Chapter 2
Channel Modeling for Vehicle-to-Vehicle Communications and Networking

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ABSTRACT
This chapter provides a description of physical layer characteristics for the mobile wireless channel for vehicle-to-vehicle (V2V) communication and networking applications. Due to the low antenna elevations, and mobility of both transmitters and receivers in the V2V environment, the V2V wireless channel can be one of the most challenging elements to ensuring reliable V2V communication.

ORGANIZATION
We first define the environment and conditions for V2V communications, along with mention of anticipated applications and a current V2V communication system standard. A concise motivation for accurate channel characterization is provided, and a short description of the channel’s effects upon communication system performance is also given. The distinguishing features of V2V channels are identified, particularly in comparison to more traditional channels such as those for cellular radio, public safety, etc. We focus on statistical models for small scale fading, but also include a short discussion of large and medium scale fading; a review of statistical channel characterization basics (in the delay, frequency, Doppler, and time domains) is provided as background. We then focus on how researchers are modeling the V2V channel. After noting some of the primary theoretical findings for V2V channels, we describe three classes of V2V channel models that appear to be the leading candidates for widespread use: these are deterministic (and quasi-deterministic) models, and two types
of empirical statistical models, the tapped delay line, and geometry-based. Example tapped delay line models are provided, and a geometry-based model is also described. The final section looks at some of the unique features of V2V channels, including statistical non-stationarity. This section also addresses multiple-input/multiple-output (MIMO), and multi-band models, and discusses V2V networking and channel estimation. We conclude with a summary and recommendations for future work in V2V channel modeling.

INTRODUCTION

Vehicle-to-vehicle (V2V) communications are envisioned to grow dramatically in the upcoming decade. Numerous projects, some of which come under the heading of Intelligent Transportation Systems (ITS) (US DoT, 2010), are being conducted by governments and industry consortia. As automobiles become more complex, and more and more vehicles travel, new features for safety and efficiency are needed. Thus, vehicular ad hoc networks (VANETS) are being researched (Bai, 2010). New short range communications for vehicle-to-infrastructure (V2I) communications (sometimes vehicle-to-roadside, V2R) are also being researched for multiple applications (Belanovic, 2010). Most important of all applications is safety (Gallagher, 2006), but numerous other applications are being studied to improve efficiency, reduce roadway congestion, and offer drivers and passengers new options for making travel more productive and pleasant (Papadimitratos, 2009).

Regardless of the application, the V2V communication signals will almost certainly travel by electromagnetic wave propagation. Past research has considered millimeter wave bands (Tank, 1997), (Wada, 1998) and even the ultrahigh frequency (UHF) band (Sai, 2009), but since both the US and European spectrum regulatory agencies have reserved spectrum in the 5 GHz band, this band is most likely for near-term V2V use. Similarly, although several transmission schemes have been studied for use in the V2V setting, the modified IEEE 802.11a standard, denoted 802.11p (Zhu, 2003), (Jiang, 2008), or WAVE (for Wireless Access in Vehicular Environments) (Uzcategui, 2009) is most likely to see application, at least initially. This standard was originally (and sometimes still is) termed the Dedicated Short Range Communication standard (Jiang, 2006).

Regardless of frequency band, propagation channel characteristics are important (Parsons, 2000). The physical layer (PHY) must transfer information across the wireless channel efficiently and accurately so that higher layers of the communications protocol stack can operate properly (Stuber, 2001). Thus, good models for the PHY wireless V2V channel are essential for system analysis and design. This chapter discusses such models. Worth noting is that these models are usually designed for use in computer simulations of communication systems, which is done in concert with design, before any system deployment.

The next section provides some general and specific definitions for the V2V channel. It also provides more detail on frequency band of operation, and the WAVE standard. This section discusses distinct features of the V2V channel in comparison to more traditional channels, and also provides motivation for accurate channel modeling.

In the third section, we review the statistical characterization of wireless channels, beginning with a brief discussion of preliminaries. The focus then turns to the channel impulse response (CIR) and channel transfer function (CTF). Correlation functions for these channel characteristics are described, as are common simplifications of wide sense stationarity (WSS) and uncorrelated scattering (US). This section also provides comments on the need for statistically non-stationary (NS) characterization.

The fourth section describes types of V2V channel models, including theoretical models and the most popular empirical models, the
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