AN ENHANCED V-BLAST MIMO SYSTEM USING JOINT SOURCE AND CHANNEL CODING

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Abstract — An enhanced Vertical Bell Laboratories Layered Space-Time (V-BLAST)-MIMO system complemented with joint source and channel coding scheme is proposed. The coding scheme is Rate Compatible Punctured Convolutional Code (RCPC Code) with Unequal Error Protection (UEP) to provide variable gain diversity with single encoder-decoder structure. The proposed system showed an ability to provide better error protection levels to data streams as the code rates decrease, and vice-versa. It is also shown that as the number of antennas increase, the overall system performance is further improved while the range of SNR covered is narrower, suggesting further bandwidth preservation.

Keywords — MIMO system, RCPC, UEP, joint source and channel coding

1. Introduction

Theoretical studies in the past decade have revealed that the multiple antennas used in both the transmitter and receiver sides of a communication link, termed Multiple Input Multiple Output (MIMO) scheme, play a role in increasing the system capacity to an enormous amount as well as handling multipath fading problem [1-3].

Techniques used to exploit the high-capacity nature of a MIMO system include Layered Space-Time architectures, namely Diagonal Bell Laboratories Layered Space-Time (D-BLAST) [3] and Vertical Bell Laboratories Layered Space-Time (V-BLAST) [1]. In these architectures the data stream is demultiplexed so as to yield \( M_t \) substreams with equal transmission rates. All substreams are simultaneously transmitted from \( M_t \) Tx antennas using the entire frequency bandwidth, resulting an increase of the transmission rate by \( M_t \) times. D-BLAST uses a diagonally-layered coding structure to spread code blocks in space and time. This scheme enables the data rates to grow linearly in proportion to the number of antennas [1]. The implementation complexities of D-BLAST triggered the invention of V-BLAST, in which the demultiplexed data stream undergoes the process of independent bit-to-symbol mapping. In V-BLAST architecture inter-substream coding is not required [1]. Encouraged by the simplicity offered by this scheme as well as its capability to realize high spectral efficiency, we investigated the chances of implementing it along with joint source and channel coding to enhance the diversity gain of a MIMO system.

Joint source and coding schemes are not typically covered in literatures about MIMO coding, owing to Shannon Separation Theory [4]. However, more recent researches have reported that the Shannon Separation Theory does not hold for certain conditions [5-6], and thus prompted a number of researches in the area of joint source and channel coding schemes. Unequal Error Protection (UEP) is one of such scheme in which source information is ordered according to its level of urgency and given different error protection levels accordingly. This scheme can be realized using Rate Compatible Convolutional Code (RCPC) which enables a system to assign different code rates as required by a source information, with a single encoder and decoder structure [7].

In [8] a jointly designed source and channel coder is implemented in layered cooperative communication scheme. This scheme provides spatial diversity through the use of antennas that belong to different user terminals, and therefore is similar to MIMO system to some extent. It is shown that the proposed layered cooperation scheme with Gaussian sources and RCPC codes has a significantly reduced end-to-end distortion level. The layered architecture proposed in this research is meant to achieve unequal error protection, in contrast to that of V-BLAST and D-BLAST which aim to increase the spectral efficiency.

A recent research [9] has proposed joint source and channel coding to minimize the expected end-to-end distortion in MIMO system. Again the layered architecture proposed is aimed towards diversity gain rather than multiplexing gain.

In [10] the use of joint source and channel coding as an approach to achieve optimal trade-off between diversity, multiplexing and delay in MIMO system is highlighted. The aims of this research include the derivation of an expression of end-to-end distortion as a function of the optimal point on the diversity-multiplexing tradeoff curve. This work does not specifically address the layered architecture or the type of joint source and channel coding used to attain the above-mentioned optimal figure.

Concluding from these previous works that joint source and channel coding is a significant contributor in terms of optimal
diversity and multiplexing gains in MIMO system, in this paper we propose an improved V-BLAST MIMO system with joint source and channel coding scheme in the form of UEP and RCPC. The theoretical BER is presented and numerical simulation is given as a starting point of the system analysis.

2. V-BLAST MIMO System

Fig. 1 illustrates a V-BLAST MIMO block diagram. The source data stream is demultiplexed and the mapped onto several transmitters by means of a vector encoder. The number of substreams yielded is equal to the number of transmitters, $M_t$, which are independent QAM modulators. The power transmitted by each transmit antennas is scaled to $1/M_t$ so that the total transmitted is constant and independent of $M_t$. In contrast to D-BLAST scheme, in V-BLAST no inter-substreams coding is required to achieve a high spectral efficiency. Our proposed system uses RCPC encoding to provide diversity gain as a complement to the inherent multiplexing gain in original V-BLAST scheme.

3. System Model

The proposed model of V-BLAST MIMO with joint source and channel coding is illustrated in Fig. 2. The input stream for the transmitter is first segregated into blocks with different error-protection requirement. Each block will be coded using certain RCPC code and demultiplexed into $M_t$ substreams, which will in turn QAM-modulated and mapped to $M_t$ transmit antennas before eventually launched into the channel. The puncturing table coupled to the encoder consists of a puncturing matrix by which a mother code processed to yield an RCPC code. The matrix used can be expressed as [7]:

$$ (\delta) 
\begin{bmatrix}
  a_{i1} \\
  a_{i2} \\
  \vdots \\
  a_{iN}
\end{bmatrix} 
\rightarrow 
\begin{bmatrix}
  P \\
  P \\
  \vdots \\
  P
\end{bmatrix} 
\rightarrow 
\begin{bmatrix}
  P \\
  P \\
  \vdots \\
  P
\end{bmatrix} 
\rightarrow 
\begin{bmatrix}
  a_{ij} \\
  a_{ij} \\
  \vdots \\
  a_{ij}
\end{bmatrix} 
\rightarrow 
\begin{bmatrix}
  \delta \\
  \delta \\
  \vdots \\
  \delta
\end{bmatrix} $$

where $P$ is the puncturing period, $N$ is the number of output bits after the encoding process, and $a_{ij}(l) \in (0,1)$ with 0 denotes a puncture. The mother code of rate $R=1/N$ will be processed using the puncturing matrix to attain code rates of

$$ R = P/P+\delta \quad \delta = 1,\ldots,(N-1)P $$

where $\delta$ is the puncturing period, $N$ is the number of output bits after the encoding process, and $a_{ij}(l) \in (0,1)$ with 0 denotes a puncture. The mother code of rate $R=1/N$ will be processed using the puncturing matrix to attain code rates of

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The signal arriving at the receiver is $r = Ha + n$ 

where $H$ is the matrix channel, $a$ is the transmitted symbol vector, and $n$ is the channel noise. The V-BLAST detection process involves the computing of nulling vectors $w_{ki}$, where $S = \{k_1, k_2, \ldots, k_M\}$

is a set of permutation of the integers $1, 2, \ldots, M$, by which order the components of $a$ are extracted. Using Zero-Forcing criterion, the $k_i$-th nulling vector is defined as the unique minimum norm vector satisfying \[ w_{ki}^T (H) k_j = \begin{cases} 0 & j \geq 1 \\ 1 & j = 1 \end{cases} \]  

The output bit stream of a V-BLAST MIMO can be stated as \[ y_{k_1} = w_{k_1}^T (H) k_j a + w_{k_1}^T n \]  

whereas incorporating the RCPC encoding will result a signal of the form

\[ y_{k_1} = w_{k_1}^T \left\{ h_{Mr1} a(\delta_1) + n_1 \right\} + \left\{ h_{Mr2} a(\delta_1/2 + n_2) + \ldots \right\} \]

where $M_r$ is the number of receive antenna and $h_{ij}$ is a component of matrix channel $H$ in the form of chi-squared variants with two degrees of freedom.  

The bit error probability of RCPC codes follows that of a Viterbi criterion \[ P_{b,RCPC} \leq \frac{1}{P} \left( \sum_{d=d_{free}}^{\infty} c_d P_d \right) \]  

in which $d_{free}$ is the minimum free distance of the code, $c_d$ is the total error bits produced by the incorrect paths and $P_d$ is the probability of picking the incorrect path in Viterbi decoding process and is influenced by the modulation type. In this paper, both $d_{free}$ and $c_d$ used are taken from \[7\]. In accordance to V-BLAST scheme, the modulation used in the simulations is QAM with Gray-coded bit assignment. For an even number of
bit per symbol, the probability of bit error per carrier for QAM is

\[ P_{bc} = \frac{4}{t} \left( 1 - \frac{1}{\sqrt{M}} \right) Q\left( \frac{3tE_b}{\sqrt{3(M-1)}N_0} \right) \]  \hspace{1cm} (11)

where \( E_b \) is the energy per bit and \( N_0 \) is the noise spectral density. Taking into account that the probability of bit error is

\[ P_b = 1 - (1 - P_{bc})^2 \]  \hspace{1cm} (12)

the probability of error for RCPC-encoded V-BLAST MIMO system is

\[ P_{RCPC-MIMO} = \frac{1}{P} \left( \sum_{d=0}^{M-1} c_d \left( 1 - \frac{4}{t} \left( 1 - \frac{1}{\sqrt{M}} \right) \right) \right) \]

\[ \left( \frac{1}{2} - \frac{1}{2} \text{erf} \left( \frac{3tE_b}{\sqrt{3(M-1)}N_0} \right) \right) \]  \hspace{1cm} (13)

In this paper we use the formulation of \( tE_b/N_0 \) from [2]

\[ \frac{tE_b}{N_0} = \frac{\rho}{M_t M_r} \sum_{i=1}^{M_r} \sum_{j=1}^{M_t} |h_{ij}|^2 \]  \hspace{1cm} (14)

with \( \rho \) the ratio of the total transmit power to noise power.

4. Simulation Results And Discussion

The simulation results for a V-BLAST MIMO \((M_r, M_t) = (2,2)\) system using RCPC and UEP scheme are shown in Fig.3. The simulations are done for a Rayleigh fading channel using rectangular 16-QAM. A rectangular constellation is chosen due to its ability to be transmitted as 2 PAM signals on quadrature carriers and its advantage of relatively simpler demodulation process. The code rates are varied from 8/9 to 8/24 and the maximum simulated \( d_{free} \) is 10. It can be observed that as the rate of a code decreases, the error-protection level improves consistently. The system can provide a BER level of \( 10^{-7} \) with SNR varying from approximately 9 dB to 16 dB. This indicates that a MIMO link by means of RCPC can attain a gain of up to 7 dB through the reduction of code rates. This reduction will boost the spectral efficiency of the system at the expense of data throughput. Nevertheless the transmission of data with high error protection level is still achievable through the use of lower code rates. Fig. 4 provides the simulation results for \((3,3)\) system. It is shown that the lower code rates consistently outperform the higher ones, signifying the ability of the system to provide better error protection levels to more important data bits. The overall performance is better compared to that of the \((2,2)\) system in terms of lower SNR required to achieve a certain BER figure. Figure 5 further confirms that the use of more transmit and receive antennas will improve the system performance. This improvement is due to the higher transmitter and receiver diversity of the system. However it should be noted that the complexity of transmitter power equalisation grows exponentially with the number of propagation paths between transmitter and receiver, therefore the number of antennas might have to be restricted in system realization. It is also shown that for the system with higher number of antennas the SNR covered is narrower, suggesting an even better spectral efficiency compared to that of a system with fewer number of antennas.

![Fig.3. V-BLAST MIMO(2,2) system with RCPC and UEP](image-url)
5. Conclusion

An enhanced V-BLAST MIMO system with joint source and channel coding has been proposed. The performance of proposed system resulted in a significant enhancement, namely the variable error protection levels provided by the varying code rates are attained in relatively low levels of SNR. It is also shown that the coding scheme provided variable diversity gains to a single MIMO link using a single encoder and decoder structure.

The addition of antenna numbers contribute to better BER performance at narrower SNR range, yet the complexity it introduces has to be taken into account when attempting to realize the proposed system. The proposed system is expected to match the requirement of high robustness and spectral efficiency. Further researches which include performance parameters other than BER, and the implementation of more recent RCPC codes are needed.

REFERENCES