Vehicle to Vehicle RF Propagation Measurements

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Abstract

We present results from vehicle to vehicle RF propagation measurements centered at 900 MHz. We focus on determining delay spread, probability distribution parameters (in particular, the Rician K factor) and path loss rates. Our results are discussed with implications for the use of RF communication between automobiles in Intelligent Vehicle Highway Systems (IVHS). Our paper consists of a description of the IVHS concept along with a brief overview of wireless propagation theory. We then discuss our measured parameters with respect to implementing an RF transmission system between vehicles.

1.0 Introduction

Recently, implementation of advanced communication technology has been propounded as a feasible alternative to solving ground transportation problems. Projects such as Road Automobile Communication Systems (RACS) in Japan, PROMETHEUS in Europe, and Partners for Advanced Transit and Highway (PATH) in the U.S. are currently engaged in the design of such systems called Intelligent Vehicle Highway Systems (IVHS) in Japan and the United States and Road Transport Informatics (RTI) in Europe. These projects encompass Automated Vehicle Control Systems (AVCS) and Advanced Vehicle Identification (AVI) as platforms from which IVHS can be realized. Many see these projects as a means of improving safety and efficiency of the highway system, which in turn would lead to an increase in the productivity of commuters as well as alleviate pollution.

Shladover et. al. have proposed a method of efficient vehicle control by grouping vehicles in platoons. Platoons consist of several cars grouped together in a single lane such that consecutive cars are separated by short distances (on the order of a few meters). In IVHS projects employing the platoon concept, vehicle-to-vehicle communication is of critical importance. Although communication occurs only over relatively short ranges, from less than one meter to tens of meters, the communication links have to be *extremely* reliable, despite the presence of multipath reflections and interference from other links using the same frequency channel.

The purpose of this paper is to present propagation measurements of RF signals between vehicles. The results will help determine the feasibility of using RF communication between vehicles in IVHS platoons. The results and discussion in the remainder of this paper will be presented as follows. Section 2.0 will consist of a review of RF propagation theories. Section 3.0 will outline our measurement procedure and present the results of our measurements. Section 4.0 will present a discussion of the results and conclude our paper. Sections 5.0 and 6.0 contain acknowledgments and a list of references respectively.

2.0 RF Propagation Review

A great deal of literature is available on RF wireless transmission research [1 - 16]. Much of the work has been focused on transmission between users in automobiles to and from a shared base station [1, 7, 8]. In such scenarios, transmission distances can be quite large, often measured in terms of city blocks. Furthermore, a line of sight (LOS) path between the transmitter and the receiver is not always likely as the base station antenna is often blocked by buildings and other obstacles.When considering IVHS vehicle to vehicle communication, the channel is quite different. Based upon the proposed platoon structures of IVHS designs, we can assume that the transmission distances will be quite small when compared to the former RF transmission cases cited above. In addition, a LOS signal path is virtually guaranteed since any obstacles in the roadway would not only be harmful to RF transmission, but also to driver safety. It is with these thoughts in mind that we are studying the wireless channel as potentially implemented with an intelligent vehicle highway system.

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There are several causes of signal corruption in a wireless channel. Fundamentally, three of the primary causes of corruption are signal attenuation due to distance, multipath transmission and channel time variation. Signal attenuation over distance is observed when the mean received signal power is attenuated as a function of the distance from the transmitter. The most common form of this is often called *free space loss* and is due to the signal power being spread out over the surface area of an increasing sphere as the receiver moves farther from the transmitter.

Multipath transmission results from the fact that the transmission channel consists of several obstacles and reflectors. Thus, the received signal arrives as a set of reflections and/or direct waves each with its own degree of attenuation and delay. *Delay Spread,* T_D, is a parameter commonly used to quantify multipath effects. Informally, delay spread is the difference in time between the first and last received signals from the transmitter to the receiver. More formally we consider the RMS and Mean Excess delay spread in which the instantaneous impulse response is treated like a probability distribution function (pdf). Multipath transmission manifests itself as variation in the received signal strength over frequency. Often researchers consider the *coherence bandwidth* as a measure of how much the received power level varies in the frequency domain. Coherence bandwidth is loosely defined as the inverse of the delay spread.

Time variation of the channel is due to the fact that we assume the communicating vehicle is in motion. Closely related to Doppler shifting, time variation in conjunction with multipath transmission leads to variation of the instantaneous received signal strength about the mean power level as the receiver moves over distances on the order of less than a single carrier wavelength. Given that the vehicles in question are in motion, time variation of the channel is realized as spatial variation and becomes uncorrelated every half carrier wavelength over distance.

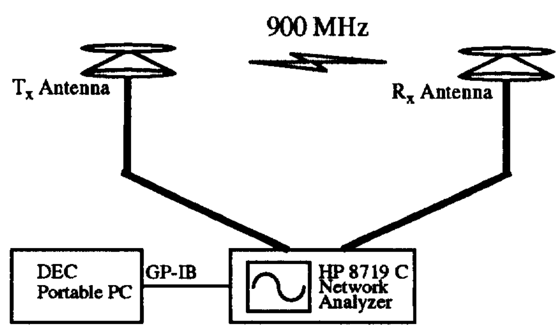
The variation of received signal amplitude in the time domain observes a probability distribution in one of two forms. The first form, known as Rayleigh fading (after the Rayleigh distribution), generally occurs when there is no direct line-of-sight path between the transmitter and the receiver. The second and more general form of multipath fading is Rician fading and occurs when a line-of-sight path is present. A Rician distribution consists of two parameters; the Rician K factor and local mean signal power. The K factor is defined as the ratio of the direct line-of-sight signal strength to the scattered (reflected) signal components. In the case of Rayleigh fading, the K factor is zero and thus the Rician distribution reduces mathematically to a Rayleigh distribution and consists of two parameters.

3.0 Measurement Setup and Results

We are primarily concerned with measurement of delay spread, Rician K factor and path loss versus distance. Our measurements were taken under stationary conditions in a roadway environment with parked cars. The antennas were supported by tripods at a height approximately equivalent to that of an automobile's front hood. Two automobiles were parked in single file a particular distance apart. As the distance was varied (from 6 to 40 feet), the parameters of interest were measured. At each distance, six measurements were taken at slightly different positions (by one half of the carrier wavelength to become uncorrelated) to average out fading.

Our measurement setup consisted of four components as shown in Figure 2. The components are receive and transmit antennas, coaxial cables, a microwave network analyzer and a portable pc. The antennas are omnidirectional discone antennas. The microwave network analyzer served as our signal generator and could cover a frequency range of 50 MHz to 13.5 GHz with maximum frequency resolution of 100 KHz. The network analyzer automatically calibrates out the coaxial cable loss. All tests had a transmit power level of +10 dBm. The network analyzer provided frequency response as well as the time domain instantaneous impulse response data corresponding to a given frequency response sweep. This data was ported to the pc for analysis via a GPIB connection.

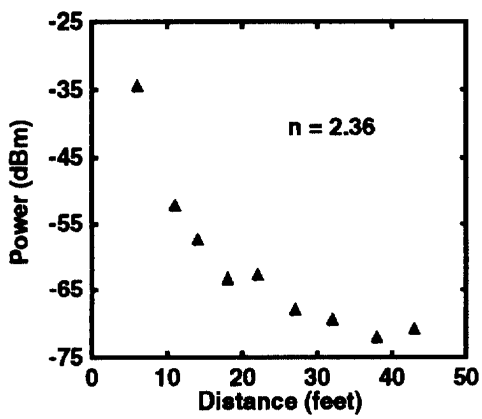
FIGURE 1. Measurement Setup



3.1 Path Loss Attenuation

We anticipate our path loss rate to be very close to, or perhaps slightly smaller than that of free space loss. As Figure 2 shows, our measured rate was 2.36. A possible explanation for this somewhat large path loss value could be due to our inclusion of the measurement taken at the shortest distance. Indeed, with our carrier wavelength on the order of 1 foot in length (0.3333 meters to be exact), the short distance of 6 feet separating the two antennas comes somewhat close to the point at which antennas cease to act as "point sources" and we are no longer clearly in the far field. If this is the case, the path loss rate no longer follows the simple inverse square law. Indeed, when the path loss was calculated without the first point of Figure 2, the new rate was 1.53. This question of being in the antennas far field was a primary reason for why measurements significantly closer (than 6 feet) were not taken.

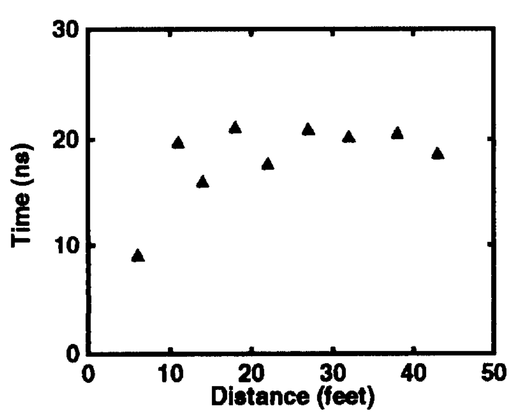
FIGURE 2. Path Loss



3.2 Delay Spread

We measured delay spread using the technique presented in [5]. There are two interesting issues to note with our delay spread measurements. First we note that the results are, quite reasonably, very small. Compared to indoor wireless measurements that we have taken at 2.4 GHz, we see that with the same antenna separation

FIGURE 3. RMS Delay Spread



distance, the vehicle to vehicle measurements have significantly smaller delay spreads (as much as 100%). We believe that this difference is not due to the difference in carrier frequency but rather a difference in the two types of channel. One case being a relatively tame channel between two closely spaced automobiles, and the other being a relatively cluttered office cubicle environment. Given this difference, it seems quite reasonable that the vehicle to vehicle channel provides few obstacles that can lead to significant reflections, which is the primary cause of delay spreads.

A second interesting point is that the delay spread values increase slightly with distance but in a consistent zig-zag motion. As shown in Figure 3, the rms delay spread has an oscillating motion as no four consecutive points can be connected by a monotonic curve. Again we refer to our indoor measurements as well as those of others [5, 12] and note that this is uncharacteristic. Recall that each data point in Figure 3 represents six separate measurements taken within a small region to average out the effects of fading.

This result suggests that the relative received signal strength of "long" reflections in the channel oscillate as a function of antenna separation distance. The significant objects in our channel are simply two consecutive vehicles and a flat roadway. Furthermore, our test environment did not have any objects above the vehicles or to the left or right that were close enough to have a serious impact on the channel.

This observation has implications for many of the n-ray models (for integer n, typically small) that are being proposed to characterize channels. Models which describe a wireless channel as having a small, finite number of signal paths can afford an almost deterministic approach due to the reduced number of variables to consider. In effect, it may become possible to "predict" locations at which certain reflections may be cancelled out. It is this kind of prediction that would lend itself to Figure 3.

Note, that the oscillations of Figure 3 are reduced as distance is increased. This makes sense. A large antenna separation distance should overshadow the variations that occur on the order of a wavelength. In addition, greater distances allow for more reflections which reduces the significance of any single reflection.

3.3 Rician K Factor

The Rician K Factor is very important in completing our knowledge of the associated probability density function of a wireless channel. Indeed, to know the distribution of a wireless channel without knowing the parameters about which the distribution occurs is useless. Knowledge of the Rician K Factor can be useful in determining the bit error rate of a channel among other useful metrics.

Note that our search for a Rician K Factor implicitly suggests that we assume a Rician distribution. Given our understanding of a Rician distribution as having a strong LOS component, this assumption is readily justified.

We applied the method of moments to determine the Rician K Factor. This method sets the sample mean equal to the theoretical mean (both of the received signal amplitude). Equation 1 shows the theoretical mean of a Rician distributed random variable (y).

$$E\rho = e^{-K/2}\sqrt{\frac{\pi}{2(K+1)}\bar{p}}\left[(1+K)I_0\left(\frac{K}{2}\right)+KI_1\left(\frac{K}{2}\right)\right] \quad \text{(Eq. 1)}$$

We can determine both the local mean power, $\bar{p}$, and the sample mean, $E\rho$. We then use Equation 1 to solve for K.

The largest measured K factor was almost 18.0. This value occurred several times. More typical values were in the range of 5.0 to 11.0. We anticipate high K factors due to the obvious strong LOS signal that is present between the two vehicles. Contrary to our anticipations, however, were occasional measured K factors at around 1.5 (our lowest was 1.38). This is intuitively inconsistent with what one would expect.

Recall that the K factor represents the ratio of the received LOS component to the received scattered components. This concept of K factor, first put forth in [9], is very difficult to measure in a physically meaningful manner; i.e., by isolating the direct signal from the scattered components. Since the K factor can serve as a metric for differentiating Rician from Rayleigh distributions, the question becomes, "how large must K be to truly have a Rician distribution."

We feel that the consistency of larger measured K factors (i.e., 11.11, 17.6, etc.) is evidence that we do indeed have a Rician distribution. However, the few low values we measured does cause concern. It seems more likely that the channel is Rician with a dominant component consisting of at least two paths; an LOS and a reflection off of the roadway. These two components may be interacting with one another in such a way as to have a sinusoidal type of frequency response which affects the computations

As part of future work, we will employ an alternative method for measuring the K factor. One, very nonexplicit method for accomplishing this task is to match various (with differing parameters) Rician distribution functions to the tabulated results from our measurements. The distribution (and corresponding K factor) that most closely matches is optimum.

4.0 Conclusion

We have presented the results from RF wireless vehicle to vehicle measurements. Our results included path loss with a measured drop off rate of 2.36 and rms delay spread with a range of values between 8.9 to 20.8 ns. We noted that the rms delay spreads had an "oscillating" behavior that can lend itself to many of the n-ray channel characterization models. In addition we presented Rician K factor results mostly ranging from 5.0 to 11.0 with extreme values as high as 17.6 and as low as 1.38. Our feeling is that the channel is not strictly Rician. Unlike the traditional view of a Rician channel, we feel that the channel consists of two dominant components. One dominant component is the LOS signal and the other is a strong reflection off of the roadway. Over distance the two dominant components sum up in a oscillatory manner. The authors welcome all comments and ask that they be directed to:

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5.0 Acknowledgments

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