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DESIGN OF THE COMMUNICATION NETWORK TO BE USED IN SMART TRANSPORTATION SYSTEMS

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DESIGN OF THE COMMUNICATION NETWORK TO BE USED IN SMART TRANSPORTATION SYSTEMS

AKILLI ULAŞIM SISTEMLERINDE KULLANILACAK HABERLEŞME AĞININ PLANLANMASI

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ÖZ

AKILLI ULAŞIM SISTEMLERINDE KULLANILACAK HABERLEŞME AĞININ PLANLANMASI

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Bu çalışmada; akıllı ulaşım sistemlerinde trafik güvenliği ve trafik yönlendirmesi uygulamalarında kullanabilecek, çeşitli kablosuz haberleşme teknolojileri kullanılarak geliştirilen bir sistem önerilmektedir. Geliştirilen sistem ile araçsal ağlarda ses, görüntü, çeşitli dosya ve metin gönderimi yapılabilmektedir. Ayrıca sistem, GPS ve ivme sensörü kullanarak kaza tespiti ve konumlandırılmasına olanak vermektedir. Bu özellikler sayesinde kaza durumunda tıbbı müdahalenin ulaşma süresi kısalmaktadır. Çeşitli ortamların, antenlerin ve araç hızının, araçlar arası haberleşmeye ve araç ile yol kenarı istasyonu arasındaki haberleşmeye etkisini incelemek için farklı ortamlarda yönlü ve yönsüz antenler kullanılarak çeşitli testler gerçekleştirilmiştir. Testler araçlar arası haberleşme ağlarında ses ve görüntü aktarımı için IEEE 802.11b/g standartları kullanılarak gerçekleştirilmiştir. Sonuçlar göstermektedir ki alıcı ve verici arası uzaklık, LOS haberleşme ve ortam koşulları araçsal ağları etkileyen en önemli faktörlerden bazılarıdır.

ANAHTAR SÖZCÜKLER: Araçsal ağlar, araçlar arası haberleşme, araç ile yol kenarı istasyonu haberleşmesi, akıllı ulaşım sistemleri, IEEE 802.11b/g, ses ve görüntü aktarımı
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ABSTRACT

DESIGN OF THE COMMUNICATION NETWORK TO BE USED IN SMART TRANSPORTATION SYSTEMS

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In this thesis, an intelligent data transmission system based on different wireless technologies is introduced to provide traffic safety control and warning assistance systems for ITS applications. The developed system has been designed to transmit image (jpeg, bmp), audio (mp3), office, pdf files and text messages in vehicular networks. Additionally, the developed system is featuring automatic detection and positioning traffic accidents by the help of GPS and accelerometer.
The system proposes facilities that can shorten time to reach medical help. In order to investigate effects of different environments, antennas and vehicle speed on V2V and V2I communications, a set of experiments were performed with omni directional and directional antennas in different environments. Results show that IEEE 802.11b/g standards can be used for transmitting multimedia files in vehicular networks. Results also show that distance, line of sight communication and environmental conditions are the main factors affecting the vehicular network connectivity.

KEYWORDS: Vehicular Networks, V2I, V2V, ITS, IEEE 802.11b/g, image and audio transmission
Advisor: Assistant. Prof. Dr. Aysel ŞAFAK, Başkent University, Department of Electrical and Electronics Engineering

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LIST OF ABBREVIATIONS

ARQ	Automatic Repeat Request
BER	Bit Error Rate
BPSK	Binary Phase Shift Keying
CRC	Cycling Redundancy Check
CSMA/CA	Carrier Sense Multiple Access With Collision Avoidance
dBm	Decibels Relative to One Miliwatt
DSRC	Dedicated Short Range Communications
DSSS	Direct Sequence Spread Spectrum
EIRP	Effective Isotropic Radiated Power
ETSI	European Telecommunications Standard Institute
FCC	Federal Communications Commission
FHSS	Frequency Hopping Spread Spectrum
GPRS	General Packet Radio System
GPS	Global Positioning System
GUI	Graphical User Interface
IEEE	Institute of Electrical and Electronics Engineering
IP	Internet Protocol
ISM	Industrial Scientific Medical
ITS	Intelligent Transportation Systems
LOS	Line of Sight
MAC	Medium Access Control
MSE	Mean Squared Error
OBU	On Board Unit
OFDM	Orthogonal Frequency Division Multiplexing
PER	Packet Error Rate
PHY	Physical
PNSR	Peak Signal to Noise Ratio
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase Shift Keying
RSU	Road Side Unit
RTT	Round Trip Time
SNR	Signal to Noise Ratio
TCP	Transport Control Protocol
UDP	User Datagram Protocol
UMTS	Universal Mobile Telecommunication System
V2I	Vehicle to Infrastructure
V2V	Vehicle to Vehicle
WAVE	Wireless Access in Vehicular Environment
WLAN	Wireless Local Area Network
WME	Wave Management Entity
WSMP	Wave Short Message Protocol

1. INTRODUCTION

Intelligent Transportation Systems (ITS) apply communications, control, sensing and detecting technologies to all kinds of transportation systems in order to improve traffic safety and efficiency by transmitting real time information [1]. To achieve aim of ITS, an effective communication is needed. For this requirement, vehicular communication systems are effective in decreasing the accidents and relieving traffic congestions. Vehicular networks can provide safety [2], entertainment [3], or driving assistance [4] applications. Road information, email access, web browsing and video or music broadcasting to moving cars are the most main usage areas of vehicular networks. For example, a vehicle recognizing a traffic jam or a hazard on the road can inform approaching vehicles by using vehicular networks.

Vehicular networks can be operated in either infrastructure or ad hoc modes. In contrast to cellular networks, infrastructure is not required for communication between vehicles. Vehicle to Vehicle (V2V) communication is the communication between the vehicles. On the other hand, Vehicle to Infrastructure (V2I) communication is the communication between the vehicle and the infrastructure [6-7]. Due to direct communication between vehicles, lower latency is provided compared to existing wireless solutions [28]. However, vehicular networks have challenges which other wireless systems are not dealing. One challenge is the high relative speed occurred when two vehicles moving fast in the opposite direction. Another challenge is to satisfy high transfer rates and low communication latency in order to provide safety services and entertainment or driving assistance applications [5]. Moreover, vehicular communication has to deal with much faster fading and much Doppler frequency spread than other wireless systems because of its rapidly changing topology.

Different wireless technologies, such as IEEE802.11a/b/g, Dedicated Short Range Communications (DSRC), General Packet Radio System (GPRS) and Universal Mobile Telecommunication System (UMTS) have used for vehicular communications under the umbrella for ITS. GPRS or UMTS technologies provide large network coverage but their bandwidth is limited [6].

IEEE 802.11 is a set of standards which implement Wireless Local Area Network (WLAN) communication in the 2.4, 3.6 and 5 GHz frequency bands. IEEE 802.11b is one of the popular members of IEEE 802.11 family. It is operating on 2.4 GHz band and has a maximum raw throughput of 11 Mbps. The modulation technique used in IEEE 802.11b is Direct Sequence Spread Spectrum (DSSS). In 2003, IEEE 802.11g standard which offers 54 Mbps raw throughput was proposed. Like IEEE 802.11b, its frequency band is 2.4 GHz. The key difference is the Orthogonal Frequency Division Multiplexing (OFDM) modulation usage. IEEE 802.11a is another family member which offers 54 Mbps raw throughput. It is very similar to IEEE 802.11g but it is operating on 5 GHz ISM Band.

DSRC has an allocated 75MHz spectrum at 5.9GHz for vehicle-to-vehicle and vehicle-to-infrastructure communications. DSRC provides very high data transfer rates and low latencies for vehicular communication links. An IEEE 802.11 standard, called IEEE 802.11p is designed as the communication protocol for DSRC. IEEE 802.11p is based on IEEE 802.11a but provides enhancements to low layers of IEEE 802.11a.

A number of studies have proposed measurement results with UMTS, DSRC and IEEE 802.11a/b/g standards to evaluate the capability of vehicular networks. Wewetzer et al. [36] have compared throughput performance of UMTS and IEEE802.11a/b standards for inter vehicle communication. They derived that maximum throughput can be achieved with WLAN is 20 times higher than UMTS. Rubinstein et al. [8] use User Datagram Protocol (UDP) and Transport Control Protocol (TCP) ethernet protocols to transfer data between two cars. They did not use external antennas in the experimental vehicles. They investigate performance of IEEE 802.11a/g standards with different vehicle speeds and packages sizes [8]. Results show that transfer capacity is directly related to vehicle speed and decrease in packet size reduces the transfer capacity. Min et al [22] use a similar scenario to Rubinstein et al., but they used external antennas in the cars. They investigated performance of IEEE 802.11g on V2V communication in different environments with varying speeds from 5 to 140 km/h. Results show that driving speed does not affect the delay and loss performance and link between vehicles is more available in rural environment than urban and congested environments. Bucciol et al. [11] discuss V2V communication connectivity using two vehicles equipped with IEEE 802.11b devices. They performed tests using a multimedia application in urban and highway environments The authors argue that the link is more available in a highway then in an urban area.

Ott and Kutscher [9] worked on network connection between a car equipped with an external antenna and a fixed access point station over an IEEE 802.11b channel. The tests were performed on a German freeway with varying speeds from 80 to 180 km/h. Their goal was to examine the impact of vehicle speed and ethernet protocols on V2I communication. Results show that throughput is about 4Mbps for UDP when in range of the access point. Throughput achieved with TCP is lower than UDP. Additionally, the amount of data can be transferred in a single pass is 8.8 Mbytes for UDP and 6 Mbytes for TCP. Gass et al. [10] use a similar experimental setup to Ott and Kutscher but they did not use an external antenna in the car. They performed V2I tests in California desert, where there are no interferences from other wireless systems. Car speed varied from 8 to 120 km/h. Results show that 92 Mbytes can transferred when moving at 8 km/h and 6.5 Mbytes at 120 km/h.

Buccoil et al. [23] tested V2I communication with a developed application that can transmit mp3 streams over UDP. They equipped car and infrastructure with IEEE 802.11b devices. They did not use external antenna in the vehicle. Car speeds varied from 40 to 70 km/h. To investigate impact of antennas on V2I communication, they used different antennas in the infrastructure. The results show that number of received packages is decreasing clearly when car speed increases. Additionally, package loss rate decreases when high gain antennas used. Bae et al. [12] studied V2I and V2V communication with a develop system based on the IEEE 802.11a/g standards. They investigated impact of vehicle speed on the throughput. The authors come out with the following results: (i) when the vehicle moves at a certain velocity, the throughput is decreased because of fading, (ii) for relatively low data rates of 6, 9, 12, 18, or 24 Mbps, the throughputs are very similar regardless of velocity, (iii) for high data rates of 36, 48, and 54 Mbps, the throughputs are decreased by weak error correction ability.

Lin et al. [18] compare performance of IEEE 802.11a and IEEE 802.11p standards for V2I communication. They used WAVE/DSRC communication units which can also implement IEEE 802.11a. For both standards, they compared contact duration between vehicle and infrastructure with varying speeds from 20 to 60 km/h. Throughput performance of IEEE802.11p was also investigated in terms of modulation and distance. Results show that at the speed of 60 km/h, the contact duration with IEEE 802.11p can be long as 14 seconds while IEEE 802.11a can not set a connection. Moreover, when the highest rate 64 Quadrature Amplitude Modulation (QAM) is used for IEEE 802.11p; throughput could quickly drop to zero with distances more than 40 meters. On the other hand, when the Binary Phase Shift Keying (BPSK) modulation is used, a stable throughput of 2 Mbps can be achieved up to 150 meters.

The aim of this thesis is to develop an intelligent data transmission system for V2V and V2I communications to provide development of traffic safety control and warning assistance systems. Due to availability problems and high cost of DSRC/WAVE communication units mentioned in Appendix 1, IEEE 802.11b/g and 900 MHZ Frequency Hopping Spread Spectrum (FHSS) transceivers are used in this work. To achieve goal of this thesis, vehicular communication systems based on different wireless technologies are developed. The developed systems are unique as they can both transmit collision detection information, data, image and audio files. The rest of the thesis is organized as follows.

In Chapter 2, ITS, Wireless Access in Vehicular Environment (WAVE), DSRC, IEEE 802.11p concepts and other IEEE 802.11 wireless communication standards are described.

In Chapter 3, vehicular communication system based on FHSS technology is introduced. In order to measure capability of the system, several tests were performed. Additionally, test results for V2I communication and collision detection are shown.

In Chapter 4, vehicular communication system based on IEEE802 b/g standards is presented. To investigate effects of environment and vehicles speed on V2V and V2I communications, a set of experiments were performed in different environments with omni-directional and directional antennas .Test results for collision detection, V2I and V2V communications are presented.

In Chapter 5, thesis is summarized and test results are overviewed.

2. WIRELESS AND VEHICULAR COMMUNICATION STANDARDS

In this chapter, the standards, WAVE, DSRC, IEEE 802.11p related to ITS are reviewed and differences between IEEE 802.11p and most common wireless standards are discussed. Modulation techniques, tradeoff between data rate and signal to noise ratio and the parameters affecting the free space path loss, the transmission power, the antenna gain are analyzed.

2.1 Intelligent Transport Systems (ITS)

ITS is related to communications, control, sensing and detecting technologies to all kinds of transportation systems in order to improve traffic safety and efficiency by transmitting real-time information [1].

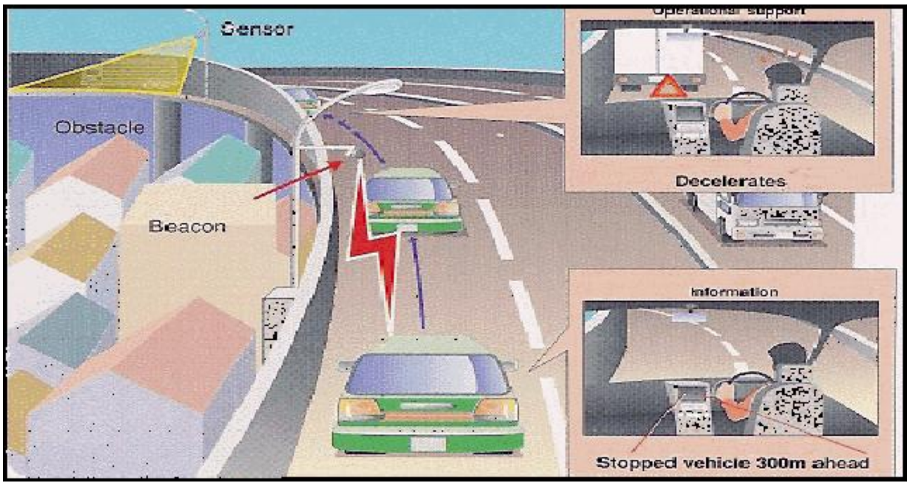

Figure 2.1 ITS Warning System.

ITS technologies are applied to vehicles and roadsides to provide communications, data processing, traffic control, surveillance, navigation, sensing, and other various applications. Figure 2.1 shows an accident warning assistance system.

2.2. Dedicated Short Range Communications (DSRC)

DSRC is a short to medium range wireless communication that offers both public safety and private data transfer in vehicle to infrastructure and vehicle-to-vehicle communications such as entertainment, accident avoidance, intersection coordination and danger warning [15].

In 1999, the U.S. Federal Communications Commission (FCC) allocated 75 MHz at 5.9GHz to be used exclusively for vehicle-to-vehicle and infrastructure-to-vehicle DSRC communications. 75 MHz spectrum is divided into seven 10-MHz channels and a 5 MHz guard band and as in shown in Figure 2.2 [16].

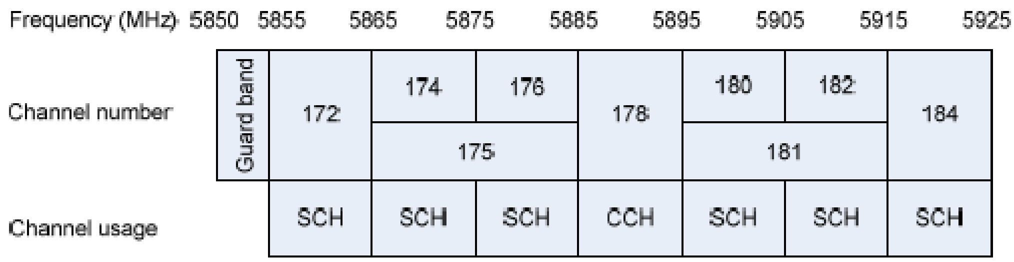

Figure 2.2 The DSRC Frequency Allocation in US.

Seven 10 MHz channels are arranged into 1 control channel (CCH) and 6 service channels (SCH). The control channel is reserved for carrying high priority short messages or management data, while less priority data are transmitted on the service channels. As shown in Figure 2.2, channel 178 is the control channel, which is reserved for only high priority communications. The pair of channels channel 174 and 176, and channel 180 and 182 can be combined to form a single 20-MHz channel. Channel 175 and 181 are the combined 20 MHz channels. The two channels at the edges of the spectrum are reserved for future accident avoidance and high power public safety applications. The other service channels are available for both safety and non safety usage [17]. Usually, the maximum allowed Effective Isotropic Radiated Power (EIRP) is 33 dBm for service channels. The maximum allowed EIRP of control channel is 44.8 dBm and this would theoretically allow broadcasting safety messages up to 1000 meters. In reality this range is hard to achieve due to fading and interferences which will be mentioned in Section 2.5. Other frequency bands have also been used for DSRC applications in various regions as shown in Figure 2.3.

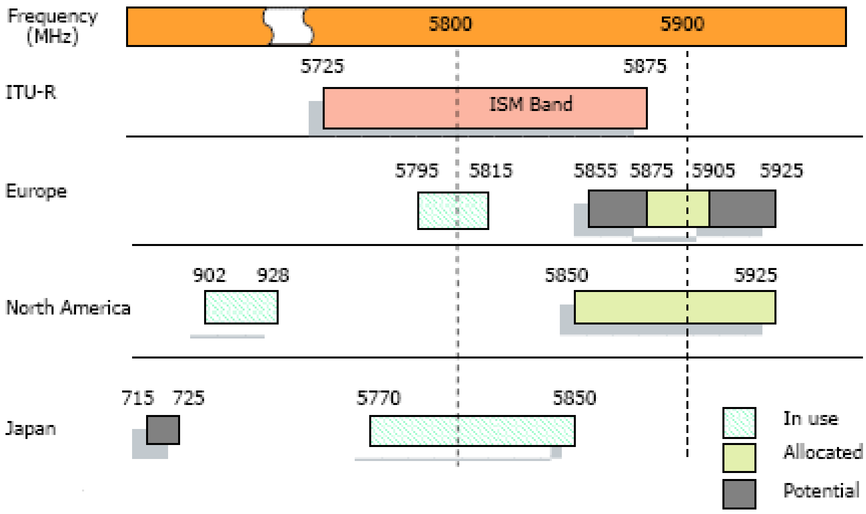

Figure 2.3 Spectrum Allocation for DSRC.

There are two basic types of nodes in a DSRC networks. An OBU is located on vehicles and acts as a mobile station, while a RSU is located on the road side and serves as a base station [18]. Figure 2.4 shows illustration of DSRC and WAVE networks. WAVE networks can be operated in either infrastructure or ad hoc modes. To meet the vehicular ad hoc requirements, a new standard IEEE 802.11p based on IEEE 802.11a is proposed. IEEE 802.11p defines physical and the medium access control layers of DSRC. The PHY and MAC layer's details of IEEE802.11g are mentioned in the next section. DSRC devices are assumed to support both standards.

As shown in Figure 2.5, WAVE consists of management and data planes. Management Plane is used to configure and manage the system with WAVE Management Entity (WME). Data Plane includes IPv6 protocol and WAVE Short Message Protocol (WSMP). WSMP is designed to control physical parameters such as the transmission power, the data rate and the channel number [19].

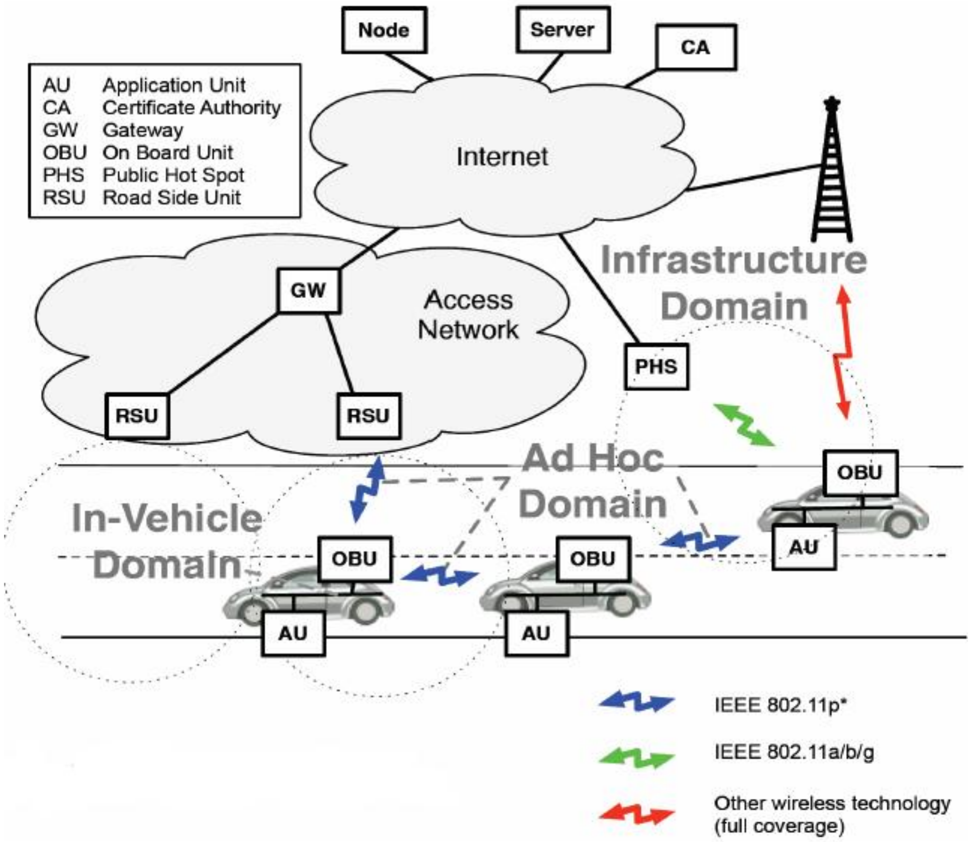

Figure 2.4 DSRC networks.

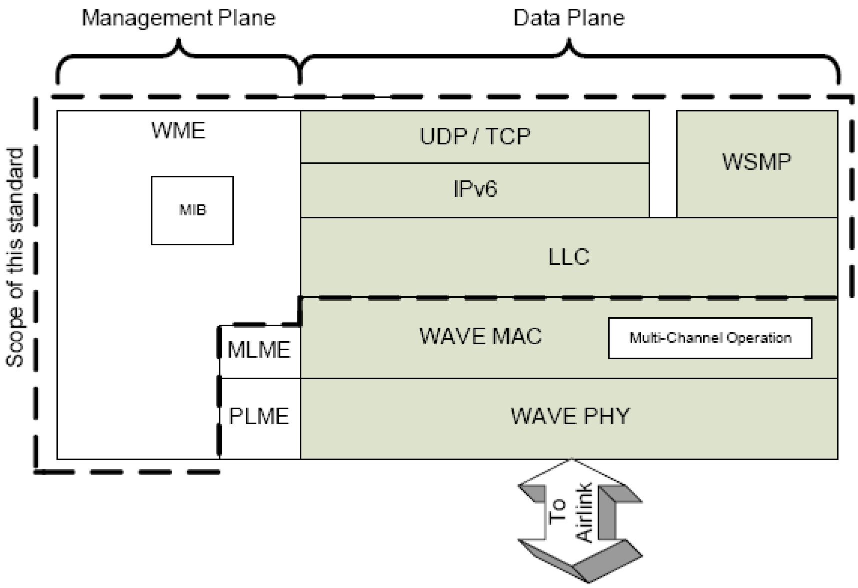

Figure 2.5 WAVE protocol stack.

2.2.1 IEEE 802.11p standard physical layer

IEEE improved all older versions of the Physical (PHY) and the Medium Access Control (MAC) layers into the IEEE 802.11–2007 edition. IEEE 802.11p is an amendment to the IEEE 802.11-2007 for WAVE applications. Its PHY layer is based on the IEEE 802.11a standard. IEEE 802.11p implements OFDM modulation on 10-MHz channels in the 5.9 GHz frequency band. On the other hand, the IEEE 802.11a/b/g standards implement OFDM modulation on the 20 MHz and 22 MHz channels. As mentioned in Section 2.2, two adjacent service channels can be combined optionally to form one 20 MHz channel. Table 2.1 shows comparison of IEEE 802.11p with the most common wireless standards.

Table 2.1 IEEE 802.11p versus IEEE 802.11a/b/g.

Standard	**IEEE 802.11a**	**IEEE 802.11b**	**IEEE 802.11g**	**IEEE 802.11p**
Transmission Technique	OFDM	DSSS	OFDM	OFDM
Frequency (GHz)	5 GHz ISM Band	2.400-2.485	2.400-2.483	5.850-5.925
Channel Bandwidth (MHZ)	20	22	22	10/(20)
No. of Channels /non-overlapping	12/8	14/3	14/3	7/7
Data Rate (Mbps)	54	11	54	27/(54)

IEEE 802.11b is a popular member of IEEE 802.11 family that extended raw throughput up to 11 Mbps using the 2.4 GHz band. Different from other wireless standards, its modulation technique is DSSS [24]. IEEE 802.11g uses 2.4 GHz band like IEEE 802.11b but offers raw throughput up to 54 Mbps. The key difference is the OFDM transmission technique usage. Figure 2.6 shows IEEE 802.11b/g channels in 2.4 GHz band [25]. As shown in Figure 2.6 there are overlapping channels for both IEEE 802.11b and IEEE 802.11g standards.

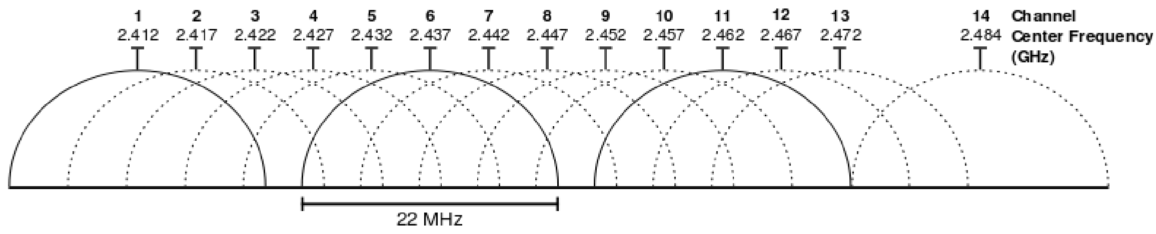

Figure 2.6 IEEE 802.11b/g channels in 2.4 GHz band.

IEEE 802.11a standard is nearly the same with IEEE 802.11g expect operating frequency and number of overlapping non-overlapping channels. It is operating on 5 GHz ISM Band and has a raw data rate of 54 Mbps [26].

The IEEE 802.11a uses a 52-subcarrier OFDM technique with 8 different data rates. The data rate can be increased to 6, 9, 12, 18, 24, 36, 48 and 54 Mbps by using BPSK, QPSK, 16-QAM and 64-QAM modulation techniques. PHY provides 64 subcarriers, but only 52 subcarriers are utilized for actual transmission. These 52 subcarriers consist of 48 data subcarriers and 4 pilot sub-carriers with a carrier separation of 0.3125 MHz. Each of the 48 data subcarriers can be modulated with BPSK,QPSK,16-QAM or 64-QAM. The total channel bandwidth is 20 MHz. The symbol duration is 4 microseconds with a guard interval of 0.8 microseconds [26].

Table 2.2.shows the PHY layer parameters comparisons of IEEE 802.11a and IEEE 802.11p standards. Compared to the IEEE 802.11a PHY, the subcarrier spacing and the data rate of IEEE 802.11p are reduced by half. Symbol length is doubled in order to make the signal more robust against fading. In IEEE 802.11p; generally the 10 MHz bandwidth is usually used. Optionally, 20 MHz bandwidth can be implemented as mentioned in Section 2.2. Due to the reduced frequency bandwidth, all parameters in time domain for IEEE 802.11p are doubled compared to the IEEE 802.11a PHY. The halved frequency bandwidth reduces the effects of Doppler spread by having a smaller frequency bandwidth. Additionally, the inter-symbol interference induced by multi-path propagation is reduced as a result of doubled guard interval [19].

Table 2.2 IEEE 802.11p and IEEE 802.11a PHY layer parameters comparison.

Parameters	IEEE 802.11a	IEEE 802.11p	Changes
Channel Bandwidth	20 MHz	10 MHz	Half
Frequency	5.0 GHz ISM Band	5.850-5.925 MHz	Different
Data Rate	6-54 Mbps	3-27 Mbps	Half
Modulation	BPSK, QPSK, 16-QAM, 64-QAM	BPSK, QPSK, 16-QAM , 64-QAM	No change
Error Correction Coding	Convolutional Coding-K=7	Convolutional Coding-K=7	No change
Coding Rate	1/2,2/3,3/4	1/2,2/3,3/4	No change
Number of Subcarriers	52	52	No change
Symbol Duration	4.0 μs	8.0 μs	Double
Guard Period	0.8 μs	1.6 μs	Double
FFT Period	3.2 μs	6.4 μs	Double
Subcarrier Spacing	0.3125 MHz	0.15625 MHz	Half

2.2.2 IEEE 802.11p MAC layer

Two packages can be received at the same time due to fading and interferences. For this situation, both packages can be failed. MAC layer provides a solution to this collision problem with the Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) scheme based on Distributed Coordination Function (DCF) [20].

2.3 Link Budget

Link budget formula can be used to predict communication distance and throughput for wireless data links. There are several factors that may impact the performance of a data link system. Link budget formula is the sum of all these factors in a telecommunication system. It accounts transmission power, attenuation of the transmitted signal due to propagation, the antenna gains, feed lines and miscellaneous losses [29]. The following equation shows the basic factors need to be considered when calculating a link budget:

$$P_{RX} = P_{TX} + G_{TX} - L_{TX} - L_{FS} - L_M + G_{RX} - L_{RX} \qquad (2.1)$$

Where R_{RX}= received power (dBm)

P_{TX} = transmitter output power (dBm)

G_{TX} = transmitter antenna gain (dBi)

L_{TX} = transmitter losses (coax, connectors...) (dB)

L_{FS} = free space loss or path loss

L_M = miscellaneous losses (fading margin, body loss, polarization mismatch, other losses...) (dB)

G_{RX} = receiver antenna gain (dBi)

L_{RX}= receiver losses (coax, connectors...) (dB)

L_{FS} and L_M are mentioned in detail in the next sections. If transmitter and receiver are in view of each other without an obstacle and interference, the type of communication is called Line of sight (LOS).

2.4 Free Space Path Loss

Free space path loss is the loss in strength of an electromagnetic wave through the medium. Path loss is proportional to the square of the distance between the transmitter and receiver and the square of the frequency of the signal [27]. Equation 2.2 shows path loss formula as a function of distance, frequency and speed of light.

$$L_{FS}\ (dB) = 10\log_{10}(4\Pi df/c)^2 \quad (2.2)$$

Where f is signal frequency in Hz, d is distance in meters (m) and c is the speed of light in a vacuum (3 x 10^8 m/s)

The free space path loss equation can be further simplified as follow:

$$L_{FS}\ (dB) = 20\log_{10}(d) + 20\log_{10}(f) + 20\log_{10}((4\Pi)/c) \quad (2.3)$$

$$L_{FS}\ (dB) = 20\log_{10}(d) + 20\log_{10}(f) + 32.45 \quad (2.3)$$

Where d is distance in kilometers (km) and f is signal frequency in MHz

Table 2.3 shows calculated path loss values for 900MHz, 2.4GHz, and 5.8GHz links.

Table 2.3 Free space path loss.

	Free Space Path Loss (dB)		
Distance	900 MHz	2.4 GHz	5.8 GHz
1 km	91.53	100.05	107.72
2 km	97.56	106.07	113.74
3 km	101.58	109.60	117.26
4 km	103.58	112.10	119.76
5 km	105.51	114.03	121.70
10 km	111.53	120.05	127.72
20 km	117.56	126.07	133.74
30 km	121.08	129.60	137.26
40 km	123.58	132.10	139.76
50 km	125.51	134.03	141.70

As shown in Table 2.3, free-space path loss increases significantly over distance and frequency.

2.5 Multipath Fading and Fade Margin

Multipath occurs when waves travel along different paths and cause unwanted interference with the waves travelling on the direct LOS path [27]. Figure 2.7 shows this case referred to as fading. A worst case scenario occurs when waves travelling along different paths merge out of phase and cancel each other. Having enough link margin is a way to overcome this problem. The amount difference between the received power and the receiver sensitivity is called the link margin.

$$\text{Link Margin} = \text{Received Power} - \text{Receive Sensitivity} \quad (2.4)$$

Fading due to multipath may result in a signal reduction of more than 30dB. It is highly recommended to have enough link margin for overcoming signal loss when designing a wireless system. The amount of extra RF power radiated to overcome this problem is referred as fade margin. The exact amount of fade margin required depends on the desired reliability of the link, but a good rule of-thumb is to preserve 20dB to 30dB of fade margin at all times.

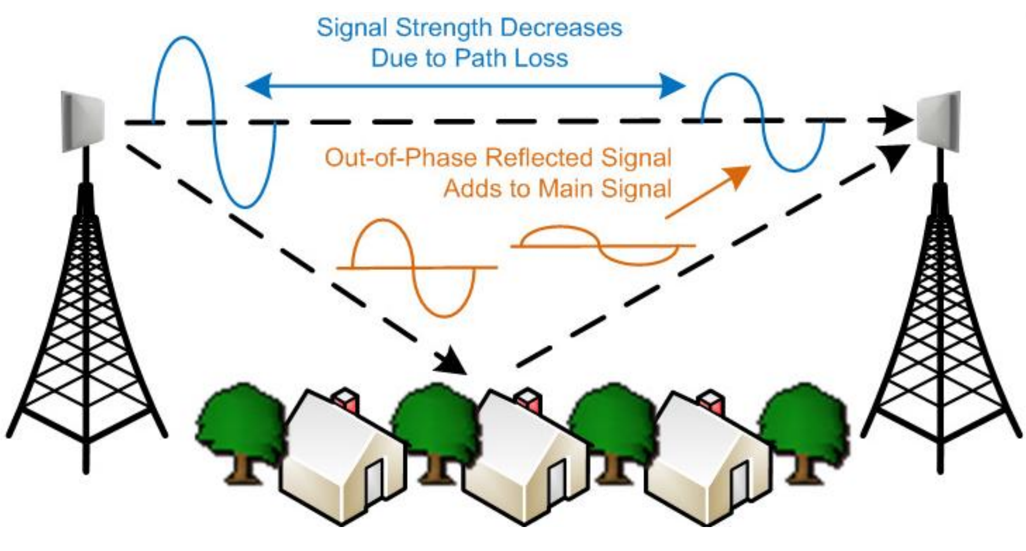

Figure 2.7 Multipath Fading.

Table 2.4 shows the Rayleigh Fading Model, which highlights the relationship between the amount of available link margin and link availability as a percentage of time. According to the Rayleigh Fading Model, 18 dB of fade margin is to be maintained to achieve %99 link availability.

Table 2.4 Rayleigh Fading Model.

Time Availability (%)	Fade Margin (dB)
90	8
99	18
99.9	28
99.99	38
99.999	48

2.6 Signal to Noise Ratio

As shown in below equation, Signal to Noise Ratio (SNR) is the difference between the received power and the channel noise.

$$\text{SNR} = \text{Received Power} - \text{Channel Noise} \tag{2.5}$$

$$\text{Channel Noise} = k\ T\ B \tag{2.6}$$

Where:

P is the power in watts

k is Boltzmann's constant (1.38×10^{-23} J/K)

T is the temperature in K

B is the bandwidth in Hertz

Equation 2.8 determines input noise for a receiver at room temperature (290K). By using this formula, noise floor for the receiver can be calculated:

$$\text{Noise floor} = -174 + \text{NF} + 10\log_{10}(\text{Bandwidth}) \tag{2.7}$$

Where NF is the noise figure, dBm is the power level expressed in decibels relative to one milliwatt.

Modulation techniques determine system bandwidth and channel capacity. There is always a trade-off between data rate and distance. Table 2.5 shows Cisco product's minimum SNR required values for different modulations [37]. For SNR requirements of different modulations, a system packet error rate (PER) of no more than 10 percent is specified. A package consists of 1024 bytes (8192 bits). From following equations, bit error rate (BER) is calculated from PER.

$$P_{PC} = (1 - P_{BE})^{N} \tag{2.8}$$

$$P_{PE} = 1 - P_{PC} = 1 - (1 - P_{BE})^{8192} \tag{2.9}$$

Where P_{PC} = Probability that a package is received correctly

P_{BE} = Probability that a bit is received in error

P_{PE} = Probability that a package is received in error

N = Package Length

When Equation 2.9 is solved for $P_{PE} < 0.1$, BER (P_{BE}) is calculated as PBE < $1e\text{-}^{5}$.

Table 2.5 Data Rates vs. Minimum SNR.

Modulation	Coding Rate R	Data Rate (Mbps)	Minimum Required SNR (dB)
BPSK	1/2	6	5
BPSK	3/4	9	6
QPSK	1/2	12	7
QPSK	3/4	18	9
16-QAM	1/2	24	13
16-QAM	3/4	36	17
64-QAM	2/3	48	19
64-QAM	3/4	54	22

As shown in Table 2.5 high data rate modulation techniques such as 64-QAM require greater SNR, while low data rate modulation techniques such as BPSK require less SNR. Therefore, BPSK can provide longer range communication than 64-QAM.

3. VEHICULAR COMMUNICATION SYSTEM BASED ON FHSS

In this chapter, vehicular communication system based on FHSS technique is introduced. The developed system is unique because it can transmit any kind of folder format (jpg, bmp, mp3, word, excel, powerpoint, pdf etc.) without any data loss. Additionally, the developed system can detect and locate traffic accidents by the help of accelerometer and GPS receiver.

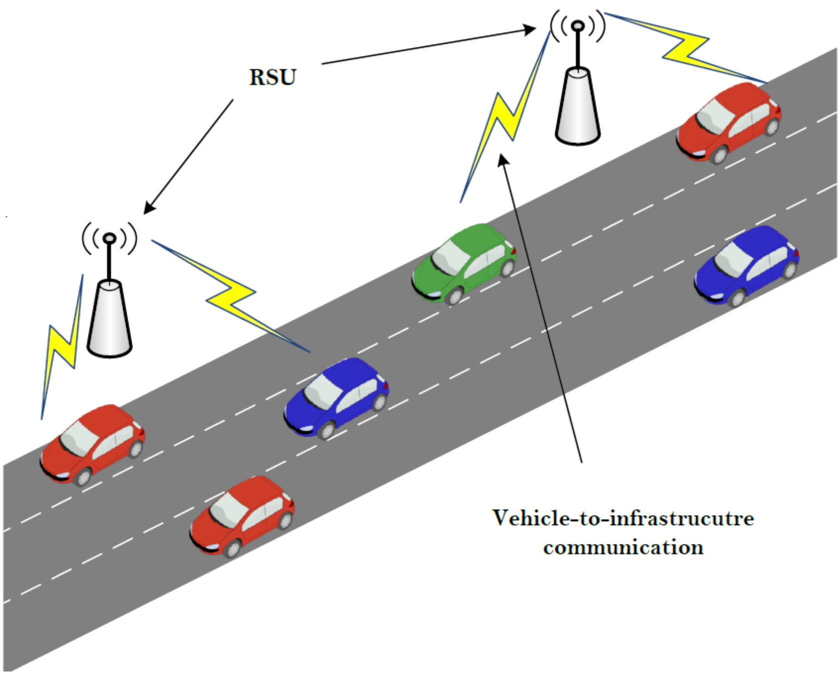

Figure 3.1 Vehicle to infrastructure communication system.

Moreover in this chapter, system units, developed software, file transfer procedure and accident detection algorithm will be described. Finally, tests results for V2I communication shown Figure 3.1 will be given and the achieved performance parameters such as throughput, package loss rate, connection time between vehicle and infrastructure and the amount of data transferred in a single pass will be discussed.

3.1 Experimental Setup to Analyze Vehicular Communications

The configuration of the system in a vehicle is composed of RFM DNT900DK transceiver, Javad GPS receiver, Javad GPS antenna, WebCam, accelerometer and a laptop to control the system. DNT900DK and GPS antenna were mounted on top of the car as in Figure 3.2. The aim of mounting DNT900DK on top the car is to achieve high signal quality. This vehicle system illustration and its detailed connection configurations are shown in Figure 3.3 and 3.4, respectively.

Figure 3.2 The experimental setup and vehicle**.**

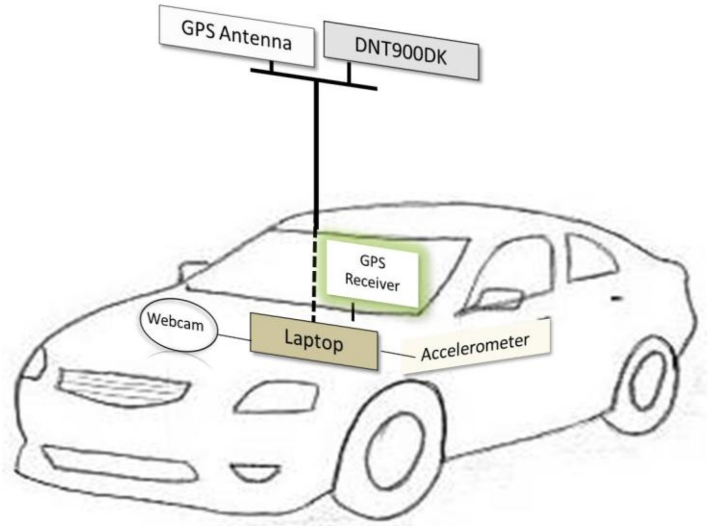

Figure 3.3 The vehicular communication system illustration**.**

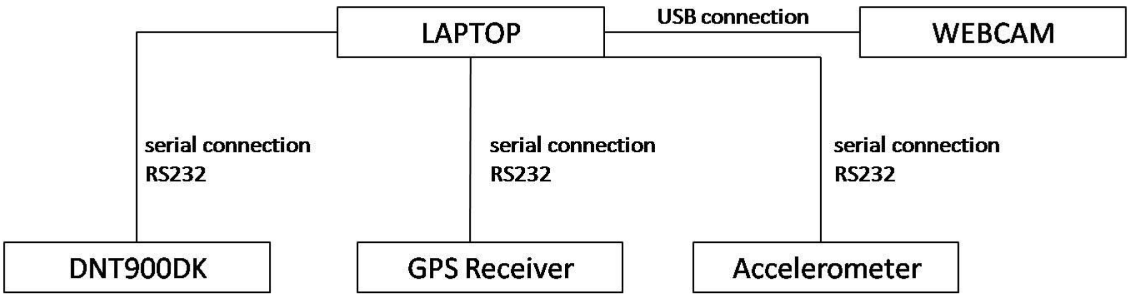

Figure 3.4 The vehicular communication system configuration.

For infrastructure system, configuration is composed of a DNT900DK transceiver and a desktop computer or a laptop. Computers located on vehicle and infrastructure run developed V2X communication application. The infrastructure system and its configuration are shown in Figure 3.5 and 3.6, respectively.

Figure 3.5 The infrastructure system of vehicular communication

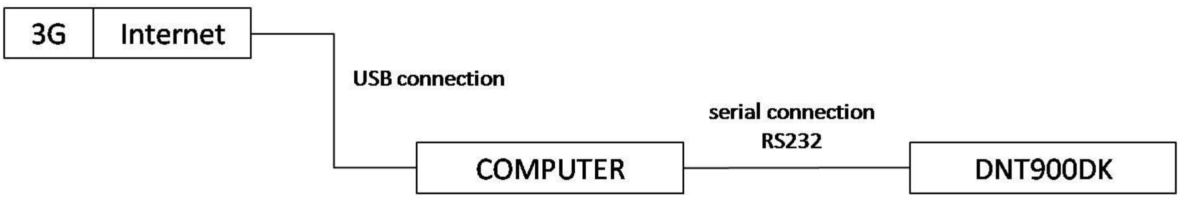

Figure 3.6 The infrastructure system configuration.

Communication between vehicle and infrastructure is half duplex. They can send or transmit, but not both at the same time. Figure 3.7 shows V2I configuration.

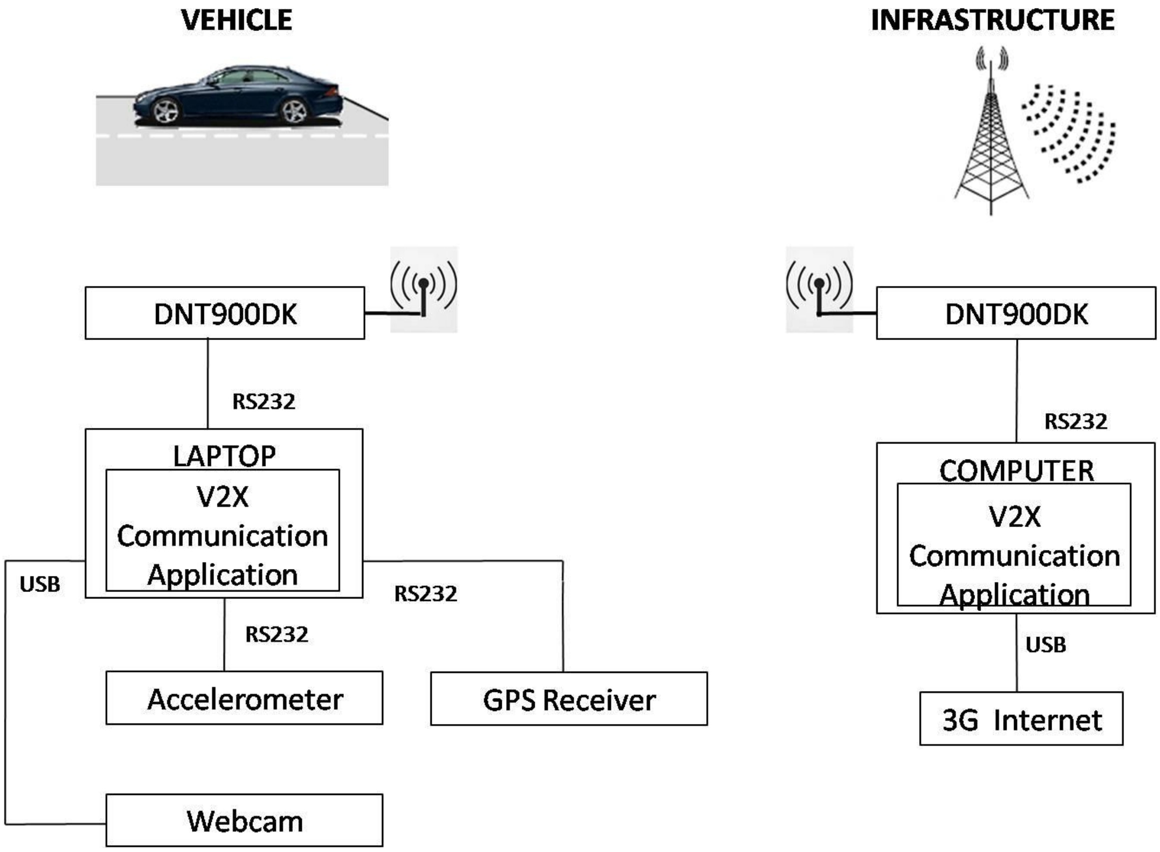

Figure 3.7 V2I configuration with DNT900DK transceivers.

3.2 Components of the Experimental Setup

RFM DNT900DK is a FHSS transceiver for either point-to-point or point-to-multipoint applications [31]. Its frequency hopping spread spectrum technology ensures maximum resistance to multipath fading and robustness in the presence of interfering signals. The DNT900DK kit and its features are shown in Figure 3.8 and 3.9 respectively. DNT900DK has 50 frequency channels and it periodically hops on these channels. It supports serial port communication up to 460.8 kbps.

Figure 3.8 DNT900DK Kit.

Characteristic	Sym	Minimum	Typical	Maximum	Units
Operating Frequency Range		902.75		927.25	MHz
Hop Dwell Time		5		200	ms
Number of RF Channels				50	
Modulation		FSK			
RF Data Transmission Rates		38.4, 115.2, 200 and 500			kb/s
Receiver Sensitivity:					
10^{-5} BER @ 38.4 kb/s			-108		dBm
10^{-5} BER @ 200 kb/s		-98			dBm
10^{-5} BER @ 500 kb/s			-94		dBm
Transmitter RF Output Power Levels		1, 10, 100, 250, 500, 1000 at 38.4 to 200 kb/s 1, 10, 85 at 500 kb/s			mW
Optimum Antenna Impedance			50		Ω
RF Connection		U.FL Connector			
Network Topologies		Point-to-Point, Point-to-Multipoint, Peer-to-Peer, Tree Routing			

Figure 3.9 Features of DNT900DK.

DNT900DK has a Graphical User Interface (GUI) operating on Windows. Figure 3.10 shows GUI of DNT900DK. By using this GUI, users can set parameters like data rate, transmitter power, serial port baud rate, hop duration, etc. Additionally, GUI features text message transmission. It has no capability to send multimedia files so a communication application for vehicular networks is developed. Details of this application will be given in Section 3.4.

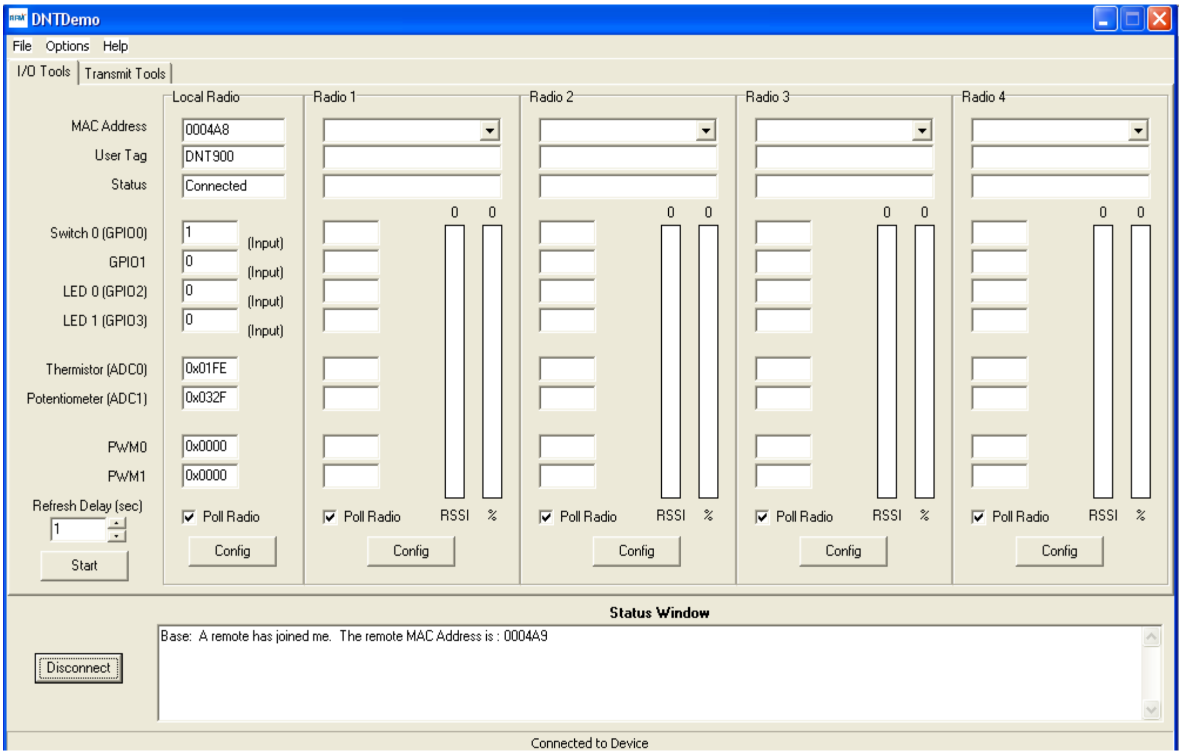

Figure 3.10 GUI of the DNT900DK.

During one frequency hop, the maximum data length can be sent with DNT900DK is 240 bytes. For 500kb/s data rate, 10.25 ms hop duration is needed to transmit 240 bytes. The maximum output power for 500kb/s data rate is 18 dBm. Also, receiver sensitivity for the same data rate is -94 dBm. If 2 dBi omni directional antennas on the kit are used both on transmitter and receiver, theoretically communication up to 2 kilometers can be established according to the link budget formula mentioned in Section 2.3.

Javad Global Positioning System (GPS) GNSS receiver [32] was used with an external antenna. As mentioned in Section 3.2, GPS antenna was mounted on the top the car. GPS receiver supports serial port communication up to 460.8 kbps. Figure 3.11 shows GPS receiver and antenna.

Figure 3.11 GPS Receiver And Antenna.

GPS receiver returns position information in NMEA 0183 protocol. In this study, GGA sentence format is used. Figure 3.12 shows the GGA sentence format.

GGA Global Positioning System Fix Data. Time, Position and fix related data for a GPS receiver

```
                                                11
       1         2        3 4        5 6 7  8   9  10 |  12 13  14   15
       |         |        | |        | | |  |   |   | |   | |   |    |
$--GGA,hhmmss.ss,llll.ll,a,yyyyy.yy,a,x,xx,x.x,x.x,M,x.x,M,x.x,xxxx*hh

 1) Time (UTC)
 2) Latitude
 3) N or S (North or South)
 4) Longitude
 5) E or W (East or West)
 6) GPS Quality Indicator,
    0 - fix not available,
    1 - GPS fix,
    2 - Differential GPS fix
 7) Number of satellites in view, 00 - 12
 8) Horizontal Dilution of precision
 9) Antenna Altitude above/below mean-sea-level (geoid)
10) Units of antenna altitude, meters
11) Geoidal separation, the difference between the WGS-84 earth
    ellipsoid and mean-sea-level (geoid), "-" means mean-sea-level below ellipsoid
12) Units of geoidal separation, meters
13) Age of differential GPS data, time in seconds since last SC104
    type 1 or 9 update, null field when DGPS is not used
14) Differential reference station ID, 0000-1023
15) Checksum
```

Figure 3.12 GGA Sentence Format.

For accelerometer, SparkFun Serial Accelerometer Dongle [33] was chosen for being a 3 axis accelerometer up to +/-6g with a simple serial interface. Figure 3.13 shows serial accelerometer dongle.

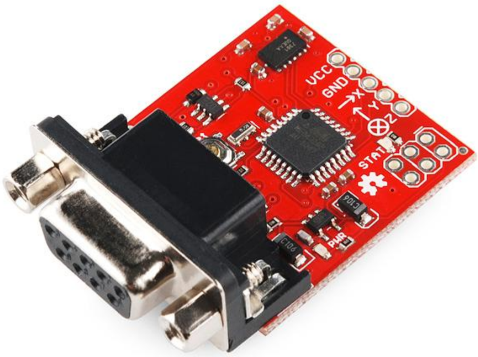

Figure 3.13 Serial Accelerometer Dongle.

For safety applications, in order to get real time image from vehicle a high resolution camera Logitech HD Webcam C615 was used. C615 gives availability to take 8-megapixel snapshots. Figure 3.14 shows Logitech HD Webcam C615.

Figure 3.14 The Webcam.

3.3 Developed Software in an Experimental Setting

Developed software has been designed to transmit image (jpeg, .bmp), audio (mp3), office, pdf files and text messages between vehicles and vehicle to infrastructure. Additionally, software can automatically detect and locate traffic accidents by the help of accelerometer and GPS receiver. V2I and V2I communication application is developed under Java. GUI of the application is in Figure 3.15.

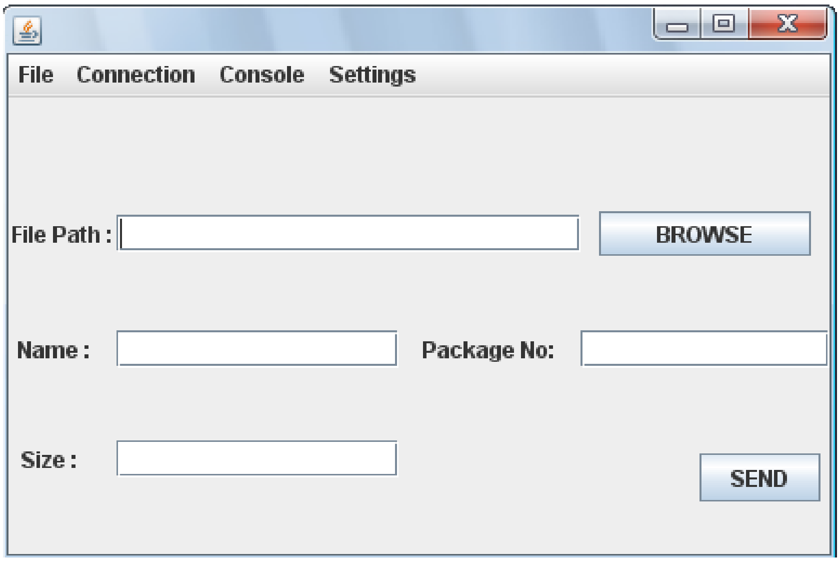

Figure 3.15 GUI of the V2I and V2I communication application.

Under connection menu in the GUI, there are communication dialogs with system units. Because of changes can be in serial port numbers in different computers, user sets the connection parameters with the units. Figure 3.16 to Figure 3.19 show communication dialogs with system units, respectively. User can only send text message or files when serial connection between transmitter and receiver is established. If users attempt to send file or text message without preparing serial connection, a warning to set serial connection will appear.

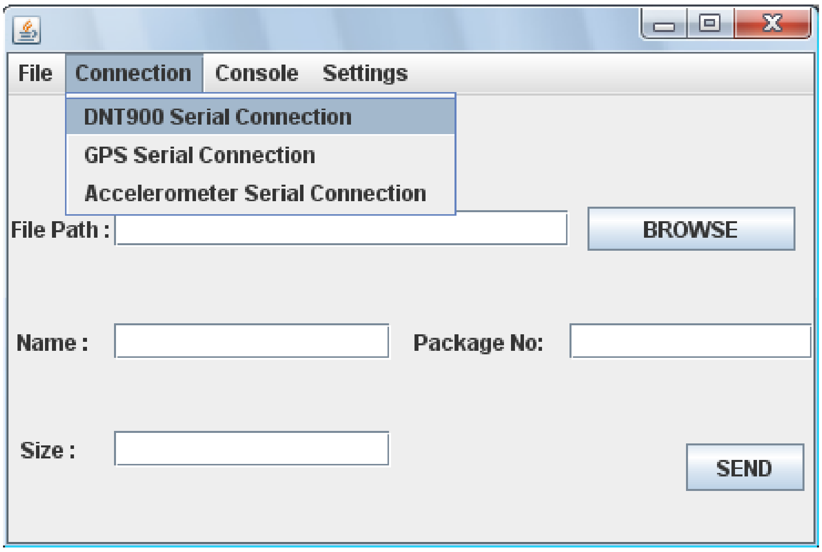

Figure 3.16 Connection Menu of the V2I and V2I communication application.

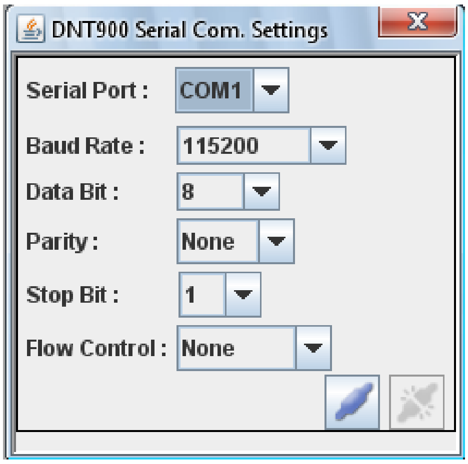

Figure 3.17 DNT900DK Connection Dialog.

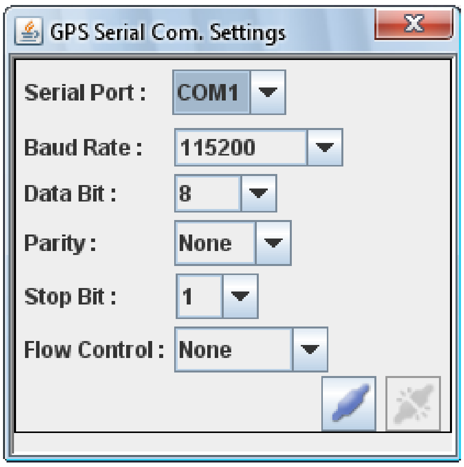

Figure 3.18 GPS Serial Connection Dialog.

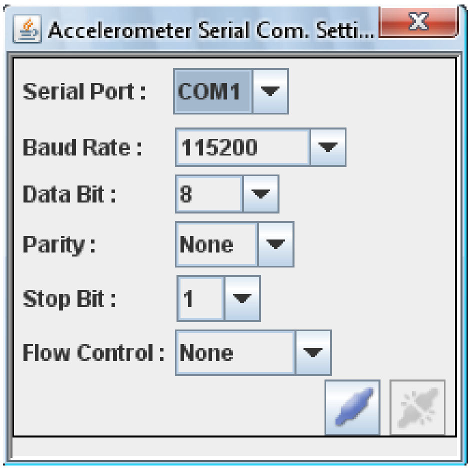

Figure 3.19 Accelerometer Serial Connection Dialog.

Figure 3.20 and 3.21 show consoles of V2I and V2I communication application, respectively. By this consoles user can send and receive text messages and get information about system situations. Additionally, Figure 3.22 shows the menu for user settings. By using this menu, user can control G Limit threshold analysis of accelerometer data.

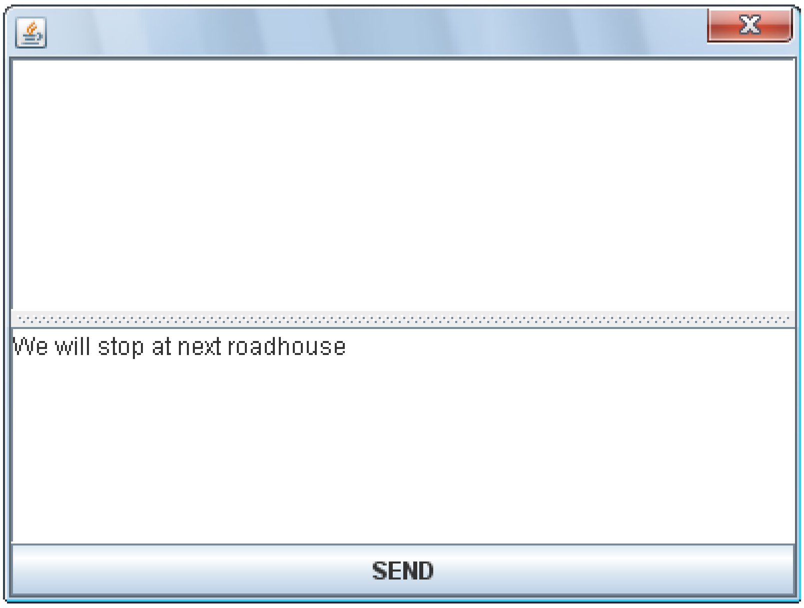

Figure 3.20 Text Message Console.

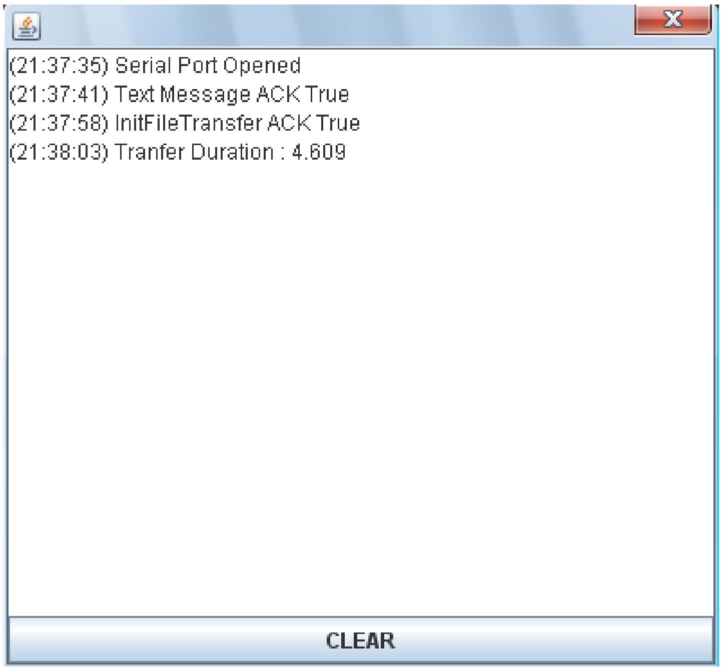

Figure 3.21 User Console.

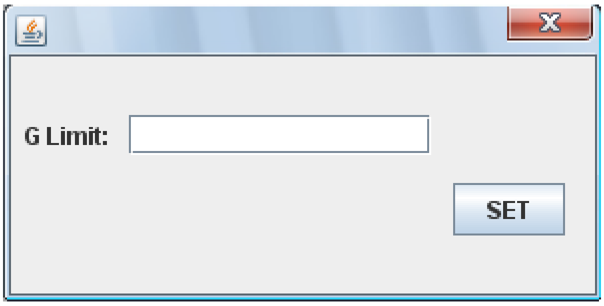

Figure 3.22 User Settings.

3.3.1 Package structures in experimental setting

In order to transmit files, packetization and depacketization method between transmitter and receiver is followed. In this method, transmitter separates file into packages and transmits them consequently. These packages are collected at the receiver side to reconstruct the file. For this method, to avoid data losses can be occurred during transmission, a package structure format is developed. Figure 3.23 shows packages generated during different type of applications.

Init File Transfer Package

PL	MC	FT	FL	CRC
1 Byte	1 Byte	1 Byte	4 Byte	2 Byte

Init File Transfer ACK. Package

PL	MC	ACK	CRC
1 Byte	1 Byte	1 Byte	2 Byte

File Transfer Package

PL	MC	PN	DATA	CRC
1 Byte	1 Byte	2 Byte	User Defined	2 Byte

File Transfer ACK. Package

PL	MC	PN	ACK	CRC
1 Byte	1 Byte	2 Byte	1 Byte	2 Byte

Text Message Package

PL	MC	DATA	CRC
1 Byte	1 Byte	User Defined	2 Byte

Text Message ACK. Package

PL	MC	ACK	CRC
1 Byte	1 Byte	1 Byte	2 Byte

GPS Message Package

PL	MC	DATA	CRC
1 Byte	1 Byte	GPS Sentence Defined	2 Byte

GPS Message ACK. Package

PL	MC	ACK	CRC
1 Byte	1 Byte	1 Byte	2 Byte

PL (Package Length): is defined as the length of message

MC (Message Code): specifies the type of message.

FT (File Type): specifies the format of tranmistted file.

FL (File Length): specifies the size of tranmistted file

ACK: Acknowledgment Byte

CRC: Cycling Redundancy Check

PN (Package No): specifies the package of the message

DATA: specifies the data read from transmitted file,GPS Receiver, user text message
Length of data is determined by the user.

Figure 3.23 Package Structures in Experimental Setting.

Message Code Details

Command	Description
0x01	MESSAGE_CODE_FILE_TRANSFER
0x02	MESSAGE_CODE_INIT_FILE_TRANSFER
0x03	ACKNOWLEDGMENT _CODE
0x04	INIT_ACKNOWLEDGMENT _CODE
0x05	MESSAGE_CODE_TEXT
0x06	TEXT_ACKNOWLEDGMENT _CODE
0x07	MESSAGE_CODE_GPS
0x08	GPS_ACKNOWLEDGMENT _CODE
0x09	ACCIDENT_MESSAGE_CODE

File Type Details

Command	Description
0x01	FILE_TYPE_JPG
0x02	FILE_TYPE_MP3
0x03	FILE_TYPE_ACCIDENT_JPG
0x04	FILE_TYPE_BMP
0x05	FILE_TYPE_PDF
0x06	FILE_TYPE_DOC
0x07	FILE_TYPE_DOCX
0x08	FILE_TYPE_XLS
0x09	FILE_TYPE_XLSX
0x10	FILE_TYPE_PPT
0x11	FILE_TYPE_PPTX

Figure 3.24 Message and File Type Commands.

Some main features of package structures are below:

- First two bytes of all packages, contains package length. When receiver is received a package, it compares total length and first two bytes of the package. If they are not same due to breakdowns while transmission, receiver will not decode the package.
- Third byte of all packages contains message code. Message code specifies the type of message whether it is a file transfer message, text message etc. Details of message codes are shown in Figure 3.24. Message Code Byte provides receiver to correctly decode the received package.
- For File Transfer, Text Message and Ping Test packages the amount of data transfer is controlled by the user. Additionally, GPS package length is determined by sentence returned from GPS Receiver.
- File Transfer Message and its acknowledgment include package number in order to avoid interferences for transmitted and received packages. Up to received package number transceiver determines the next operation. Transmitter sends the next package up to received number and the receiver is carefully checking package number. If a file transfer message with same number is received two times. Receiver will not decode the second package.

- To avoid package drops and corruptions while transmission, CCIT 16 bit Cyclic Redundancy Check (CRC) is added to the end of every generated package.
- Init-File Transfer package is the first message will be transmitted during file transfer. It specifies file type and file size to be transferred. Init-File Transfer package is encoded and decoded up to file type commands shown is Figure 3 24. This structure enables transfer of any kind of file format.

3.3.2 File transfer procedure

When software takes a file in input by user, file format is checked firstly. If the user file is not a supported format, user will get a warning. If it is a supported format, file will be separated into packages up to package structures. After packetization is completed, total number of packages will be transmitted is calculated and a file transfer procedure is followed as below:

- Figure 3.25 shows file transfer procedure. Firstly, transmitter broadcasts Init-File Transfer package and waits for acknowledgment. If no acknowledgement is received like Figure 3.26, transmitter will rebroadcast Init-File Transfer package up to a user defined value.
- When Init-File Transfer package is received by receiver, it calculates CRC of received package and compare with the CRC in the package. According to the comparison, receiver will send true or false acknowledgement. If CRC check is true, it gets file size and type from Init-File Transfer package.
- If false Init-File Transfer acknowledgement is received by transmitter like Figure 3.27, transmitter will rebroadcast Init-File Transfer package up to a user defined value. If true Init-File Transfer acknowledgement is received, transmitter will send first File Transfer package.
- When File Transfer package is received by receiver, it controls CRC and message length. According to these checking, it will send true or false acknowledgement. If checking is true, receiver will get file data and write it into a buffer.

- If false File Transfer acknowledgement is received by transmitter, transmitter will rebroadcast the last File Transfer package up to an Automatic Repeat Request (ARQ) Limit. If true Init-File Transfer acknowledgement is received, transmitter will send the next File Transfer package.
- When true File Transfer package acknowledgements reach to the total number of packages needed to transmitted, file transmission is completed. Receiver will then construct file by using data in buffer and file type received in Init-File Transfer package.

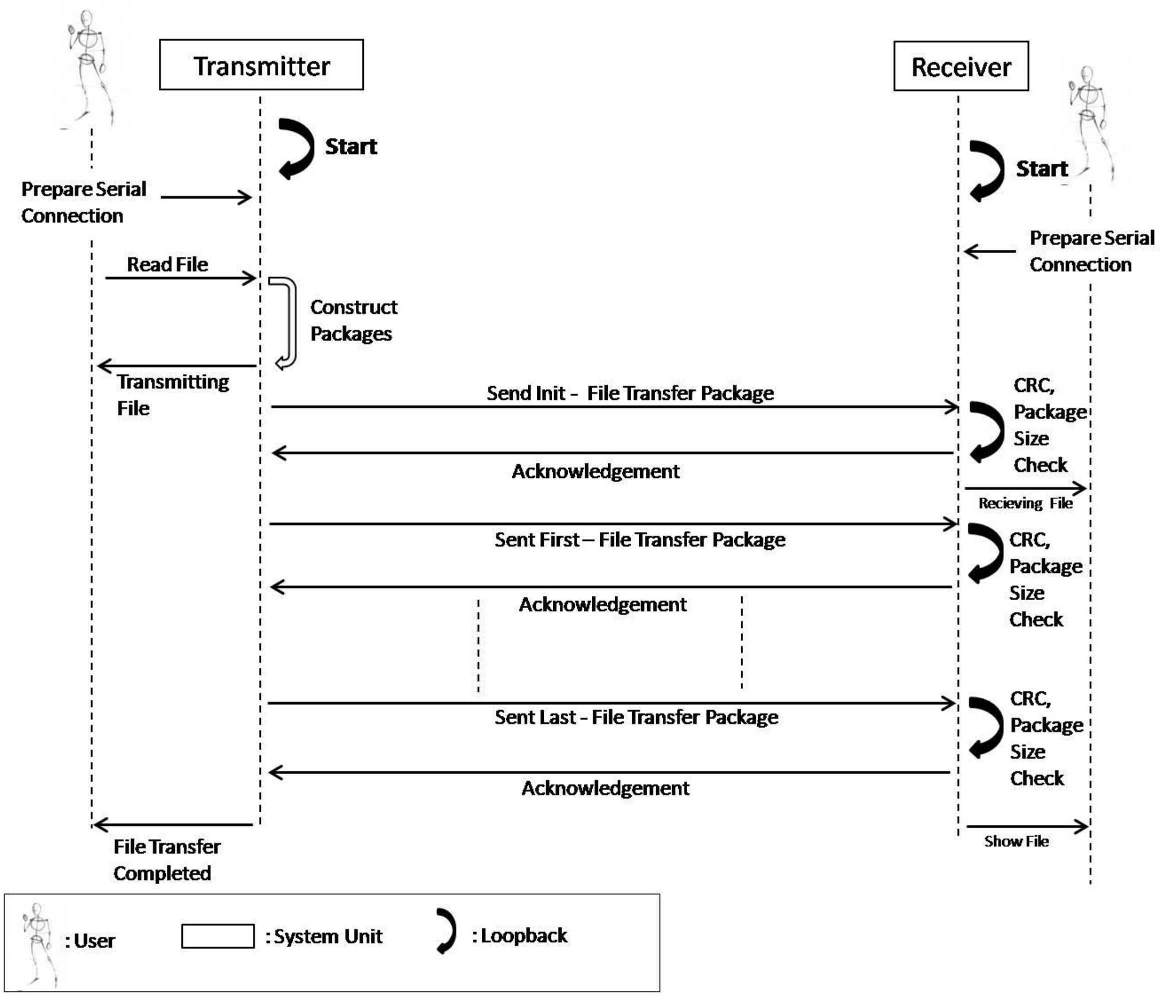

Figure 3.25 File transfer procedure in experimental setting.

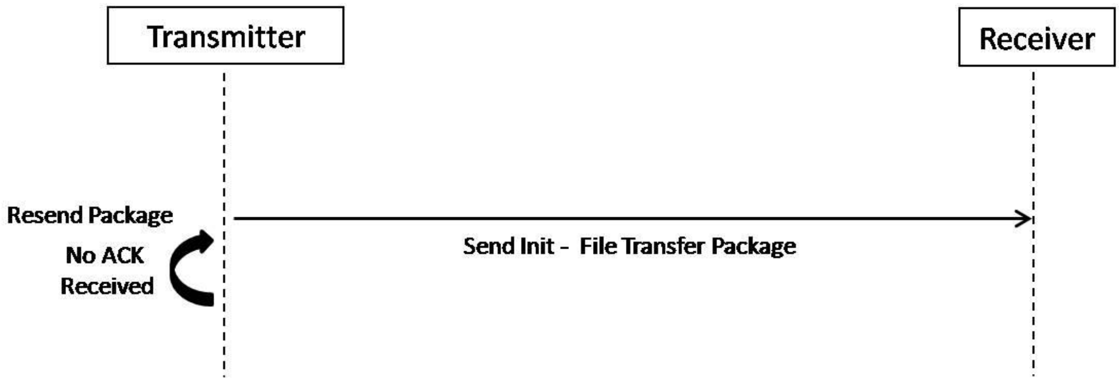

Figure 3.26 No acknowledgment received case.

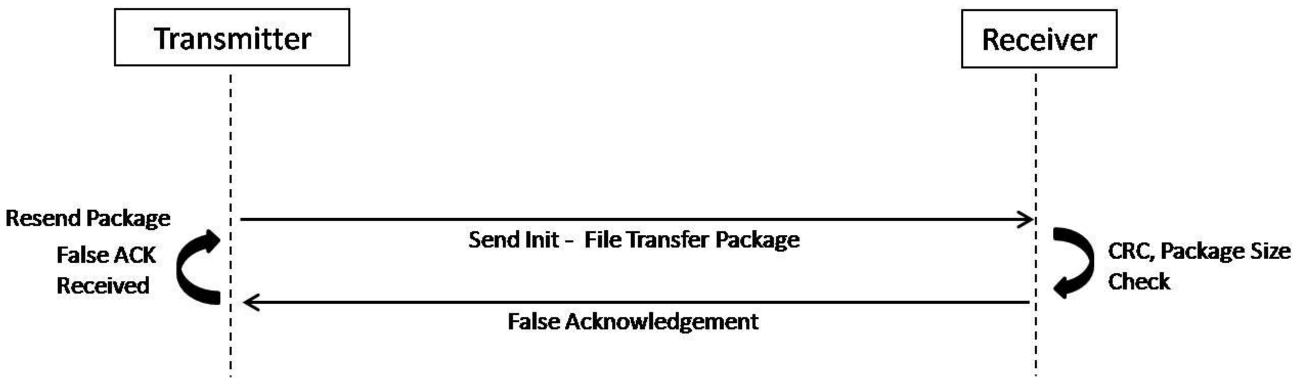

Figure 3.27 False acknowledgment received case.

3.3.3 Accident detection algorithm

Traditional vehicle accident detection systems are based on sensors located in the cars and interaction with the vehicle's electronic control units [13]. These sensors detect acceleration/deceleration, collision and airbag deployment. Accelerometers are mounted to chassis of the vehicles to detect same forces which vehicles experienced. Airbag deployments may occur up to these forces. As, it would be difficult to access electronic control units of vehicles, on board accelerometer is used to detect accident. The accelerometer used in system measures accelerations and decelerations experienced up to +/-6g. Figure 3.28 shows the acceleration on each axis during stationary condition.

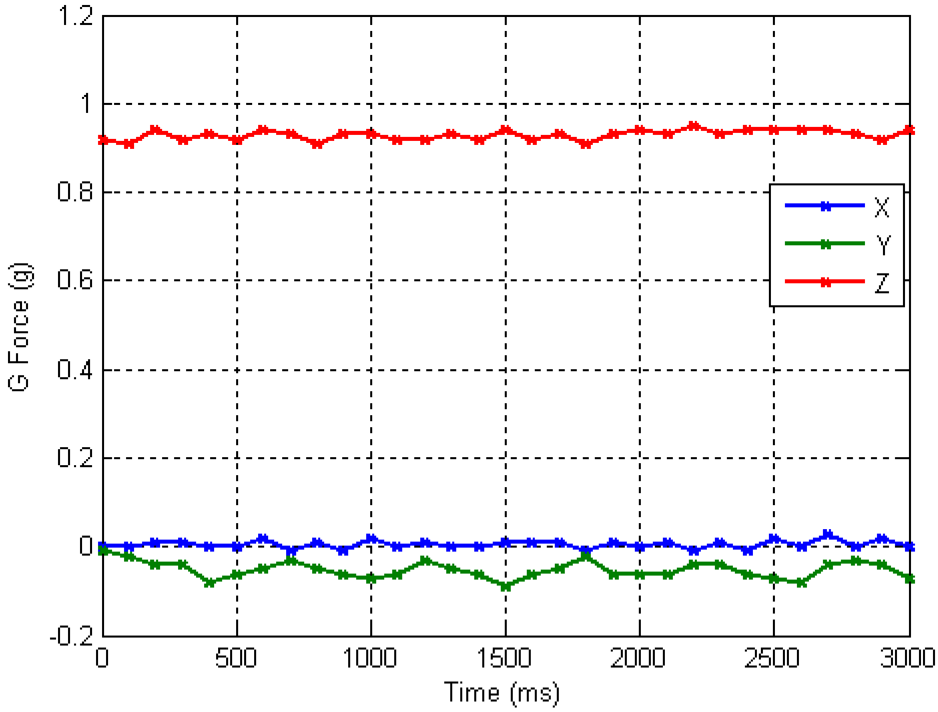

Figure 3.28 Acceleration during stationary condition.

As it is shown in Figure 3.28, nearly 0G's on the x and y axis is experienced. Differently, nearly 1G's on the z axis is experienced due to earth's gravity. Related works shows that during an accident high G forces is experienced and a threshold G value is needed to detect an accident.

Thompson and White [13] use mobile phones on board accelerometers to detect traffic accidents. They filter accelerometer information to eliminate false detections, such as a drop mobile phone inside the vehicle or a sudden stop. The authors determined 4G's as the threshold value of accident detection and they ignore any acceleration events below 4G's.

Geotab Accelerometer Crash Testing [14] was performed with two vehicles, equipped with high sensitivity accelerometers. They performed several tests at both 5km/h and 20km/h and included vehicle into vehicle collisions as well as vehicle collisions into a concrete median. Results showed that different thresholds would be needed for small and large vehicles. Like Thompson and White [13], sudden stop test is performed while driving 90km/h, in order to eliminate false detections. Figure 3.29 shows the acceleration on each axis during sudden stop.

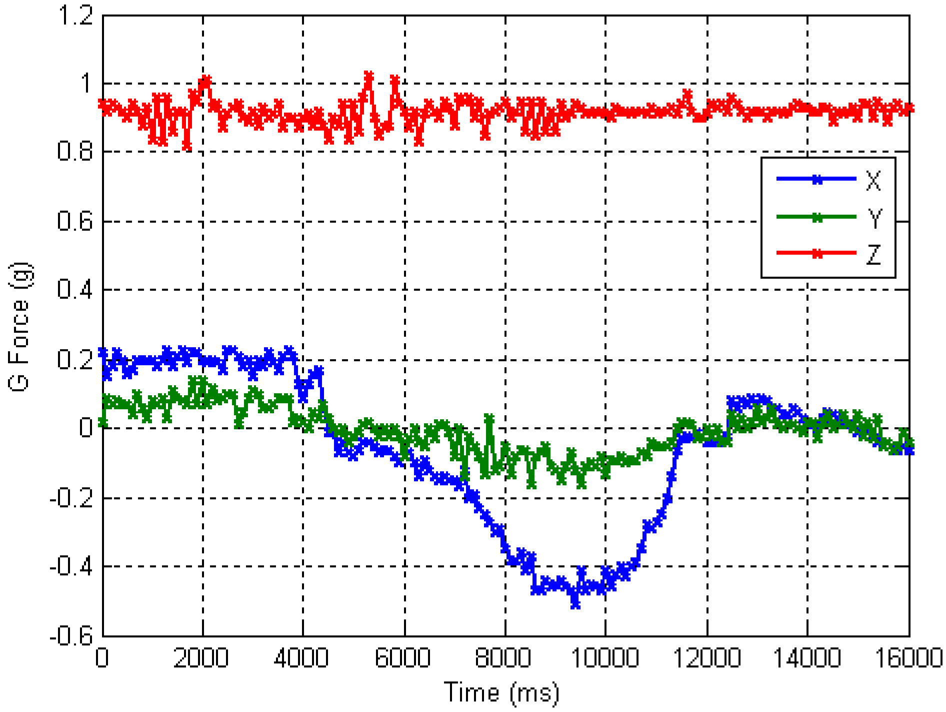

Figure 3.29 Acceleration of a sudden stop in an environmental setting.

During the test accelerometer remained stationary relative to the vehicle, as it experienced the same forces as the vehicle. As shown in Figure 3.29, maximum G Value experienced by the device is approximately -0.5G's on the x axis. According to this observation, it is agreed that realistic driving does not prevent false detection. Geotab [14] results showed that during an accident, a car is experienced 2G's nominal force on any axis.

Based on the test results and related works, detection algorithm checks whether 2G difference is occurred with stationary condition. If 2G's difference is not occurred on any axis, acceleration events are ignored. However, according to Geotab [14] statements, developed software also allows user to change threshold value from the graphical user interface for small and large vehicles. If 2G's difference is occurred on any axis, accident detection procedure shown in Figure

3.30 is followed. In this procedure, x-axis, y-axis, z-axis acceleration values are continuously observed to detect an accident. If these values exceed determined detection threshold, webcam will automatically take a snapshot of accident to determine if driver or passengers need emergency services. The scenario is then respectively continuing with transmitting accident photo and GPS position to infrastructure. Infrastructure will then connect to Google Maps and find accident location.

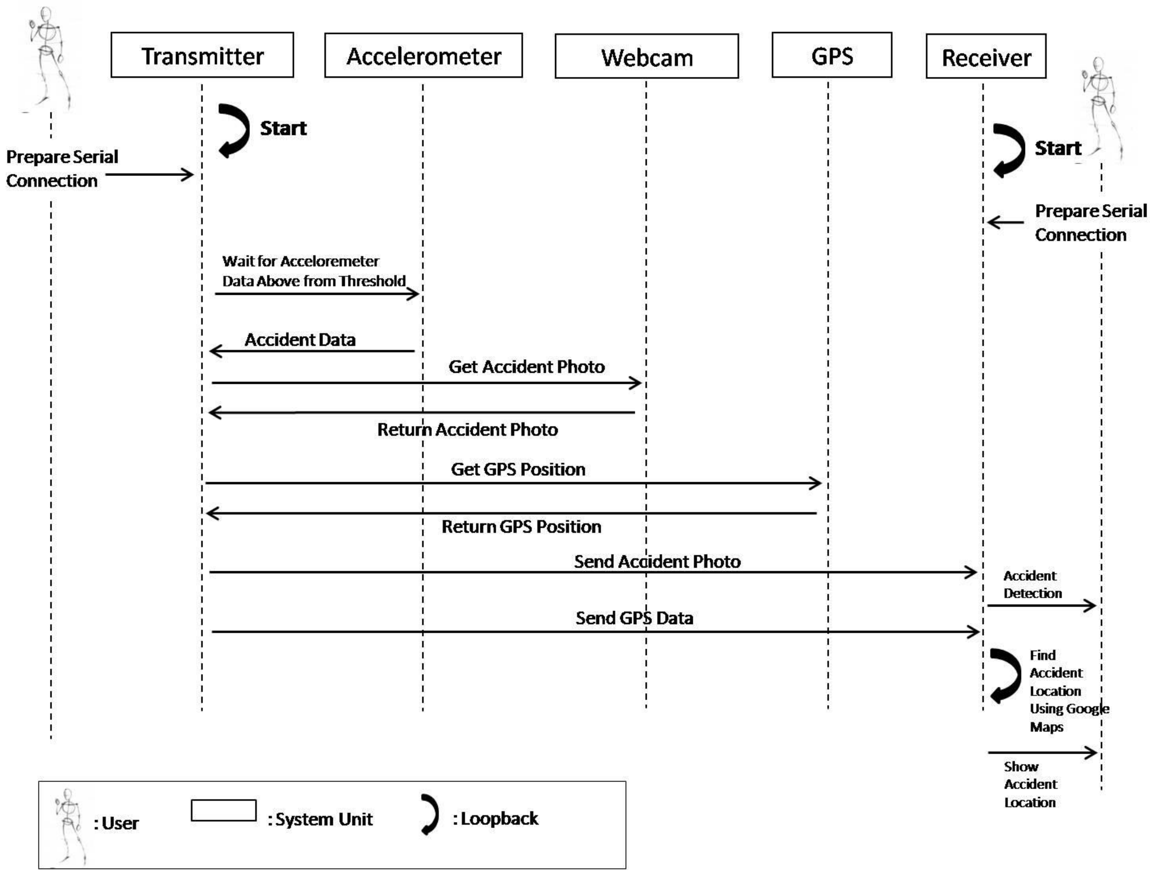

Figure 3.30 Configuration of the accident scenario.

With the developed accident detection system, accident location can be send to hospital or police to shorten the duration to reach medical help. Additionally, infrastructure may transmit nearest hospital position from the accident location to guide emergency services.

3.4 File Transmission Quality of the Vehicular Communication System

In order to qualify the quality of the file transmission, Peak Signal to Noise Ratio (PSNR) parameter is used. PSNR is the ratio between the maximum possible power of a signal and the power of corrupting noise that affects the quality of its representation [30]. Because many signals have a very wide ratio between the largest and smallest possible values of a changeable quantity, PSNR is usually expressed in terms of the logarithmic decibel scale. It is most easily defined over the Mean Squared Error (MSE). For a noise free $m \times n$ monochrome image I and its noisy approximation K, MSE is defined as:

$$MSE = \frac{1}{m\,n}\sum_{i=0}^{m-1}\sum_{j=0}^{n-1}[I(i,j) - K(i,j)]^2 \tag{3.1}$$

Where

m represents the numbers of rows of pixels of the images and i represents the index of that row

n represents the number of columns of pixels of the image and j represents the index of that column

The PSNR is defined as:

$$\begin{aligned} PSNR &= 10 \cdot \log_{10}\left(\frac{MAX_I^2}{MSE}\right) \\ &= 20 \cdot \log_{10}\left(\frac{MAX_I}{\sqrt{MSE}}\right) \\ &= 20 \cdot \log_{10}(MAX_I) - 10 \cdot \log_{10}(MSE) \end{aligned} \tag{3.2}$$

Where

MAX_I is the maximum possible pixel value of the image

When the two images are identical, the MSE will be zero. For this value the PSNR is undefined. As it is mentioned in Section 3.3.2, CRC checking of every package, retransmission of loss or corrupted packages provides transmitting files identically.

3.5 Description of the Vehicular Communication Tests

In order to evaluate the performance of V2I communication, several experiments were performed in different environments in the surrounding of the city of Ankara, Turkey. As described in Section 3.3, the maximum data length can be sent with DNT900DK is 240 bytes during one frequency hop. Therefore in V2I tests, package size of 240 bytes was selected to achieve maximum performance. The parameters adopted within experiments are listed in Table 3.1.

Table 3.1 The parameters adopted in experiments.

Parameter	Value
Serial Port Baud Rate	460.8 kb/s
Data Rate	500 kb/s
Tx Power	18 dBm
Antenna gain	2 dBi(Omni)
Speed	10 km/h
Package Size	240 bytes

3.5.1 Spectrum analyzer tests

In this part of tests, frequency channels and hops of DNT900DK were analyzed. output of transceiver was measured with Agilent E4440A PSA Spectrum Analyzer (3 Hz - 26.5 GHz). Figure 3.31 shows Agilent E4440A PSA Spectrum Analyzer.

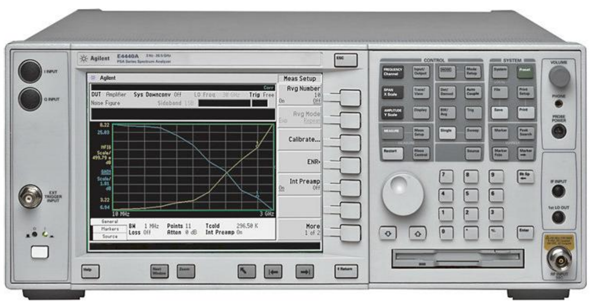

Figure 3.31 Agilent E4440A PSA Spectrum Analyzer.

3.5.2 Indoor tests

Indoor test was conducted in Meteksan Defence laboratory. Transceiver kits were put in close to establish LOS communication. Distance between kits was around 3 meters.

3.5.3 Outdoor tests

In this test, infrastructure was located in Meteksan Defence building and a vehicle was moving towards to Bilkent University East Campus Entrance, with low (10 km/h) speed. Satellite view of the test environment is shown in Figure 3.32. Green markers show test road and the red marker shows infrastructure location. Distance between vehicle and infrastructure was more than 1 kilometers and performance in longer distances was measured.

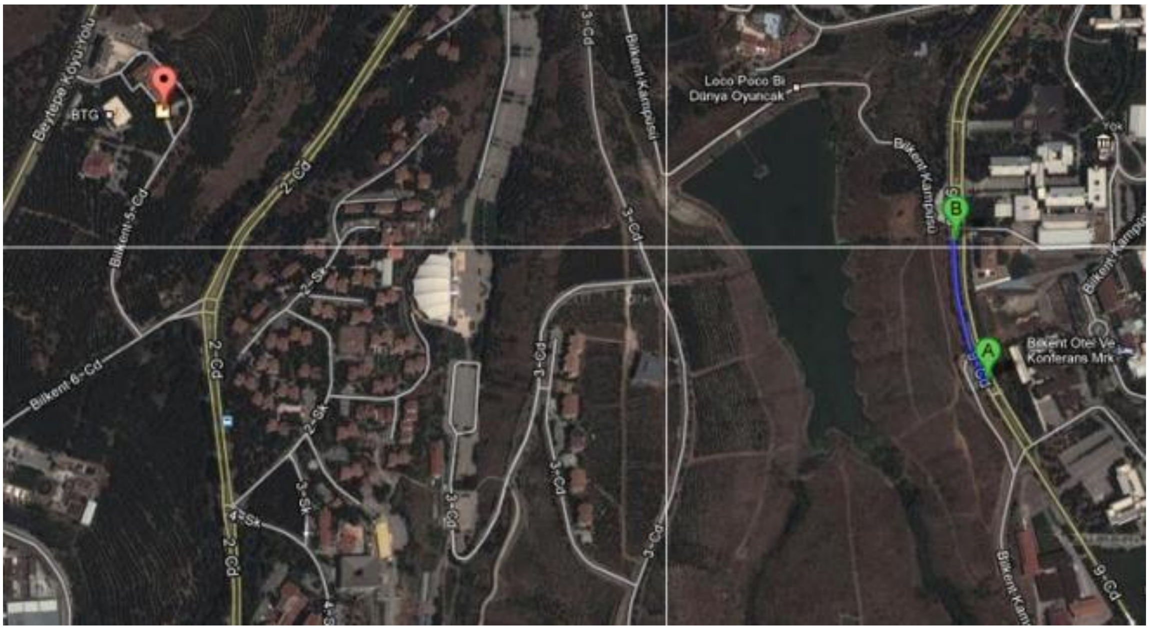

Figure 3.32.Satellite view of outdoor tests.

3.5.4 Accident Detection Tests

In this test, accident detection system mentioned in Section 3.3.3 was tested in Meteksan Defence’s park area.

3.6 Results and Discussions

The performance metrics used to evaluate performance the connectivity between vehicle and infrastructure are:

- Throughput: To determine the actual data rate of a network or connection, the "throughput" measurement definition is used. Throughput is the amount of data moved successfully from one place to another in a given time period.
- Package Loss Rate: percentage of data packages dropped due to network difficulties. Every package loss is GPS logged**.**
- the period of connection between vehicle and infrastructure.
- the amount of data can be transferred in a single pass.

3.6.1 Spectrum analyzer test results

The measurement setup consists of DNT900DK, two sma cables, 20 dB high power attenuator and a spectrum analyzer. 20 dB attenuator was used to control the power at the input of spectrum analyzer. Measurement setup and frequency spectrum of DNT900DK are shown in Figures 3.33 and 3.34 respectively.

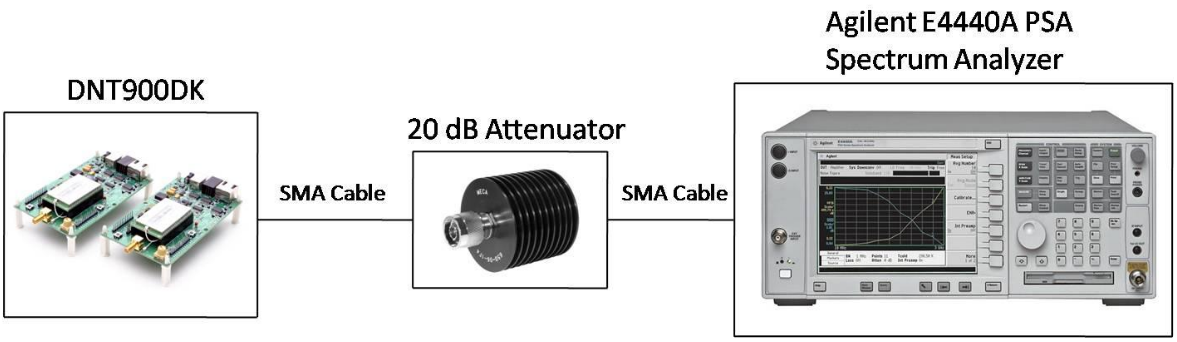

Figure 3.33 Measurement Setup.

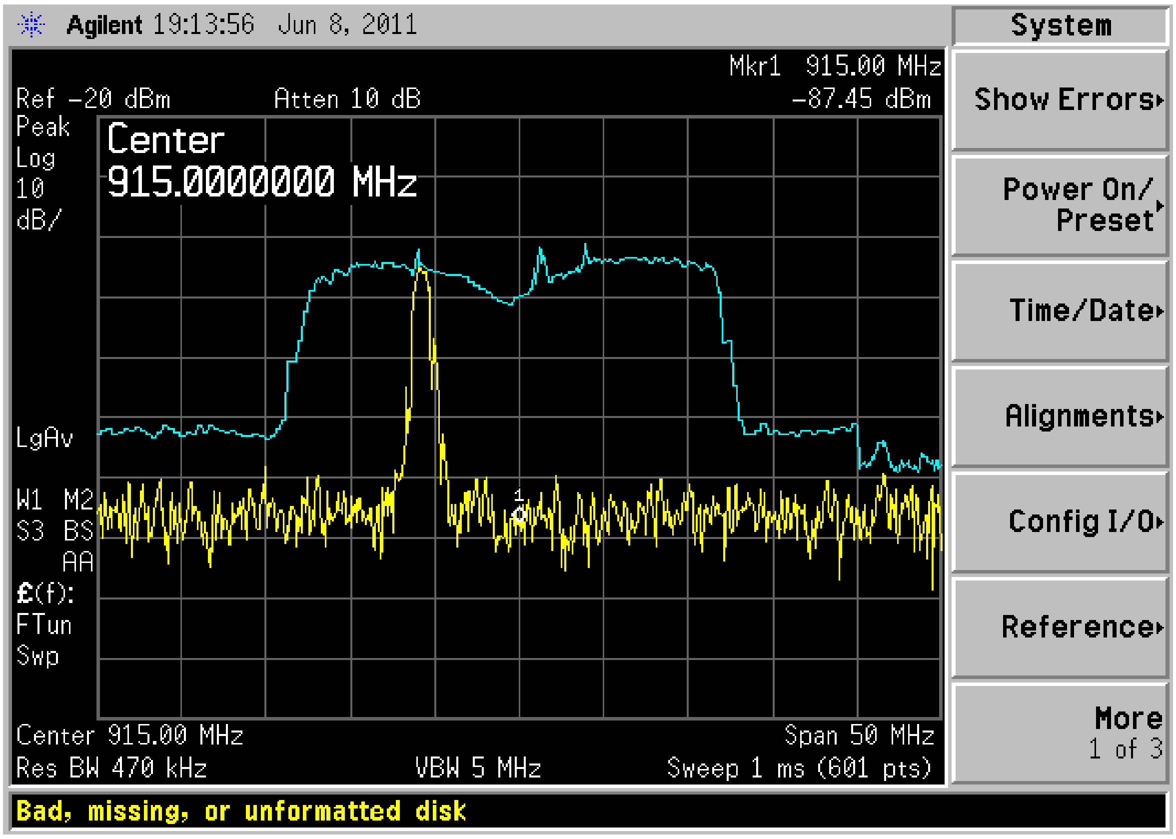

Figure 3.34 Frequency Spectrum of DNT900DK.

In Figure 3.34, the yellow line shows current frequency hops and the blue line shows previous hops. Measurement results show that transceiver is operating on data sheet values (Figure 3.8) with frequency hopping.

3.6.2 Indoor test results

During this test, serial baud rates and data rate settings were set to 460.8 kb and 500 kb/s on both transceivers and the package size was 240 bytes. Figure 3.35 shows the average throughput between DNT900DK kits in LOS communication. Average throughput was about 34.2 Kbps during indoor tests. Minor changes in throughput occurred due to serial port communication between experimental computers and transceivers. In addition, package losses did not occur because of short distance and LOS condition.

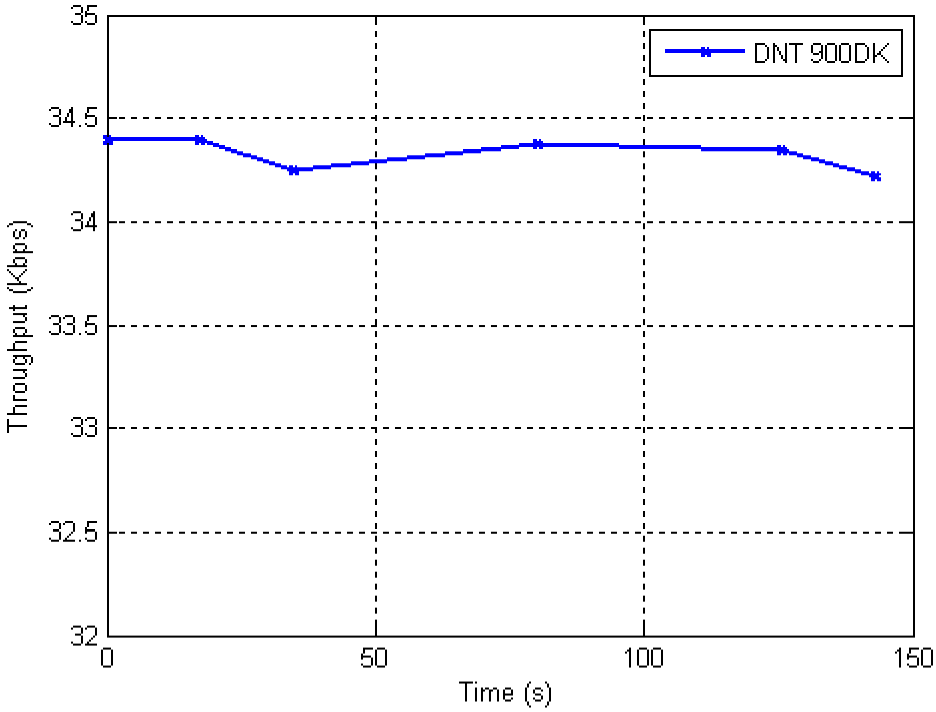

Figure 3.35 Performance comparison: average throughput versus time.

3.6.3 Outdoor test results

Figure 3.36 shows average throughput achieved through the test road. Maximum throughput was about 27 Kbps. Throughput is decreased along the road because of increasing distance, latency of transmitted packages and retransmission of the loss packages. Figure 3.37 shows package losses during outdoor tests. When the distance exceeds 1200 meters, throughput starts to decrease and package losses occur.

Table 3.2 Average amount of data transferred, and contact time for vehicle to infrastructure.

Speed	Package Size	Wireless technology	Transferred data	Contact time
10 km/h	230 bytes	FHSS	195 KB	60 seconds

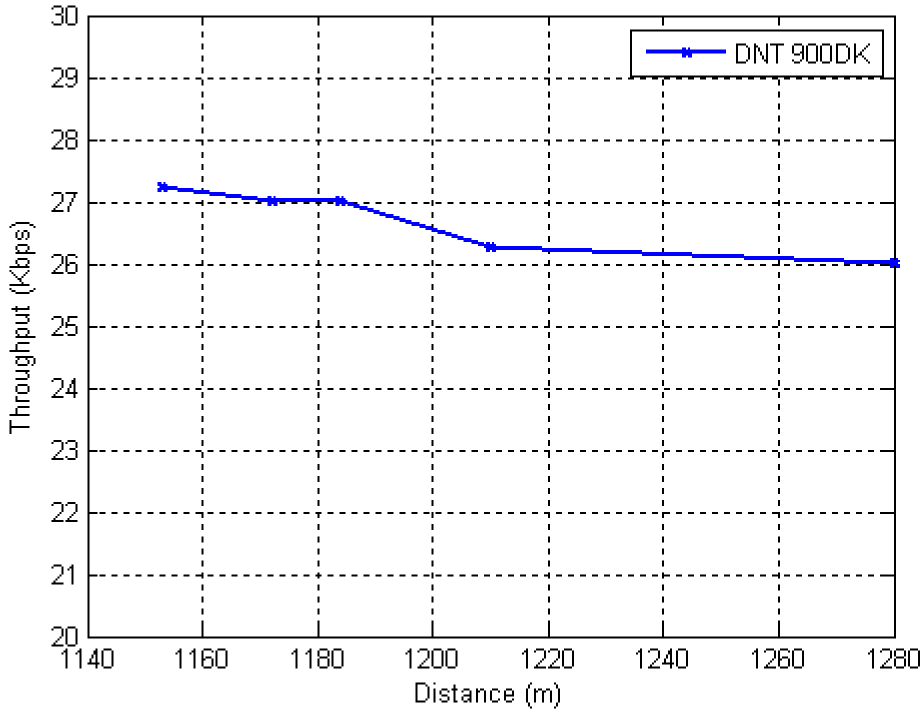

Figure 3.36 Average throughput while vehicle was moving at 10 km/h.

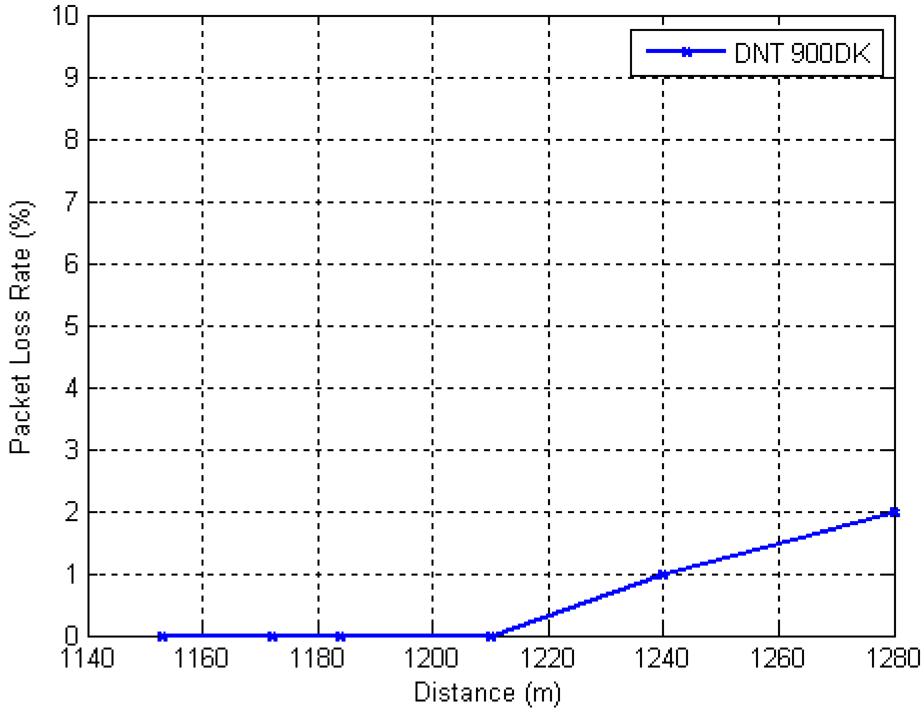

Figure 3.37 Performance comparison package loss rate versus distance.

Table 3.2 shows connection time and the amount of transferred data between vehicle and infrastructure. In a single pass, 195 Kbytes were transferred. The amount of transferred data and throughput between vehicle and infrastructure with DNT900DK kits are not satisfying requirements of vehicular networks. To solve this issue, another vehicular communication system based on IEEE802.11b/g standards is developed. The details are mentioned in Chapter 4.

3.6.4 Accident detection test results

During accident detection tests, serial accelerometer was turned upside down to simulate an accident. When accident was detected by analyzing accelerometer data, the system in vehicle transmitted accident photo and GPS position to infrastructure as mentioned in Section 3.3.3. Size of the accident photo and the transfer duration were 9.79 KB and 2.3 seconds, respectively. Any package losses did not occur while image and GPS position transmission.

4. VEHICULAR COMMUNICATION SYSTEM BASED ON IEEE 802.11B/G

In this chapter, V2I and V2V communication system based on IEEE 802.11b and IEEE 802.11g standards is introduced. Features of the system are identical to the system mentioned in Chapter 3. Unlike Chapter 3, requirements of vehicular networks are satisfied with IEEE 802.11b and IEEE802.11g standards. Figure 4.1 shows an illustration of V2V communication.

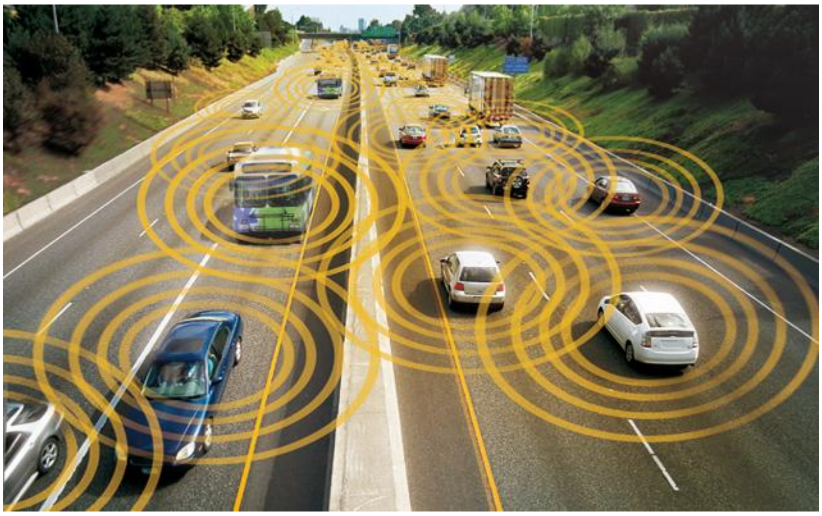

Figure 4.1 V2V Communication.

This experimental study is unique, as V2I and V2V communications are both examined in different environments with omni-directional and directional antennas. In order to investigate effects of different environments and vehicle speed on V2V and V2I communications, a set of experiments were performed.

Tests results for V2I and V2V communications will be given and the performance parameters such as throughput, round trip time, package loss rate, connection time between vehicle and infrastructure and the amount of data can be transferred in a single pass will be discussed in Chapter 4.

4.1 Experimental Setup of Vehicular Communication System

The configuration of the system in a vehicle is composed of a TP-Link TL-WA5210G wireless access point, Javad GPS receiver, Javad GPS antenna, WebCam, accelerometer and a laptop to control the system. TL-WA5210G and GPS antenna were mounted on top of the car as in Figure 4.2. The aim of mounting TL-WA5210G on top the car is to use high gain directional antenna of the access point. This vehicle system illustration and its detailed connection configurations are shown in Figure 4.3 and 4.4, respectively.

Figure 4.2 The vehicles used in vehicular commication.

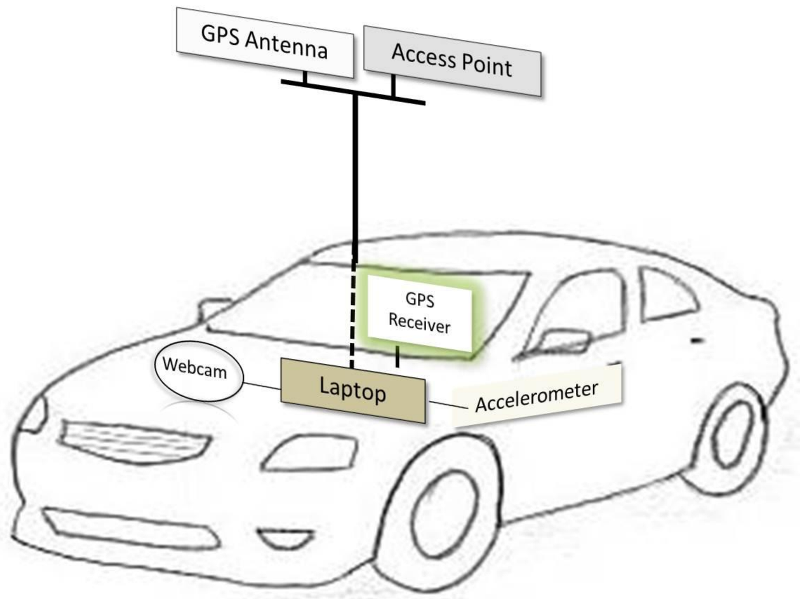

Figure 4.3 The vehicle system illustration.

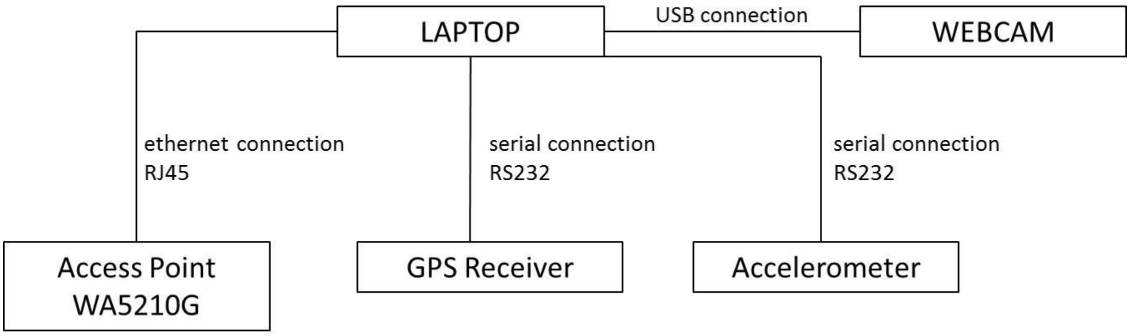

Figure 4.4 The vehicle system configuration.

For infrastructure system, configuration is composed of a TP-Link TL-WA5210G wireless access point and a desktop computer or a laptop. Computers located on vehicle and infrastructure run developed V2X communication application. The infrastructure system and its configuration are shown in Figure 4.5 and 4.6, respectively.

Figure 4.5 The infrastructure system.

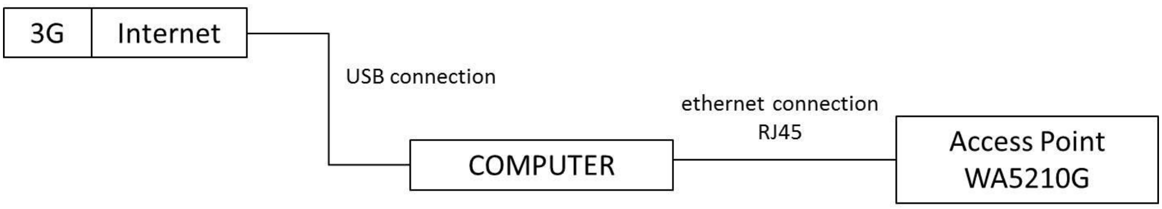

Figure 4.6 The infrastructure system configuration.

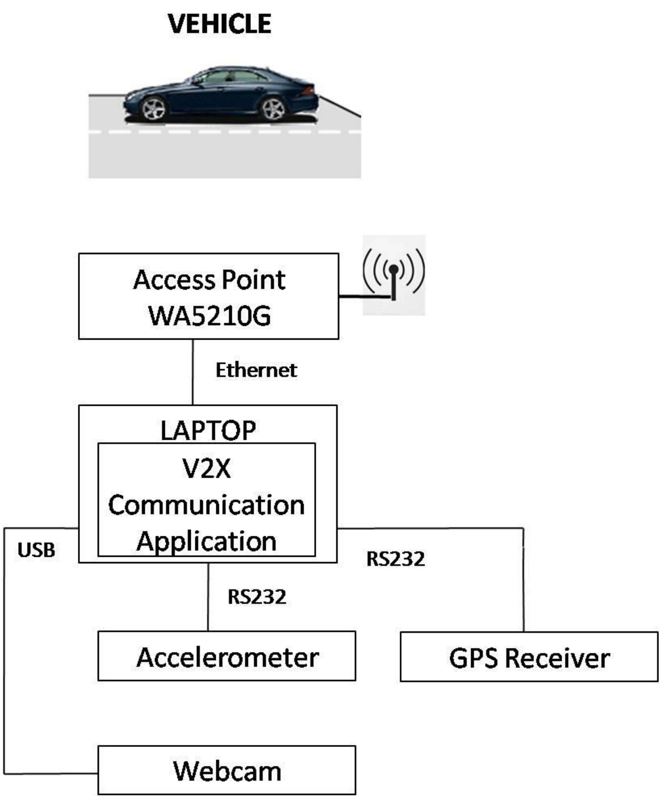

Figure 4.7 V2I configuration with access points.

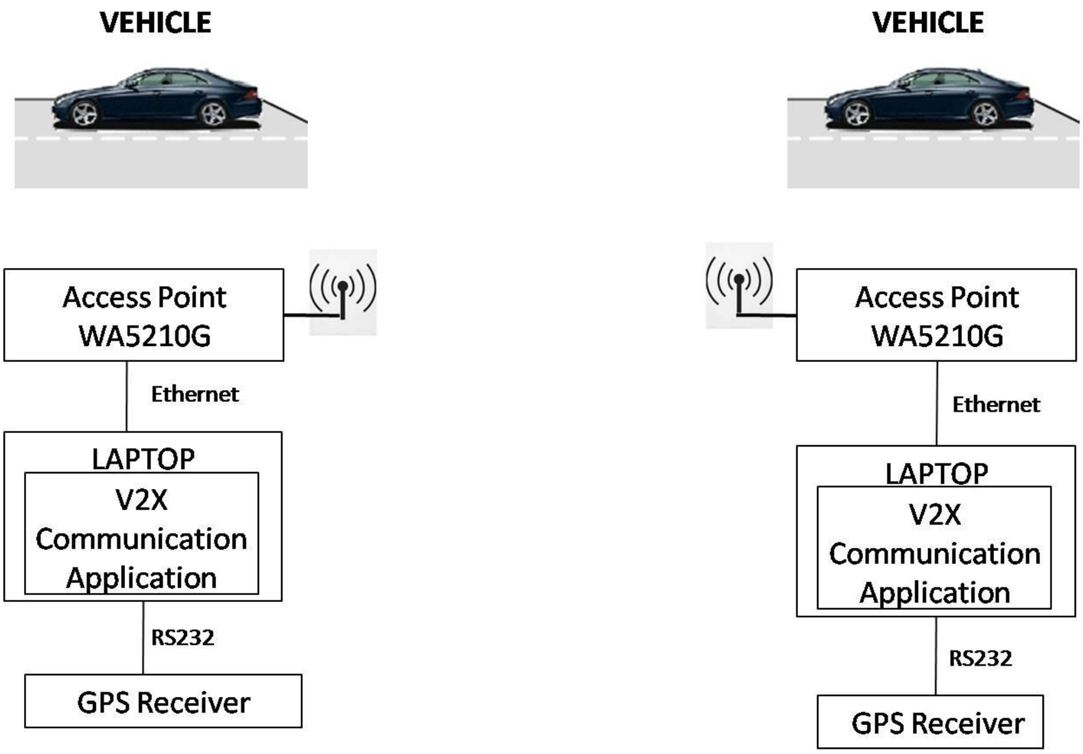

Figure 4.8 V2V configuration with access points.

Communication between vehicles and vehicle to infrastructure is half duplex. They can send or transmit, but not both at the same time. Figure 4.7 and Figure 4.8 shows V2I and V2V configurations.

4.2 Units of the Vehicular Communication System

TP-Link TL-WA5210G Wireless Access Point [35] supports IEEE 802.11b/g standards. It features 12dBi high gain directional antenna, high output power and high RX sensitivity can significantly extend the transmission range to deliver a more stable wireless connection. Figure 4.9 shows the features of TL-WA5210G.

Standards	IEEE 802.11g IEEE 802.11b
Interface	One 10/100M Auto-Sensing RJ45 Port(Auto MDI/MDIX), supporting Passive PoE
Wireless Signal Rates With Automatic Fallback	11g:108/54/48/36/24/18/12/9/6 Mbps (Dynamic) 11b:11/5.5/3/2/1 Mbps (Dynamic)
Frequency Range	2.4-2.4835GHz
Wireless Transmit Power EIRP	<20dBm (For countries using CE) <27dBm (For countries using FCC)
Antenna	12dBi Dual-Polarized Aluminum Antenna
Beamwidth (HPBW)	Horizontal: 60° Vertical: 30°
Enclosure	Outdoor weatherproof ABS
ESD Protection	15kV ESD Protection
Lightning Protection	Grounding Terminal
Modulation Type	IEEE 802.11b: DQPSK, DBPSK, DSSS, and CCK IEEE 802.11g: BPSK, QPSK, 16QAM, 64QAM, OFDM
Receiver Sensitivity	802.11g 54M: -76dBm 48M: -78dBm 36M: -82dBm 12M: -91dBm 9M:-92dBm 802.11b 11M:-90dBm 5.5M:-92dBm 1M:-98dBm
Power Supply Unit	Input: localized to country of sale Output: 12VDC / 1A Switching PSU
Certifications	CE, FCC
Operating Temperature	-30°C~70°C (-22°F~158°F)
Relative Humidity	10% ~ 90%, non condensation
Dimensions	10.4 × 4.7 × 3.2 in. (265x120x83mm)

Figure 4.9 Features of TL-WA5210G.

Other system units such as the GPS, the accelerometer and the webcam are the same mentioned in Section 3.2.

4.3 Developed Software in Experimental Setting

Features of the developed software are identical to the previous one mentioned in Section 3.3. The new version has also been designed to transmit image (jpeg, bmp), audio (mp3), office, pdf files and text messages between vehicles and vehicle to infrastructure. It can also detect and locate traffic accidents by using system units. The new version of V2I and V2I communication application GUI is shown in Figure 4.10.

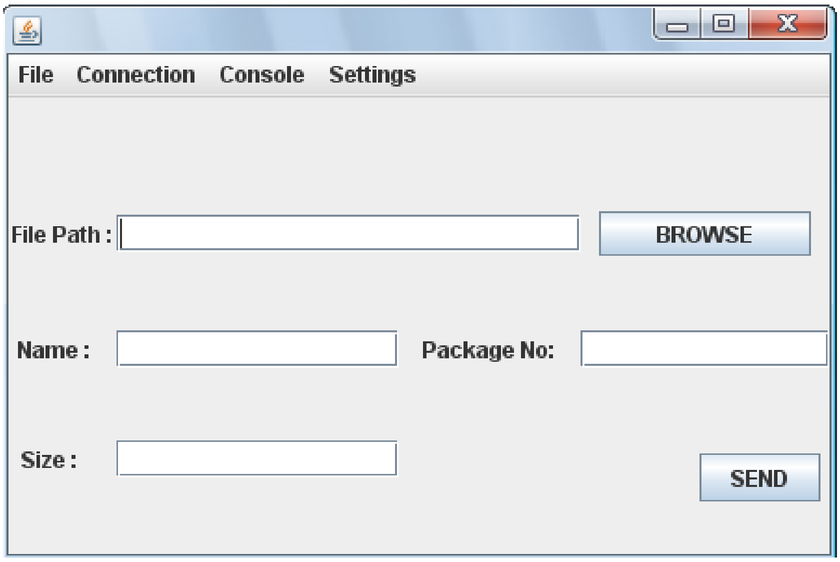

Figure 4.10 GUI of the V2I and V2I communication application.

Under connection menu in the GUI, there are communication dialogs with system units. Because of changes can be in serial port numbers, computer's Internet Protocol (IP) addresses, user sets the connection parameters with the units. Figures 4.11 to 4.13 show communication dialogs with system units, respectively. Different from software mentioned in Section 3.2, ethernet protocol was used to communicate with the transceiver. User can only send text message or files when ethernet connection between transmitter and receiver is established. Fixed IP addresses of the computers are used both at transmitter and receiver. Users at both side set ethernet connection to a before known IP address by using the dialog shown in Figure 4.11. If users attempt to send file or text message without preparing ethernet connection, a warning to set ethernet connection will appear.

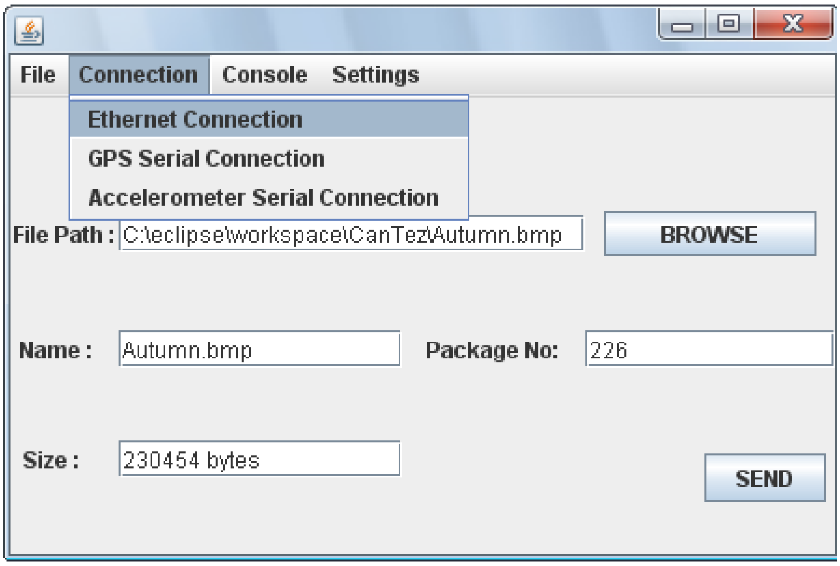

Figure 4.11 Connection Menu of the V2I and V2I communication application.

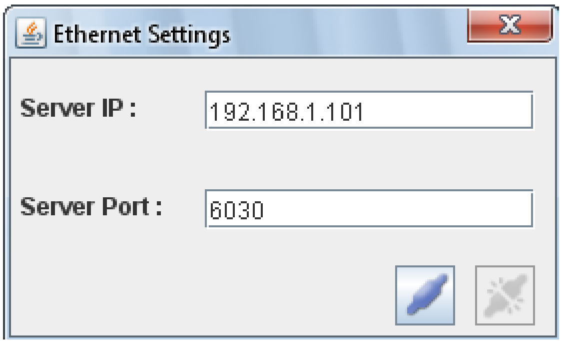

Figure 4.12 Ethernet Connection Dialog.

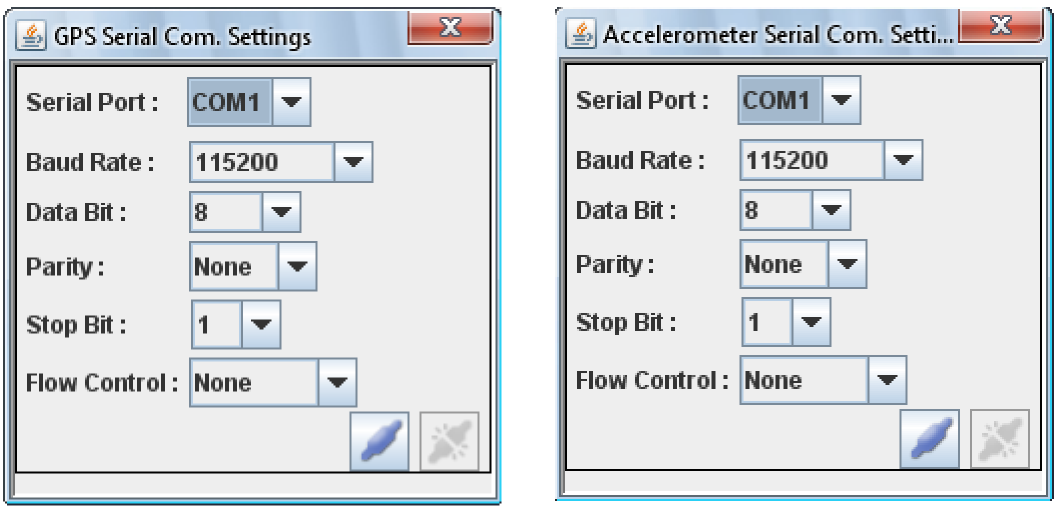

Figure 4.13 GPS and Accelerometer Serial Connection Dialogs.

Ethernet transport protocol used in this work is UDP. The UDP is a communication protocol between computers in a network that uses the IP. With UDP, computer applications can send data units referred as datagrams, to other hosts on an IP network without requiring prior communications to set up special transmission channels or data paths. The theoretical limit on Java for the maximum size of a UDP package is 64 Kbytes. Although theoretical limit is 64 Kbytes, package size larger than 16024 bytes caused problems during laboratory tests. Based on this observation, UDP package sizes up to 16024 bytes are used during outdoor tests.

Figure 4.14 and 4.15 show consoles of V2I and V2I communication application, respectively. By this consoles user can send and receive text messages and get information about system situations. Additionally, Figure 4.16 shows the menu for user settings. User can control G Limit threshold analysis of accelerometer data, ping test message size, ARQ limit and log files of file transmission and ping test.

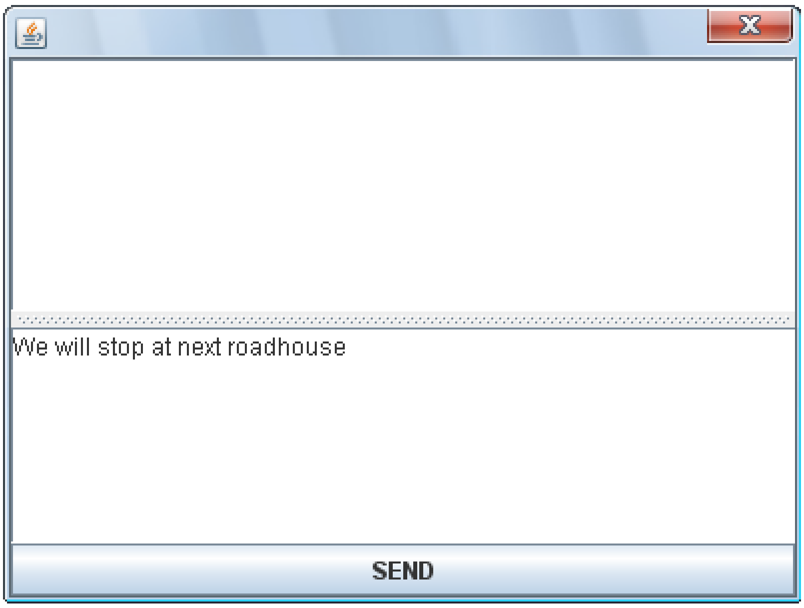

Figure 4.14 Text Message Console.

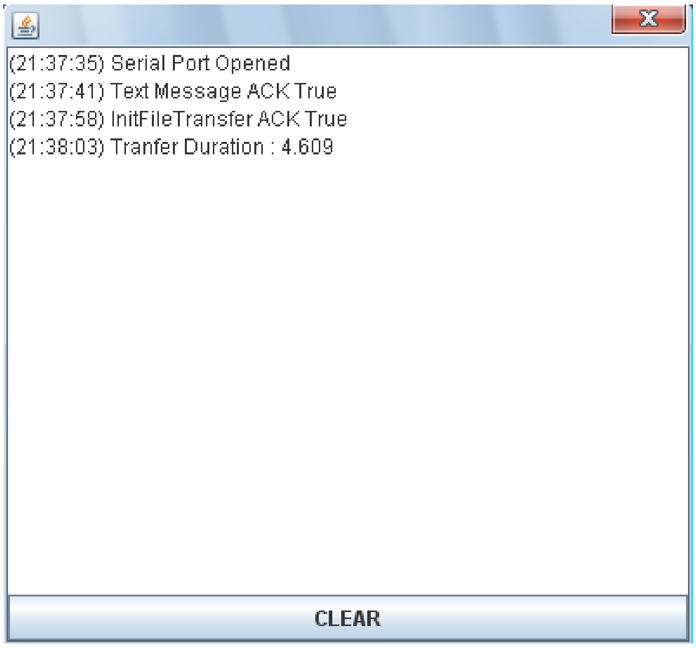

Figure 4.15 User Console.

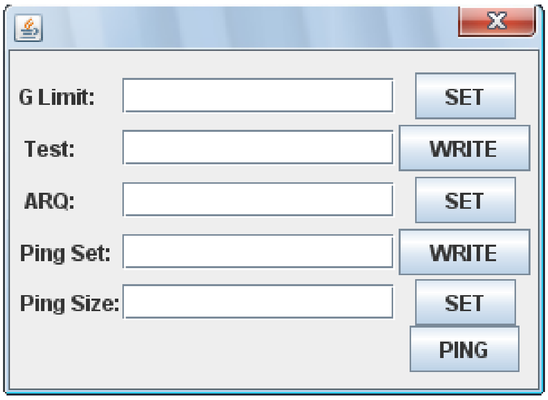

Figure 4.16 User Settings.

4.3.1 Package structures in experimental setting

As declared in Section 3.3.1, packetization and depacketization method between transmitter and receiver is again followed for the ethernet communication based software. Some additions were made to package structure formats described in Section 3.3.1. Fig 4.17 shows rearranged packages generated during different type of applications.

Init File Transfer Package

PL	MC	FT	FL	CRC
2 Byte	1 Byte	1 Byte	4 Byte	2 Byte

Init File Transfer ACK. Package

PL	MC	ACK	CRC
2 Byte	1 Byte	1 Byte	2 Byte

File Transfer Package

PL	MC	PN	DATA	CRC
2 Byte	1 Byte	2 Byte	User Defined	2 Byte

File Transfer ACK. Package

PL	MC	PN	ACK	CRC
2 Byte	1 Byte	2 Byte	1 Byte	2 Byte

Text Message Package

PL	MC	DATA	CRC
2 Byte	1 Byte	User Defined	2 Byte

Text Message ACK. Package

PL	MC	ACK	CRC
2 Byte	1 Byte	1 Byte	2 Byte

GPS Message Package

PL	MC	DATA	CRC
2 Byte	1 Byte	GPS Sentence Defined	2 Byte

GPS Message ACK. Package

PL	MC	ACK	CRC
2 Byte	1 Byte	1 Byte	2 Byte

Ping Test Package

PL	MC	DATA	CRC
2 Byte	1 Byte	User Defined	2 Byte

Ping Test ACK. Package

PL	MC	DATA	CRC
2 Byte	1 Byte	User Defined	2 Byte

PL (Package Length): is defined as the length of message

MC (Message Code): specifies the type of message.

FT (File Type): specifies the format of tranmistted file.

FL (File Length): specifies the size of tranmistted file

ACK: Acknowledgment Byte

CRC: Cycling Redundancy Check

PN (Package No): specifies the package of the message

DATA: specifies the data read from transmitted file,GPS Receiver, user text message
Length of data is determined by the user.

Figure 4.17 Package Structures.

Package length header increased to two bytes in order to transmit larger packages. Also, ping test package was added to package format so that latency between transmitter and receiver could be measured. Fig 4.18 shows message code details required during decoding and encoding packages. Unlike previous message code details mentioned in Section 3.3.1, ping message codes were added to measure latency.

Message Code Details

Command	Description
0x01	MESSAGE_CODE_FILE_TRANSFER
0x02	MESSAGE_CODE_INIT_FILE_TRANSFER
0x03	ACKNOWLEDGMENT _CODE
0x04	INIT_ACKNOWLEDGMENT _CODE
0x05	MESSAGE_CODE_TEXT
0x06	TEXT_ACKNOWLEDGMENT _CODE
0x07	MESSAGE_CODE_GPS
0x08	GPS_ACKNOWLEDGMENT _CODE
0x09	ACCIDENT_MESSAGE_CODE
0x10	PING_MESSAGE
0x11	PING_MESSAGE_ACK

File Type Details

Command	Description
0x01	FILE_TYPE_JPG
0x02	FILE_TYPE_MP3
0x03	FILE_TYPE_ACCIDENT_JPG
0x04	FILE_TYPE_BMP
0x05	FILE_TYPE_PDF
0x06	FILE_TYPE_DOC
0x07	FILE_TYPE_DOCX
0x08	FILE_TYPE_XLS
0x09	FILE_TYPE_XLSX
0x10	FILE_TYPE_PPT
0x11	FILE_TYPE_PPTX

Figure 4.18 Message and File Type Commands.

4.3.2 File transfer procedure

File transfer procedure is identical to the procedure explained in Section 3.3.2 Firstly, file format is checked before transmission. If the input file is not in an appropriate format, the software warns the user. If it is a supported format, file will be separated into packages according to rearranged package structures. After packetization is completed, total number of packages that will be transmitted is calculated and file transfer procedure is followed as described in Section 3.3.2.

Figure 4.19 shows file transfer procedure. File transfer procedure is based on acknowledgments. Figure 4.20 and 4.21 shows the procedure process in cases when no acknowledgments and false acknowledgments are received. In such cases, transferred package is resent.

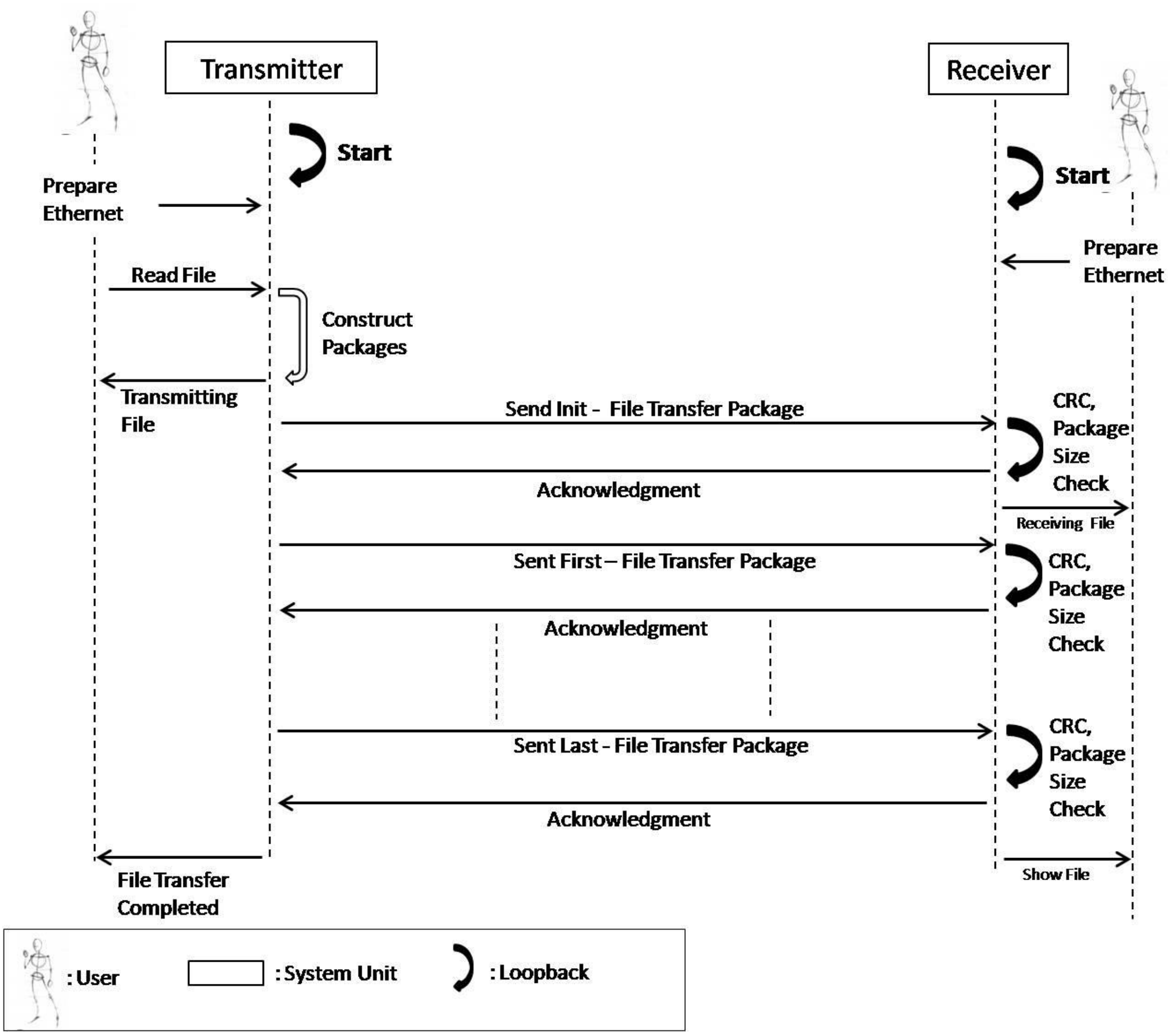

Figure 4.19 File transfer procedure.

Figure 4.20 No acknowledgment received case.

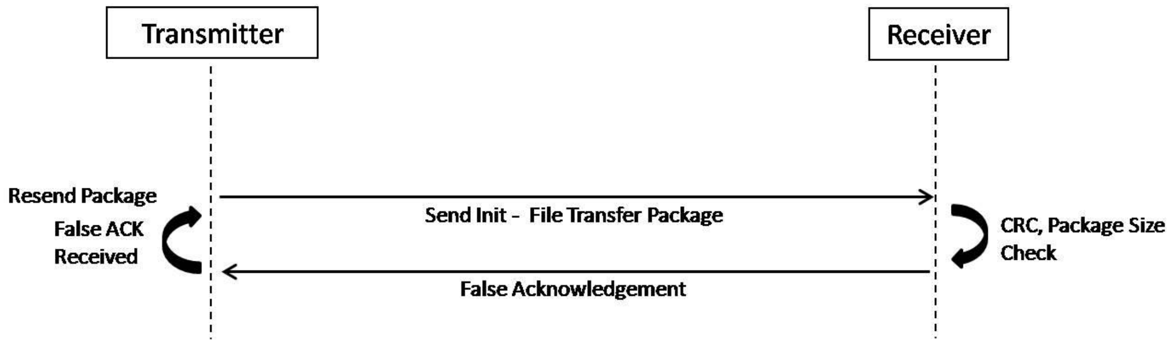

Figure 4.21 False acknowledgment received case.

4.3.3 Accident detection algorithm

To detect and locate traffic accident same algorithm was used in described in Section 3.3.3. The same accelerometer and GPS were used to detect accident. Configuration of the accident detection scenario is shown in Figure 4.22.

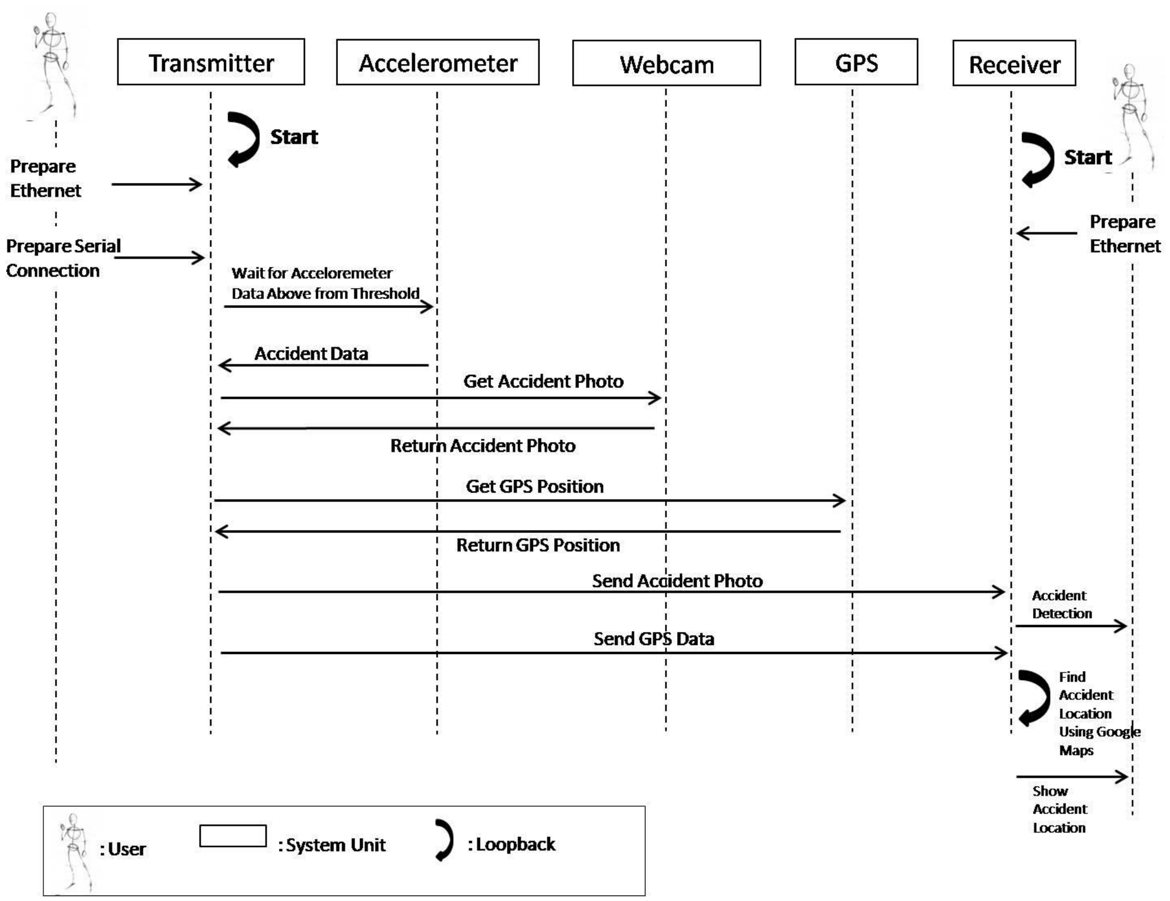

Figure 4.22 The accident scenario configuration.

In order to detect an accident, x-axis, y-axis, z-axis acceleration values are continuously observed. If these values exceed accident detection threshold established in Section 3.3.3, webcam takes a snapshot of accident to determine if driver or passengers need emergency services. Accident photo and GPS position is transmitted to infrastructure and accident location is detected using Google Maps. Higher resolution photos can be transmitted in shorter time by means of IEEE 802.11b/g based communication system compared to FHSS communication system mentioned in Section 3.3.3.

4.4 File Transmission Quality of the System

As expressed in Section 3.4, peak signal-to-noise ratio, PSNR, is the ratio between the maximum possible power of a signal and the power of corrupting noise that affects the fidelity of its representation. It is most easily defined via the mean squared error (MSE) which for two $m\times n$ monochrome images I and K where one of the images is considered a noisy approximation of the other is defined as:

$$MSE = \frac{1}{m\,n}\sum_{i=0}^{m-1}\sum_{j=0}^{n-1}[I(i,j) - K(i,j)]^2 \tag{4.1}$$

The PSNR is defined as:

$$\begin{aligned} PSNR &= 10 \cdot \log_{10}\left(\frac{MAX_I^2}{MSE}\right) \\ &= 20 \cdot \log_{10}\left(\frac{MAX_I}{\sqrt{MSE}}\right) \\ &= 20 \cdot \log_{10}(MAX_I) - 10 \cdot \log_{10}(MSE) \end{aligned} \tag{4.2}$$

If two images are identical, mean squared error will be zero; for this value PSNR is undefined. As mentioned in section 4.3.2, file transfer procedure allows transmitting files identically.

4.5 Description of the Tests

Two sets of experiments were performed for V2I and V2V communications.

4.5.1 V2I experiments

In order to evaluate the performance of V2I communication, four experiments were performed in four different environments in the surrounding of the city of Ankara, Turkey. The parameters adopted within experiments are listed in Table 4.1. For the figures 4.23 to 4.25 green markers show test road and the red marker shows the infrastructure location.

Table 4.1 The parameters adopted in experiments.

Parameter	Value
Wireless technology	IEEE 802.11b/g
IP address	Fixed
Channel	Fixed
Data Rate	Auto
Tx Power	8 dBm
Antenna gain	7 dBi(Omni),12dBi(Directional)
Transport Protocol	UDP
Speed	0/10/20/40/70/80 km/h
Package Size	1024/2024/4024/8024/16024 bytes

4.5.1.1 <u>Static scenario</u>

Static scenario was conducted in Meteksan Defence building’s roof. Two access points were placed face to face in order to establish LOS communication. Distance between access points was set to 36 meters. In both transmitter and receiver side, high gain internal antennas of access point were used.

4.5.1.2 Rural area scenario

In this scenario, infrastructure was located in Meteksan Defence building and a vehicle was moving in Hacettepe University Campus, with low (10km/h) speed. Satellite view of the test environment is shown in Figure 4.23.

Figure 4.23 Satellite view of rural area scenario.

High gain internal antennas of access point were used at both sides to communicate in long ranges. The nature of university campus with frequent trees and a mountain parallel to the test road caused decrease in signal quality. In order to achieve connection between vehicle and infrastructure, IEEE802.11b standard was used because of its better receiver sensitivity.

4.5.1.3 Long distance performance scenario

In this scenario, infrastructure was located in Meteksan Defence building and a vehicle was moving towards to Bilkent University East Campus Entrance, with low (20km/h) speed. Satellite view of the test environment is shown in Figure 4.24. Like rural area tests described in section 4.4.1.2, high gain internal antennas of access point were used at both sides to communicate in long ranges. In this experiment, maximum performance that can be reached in long ranges was aimed.

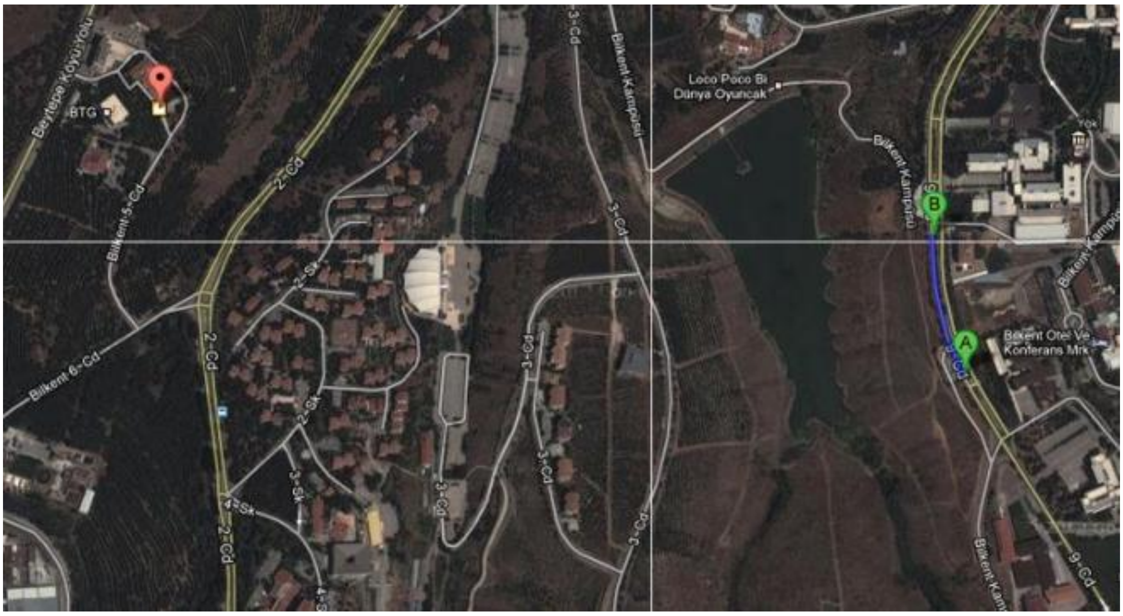

Figure 4.24 Satellite view of long distance performance scenario.

4.5.1.4 <u>Speed effect on V2I communication scenario</u>

In this scenario, infrastructure was located in Meteksan Defence building and a vehicle was moving in Beytepe Village Road, with varying speeds (0 to 80 km/h). Satellite view of the test environment is shown in Figure 4.25.

Unlike tests mentioned in sections 4.4.1.2 and 4.4.1.4, the vehicle was parked at some specified locations to figure out vehicle’s speed effect on V2I communication. Horizontal beamwidth of internal access point antenna reduced signal quality while car was moving away from infrastructure. In order to observe speed effect on V2I communication, 7 dBi omni directional antennas were used at the tests.

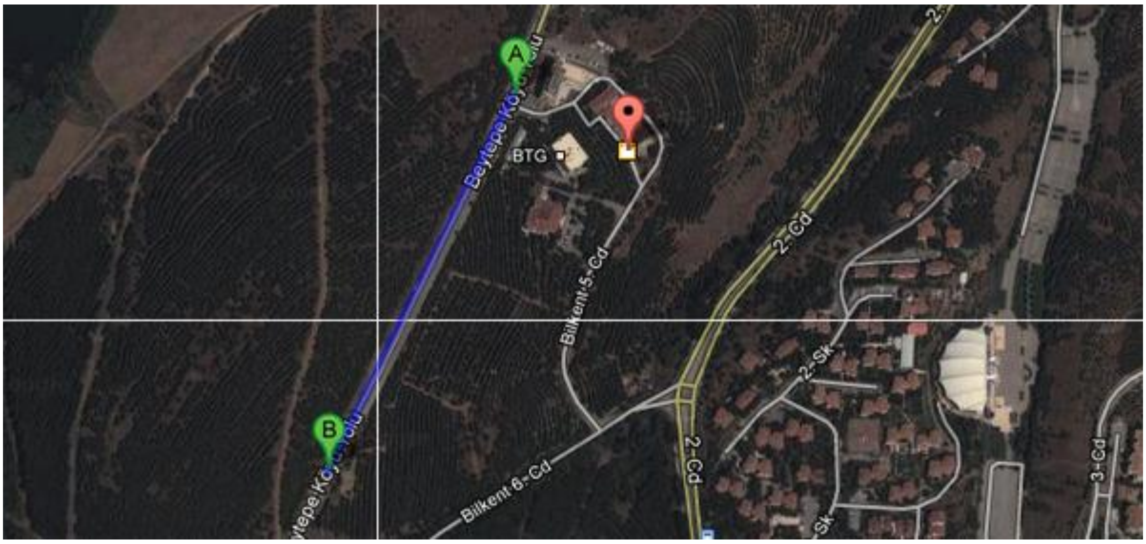

Figure 4.25 Satellite view of speed effect on V2I communication scenario.

4.5.2 V2V experiments

In order to evaluate effects of the environment and vehicle speed on V2V communication, two different environments were performed in the surrounding of the city of Ankara, Turkey. The parameters adopted within experiments are listed in Table 4.2. During V2V tests, vehicles velocity and the distance from each other was recorded by GPS receivers. After the data collection, GPS sentences with the same UTC times are matched.

Table 4.2 The parameters adopted in experiments.

Parameter	Value
Wireless technology	IEEE 802.11b/g
IP address	Fixed
Channel	Fixed
Data Rate	Auto
Tx Power	8 dBm
Antenna gain	7 dBi(Omni)
Transport Protocol	UDP
Speed	Up to 80 km/h
Package Size	2024 bytes

4.5.2.1 <u>One vehicle following the other in a rural environment</u>

This part of the V2V experiments was performed in Hacettepe University campus entrance road. The rural area was filled with frequent trees and sparsely populated areas. Satellite view of the test environment is shown in Figure 4.26. Two cars followed each other with varying distances. In this scenario, average speed of first car was limited to 50 km/h while second car could fasten up to 80 km/h.

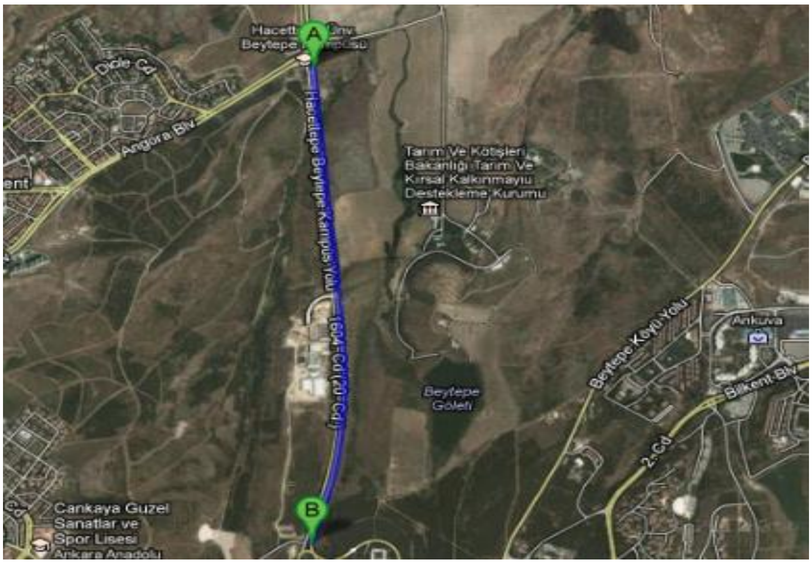

Figure 4.26 Satellite view of rural test environment.

4.5.2.2 <u>One vehicle following the other in a suburban area</u>

Suburban scenario was performed in Beytepe Village road and Hacettepe University campus. The suburban area was usually filled with houses, story buildings and trees. Satellite view of the test environment is shown in Figure 4.27. During this part of experiments, the traffic was followed without controlling the cars speed and the distance between cars.

4.5.3 Accident Detection Tests

In this test, accident detection system mentioned in Section 4.3.3 was tested in Meteksan Defence’s park area.

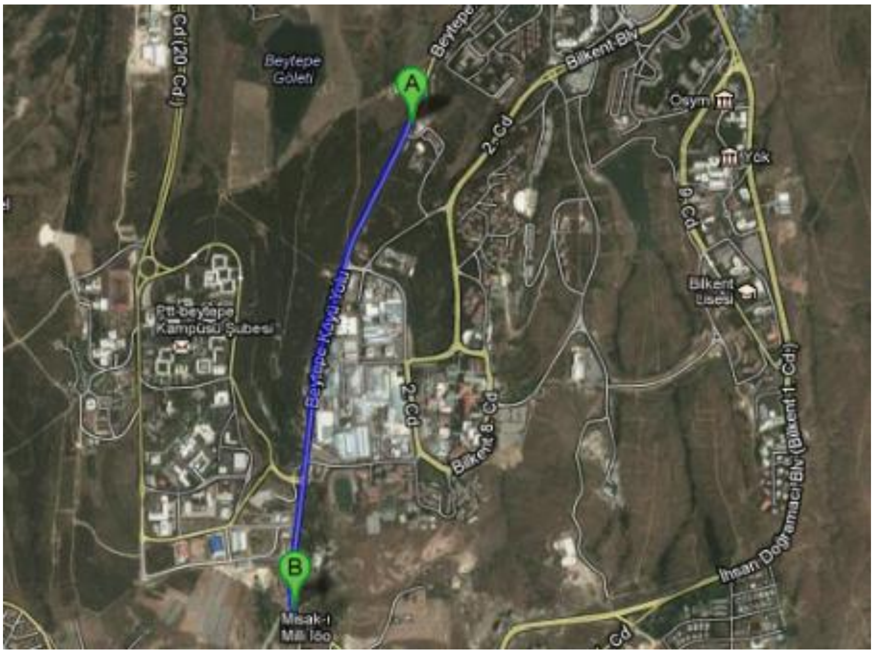

Figure 4.27 Satellite view of suburban test environment.

4.6 Results and Discussions

4.6.1 V2I experiments results

The performance metrics used to evaluate performance the connectivity between vehicle and infrastructure are:

- Throughput: To determine the actual data rate of a network or connection, the "throughput" measurement definition is used. Throughput is the amount of data moved successfully from one place to another in a given time period.
- Package Loss Rate: percentage of data packages dropped due to network difficulties. Every package loss is GPS logged**.**
- Round Trip Time (RTT): is the time elapsed for a package to a remote place and back again. It is measured in ms. In order to avoid wrong calculations can be caused by operating systems, network delays; RTT is measured over 1,000 transmissions.
- the period of connection between vehicle and infrastructure.
- the amount of data can be transferred in a single pass.

4.6.1.1 Static scenario results

Figure 4.28 shows the average throughput for different package sizes between access points looking face to face. As it is shown in Figure 4.28 transmitting files with larger packages allows higher throughput.

For IEEE802.11g standard, the peak throughput is of 9.59 Mbps, obtained with 16024 byte packages. On the other hand for IEEE802.11b standard, the peak throughput is of 4.06 Mbps, obtained with 16024 byte packages. When results obtained for IEEE802.11 b/g standards are compared, IEEE 802.11g can supply higher throughput because of its higher data rate. During this test, any package loss did not occur due to short distance between access points and LOS communication.

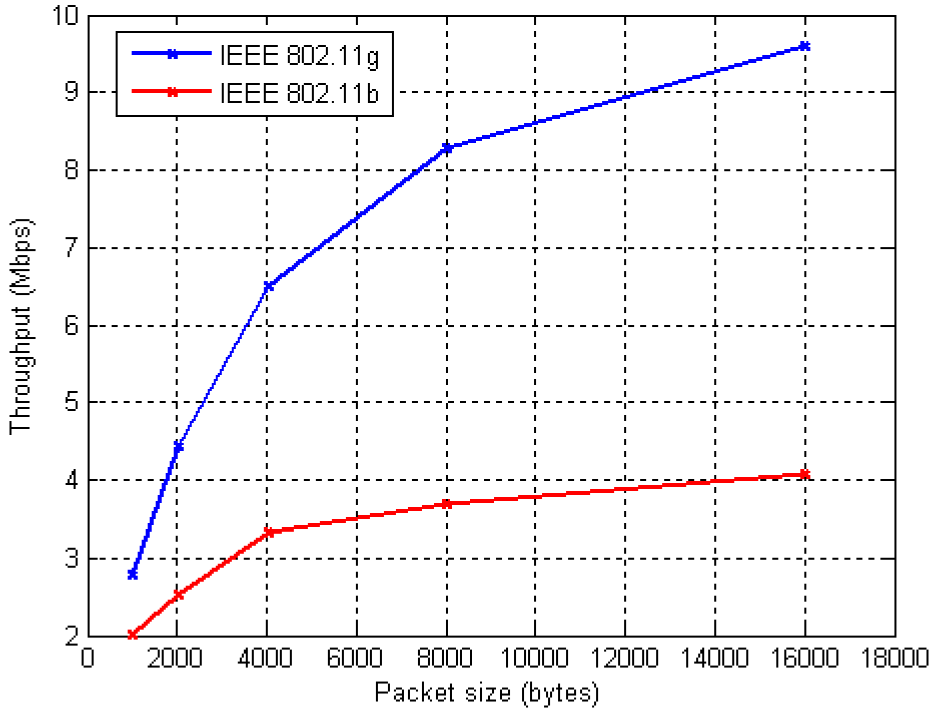

Figure 4.28 Average throughputs for static scenario over UDP using IEEE 802.11b/g in terms of package size.

4.6.1.2 Rural area scenario results

During this experiment, communication could not establish through the road because of frequent trees and a hill parallel to test road. Figure 4.29 shows package losses rates occurred through the entire road. Effect of trees and hill can be explained due to fading.

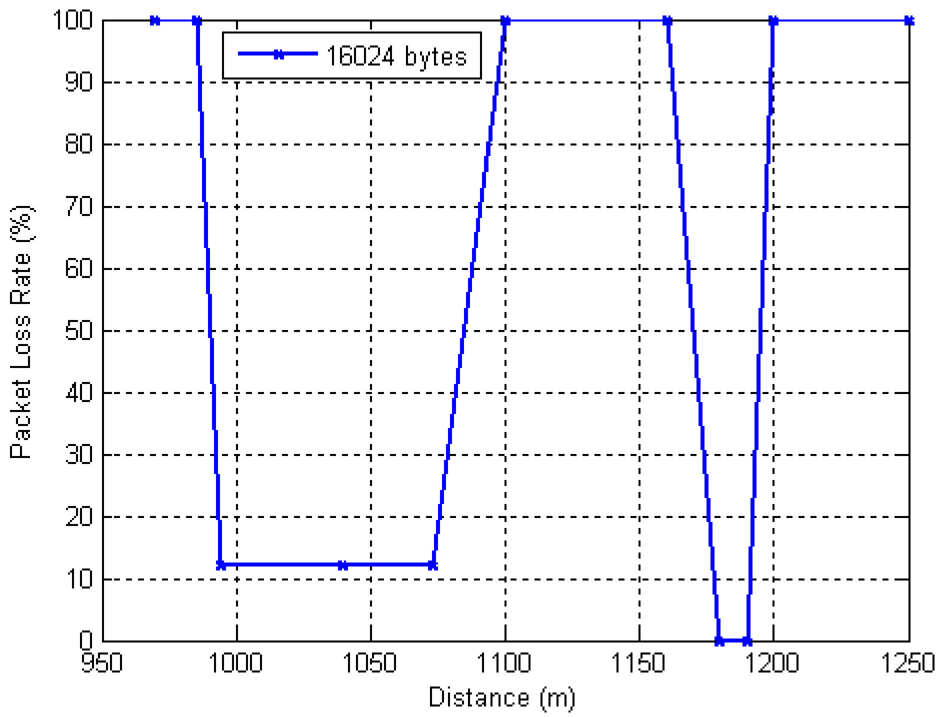

Figure 4.29 Performance comparison for rural area: package loss rate versus distance.

Figure 4.30 shows average throughput when vehicle was moving at 10 km/h. As shown in Figure 4.30, throughput is about 1 Mbps at distances 1000 to 1100 meters. Rural area environment, long range distance and retransmission of the loss packages had a negative impact on throughput at those distances. Communication without package losses only occurred in short range between 1180 to1190 meters. At these points where LOS condition communication is satisfied, throughput around 3 Mbps is achieved for 16024 byte packages.

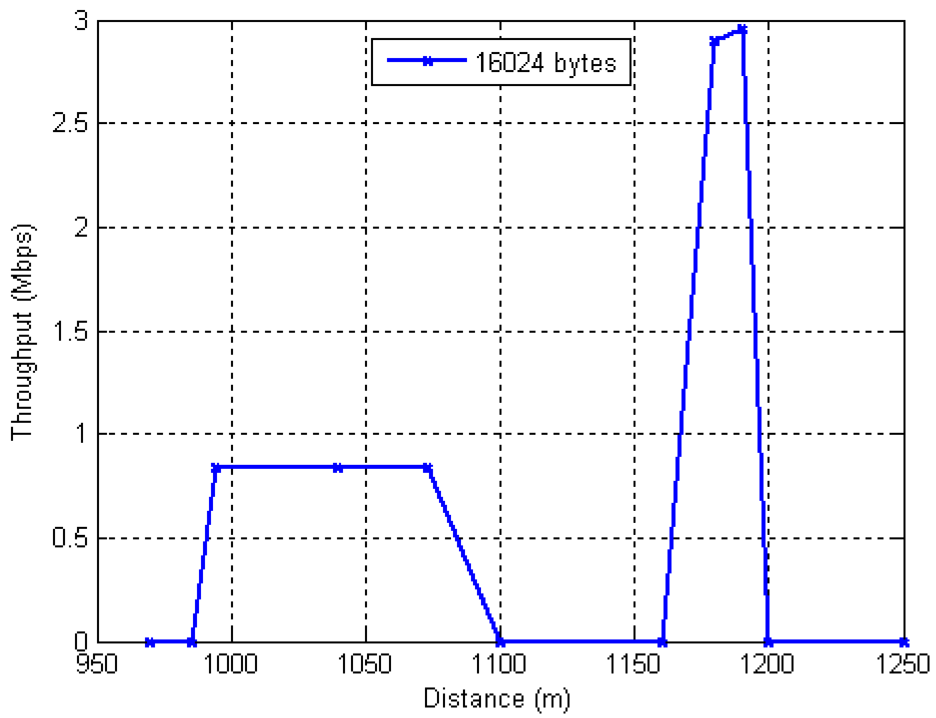

Figure 4.30 Average throughput for rural area over UDP using IEEE 802.11b while vehicle was moving at 10 km/h.

Table 4.3 shows connection time and the amount of transferred data between vehicle and infrastructure. As shown in Table 3, the average contact time was about 54 seconds and 4.39 Mbytes of data were transferred from rural area using 16024 byte packages.

Table 4.3 Average amount of data transferred, and contact time for vehicle to infrastructure transfers over UDP and IEEE 802.11b for rural area

Speed	Package Size	Wireless technology	Transferred data	Contact time
10 km/h	16024 bytes	IEEE 802.11b	4.39 MB	54 seconds

4.6.1.3 <u>Long distance performance scenario results</u>

Different from tests mentioned in Section 4.5.1.2, long range performance of IEEE 802.11g standard was measured. As it is shown in Fig 4.31, maximum throughput for IEEE802.11b is 2.98 Mbps and 7.08 Mps for IEEE802.11g. For both standards, throughput is decreasing along the road because of increasing distance, retransmission of the loss packages and changes in signal to noise ratio at the receiver due to fading.

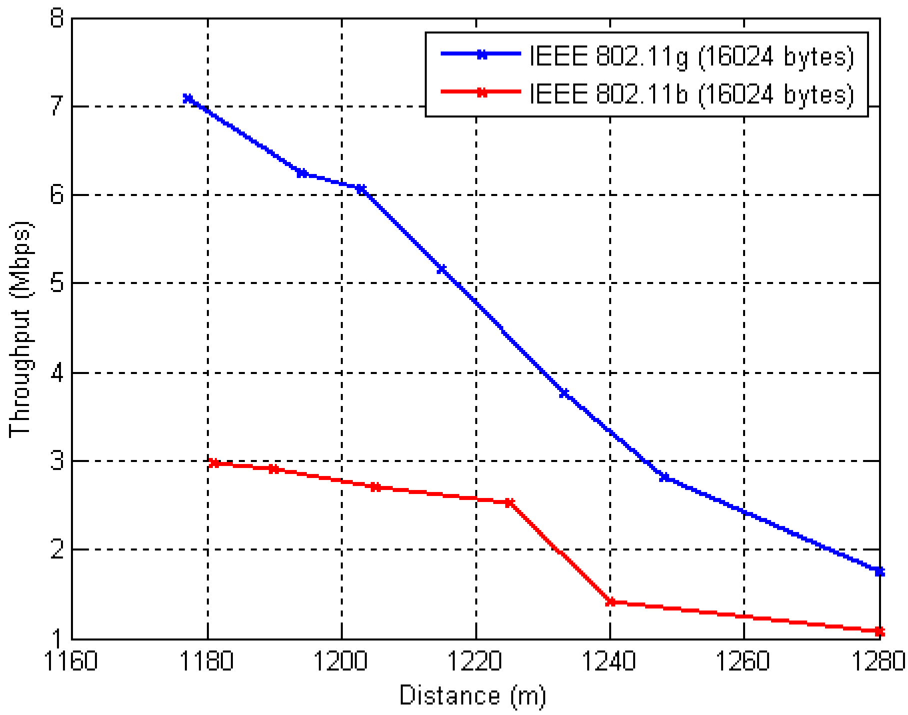

Figure 4.31 Average throughputs for long distances over UDP using IEEE 802.11b/g while vehicle was moving at 20 km/h.

Figure 4.32 shows package losses occurred through the road. With distance more than 1240 meters where throughput decreased, package losses increased rapidly.

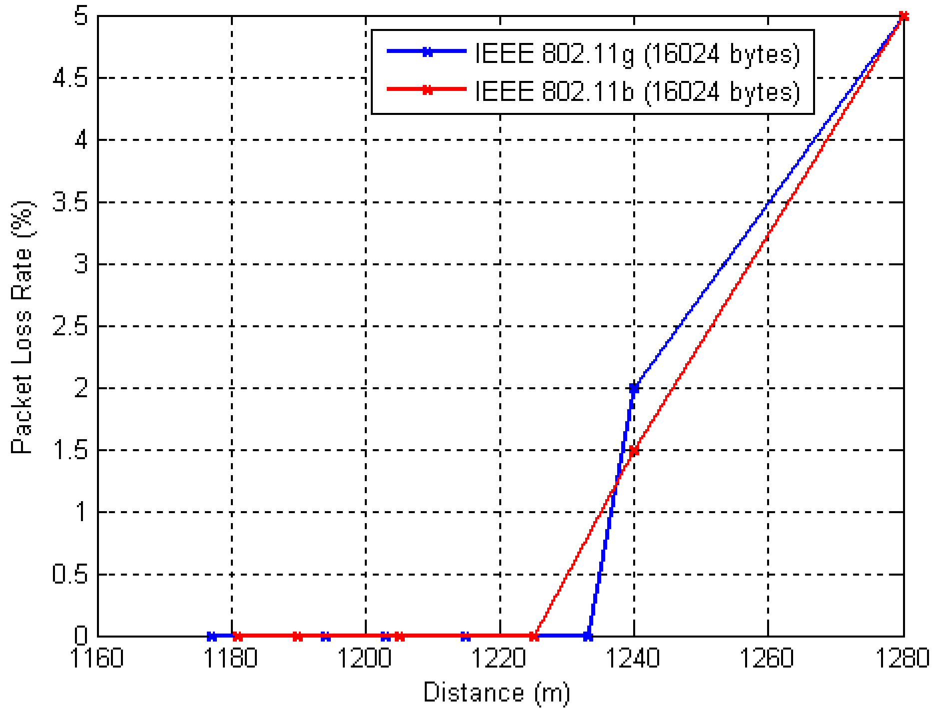

Figure 4.32 Performance comparison for long distances 3: package loss rate versus distance.

Table 4.4 Average amount of data transferred, and contact time for vehicle to infrastructure transfers over UDP and IEEE 802.11b/g for long distances.

Speed	Package Size	Wireless technology	Transferred data	Contact time
20 km/h	16024 bytes	IEEE 802.11b	8.01 MB	36 seconds
20 km/h	16024 bytes	IEEE 802.11g	18.69 MB	36 seconds

Table 4.4 shows connection time and the amount of transferred data between vehicle and infrastructure. In a single pass, 8.01 Mbytes were transferred using 16024-byte packages for IEEE 802.11b and 18.69 Mbytes were transferred using 16024-byte packages for IEEE 802.11g. It can be clearly observe from Table 4 that IEEE 802.11g standard allows transferring greater amounts of data rather than IEEE 802.11b standard because of its high data rate.

4.6.1.4 Speed effect on V2I communication scenario results

In this part, vehicle's speed effect on V2I communication performance was tested. To see these effects, a test road on which a vehicle could reach high speeds was selected. As mentioned in the test description, 7 dBi omni-directional antennas were used instead of access points internal high gain (12 dBi) directional antennas. Before the test, the link budget formula shown below was calculated to estimate communication distance.

$$P_{RX} = P_{TX} + G_{TX} - L_{TX} - L_{FS} - L_M + G_{RX} - L_{RX} \quad (4.3)$$

P_{RX} = received power (dBm) = -92dBm (6 Mbps receiver sensitivity for IEEE802.11g)

P_{TX} = transmitter output power (dBm) = 8 dBm

G_{TX} = transmitter antenna gain (dBi) = 7 dBi

L_{TX} = transmitter losses (coax, connectors...) (dB) = 0 dB

L_{FS} = free space loss or path loss (dB)

$$L_{FS}\text{ (dB)} = -27.55\text{ dB} + 20*\log(\text{frequency(MHz)}) + 20*\log(\text{distance(m)}) \quad (4.4)$$

$$L_{FS}\text{ (dB)} = -27.55\text{ dB} + 20*\log(2420)+20\log(d)$$

$$L_{FS}\text{ (dB)} = 40.13\text{ dB} + 20\log(d)$$

L_M = miscellaneous losses (fading margin, body loss, polarization mismatch, other losses...) (dB) = 20 dB (%99 availability for rayleigh fading model)

G_{RX} = receiver antenna gain (dBi) = 7 dBi

L_{RX} = receiver losses (coax, connectors...) (dB) = 0 dB

According to link budget calculation, communication between vehicle and infrastructure can be established in 500 meters. Like tests mentioned in Section 4.5.1.1, transmitting files with larger packages again allowed higher throughput. Figures 4.33 to 4.35 show performance of throughput, package loss rate, and average round trip time for 0 km/h, respectively. As calculated from link budget formula totally 10 dBi antenna gain attenuation reduced communication distance to 500 meters.

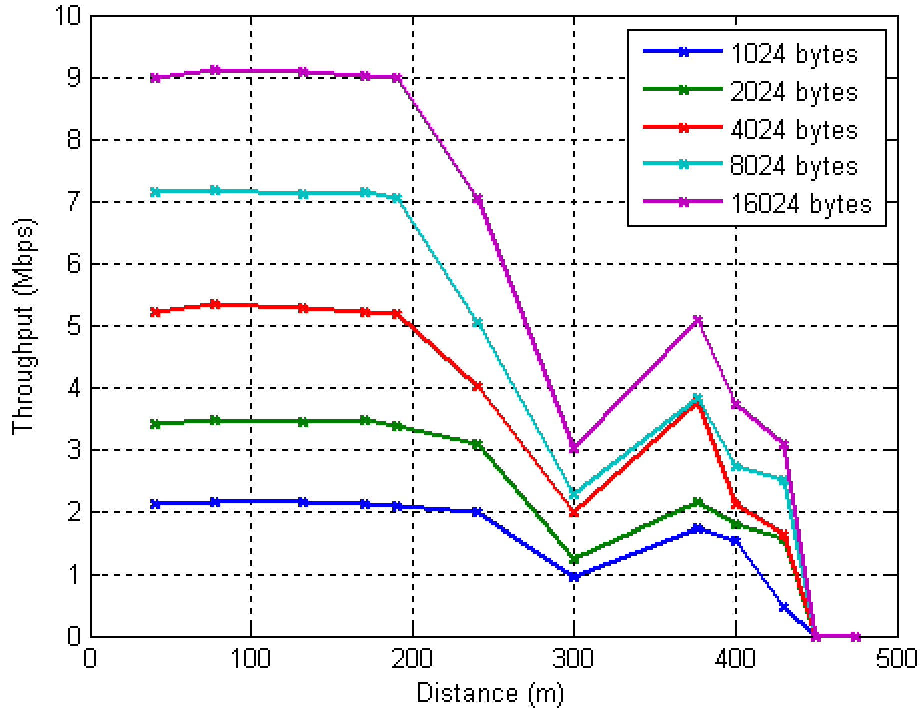

Figure 4.33 Average throughput using IEEE 802.11g while vehicle is stationary.

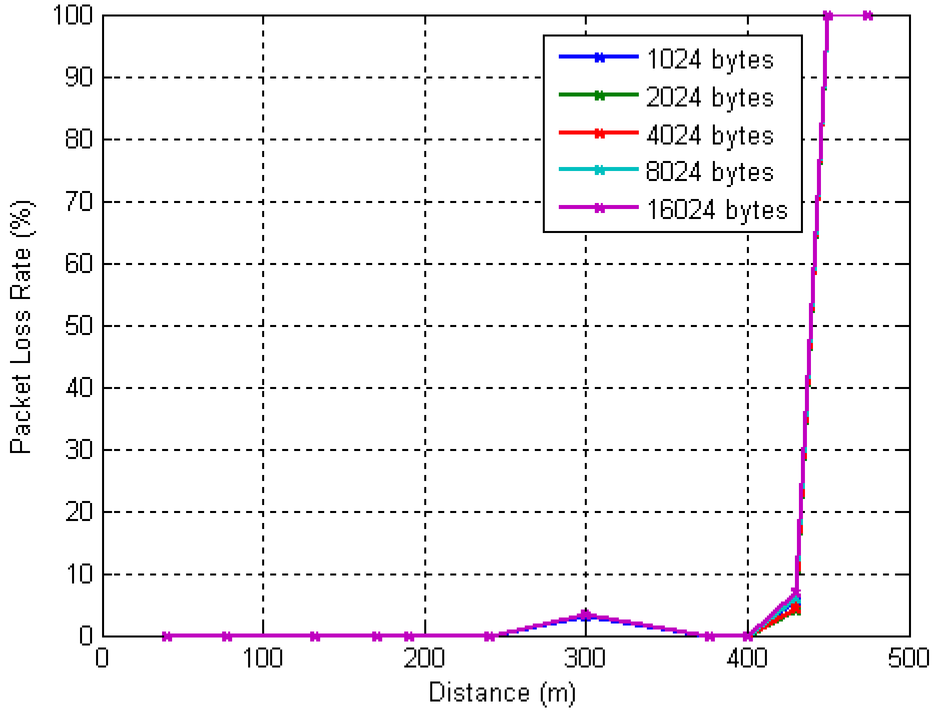

Figure 4.34 Performance comparison: package loss rate versus distance.

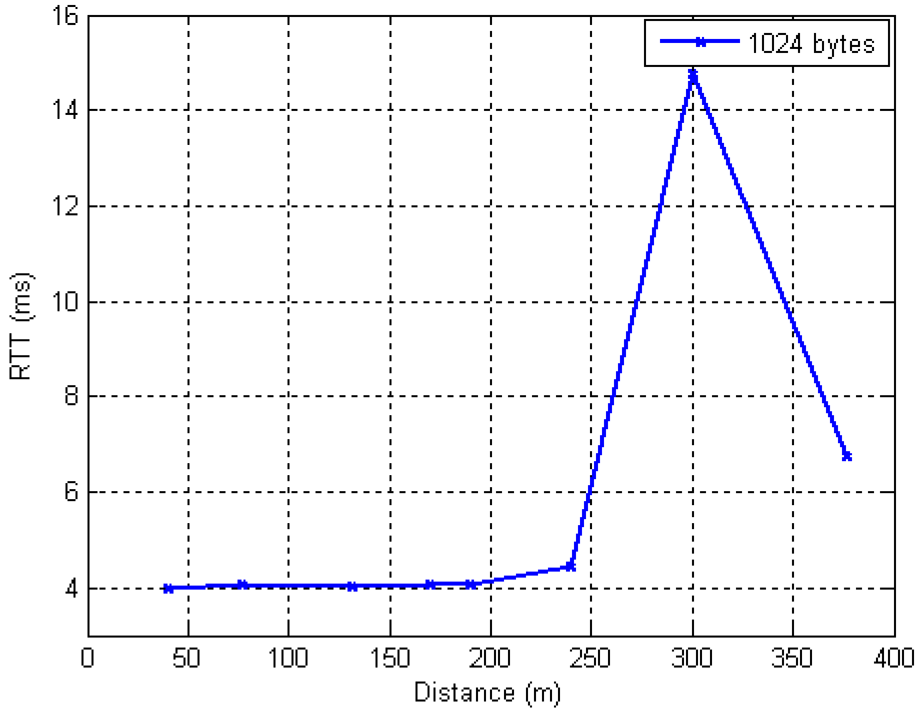

Figure 4.35 Average Round Trip Time using IEEE802.11g in terms of distance.

As shown in these figures, throughputs are almost same up to 200 meters. With the distance more than 200 meters, the package loss rate and average round trip time increased rapidly.

Based on the observation, vehicle-infrastructure distance is not critical up to 200 meters. To identify effects of vehicle speed on throughput, packet loss rate and round trip time, the test road was fixed to 200 meters and the performance metrics was measured again with varying speeds from 0 to 80 km/h. Any package losses did not occur during speed tests. According to this result, it is confirmed that driving speed does not affect package loss rate performance. Figures 4.36 to 4.38 show average throughput in terms of distance, package size and speed. As in [12], vehicle speed decreases throughput slightly compared to stationary condition. This is because Doppler shift impact degrades signal quality as described in [21].

Figure 4.39 shows round trip time as a function of distance and vehicle speed. Vehicle speed does not affect delay performance of V2I communication as shown in Figure 4.39. Round trip time measurements are centered at 4 milliseconds.

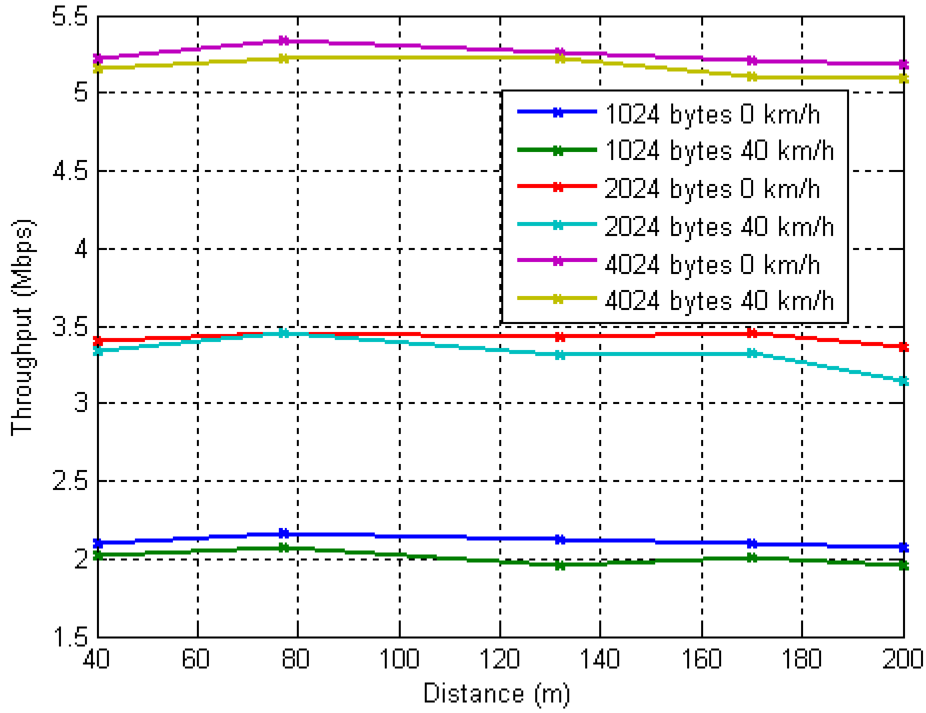

Figure 4.36 Average throughput using IEEE 802.11g in terms of speed, package size and distance.

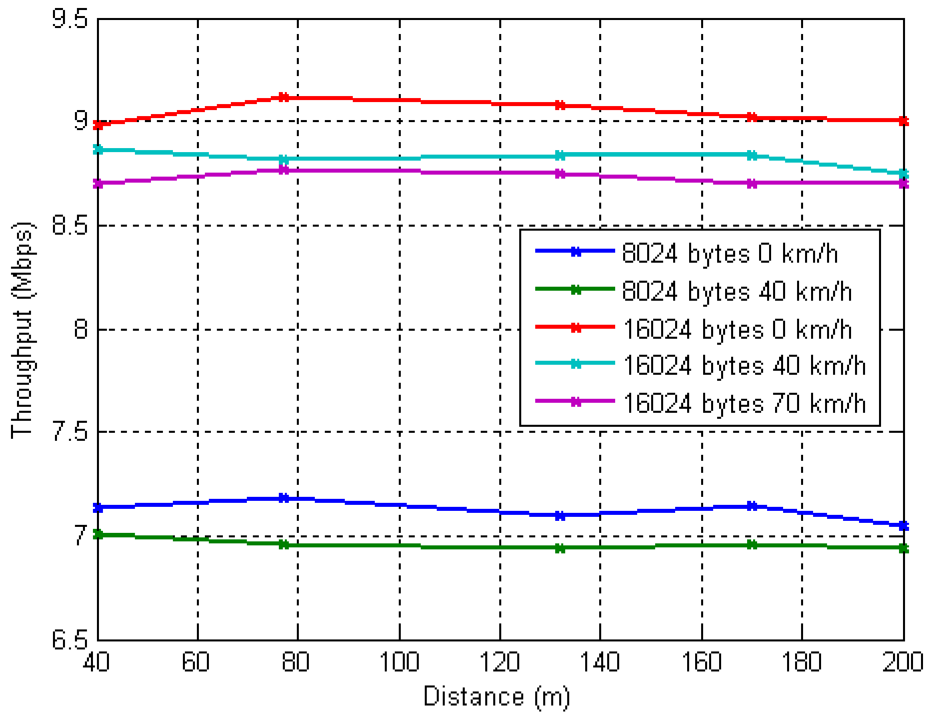

Figure 4.37 Average throughput using IEEE 802.11g in terms of speed, package size and distance.

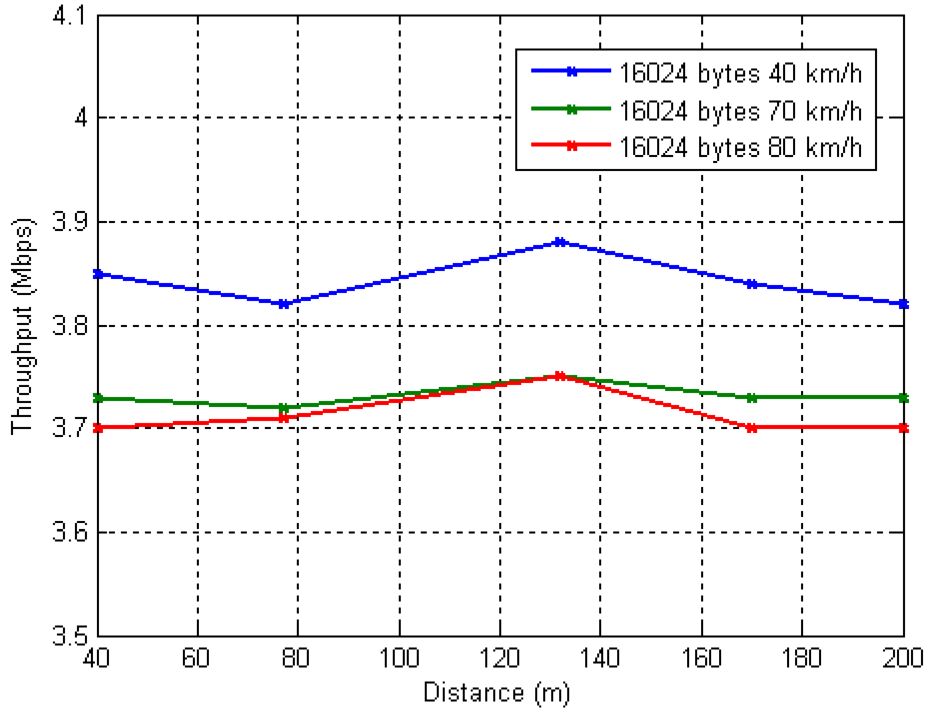

Figure 4.38 Average throughput using IEEE 802.11b in terms of speed and distance.

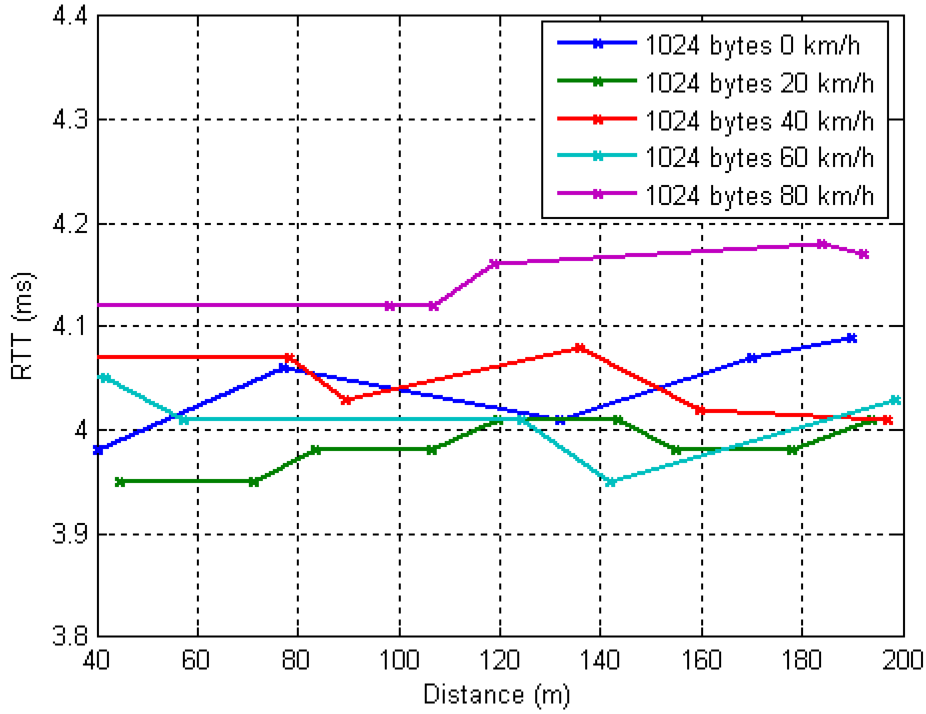

Figure 4.39 Average Round Trip Time using IEEE802.11g in terms of speed and distance.

Results show that there is a clear relationship between package size and throughput, depending on the car speed, and this relationship is not linear. Table 4.5 and 4.6 shows connection time and the amount of transferred data between vehicle and infrastructure. As shown in Table 4.5 and 4.6, the average contact time between vehicle and infrastructure was about 42 seconds for 40km/h and 24 seconds for 70 km/h.

Table 4.5 Average amount of data transferred, and contact time for vehicle to infrastructure transfers over UDP and IEEE 802.11g.

Speed	Package Size	Wireless technology	Transferred data	Contact time
40 km/h	1024 bytes	IEEE 802.11g	6.06 MB	42 seconds
	2024 bytes	IEEE 802.11g	8.516 MB	42 seconds
	4024 bytes	IEEE 802.11g	10.406 MB	42 seconds
	8024 bytes	IEEE 802.11g	12.51 MB	42 seconds
	16024 bytes	IEEE 802.11g	13.75 MB	42 seconds
70 km/h	16024 bytes	IEEE 802.11g	7.23 MB	24 seconds

Table 4.6 Average amount of data transferred, and contact time for vehicle to infrastructure transfers over UDP and IEEE 802.11b.

Speed	Package Size	Wireless technology	Transferred data	Contact time
40 km/h	1024 bytes	IEEE 802.11b	2.76 MB	42 seconds
	2024 bytes	IEEE 802.11b	3.22 MB	42 seconds
	4024 bytes	IEEE 802.11b	3.68 MB	42 seconds
	8024 bytes	IEEE 802.11b	4.14 MB	42 seconds
	16024 bytes	IEEE 802.11b	4.63 MB	42 seconds
70 km/h	16024 bytes	IEEE 802.11b	2.82 MB	24 seconds

With 40km/h driving speed, 4.63 Mbytes were transferred using 16024-byte packages for IEEE 802.11b and 13.75 Mbytes were transferred using 16024-byte packages for IEEE 802.11g in a single pass. As the vehicle speed increased, the contact time between nodes decreased. Due to decrease of the contact time, the amount of data transferred was also decreased. With 70km/h driving speed, 4.63 Mbytes were transferred using 16024-byte packages for IEEE 802.11b and 13.75 Mbytes were transferred using 16024-byte packages for IEEE 802.11g in a single pass. Within the contact time, larger packages allow greater amounts of data to be transferred because of the smaller package headers.

4.6.2 V2V experiments results

The performance metrics used to evaluate performance of vehicle to vehicle communication are:

- Throughput: To determine the actual data rate of a network or connection, the "throughput" measurement definition is used. Throughput is the amount of data moved successfully from one place to another in a given time period.
- Package Loss Rate: percentage of data packages dropped due to network difficulties. Every package loss is GPS logged.
- Round Trip Time (RTT): is the time elapsed for a package to a remote place and back again. It is measured in ms. In order to avoid wrong calculations can be caused by operating systems, network delays; RTT is measured over 1,000 transmissions.

4.6.2.1 One vehicle following the other in a rural environment results

In this experiment, firstly throughput between the two vehicles with varying distances was measured. Speed of the cars was fixed at 50km/h and 60 km/h, respectively. Fig. 4.40 shows throughput between two vehicles as a function of the inter-vehicle distance.

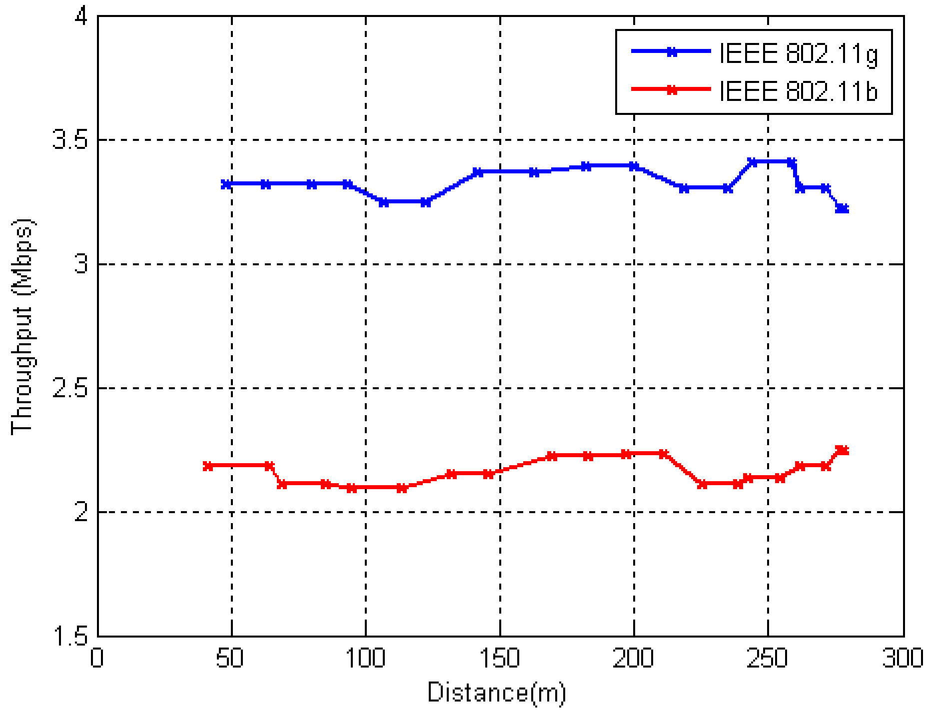

Figure 4.40 Average throughput using IEEE 802.11b/g while vehicles are following each other.

As shown in Fig 4.40 distance between vehicles did not affect throughput performance in 300 meters. For 2024 bytes packages, average throughputs are about 2.1 Mbps for IEEE802.11b and about 3.2 Mbps for IEEE802.11g. Additionally, during this test any package loss did not occur. In order to measure the impact of vehicle speed on the throughput, distance between vehicles was fixed to 200 meters. Scenarios with low speed and high speed were applied. In both scenarios, first car's speed was limited to 50 km/h. While second car fastened up to 60 km/h. for low speed and 80 km/h for high speed scenarios. Fig 4.41 shows throughput of IEEE802.11g for low speed and high speed conditions. As it is shown in Figure 4.41, increase in relative speed between cars decreases throughput slightly. This is similar to Experiment 4 vehicle to infrastructure throughput measurements (Figure 4.36). Also, package loss did not occur during low and high speed tests. As in [22], vehicle speed is not affecting package loss rate. During low speed scenario round trip time was also measured. Fig 4.42 shows round trip time between two vehicles as a function of distance.

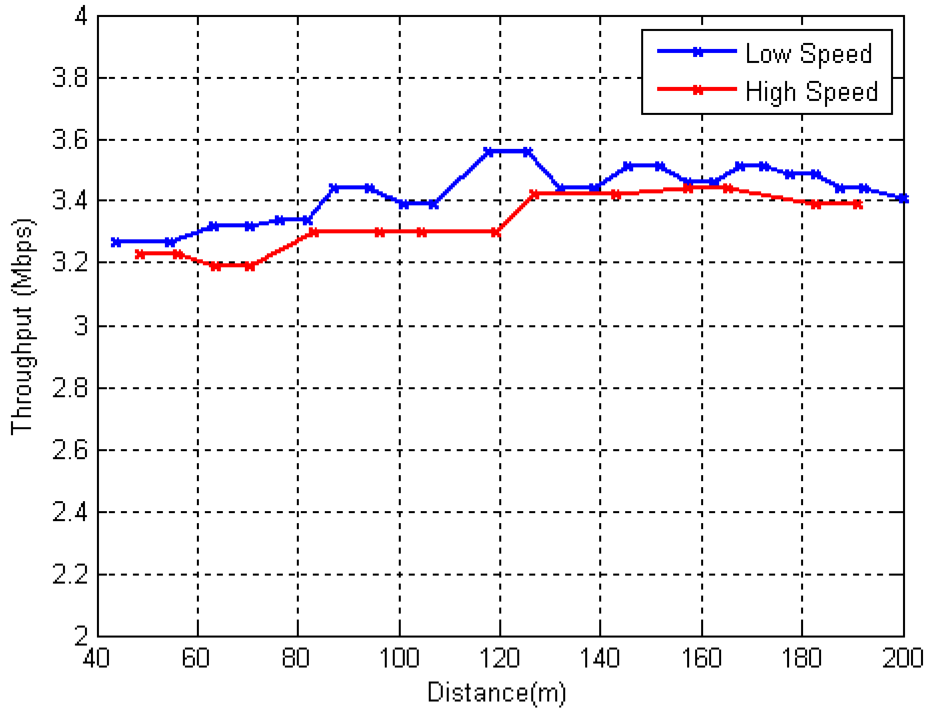

Figure 4.41 Average throughput using IEEE802.11g in terms of speed and distance.

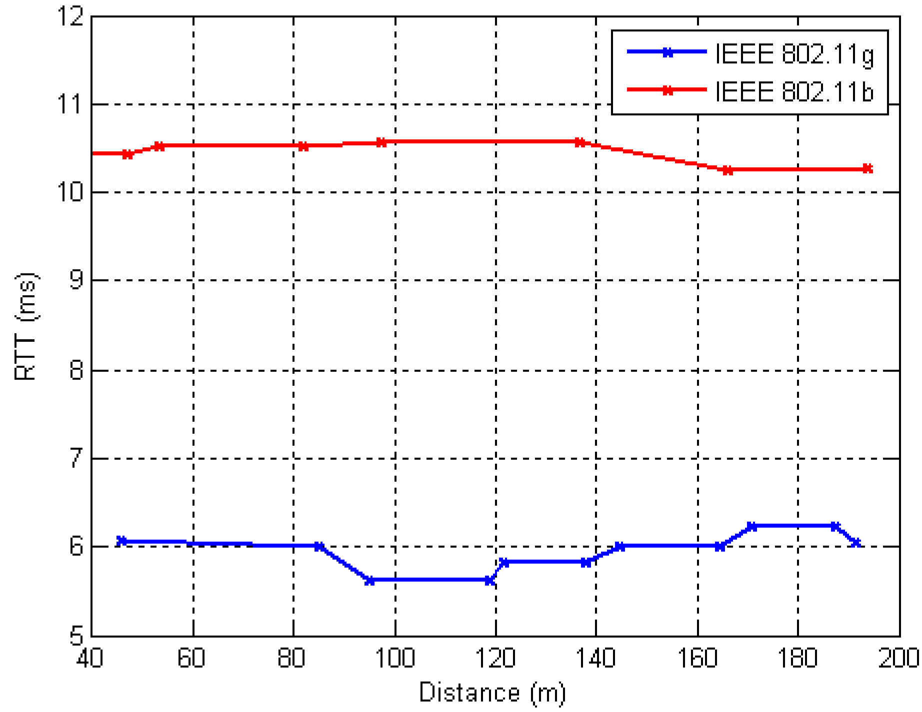

Figure 4.42 Average Round Trip Time using IEEE802.11b/g in terms of distance.

Average round trip time about 10.5 ms for IEEE802.11b and about 6 ms for IEEE802.11g were measured. Results showed that for rural areas, round trip time does not change while driving and only slightly increases when compared with the laboratory delay measurements shown in Fig 4.43.

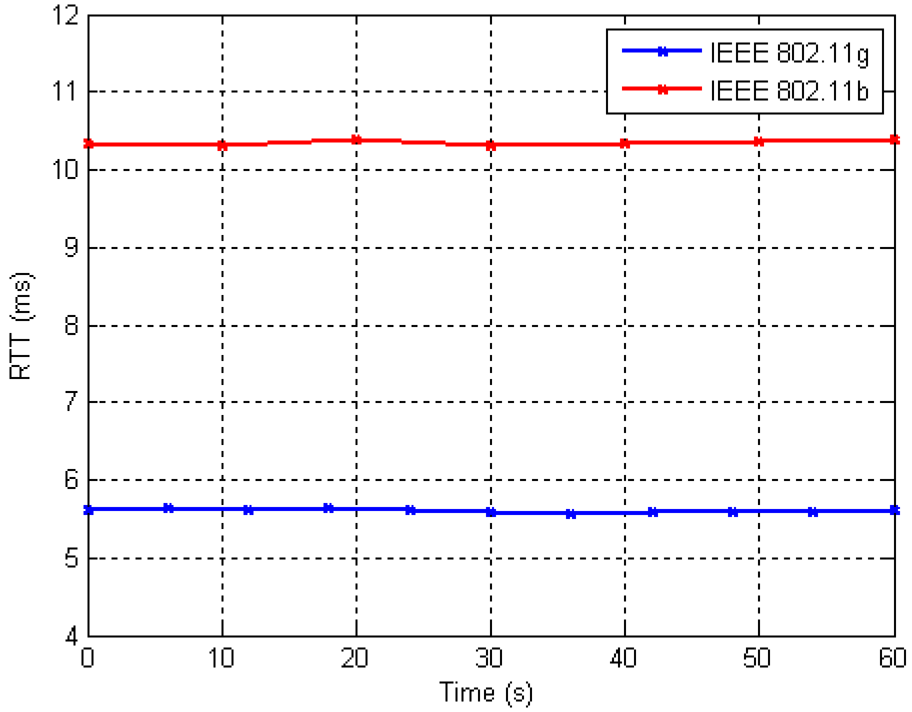

Figure 4.43 Average Round Trip Time measured in laboratory.

4.6.2.2 <u>One vehicle following the other in a suburban area results</u>

During this experiment, effects of the suburban environment on the throughput and the round trip rime were evaluated. The measured data showed that the speed of vehicles was under 60 km/h and the distance between the vehicles was below 300 meters. Fig 4.44 and Fig 4.45 show throughput between two vehicles in suburban area. In contrast to Figure 4.41, major changes in throughput occurred due to reflections from metal hulls of the vehicles got in between experimental cars and buildings. As it is shown in Figure 4.45, a major decrease in throughput was occurred due to retransmission of the loss packages entrance in the entrance of a crowded area with frequent trees and buildings.

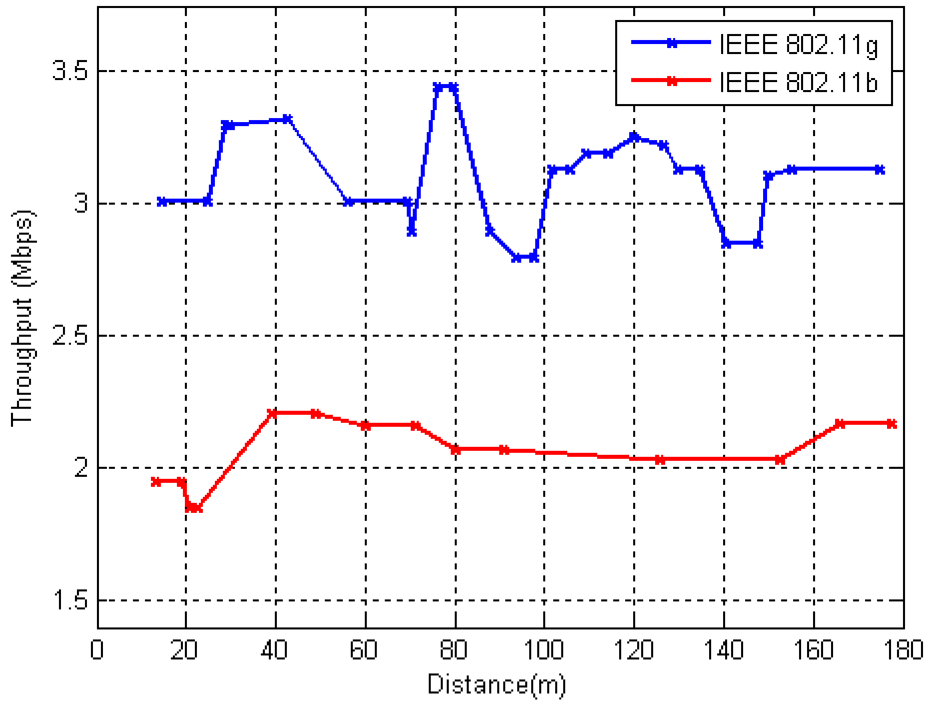

Figure 4 44 Average throughput using IEEE802.11b/g in terms of distance for suburban area.

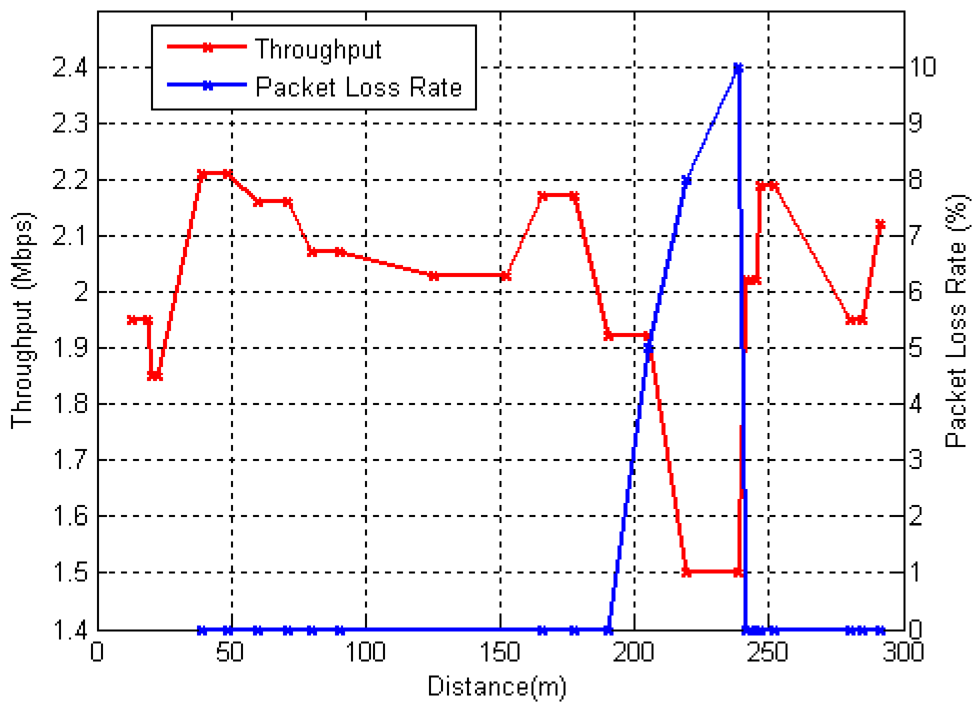

Figure 4.45 Average throughput using IEEE802.11b in terms of distance for suburban area.

Suburban area also has a negative impact on round trip time. Figure 4.46 shows round trip times measured while driving in sub urban area. Major spikes are again caused due to fading from congested environment.

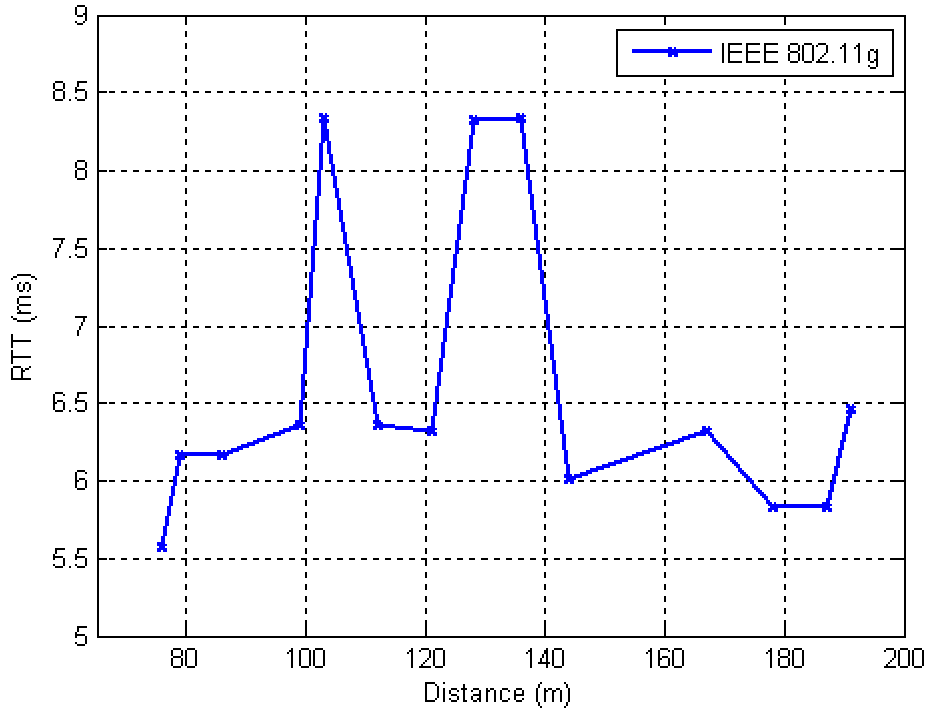

Figure 4.46 Average Round Trip Time using IEEE802.11g in terms of distance.

4.6.3 Accident detection test results

During accident detection tests, serial accelerometer was turned upside down to simulate an accident. When accident was detected by analyzing accelerometer data, the system in vehicle transmitted accident photo and GPS position to infrastructure as mentioned in Section 4.3.3. Size of the accident photo and the transfer duration were 900 KB and 0.9 seconds, respectively. Any package losses did not occur while image and GPS position transmission. When compared with the results mentioned in Section 3.6.4, higher resolution photos can be transmitted in shorter time by means of IEEE 802.11b/g based system.

5. CONCLUSION

In this study, an intelligent data transmission system based on different wireless technologies is introduced to provide traffic safety control and warning assistance systems for ITS applications. The developed system has been designed to transmit image (jpeg, bmp), audio (mp3), office, pdf files and text messages in vehicular networks. Additionally, the developed system is featuring automatic detection and positioning traffic accidents by the help of GPS and accelerometer.

In Chapter 2, ITS, WAVE, DSRC, IEEE 802.11p concepts in vehicular communication are overviewed. Also, differences between IEEE 802.11p and most common wireless standards are introduced. In addition, signal to noise ratio requirements of modulation techniques and data rate versus signal to noise ratio trade off in wireless communication are described. Moreover, link margin, fade margin concepts and Rayleigh fading model are described. Finally, the link budget formula is defined and the parameters affecting the formula such as the free space path loss, the transmission power, the antenna gain are discussed.

In Chapter 3, DNT900DK transceiver with FHSS technique is investigated. To analyze the performance of image and audio communication in vehicular networks, serial interface communication application has been developed and tested in different environments. Indoor and outdoor tests were performed for V2I communications. Results show that the achieved throughput and amount of data transferred during in a single pass with DNT900DK transceivers are not appropriate to transmit multimedia files in vehicular networks. To solve this issue, another vehicular communication system based on IEEE802.11b/g standards has been developed as mentioned in Chapter 4. Moreover, file transfer procedure and accelerometer behavior during an accident and routine driving conditions are described. In order to prevent false accident detections, a sudden stop test was performed while driving 90 km/h. According to the results, it is confirmed that realistic driving does not prevent false detections. Finally, an accident detection procedure that can shorten the duration to reach medical help is proposed. In this procedure, the system located in vehicle is transmitting accident photo and GPS position to infrastructure to determine if driver or passengers need emergency services. Accident detection test results show that low resolution accident photos can be transmitted in a short time with DNT900DK transceivers.

In Chapter 4, V2I and V2V communication system based on IEEE 802.11b and IEEE 802.11g standards is introduced. File transfer and accident detection procedures have remained same with the procedures in Chapter 3. But some changes in package structures and transceiver communication protocol are done to achieve vehicular communication requirements. Package size lengths are increased up to 16024 bytes and communication protocol with transceiver is changed to UDP ethernet communication protocol. Different from Chapter 3, V2I and V2V communications are both examined. In order to investigate effects of different environments, antennas and vehicle speed on V2V and V2I communications, a set of experiments were performed with omni directional and directional antennas in different environments.

V2I tests show that transmitting files with larger packages allows higher throughput and the throughput is slightly decreasing according to the increasing vehicle speed. This decrease is caused due to Doppler shift as mentioned in Section 4.6.1.4. Additionally, vehicle speed does not affect package loss rate and delay performance in vehicular networks. The tests with high gain 12 dBi directional antennas show that communication between vehicle and the infrastructure can be established in more than 1 kilometers when directional antennas are carefully positioned. Results also show that IEEE 802.11b/g standards can be used for transmitting multimedia files in vehicular networks. Finally, the distance between transceivers, LOS communication and environmental conditions are the main factors affecting the V2I communication.

V2V tests clearly demonstrate effects of environments and vehicle speed on V2V performance parameters. Rural area and suburban area tests were performed. In rural area test, vehicles followed each other with different speeds. Results show that increase in relative speed between cars decreases throughput slightly and this observation is similar to V2I throughput measurements. Also vehicle speed impact on package loss rate is investigated. It is observed that vehicle speed does not affect package loss rate performance in V2V communication. Additionally, round trip time does not change while driving in rural areas. It only slightly increases when compared to the laboratory delay measurements. In suburban area tests traffic is followed without controlling the speed of vehicles and the distance between them. In contrast to rural area tests, major changes in throughput occurred due to reflections from metal hulls of the vehicles got in between experimental cars and buildings. Similarly, major changes in round trip time occurred due to interferences from other cars and fading from suburban environment. Finally, accident detection test was performed with IEEE 802.11b/g based system. Results show that higher resolution accident photos can be transmitted in shorter time by means of IEEE 802.11b/g communication system compared to FHSS communication system.

REFERENCES

[1] Intelligent Transport Systems, http://www.etsi.org/website/Technologies/IntelligentTransportSystems.aspx

[2] Chen, Wai and Cai, Shengwei, “Ad Hoc Peer-To-Peer Network Architecture for Vehicle Safety Communications,” IEEE Communications. Magazine, vol. 43, issue. 4, pp. 100 - 107, Apr. 2005.

[3] Nandan, A., Das, S., Pau, G., Gerla, M. and Sanadidi, M.Y, “Co-Operative Downloading in Vehicular Ad-Hoc Wireless Networks,” IEEE Wireless On-demand Network Systems and Services Conference, pp. 32 – 41, Jan. 2005.

[4] Wischhof, L., Ebner, A.; Rohling, H.; Lott, M.; Halfmann, R., “SOTIS: A Self-Organizing Traffic Information System,” IEEE Vehicular Technology Conference, vol.4, pp. 2442 – 2446,.Apr.2003.

[5] Jerbi, M., Marlier, P.and Senouci, S.M., Experimental Assessment of V2V and I2V Communications, IEEE Mobile Adhoc and Sensor Systems Conference, pp. 1-6, Oct. 2007.

[6] Kandar, D., Revathy, J., Padma, P.S., Kalpana, R.A., Anujıt, A., Guchhaıt A. and Majı B, Multimedia Transmission Using Spread Spectrum Based Dedicated Short Range Communication Channel For Intelligent Transportation System, Journal Of Information Systems And Communication, vol. 3, issue:1, pp.339 - 342., Feb. 2012.

[7] Alasmary, W. and Basir, O., Achieving Efficiency and Fairness in 802.11-based vehicle-to-infrastructure Communications, IEEE 73rd Vehicular Technology Conference, pp.1-6, May 2011.

[8] Rubinstein, M.G., Ben Abdesslem, F.,De Amorim, M.D., Cavalcanti, S.R., Dos Santos Alves, R., Costa, L.H.M.K., Duarte, O.C.M.B., Campista, M.E.M., Measuring the capacity of in–car to in–car vehicular networks, IEEE Communications Magazine, vol. 47, issue:11, pp. 128–136, Nov. 2009.

[9] Ott, J. and Kutscher, D., Drive-thru Internet: IEEE 802.11b for “Automobile users,” IEEE INFOCOM, vol.1, Mar. 2004.

[10] Gass, R., Scott, J., and Diot, C., Measurements of In-Motion 802.11 Networking, IEEE WMCSA, pp. 69 – 74, Apr. 2006.

[11] Bucciol, P., Masala, E., Kawaguchi, N. Takeda, K. and De Martin, J.C Performance Evaluation of H.264 Video Streaming over Inter-Vehicular 802.11 Ad Hoc Networks, IEEE International Symposium on Personal Indoor and Mobile Radio Communications (PIMRC), vol.3, pp. 1936 - 1940 , Sep. 2005.

[12] Bae, Jeong Kyu., Song, Jung Hoon., Ahn, Tae Sik., Park, Jeon Hong. and Han, Dong Seog, A Vehicular Communication System based on IEEE 802.11a/g for Ubiquitous Transportation Sensor Network, Consumer Electronics (ICCE), Digest of Technical Papers International Conference, pp. 425 – 426, Jan. 2010.

[13] Thompson, C., White, J., Dougherty, B., Albright, A., and Douglas C. Schmidt, Using Smartphones to Detect Car Accidents and Provide Situational Awareness to Emergency Responders, Third International Conference, Mobilware, pp. 29-42, 2010.

[14] Geotab Inc., Accelerometer Crash Test Investigation, http://www.geotab.com/geodownloads/support/Geotab%20Accelerometer%20Crash%20Testing.pdf

[15] Mak, T., Xu, Q., Zennaro, M., Wireless Communication Enabling Technologies for Intersection Decision Support System http://zennaro.net/papers/ids.pdf

[16] Sikora, A., Watch-Over Cooperative Vulnerable Road Users, Vehicle to Vulnerable Road User Cooperative Communication and Sensing to Technologies to Improve Transport Safety, D4.1 Communication Technologies Specifications, http://www.watchover-eu.org/download/WATCH-OVER_D4.1_Communication_technologies_specifications.pdf

[17] Jiang, D., Delgrossi, L., Mercedes Benz Research and Development North America, Inc., "IEEE 802.11p: Towards an International Standard for Wireless Access in Vehicular Environments, IEEE Vehicular Technology Conference, pp. 2036-2040., May 2008.

[18] Lin, Wei-Yen, Li, Mei-Wen, Lan, Kun-Chan and Hsu, Chung-Hsien, A comparison of 802.11a and 802.11p for V-to-I communication: a measurement study in ICST QShine, November 2010.

[19] Li, Yunxin Jeff, An Overview of the DSRC/WAVE Technology, International Conference on Heterogeneous Networking for Quality, Reliability, Security and Robustness (QShine) and Dedicated Short Range Communications Workshop, pp. 544-558 , November 2010.

[20] Eriksson, M., A Performance Evaluation on the use of IEEE 802.11 for Long Range Communication, M.Sc. thesis ,Lulea University of Technology, Msc Programmes in Engineering, Department of Computer Science and Electrical Engineering Division of Computer Communication, Feb 2005.

[21] Albarazi, K., Mohammad, U., and Al-holou, N., Doppler Shift Impact On Vehicular Ad-hoc Networks, Canadian Journal on Multimedia and Wireless Networks, vol. 2, no. 3, Aug. 2011.

[22] Min, Juhong, Ha, Jihun, Yun, Sangki, Kang, Inhye, and Kim, Hyogon, Secure Vehicular Communication for Safety Applications – A Measurement Study, IEEE Vehicular Technology Conference, pp. 3016 - 3020, May 2008.

[23] Bucciol, P., Ridolfo, F. and De Martin, J.C, Audio Communication in Multicast 802.11 Vehicular Ad Hoc Networks for Safety Applications, Seventh International Networking Conference (ICN), pp 746 – 751, Apr. 2008.

[24] Norihiko, M., Kohno, R., Sampei, S., Wireless Communication Techologies New Multimedia Systems, Kluwer Academic Publishers, 2002.

[25] IEEE 802.11g-2003: Further Higher-Speed Physical Layer Extension in the 2.4 GHz Band, 2003.

[26] IEEE 802.11a-1999: High-speed physical layer in the 5 GHz band, 1999.

[27] Blake, R., Chartrand, L., Wireless Communication Techonology, Delmar Publishers Inc; 1 edition, 2000.

[28] Wischhof, L., Self-Organizing Communication in Vehicular Ad Hoc Networks, PhD thesis, Technical University of Hamburg, 2007.

[29] Olexa, R., Implementing 802.11, 802.16 and 802.20 Wireless Networks, Newnes Publications, 2005.

[30] National Instruments, Peak Signal-to-Noise Ratio as an Image Quality Metric http://www.ni.com/white-paper/13306/en

[31] RFM DNT900DK 900 MHZ Development Kit, http://www.rfm.com/products/spec_sheet.php?record=DNT900DK

[32] JAVAD GPS GNSS receiver and antenna, http://www.javad.com/jgnss/index.html

[33] SparkFun Serial Accelerometer Dongle, https://www.sparkfun.com/products/10537

[34] Logitech HD Webcam C615, http://www.logitech.com/en-us/webcam-communications/webcams/hd-webcam-c615

[35] TP-Link TL-WA5210G Wireless Access Point, http://www.tp-link.com/en/products/details/?categoryid=216&model=TL-WA5210G

[36] Wewetzer. C., Caliskan, M., Meier and K., Luebke, A., Experimental evaluation of UMTS and Wireless LAN for inter-vehicle communication, 7th International Conference on ITS (ITST), pp. 1 – 6, Jun. 2007.

[37] Cisco Wireless LAN Controller Configuration Guide, Release 7.0, http://www.cisco.com/en/US/docs/wireless/controller/7.0/configuration/guide/c70mesh.html

Appendix-1 NEC LinkBird MX4 DSRC Transceiver

LinkBird MX4 is equipped with a dual European 802.11p transceiver for vehicular communications at 5.9 GHz on 2 channels simultaneously. It can be used both as an on-board unit (OBU) as well as a road-side unit (RSU).It provides 10 MHz and 20 MHz bandwidth options with maximum 21 dBm transmit power. Above tables and figure show system interfaces and features of LinkBird-MX4 unit.

Table 1 LinkBirdMX4 system interfaces

Connector	Details
Ethernet Port	RJ45 10/100Base-T (x1)
Integrated UART	DE-9 2-wire CAN port (x1) for embedded NEC 78K0/FC2 transceiver; DE-9 5-wire RS232C port (x1) for console terminal/debug DE-9 5-wire RS232C port (x1) for external GPS receiver (not included) or other serial devices;
USB	USB 2.0 (x2) for e.g. external UMTS modem
SMA (Female)	4 connectors for 2 WLAN modules with configurable antenna diversity
mini-PCI	x2 internal slots: embedded WLAN card (IEEE802.11 a/b/g/p)
Power	DC12 (x1 port)

Table 2 Features of LinkBirdMX4

Parameters	Details
Frequency/Bandwidth	5725MHz (145CH) – 5925MHz (185CH) 10MHz / 20MHz
Transmit Power	21 dBm
Data rate	6, 9, 12, 18, 24, 36, 48, 54 Mb/s with 20MHz channel bandwidth 3, 4.5, 6, 9, 12, 18, 24, 27 Mb/s with 10MHz channel bandwidth
Multi-channel Operation	2 transceivers operating simultaneously on the desired channels

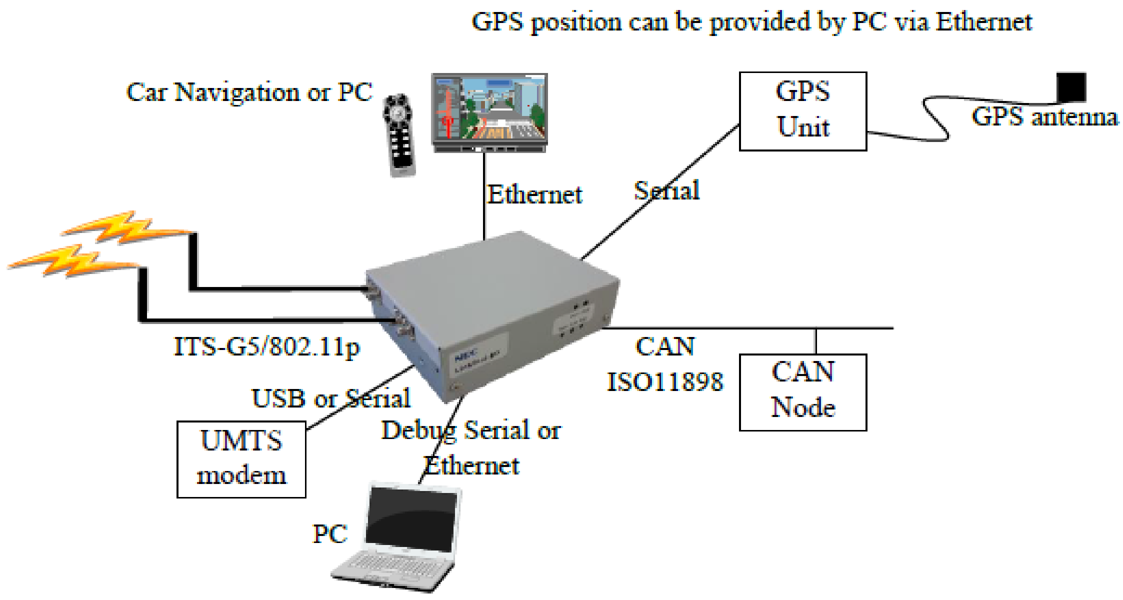

Figure 1 LinkBird MX4 system configuration example

Additionally, unit price of NEC LinkBird MX4 is around 4000€.