used. The achievement of 2 USRP platforms can be configured easily as OBU and RSU. OBU are installed in the vehicles to perform measurements for V2I applications. The packet error rate, bit error rate, throughput, and average correct received packet ratio have been investigated by varying the distances between the RSU and OBU. The results show an improvement in the traditional ITS/DSRC system's performance. The proposed system increases the reliability for drivers when a small bit error rate occurred. The proposed system gains a high system throughput. Then, the ITS/DSRC communication system can transmit important information at a high data rate.

Keywords: Software-defined radio, multiple antennas, multiple-input and multiple-output, Alamouti, V2I, electronic toll collection, Universal Software Radio Peripheral, GNU Radio

Introduction

Recently, traffic problems have become one of the most important problems for governments around the world. Transportation systems are significant factors for human life such as for travel, medical purposes, and logistics. The number of vehicles increases in direct proportion to the numbers of the populations. This has an effect on traffic flows. If a government does

¹ School of Telecommunication Engineering, Suranaree University of Technology, Muang, Nakhon Ratchasima, Thailand, 30000. E-mail: D5440092@g.sut.ac.th, uthansakul@sut.ac.th, mtp@sut.ac.th

² Carnegie Mellon University, ECE Dept., Pittsburgh, PA 15213-3890, USA. E-mail: tonguz@ece.cmu.edu

* Corresponding author

not build roads to support the vehicles, it causes traffic problems and dangerous roads. The researchers suggest that telecommunication technology, called intelligent transportation systems (ITS), be used to improve the traditional transportation system. The ITS can solve traffic problems such as traffic congestion and accidents. The final goals of the ITS are to improve traffic efficiency and mobile safety without new road construction being required. Dedicated short range communications (DSRC) is an enabling technology that allows vehicles to communicate with each other and supports short to medium range communications and defines the infrastructure of the communication system. DSRC has provided high data rate services. The most popular application of the ITS and DSRC is electronic toll collection (ETC) using radio-frequency identification (RFID) technology (Li *et al.*, 2011). The effect of vehicle mobility can degrade a system's performance because RFID cannot completely read all the data when there is high vehicle mobility (Kukshya and Krishnan, 2006). As a result, the performance of the communication link between the roadside units (RSU) and on-board units (OBU) is very poor under such a condition. According to the literature (Mar *et al.*, 2008), many works have studied the effect on vehicle mobility of the performance of the communication system between the RSU and OBU. They introduce problems such as the effect of multipath fading by the surroundings of the communication area. A high bit error rate (BER) degrades the system's performance (Biswas *et al.*, 2006) and reduces the reliability of the communication system, thus providing a low system throughput which degrades the system's performance. In the case of the ETC system, the high BER decreases the user's payment reliability. An error occurs such as when the receiver cannot receive the overall packet, so that the receiver station at the toll gate cannot read the user's payment data. The low system throughput transmits the data packet slowly. Then the wooden barrier at the toll gate opens slowly because the data packets require more time. Also, Sibecas *et al.* (2002) concluded that

vehicle mobility and multipath fading are the major problems directly affected by the ITS and DSRC system. The researchers determined the need for new technology for the conventional ITS/DSRC system. The use of orthogonal frequency-division multiplexing (OFDM) technology has been promoted. The researchers (Lin *et al.*, 2009) have found the feasibility of using the IEEE 802.11p wireless access for vehicular environments (WAVE) standard (IEEE, 2010). The advantages of the IEEE 802.11p standard are achieved by using the OFDM technique. It eliminates the effect of multipath fading or inter-symbol interference problems. IEEE802.11p introduces outdoor broadband communication such as DSRC and so protects against multipath fading as well as supporting a high mobility user while providing a high data rate transmission. Tarokh *et al.* (1999); Shan *et al.* (2004) introduced new technology that reduced the BER and provided a high system throughput. They found that the multiple-input multiple-output (MIMO) technique is one of the most promising technology developments that overcomes fading channels while maintaining the benefits of high data rate transmission as well as a low bit error rate. By using multiple antennas at both the transmitters and receivers, the system with space-time coding can provide more reliable transmission than a conventional system employing only 1 antenna at the transmitter and receiver. Also, the MIMO system can improve other system performances such as a high spectral efficiency, high system capacity, high coverage area, and high gain. In this light, this paper adapts the concept of the MIMO technique to apply it to the communication link between the RSU and OBU. This technique is able to be implemented for practical use comparatively more easily than the power control plus coding technique. Hence, it is believed that the MIMO technique can both defeat the effect of vehicle mobility and destroy the impediment between the RSU and OBU. The authors developed their own transmitter and receiver using the software defined radio (SDR) technology. The researcher

can control the waveform with 2 host computers. Radio waveforms are controlled by the software corresponding to the parameters' configuration inside the host computer. The SDR technology changed the hardware problems to software problems. Marwanto *et al.* (2009), presented a basic concept in their study of GNU Radio and the Universal Software Radio Peripheral (USRP). The results showed that GNU Radio and the USRP is a rapid and low cost prototype suitable for any wireless technologies. Biddlestone and Redmill (2009) presented an implementation of the OFDM transmission by using the USRP and GNU Radio platform, but many parameters of the OFDM signals in the IEEE 802.11p standard such as modulation type, power level, fast Fourier transform bins, and frame format are totally different from IEEE 802.11a (IEEE, 1999). However, the implementation of the IEEE 802.11p standard is presented in Fuxjäger *et al.* (2010) with the offline experiments. Lan and Li (2010) transmitted the FM data over the air interface via GNU Radio and the USRP and collected the data and investigated the system performance. In this paper, the USRP and GNU Radio softwares are used to measure the data in an offline situation according to the IEEE 802.11p standard. Many parameters such as the packet error rate (PER), BER, and throughput have been collected. Maier *et al.* (2012) investigated multiple antennas at the receiver for the ITS. They introduced selection combining, equal gain combining, and the maximum ratio combining algorithms. This work increased the frame success ratio by 25%. Agostini *et al.* (2013) introduced the SDR for the ITS which provided the flexibility for the next generation of vehicular networks. The work of Mata *et al.* (2013) presented the computer simulation of the MIMO-OFDM for the ITS. The system performance of the ITS/DSRC was done by computer simulation and the results showed the improvement of the traditional ITS. In the literature, there has never been presented the SDR technology with the MIMO system concept for the ITS. Thus, the authors also were interested in the

enhancement of the ITS/DSRC by using the SDR technology and MIMO techniques.

This work introduces an implementation of the MIMO technique. The communication system integrates with the SDR technology to enhance the performance of the 5.9GHz IEEE 802.11p standard such as for the ETC communication between the RSU and OBU. All system configurations are based on the IEEE 802.11p standard. This is because the fading channel due to the effect of buildings around the roads and vehicular environments still performs the same as for any other standards. In experimentation, the BER, throughput, and PER performances have been investigated by varying the distances between the RSU-OBUs and the received power at the receiver. The comparisons between the proposed and conventional system indicate the benefits of the proposed technique.

The consequences of this paper are shown as follows:

- For the ETC system, the good received signal power in the receiver promotes the lower BER and PER of the proposed system and is less than that of the ITS/DSRC conventional system. This refers to the improvement of the system's reliability for the user payment at the toll gate. The results will produce reliability for the drivers by ensuring that the proposed system can operate with more accurate data transmission and reception.

- The average correct received packet of the proposed system promotes the enhancement of the conventional ITS/DSRC system. The proposed system received more packets.

- Focusing on the ETC system, the proposed system can operate with more throughput than the conventional system. The vehicle can transmit the data at a high data rate to the toll gate, so that the wooden barrier opens quickly. This will reduce the waiting time in front of the toll gate, reduce the travelling time, and save fuel. The reduction of emissions in front of the toll gate is the most important consequence.

- For the collision avoidance system, the lower PER and BER promote an

improvement in the accuracy of the warning message. This increases road or traffic safety and the MIMO system reduces the chance of an accident.

The remainder of this paper is arranged as follows: Materials and Methods present the system model, system configuration, experiments, and measurement setup. Results and Discussions have been explained. Finally, there is the conclusion to this article.

Materials and Methods

System Model

Conventional System

The ITS is an emerging technology between telecommunication technology and conventional transportation systems. It improves road convenience, and traffic safety for the driver and traffic congestion are its main purposes. The ITS operates DSRC technology which communicates with a short to medium communication range. The ITS's

popular applications include traffic reports which send traffic information to the driver such as text, video, and audio. Next are intelligent traffic signs which present traffic signs to the driver. The information provided is about traffic congestion and suggests a good way for the driver to proceed. A Global Positioning System (GPS) tracking system is used for logistics management, using a GPS signal to manage a time table for logistics companies. The GPS signal navigates so that the truck driver can go faster to the destination. The managers manage the time table of the trucks. Parking guidance systems instruct the driver to drive a vehicle to pass over a parking gate and then park at an empty space. The most famous of the ITS services is the ETC system; this system improves the conventional toll collection system. For the traditional ETC system, drivers pay the toll to a human. The problems of the conventional toll collection system are that it is not fast because there are traffic jams at the toll gate and, because drivers accelerate and brake frequently, there

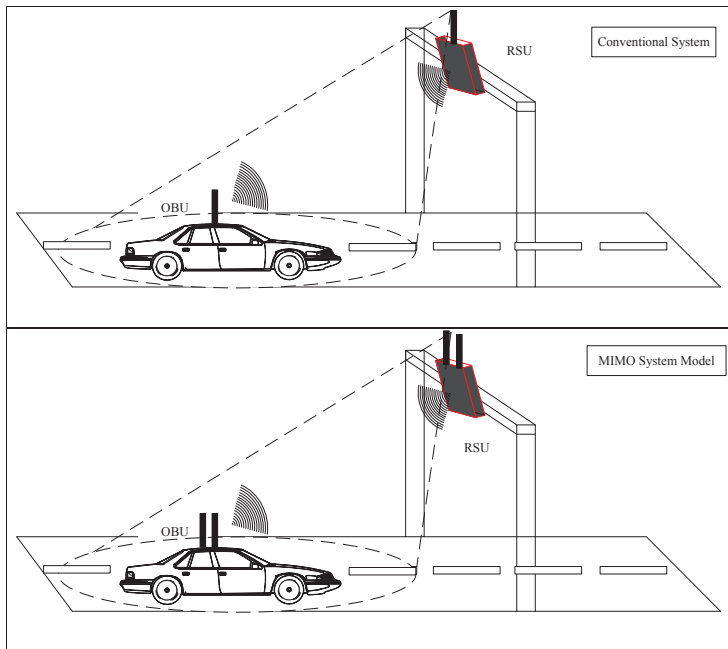


Figure 1. Conventional ITS/DSRC system versus integrated MIMO system: ETC (electric toll collection)

are high emissions at the toll gate from the exhausts of the vehicles.

The DSRC technology defines a standard of communication infrastructure for a short to medium communication range. It is categorized into 2 main communication procedures. The first is vehicle-to-infrastructure (V2I) which defines a standard of radio data transmission between a vehicle and a roadside unit. Secondly, vehicle-to-vehicle (V2V) defines the standard for data transmission between a vehicle and another vehicle. The components of the V2V and V2I systems are the RSU and OBU, as shown in Figure 1 in which the RSU is located beside the road or on the top of a tower that is positioned over the road. The OBU is placed on the dash-board of a vehicle or located on the top of the vehicle's roof. The ITS/DSRC standard is the IEEE 802.11p standard for WAVE-DSRC. Table 1 shows the characteristics of the IEEE 802.11p standard which increased the duration of the symbol time from $4\mu\text{s}$ to $8\mu\text{s}$. It protects from multi-path fading and provides strength against the effects of vehicular environments. The use of the OFDM modulation scheme is appropriate for the new technology that requires a high data rate according to the data size, such as a traffic report, caution sign, picture, and video between the RSU and OBU data transmission.

MIMO System

There are 2 main techniques for the MIMO encoder including spatial multiplexing

and space-time coding. In this paper, the concept of space-time coding has been chosen. There is a tolerance to a fading channel that is caused by the road surroundings. In this paper, the Alamouti space-time block code (STBC) is employed which is the simplest form of STBC and was invented by Alamouti (1998). This code is designed for a 2 transmit antennas system and operated on a block of input symbols. The columns of the coding matrix present the time and the rows show the antennas. The main feature of the STBC is a very simple decoding scheme and the code matrix is given as

$$X_{2 \times 2} = \begin{bmatrix} s_1 & s_2 \\ * & * \\ -s_2^* & s_1^* \end{bmatrix} \quad (1)$$

for $N_r, N_t = 2$

At a given symbol period, 2 signals simultaneously transmit from the 2 antennas, namely S_1 from the first antenna and S_2 from the second antenna. In the next symbol period the $(t + T_s)$ signal $-S_2^*$ and S_1^* are transmitted from the first and the second antennas, where T_s denotes the symbol period. The columns of the matrix correspond to the antennas and a row corresponds to the time slot. This code matrix from equation (1) is orthogonal. At the receiver site, the space-time combiner combines the received signals as follows in equation (2):

Table 1. IEEE 802.11p specifications

Service	Specification
Modulation type	BPSK
Data rate	3-27 Mbps
Frequency band	5.850-5.925 GHz
Number of data subcarriers	48
Number of cyclic prefix	4
Total subcarrier	52
OFDM symbol duration	$8\mu\text{s}$

$$\begin{pmatrix} \tilde{s}_1 \\ \tilde{s}_2 \end{pmatrix} = \frac{1}{\|H\|^2} \sum_{j=1}^{N_r} \begin{pmatrix} * & * \\ h_{1,j}r'_{1,j} + h_{2,j}r'_{2,j} & * \\ * & * \\ h_{2,j}r'_{1,j} - h_{1,j}r'_{2,j} & * \end{pmatrix} \quad (2)$$

for $N_r, N_t = 2$.

S_1 and S_2 present the estimated symbols in the codeword matrix. The symbols $h_{i,j}$ present the estimated channel from the transmit antennas and $\|H\|^2$ receive antennas and presents the summation of the channel power per link.

System Block Diagram

Figure 2 shows the system block diagram consisting of the equipment as specified in Table 2. The system block diagram consists of 2 host computers which are used as 1 for the transmitter and 1 for the receiver. The host computers are connected with the USRP motherboard. The authors plugged an XCVR2450 daughterboard as the radio frequency (RF) front end inside the USRP motherboard. The VERT2450 transmit and receive antennas were connected with 2 XCVR2450 daughterboards. At the transmitter, signals flow from the software which was

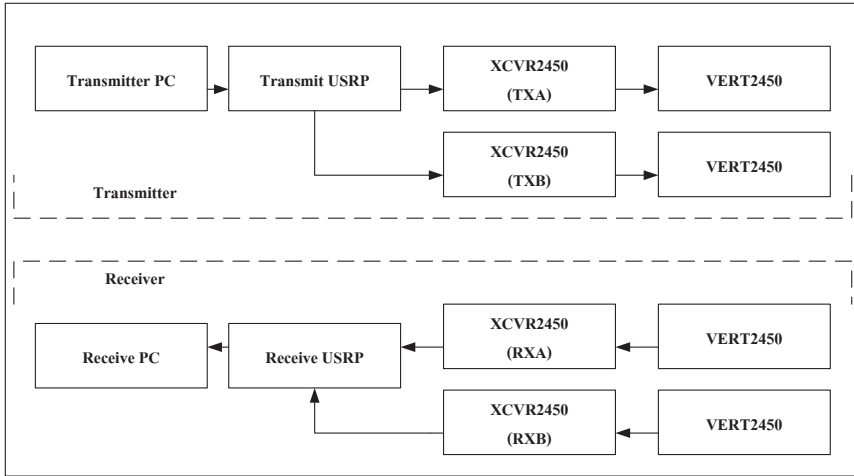


Figure 2. System block diagram for the setup of the MIMO implementation

Table 2. Equipment specifications

Devices	Quantity	Specification
Host Computer	2	Intel Core i5 DDR3-4GB Ram Ubuntu 10.04 Operating System with GNU Radio instal
USRP Daughterboard	2	USRP V.1
	4	XCVR2450 Frequency: 2.4 to 2.5GHz, and 4.9 to 5.9GHz 2 for Transmitter 2 for Receiver
Antenna	4	VERT2450 Frequency: 2.4 to 2.5GHz, and 4.9 to 5.9GHz Gain:3dBi

designed by the authors. Digital signals are generated via the USRP motherboard and sent through the XCVR2450 RF front end. The RF front end converted the digital signals to analog signals. Finally, an analog signal flowed to the VERT2450 transmit antennas sending analog signals over the air interface. At the receiver, the procedures of the signals flow were the inverse of those for the transmitter.

System Configuration

Hardware: USRP

Figure 3 presents the USRP platform. The USRP was developed by Ettus Research LLC of Mountain View, CA, USA. Inside the USRP, there are 2 main components. First, the motherboard field-programmable gate array (FPGA) is the main component of the USRP. The responsibilities of the FPGA are to calculate and process the signals at the transmitter and the receiver. At the transmitter, the USRP includes high speed digital to analog converters (DACs) which convert the digital signals to analog signals. After that, the signals have gone to the RF part. At the receiver, high speed analog to digital converters (ADCs) are installed to reverse the analog signal to a digital signal before sending the signal to the FPGA. The main idea of the FPGA is that all the high-speed general purpose operations like digital

up and down conversion, decimation, and interpolation are done on it. Secondly, the daughterboards the duty of which is to hold the RF receiver interface or tuner and the RF transmitter. The daughterboards are plugged inside a USRP motherboard. The complete USRP and daughterboards equipment is for the convenience of the radio engineer. The authors created their own communication system. The inside of the motherboard contains an Altera Cyclone EP1C12 FPGA. This FPGA consists of 4 ADCs which run on 12 bits per sample with 64 Msamples/sec. The 4 DACs run on 14 bits per sample with 128 Msamples/sec. With regard to the daughterboards' work in the field of the RF front end, this paper employs XCVR2450 daughterboards which respond to the RF in dual bands, 2.4 GHz and 5.9 GHz. All the components are assembled in 1 USRP box using a 3A 6V power supply. Finally, the USRP connects to the host PC via a Universal Serial Bus 2.0.

Software: GNU Radio and MIMO Implementation

GNU Radio is an open source software package which controls and processes the signals. GNU Radio is written in both the Python and C++ programming languages as shown in Figure 4. The C++ programming language was created for the signal processing block. The main role of the Python programming

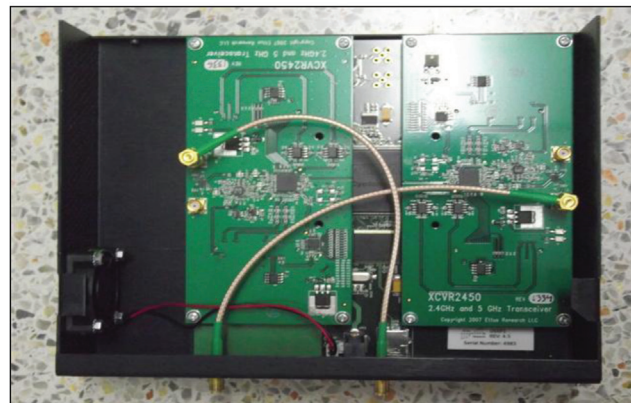


Figure 3. Universal Software Radio Peripheral

language is to connect and glue the entire signal processing blocks. GNU Radio provided the frequently used blocks for the researchers. They created the communication system such as the modulator, demodulator, filter, and the many signals processing blocks inside this package. GNU Radio worked with the USRP hardware and the authors developed and applied their own codes for the configuration of the radio communication system.

Figure 5 and Figure 6 have shown the transmitter and receiver structures, respectively. The directions to create the MIMO system were set out in Wee *et al.* (2009a, 2009b). The authors applied the source codes from the GNU Radio software package and they used the C++ language for the digital signal processing program. The Python programming language glued all of the signals processing blocks. The authors defined the pilot signals x_1 and x_2 for estimating the channel coefficient at the receiver, and the data streams as the payloads S_1 and S_2 for the transmission in the first period. For the second period, the authors sent $-S_2^*$ for payload 1 and S_1^* for payload 2. After that, payload 1 was transmitted to antenna 1 and payload 2 was sent to the transmit antenna 2, respectively. Finally, our program checked the status of any more data to be sent and the end of program. The signals'

flow at the receiver is shown in Figure 6. The authors received the pilot signals from both symbol periods and obtained the channel coefficient by estimating from the pilot signals x_1 and x_2 . The authors extracted the receiver payload at the first symbol period and the second symbol period and then the program processed the signals. The codes applied a decision rule for the raw data. After that, the program stopped and the authors extracted the raw data which consists of pktno (packet number), n_rcvd (number of received packets), and n_right (number of correct received packets). Finally, the authors calculated the system performances such as the PER, BER, and throughput by varying the distances between the RSU and OBU.

Experiments and Measurements Setup

The experimentation contained the transmitter or RSU and the receiver or OBU. The transmitter consisted of the USRP motherboard and XCVR 2450 daughterboards. The software was developed and installed on the motherboard. The authors configured the data packets as the IEEE 802.11p (WAVE-DSRC) standard. Also, the authors transmitted the signals over the air interface. At the receiver, all parameters were configured similar to the transmitter based on the same standard.

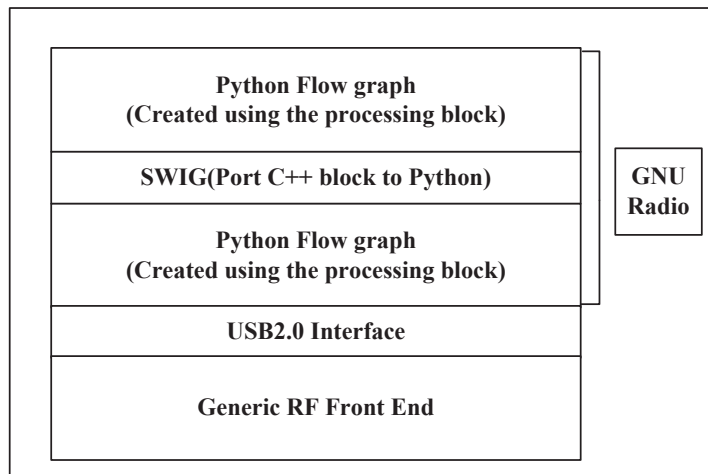


Figure 4. GNU Radio structure

The authors configured the decimation rate, interpolate rate, and number of samples per symbols at the receiver and receiver, respectively. Also the signals were tested in the laboratory before real experimentation,

so that the authors could check the validation of using our software.

At the OBU, the USRP was connected to the laptop. The authors connected the USRP RSU to a personal computer (PC). Both

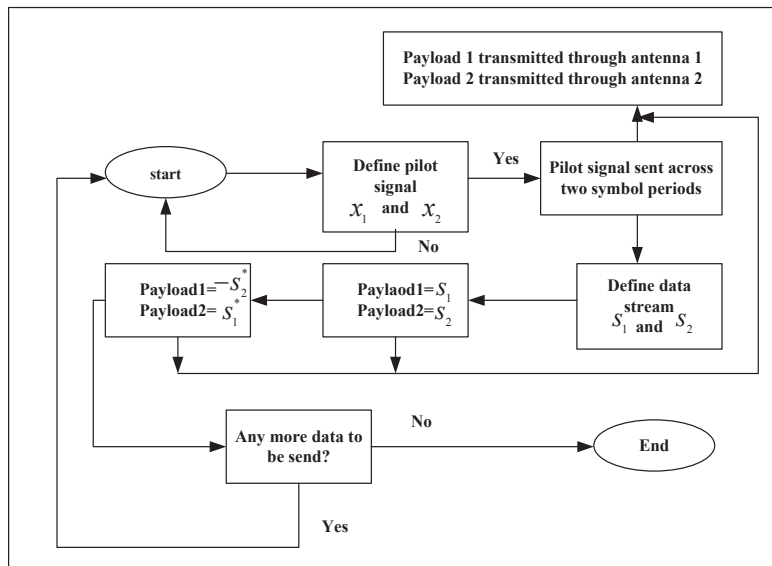


Figure 5. Signals flow diagram at the transmitter (Wee *et al.*, 2009a)

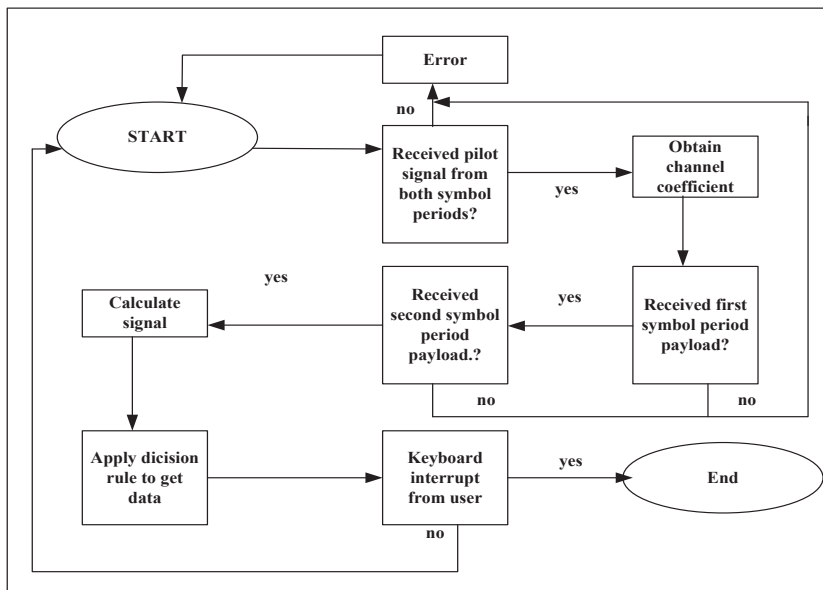


Figure 6. Signals flow diagram at the receiver (Wee *et al.*, 2009b)

the laptop and PC generated and collected the data packets. The XCVR2450 daughterboards were used for these experiments at both the OBU and RSU. The authors configured the transmitter and the receiver as the MIMO-Alamouti encoded and decoded operation with 2×2 antennas. The single-input single-output (SISO) system consists of 2 antennas, 1 at the transmitter side and 1 at the receiver side. The differences in the systems' configurations are the number of transmit antennas and the STBC code for the MIMO system. The frequency band for this experimentation is the 5.9 GHz band. The USRP A was configured as the OBU and was located on the roof of a car, as shown in Figure 7. The USRP B in Figure 8 was configured as the RSU and located beside

the road. The experimentation was conducted in an outdoor environment. The maximum distance between the RSU and OBU is 5 m, because of the USRP's limited specification. The authors measured for a vehicular environment which was a 2 lane road. All of the system specifications were configured as the IEEE 802.11p (WAVE-DSRC) standard (IEEE, 2010; IEEE 1609.3, 2006; IEEE 802.11p: Part11, 2010). For each of the measurement locations, 10 times of data collection were performed. The measurement methodology was categorized into 2 procedures per point. First, the authors investigated the SISO system in Figure 9(a), and then the MIMO measurement in Figure 9(b). Every point varied the distance between the RSU and OBU. The authors collected the



Figure 7. On-Board unit (located on the roof of a car)



Figure 8. Roadside unit



(a)



(b)

Figure 9. Experiment and measurement setup a) SISO b) MIMO

received power in each position, and the off-line data, and extracted all the data. The authors computed the system performances such as the PER, BER, and throughput. The aims of these experiments determined the relationship between the PER, BER, and throughput versus a distance between the RSU and OBU and the received power with the binary phase-shift keying (BPSK) modulation type. The authors got the raw offline data from the experimentation. The experimentation measured 10 times/points and varied the distances between the RSU and OBU. The authors extracted the raw data and determined the average values of $pktno$, n_right , n_rcvd , and received power. After that, the authors used equation (3) in order to calculate the PER performance and computed the BER by equation (4).

$$PER = \left(1 - \left(\frac{n_right}{pktno}\right)\right) \times 100\% \quad (3)$$

$$1 - PER = (1 - BER)^L \quad (4)$$

n_right is the number of correct receive packets
 $pktno$ is the packet number
 L is the packet length

Results and Discussions

The experimentation investigates the system performance. There are the PER, BER, and throughput. The authors varied only the distances between the RSU and OBU. Table 3 presents the results. The PER of the MIMO 2x2 versus the distance between the RSU and OBU is less than the conventional SISO system. For the BER performance, the BER increased when the distance between the RSU and OBU increased. The BER performance of the proposed system is less than that of the SISO system. For example, in the ETC system, these results increase the reliability

Table 3. Experimentation results for the PER, BER, and throughput vs. distance (m.) and average received power (dBm)

Variable	Average received power (dBm)	Distance between RSU and OBU (m)	Conventional system	MIMO 2x2
PER	-61.3	1	39.42%	39.04%
	-70.1	2	60.40%	59.10%
	-74.8	3	84.02%	83.41%
	-77.7	4	97.04%	96.44%
	-81.2	5	98.73%	98.40%
BER	-61.3	1	1.25×10^{-3}	1.19×10^{-3}
	-70.1	2	2.31×10^{-3}	2.23×10^{-3}
	-74.8	3	4.57×10^{-3}	4.48×10^{-3}
	-77.7	4	8.76×10^{-3}	8.30×10^{-3}
	-81.2	5	1.10×10^{-2}	1.00×10^{-2}
Throughput	-61.3	1	1.81×10^6	1.90×10^6
	-70.1	2	1.18×10^6	1.23×10^6
	-74.8	3	4.80×10^5	4.97×10^5
	-77.7	4	8.88×10^4	1.07×10^5
	-81.2	5	3.81×10^4	5.37×10^4

for drivers by ensuring that the proposed system can operate with more accuracy. Our results promote the reliability for user payment at the toll gate. The reliability of the communication system in the ITS is affected by the multipath fading channel (Ma *et al.*, 2012). The PER in this work is measured under the fading channel. The PER threshold, based on the ASTM E2213-03 standard (ASTM, 2010) for data transmission in the ITS is 10% at 1000 bytes packet length. The PER and BER relationship is presented in Equation (4). Moreover, the PER refers to the probability of the correct received packet at the receiver side. The PER indicates a low reliability of the communication system when high PER. Also, the reliability of the communication in the ITS is indicated by the PER and BER. Focusing on the system's accuracy, both the PER and BER indicate the accuracy of the information received at the receiver. The packet lengths of 400 bytes are transmitted by the transmitter. As to the measurement of the results, the receiver can receive 1248 bits at a distance between the RSU and OBU of 1 m. Also, this situation promotes the accuracy of the receiver side in a communication system in the ITS.

Therefore, the proposed system can confirm that the MIMO technique and SDR technology improved the traditional system's performance. The SDR technology promotes convenience for engineers to configure communication systems. Furthermore, the throughput of the proposed system is more than that of the conventional system. The results show that the proposed system is able to operate for high speed data communication. From the reasons above, it allows the user to transmit huge data packets such as audio, image, and video. Table 3 shows the investigation of the average received power. When a vehicle moves far from the RSU, the average received power at the receiver decreases. The overall results demonstrate the improvement of the proposed system which improves the link quality of the ITS/DSRC system. As to the ETC systems, the use of the MIMO system improves the

system's performance. Furthermore, when considering the collision avoidance system, the use of the proposed system can improve the accuracy of the warning message. The effect of this has increased road or traffic safety and the MIMO system has decreased the chance of an accident. Finally, the authors investigated the system's performance of the average correct received packet ratio. The result is the comparison between the distances of the RSU and OBU versus the average received power. Figure 10 presents the relationship of the average correct received packet ratio versus the distance between the RSU and OBU. The average correct received packets are counted under the same total number of transmitted packets. At 3 m, the results reveal that the proposed system received 415 packets more than the conventional system which received 390 packets. Our result confirms that the MIMO system received more packets than the traditional system. Figure 11 compares the average correct received packet versus the average received power. For example, at -80 dBm, the value shows the system's sensitivity and confirms that the receiver can receive packets from the transmitter. For -80 dBm, the transmitter is about 5 m from the receiver. The results indicate that the MIMO system can receive 70 packets and the conventional system can receive 45 packets. All our results promote the proposed system as being able to be operated with more efficiency than the conventional SISO system. The proposed system's use as an ETC system improves reliability for drivers, because when they are in front of the toll gate they are sure of the reliability of the payment data. In front of the toll gate, the proposed system reduces the waiting time because of a high system throughput that can send the data packet with a fast data stream. The effect is to reduce the waiting time in front of the toll gate, reduce the travelling time, save fuel, and most importantly reduce exhaust emissions in front of the toll gate. The average correct received packets ratio of the MIMO system is more than that of the conventional system. This

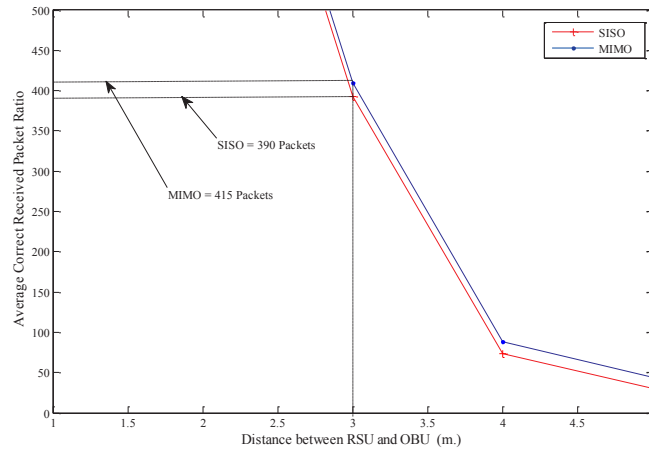


Figure 10. Average correct received packet ratio versus distance between the RSU and OBU

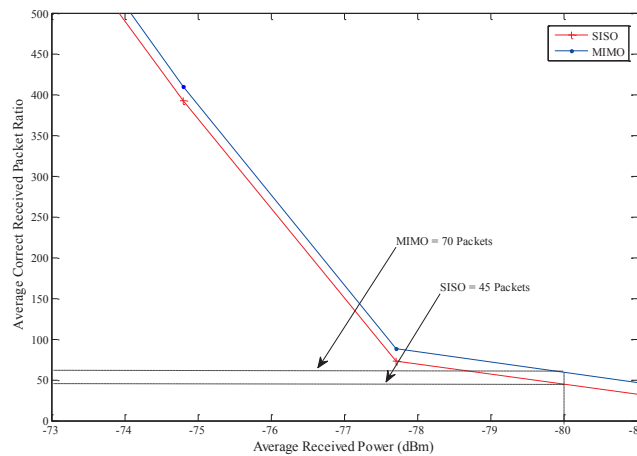


Figure 11. Average correct received packet ratio versus average received power (dBm)

MIMO system can receive more packets in the same time than the traditional system. Because of the limitations of the equipment with a low transmission power and a small gain from the antennas, this system cannot be implemented providing a coverage range of more than 5 m. In the future the authors will improve this limitation and experiment with vehicle movement at varying speeds of the vehicle. We have investigated the system's performance and compared it with the ITS/DSRC communication system.

Conclusions

This paper introduces an implementation of the SDR technology using the MIMO technique. The proposed system improves the ITS/DSRC conventional services. The authors apply the GNU Radio and USRP platforms to the IEEE 802.11p (WAVE-DSRC) standard. The PER, BER, average correct received packets, and throughput have been investigated by varying the distances between the RSU and OBU. The results will provide

reliability for drivers to ensure that the proposed system can operate with more accuracy. In the future, the authors will improve and develop the system to support a moving vehicle.

Acknowledgement

This work is financially supported by the Royal Golden Jubilee Scholarship, TRF Fund (Grant No. PHD/0041/2553).

References

- Agostini, P., Knopp, R., Harri, J., and Haziza, N. (2013). Implementation and test of a DSRC prototype on OpenAirInterface SDR platform. Proceedings of the IEEE International Conference on Communications Workshops; June 9-13, 2013; Budapest, Hungary, p. 510-514.
- Alamouti, S. (1998). A simple transmit diversity technique for wireless communications. IEEE J. Sel. Area. Comm., 16(8):1451-1458.
- ASTM. (2010). ASTM E2213-03. Standard Specification for Telecommunications and Information Exchange Between Roadside and Vehicle Systems — 5 GHz Band Dedicated Short Range Communications (DSRC) Medium Access Control (MAC) and Physical Layer (PHY) Specifications. ASTM International, West Conshohocken, PA, USA.
- Biddlestone, S. and Redmill, K.A. (2009). A GNU Radio based testbed implementation with IEEE 1609 WAVE functionality. Proceedings of the IEEE Vehicular Networking Conference; October 28-30, 2009; Tokyo, Japan, p. 1-7.
- Biswas, S., Tatchikou, R., and Dion, F. (2006). Vehicle-to-vehicle wireless communication protocols for enhancing highway traffic safety. IEEE Commun. Mag., 44(1):74-82.
- Fuxjäger, P., Costantini, A., Valerio, D., Castiglione, P., Zacheo, G., Zemen, T., and Ricciato, F. (2010). IEEE 802.11p transmission using GNU Radio. Proceedings of the 6th Karlsruhe Workshop on Software Radios; March 3-4, 2010; Karlsruhe, Germany, p. 1-4.
- IEEE. (1999). Standard 1455. IEEE Standard for message sets for vehicle/roadside communications. IEEE Standards Association, The Institute of Electrical and Electronics Engineers, Inc., New York, NY, USA.
- IEEE. (1999). Standard 802.11a. IEEE Standard for telecommunications and information exchange between systems – LAN/MAN specific requirements Part 11: Wireless medium access control (MAC) and physical layer (PHY) specifications: High speed physical layer in the 5 GHz band. IEEE Standards Association, The Institute of Electrical and Electronics Engineers, Inc., NY, USA.
- IEEE. (2006). Standard 1609.3. Trial-Use Standard for Wireless Accesses in Vehicular Environments (WAVE) – Networking services, IEEE Standards Association, The Institute of Electrical and Electronics Engineers, Inc., NY, USA.
- IEEE. (2010). Standard 802.11p. IEEE Standard for information technology – Local metropolitan networks – Specific networks – Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications Amendment 6: Wireless Access in Vehicular Environments. IEEE Standards Association, The Institute of Electrical and Electronics Engineers, Inc., NY, USA, 35p.
- Kukshya, V. and Krishnan, H. (2006). Experimental measurements and modeling for vehicle-to-vehicle dedicated short range communication (DSRC) wireless channels. Proceedings of the IEEE 64th Vehicular Technology Conference; September 25-28, 2006; Montréal, Québec, Canada, p. 1-5.
- Lan, K.C. and Li, M.W. (2010). Feasibility study of using FM radio for data transmission in a vehicular network. Proceedings of the 2010 International Computer Symposium; December 16-18, 2010; Tainan, Taiwan, p. 55-60.
- Li, M.W., Wu, T.H., Lin, W.Y., Lan, K.C., Chou, C.M., and Hsu, C.H. (2011). On the feasibility of using 802.11p for communication of electronic toll collection systems. ISRN Communications and Networking, Volume 2011, Article ID 723814, 11p.
- Lin, S., Sun, C.K., and Lin, J.C. (2009). Performance evaluations of channel estimations in IEEE 802.11p environments. Proceedings of the International Conference on Ultra Modern Telecommunications & Workshops; October 12-14, 2009; St. Petersburg, Russia, p. 1-5.
- Ma, X., Yin, X., and Trivedi, K. S. (2012). On the reliability of safety applications in VANETs. Int. J. Perform. Eng., (2):115-130.
- Maier, G., Paier, A., and Mecklenbrauker, C.F. (2012). Performance evaluation of IEEE 802.11p infrastructure-to-vehicle real-world measurements with receive diversity. Proceedings of the 2012 8th International Wireless Communications and Mobile Computing Conference; August 27-31, 2012; Limassol, Cyprus, p. 1113-1118.
- Mar, J., Lung, Y.R., Lin, T.H., and Kuo, C.C. (2008). Design of a software defined radio channel simulator for mobile communications: Performance demonstration with DSRC for different vehicle speeds. Proceedings of the International Conference on Communications,

- Circuits and Systems; May 25-27, 2008; Fujian, China, p. 345-349.
- Marwanto, A., Sarijari, M.A., Faisal, N., Yusof, S.K.S., and Rashid, R.A. (2009). Experimental study of OFDM implementation utilizing GNU Radio and USRP – SDR. Proceedings of the IEEE 9th Malaysia International Conference on Communications; December 15-17, 2009; Kuala Lumpur, Malaysia, p. 132-135.
- Mata, T., Naito, K., Boonsrimuang, P., Mori, K., and Kobayashi, H. (2013). Proposal of STBC MIMO-OFDM for ITS systems. Proceedings of the 10th International Conference on Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology; May 15-17, 2013; Krabi, Thailand, p. 1-6.
- Sibecas, S., Corral, C.A., Emami, S., and Stratis, G. (2002). On the suitability of 802.11a/RA for high-mobility DSRC. Proceedings of the IEEE 55th Vehicular Technology Conference; May 6-9, 2002; Birmingham, AL, USA, vol.1, p. 229-234.
- Shan, C., Kam, P.Y., and Nallanathan, N. (2004). Theoretical performance of space-time block coded systems with channel estimation. Proceedings of the IEEE Global Telecommunications Conference; November 29-December 3, 2004; Dallas, TX, USA, 6:3666-3670.
- Tarokh, V., Jafarkhani, H., and Calderbank, A.R. (1999). Space-time block codes from orthogonal designs. IEEE T. Inform. Theory, 45(5):1456-1467.
- Wee, S., Ros, M., and Vial, P.J. (2009a). Mitigation against MAI in a space time spreading software defined radio test bed. Proceedings of the 6th International Conference on Information Technology: New Generations; April 27-29, 2009; Las Vegas, NV, USA, p. 534-540.
- Wee, S., Ros, M., and Vial, P.J. (2009b). Comparison of Alamouti and STS implementations using a software defined radio test bed. Proceedings of the 3rd International Conference on Signal Processing and Communication Systems; September 28-30, 2009; Omaha, NE, USA, p. 1-8.

