A Combination of AOC-SS Modulation, Mapping Technique and Space-Time Coding for Variable High-Rate Transmission

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Abstract

AOC-SS (Advanced Orthogonal Code-Spread Spectrum) modulation [1] is a flexible scheme to obtain a multi-rate transmission but PAPR (Peak-to-Average Power Ratio) increases in proportion to the number of AOCs and thus, the mapping technique is proposed to solve this problem. Moreover, by combining with space-time coding (STC), AOC-SS is capable of resistance to multi-path fading. The simulation programs have been performed to verify the validity of the suggested scheme.

1. Introduction

The next generation communication systems are expected to meet a drastically increasing demand of information, communication and entertainment services such as voice, data, image, video and etc, which can be accessed anywhere in anytime. In W-CDMA, Mc (Multi-code)-modulation has been proposed for supporting high data rates as well as multi-media wireless communications, but it has some serious problems. First, it uses typically so many orthogonal sequences [2]-[3] that the hardware complexity to implement increases dramatically. Second, the linear combination of orthogonal codes also creates large amplitude fluctuation (high PAPR) because the amplitude levels constructed by successive "zeros" often appear [2]-[3]. In [1], we investigated and proposed the technique called AOCG (AOC Group) to reduce the number of orthogonal sequences for the high-speed data transmission without increasing the number of OCs (Orthogonal Codes). However, the problem of high PAPR has not been solved yet. In this paper, we add a mapping block right after spread spectrum part by AOCG to map the PAM (Pulse Amplitude Modulation) signal into the M-PSK signal constellation which produces a PAPR of 1.

Obtaining high bit rates at low BER over wireless channel is a difficult task because transmission over wireless and mobile channels is severely restricted by the propagation characteristics of the wireless environment. Recently, the transmit diversity has been studied widely as a method of combating adverse effects in wireless fading channels because of its relative simplicity of implementation and feasibility of having multiple antennas at the base station [4]. Therefore, in order to support the AOC-SS technique in achieving high bit-rate with low BER in fading channels, it is logical to combine it with space time coding (STC). In this paper, we limit the size of STC to 2x2 so as to keep the spectrum efficiency the same as conventional AOC-SS.

The rest of the paper is organized as follows. Section 2 summarizes the conventional AOC-SS to point out its disadvantages. Then, all details on the suggested modulation-coding technique are introduced in part 3 and simulation results are presented in section 4. Finally, the paper is ended with conclusion in part 5.

2. Conventional AOC-SS

AOC-SS modulator can be simply designed by block diagram as shown in Fig. 1a [1], where AOCs is obtained from AOCG of size L×L (see Fig. 2). For example, consider a 8x8 Walsh-Hadamard matrix in Fig. 3, there are two feasible AOCGs with the sizes 2x2 and 4x4 as follows

$$AOCG_{2x2}=\begin{pmatrix}1 & 1\\ 1 & -1\end{pmatrix}$$

$$AOCG_{4x4}=\begin{array}{cl}\begin{pmatrix}1 & 1 & 1 & 1\\ 1 & -1 & 1 & -1\\ 1 & 1 & -1 & -1\\ 1 & -1 & 1 & -1\end{pmatrix} & \begin{array}{l}\longleftarrow \mathrm{AOC}_1\\ \\ \longleftarrow \mathrm{AOC}_3\\ \\ \end{array}\end{array}$$

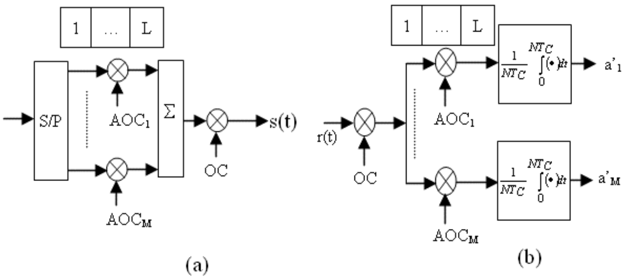


Fig. 1 Block diagram of AOC-SS modem (a) modulator (b) demodulator

Also, OC is constructed by using Hadamard matrix technique which is used in CDMA system as Walsh code of N×N. The duration of OC and AOC is related by $NT_c=LT_{AOC,}$ in which T_c and T_{AOC} represent the duration time of OC and

AOC, respectively.

The output signal of the modulator is given by

$$s(t)=\sum_{m=1}^{M} a_m AOC_m(t)OC(t) \tag{1}$$

where a_m is modulated data-symbol.

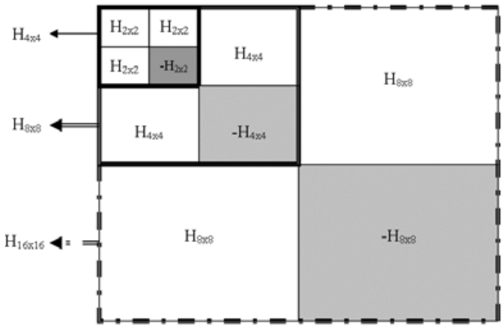


Fig. 2 Construction of WH-matrix and AOCGs (filled areas are the AOCGs for any Hadamard matrix with size NxN)

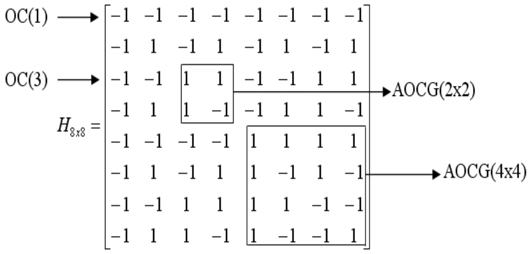


Fig. 3 Example of WH-matrix for OCs and AOCGs

A linear combination of OCs in Eq. (1) yields successive "zero" sequences and thus causing a large amplitude variation which reduces the efficiency of nonlinear amplifiers. The peak power of signal s(t) can be up to M^2.

The demodulation is easily performed by schematic diagram in Fig. 1b as

$$a_m^{'}=\frac{1}{NT_C}\int_0^{NT_C} r(t)OC(t)AOC_m(t)dt \tag{2}$$

in which r(t) is input signal of demodulator and a'$_m$ is recovered symbol of a$_m$.

3. Proposed AOC-SS-STC technique

3.1 Transmitter

Since value of AOC$_m$(t) is unchanged over duration of T$_{AOC}$, we can rewrite Eq. (2) as

$$a_m^{'}=\frac{1}{L}\sum_{l=1}^{L}\left(AOC_m(lT_{AOC})\frac{1}{T_{AOC}}\int_{(l-1)T_{AOC}}^{lT_{AOC}} r(t)OC(t)dt\right) \tag{3}$$

Moreover, Fig. 1a shows that high PAPR of AOC-SS modulator only happens after the summation of AOCs. Therefore, a *(M+1)-PSK* mapping block should be inserted after spread spectrum part by AOCG at the transmitter as in Fig. 4a and a *(M+1)-PSK* demapping block between OCs and AOCs at the receiver (see Fig. 4b). The function of mapping block is to map the PAM signal S$_1$(t) at the output of AOC-spread part into *(M+1)-PSK* signal constellation S$_2$(t) related by the expression

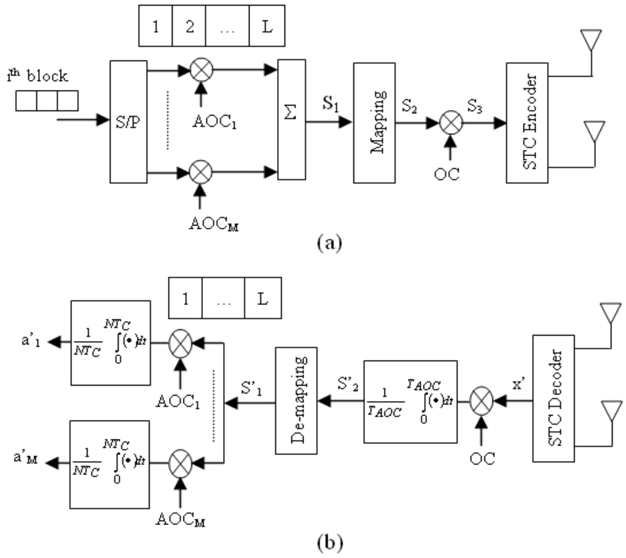
$$S_1(t)=\sum_{m=1}^{M} a_m AOC_m(t) \tag{4}$$

$$S_2(t)=e^{j\pi S_1(t)/(M+1)} \tag{5}$$

Next, the signal S$_2$(t) continues to be spread by OC to generate the following waveform

$$S_3(t)=S_2(t)OC(t)=\sum_{n=1}^{N} S_3(n)p(t-nT_C) \tag{6}$$

where S$_3$(n)=S$_2$(nT$_C$)OC(nT$_C$) and p(t) is the unit-amplitude rectangle pulse with duration T$_C$.



(a)

(b)

Fig. 4 Block diagram of AOC-SS-STC (a) Transmitter (b) Receiver

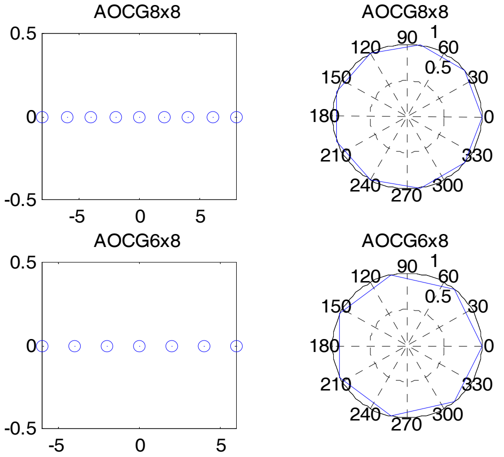


Fig. 5 Mapping for AOCG8x8 and AOCG6x8

AOCG	PAM	-8	-6	-4	-2	0	2	4	6	8
8x8	Phase (⁰)	-160	-120	-80	-40	0	40	80	120	160

Table 1 Look-up table for mapping

Fig. 5 illustrates the mapping mechanism for AOCGs of size 8x8 (M=8, L=8) and 6x8 (M=6, L=8) adopted from 64x64-size Walsh-Hadamard matrix. This mapping scheme guarantees that PAPR at the output of AOC-SS modulator always equals 1 regardless of the number of AOCs.

In many situations, the wireless channel is neither considerably time-variant nor highly frequency selective. As a result, it is appropriate to consider the possibility of deploying multi-antennas at both the transmitter and receiver to achieve spatial diversity which usually uses a class of special codes called space-time coding. Among these codes, the space-time code of size 2x2 [4] is selected because code rate equals 1. This means that the application of STC keeps the bandwidth same as the conventional AOC-SS technique.

STC for two transmit antennas is represented by a transmission matrix [4]

$$STC = \begin{pmatrix} x_1 & x_2 \\ -x_2^* & x_1^* \end{pmatrix} \tag{7}$$

where x_1 and x_2 are two consecutive chips at the input of STC encoder: $x_1=S_3(n)$ and $x_2=S_3(n+1)$.

The signal transmission on two transmit antennas is processed as follows. At the first time slot, x_1 and x_2 simultaneously are sent on antenna 1 and 2. Then, $-x_2^*$ and x_1^* continue to be transmitted on antenna 1 and 2 at the second time slot.

3.2 Channel model

The flat fading channel is usually assumed for most spatial diversity systems in which path gains $\alpha_{i,j}$ from transmit antenna i to receive antenna j are modeled as samples of independent complex Gaussian random variables with zero-mean and are constant during two-chip durations.

3.3 Receiver

The block diagram of AOC-SS-STC receiver is shown in Fig. 4b. It processes the received signal for two consecutive OC chips. These signals are given by

$$\begin{aligned} r_{1,j} &= x_1\alpha_{1,j} + x_2\alpha_{2,j} + n_{1,j} \\ r_{2,j} &= -x_2^*\alpha_{1,j} + x_1^*\alpha_{2,j} + n_{2,j} \end{aligned} \tag{8}$$

where $r_{1,j}$ and $r_{2,j}$ are the received signals at the 1st and 2nd chip times of antenna j; $n_{1,j}$ and $n_{2,j}$ are independent complex Gaussian random variables with zero-mean and variance σ^2.

Then receiver calculates the metric

$$\left|r_{1,j} - \left(x_1\alpha_{1,j} + x_2\alpha_{2,j}\right)\right|^2 + \left|r_{2,j} - \left(-x_2^*\alpha_{1,j} + x_1^*\alpha_{2,j}\right)\right|^2 \tag{9}$$

over all possible codeword pair (x_1, x_2) to find a pair that minimizes Eq. (9).

By expanding Eq. (9), removing the parts independent of x_1 and x_2 and decomposing the resultant metric into two terms, we have

$$\left|\left[\sum_{j=1}^{J}\left(r_{1,j}\alpha_{1,j}^* + \left(r_{2,j}\right)^*\alpha_{2,j}\right)\right] - x_1\right|^2 + \left(-1 + \sum_{j=1}^{J}\sum_{i=1}^{2}\left|\alpha_{i,j}\right|^2\right)\left|x_1\right|^2 \tag{10}$$

for detecting x_1 and

$$\left|\left[\sum_{j=1}^{J}\left(r_{1,j}\alpha_{2,j}^* - \left(r_{2,j}\right)^*\alpha_{1,j}\right)\right] - x_2\right|^2 + \left(-1 + \sum_{j=1}^{J}\sum_{i=1}^{2}\left|\alpha_{i,j}\right|^2\right)\left|x_2\right|^2 \tag{11}$$

for decoding x_2, where J is the number of receive antennas.

With a small thought, if the channel state information is known, the estimation of x_1 and x_2 that minimizes the metrics in Eqs. (10)-(11) can be obtained by

$$x_1' = \sum_{j=1}^{J}\left(r_{1,j}\alpha_{1,j}^* + \left(r_{2,j}\right)^*\alpha_{2,j}\right) \tag{12}$$

$$x_2' = \sum_{j=1}^{J}\left(r_{1,j}\alpha_{2,j}^* - \left(r_{2,j}\right)^*\alpha_{1,j}\right) \tag{13}$$

since the second term of Eqs. (10)-(11) is constant because of constants $|x_1|^2$ and $|x_2|^2$.

Substituting $r_{1,j}$ and $r_{2,j}$ from Eq. (8) into Eqs. (12)-(13), we have

$$x_1' = \sum_{j=1}^{J}\left(\left|\alpha_{1,j}\right|^2 + \left|\alpha_{2,j}\right|^2\right)x_1 + n_1 \tag{14}$$

$$x_2' = \sum_{j=1}^{J}\left(\left|\alpha_{1,j}\right|^2 + \left|\alpha_{2,j}\right|^2\right)x_2 + n_2 \tag{15}$$

where

$$n_1 = \sum_{j=1}^{J} n_{1,j}\alpha_{1,j}^* + n_{2,j}^*\alpha_{2,j} \tag{16}$$

$$n_2 = \sum_{j=1}^{J} n_{1,j}\alpha_{2,j}^* - n_{2,j}^*\alpha_{1,j} \tag{17}$$

Eqs. (14)-(15) show that STC provides exactly performance as the 2J level receive maximum ratio combining.

The effect of noise terms in Eqs. (14)-(15) can be reduced by averaging them over the duration of AOCs T_{AOC} to have S'₂.

$$S_2'(m) = \frac{1}{T_{AOC}}\int_0^{T_{AOC}} x'OC(t)\,dt \tag{18}$$

where x' is a sequence of x'_1 and x'_2 as below.

	x'				
Sequence	x'_1	x'_2	x'_1	x'_2	….
Time	T_C	$2T_C$	$3T_C$	$4T_C$	….

De-mapping to regenerate PAM signal is performed by first finding $S_2(i)$ among all available *(M+1)-PSK* signal constellations so that the Euclidean distance between $S'_2(m)$ and $S_2(i)$ is smallest:

$$\min_{all S_2(i)}\left|S_2'(m) - S_2(i)\right|^2 \tag{19}$$

Then looking-up the position of *(M+1)-PSK* constellation point $S_2(i)$ in the mapping table (see an example in Table 1) will yield the corresponding PAM signals $S'_1(m)$.

Finally, PAM signals are despread once again to recover the original symbols.

$$a_m' = \frac{1}{NT_c}\int_0^{NT_c} S_1'(m)AOC_m(t)\,dt \tag{20}$$

4. Simulation results

The simulation results in this part compare QAM-SS technique [5] and AOC-SS-STC with different sizes of square QAM constellation and the distinct number of transmit and receive antennas but both techniques have the same bandwidth and bit-rate. Moreover, the channel is assumed to be constant over two consecutive chips and OC has length of 64.

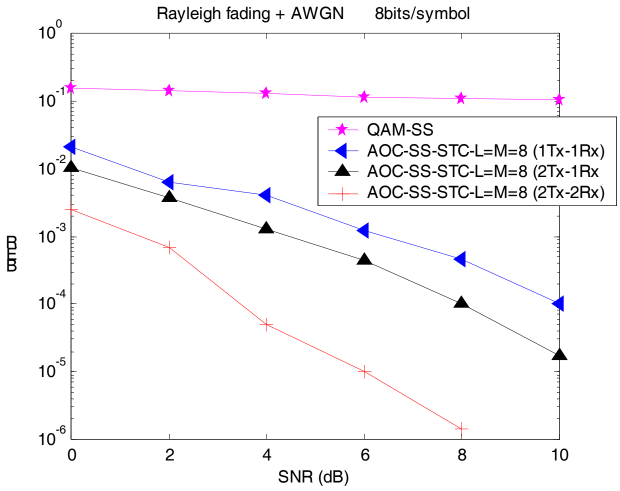


Fig. 6 BER comparison between QAM-SS modulation and AOC-SS-STC

BER performance of 256-QAM-SS modulator shown in Fig. 6 reveals that this modulation technique is significantly degraded by fading while AOC-SS-STC with L=M=8, an equivalent scheme of 256-QAM-SS, can achieve a very high performance with the considerable gain of SNR over it. Furthermore, the proposed technique has another advantage of low PAPR. For 256-QAM-SS, its PAPR is 2.6471 while that of AOC-SS-STC is always 1. Also seen in Fig. 6, the performance of AOC-SS-STC can be improved further by increasing the number of transmit and receive antennas to make the spatial diversity at most so as to remedy the detrimental effect of multi-path fading.

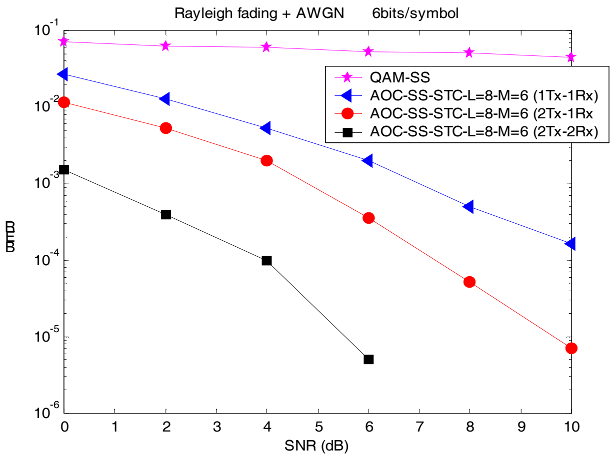


Fig. 7 BER comparison between QAM-SS modulation and AOC-SS-STC

For AOC-SS-STC, it is easy to create a multi-level modulator for variable high-speed transmission by simply changing the length of AOC *L* and the number of parallel branches *M*. As an example in Fig. 7, in order to generate a 64-level modulator as 64-QAM, we only need to choose L=8 and M=6. Fig. 7 also demonstrates that the proposed combination always attains dramatically better performance than QAM-SS and especially, this performance gain accelerates with respect to the number of antennas. The similar remarks can also be deduced from Fig. 8.

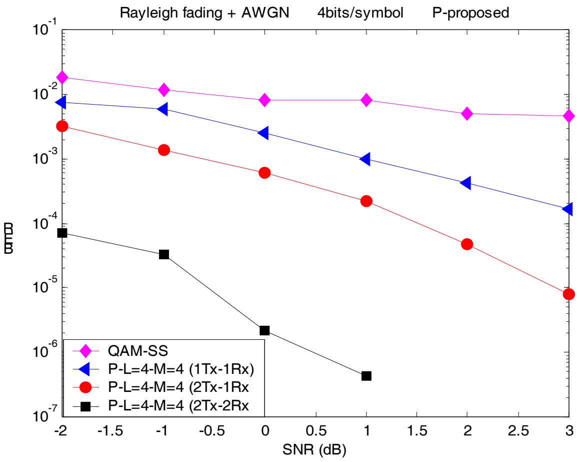


Fig. 8 BER comparison between QAM-SS modulation and AOC-SS-STC

5. Conclusion

AOC-SS modulation technique combined with STC is proposed in this paper. Such new modulation-coding scheme brings about the advantages such as low computation complexity, constant PAPR of 1 and extremely high performance in flat-fading channel. Moreover, this model can create an arbitrary multi-level modulator by alternating two parameters M and L without increasing the transmission bandwidth as well as the number of OC. Therefore, it should be exploited for high-speed transmission and multi-rate services on demand.

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6. References

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