WALSH CODING ACROSS MULTIPLE ANTENNAS FOR HIGH DATA RATE WIRELESS SERVICES

A. C. McCormick, P. M. Grant and J. S. Thompson

Dept. of Electronics & Electrical Engineering
The University of Edinburgh
The King's Buildings, Mayfield Road
Edinburgh, EH9 3JL, Scotland, UK

ABSTRACT

The combination of Walsh coding with a layered space-time architecture is investigated. This provides a system with flexible coding rates and low complexity linear decoding. The codes allow exploitation of the diversity of the multiple antenna channel while allowing code rates up to 1, while still providing a performance improvement over an uncoded system. Simulations provide comparison with repetition coded and uncoded systems.

1. INTRODUCTION

The use of multiple transmit and receive antennas in wireless communication systems has received much attention recently due to the potential for highly spectrally efficient systems [1, 2]. For systems where the channel is unknown at the transmitter, a layered space-time architecture [3] can be employed to achieve a channel capacity far in excess of a single antenna system. In these systems, each data bit is spread across different antennas and across time. In this paper, the spreading across space and time of the data using Walsh codes is investigated as this approach allows many orthogonal Walsh codes to be transmitted in the available bandwidth producing a flexible and adaptable coding structure.

Walsh coding is used in some CDMA systems to provide orthogonal codes for different users. When combined with OFDM as in the case of Multi-Carrier CDMA systems [4], it can allow exploitation of the diversity of the multiple carriers without the channel knowledge required at the transmitter for differentially loading each carrier. If only a single user is assumed, who can be assigned as many codes as is required for the data rate (which can be varied up to a maximum rate of 1), then the Walsh coded system can significantly outperform an uncoded OFDM system and even some convolutionally coded systems due to its exploitation of channel diversity [5]. The spreading across all carriers results in an equal bit error rate for all data bits which is a benefit if packet error performance is important. The decoder structure is a simple linear transform which is much less complex than the Viterbi decoder required for an equivalent strength convolutional code. Quadrature amplitude modulation and M-ary phase shift keying symbols can also be Walsh coded allowing higher data rates if the SNR allows.

A similar approach can be applied in multiple antenna systems where the channel is unknown at the transmitter. In this case the objective is to exploit the diversity of the multiple paths between the transmit and receive antennas. To exploit Walsh coding in a single narrowband frequency, multiple antenna system, the data symbols are spread across multiple antennas instead of across multiple frequencies. There is some correlation between data symbols transmitted at the same time on different antennas, therefore better diversity can be achieved by using a space-time architecture such as the Bell Labs Layered Space Time (BLAST) [3] system to spread the data in space and time, ensuring that each sub-component of the Walsh code is independently transmitted.

In the next section, the combination of Walsh coding with the multiple transmit and receive antenna architecture will be described. Some simulations of the Walsh coded space-time architecture with be shown in section 3, and some conclusions drawn in section 4.

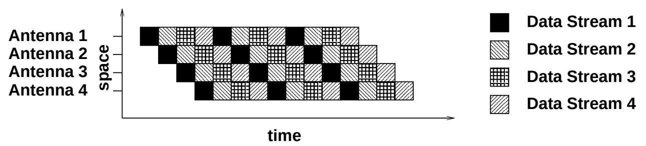

Fig. 1. Transmission of data on Layered Space Time Architecture

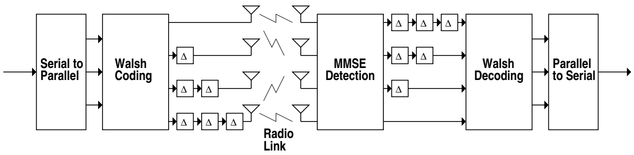

Fig. 2. Walsh Coded Space Time Architecture

2. A WALSH CODED LAYERED SPACE TIME ARCHITECTURE

The multiple transmit and receive antenna architecture supports a variety of possible coding options including convolutional and block coding. In this paper we consider the use of Walsh coding as an alternative approach to allow code rates up to 1 while still exploiting the space-time diversity.

At the transmitter, the data is divided into a number of data streams depending on the number of transmit antennas. Figure 1 shows the distribution of data streams across a 4 antenna system. A data bit from each stream is transmitted on each antenna every time interval. In successive time intervals, the data symbols from the same stream are transmitted on different antennas until the stream cycles round to the first antenna.

At the receiver end, a variety of detection algorithms can be employed to separate out the data streams. These include linear transforms such as the linear decorrelating detector or minimum mean square error (MMSE) detectors, as well as systems which subtract estimated streams such as the D-BLAST and V-BLAST algorithms.

With all these systems, the data streams can be coded. The simplest approach is to use a rate $1/N$ repetition code which can be implemented by repeating each data symbol N times on each stream. This provides diversity by transmitting the data on several or possibly all of the antennas. A single Walsh code also achieves this, transmitting each data bit on N carriers, but with a phase shift of π from certain antennas. However, since Walsh codes are orthogonal, up to N can be transmitted simultaneously in the same data stream thus bringing the code rate back up to 1. At the receiver, due to the effect of the channel, the orthogonality will have been lost, but this can be restored using a decorrelating detector. Unfortunately this detector can amplify the additive noise and therefore a minimum mean square error detector is the preferred linear solution. This however requires no additional computation if an MMSE detector is used to separate the data streams as this also restores the orthogonality within the limits set by the additive noise. However the slight loss in orthogonality means that the performance of a fully loaded system will be worse than the repetition $1/N$ system, but due to the diversity exploitation, the performance should be better than the uncoded system.

Figure 2 shows the architecture of the Walsh Coded space time system. The serial data stream is split into vectors of length M, $1 \leq M \leq N$, where N represents the number of transmit antennas. This is then multiplied by a $(N \times M)$ Walsh-Hadamard matrix containing M length N codes, giving a code rate of M/N. The output of the Walsh coding is then transmitted on the multiple antennas with the signals delayed by an different number of symbol intervals to produce the diagonal distribution of data streams shown in figure 1. These signals are then transmitted across the radio link.

The receiver does not necessarily have to have the same number of antennas as the transmitter, however having more receive antennas than transmit antennas helps performance. The data streams are separated using the MMSE detector, with linear transform [6]:

$$C_{MMSE} = \sqrt{\frac{P}{N}}\mathbf{H}'[\frac{P}{N}\mathbf{H}\mathbf{H}' + \sigma^2\mathbf{I}]^{-1} \qquad (1)$$

where $\mathbf{H}$ represents the channel, P the signal power, $'$ the adjoint matrix operation. This provides an estimate of the symbol transmitted on each antenna at any given time.

The streams are reconstructed into vectors of length N by delaying the MMSE outputs by the appropriate amount. This is then decoded by multiplying the vector by the transpose of the Walsh-Hadamard coding matrix, to provide parallel data output which is then recombined into a single data stream.

3. SYSTEM SIMULATIONS

The performance of the Walsh coded space-time architecture was investigated by performing Monte-Carlo simulations of the system. The channel between the $N = n_T$ transmit and n_R receive antennas was modelled as flat fading, using a $n_T \times n_R$ matrix with elements taken from a Rayleigh distribution. Simulations were performed for systems with 4,8 and 16 transmit and receive antennas.

Simulations were repeated with 5000 to 50000 different channel matrices (more simulations were performed at higher SNR). Each simulation was run for a duration of 128 symbol lengths, with the total number of bits transmitted depending on coding rate and number of antennas, but the minimum number of bits transmitted in a simulation was 640000.

Comparison was made with a repetition coding scheme where each data bit transmitted was repeated over a number of antennas to produce the required rate. The rates were reduced to a minimum rate of $1/N$ where N is the number of antennas. In this case, the Walsh coding system and the repetition coding are the same. At higher rates, the repetition coding uses fewer transmit antennas per bit.

Figure 3 shows the performance of the 4 transmit, 4 receive antenna system. The best performance is achieved with the 1/4 rate code. When the code rate is increased to 1/2, the Walsh code performs slightly better than the repetition code with a coding gain of around 0.5 dB at a BER of 10^{-3}. Increasing the code rate to full rate, however results in the Walsh coding performing 4dB better than the uncoded system at a BER of 10^{-3}.

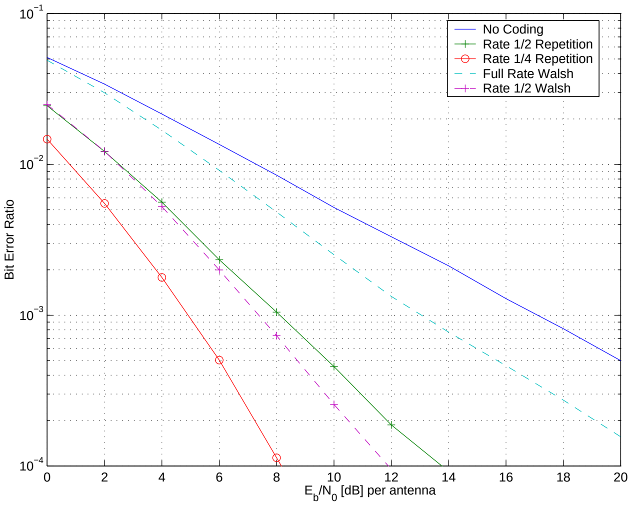

Fig. 3. Performance of Walsh Coding and Repetition Coding using a (4,4) Antenna system

Figure 4 shows the performance of the 8 transmit, 8 receive antenna system. Again some gains are produced compared with the equivalent rate uncoded and repetition coded systems. Similar coding gains are observed at a BER of 10^{-3} of almost 4 dB at full rate and 0.5 dB at 1/2 rate.

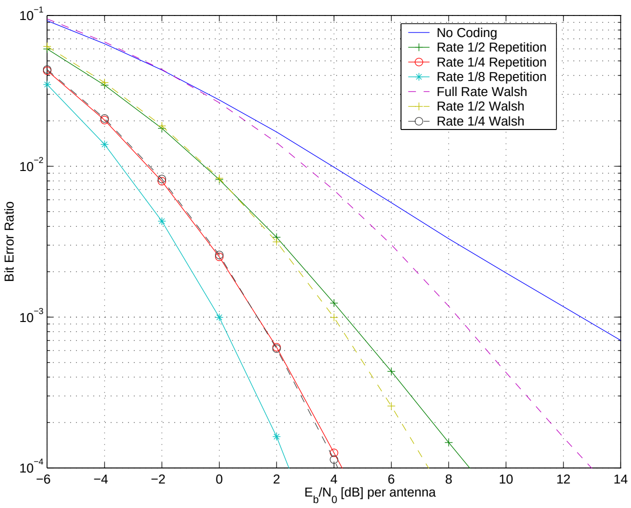

Fig. 4. Performance of Walsh Coding and Repetition Coding using a (8,8) Antenna system

Figure 5 shows the performance of the 16 transmit, 16 receive antenna system. A similar pattern is observed here with the Walsh coded systems providing significant performance improvements at higher data rates.

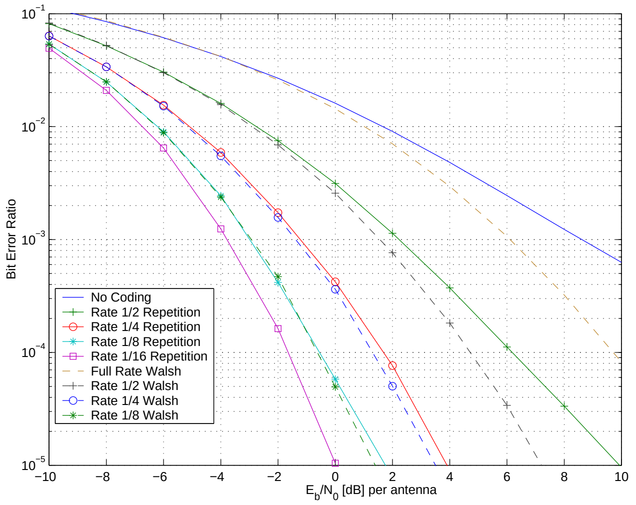

Fig. 5. Performance of Walsh Coding and Repetition Coding using a (16,16) Antenna system

These results indicate that by using Walsh coding and exploiting the diversity, an improvement in performance can be achieved without sacrificing the data rate. Another possible approach for achieving this is through combining modulation schemes with more bits per symbol such as QPSK and QAM with coding schemes. In figure 6, full rate systems are simulated using QPSK combined with a 1/2 rate code (Walsh and repetition) and 16-QAM combined with a 1/4 rate code.

It is clear that the 1/2 rate repetition code combined with QPSK provides better full rate performance than the uncoded full rate system, but does not perform as well as either the Walsh coded BPSK or QPSK systems. Using 16-QAM with a 1/4 rate code however provides a poor solution.

Obviously better performance can be achieved through the use of stronger convolutional codes, but these would require far more complex receiver architectures which may be an important issue if low cost, low power mobile systems are desired. The Walsh codes can also be concatenated with convolutional codes to improve the performance if required.

4. CONCLUSIONS

A layered space-time architecture for communication across multiple transmit and receive antennas incorporating Walsh coding has been described and simulated. This system provides a very flexible range of coding rates which can vary up to a rate of 1. This approach has been shown to provide significant performance improvements over uncoded systems

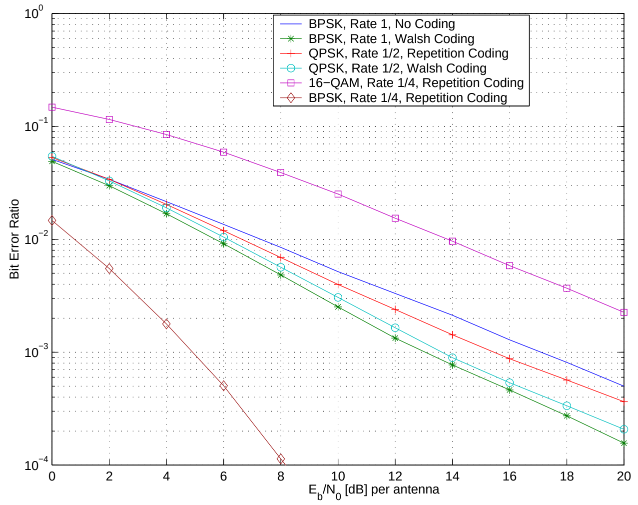

Fig. 6. Performance of Combined QAM and Repetition Coding System using a (4,4) Antenna system

while not requiring a reduction in the data rate. The system therefore has potential uses in systems requiring spectral efficiencies of N bits/s/Hz, where N is the number of transmit and receive antennas, especially in situations where a low complexity receiver is desired.

5. ACKNOWLEDGEMENT

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