Enhanced Power Effect on Detection Performance in High Mobility Vehicular Networks

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Abstract:- Vehicular networks are perturbed by a wide range of noise sources which cause poor signal detection that accounts for high BER. Multipath propagation and shadowing are noise sources that are mitigated by channel equalization algorithms. However, channel equalization fails to enhance BER performance in high vehicular mobility conditions because of the prevalent Doppler shift. In this paper, received power enhancement realized by MIMO techniques is deployed to improve detection in high vehicular mobility conditions. Simulation results show that 2x2 MIMO system delivers 12 dB better than the conventional system based on single antenna configuration.

***Keywords*:-** *BER; Detection; Doppler shift; MIMO; SNR; VANET.*

I. INTRODUCTION

Vehicular communication is deployed as vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication as an element of vehicular ad hoc networks (VANETs) [1]. V2V communication allows nearby vehicles to communicate with the other vehicles without the dependence on any infrastructure, enabling vehicles to exchange critical information to minimize collisions [2].

The enabling technology for VANETs is based on IEEE 802.11p/WAVE (wireless access in vehicular environment) standard operating on the dedicated short range communication (DSRC) frequency band of 75 MHz at 5.9 GHz [3]. The standard is the second amendment to IEEE 802.11, the standard for wireless communication [4]. The first amendment, IEEE 802.11a, adopted orthogonal frequency division multiplexing (OFDM) at 20 MHz bandwidth in its physical layer (PHY) to improve BER performance. The second amendment halved the bandwidth in 802.11p to adapt it to the high mobility conditions associated with VANETs to also enhance BER performance by minimizing inter-symbol interference (ISI).

One of the major challenges to implementation of VANETs is poor signal detection caused by Doppler Effect. When a receiver is in motion with respect to a source, a change in the received signal frequency is experienced. When the receiver is moving towards the source the received frequency is increased whereas if it is moving away from the source the received frequency is decreased [5]. This effect, called Doppler shift, causes a frequency offset with the local oscillator and it is the source of increased BER experienced in a vehicular channel as inter-carrier interference (ICI).

Detection enhancement in high mobility conditions has been reported in the recent literature. Detection performance in vehicular ad hoc networks by analytical estimation of Doppler shift has been investigated in [6] and found that analytically evaluated Doppler shift estimates yielded improved detection performance. These findings compare closely with [7] where enhanced detection in short text messaging is achieved by deploying channel matrix inversion method. Doppler shift impact on the quality of transmitted signal has been investigated by Albarazi [8] and mitigated through adaptation of modulation and coding schemes in both additive white Gaussian noise (AWGN) and Rayleigh fading channel models. In OFDM systems Zhou and Lam [9] obtained Doppler shift estimation using an algorithm employing pilot carriers whereas Jeng [10] obtained accurate Doppler shift values using accurate values of angle of arrival (AoA) for compensation in a smart antenna system. On the other hand, Jakakrishnan [11] investigated MIMO-OFDM systems in outdoor environment under WiFi conditions and established that shadowing is the main cause of performance degradation whereas Tarokh [12] obtained enhanced detection performance using space-time block codes.

In this paper, a Doppler shift impaired signal is processed by MIMO techniques to enhance detection. Simulation results indicate that a 2x2 MIMO system delivers 12 dB better than the conventional system based on single antenna configuration at a critical vehicular speed. Power variation evaluation in high speed vehicular ad hoc networks has not been reported in the recent literature.

The rest of the paper is arranged as follows. Section II is the system model; Section III is the signal measurement; Section IV is numerical results and Section V is the conclusion.

II. SYSTEM MODEL

In V2V communication under consideration the instantaneous received multipath signal at the receiver is expressed as [13]

$$r(t) = \sum_{i=0}^{N-1} \alpha_i \exp\left(j\theta_i(t,\tau)\right) \tag{1}$$

and the instantaneous power at the receiver is given by

$$\left|r(t)\right|^2 = \left|\sum_{i=0}^{N-1} \alpha_i \exp\left(j\theta_i(t,\tau)\right)\right|^2 \tag{2}$$

where α_i is the signal strength, N is the number of independent paths and θ_i is the phase angle expressed as

$$\theta_i = \frac{2\pi d_i}{\lambda} = \frac{2\pi v_i t}{\lambda} \qquad (3)$$

where λ is the wavelength of the carrier signal at 5.9 GHz and d is the distance between transmitter receiver. Thus, θ_i is a measure of Doppler shift where the maximum Doppler shift

$$f_d = \frac{v}{\lambda} \qquad (4)$$

The diversity of the Maximum Likelihood (ML) detector is given by [14],

$$P\left(x \to x \mid H_j\right) = Q\left(\sqrt{\frac{\left\|H_j\left(x - x\right)\right\|^2}{2\sigma^2}}\right) \qquad (9)$$

where H is the MIMO channel matrix, $(.)^H$ denotes the Hermitian transpose, $(\tilde{.})$ denotes estimated symbol and σ^2 is the noise variance at the receive antenna.

BER for BPSK Rayleigh fading channel is evaluated by the equation

$$P_b = \frac{1}{2}\left(1 - \sqrt{\frac{E_b / N_0}{1 + E_b / N_0}}\right) \qquad (10)$$

where E_0 is the bit energy and N_0 is the noise power. The AWGN model BER on the hand is evaluated by

$$P_b = \frac{1}{2} erfc\left(\sqrt{\frac{E_b}{N_0}}\right) \qquad (11)$$

III. SIGNAL MEASUREMENT

Our proposed scheme combines antenna diversity in the 2x2 MIMO system and interference cancellations in the OFDM symbol based on the decoding algorithm namely, Maximum Likelihood (ML) in order to increase received power to achieve higher upper bound error-free velocity within the realistic VANET range.

The Maximum Likelihood algorithm under the BPSK modulation $(x = \pm 1)$ tries to find the estimated symbol which minimizes $J = \left|y - Hx\right|^2$, according to (10), that is

$$J_{x_1,x_2} = \left\| \begin{bmatrix} y_1 \\ y_2 \end{bmatrix} - \begin{bmatrix} h_{1,1} & h_{1,2} \\ h_{2,1} & h_{2,2} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} \right\|^2 \qquad (12)$$

The estimate of the transmit symbol is chosen based on the minimum value from the four possible results:

If the minimum is $J_{+1,+1} \Rightarrow [1 \quad 1]$, $J_{+1,-1} \Rightarrow [1 \quad 0]$, $J_{-1,+1} \Rightarrow [0 \quad 1]$ and $J_{-1,-1} \Rightarrow [0 \quad 0]$. This operation is significant as it is responsible for the enhanced BER performance under this scheme.

Error rate is finally computed by comparing the received and transmitted data.

IV. NUMERICAL RESULTS

A Matlab script was written for computing the BER for BPSK modulation in a Rayleigh fading channel with two transmit and two receive antennas constituting 2x2 MIMO system. The Rayleigh faded signal was generated on the channel to emulate high speed channel noise associated with vehicular motion and the BER was computed by means of equation (10) in a maximum likelihood (ML) detector. The results are presented in Figs. 1 – 4.

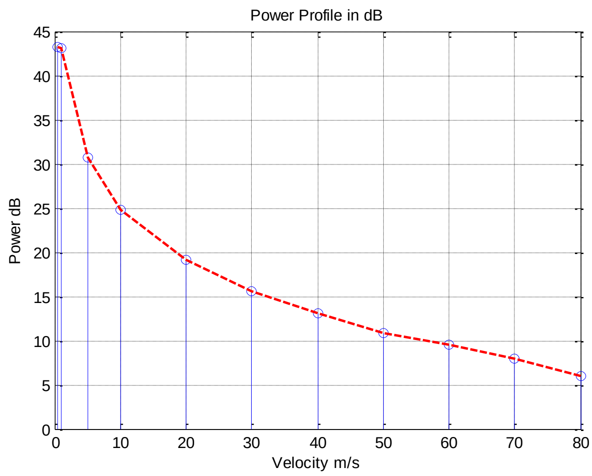

Fig 1:- Received power profile

The received power values in Fig.1 range from the high of 43 dB in stationary conditions to the low of 6 dB at 288 km/h. At low speeds the effect of Doppler shift is negligible. However, as the speed increases beyond the threshold the Doppler Effect increasingly becomes significant and reduces received power to insignificant levels.

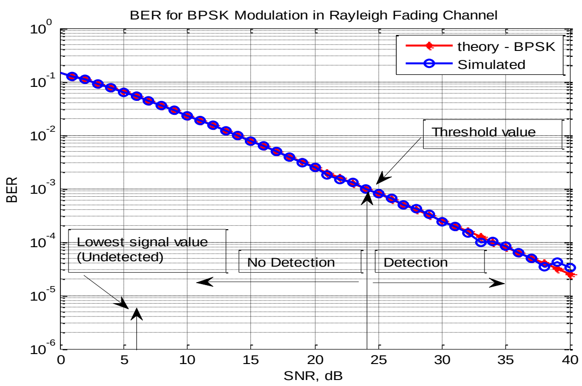

Fig 2:- BER for BPSK Modulation in Rayleigh Fading Channel

The BER threshold for reliable communication in wireless fading environment is 10^{-3} [4]. In Fig.2 the threshold value is the horizontal line representing BER equal to 10^{-3}.

The intersection of the threshold line and the characteristic curve defines the threshold point as the SNR value below which detection is not possible. This value is 24 dB. This means that all points lying below 24 dB cannot be decoded, contributing to post detection bit errors in the SISO channel.

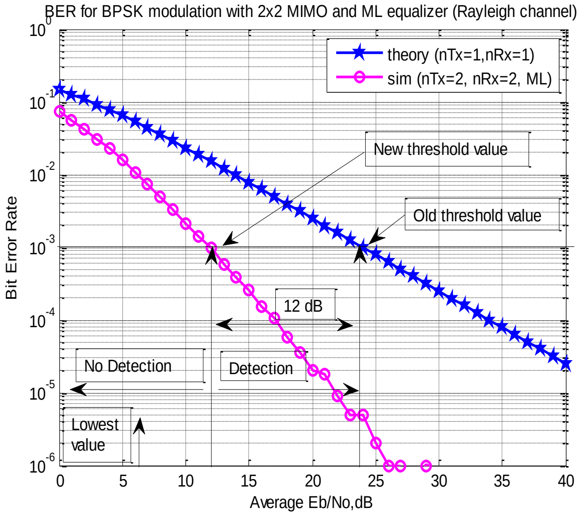

Fig 3:- 2×2 MIMO-implemented BER for BPSK modulation.

Two transmit and two receive antennas are introduced to create a 2×2 MIMO channel employing a maximum likelihood (ML) equalizer. The operation shifts the characteristic curve in Fig.3 towards the AWGN-like characteristics of Fig.4. In other words, MIMO transforms the Rayleigh fading characteristics to AWGN-like characteristics to enable optimized operation in low SNR regime.

The detection performance significantly improves as indicated in Fig.3. The response curve shifts to a new regime where more points in the received power vector now lie above the threshold point thus, lowering the detection threshold. The new threshold point is at 12 dB having shifted 12 dB from the previous 24 dB. The shift of 12 dB represents the MIMO gain over the conventional single antenna method.

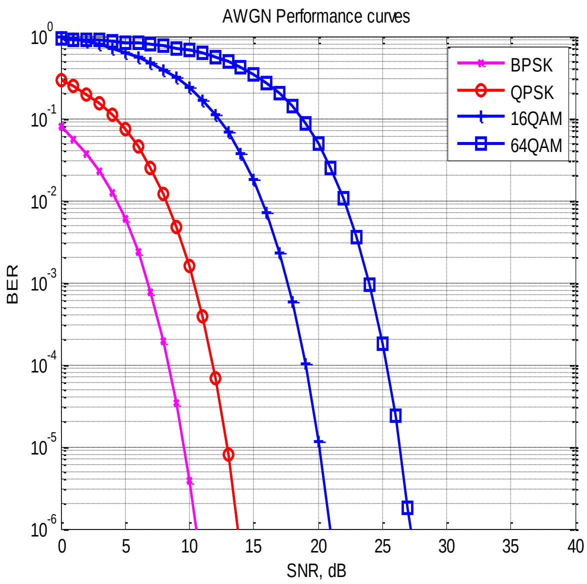

Fig 4:- Modulation performance in AWGN channel.

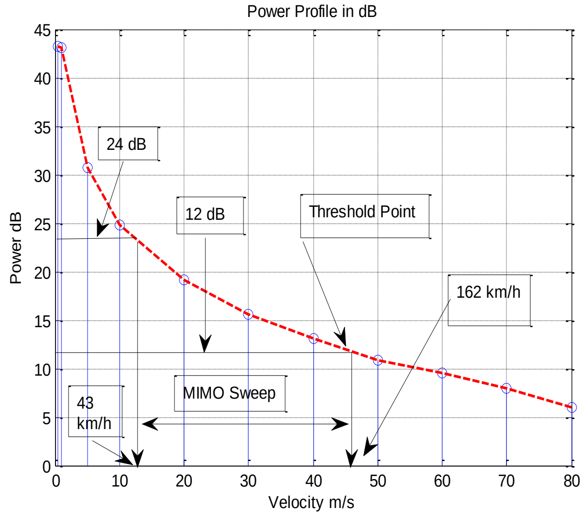

Fig 5:- New velocity threshold set by MIMO

The results indicate that for velocities up to 162 km/h error-free decoding will be possible, providing a MIMO sweep of 119 km/h. This is the difference between the SISO and MIMO threshold points in terms of velocity limits. In realistic circumstances, however, the MIMO threshold velocity is much lower due to other noise sources prevalent on the wireless channel [14].

Implementation of 2×2 MIMO system has enhanced detection by pulling the threshold up from 43 km/h to 162 km/h. This is an improvement of 12 dB over the single-antenna configuration. Equivalently, it can be said that a MIMO gain of 12 dB has been achieved in the process.

V. CONCLUSION

The low SNR values in vehicular networks are a result of cumulative effects but with Doppler shift as a major contributor owing to high mobility characteristics of the vehicular nodes. These low SNR values lower the detection threshold values in terms of vehicular velocity. In SISO configuration the threshold was evaluated at 43 km/h. With 2×2 MIMO the new threshold was established at 162 km/h. This represented a MIMO gain of 12 dB over the SISO channel gain when BPSK baseband modulation scheme and maximum likelihood (ML) equalizer are selected.

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