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Low-complexity transmit diversity scheme using moderate-sized signal constellations

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A Low-Complexity Transmit Diversity Scheme Using Moderate-Sized Signal Constellations

B. K. Khoo, P. Xiao, S. Y. Le Goff, B. S. Sharif, C. C. Tsimenidis

In the conventional space-time coding technique [1], n_T radio frequency (RF) chains are employed to transmit signals simultaneously from n_T transmit antennas. In this Letter, a low-complexity transmit diversity scheme with $n_T = 2$ transmit antennas is proposed. The proposed system employs only one RF chain as well as a low-complexity switch for transmission.

Introduction: Antenna selection scheme was introduced as a low-complexity and low-cost approach for multiple-antenna systems [2]. The idea is to select L antennas out of K antennas $(L < K)$ at the transmitter/receiver side in a way that only L RF chains and a switch are needed in the radio front end. In this Letter, we propose a novel technique to reduce the usage of RF chains in a $n_T = 2$ transmit antennas system. This technique consists of using one RF chain and a low-complexity switch to select the transmit antenna sequentially for transmission. Unlike the antenna selection method, the proposed system does not require any feedback information from the receiver to the transmitter for transmit antenna selection. In what follows, we compare the structure and performance of our proposed system to that of the well-known Alamouti transmit diversity scheme [3].

Alamouti's scheme: Fig. 1(a) illustrates the system model of a conventional Alamouti's scheme using $n_T = 2$ transmit antennas and $n_R = 1$ received antenna. In the classical Alamouti's scheme, at a given time t, signals x_1 and x_2 are transmitted simultaneously from antennas 1 and 2, respectively. Subsequently, at time $t+T$, where T is the symbol duration, signals $-x_2^*$ and x_1^* are transmitted at the same time from antenna 1 and 2, respectively. The received signals after transmission through the wireless channel are given by

$$
\begin{aligned}
y_1 &= y(t) = h_1 x_1 + h_2 x_2 + n_1, \\
y_2 &= y(t+T) = -h_1 x_2^* + h_2 x_1^* + n_2, \qquad (1)
\end{aligned}
$$

where y_1 and y_2 are the received signal at time t and $t+T$, respectively; h_1 and h_2 are Rayleigh fading coefficients; n_1 and n_2 are the white Gaussian noise samples with zero mean and variance σ^2. The two received signals are subsequently combined as follows:

$$\hat{x}_1 = (h_1^* y_1 + h_2 y_2^*)/(|h_1^2| + |h_2^2|),$$
$$\hat{x}_2 = (h_2^* y_1 - h_1 y_2^*)/(|h_1^2| + |h_2^2|). \quad (2)$$

The transmitted signals can be estimated by passing $\hat{x}_1$ and $\hat{x}_2$ to the maximum likelihood detector.

Proposed system: Figs. 1(b) and 1(c) show the block diagram of the proposed system, where two signals are transmitted sequentially from two transmit antennas using one RF chain and a low-complexity switch. At a given time t, antenna 1 is selected to transmit signal x_1 as illustrated in Fig. 1(b). Then, at time $t+T$, antenna 2 is selected and the same signal x_1 is transmitted again as shown in Fig. 1(c). Note that, in order to keep the data rate unchanged compared to the classical Alamouti's scheme, the size of the signal constellation needs to be increased. Assuming the use of an M-ary signal constellation in the classical Alamouti's scheme, the proposed system must employ an M^2-level signal constellation to avoid any loss in the transmission rate. To simplify the power amplifier design, we only consider moderate-sized signal constellations in the proposed system, i.e. QPSK and 16-QAM modulations. Since the proposed system uses only one RF chain and a low-complexity switch, a significant reduction in both complexity and size of the wireless devices can be achieved compared to the conventional space-time coded systems.

In the receiver, a buffer is employed in order to store the signal transmitted from antenna 1 before combining with the signal transmitted from antenna 2. The two received signals are given as follows:

$$y_1 = h_1 x_1 + n_1, \qquad y_2 = h_2 x_1 + n_2, \quad (3)$$

where y_1 and y_2 are the received signals from antenna 1 and 2, respectively. Once both signals from antenna 1 and antenna 2 are received, the maximal-ratio combining scheme is then applied to combine both received signals. Hence, the combined signal is given by

$$\hat{x}_1 = (h_1^* y_1 + h_2^* y_2)/(|h_1^2| + |h_2^2|), \tag{4}$$

and finally sent to a maximum-likelihood detector. Note that the proposed system discussed so far employs two transmit antennas and a receive antenna. It is, however, applicable to any configuration with two transmit antennas and an arbitrary number of n_R receive antennas.

Simulation results: To illustrate the error performance of the proposed system, we consider in this section the proposed system employing either QPSK or 16-QAM modulation. Figs. 2 and 3 illustrate the bit-error rate (BER) versus E_b/N_0 curves, where E_b is the transmitted information bit energy and N_0 is the one-sided noise power spectral density, for the proposed system using Gray-coded QPSK and 16-QAM modulations, respectively. For comparison purposes, the error performances of the BPSK and QPSK Alamouti's schemes are provided in Figs. 2 and 3, respectively. In all cases, both ($n_T = 2$, $n_R = 1$) and ($n_T = 2$, $n_R = 2$) configurations are shown. In order to illustrate the diversity gain, the error performances of the corresponding single-input single-output (SISO) systems are also plotted. To this end, we assume transmissions over uncorrelated Rayleigh flat fading channels with perfect channel state information at the receiver side.

From Fig. 2, we observed that the proposed system with QPSK outperforms the Alamouti's scheme with BPSK by approximately 3 dB for both configurations. It is also illustrated in the same figure that both SISO BPSK and QPSK systems have the same error performance. Thus, the proposed system with QPSK achieves 3 dB gain compared to the Alamouti's scheme using BPSK due to the fact that full/half signal energy radiates at each transmit antenna in the proposed/Alamouti's system. In Fig. 3, the proposed scheme with 16-QAM is compared to the Alamouti's scheme with QPSK. In this case, the error performance of the proposed system is 0.5 dB and 0.7 dB worse than that of the Alamouti's scheme at BER = 10^{-5} for the ($n_T = 2$, $n_R = 1$) and ($n_T = 2$, $n_R = 2$) configurations, respectively. The performance gaps are mainly due to the expansion of the signal constellation, which requires more energy to transmit symbols with the proposed scheme. Unlike the classical Alamouti's system, in which each transmit antenna radiates half of the energy, each of the transmit antenna in the proposed system radiates in full energy since only one antenna operates at any given time. Hence, the additional energy required due to the expansion of the signal constellation is largely compensated.

Conclusion: In this Letter, we proposed a low-complexity transmit diversity scheme using one RF chain and a low-complexity switch to transmit signals from two transmit antennas sequentially. It is demonstrated using computer simulations that, without any bandwidth expansion, the error performance of the proposed system using QPSK (16-QAM) modulation is superior (comparable) to that of the classical Alamouti's scheme with BPSK (QPSK) modulation.

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Figure captions:

Fig. 1 System models. (a) Classical Alamouti's scheme with ($n_T = 2$, $n_R = 1$) configuration. (b) Proposed system with ($n_T = 2$, $n_R = 1$) configuration at given time t. (c) Proposed system with ($n_T = 2$, $n_R = 1$) configuration at given time $t + T$.

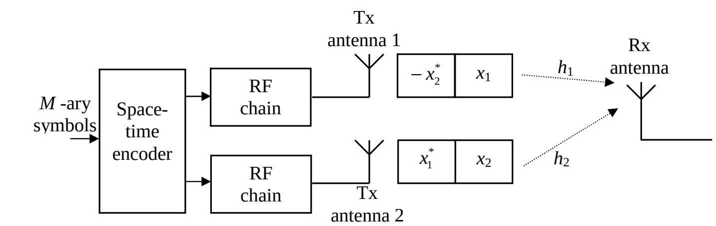
Fig. 2 BER performance comparison between proposed and Alamouti's schemes for ($n_T = 2$, $n_R = 1$) and ($n_T = 2$, $n_R = 2$) configurations. For comparison purposes, the BER curves obtained with SISO BPSK and QPSK systems are also plotted.

◊ BPSK System (SISO)
◯QPSK System (SISO)
△BPSK Alamouti's Scheme (2,1)
□ QPSK Proposed System (2,1)
▲ BPSK Alamouti's Scheme (2,2)
■ QPSK Proposed System (2,2)

Fig. 3 BER performance comparison between proposed and Alamouti's schemes for ($n_T = 2$, $n_R = 1$) and ($n_T = 2$, $n_R = 2$) configurations. For comparison purposes, the BER curves obtained with SISO QPSK and 16-QAM systems are also plotted.

◊ QPSK System (SISO)
◯16-QAM System (SISO)
△QPSK Alamouti's Scheme (2,1)
□ 16-QAM Proposed System (2,1)
▲ QPSK Alamouti's Scheme (2,2)
■ 16-QAM Proposed System (2,2)

Figure 1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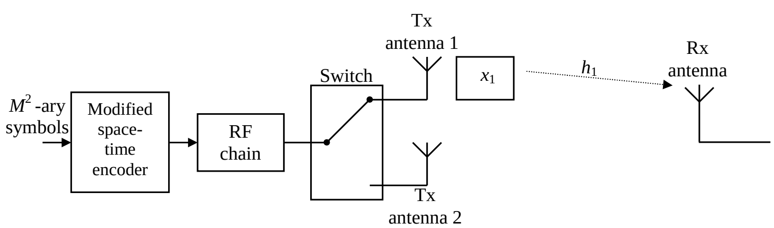
antenna 1
Rx
antenna
M -ary
symbols
Space-
time
encoder
RF
chain
RF
chain
$-x_2^*$
x_1
x_1^*
x_2
h_1
h_2
Tx
antenna 2

(a)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antenna 1
Rx
antenna
Switch
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symbols
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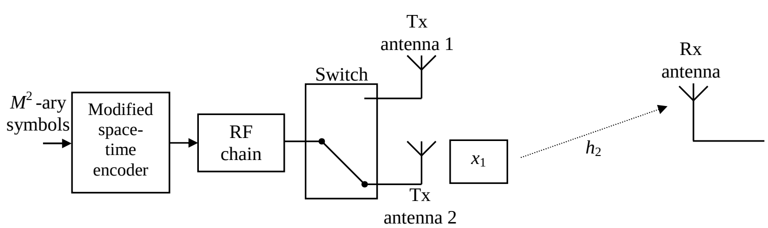
chain
x_1
h_1
Tx
antenna 2

(b)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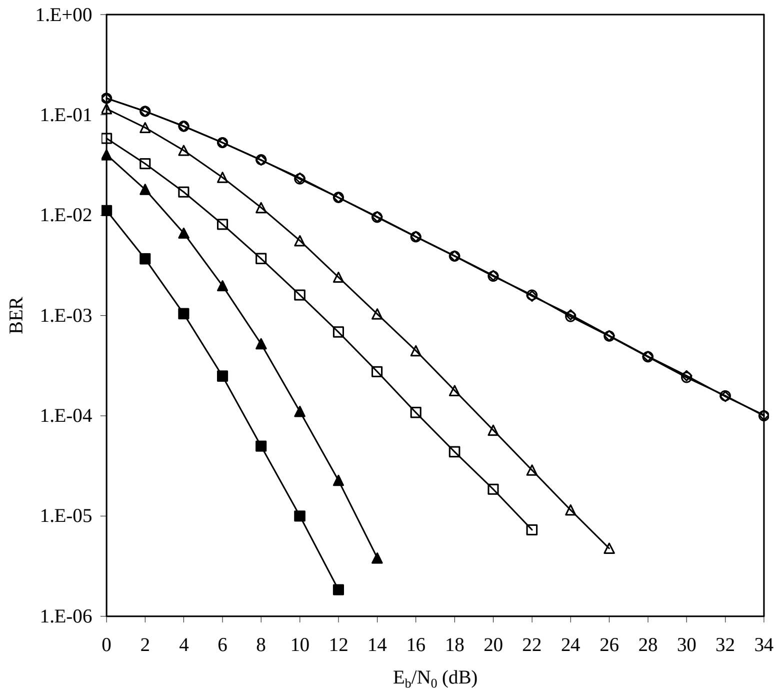
antenna 1
Rx
antenna
Switch
M^2 -ary
symbols
Modified
space-
time
encoder
RF
chain
x_1
h_2
Tx
antenna 2

(c)

Figure 2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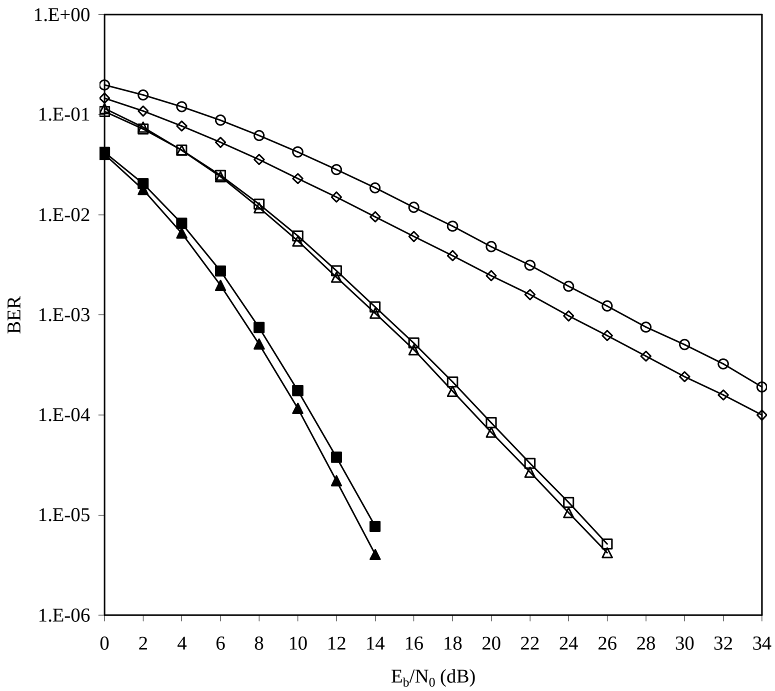
1.E-01
1.E-02
1.E-03
1.E-04
1.E-05
1.E-06
BER
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34
E_b/N_0 (dB)

Figure 3


1.E+00
1.E-01
1.E-02
1.E-03
1.E-04
1.E-05
1.E-06
BER
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34
E_b/N_0 (dB)