PERFORMANCE OF DSRC FOR V2V COMMUNICATIONS IN URBAN AND HIGHWAY ENVIRONMENTS

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ABSTRACT

This paper presents a study of the Dedicated Short Range Communication (DSRC) Physical Layer in order to determine its reliability for Vehicle-2-Vehicle (V2V) communication under varying Signal-to-Noise Ratio (SNR), vehicle speed, delay spread, and packet lengths. In particular, we focus on computing the expected delay when packets with errors are retransmitted until received correctly. IEEE 802.11a MatLab model was used to simulate the DSRC Physical Layer.

***Index Terms*—** ITS, IEEE 802.11p, V2V, DSRC, WAVE

1. INTRODUCTION

1.1. Introduction to DSRC

The Dedicated Short Range Communications (DSRC) is a wireless standard developed specifically to support Intelligent Transportation Systems (ITS) applications. The US Federal Communications Commission (FCC) dedicated 70 MHz in the 5.9 GHz range to implement wireless systems for Vehicle to Vehicle (V2V) and Vehicle to Infrastructure (V2I) communications in accordance with the DSRC standard. In the technical report that was issued in 2005 by the National Highway Traffic Safety Administration (NHTSA) and U.S. Department of Transportation (USDOT), some requirements for intelligent vehicle safety applications using DSRC were stated. Some important definitions are:

- Transmission Mode: describes whether the transmission event-driven or it is periodic (event-driven transmission mode was considered in this paper).
- Minimum Frequency: which is the information update rate in (Hz).
- Allowable Latency: the maximum allowed time between information generated, transmitted and received by the other side in sec (maximum delay time 0.1 sec).
- Type of Data to be Transmitted and/or Received
- Maximum Required Range of Communication: different applications require different distances between the two units in (m) (from 150m to 1000m).

In this paper we will examine the conditions under which these requirements will be satisfied. We present an analysis of the wireless link between moving cars and determine under what conditions the stated requirements will be satisfied.

2. SYSTEM MODEL

2.1. Channel model

V2V communications is a multipath fading channel which is normally modelled as a Rayleigh fading process with additive Gaussian noise. In order to simulate the multi-path channel effect on a signal a Multi-path Rayleigh Fading Channel was used. Two effects was simulated using the Multi-path Rayleigh Fading Channel: time selectivity of the channel due to motion (Doppler shift), and frequency selectivity due to resolvable multi-path components (delay spreading). In order to simulate the Doppler shift an interpolated filtered Gaussian noise source was used[1].

2.2. Explanation of the developed SNR/Doppler shift generator model

This section explains the model that has been developed and used in this research to generate SNR and Doppler shift values to be applied by the IEEE 802.11a model that was explained earlier. The main reason for the SNR/Doppler Shift Generator model is to study the effect of distance, speed and environment on the reliability of the DSRC wireless communication channel. Calculating SNR values at different distances between transmitter and receiver tests the change in distance factor. In order to generate the SNR values we need to calculate the transmitted power using equation 1, which is in dB, then calculating the received power using equation 3, which is done by subtracting the Free Space Path Loss (FSPL), which was calculated using equation 2, from the transmitted power.

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Table 1. Path-loss exponents for different test environments [2] [3]

Test Area	Path-loss Exponent
Highway	γ_1 = 1.9 [4] γ_2 = 1.85 [5]
Urban	γ_1 = 1.61 (LOS) [5] γ_2 = 2.8 (NLOS) [6]

The transmitted power and received power are constant for a certain transmitted power.

$$P_t \;=\; 10\log T_x \tag{1}$$

$$FSPL\,(dB) \;=\; 20\log(d) \;+\; 32.45 \tag{2}$$

$$Pr \;=\; Pt \;-\; FSPL \tag{3}$$

Using the received power value calculated before we can calculate the path loss value, which depends on the distance. There are two different ways of calculating the path-loss, which are single-slope and dual slope models. The single-slope model usually is used for calculating the path-loss exponent for highway environment. This model is represented in equation 4. This model has a path-loss exponent γ , standard deviation σ and a reference distance between the transmitter and the receiver d_0. The standard deviation was used for applying Gaussian noise for generating SNR values X_σ.

Communications among cars is a new environment for channel modelling. Traditional propagation models typically assume that one if not both of the communicating antennas are well elevated above ground. In V2V both the transmit and receive antennas are low (between one and two meters above ground. At 5.9 GHz, there is not enough Fresnel clearance and the free space model cannot be applied even if the two cars are in open space outside the city. Since typically, there are no electromagnetic barriers among cars, many researchers suggested the use of two-ray model. In the two-ray model, the channel consists of two rays: a direct line of sight ray and a second ray reflected off the ground. Of course there could be other reflections from adjacent buildings and other objects but those are usually neglected in the two-ray model. The geometry of the model is well known, and it uses the antenna heights and the horizontal distance between the two cars to determine the differential delay between the two assumed rays. For certain antenna heights: h_T and h_R (transmitter and receiver antenna heights respectively), there is a critical distance known as the Fresnel Distance, $d_F = (4h_T h_R)/\lambda$ where λ is the carrier frequency wavelength in free space. At d_F the differential delay between the two rays translate into 180° phase shift, which allows the two rays to interfere with each other. When the distance between the transmitter and receiver $d \leq d_F$ the two rays do not interfere with each other and this is known as the Fresnel clearance region. In this region, the path-loss of the signal is small and the signal strength decays at a low rate. Beyond d_F, however, the two rays interfere with each other and the signal strength decays at a faster rate. The two distance path-loss indices, γ_1 and γ_2, in the two regions are different and typically are determined empirically. Table 1 shows some typical empirical values for γ_1 and γ_2 in different environments.

$$P\,(d) \;=\; Pr \;-\; 10\lambda\log(d/d_0) \;+\; X_\sigma \tag{4}$$

On the other hand dual-slope path-loss model is used for calculating the path-loss value for urban environments. We characterize this model by a path-loss exponent λ and standard deviation σ. If the distance between the transmitter and the receiver is between the reference distance d_0 and critical distance d_F then the model will use the first part of equation 5 and if the distance is greater than d_F then the model will use the second part of the equation.

$$P(d) = \begin{cases} Pr - 10\lambda_1\log(d/d_0) + X_{\sigma_1} & \text{if } d_0 \leq d \leq d_F \\ \\ Pr - 10\lambda_1\log(d_F/d_0) & \\ -10\lambda_2\log(d/d_F) + X_{\sigma_2} & \text{if } d > d_F \end{cases} \tag{5}$$

At the same time the change in the path-loss decreases the signal to noise ratio (SNR). According to the following equation (when $N_0 = -99dBm$ [7]):

$$SNR\,(dBm) \;=\; P(d) \;-\; N_0 \tag{6}$$

The current research model uses equations (4 and 5) to calculate the path-loss, 100 different path-loss values are generated by generating 100 X_σ values, and then the resulting value is used to generate SNR values that is applied in the IEEE 802.11a model.

Because the speed of source (v_r positive if the receiver is moving towards the source) and the receiver (v_s positive if the source is moving away from the receiver) to the medium is lower than the velocity of the waves in medium ($c = 3 \times 10^8 m/sec$), the relationship between the emitted frequency ($f_0 = 5.9GHz$) and the observed frequency (f) is given by equation 7. For estimating the effect of the speed factor on the performance of the multi-path channel, equation 7 was used to calculate the Doppler shift, which is calculated by subtracting the original frequency (f_0) from the new calculated frequency (f), equation 8.

$$f = \left(\frac{c \;+\; v_r}{c \;+\; v_s}\right)\; f_0 \tag{7}$$

$$\Delta f = f - f_0 \tag{8}$$

Testing the reliability of DSRC for different environments such as highways, and urban environments, can be done by changing the path-loss exponents. Each test area has different

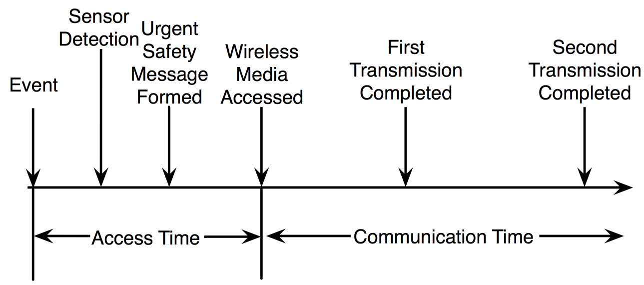

Fig. 1. Delay Components

path-loss exponents, such as, highways, and urban environments. These path-loss exponents values are represented in Table 1.

2.3. Delay calculation

In DSRC there are 8 channels, one channel is used for control, one for safety messages, one for urgent messages and the remaining 5 channels are used for non-safety applications. The process is triggered when an urgent event (accident) is detected, the vehicle that is in the accident sends a high priority urgent message which will be repeated for a period of time or until it is turned off manually. When a vehicle behind it receives that message it will relay that message to other vehicles behind it, and the relayed message will be sent as a safety application on a safety channel. The total delay is divided into two major parts. The first part is called the access time and it consists of a mechanical part where the car sensors detect the event and an electrical part where the microprocessor assemble the message and the communication device triggers the MAC protocol to access the media.

Once the media is accessed, the source car sends the urgent message several times. Each receiving car tries to decode the message and it might fail. Assuming that the decoding of each copy of the transmitted message succeeds with probability (1-P), where P is the packet error rate. Further assume that several transmission trials are statistically independent then the average number of trials needed to decode the packet correctly is approximately n_{av}. The number of trials (transmissions) is N. The probability that all N trials fail is P^N the probability that success occurs on the last trial is $(1-P)P^{N-1}$..., the probability that success will occur on the second last trial is $(1-P)P^{N-2}$ and so on. The average number of trials till success is:

$$n_{av} = \sum_{k=1}^{N} k\,(1-P)\,P^{k-1} \tag{9}$$

When N is infinite, $n_{av} = 1/(1-P)^N$. P is a function of several parameters including distance. The main parameters are:

- Packet length
- RMS delay spread
- Delay spread profile
- Relative speed between the source and destination
- Path-loss distance factor
- Variance of path-loss
- Distance

For a fixed set of parameters, the probability of packet failure increases with distance. Therefore, cars further away from the accident will take longer to decode the message correctly. Essentially, each driver should be given enough reaction time, T_C. A car located at distance, d, from the accident and is traveling towards accident location at speed v, has total time to react of d/v. This time must be larger than or equal to the critical time T_C.

3. PERFORMANCE OF DSRC IN DIFFERENT ENVIRONMENTS

3.1. Background

For V2V critical communication a high data rate and low number of lost messages are required, especially at high vehicle speeds and critical conditions, such as potential accidents. The DSRC physical layer has been simulated using IEEE 802.11a Physical layer model available in MatLab v7.9.0 (R2009b).

So in this research, the criterion used to determine at what distance the communication medium is not reliable for V2V communications was to test when 90% of the 10,000 messages that have been sent from the source arrived to the destination for each distance. In all the simulated tests that were done in this research, the average PER, BER, Bit Rate was calculated to generate all results figures for several ITS safety applications, each with different packet size, which is mentioned in Table 2. Bit error rate (BER) was used to measure the packet performance. Adaptive modulation and coding was considered when obtaining the performance curves. This section discusses some test results that have been collected for all test environments.

3.2. Highway environment

For highway environment as it is known, usually vehicles drive with high speeds between 100-120 km/h. This test concentrated on 25 and 50 km/h speed difference between two vehicles, to test the effect of higher speed on the reliability of the IEEE 802.11a communication channel. It was founded

Table 2. Requirements for different types of safety applications [8]

No.	Application	Required No. of Bits	
1	Curve Speed Warning	238	
2	Emergency Electronic Break Light	288	
3	Cooperative Pre-Crash sensing	Static Vehicle	Dynamic Vehicle
		172	263
4	Cooperative Forward Collision Warning	419	

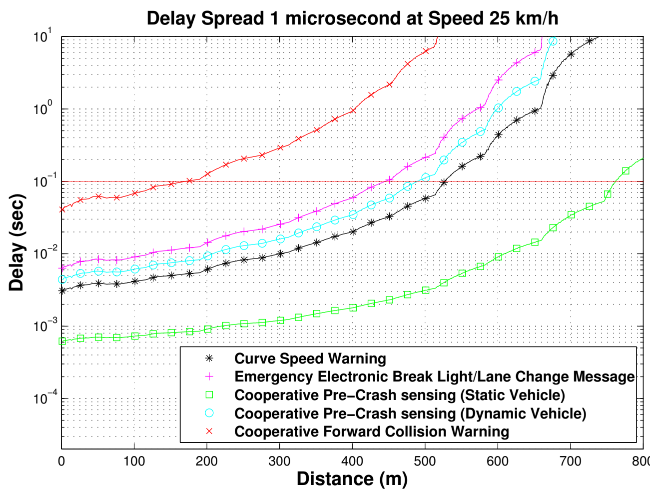

Fig. 2. Delay time vs. Distance (m) for multiple packet sizes at 25 km/h

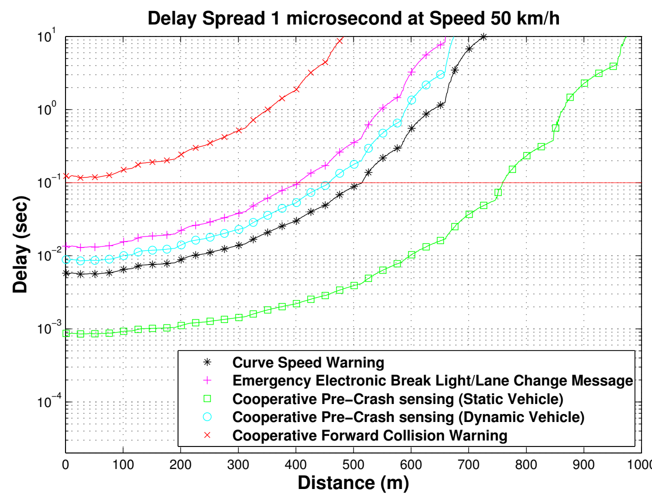

Fig. 3. Delay time vs. Distance (m) for multiple packet sizes at 50 km/h

from the two highway tests that the effect of increasing vehicle speed (Doppler shift) on the reliability of DSRC channel. Figure 2 show that at speed 25 km/h, all the five applications pass the distance and delay time requirement (0.1 sec and 150 m) on the other hand, figure 3 shows that for cooperative forward collision warning at speed 50 km/h does not pass the requirement which means that DSRC communication channel is not practical for that application at higher speeds.

3.3. Urban environment

For urban environments, two types of tests were simulated, with Line-of-Sight (LOS) and with No-Line-Of-Sight (NLOS). In this environment it was found that the reliable distance when there is LOS is between 400 and 2000 m which means it is acceptable for all our applications. On the other hand, when there was NLOS the distance went down dramatically to between 30 and 110 m and that makes DSRC communications in urban areas not very practical when there is NLOS. The reason for that big difference is that in urban environments buildings will act like a tunnel and that will increase the signal power, which means that it will travel for a longer

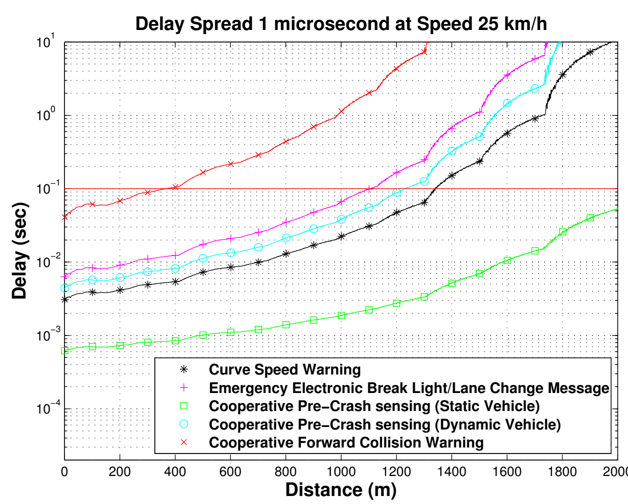

Fig. 4. Delay time vs. Distance (m) in urban areas (LOS) for 25 km/h

distance. Figure (4 and 5) shows the difference in distance

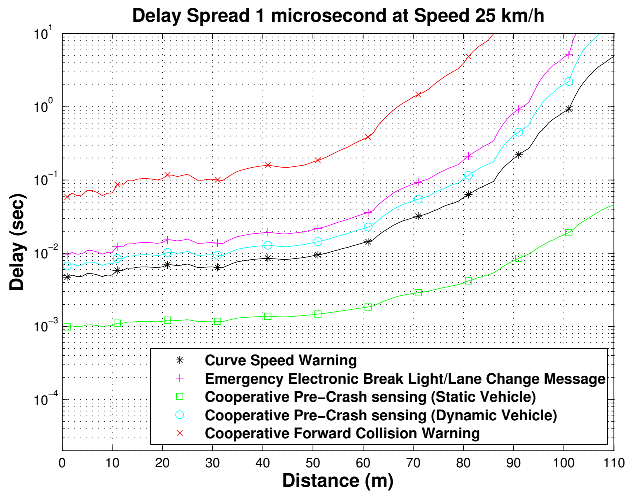

Fig. 5. Delay time vs. Distance (m) in urban areas (NLOS) for 25 km/h

between the two tests at 25 km/h speed.

4. CONCLUSION

As intelligent transportation systems ITS advance, they require higher safety applications in order to reduce number of accidents, which results in reducing number of fatalities or injuries caused by accidents. Also the advancements in ITS reduce the costs occurred from accidents. V2V communication is a vital application of ITS in order to allow vehicles to exchange vehicles or roads information with surrounding vehicles or infrastructure.

This paper provides a comprehensive study of the 5.9 GHz DSRC wireless communication, which is assigned for vehicular applications, and identified the challenges that exist in various vehicular environments. Several studies have been conducted by other researchers to calculate the path-loss exponent for different environments on DSRC communication between two terminals. The DSRC physical layer was evaluated in this paper using the previous path-loss exponents, and multiple tests were simulated in this paper for highway, and urban areas.

In environments with low path-loss exponents, such as highway and urban (with LOS) environments, and lower vehicle speed (25-50 Km/H), the DSRC showed a high reliability for longer distances compared to environments with high path-loss exponents, such as urban (with NLOS) environment. For higher vehicle speeds (50 Km/H), all tests showed a large drawback in the reliability of DSRC. The effect of delay spread was also simulated in this research, and it was concluded that at low delay spreads (0.1 μsec and 0.5 μsec) the effect of the delay spread was not very noticeable. But at higher delay spreads (1 μsec) the BER increased compared to the other cases, which made DSRC not practical for some applications in some cases, e.g. urban (NLOS).

Finally, it can be concluded that at higher vehicle speeds, delay spread, and path-loss exponents, certain changes need to be taken into account when designing the MAC layer for DSRC networks.

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