DOPPLER POWER SPECTRA FROM VEHICLE-TO-EVERYTHING PROPAGATION EXPERIMENTS

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ABSTRACT

This paper presents the results of vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) propagation experiments. The experimental results are summarized by Doppler power spectra. Our measurements indicate the need for a dynamic system that can handle the variable channels experienced in vehicle-to-everything communications.

INTRODUCTION

V2V and V2I communications, also known as vehicle-to-everything (V2X) communications, comprise a network of vehicles that communicate one with another, as well as with nodes located at fixed points that they pass during transit. Potential applications for V2X networks include the transmission of data intended to improve the safety of those in and around any vehicles, as well as to increase the efficiency of traffic flow [1]. Other applications may include the sharing of encrypted data with a limited number of recipients.

Because the V2X nodes are mobile, an understanding of mobile communication channel, such as the Doppler power spectrum, becomes necessary for system design [2, 3]. A Doppler power spectrum may be obtained through radio propagation experiments. In this paper, we report the results of propagation experiments conducted in downtown Provo, Utah. We computed a number of Doppler power spectra from the measured data. The Doppler power spectra provide insights into the requirements for the design of a system intended for use in V2X networks [4].

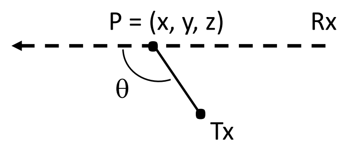
BASIC CONCEPTS

A. Multipath Propagation

The reliability of a wireless network is greatly impacted by the environment in which it is found. One of the main factors is multipath propagation which occurs when a propagating radio wave is reflected, scattered, or attenuated by the environment [5]. In a V2X network it is common to have objects such as buildings, trees, and other vehicles all contributing to multipath propagation. Consequently, multiple copies of the transmitted signal may arrive at the receive antenna, although not all at the same time, or in phase with one another. Thus, the channel may experience fading, amplification, a complete loss of signal, or any combination of these effects.

B. Doppler Shift and Doppler Power Spectrum

The Doppler shift is a frequency shift caused by relative motion between a transmitter and a receiver. The frequency shift experienced by a receiver at position $\mathbf{P}$ with velocity vector $\mathbf{v}$ is given by



$$f = |\mathbf{v}| \times \frac{\cos(\theta)}{\lambda}, \tag{1}$$

where θ is the angle between $\mathbf{v}$ and the line defined by the transmitter and $\mathbf{P}$ as shown next to Eq. (1), and λ is the wavelength of the electromagnetic wave. When the receiver is moving towards the source of the transmission, $0 \leq \theta \leq \pi/2$, and each crest of the radio wave has less distance to travel than the previous crest, resulting in a positive Doppler shift. When the receiver is moving away from the transmitter, $\pi/2 \leq \theta \leq \pi$, and the Doppler shift is negative.

The Doppler power spectrum quantifies the statistical temporal variations in the channel [6]. The Doppler power spectrum is measured by transmitting an unmodulated carrier

$$s(t) = \cos(2\pi f_0 t). \tag{2}$$

Due to temporal variations in the propagation medium, the receive signal may be expressed as

$$r(t) = A(t)\cos(2\pi f_0 t + \phi(t)) + n(t), \tag{3}$$

where $A(t)$ and $\phi(t)$ are the amplitude and phase variations, respectively, due to changes in the propagation medium, and $n(t)$ is additive noise. The Doppler power spectrum $S_D(f)$ is the power spectral density of the equivalent low-pass waveform

$$A(t)e^{j\phi(t)}. \tag{4}$$

The Doppler spread B_D is the bandwidth of $S_D(f)$ and indicates how rapidly the channel changes [7]. Understanding the rate of change is important for system design, as the system must update at a rate that is greater than, or equal to, the rate of the changes in the channel.

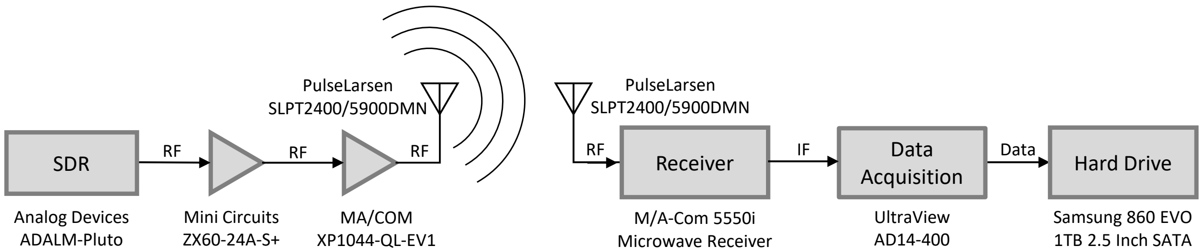


Figure 1: Block diagram of system setup.

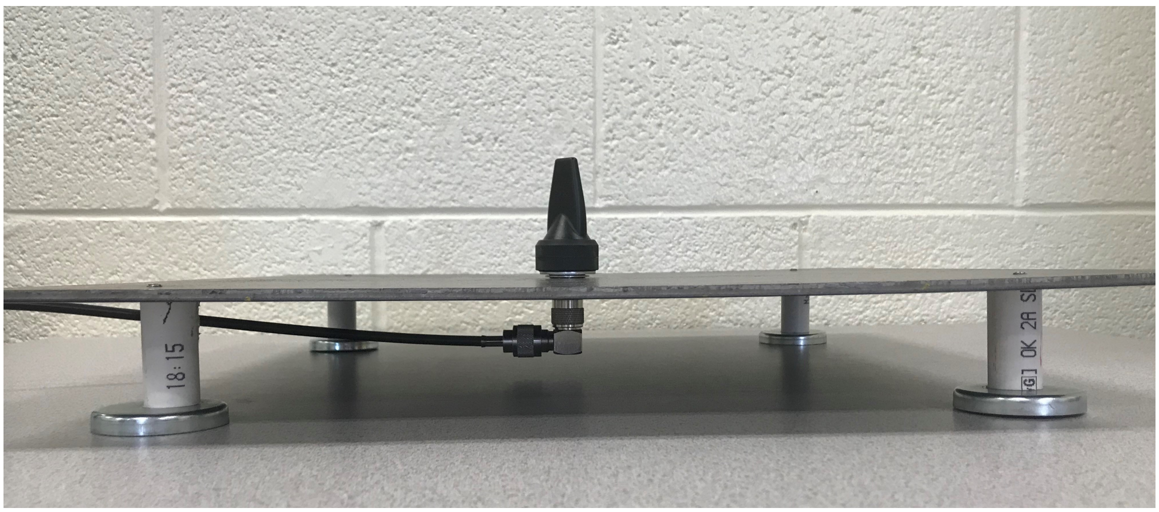


Figure 2: Antenna mount setup.

EXPERIMENTAL PROCEDURE

The IEEE 802.11p standard for V2X [8] allocates a 10 MHz bandwidth located in the 5900 MHz band. The experimental configuration is summarized by Fig. 1. A software-defined radio was used to generate an unmodulated carrier at 5900 MHz which was then amplified to 30 dBm and transmitted from an omnidirectional V2X antenna, mounted on the top of a van as illustrated in Fig. 2.

A receive antenna, identical to the transmit antenna, was mounted on top of a second van. The receive signal was filtered, amplified, and downconverted to 70 MHz IF. The IF signal was sampled at 11.2 Msamples/s and stored in solid state memory. Both vans were equipped with GPS units that recorded the location for use in tracking the relative locations and speeds of the vehicles in use.

The channel measurements were gathered in the city of Provo, Utah. In order to experience the effects of an urban environment with the presence of many tall buildings and a variety of other vehicles in close proximity, the experiments were performed in the downtown area. Each of the

Figure 3: Routes for the channel measurement test points. V2I measurements were collected by parking the van with the transmit antenna at the location marked with a white "×", while the red arrow marks the route followed for both V2I and V2V measurements. For each V2V test point the vehicles followed the same route but with varying degrees of separation between one another.

test points and routes for the channel measurements are summarized in Fig. 3.

EXPERIMENTAL RESULTS

Post processing of the recorded data was done using MATLAB®. The measured data were down-converted to I/Q baseband before being resampled. We used Welch's method of averaged periodograms to compute the power spectral density estimate. The samples were then used to create the plots found in Fig. 4 and Fig. 5. The frequency offset due to oscillator uncertainty was removed by computing the weighted average frequency and then shifting the center of the plots accordingly.

The V2I test, with a stationary transmitter located at position "x" in Fig. 3 and a mobile receiver following the red arrow in the same figure, is shown by Fig. 4 (a). Initially the vehicle was moving towards the transmitter, so that $0 \leq \theta \leq \pi/2$, resulting in a positive Doppler shift with a maximum of 140 Hz. The moment at which the peak gain is centered on 0 is when $\theta = \frac{\pi}{2}$ and the receiver is at the transition point between moving towards and moving away from the transmitter. After that

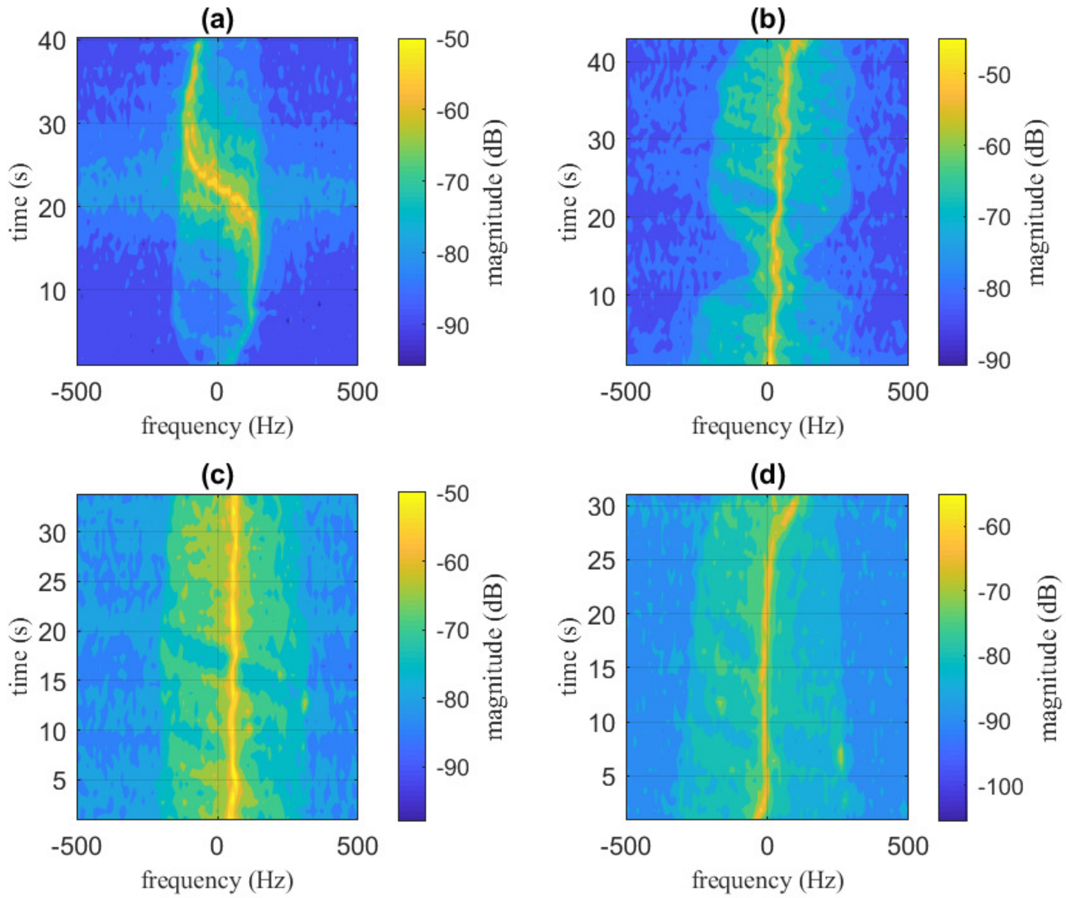


Figure 4: Top view of the gain in the channel with respect to time. Yellow corresponds to a higher gain, while blue corresponds to a lower gain that approaches zero. Four test points were measured and correspond to (a), (b), (c), and (d).

point, $\pi/2 \leq \theta \leq \pi$ and the Doppler shift is negative, with a maximum of -120 Hz.

The remaining three plots in Fig. 4 represent a V2V environment. Both vehicles followed the same route, depicted by the red arrow in Fig. 3, with the receiver following the transmitter. For all three cases, the vehicles maintained a speed of approximately 15 miles per hour (6.7 m/s). Given the tolerance in each vehicle's speedometer and the dynamic environment, the actual speeds of the vehicles varied slightly. The angle of θ for each case was 0, so the spread in the Doppler power spectra was mostly caused by the differences in relative speeds of the vehicles and multipath propagation.

In Fig. 4(b) the van with the receive antenna was following behind the transmitter at a distance of approximately 10 m. The change in the Doppler shift over the duration of the test point is approximately 50 Hz, which gives us a relative velocity difference of 2.5 m/s, or 5.7 mph. Plot (c) shows the results when the receiver followed 50 m behind the transmitter. The Doppler shift was

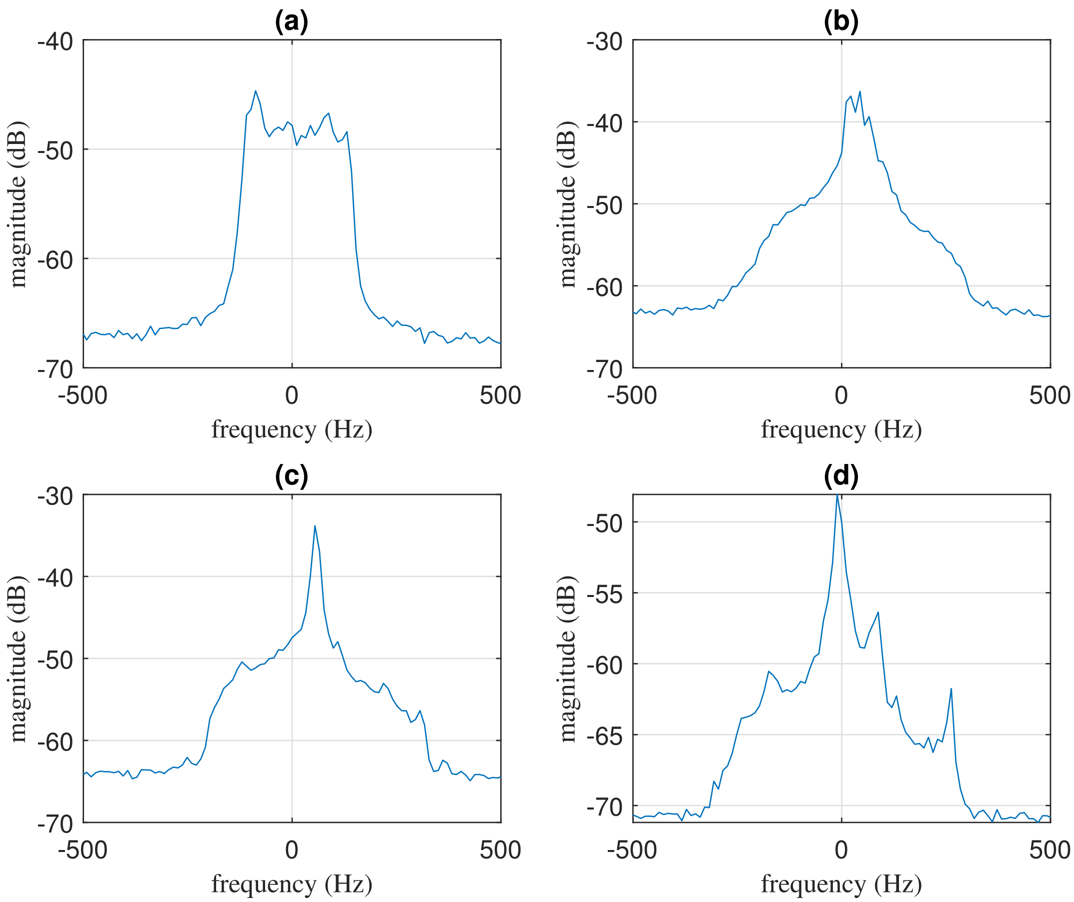


Figure 5: Doppler power spectrum for each of the test points.

a constant 50 Hz, which translates to a relative velocity of approximately 5.7 mph. Lastly, for (d), the receiver followed at a distance of 100 m and the Doppler shift varied from an initial 15 Hz, down to 10 Hz, before rising to 40 Hz. These changes correspond to relative frequencies of 1.7 mph, 1.1 mph, and 4.5 mph respectively.

The Doppler power spectrum for each test point can be found in Fig. 5, with (a) corresponding to the V2I measurements and (b), (c), and (d) representing the V2V measurements. We calculated the Doppler spread by measuring from the center of the Doppler power spectrum out to the furthest edge, whether it be positive or negative. From our measurements, Fig. 5 (a) has a Doppler spread of 200 Hz at 65 dB of attenuation, (b) has a spread of 300 Hz at 60 dB, (c) of 320 Hz at 60 dB, and (d) of 320 Hz at 70 dB.

CONCLUSIONS

This paper explored the Doppler power spectra for V2X networks by performing propagation experiments in an urban area of Provo, Utah. From the results of our experiments we found that V2I and V2V networks express different behavior in the Doppler shift over time, and that varying distances for V2V scenarios do affect the variability of the channel. From the Doppler power spectra observed, and the Doppler spread that was presented in each test point, we know that any system designed for V2X communications will need to be dynamic in nature. To fully understand the requirements for system design, additional work may include channel measurements in other scenarios. Some potential areas of interest may include canyons, tunnels, and heavily forested areas.

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