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**Abstract** | In [1], efficient MIMO soft packet combining schemes based on Alamouti space-time block code (STBC) were proposed for systems with 2 and 4 transmit antennas. In this contribution, we present a soft packet combining scheme which improves upon the performance of the 4-antenna schemes proposed in [1]. The scheme introduces a unitary transformation prior to space-time block coding. The transformation is taken from a finite predetermined set of matrices and changes upon retransmission request. It is demonstrated that with a simple set of unitary matrices, the scheme provides 5dB and 1.7dB gain for matrix option B and C, respectively.
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Enhancement for 4-antenna soft packet combining scheme using unitary transformation

Eko Onggosanusi, Anand Dabak, and Muhammad Ikram

1. Introduction

In [1], efficient MIMO soft packet combining schemes based on Alamouti space-time block code (STBC) were proposed for systems with 2 and 4 transmit antennas.

In this contribution, we present a soft packet combining scheme which improves upon the performance of the 4-antenna schemes proposed in [1]. The scheme introduces a unitary transformation prior to space-time block coding. The transformation is taken from a finite predetermined set of matrices and changes upon retransmission request. It is demonstrated that with a simple set of unitary matrices, the scheme provides 5dB and 1.7dB gain for matrix option B and C, respectively.

2. The current STBC-based 4-antenna HARQ scheme

STBC-based MIMO HARQ scheme was proposed by Nortel in [1]. The scheme maximally exploits retransmission diversity gain for systems with 2 transmit antennas. For 4-antenna systems, two STBC blocks are used as described below in Figs. 1 and 2 (for matrix option B and C):

![Figure 1: Current 4-antenna HARQ: matrix option B](image1)

![Figure 2: Current 4-antenna HARQ: matrix option C](image2)
3. The proposed 4-antenna HARQ scheme

We propose to introduce unitary transformation prior to space-time block coding. The schemes for matrix option B and C are depicted in Figs. 3-4. The 4x4 unitary transformation \( V \) is taken from a finite predetermined set of matrices \( S = \{ V_0, V_1, \ldots, V_{N-1} \} \). Upon retransmission request (NAK) \( n \) \((n=0,1,\ldots)\), different matrix is chosen from the set \( S \). Given a certain ordering of the set elements, a certain matrix “hopping” pattern (choice of matrix index for the n-th NAK) can be chosen. While the ordering and hopping patterns are arbitrary, we can choose a certain set ordering and a simple hopping pattern. We propose the following simple hopping pattern for option B and C:

\[
\text{Option B : } \quad \text{IDX}(n) = \text{mod}(n,N), \quad n = 0,1,\ldots, L
\]
\[
\text{Option C : } \quad \text{IDX}(n) = \text{mod}\left(\left\lfloor \frac{n}{2} \right\rfloor, N \right), \quad n = 0,1,\ldots, L
\]

Notice that the transformation changes upon every NAK for option B. For option C, the transformation is changed every other NAK since it takes 2 transmissions to form a complete STBC codeword.

The receiver operation at the n-th soft combining stage can be explained as follows. Let \( r(n) \) denote the Q-dimensional received signal vector associated with the n-th retransmission \( n=0 \) indicates the first transmission), where Q is the number of receive antennas. Also, \( h_p(n) \) denotes the channel vector associated with n-th retransmission and p-th transmit antenna. \( V(n) = V_{\text{IDX}(n)} \) is the transformation chosen upon the n-th retransmission. For option C, the composite received signal vector can be written as follows for n=1:
with To 4.

This we find that the following simple 7-element matrix set provides good performance:

\[
\begin{bmatrix}
    r(0) \\
    r(1) \\
    r(2) \\
    r(3)
\end{bmatrix} =
\begin{bmatrix}
    h_1(0) & h_2(0) & h_3(0) & h_4(0) \\
    h_2(1) & -h_1(1) & h_4(1) & -h_3(1) \\
    h_1(2) & h_2(2) & h_3(2) & h_4(2)
\end{bmatrix} V(0) [s_1] + w \quad \ldots (2)
\]

And for n=2:

\[
\begin{bmatrix}
    r(0) \\
    r(1) \\
    r(2)
\end{bmatrix} =
\begin{bmatrix}
    h_1(0) & h_2(0) & h_3(0) & h_4(0) \\
    h_2(1) & -h_1(1) & h_4(1) & -h_3(1) \\
    h_1(2) & h_2(2) & h_3(2) & h_4(2)
\end{bmatrix} V(0) [s_1] + w \quad \ldots (3)
\]

Extension to arbitrary n is straightforward. From (2-3), different spatial interference resistant MIMO receivers can be used. In this contribution we use linear zero forcing (LZF) receiver as in [1]. For option B, the received signal at the 1st retransmission takes the following form (extension to arbitrary n is straightforward), where i denotes the i-th symbol interval in the STBC codeword:

\[
\begin{bmatrix}
    r_i(0) \\
    r_{i+1}(0) \\
    r_i(1) \\
    r_{i+1}(1)
\end{bmatrix} =
\begin{bmatrix}
    h_1(0) & h_2(0) & h_3(0) & h_4(0) \\
    h_2(0) & -h_1(0) & h_4(0) & -h_3(0) \\
    h_1(1) & h_2(1) & h_3(1) & h_4(1)
\end{bmatrix} V(0) [s_1] + w \quad \ldots (4)
\]

Again a host of MIMO receivers is available.

For a given set cardinality N, the elements of matrix set \( S \) can be chosen to maximize the performance at each soft packet combining stage. While an exhaustive search approach can be done for a given N, we find that the following simple 7-element matrix set provides good performance:

\[
V_0 = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}, \quad V_1 = \begin{bmatrix} 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & -1 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{bmatrix}, \quad V_2 = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{bmatrix}, \quad V_3 = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix},
\]

This set can be extended for larger N. The above set of transformations only involves shuffling without any multiplication.

4. Simulation results

To demonstrate the potential gain provided by the proposed shuffling scheme, we simulate the system with minimum number of receive-antennas required for option B and C (2 for option B and 4 for option C). QPSK modulation and linear zero forcing receiver are assumed. Raw bit error rates vs. Eb.N0 are shown in Fig. 5 for option B and 6 for option C. Observe that:

- For option B (4x2), 5dB gain at 1% BER over the scheme in [1] is observed at the \( 3^{rd} \) retransmission (4\textsuperscript{th} transmission).
• For option C (4x4), 1.7dB gain at 1% BER over the scheme in [1] is observed at the 7\textsuperscript{th} retransmission (8\textsuperscript{th} transmission).

The additional gain comes from increased spatial interference averaging due to matrix hopping.

5. Proposed Text Changes

[Additional material in Section 8.4.8.9 under table 314b.

-------- Start text proposal --------

For a given matrix set $S = \{V_0, V_1, ..., V_{N-1}\}$, a matrix is chosen from the set upon the n-th retransmission request (NAK). The following selection pattern is used:

$$IDX(n) = \text{mod}\left(\frac{n}{2}, N\right), \quad n = 0,1, L$$

where the selected matrix is $V_{IDX(n)}$ and $N=7$. The following matrix sets are used:

$$V_0 = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}, \quad V_1 = \begin{bmatrix} 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & -1 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{bmatrix}, \quad V_2 = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}, \quad V_3 = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{bmatrix},$$

$$V_4 = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}, \quad V_5 = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \end{bmatrix}, \quad V_6 = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1 \end{bmatrix}.$$

-------- End text proposal --------

6. References

Figure 5: Enhancement of matrix option B: 4 transmit and 2 receive antennas
Figure 6: Enhancement of matrix option C: 4 transmit and 4 receive antennas.