Space-Time Shaped Offset QPSK

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ABSTRACT

This paper describes the use of orthogonal space-time block codes to overcome the performance and complexity difficulties associated with the use of Shaped Offset QPSK (SOQPSK) modulation, a ternary continuous phase modulation (CPM), in multiple-input multiple-output telemetry systems. The orthogonal space-time block code is applied to SOQPSK waveforms in the same way it would be applied to symbols. The procedure allows the receiver to orthogonalize the link. The main benefits of this orthogonalization are the easy realization of the transmit diversity for the offset-featured SQOSPK, and the removal of the noise correlation at the input to the space-time decoder and the elimination of I/Q interference when space time orthogonalization is applied to the symbol level.

KEY WORDS

BER (Bit Error Rate), MIMO (Multiple Input Multiple Output), SOQPSK (Shaped Offset Quadrature Phase Shift Keying)

INTRODUCTION

Research on wireless communications through multiple input multiple output antennas over none-selective fading channels has received considerable attention [1-3]. Codes design techniques like space-time block codes [5] and space-time trellis codes [6] with linear modulation have been extensively investigated to provide diversity gains and coding gains.

Space-time coded CPM have received a great deal of interest because of the advantage of bandwidth and power efficiency relative to linear modulation. However, owing to the nonlinearity and
inherent memory in CPM signal, a direct application of results obtained from the linear modulation to the construction of space-time CPM is very difficult [7-8].

In [5], Alamouti space time code was proposed to BPSK and QPSK on the symbol level, which achieved the transmit diversity, and kept the I/Q interference free and noise white. A direct application of Alamouti to SOQPSK was investigated in [7], but the detection complexity, I/Q interference, and colored noise are unavoidable. Alamouti space time code applied to waveform was first reported by Silvester in [1] for general CPM, which obtained transmit diversity and showed the simplicity.

In this paper, in order to overcome the difficulties of I/Q interference and correlated noise at the matched filter outputs, and to achieve a simple way of transmit diversity for SOQPSK, Alamouti orthogonal code is added to SOQPSK frame waveform at the transmitter. While at the receiver, the received signal is stacked according to Alamouti scheme, then the signal can be detected like SISO with real and imaginary parts separately. This simple detector not only keeps the transmit diversity, but also removes the inherent I/Q interference and has about 1.3 dB difference at bit error rate of $5 \times 10^{-3}$ compared with Alamouti QPSK results for a 2 by 1 MISO system.

Section II models the transmitted signal, Section III describes the derivation of the optimum trellis detection. Section IV gives the simulation of the error performance and section V makes the conclusions.

**SYSTEM MODEL**

Let us consider a MISO wireless communication system with 2 transmit antennas and 1 receive antennas. As shown in Figure 1, let $i$ is the transmit antenna index, $k = 0, 1, 2, \ldots$, be the frame index, the $N_F$ binary bit long frame $b_i(k) = [b_i(kN_F + 1), b_i(kN_F + 2), \ldots, b_i(kN_F + N_F)]$ is the input to the mapper to obtain $d_i(k) = [d_i(kN_F + 1), d_i(kN_F + 2), \ldots, d_i(kN_F + N_F)]$, where $d_i(kN_F + n) \in \{-1, 1\}$ is generated by $d_i(kN_F + n) = 1 - 2b_i(kN_F + n), n = 1, \cdots, N_F$. Each binary data stream $d_i(k)$ is then used as input toward its SOQPSK modulator. The modulated SOQPSK signal $X(t, d_i(k)), kN_FT_b \leq t < (k + 1)N_FT_b$ can be written as

$$X(t, d_i(k)) = X(t, a_i(k)) = \sqrt{\frac{E_s}{M_T}} \exp\left(j\phi(t, a_i(k))\right), i = 1, 2,$$

(1)

where $E_s$ is the average symbol energy, $\mu = 1/2$ is the continuous phase modulation index, $q(t)$ is the correspondent phase shaping function defined in [7], $T_b$ is the binary data time interval. The information-bearing phase function is

$$\phi(t, a_i(k)) = 2\pi\mu \sum_{l=1}^{N_F} a_i(kN_F + l)q(t - kN_F - lT_b),$$

(2)
where $a_i(k) = [a_i(kN_F + 1), a_i(kN_F + 2), \ldots, a_i(kN_F + N_F)]$, and the characteristic ternary encoder which is immediately before the standard continuous phase modulator in SOQPSK modulator, can be defined by $a_i(l) \in \{-1, 0, 1\}$

$$a_i(kN_F + l) = (-1)^{(kN_F+l+1)}d_i(kN_F + l - 1)(d_i(kN_F + l) - d_i(kN_F + l - 2))$$

(3)

For a 2 by 1 MISO system, the block of the orthogonal waveform is actually the Alamouti scheme. The orthogonal wave-forming block inserts a conjugate waveform for every new $N_F \times T_b$ long waveform, but different than the Alamouti block coding scheme, the Alamouti transmit scheme here is applied to the modulated waveforms. During $2kN_F T_b \leq t < (2k + 1)N_F T_b$ time interval, $X(t, d_1(k))$ and $X(t, d_2(k))$ are transmitted over antenna 1 and antenna 2, respectively. During the following $(2k + 1)N_F T_b \leq t < (2k + 2)N_F T_b$ time interval, $-X^*(t - N_F T_b, d_2(k))$ and $X^*(t - N_F T_b, d_1(k))$ are transmitted over antenna 1 and antenna 2, respectively.

By doing this, we assume that the channel is quasi-static over $2N_F T_b$ long time interval. For $M_T > 2$, this orthogonal transmit scheme is still possible, but it requires the channel to be quasi-static longer.

**OPTIMUM DETECTOR**

In a MISO or MIMO environment, the complex Gaussian channels and the offset feature of the I/Q waveforms of MSK would unavoidably introduce the interference between inphase and quadrature and also color the white noise, which will severely degrade the performance of the maximum likelihood detector [1].

**Orthogonal Wave-Forming**

In the proposed transmit scheme, we have the transmitted waveform in Alamouti format, so at the receive side, we can use the orthogonal waveform to get rid of the complex rotation of the channel as shown in Figure 2. For $2kN_F T_b \leq t < (2k + 1)N_F T_b$, the received signal $y_{2k}(t)$ is
where the variance of each element in $N_{2k}(t)$ is $N_o$ and $H = [h_1, h_2]$ for a 2 by 1 MIMO system or $H = [h_{11}, h_{12}, h_{21}, h_{22}]$ for a 2 by 2 system. For $(2k + 1)N_FT_b \leq t < (2k + 2)N_FT_b$, the received signal $y_{2k+1}(t)$ is

$$y_{2k+1}(t) = H \begin{bmatrix} -X^*(t - N_FT_b, d_2(k)) \\ X^*(t - N_FT_b, d_1(k)) \end{bmatrix} + N_{2k+1}(t).$$

The receiver forms a rearranged waveform vector $Y(t)$ as

$$Y(t) = \begin{bmatrix} y_{2k}(t) \\ y_{2k+1}^*(t) \end{bmatrix} = H_e \begin{bmatrix} X(t, d_1(k)) \\ X(t, d_2(k)) \end{bmatrix} + \begin{bmatrix} N_{2k}(t) \\ N_{2k+1}^*(t) \end{bmatrix},$$

where $N_{2k}(t)$ and $N_{2k+1}(t)$ are the corresponding complex Gaussian noise respectively. $H_e$ is the equivalent orthogonal MIMO channel matrix. For example, in a 2 by 1 system, it can be written as

$$H_e = \begin{bmatrix} h_1 \\ h_2^* \end{bmatrix}.$$

The orthogonal property of $H^H_e H_e = \|H\|^2_F I$ allows us to multiply the two sides of equation by $H^H_e$ to obtain

$$Z(t) = H^H_e \begin{bmatrix} y_{2k}(t) \\ y^*_{2k+1}(t) \end{bmatrix} + H^H_e \begin{bmatrix} N_{2k}(t) \\ N_{2k+1}^*(t) \end{bmatrix},$$

note that the noise is

$$\begin{bmatrix} \tilde{N}_{2k}(t) \\ \tilde{N}_{2k+1}^*(t) \end{bmatrix} = H^H_e \begin{bmatrix} N_{2k}(t) \\ N_{2k+1}^*(t) \end{bmatrix},$$

which is still white with zero mean and variance $\|H_e\|^2_F N_o I$. We have

$$Z(t) = \|H\|^2_F \begin{bmatrix} X(t, d_1(k)) \\ X(t, d_2(k)) \end{bmatrix} + \begin{bmatrix} \tilde{N}_{2k}(t) \\ \tilde{N}_{2k+1}^*(t) \end{bmatrix},$$

Figure 2: Block diagram of space time SOQPSK Receiver
It is well known that in single input single output (SISO) environment the complex offset QPSK is demodulated by two orthogonal branches of real (in-phase) and imaginary (quadrature) with $T_b$ time offset. In MISO environment, if Alamouti outer code is applied at the transmitter to counteract the rotation of the channels, then at the receiver, we can form a rearranged vector $Y(t)$ as in (6) which leads to a decision statistics $Z(t)$ with a signal gain of $\|H\|^2_F$, we can still split the $Z(t)$ into the branches of real and imaginary and can demodulate the real and imaginary alternately at the receiver.

**MLSD Detector**

It is well known that SOQPSK has an expression as an offset in-phase and quadrature implementation, i.e., for $kN_F + nT_b \leq t < kN_F + (n + 1)T_b$:

$$X(t, d_i(kN_F + n)) = \sum_n \alpha_i(kN_F + n)p_{I(n)}(t - kN_FT_b - (2n - 1)T_b)$$

$$+ j \sum_n \beta_i(kN_F + n)p_{Q(n)}(t - kN_FT_b - 2nT_b),$$

where $p_{I(n)}(t), p_{Q(n)}(t)$ is the time-variant pulse-shaping functions, and

$$\alpha_i(kN_F + n) = d_i(kN_F + 2n - 1);$$

$$\beta_i(kN_F + n) = d_i(kN_F + 2n)$$

$a_i(kN_F + 2n - 1) \in \{-1, 1\}$ and $b_i(kN_F + 2n) \in \{-1, 1\}$ are the odd/even split of the sequence $d_i(kN_F + n) \in \{-1, 1\}$.

As mentioned before, Alamouti scheme is applied to counteract the rotation of the channels, which leads to a signal gain of $\|H\|^2_F$, at the receiver, $Z(t)$ can be divided into the branches of real and imaginary and can be detected in the real and imaginary alternately at the receiver.

The optimum receiver is the maximum likelihood sequence detector (MLSD). Let $Z$ be the input signal as defined in equation (8). The optimum estimation of $\hat{b}$ should satisfy

$$\hat{b}(k) = \arg \min_b \left\{ \int_{(K+1)N_FT_b}^{(K+1)N_FT_b} \|Z(t) - \|H\|^2_F X(t, d(k))\|^2 dt \right\}.$$  

**SIMULATIONS**

In this section, we present some simulation results to verify the proposed scheme above. The frame lengths are 260 binary bits or 130 QPSK symbols. Each spatial channel is modeled as independent complex AWGN quasi-static channel. Because SOQPSK has a huge set of shaping-pulses in in-phase and quadrature, the integrate and dump filter is used as the matched filter in the receiver.
Figure 3 is the simulation results of 2 by 1 antennas. The performance of Alamouti is from [2]. We can see from the slope of the BER curve that the transmit diversity is obtained through the waveform orthogonalization. For BER at $5 \times 10^{-3}$, there is a SNR difference of around 1.3 dB compared with Alamouti QPSK, which is due to the decrease of minimum Euclidean distance in SOQPSK and the Integrate and Dump matched filter performance.

CONCLUSION

In summary, this paper provides a new optimum transmitter and receiver structure for space-time Shaped Offset QPSK. The transmit diversity is achieved which is based on the waveform orthogonalization of the Alamouti scheme. This space-time detector is absolutely guaranteed I/Q interference-free and still keeps the noise white.

REFERENCES


