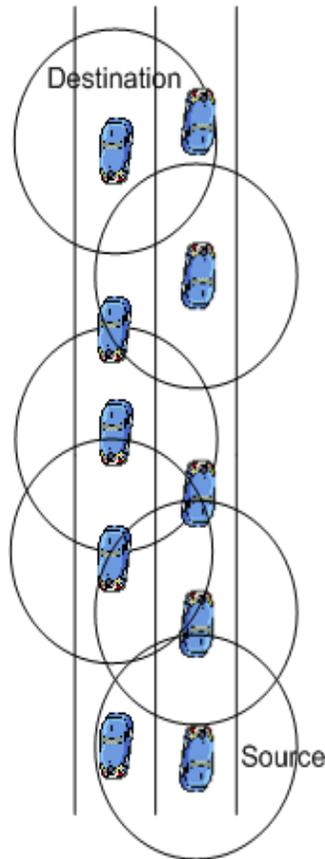


Experimental Analysis towards Vehicular Ad-Hoc Networks

RESUMEN



Presentamos en este trabajo resultados de medición y análisis realizado sobre importantes características de modelos de propagación inalámbrica en Redes Ad-hoc Vehiculares (RAV) en autopistas: Efecto Doppler, propagación de las señales en espacio libre, pérdidas por trayectoria y el margen de operación del sistema. En este trabajo hemos considerado tarjetas inalámbricas 802.11b para la comunicación inter-vehicular. En el análisis analítico, se han usado dos modelos de propagación: modelos a pequeña y gran escala. Por un lado, de acuerdo a los modelos de gran escala, la máxima distancia entre el transmisor y el receptor es de 446 m., con un margen de operación del sistema (MOS) de 13 dB, el cual está sobre el mínimo margen recomendado. Por el otro lado, se ha encontrado con el resultado de modelos a pequeña escala, que el efecto Doppler no afecta la comunicación entre transmisor y receptor en altas velocidades. Finalmente, se ha realizado un experimento que permite validar los resultados obtenidos analíticamente en el escenario más adverso posible, que es cuando el transmisor y receptor viajan en direcciones opuestas. Con los resultados experimentales se ha concluido que es posible enviar un mínimo de 8 mensajes cuando las antenas del transmisor y receptor se montan al interior de los automóviles.

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PALABRAS CLAVES

Características de propagación inalámbrica, Redes Ad-Hoc Vehiculares, Efecto Doppler, Propagación de señales en espacio libre, Pérdidas por trayectoria, Margen de operación del sistema.

ABSTRACT

This paper presents the measurements and analytical results made over important characteristics of wireless propagation models for Vehicular Ad-hoc Networks (VANET) in motorway

environments, including Doppler Effect, Free Space Signal propagation, path loss and system operating margin. In this work, we employ IEEE 802.11b wireless cards for inter-vehicular communication to analyze large and small-scale propagation models. On one hand, according to large-scale models, the maximum distance between the transmitter and the receiver is 446 m. additionally; the feasible System Operating Margin (SOM) of 446 m is over 13 dB, which is over the minimum margin recommended. Our results show that the Doppler Effect does not affect transmission between communication partners at high speeds in small-scale models. Finally, we realize an experiment to validate the former results in the worst case scenario, when the transmitter and receiver are traveling in opposing directions on a straightaway. Results show that at least 8 packets can be relayed when the transmitter and receiver antennas are mounted on automobile dashboards.

KEYWORDS

Wireless propagation characteristics, vehicular ad-hoc networks, Doppler Effect, free space signals' propagation, path loss, system operating margin

1. INTRODUCTION

Current tendencies show that future wireless communication services will increasingly depend on the vehicular ad-hoc network (VANET) concept to more efficiently communicate mobile networks and provide inexpensive infrastructure-less networks. This concept involves relatively short radio multi-hops (between 200 - 1000 m), low cost antennas deployed in each car, and low transmitter power (around 32 mW). Communication in future VANET networks will not be restricted to neighboring vehicles traveling within a specific radio transmission range, which is presently the case in typical wireless networks. The VANET system will provide multi-hop communication capabilities by using intermediate "relay" vehicles that are located between the sender and receiver.

Some measurements have been conducted in wireless environments [1-3]. None of these, however, have focused on potential Doppler Effect impact, which can significantly shift carrier frequencies.

Two simple large-scale and small-scale propagation models can be used to estimate the radio coverage

area of a transmitter and receiver. Large-scale models are characterized by their substantial signal power over large Transmission – Reception (T-R) separation distances, which can range from several hundred to several thousand meters. Propagation models that suffer from rapid received signal strength fluctuations over very short travel distances (a few wavelengths) or short time duration (on the order of seconds) are called small-scale or fading models.

2. LARGE-SCALE FADING

As the distance increases between a mobile node and a transmitter, the local average received signal will gradually decrease, and it is the local average signal level that is predicted by large-scale propagation models.

2.1 Free-space propagation model

The Free Space Propagation model (FSP) is used to predict received signal strength when the transmitter and receiver have a clear, unobstructed line-of-sight path between them [6]. The FSP model can be calculated with the formula listed below, which represents the transmission range between a T-R pair.

$$P_r(d) = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2} \quad (1)$$

Where:

P_t is the transmitted power, $P_r(d)$ is the receiver power, which is a function of the transmission – reception separation.

G_t is the transmitter antenna gain, G_r is the receiver antenna gain, d is the transmission – reception separation distance in meters and λ is the wavelength in meters.

Received power $P_r(d)$ is generally the most important parameter predicted by large-scale propagation models.

2.2 System Operating Margin

System Operating Margin (SOM) (also referred to as Fade Margin) is defined as the difference between the received signal level and the receiver sensitivity (in dBm) needed for error free reception. Also, the System Operating Margin can be calculated using the formula listed below. SOM,

basically, is the difference between the signals a radio is actually receiving vs. what it needs for good data recovery (receiver sensitivity).

$$SOM = \text{Received_Signal}(dBm) - \text{Receiver_Sensitivity}(dBm)$$

The System Operating Margin predicts the area of optimal reception between the transmitter and receiver. The minimum SOM recommended is 10 dB, and 20 dB is considered excellent.

3. SMALL-SCALE FADING

As a mobile node moves over very small distances, the instantaneous received signal strength may oscillate rapidly giving rise to small scale-fading. Small-scale fading, or simple fading, is used to describe the rapid fluctuations of amplitude, phase or multi-path delay of a radio signal over a short period of time or travel distance, so that large-scale path loss effects may be ignored. In vehicular ad-hoc wireless networks (VANET), each multi-path wave experiences an apparent shift in frequency due to the relative motion between the transmitter and receiver.

3.1 Impact of Doppler shift

We have considered the worst case scenario to evaluate the impact of Doppler shift. We have assumed an average vehicular speed of 42 m/s (150 km/h), with each vehicle equipped with an IEEE 802.11b wireless card. One of the goals of our research is to determine the maximum speed at which two vehicles can travel in opposing directions without being affected by Doppler shift.

There are two types of small-scale fading based on Doppler Spread: fast fading and slow fading.

3.1.1 Fast Fading

Depending on how rapidly the transmitted base band signal changes compared to the rate of channel change, a channel may be classified either as a fast fading or slow fading. Therefore, a signal undergoes fast fading if $T_S > T_C$ and $B_S < B_D$.

Where: T_S is the reciprocal bandwidth, T_C is the coherence time, B_S is the Bandwidth, and B_D is the Doppler Spread.

The coherence time describes the time varying nature of the channel in a small-scale region and is caused by the relative motion between the vehicles.

Here, we test if our scenario is fast fading or slow fading. The signal base band in IEEE 802.11b is 11 MHz, so $T_S = 90$ ns.

$$f_m = \frac{v}{\lambda} = \frac{84 \text{ m/s}}{0.125 \frac{\text{m/s}}{\text{Hz}}} = 672 \text{ Hz}$$

The coherence time is defined in [4], as the period of time over which the time correlation function is greater than 0.5,

$$T_C = \frac{0.423}{f_m} \quad (4)$$

Where f_m is the maximum Doppler shift. Using equation (4), we obtain:

$$T_C = \frac{0.423}{672 \text{ Hz}} = 629 \mu\text{s}$$

$$T_S = 90 \text{ ns} < 629 \mu\text{s} = T_C, \text{ and}$$

$B_S = 11 \text{ MHz} > 672 \text{ Hz} = B_D$. This is not a fast fading channel.

3.1.2 Slow Fading

A slow fading channel may be assumed to be static over one or several reciprocal bandwidth intervals. In the frequency domain, this implies that the Doppler spread of the channel is much less than the bandwidth of the base band signals. Therefore, a signal undergoes slow fading if:

$$T_S \ll T_C \text{ and } B_S \gg B_D.$$

It should be clear that the velocity of the mobile node (or velocity of objects in the channel) and the base band signal determines whether a signal undergoes fast or slow fading.

The channel in our scenario is slow fading because:

$$T_S = 90 \text{ ns} \ll 629 \mu\text{s} = T_C \text{ and}$$

$$B_S = 11 \text{ MHz} \gg 672 \text{ Hz} = B_D.$$

If the base band signal bandwidth is much greater than B_D , the effect of Doppler Spread is negligible at the receiver [4].

Now, we are able to analytically determine the maximum speed that the vehicle can travel before it is affected by Doppler Effect. Considering the maximum Doppler Spread of 22 MHz, we obtain:

$$v = f_m * \lambda, v = 22\text{MHz} * 0.125 \frac{\text{m/s}}{\text{Hz}} \quad v=9,900,000 \text{ km/h.}$$

The results obtained indicate that the Doppler Effect will not affect the communication between vehicles, using the IEEE 80.11b Wireless cards.

4. TEST SET UP AND EXPERIMENTAL DETAILS

Very few test-beds have been deployed to evaluate the performance of wireless networks for inter-vehicular communication [1-3]. The authors in [1] used ORINOCO IEEE 802.11b WLAN cards and enhanced the range of connectivity by deploying ORINOCO omni-directional antennas on top of cars. One laptop was set up as a receiver and the other as a transmitter that streamed UDP packets. They evaluated performance in sub-urban, urban and freeway settings. An arbitrary speed of 65 miles per hour (104 km/h) was used in a freeway environment and measurements were recorded of vehicles first following and later passing each other in opposing directions. Authors in [2] have reported that they deployed eight nodes within a 700m by 300m site using the Dynamic Source Routing (DSR) protocol with each vehicle equipped with a Lucent Wave LAN Wireless LAN radio on the roof. The ad-hoc network included five mobile car-mounted nodes. In this experiment, one car followed the one immediately in front of it with a separation of 90m. In another experiment, [3], employ a single inter-vehicular communication system using commercially available DS/SS wireless LAN modems with omni-directional antennas at a communication frequency of 2.4 GHz ISM (Industrial, Scientific and Medical) band. They showed that inter-vehicular communication can be realized at low cost with existing equipment.

The experiment was realized with two vehicles. In one vehicle, a notebook computer (PC-1) was connected to a JRL 200 wireless LAN adapter via an Ethernet hub, to which an Internet camera was also connected. In the other vehicle, another notebook computer (PC-2) was connected directly to another JRL 200 wireless LAN adapter, both via a PCMCIA LAN card. Both computers and the camera were assigned an IP address. In this way, a small LAN was formed with one of the links being wireless between the two vehicles.

By using the UNIX ping command, the packet loss and round trip delay of packets transferred between the computers was measured every two seconds.

Additionally, the data transfer rate was measured using the file transfer protocol command, and images were viewed in real time at a rate of 1 picture per second from the Internet camera on the PC-2 computer.

In our experiment, we were interested in the worst case scenario, where vehicles travel in opposing directions in opposing lanes of a motorway.

The first part of our experiment focuses on determining the maximum distance of the received power between the transmitter and the receiver. To do this, we employed two Enterasys' wireless cards and two omni-directional antennas. According to specifications, the antenna had a transmission power of 15 dBm or 32 mW, and the omni-directional antennas had a gain of 5 dBi. We realized the experiment at the local private airport of Colima, Mexico, and repeated the test three times.

Table 1 indicates the receiver sensitivity values for the Enterasys' wireless cards, according to the data rates and distance between transmitter and receiver.

Table 1. Theoretical values specified for receiver sensitivity in Enterasys' wireless cards.

	11 Mbps	5.5 Mbps	2 Mbps	1 Mbps
Distance	160	270	400	550
Receiver Sensitivity (dBm)	-82	-87	-91	-95

Figure 1 provides the theoretical, experimental and analytical results of the received signal power over different distances between the transmitter and receiver. The values expressed are the values shown in the Enterasys' Wireless cards. On the other hand, the values obtained experimentally correlated well with those used to obtain the analytical results.

The maximum experimental distance between the transmitter and the receiver with 802.11b Enterasys' Wireless Cards and 5dBi car-mounted omni-directional antennas is 446 m.

The following experiment focused on determining the System Operating Margin between transmitter and receiver (Figure 2). Experimental results show good System Operating Margin values between the transmitter and the receiver at a distance of 300 m. and a SOM of 17dBm.

The next experiment consisted in sending Hello messages in the worst case scenario. The speed of the vehicles was maintained constant at 5 specific

speeds in each test, and we repeated the test three times at specified speeds between 60 km/h and 140 km/h. Hello messages were periodically transmitted to announce the presence of mobile node because they disseminate location information between neighboring nodes in common position-based routing algorithms.

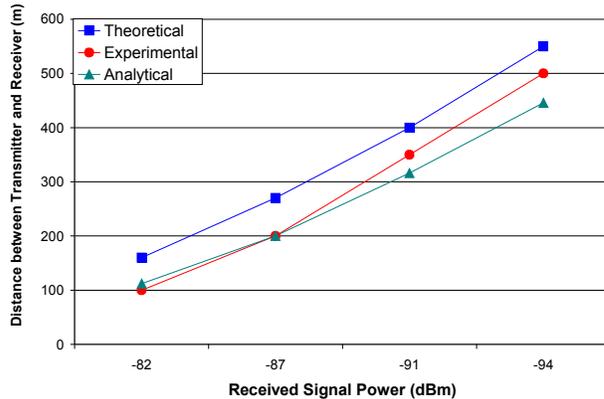


Figure 1. Received signal power between transmitter and receiver.

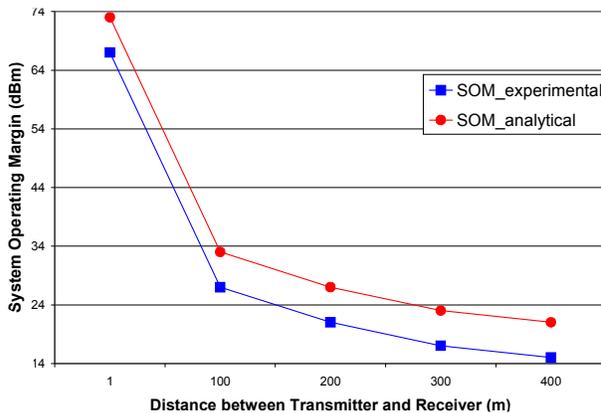


Figure 2. System Operating Margin (SOM)

The tests were conducted by driving in opposing directions on a straightaway at varying speeds. The two vehicles had laptops running Linux and were equipped with Enterasys' IEEE 802.11b WLAN cards. The range of connectivity was enhanced by deploying an omni-directional antenna inside of each car.

One laptop was set up as a receiver and the other as a sender that streamed UDP packets. Additionally, the wireless cards were configured to operate in broadcast ad-hoc mode and the UDP packets were of 64 bytes in length.

Figure 3 shows the results for delivery ratio using OPNET for simulation of the worst case scenario

and compares the results with those obtained experimentally. Our results are slightly different from the OPNET network simulator, because our omni-directional antennas were mounted inside of the cars instead of on the roof of each. The pigtail cable used in the experiment was too small to extend it more than 1m. Similar results are reported in [3], who investigated the effect antenna position had on the packet delivery ratio an important degradation. They found that antennas mounted on rooftops provide better reception than those mounted on the dashboard. Mounting the antennas on dashboards proved to make communication more difficult.

Similar results are reported in [5], where vehicles traveling in opposing directions at 140 km/h are within communication range for 12.5 seconds.

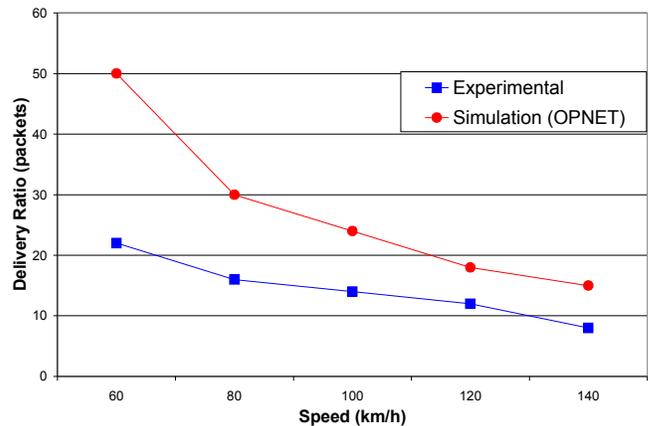


Figure 3. Delivery Ratio compared between experimental and OPNET results

5. CONCLUSIONS AND FUTURE WORK

In this work, we have shown that IEEE 802.11b wireless networks are suitable for inter-vehicular communication and have supported our hypothesis with the results of two propagation models. On one hand, according to large scale models, the maximum distance between the transmitter and the receiver is 446 m. In addition, the System Operating Margin (SOM) feasible at 446 m is over 13 dB, which is over the minimum margin recommended. On the other hand, we have found that the Doppler Effect does not alter the communication between communication partners at high speeds in small-scale models. Finally, we have realized an experiment that allows us to validate the former analytical results in the worst case scenario, when

the transmitter and receiver are traveling in opposing directions. Results show that a minimum of 8 packets can be delivered when the transmitter and receiver antennas are mounted on the dashboard.

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