Performance of LTE in Vehicle-to-Vehicle Channels

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Abstract- **Vehicle-to-vehicle (V2V) communications have seen growing attention in the last few years. In this work, we address the use of the 3GPP Long Term Evolution (LTE) standard technology applied to V2V. We employ empirical models for the V2V channel, and show results from comprehensive computer simulations, based upon both the uplink (UL) and downlink (DL) standards for LTE. We provide results for 10 MHz and 20 MHz channels, in terms of BER, BLER, spectral efficiency and throughput, using multiple MIMO modes. Results show the attractive feasibility of the LTE technology in V2V communication systems.**

I. INTRODUCTION

Work on vehicle-to-vehicle (V2V) communications has grown steadily in recent years [1]. There have been numerous papers, workshops, conference sessions, and conferences focused on this important area. The most important applications are for road safety, but there are also numerous other applications that aim to reduce energy use, increase traffic efficiency, and make the passenger experience more pleasurable ("comfort" or "infotainment" applications) [2]. Example applications include broadcast of traffic warnings for road obstacles, accidents, work zones, weather, etc. Broadcast applications would employ local transceivers at roadsides, and would be classed as vehicle-to-roadside (V2R) or vehicle-to-infrastructure (V2I) communication. V2V networking is also possible, wherein multiple V2V links (hops) would be used to relay information [3]. In the US, some work on V2V/V2R technologies comes under the area of Intelligent Transportation Systems (ITS) [1]. Mobile ad hoc networking is also an area of study within V2V communications; similarly, military organizations are also interested in vehicular ad-hoc networks (VANETs). The literature on V2V/V2R communications is burgeoning [4].

Environments for V2V communication are generally paved roads, and these can be in urban, suburban, and rural areas. The V2V environment is significantly different from traditional cellular environments[1]. Specifically, in the V2V setting, both transmitter (Tx) *and* receiver (Rx) may be mobile, and both may have multiple scattering/reflecting objects nearby, which are also mobile. The scattering geometry will mostly be non-isotropic, and may be rapidly time-varying. This will produce time varying Doppler spectra: with both Tx and Rx in motion, the rate of fading can be twice as fast as in cellular. The low-elevation antenna heights for both Tx and Rx is a primary cause of obstruction of line of sight (LOS) paths. With obstacles around both Tx and Rx, so-called "multiple scattering" can arise, and this produces more severe fading than in cellular channels. Thus in comparison to cellular channels, V2V channels can incur more severe fading, and they will be statistically stationary for shorter durations.

The importance of accurate channel models is well-known [5]. Good channel models are required for analysis, computer simulations, and hardware testing [6], all of which are key prerequisites to system design and deployment. To date there have been numerous efforts to assess and model V2V channels, using both analysis and measurements. For our study here, we employ empirical channel models from [7] and [8].

Past research on V2V communications has considered millimeter wave bands [9], [10] and even the ultrahigh frequency (UHF) band [11]. Some channel measurements have also been made in other bands, e.g., the 2.1-2.4 GHz band [12], [13], and the 900 MHz band [14]. Yet since both the US and European spectrum regulatory agencies have reserved spectrum in the 5 GHz band, this band is most likely for V2V use soonest. The US has allocated 75 MHz of spectrum in the 5.85-5.925 GHz band. Since most coming V2V systems are likely to be deployed in the 5 GHz band, that band is our focus here.

Similarly, although several transmission schemes have been studied for V2V use, the modified IEEE 802.11a standard, denoted 802.11p [15], [16], or WAVE (for Wireless Access in Vehicular Environments) [17] is most likely to see *initial* application. This standard was originally (and sometimes still is) termed the Dedicated Short Range Communication (DSRC) standard [18]. Our study of LTE should be useful for future V2V applications.

In Section II, we describe the model for the LTE system as applied to the V2V setting, and also describe the specific channel models we use. Section III contains a description of the simulations, along with simulation results in terms of bit error ratio (BER) and block error ratio (BLER), spectral efficiency, and throughput. In Section IV we provide conclusions.

II. SYSTEM AND CHANNEL MODEL

For our study, we employ channel bandwidths of 10 MHz and 20 MHz, and consider a highway environment. We

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[1] In the future, V2V communications will surely be used in "off-road" conditions (as they are now in generally ad hoc fashion by the military), but we do not address the "off-road" environment in this paper.

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investigate performance using both the uplink and downlink LTE formats, with various MIMO options.

A. LTE Overview

LTE comprises the Evolved UMTS Terrestrial Radio Access (E-UTRA) air interface, which is a technology designed to combine high-data-rate, low-latency and packet-optimized radio access. In order to meet these requirements, important changes were required at the physical layer, for example, new modulation and coding schemes are used and the Transmission Time Interval (TTI) was reduced. In fact, many of the features included by the 3GPP in LTE were originally considered for "4th generation" cellular systems [19].

The media access scheme for LTE is Orthogonal Frequency Division Multiple Access (OFDMA) for downlink and Single Carrier FDMA (SC FDMA) for uplink with two possible modes of transmission: FDD and TDD. The motivation behind the election of SC-FDMA for the uplink is its low Peak-to-Average Power Ratio (PAPR) that reduces the quality requirement for mobile terminal amplifiers and, therefore, the mobile terminal's cost. Additionally, advanced MIMO spatial multiplexing techniques, including (2 or 4) x (2 or 4) schemes for downlink and uplink, as well as multi-user MIMO are also supported.

The resource allocation in the frequency domain takes place with a resolution of 180 kHz resource blocks both in uplink and downlink. The uplink user specific allocation is continuous to enable single carrier transmission while the downlink can use resource blocks freely from different parts of the spectrum. The LTE solution enables spectrum flexibility where the transmission bandwidth can be selected between 1.4 MHz and 20 MHz depending on the available spectrum. The 20 MHz bandwidth can provide up to 150 Mbps downlink user data rate with 2 × 2 MIMO, and 300 Mbps with 4 × 4 MIMO. The uplink peak data rate is 75 Mbps [20].

LTE, DSRC and WiMAX all employ OFDMA and current best practices in multiple areas of their designs, including forward error correction, MIMO processing, and adaptive MAC operation. One reason for investigating use of LTE is its heritage in the cellular radio community, which has been successfully supporting ever-increasing data rates in highly mobile environments for over a decade. In contrast, the DSRC standard has evolved from the wireless LAN community, which has not previously supported mobile data. Clearly, both standards will likely improve over time.

B. V2V Channel Models

The V2V channel models in [7] and [8] are of the traditional tapped-delay line form, which is a discrete model for the channel impulse response (CIR). Amplitude fading is modeled using the flexible Weibull distribution [21], and each channel tap corresponds to a fading multipath component (MPC). Tap phases are uniformly drawn at the simulation start, and are then lowpass filtered using the same filter type as for amplitude fading (2nd-order Butterworth). The Weibull distribution requires two parameters: the shape parameter β, which is analogous to a Ricean K-factor, and the scale factor α, related to MPC mean-square value (energy).

In addition, models in [7] and [8] also incorporate statistical *non*-stationarity by virtue of the MPC persistence process, an "on-off" switching process used to model the "birth/death" of MPCs. Fig. 1 shows segments of example measured persistence processes in a small city. For the persistence processes, [7] and [8] employ 1st-order discrete Markov chains (DMCs) in which the chain state ($\in \{0,1\}$) is the output, with 0 corresponding to MPC absent, and 1 corresponding to MPC present. Each tap has a DMC associated with it, and the DMC is described by the steady state probabilities ($P(state=0)=P_0$, and $P(state=1)=P_1=1-P_0$), and a state transition matrix. The 2×2 transition matrix has elements P_{ij}, $i,j\in\{0,1\}$, representing the probability of a transition from state i to state j, with $P_{01}=1-P_{00}$, and $P_{10}=1-P_{11}$. State transitions occur on block boundaries defined by the channel coherence times. Table I provides channel parameters for a 10 MHz urban channel [7].

TABLE I. CHANNEL PARAMETERS FOR 10 MHZ URBAN CHANNEL (FROM [7]).

TAP INDEX K	ENERGY	WEIBULL SHAPE FACTOR (β_K)	$P_{00,K}$	$P_{11,K}$	$P_{1,K}$
1	0.88	3.19	NA	1.0000	1.0000
2	0.08	1.61	0.2717	0.9150	0.8956
3	0.03	1.63	0.4401	0.8171	0.7538
4	0.01	1.73	0.5571	0.7488	0.6382

We create MIMO channels from these SISO models via specification of the correlations among the various MPCs for multiple CIRs. In this manner, we can generate $M=N_TN_R$ MIMO channels with arbitrary (user-selectable) correlations between them; here N_T=#transmit antennas, N_R=# receive antennas. Our assumption is that each of the M channels has the same statistical characteristics over a simulation run.

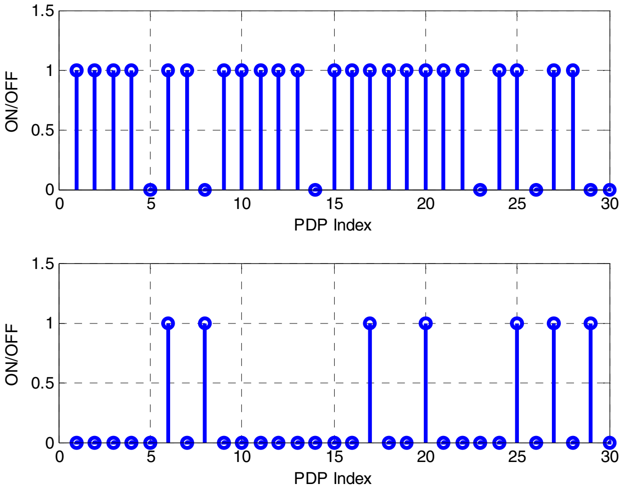

Fig. 1. Example persistence processes for V2V channel taps 3 (top) and 5 (bottom) for segment of travel in small city, from [22].

III. LTE SIMULATIONS

In this section, we describe the LTE simulations used in our study. We also describe how the V2V channel models are incorporated.

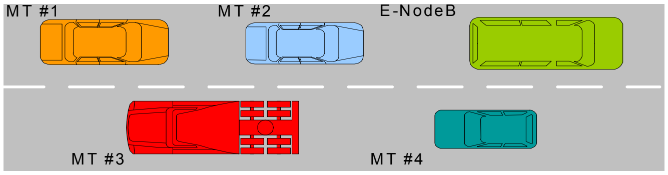

Fig. 2. Scenario under analysis.

A. Simulation Description

For our simulations we have used the WM-SIM platform [23], on which we have built both downlink and uplink simulations of LTE FDD wireless system that can operate with 10 and 20 MHz bandwidths. We analyze a highway high density scenario; it is composed of a number of vehicles working as Mobile Terminals (MTs) that are connected to another vehicle that is temporarily acting as E-NodeB. The link between each MT and the E-NodeB is assumed to be a frequency-selective radio channel; see Fig. 2. The main simulation parameters are summarized in Table II.

TABLE I. SIMULATION PARAMETERS

Carrier Frequency (f_c)	5.2 GHz
Sampling Frequency (f_s)	30.72 MHz
Channel type	NS Weibull
Cyclic prefix length	144 samples
Bandwidth	10/20 MHz
Number of data carriers	600/1200
FFT size	1024/2048

We assume the same correlation factor ρ for all MPCs at the same value of delay, i.e., if $h_{ij}(\tau_0;t)$ denotes the MPC at delay τ_0, time t for the channel from Tx antenna j to Rx antenna i, then the correlation coefficient between this MPC and those of $h_{kj}(\tau_0;t)$ and $h_{im}(\tau_0;t)$ is ρ for all k and m. In the following we consider two cases: an ideal one in which there is no correlation between MPCs among the MIMO channels (ρ=0) and a more realistic one where $\rho = 0.5$.

B. Simulation Results

BER results for the different MIMO schemes have been obtained. All results are for uncoded modulation. Maximal Ratio Combining (MRC) with one antenna at the transmitter and two at the receiver (1x2) is the preferred MIMO scheme for LTE UL. Spatial Multiplexing (SM) and Space-Frequency Block Coding (SFBC) techniques have also been evaluated in a 2x2 antenna configuration; these represent the downlink. In Fig. 3 we compare the BER performance of these schemes for the 10 MHz bandwidth, whereas in Fig. 4 we compare BLER values. In order to obtain a fair comparison, the spectral efficiency for all MIMO schemes has been set to 4 bits/s/Hz.

For SM, modulation is QPSK using 2 layers, with transport block (TB) size of 320 bits. The MRC scheme employs 16 QAM with one layer, TB size of 640 bits, and the SFBC employs the same parameters as SM.

It is shown that transmit and receive diversity techniques (SFBC and MRC) clearly outperform the spatial multiplexing scheme in terms of BER and BLER. In addition, SFBC (DL) achieves better results than MRC (UL), which is due to the different antenna configuration of DL and UL. The BER curves for MRC and SM are always above that for SFBC and the SNR gap increases as BER decreases. A similar behaviour can be found in Fig. 4 for BLER.

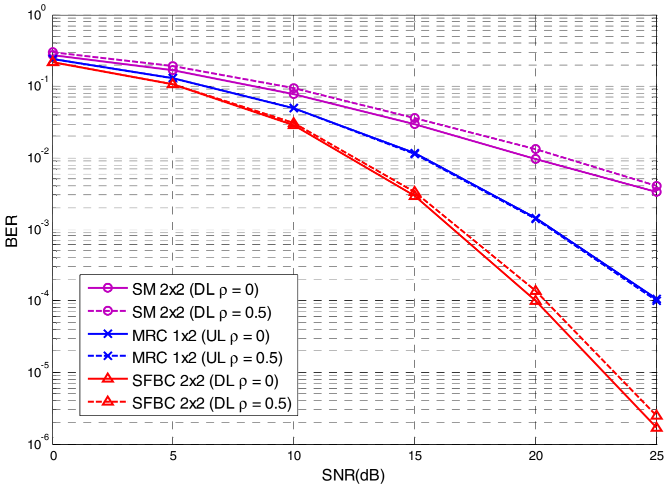

Fig. 3. BER for different MIMO configurations over the Weibull V2V fading channel (10 MHz). In all cases, the spectral efficiency is set to 4 bits/s/Hz.

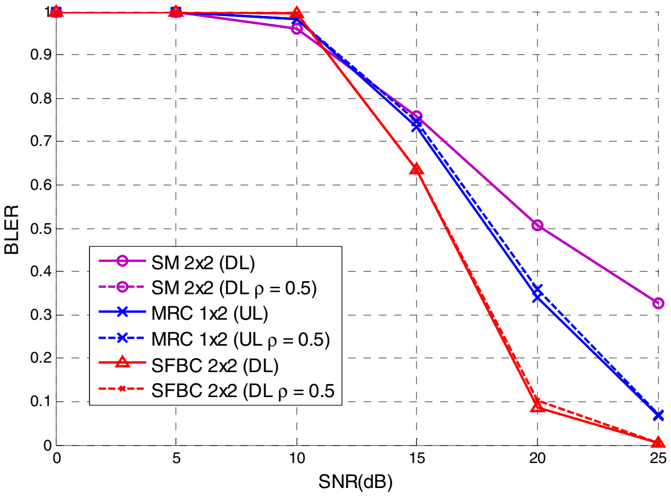

Fig. 4. BER for different MIMO configurations over the Weibull V2V fading channel (10 MHz). In all cases, the transmission is normalized to 4 bits/s/Hz.

It can be concluded from these figures that the inter-channel correlation among MPCs at the same value of delay hardly affects performance in terms of BER or BLER. At higher values of SNR there is a slight performance degradation, and this would likely increase as BER/BLER decrease.

Spectral efficiency results are depicted in Fig. 5, for a maximum tolerable BER (threshold) of 10^{-3}. As expected, SM offers the highest values as two different layers (data streams) are transmitted simultaneously. Thus, in this case the spectral efficiency is up to 12 bits/s/Hz at high SNR, whereas the other MIMO schemes only achieve a maximum of 6 bits/s/Hz. Note that spectral efficiency for SFBC is always above that for MRC—by design MRC is aimed at performance improvement, not spectral efficiency. Once again, channel correlation has little to no impact on the performance.

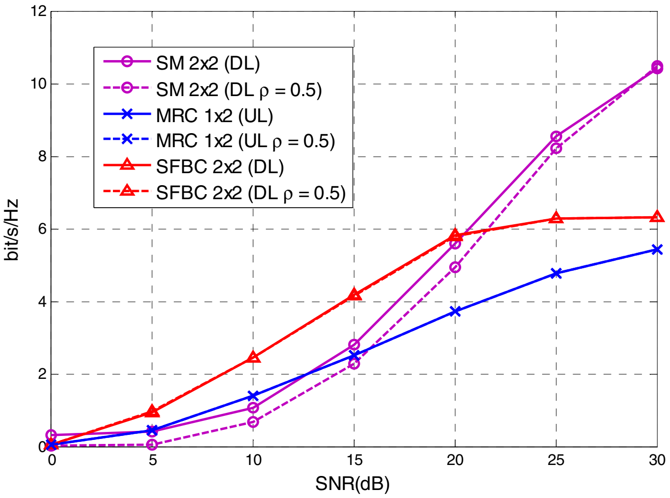

Fig. 5. Spectral efficiency for different MIMO configurations over the Weibull V2V fading channel, 10 MHz bandwidth and $BER_T=10^{-3}$.

Finally, in Fig. 6 we compare throughput results in LTE UL for the two considered system bandwidths. It can be seen how the peak data rate for LTE UL (75 Mbps for the 20 MHz bandwidth and half that for the 10 MHz bandwidth) is achieved for an average SNR of 30 dB.

IV. CONCLUSION

In this paper, we have presented a performance evaluation of the LTE technology in a V2V communication system. Our WM-SIM platform has been used to model LTE uplink and downlink transmissions for 10 MHz and 20 MHz system bandwidths. For both bandwidths, an empirical model for the Weibull frequency-selective fading channel has been employed. The study shows feasibility for broadband wireless access at data rates of multiple Mbit/s to the V2V end-user.

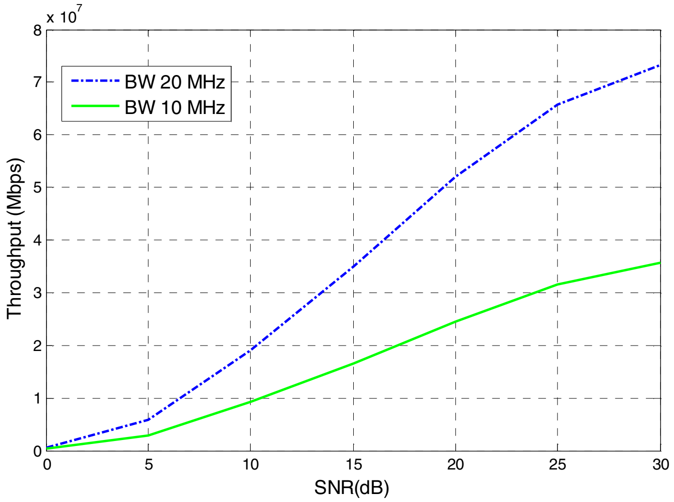

Fig. 6. Throughput results for UL transmission with 10 and 20 MHz bandwidths and $BER_T=10^{-3}$

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