A Channel Update Algorithm for VBLAST Architecture in Vehicular Networks

Ghassan M T Abdalla*, Mosa Ali Abu-Rgheff* and Sidi-Mohammed Senouci**

*University of Plymouth **Orange Labs R&D

Abstract

Vehicular networks (VANET) are being studied around the globe to provide safety, road and travel information as well as entertainment and internet access. Due to the high speed of the nodes, the communication time is limited to a few seconds and, therefore, high data rates are required. Since space and power are not a concern in these networks, we consider the use of VBLAST in VANET. VBLAST can achieve high bandwidth efficiency with reasonable hardware complexity but it requires knowledge of the channel state information (CSI) matrix to decode the signal. The CSI matrix can be estimated using a training sequence, however since the nodes in VANET move it high speeds, the channel matrix changes quickly and this technique becomes useless unless very short, inefficient packets are used. In this paper we propose a simple recursive procedure for updating the channel matrix. The algorithm assumes an initial estimate of the channel matrix possibly via a training sequence. Simulation results show considerable improvement in performance when using the developed algorithm.

Key terms: Channel Estimation, MIMO, VANET, VBLAST.

Introduction

The capacity of multiple input multiple output (MIMO) systems was shown to increase with the number of antennas [1]. Several algorithms to achieve part of this capacity have been developed, including space time block codes (STBC), space time trellis codes (STTC) and Bell Labs lAyerd Space Time (BLAST) algorithms. Space Time codes increase the reliability of the link making it possible to use higher modulations to achieve higher data rates. BLAST systems, on the other hand, assume the receive antennas are in a rich Rayleigh fading environment causing each antenna to receive an independent signal.

Vertical-BLAST (VBLAST) decodes the signal recursively. It starts with the signal with the highest SNR then cancels its contribution (interference) in the received signal vector, thus achieving better performance over the zero forcing receiver. Other BLAST algorithms exist such as Diagonal, Horizontal and Turbo BLAST but they require more complicated transmitters and/or receivers than VBLAST [2-4]. All MIMO systems need the channel matrix to decode the signal. Errors in the H matrix will lead to higher bit error rates; therefore accurate channel estimation algorithms are required. The traditional training based channel estimation for MIMO was the subject of several research papers including [5-7]. In [5] it was shown that an orthonormal training set is the optimum training sequence for MIMO. However, training based channel estimation suffers from inefficiency since part of the capacity is reserved for transmitting the known training sequence. This inefficiency can be reduced by transmitting a large number of symbols between training intervals (i.e. use longer packets).

In VANET vehicles communicate in an ad hoc mode while moving at high speeds, therefore relative speeds of 200km/hr or more are not uncommon. The frequency band allocated for VANET networks is at 5.9GHz leading to a Doppler shift of 1100Hz for 200 km/hr and a channel coherence time of approximately 162μs [8]. The short coherence time means a small number of symbols can be transmitted before the estimation is no longer valid which raises again the issue of bandwidth efficiency. This is particularly important in VANET since the communication time between the vehicles is very short therefore requiring high bandwidth efficiency.

In this paper we introduce an algorithm to update the channel estimation. We assume an initial estimate of the channel is obtained using a training sequence and the algorithm enhances this estimation so that longer packets and/or better BER can be achieved. The algorithm can work with any MIMO system but, when combined with VBLAST, can be implemented with a minor increase hardware complexity.

Mathematical Analysis

The received signal vector R can be given as:

$$R = HS + M \qquad (1)$$

Here R is the received signal vector, H is the channel matrix, S is the transmitted symbols vector and M is the AWGN vector. Throughout this paper, upper case represents vectors and matrices while lower case represents elements within the matrix. The simplest BLAST receiver (zero forcing receiver) estimates the transmitted symbols using the pseudo inverse of the channel matrix ($H^{\dagger}$) as:

$$\hat{S} = H^{\dagger} R \qquad (2)$$

The signal received at time index *n-1* is given by:

$$R_{n-1} = H_{n-1} S_{n-1} + M_{n-1} \qquad (3)$$

Let the estimated channel matrix be $\hat{H}_{n-1}$. A simple zero forcing receiver uses the estimated channel matrix to calculate an estimation of the transmitted symbols $\hat{S}_{n-1}$.

Let's define ΔH_n as:

$$\Delta H_n \hat{S}_{n-1} = R_{n-1} - \hat{H}_{n-1}\hat{S}_{n-1} \qquad (4)$$

Substituting (3) in (4) and assuming correct decoding we find:

$$\begin{aligned}\Delta H_n &= \left(R_{n-1} - \hat{H}_{n-1}\hat{S}_{n-1}\right)\hat{S}_{n-1}{}^{\dagger} \\ &= H_{n-1} - \hat{H}_{n-1} + M_{n-1}S_{n-1}{}^{\dagger} \qquad (5)\end{aligned}$$

The term $\left(R_{n-1} - \hat{H}_{n-1}\hat{S}_{n-1}\right)$ is calculated in the cancellation step of the VBLAST decoding algorithm. ΔH_n can be used to improve the channel estimation using the equation:

$$\hat{H}_n = \hat{H}_{n-1} + K.\Delta H_n \qquad (6)$$

Where K is a matrix of update parameters and the dot represents element by element multiplication.

Using an analysis similar to that given in [9] for SISO and adapting it to the VBLAST detection algorithm, we found the elements of the updated channel can be written as:

$$\begin{aligned}\hat{h}_{ij}{}^{n} &= \hat{h}_{ij}{}^{n-1} + \beta k_{ij}\,\varepsilon_{ij}{}^{n-1} \\ &\quad + k_{ij}\sum_{\substack{l=1 \\ l\neq j}}^{p} \varepsilon_{il}{}^{n-1} s_l{}^{n-1} a_j{}^{n-1} + k_{ij}\, m_i{}^{n-1} a_j{}^{n-1} \qquad (7)\end{aligned}$$

Where $\varepsilon_{ij}{}^{n-1} = h_{ij}{}^{n-1} - \hat{h}_{ij}{}^{n-1}$. The last two terms in (7) can be approximated by white noise with average power [9]:

$$\bar{N}_{0,j} = \frac{N_0}{\rho_j}\left(1 + \sum_{\substack{l=1 \\ l\neq j}}^{p} e_l\right) \qquad (8)$$

Where N_0 is the original total white noise power for the receive antenna (i), e_l is the average error covariance reduction value and ρ_j is a constant that specifies the fraction of noise associated with stream j.

After some mathematical manipulation and from [9]:

$$k_{ij} = k_j \quad \forall\, i \qquad (9)$$

$$k_j = 3.6\left(\sqrt[3]{\frac{\rho_j\,(f_D)^2}{\beta N_0\left(1 + \sum_{\substack{l=1 \\ l\neq j}}^{N} e_l\right)}}\right)$$

$$= 3.6\left(\sqrt[3]{\frac{(f_D)^2}{N_0\left(1 + \sum_{\substack{l=1 \\ l\neq j}}^{p} e_l\right)}}\right) \qquad (10)$$

$$e_j \approx \frac{0.75}{p} k_j \qquad (11)$$

$$f_D = fT_s\frac{v}{c} \qquad (12)$$

$$N_0 = \frac{1}{E_s/N_0} \qquad (13)$$

Where T_s is the symbol duration, f is the carrier frequency, v is the relative vehicle speed and c is the speed of light. We define E_s/N_0 as the total SNR if all transmitting antennas transmit the same symbol. We set β and ρ_j equal to $1/p$ since we assume equal average transmit (receive) power for each transmit (receive) antenna. The k_j parameters are calculated recursively. First we assume no interference from the other symbols and set $e_j = 0$. This is best suited for the last decoded symbol in VBLAST since all the other symbols would be cancelled out by then. We then calculate k_j and e_j for this stream. Next we substitute the new value of e_j for the next to last decoded symbol and calculate the k_j then update e_j. This process is repeated till all the k_j parameters are calculated. The parameters then can be used to update the channel estimate. The paper will present detailed analysis of the channel update algorithm and the algorithm complexity in terms of the required computing.

Simulation Results

We ran a number of simulations to study the performance of the algorithm. Figures (1) to (2) are for a 2×4 system using PSK and QPSK, packets of 512 symbols (256 per antenna), 1MSymbol/s, 5.9GHz, and various speeds for vehicle to vehicle communications. Initially the algorithm will have perfect channel knowledge, this is necessary to isolate any errors that might arise from the training sequence. As can be seen the performance improves considerably when the algorithm was used. Figures (3) and (4) show the performance of the same system using QPSK with various packet lengths for speeds of 60 and 100 km/hr respectively. As can be seen from the figures, the performance degrades as the packet length increases; this is due to two reasons. The first reason is estimation error. As the estimation process proceeds, the error in the estimation accumulates and for long packets this will lead to erroneous results near the end of the packet. The second reason is detection errors. As the packet length increases the probability of symbol errors increases. The estimation algorithm assumes correct decoding; therefore such errors will affect the performance of the algorithm.

Conclusion

In this paper we developed a simple recursive algorithm to keep track of changes in the channel and update the channel estimation matrix for VBLAST. The update algorithm enhances the channel estimation on a symbol by symbol basis, but this can be relaxed for high symbol rates and/or slow fading as the channel coherence time will be large compared to the symbol duration. Simulation results showed remarkable improvements when using the update algorithm compared to training only channel estimation in terms of packet size and BER. Further work is going on to improve the performance of the algorithm.

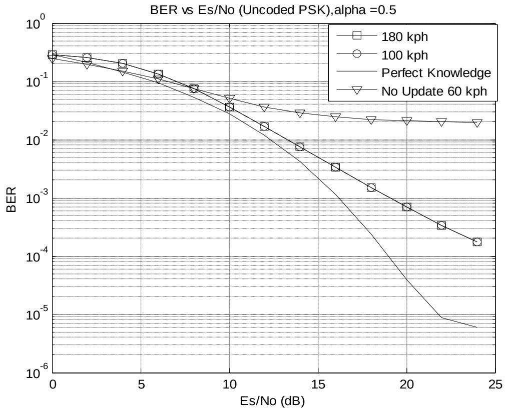

Figure (1): PSK BER performance with and without channel update

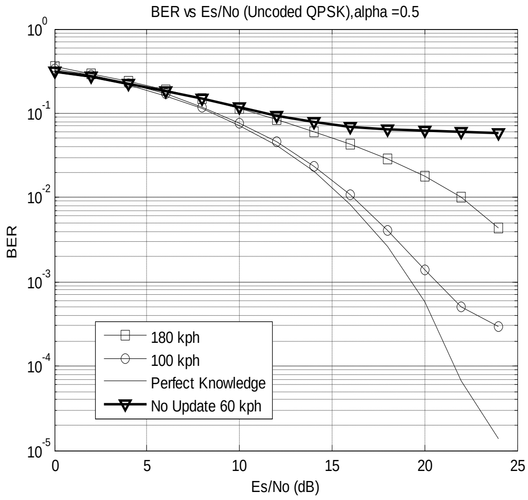

Figure (2): QPSK BER performance with and without channel update

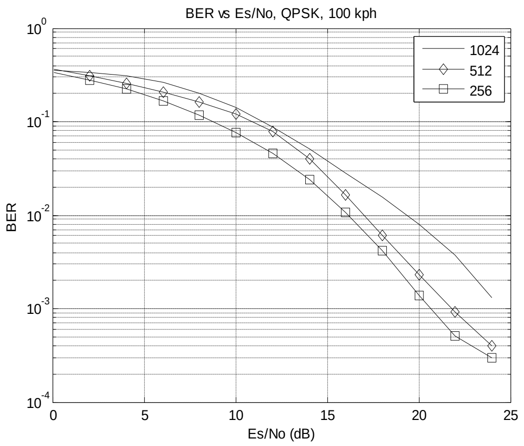

Figure (3): BER for different packet sizes, 100 km/hr

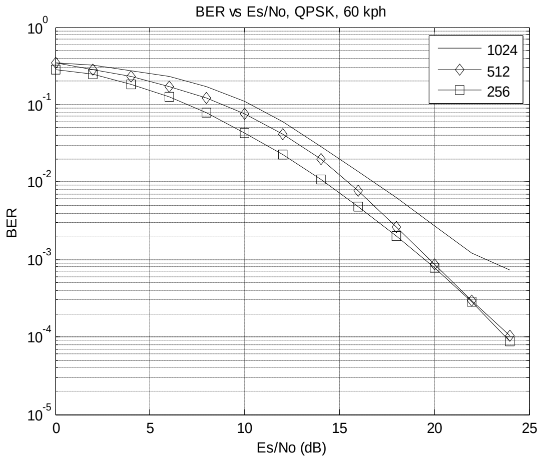

Figure (4): BER for different packet sizes, 60 km/hr

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