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Diversity Evaluation for Enhanced Detection in Multiple Input Multiple Output Vehicle - to - Vehicle Communication

Ferdinand Nyongesa
Masinde Muliro University of Science and Technology, Department of Electrical and Communication Engineering
P. O. Box 190 – 50100 Kakamega, Kenya
E-mail: fnyongesa@mmust.ac.ke

Abstract:
Vehicle-to-vehicle (V2V) communication holds a promise to revolutionize road transport operations proposed in vehicular communications as an element of Intelligent Transportation System (ITS). However, the vehicular communication channel suffers from low SNR arising from shadowing, multi-path fading and Doppler shift which degrade detection performance by increasing BER. MIMO techniques improvising diversity gain have been proposed as a mitigation factor to enhance detection. In this paper it is empirically determined that for given processing algorithm BER performance is linearly related to diversity order of the system. Simulations results indicate that detection performance increases with diversity order for a given processing algorithm dependent on the power loading algorithm.

Keywords: Diversity, vehicular network, MIMO, ITS, maximum ratio combining**.**

1. Introduction

Vehicle-to-vehicle (V2V) communication implemented in vehicular ad hoc networks (VANETs) has recently attracted interest of researchers concerned with Intelligent Transportation System (ITS) [1]. ITS is concerned with safety, security and efficiency of road transport systems and many countries have already implemented some ITS applications such as traffic management, traveller information, electronic toll management, social networking and multimedia services. When fully realized V2V communication will significantly reduce collisions among vehicles and save lives and property [2].

In V2V communication systems, vehicles can be considered as nodes in a mobile adhoc network (MANET), which implies that cellular wireless networks relying on fixed base stations are not applicable. The real-time constraints imposed on the vehicular wireless channel of low latency and high throughput sets strict requirements for a robust wireless link that experiences low BER with large bandwidth capacity.

Bandwidth problem in VANETs has been partially solved by introduction of orthogonal frequency division multiplexing (OFDM) and multiple input multiple output (MIMO) techniques in a scheme collectively known as spatial multiplexing but received signal quality still experiences high degradation as a result of shadowing, multipath fading and Doppler shift.

Multipath has been extensively studied and exploited to advantage such as in [3] using the tapped-delay line (TDL) model that modelled the channel as a finite impulse response (FIR) filter where channel optimization is reduced to a linear problem of solving for tap gains. On the other hand, the impact of Doppler shift on the quality of transmitted/received signals in a vehicular channel has been investigated in [4] and [5] where modulation and coding techniques are demonstrated to significantly reduce the effect of Doppler shift. Despite these interventions, the SNR experienced on the vehicular channel is still too low to guarantee quality of service (QoS) performance to meet the reliability constraint imposed particularly for safety application.

Diversity schemes have been deployed to improve quality of the received signal in wireless networks by applying different diversity orders and processing algorithms which include maximum likelihood (ML), minimum mean square error (MMSE) and maximum ratio combining (MRC). However, no performance evaluation of these algorithms has been reported in the recent literature.

This paper undertakes a comparative evaluation of MRC receive diversity in a spatial multiplexed VANET environment.

The rest of the paper is arranged as follows. Section II is the system modelling, Section III is simulation results and Section IV is the conclusion.

2. System Modelling

2.1 Spatial Multiplexing Techniques

When Orthogonal frequency division multiplexing (OFDM) and multiple input multiple output (MIMO) technology collectively form the spatial multiplexing technology. The first amendment to the IEEE 802.11 protocol, the IEEE 802.11a, introduced orthogonal frequency division multiplexing (OFDM) to address the increased demand for high bit rates on the 20 MHz bandwidth in WiFi fixed and portable devices. OFDM transforms a broadband frequency-selective channel into parallel narrowband overlapping frequency-flat sub channels where the sinc-shaped spectra exhibit zero crossings at all the remaining sub carriers, thereby constituting an orthogonal set. Since each subcarrier could be modulated independently, OFDM created low data rate parallel channel links with reduced BER by splitting the high data rate single-carrier channel [6].

Multiple antenna techniques can be broadly classified into two categories: Spatial multiplexing and Diversity techniques. In Spatial Multiplexing multiple independent data streams are simultaneously transmitted by the multiple transmit antennas, thereby achieving higher transmission speed at constant spectral resources and transmit power. For a MIMO system with N_T transmit and N_R receive antennas, maximum achievable transmission speed can increase by *min*(N_T,N_R). Under Diversity techniques the same information-bearing signal is received or transmitted by the same multiple antennas. The achievable transmission speeds can be much lower than the capacity of the MIMO channel but the signal gain can increase by $N_T.N_R$ [7]. Therefore, in receive diversity the signals are received by N_R receive antennas and signal processing algorithms at the receiver separate received signals and recover transmitted data with high accuracy. However, receive diversity suffers a setback of increased receiver implementation complexity that results in increased physical size and power consumption in the mobile terminal [8].

2.2 System Model

The system consists of the Alamouti encoder and decoder, linked by one transmit antenna and i receive antennas across the independently fading Rayleigh channel. The encoder consists of the binary information source, the constellation mapper and the space-time block coder deploying binary phase shift keying (BPSK) modulation scheme in the modulator.

A sequence $\{x_1 x_2 .... x_N\}$ is generated, grouped into blocks of symbols and transmitted successively on the single antenna.

The channel is flat fading Rayleigh model with independent and identically distributed (i.i.d.) complex coefficients whose real and imaginary parts are Gaussian distributed having mean $\mu_i = 0$ and variance $\sigma_i^2 = 1/2$. The channel is quasi-static, i.e. assumed constant over one time slot or symbol block but randomly varying from block to block. The system relating the received signal y and the transmitted signal x is described by

$$y=Hx+n \qquad (1)$$

where H is the channel matrix and n is the noise.

On the receive antenna, the noise n has the Gaussian probability density function with

$$p(n) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\left(\frac{n-\mu}{2\sigma^2}\right)^2} \qquad (2)$$

with mean $\mu = 0$ and variance $\sigma^2 = \frac{N_0}{2}$ [9].

The receive mechanism is based on Maximal Ratio combining (MRC) algorithm [9]. From (1), the received symbol from all the receive antennas is $y = [y_1 y_2 ... y_N]^T$, the channel gain leading to each receive antenna is $h = [h_1 h_2 ... h_N]^T$ and the noise on all the receive antennas is $n = [n_1 n_2 ... n_N]^T$, where $[.]^T$ is vector transpose. It follows that the equalized symbol is

$$\hat{x} = \left(h^H h\right)^{-1} h^H y = x + \frac{h^H}{h^H h} n \qquad (3)$$

where $h^H h = \sum_{i=1}^{N} |h_i|^2$ is the sum of the channel powers across all the receive antennas.

The instantaneous SNR at the $i-th$ receive antenna

$$\gamma_i = \frac{|h_i|^2 E_b}{N_0} \qquad (4)$$

so that with N receive antennas, the effective instantaneous SNR is

$$\gamma = \sum_{i=1}^{N} \frac{|h_i|^2 E_b}{N_0} = N\gamma_i \qquad (5)$$

The probability of error with MRC [9]

$$P_e = p^N \sum_{k=0}^{N-1} \binom{N-1+k}{k} (1-p)^k \qquad (6)$$

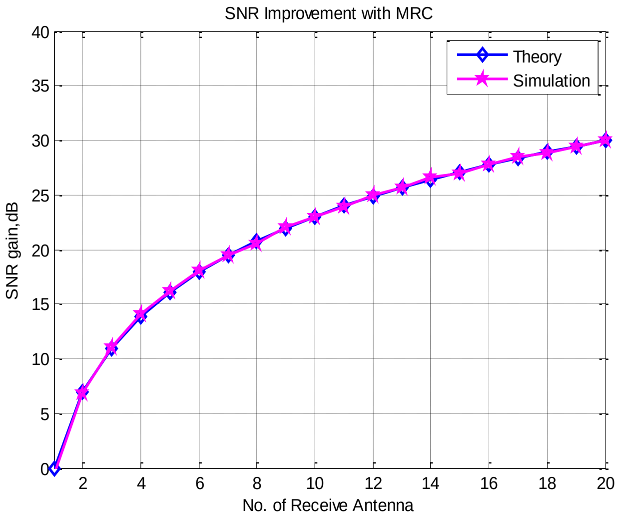
where

$$p = \frac{1}{2} - \frac{1}{2}\left(1+\frac{1}{E_b / N_0}\right)^{-1/2} \qquad (7)$$

3. Simulation Results

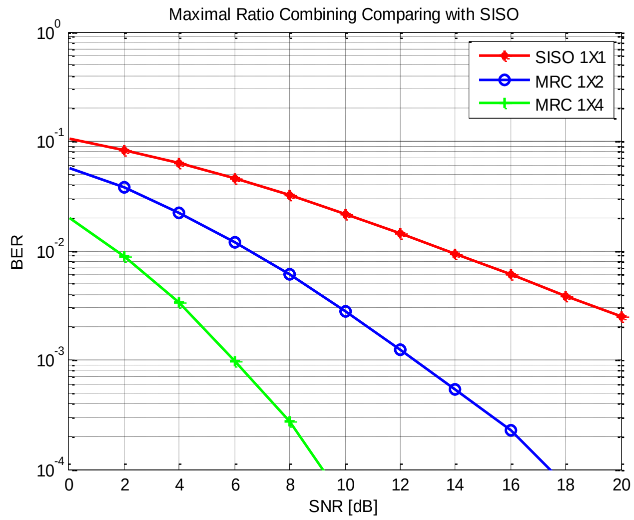
The simulations were performed in a Matlab simulator and the results compared with theoretical models with independently Rayleigh fading channel and perfect CSI knowledge at the receiver assumed.

Figure.1: MRC SNR performance with increase in receive antennas



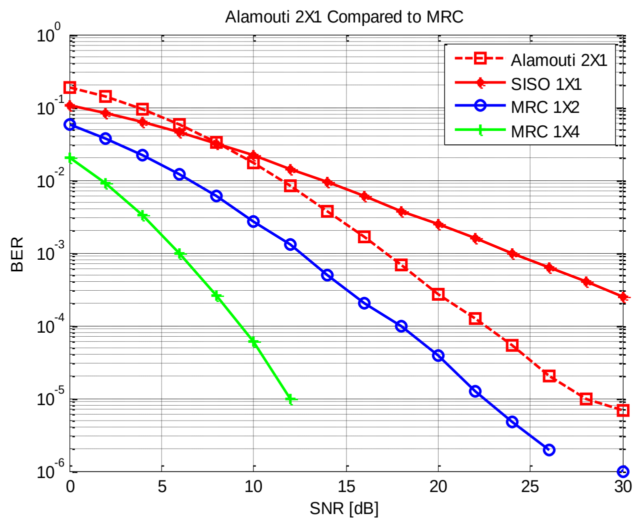
When both transmit and receive antennas increase in equal numbers for the MIMO system the MRC exhibits increasing SNR performance as indicated in Fig.1 where the simulation is in agreement with the theoretical formulation. However, a deviation from the expected linear relation is realized, where the gain increases logarithmically with the number of antennas, approaching 30 dB asymptotically. In high antenna configurations the gain accompanying an extra unit is minimal. This is explained by the high correlation existing among the sub-channels which increases with reduced antenna spacing that follows the high number of antennas implemented [10]. The optimum configuration is found to be 8 antennas, delivering a gain of 20 dB.

Figure.2: MRC BER Performance with increasing diversity order



The results in Fig.2 confirm that the output SNR may be expressed as a sum of the SNR values from the individual branches which is a specific feature of the MRC combiner [9]. The interpretation is that the instantaneous SNR improves with the number of branches which is reflected in the BER performance as confirmed in the figure where 1 transmit and 4 receive antenna system outperforms the rest which have fewer receive antennas. At BER of 10^{-3}, for example, SISO system requires more than 20 dB, Alamouti 2 receive antenna 12 dB whereas Alamouti 4 receive antenna only 6 dB to decode. The contribution per branch diminishes with increased number of receive antennas as a result of reduced power loading per channel and also due to increased channel correlation, as explained earlier in this work.

Figure.3: Alamouti 2×1 BER performance compared to 1xn MRC



Since the estimate of the transmitted symbol with the Alamouti STBC scheme is identical to that obtained in MRC, the BER should be the same in the two schemes [11]. However, this is not the case as shown in Fig.3. The slope of the curves is determined by the diversity order and it can be confirmed that MRC 1x2 system and Alamouti 2x1 with equal diversity order are in agreement, as the two curves exhibit parallelism. However, the different BER performance is explained by the energy constraint where all the energy in MRC is concentrated in the single transmit antenna whereas in Alamouti the energy is split into the two transmit antennas, to deliver lower SNR in the latter. At BER of 10^{-3} SISO requires 24 dB, Alamouti 2×1 17 dB whereas MRC 1×2 requires 13 dB. At the receiver, the detection algorithm combines the two streams of the Alamouti 2×1 and the MRC 1×2 with performance depending on the branch SNR with the SNR difference accounting for the variation. The result is that MRC technique outperforms Alamouti technique by 4 dB in providing decoding power in the receiver.

4. Conclusion

The results are consistent with the theoretical models where detection performance increases with diversity gain in consistence with the MIMO model where increase in SNR follows increasing diversity order. However, it is observed that the unequal BER performance for transmit and receive diversity 2 under consideration and the non-linear variation between SNR and diversity gain symbolize a unique characteristic of MIMO systems. The differentiated power loading in the respective branches and channel correlation which increases with the number of branches are the issues that account for the observed result.

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Author Profile

Dr. Ferdinand Nyongesa received his BSc in Physics from the University of Nairobi (Kenya) in 1983, MSc in Communications Engineering from the University of Bradford (UK) in 1990, and PhD in Electrical Engineering from Tshwane University of Technology (South Africa) in 2017. He has held industry appointments as Aeronautical Telecommunication Engineer in Civil Aviation (Kenya), Principal Research Officer at Kenya Industrial Research and Development Institute and Research Co-ordinator at the National Communication Secretariat (Kenya). He has also held academic positions in Electrical Engineering as Lecturer at Jomo Kenyatta University of Agriculture and Technology, Kenyatta University and currently at Masinde Muliro University of Science and Technology. He has a large collection of published works in Vehicular Networks.