THE JOURNAL OF THE ACOUSTICAL SOCIETY OF KOREA VOL.26, NO.3E 2007. 12 pp. 97~103

Performance Analysis of an Underwater Acoustic Communication System Combining AMC and STBC Techniques

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(Received November 5 2007; Revised December 10 2007; Accepted December 20 2007)

Abstract

We propose a combined STBC (Space Time Block Coding) and AMC (Adaptive Modulation and Coding) in the underwater multipath communication channel. Performance of UAC (underwater acoustic communication) in shallow water is degraded by complicated multipath and reverberation. For this reason, and considering the variability of the ocean channel, we combined STBC and AMC techniques, which are the spatial diversity in a multi-sensor communication system. BER (Bit error rate) of combined STBC and AMC is improved by 5dB when we compare with the BER of a single sensor based system. The proposed system shows a 3dB improvement when we compare it with the BER of the single sensor based system applying the AMC technique only.
Keywords: *UAC, STBC, AMC, BER, multipath, reverberation, diversity*

I. Introduction

Non-coherent transmission methods had mainly been studied for underwater wireless communication until the early 1990's. These do not require information for the phase of a signal. However, coherent transmission methods such as MPSK (M-ary Phase Shift Keying) and QAM (Quadrature Amplitude Modulation), which provide relatively higher transmission rates than the non-coherent method, have been studied recently by many people with the development of both computing power and underwater acoustic signal processing technology [1].

In recent years, an underwater wireless communication system, which has transmission rate of 200~20,000 bps (bits per second) using coherent methods at the distance of 0.06~50 km, has been developed [1]. Researches improving the performance of the communication system are being pursued actively in many countries including the United States. Domestically, KORDI (Korea Ocean Research and Development Institution) succeeded in transmitting acoustic image data with 10,000bps at the distance of 7.4km using QPSK (Quadrature Phase Shift Keying) [2].

The type of data being transferred by underwater communication includes order, control, voice and image data. Voice communication needs O(1 Kbps) rate and low BER of 10^{-2}~10^{-3} with the help of a variety of voice decoding methods [3].

It is difficult to transmit information without errors in shallow water due to various unfavorable circumstances such as ambient noise, the Doppler effect, and multipath effects. Therefore, the MIMO (Multi Input Multi Output) method, which provides both high channel capacity gain and transmission throughput effectiveness under a band-limited and unfavorable channel environment.

This paper simulates an underwater communication channel based on the data of KODC, 2006. All the input

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parameters for our study were calculated using this simulation. Using those parameters, the STBC method, which is robust to the selective fading channel and is appropriate in high data throughput under the band-limited environment, is adopted for our study. We also compared the performance of combined STBC and AMC techniques with the single sensor based system, based on BER capability represented by E_b/N_0. In digital communication, we more often use E_b/N_0, a normalized version of SNR (Signal to Noise Ratio). E_b is a bit energy and can be described as signal power S times the bit time T_b. N_0 is the noise power spectral density, and can be described as noise power N divided by bandwidth W. Since the bit time and bit rate R_b are reciprocal, we can replace T_b with $1/R_b$ and write [4].

$$\frac{E_b}{N_0}=\frac{S\times T_b}{N/W}=\frac{S/R_b}{N/W} \tag{1}$$

Section II describes the theoretical background and section III gives the simulation. A summary will be given in section IV.

II. Theoretical background

2.1. Transmission loss (TL) in the underwater multipath channel

TL in the underwater multipath channel is composed of geometric spreading loss and scattering loss at the surface and bottom. [5] TL by spreading could be defined as equation (2).

$$TL=10\log\frac{I_{(r)}}{I_0}=20\log r+a_a r10^{-3} \tag{2}$$

where $I_{(r)}$ and I_0 are the intensities of the sound at the distance of 1m and r from the source, respectively. The absorption coefficient, α_a, of sound, when f(kHz) is frequency of sound, is

$$a_a \simeq 3.3\times 10^{-3}+\frac{0.11f^2}{1+f^2}+\frac{44f^2}{4100+f^2} + 3.0\times 10^{-4}f^2 \tag{3}$$

and the absorption coefficient at the sea surface ,α_s, is

$$a_s=-10\log[1-0..234(fH)^{\frac{3}{2}}] \tag{4}$$

where H(ft) is an average wave height. When the acoustic impedance at the medium-1 and medium-2 are Z_1 and Z_2 respectively, the absorption coefficient at the bottom, α_b, can be defined as

$$\alpha_b=-20\log_{10}|R| \tag{5}$$

where R, the reflection coefficient is given as

$$R=\frac{Z_2/Z_1\sin\theta_i-\sin\theta_t}{Z_2/Z_1\sin\theta_i+\sin\theta_t} \tag{6}$$

where θ_i and θ_t are the incident and transmitted angle, respectively.

2.2. Space Time Block Coding techniques

In order to ensure effective communication in the band limited UAC, a specific technique which can provide a good BER and adapt to the underwater channel variability, is required. The STBC technique of multi-sensor techniques proposed by Alamouti, is a good candidate for this purpose. [6]

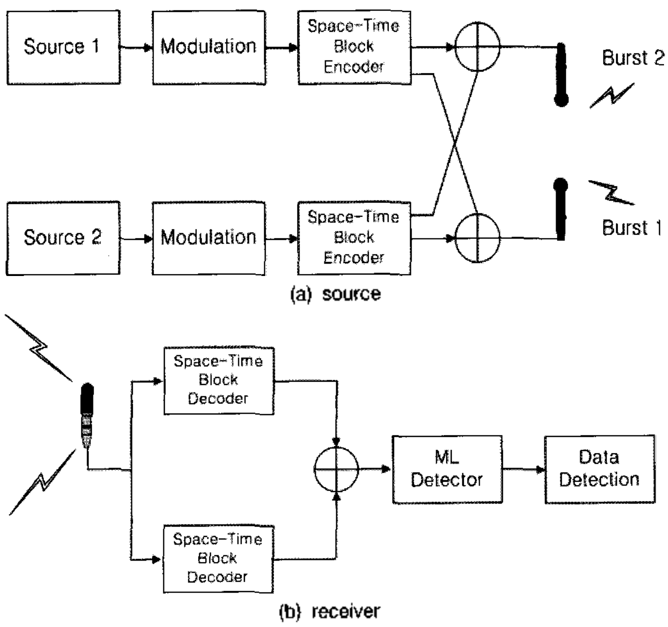


Fig. 1. 2Tx-1Rx STBC system architecture.

Figure 1 shows the structure of the 2Tx−1Rx STBC based UAC system, which has two transmitters and one receiver. A signal modulated at the transmitter end is transmitted to the each sensor of the receiver after encoding at the Space−Time Block Encoder as shown in Table 1. If we consider that h_1 and h_2 are channels, through which signals generated by the first and second transmitter are transmitted, the fading channels are assumed to not vary according to time during the two consecutive symbol's periods. [7]

When we know h_1 and h_2 at the receiver end of the STBC, each signals $r(0)$, $r(T)$ at Time 1(0) and at Time 2(T) received after T seconds can be estimated as

$$r(0)=h_1 * s_1 + h_2 * s_2 + n(0) \tag{7}$$

$$r(T)=-h_1 * s_2^* + h_2 * s_1^* + n(T) \tag{8}$$

where n is the Additive White Gaussian Noise (AWGN) and s_1, s_2 is the origin signal. The received signals are separated for detection by signal processing at the decoder block of the STBC as

$$y_1 = h_1^* * r(0) + h_2 * r^*(T) \tag{9}$$

$$y_2 = h_2^* * r(0) - h_1 * r^*(T) \tag{10}$$

Table 1. 2Tx-1Rx STBC code architecture.

	Antenna 1	Antenna 2
Time 1 (0)	s_1	s_2
Time 2 (T)	$-s_2^*$	s_1^*

* : Conjugate

Putting equations (7) and (8) into (9), and (10) result in

$$y_1 = \left(|h_1|^2 + |h_2|^2\right)s_1 + h_1^* * n(0) + h_2 * n^*(T) \tag{11}$$

$$y_2 = \left(|h_1|^2 + |h_2|^2\right)s_2 + h_2^* * n(0) + h_1 * n^*(T) \tag{12}$$

Therefore, if we divide equations (11) and (12) with $|h_1|^2+|h_2|^2$, we will be able to get the coded s_1 and s_2 at the transmitter end of the STBC. Since we assumed that we have a priori knowledge for h_1 and h_2, we will be able to ideally decode the STBC signals. [7]

2.3. Adaptive Modulation and Coding techniques

Much gain is possible through proper adjustment of the transmitting parameters according to the channel variability in UAC. AMC is a potential candidate for this purpose. The structure of the AMC is proposed as shown in figure 2. Data at the transmitter end is transmitted after channel coding, interleaving, and modulation. At the receiver end, the environment of the channel is estimated from the signal which has come through the underwater communication channel and the optimum coding rate and modulation scheme for the MCS(Modulation and Coding Scheme) is selected. [8] [9] [10]

Adaptive modulation coding techniques use different modulation methods depending on distance, which is defined as E_b/N_0. AMC employs 16 QAM over short distances where E_b/N_0 is high or 1/4 rate QPSK as distances increase. In so doing, effective transmission of a signal is possible.

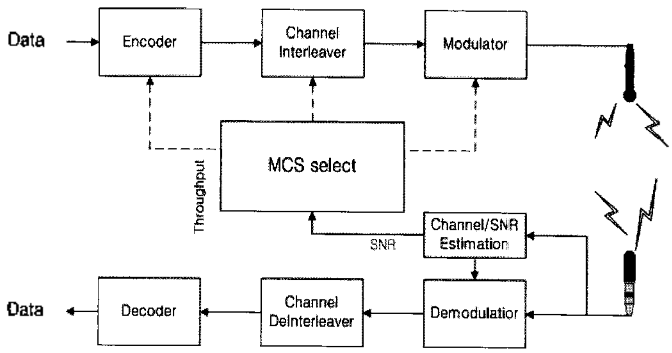


Fig. 2. AMC system architecture.

2.4. Combined STBC and AMC

The concept of the STBC system is expressed as following equation,

$$\begin{bmatrix} r_0 \\ r_1 \end{bmatrix} = \begin{bmatrix} S_0 & S_1^* \\ S_1 & S_0^* \end{bmatrix} \begin{bmatrix} H_0 \\ H_1 \end{bmatrix} \tag{13}$$

Equation (13) shows a transmission process of the STBC system which has two transmitter and one receiver. During the first symbol time, S_0 is transmitted at the first sensor and S_1^* at the second sensor. During the second symbol time, S_1 is transmitted at the first sensor and S_0^* at the second sensor, where S_1^* and S_0^* are transmitted through the channel H_1 and S_0 and S_1 are transmitted

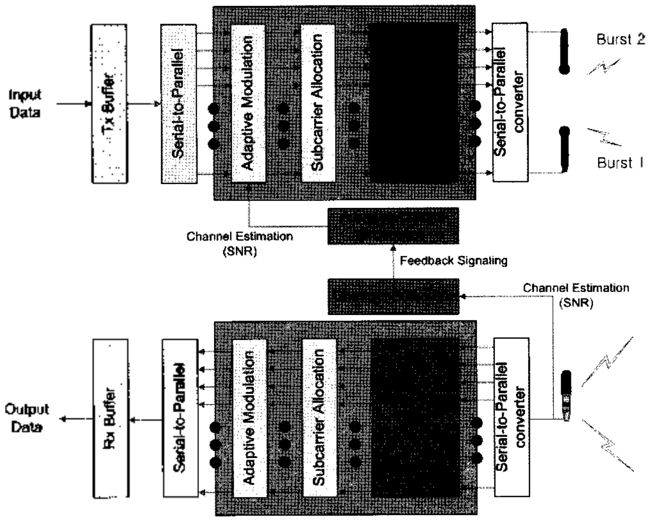


Fig. 3. Block diagram of the combined STBC and AMC system.

through the channel H_0.

When we apply AMC to the STBC, each sensor of the transmitter sends symbols of the same MCS level. The reference modulation level is mostly decided by the lowest value of the sensor's SNR value. Combined STBC and AMC system applies appropriate modulation level and coding rate to H_0 and H_1 depending on the UAC channel conditions.

The figure 3 shows the block diagram of the 2Tx−1Rx for the combined STBC and AMC.

III. Simulation

3.1. Underwater acoustic channel (UAC)

In this paper, the SVP (Sound Velocity Profile) is obtained using the water temperature data of KODC (Korea Oceanographic Data Center), obtained in April, 2006. Using this, an UAC is simulated using Ray theory.

As shown in Figure 4−a, the depth of source and receiver is 50m and 100 m, respectively and the distance between the source and the receiver is assumed to be 1 km.

The SVP is estimated using equation (14),

$$c = 1449 + 4.6T - 0.055T^2 + 0.0003T^3 + (1.39 - 0.012T)(S-35) + 0.017Z \quad (14)$$

where T is the temperature , S is the salinity and Z is the depth (m). S is assumed to be 35ppt through out the water column.

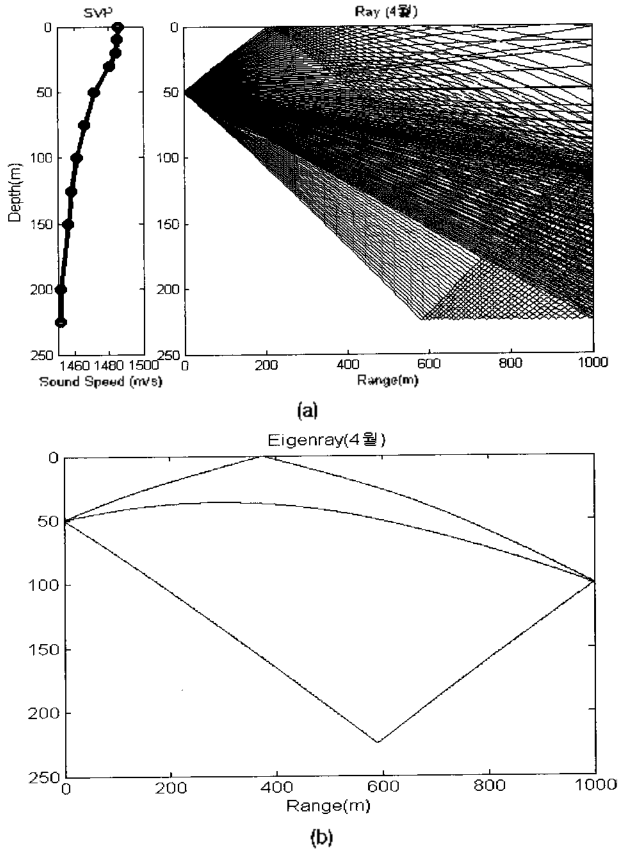


Fig. 4. April in the East sea (a)SVP, Ray (b)Eigen ray.

Figure 4−b shows the three eigen rays arriving at the receiver. TL (Transmission Loss) of the eigen rays was estimated by the sum of spreading loss and scattering loss from the bottom and surface of the sea. Input parameter values for the eigen rays are listed in Table 2. TL for the three eigen rays, arriving at the receiver sequentially, is 60 dB and is shown in figure 5. Simulation results are presented in Table 3. When we define the intensity of the signal as it arrived at the receiver as $a_i, i=1,2,3$, where i the eigen rays number, as equation (15)

$$\begin{aligned} a_1 &= 0.001361 \\ a_2 &= 0.0007028 \\ a_3 &= 0.0010389 \end{aligned} \quad (15)$$

and using equation (16)

$$S = a_1^2 + a_2^2 + a_3^2 = 3.42556e^{-6} \quad (16)$$

we will be able to get the normalized intensity of the signal, b_i, $i=1,2,3$, for the eigen rays.

$$b_1 = a_1/S = 0.735346798$$
$$b_2 = a_2/S = 0.379722065 \quad (17)$$
$$b_3 = a_3/S = 0.561316524$$

Figure 6 shows the normalized intensity of the signal for the eigen rays as it arrived at the receiver.

Table 2. Input parameter values for Eigen rays.

No	Frequency [kHz]	H [ft]	Range [m]	Transmission Loss [dB]	Up bounce	DOWN bounce
1	1	•	1003.9	60.0693	0	0
2	1	1.65	1011.7	60.2107	1	0
3	•	•	1044.1	60.3748	0	1

Table 3. Result of simulation.

No	Arrival Time [s]	Range [m]	TL [dB]	Arrival Amplitude	Up bounce	DOWN bounce
1	0.68216	1003.9	60.0693	0.00136	0	0
2	0.68469	1011.7	60.2107	0.00070	1	0
3	0.71655	1044.1	60.3748	0.00103	0	1

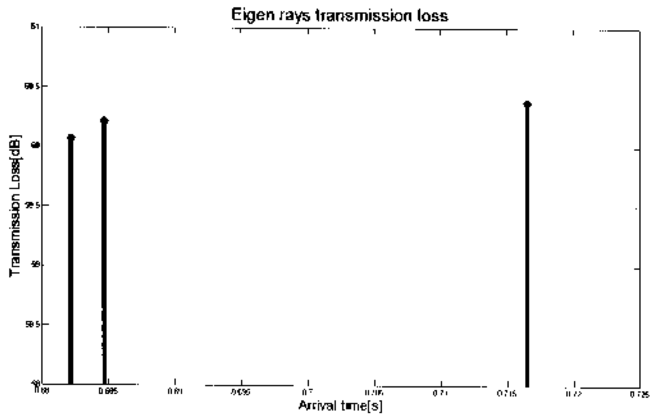


Fig. 5. eigen rays transmission loss on East sea.

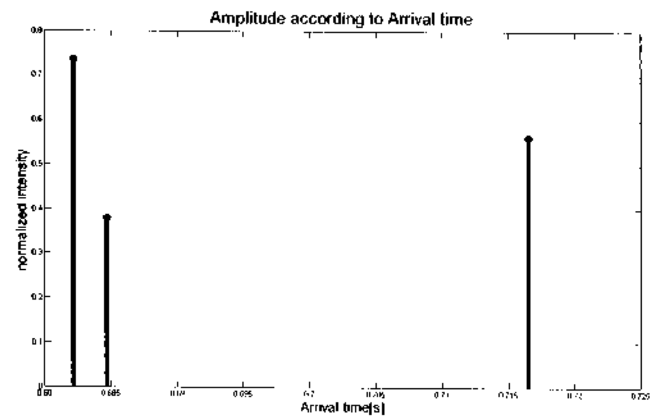


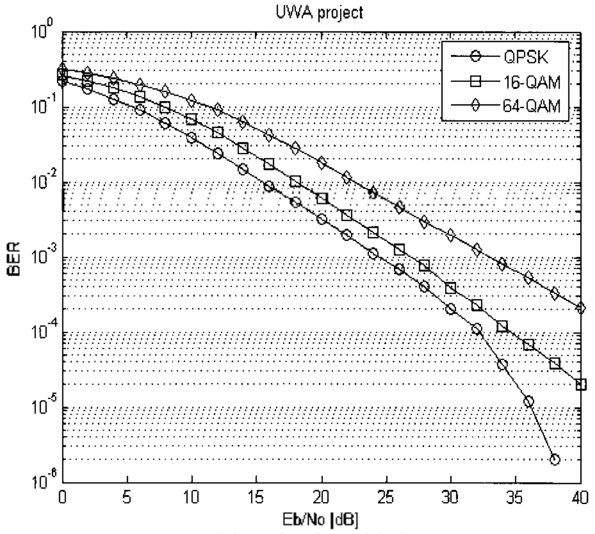
Fig. 6. Amplitude According to Arrival time.

3.2. Analysis of STBC performance

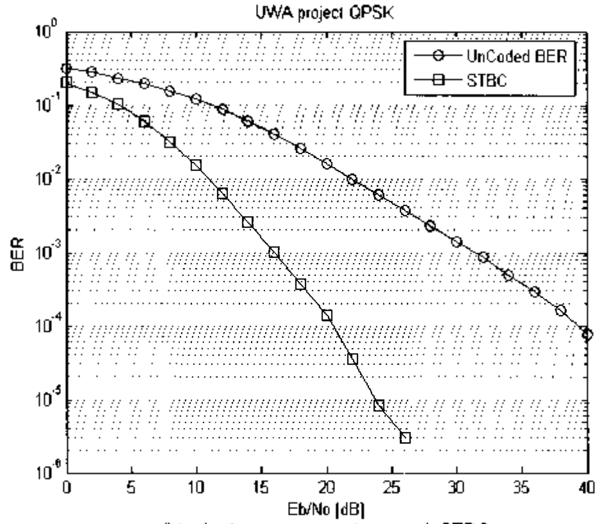
Arrival time (τ) and the normalized intensity of the signal are used as input parameters in order to analyze the performance of the STBC techniques. The number of the original bit (n) is set to 100 and modulation order(M) was variably from 4, 16, or 64. The number of bits per symbol (k) is given as equation (17)

$$k = \log_2(M) \quad (17)$$

As conditions for simulation, Rayleigh fading and AWGN are adopted. The UAC system is composed of a single carrier frequency based system. Figure 7-a shows the BERs represented by E_b/N_0 based on different modulation methods. QPSK (Quadrature Phase Shift Keying), 16-



(a) each of modulation



(b) single sensor system and STBC

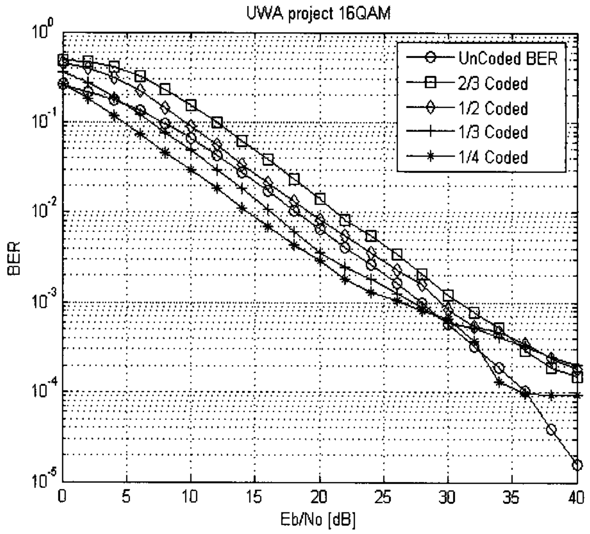
Fig. 7. Underwater Communication BER performance.

QAM (Quadrature Amplitude Modulation), and 64-QAM were used for the simulations. As a result, when BER was fixed at 10^{-2} to 10^{-3}, QPSK outperformed both 16-QAM and 64-QAM by 2.5 dB and 7.5dB, respectively. Therefore, the QPSK method, which has a lower BER than any other modulation method, was employed as a candidate for the 2Tx-1Rx STBC system in our study. Comparison of performance between an STBC based system and a single sensor based system is shown in figure 7-b. In the case of a BER of 10^{-3}, as shown in figure 6-b, the STBC based system is 14 dB better than the single sensor based system.

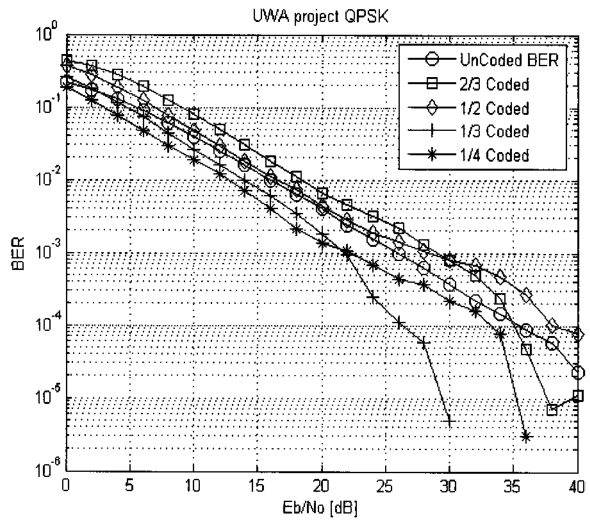
3.3. Analysis of AMC performance

Under the assumption that channel estimation and synchronization are perfectly accurate, the input parameters for analysis of AMC performance were the same as those of STBC case. QPSK and 16-QAM were employed for the analysis due to their low BER, as shown in Figure 7-a. The convolution code was employed for channel coding. Coding rate is shown in Table 4 and results of the simulation for different modulation methods are shown in figure 8.

In the case of a BER of 10^{-3}, as shown in figure 8, the 1/4 coded BER is about 2.5 dB better than the un-coded BER.



(a) 16-QAM



(b) QPSK

Fig. 8. BER performance of AMC techniques.

Table 4. Modulation and Coding Scheme.

Modulation	Convolution code rate	Modulation	Convolution code rate
QPSK	1/2	16-QAM	1/2
QPSK	1/3	16-QAM	1/3
QPSK	1/4	16-QAM	1/4
QPSK	2/3	16-QAM	2/3

IV. Summary and results

In this paper, we proposed methods to improve the BER performance of the UAC systems by combining the STBC method, a space diversity method in the multipath UAC channel, with the AMC method.

As the figure 9 indicates, when the BER was fixed at 10^{-3}, the BER performance of the AMC method is 2 dB better than the non-coding system. Furthermore, the BER performance of the combined STBC and AMC method is 5dB better than the single sensor based system.

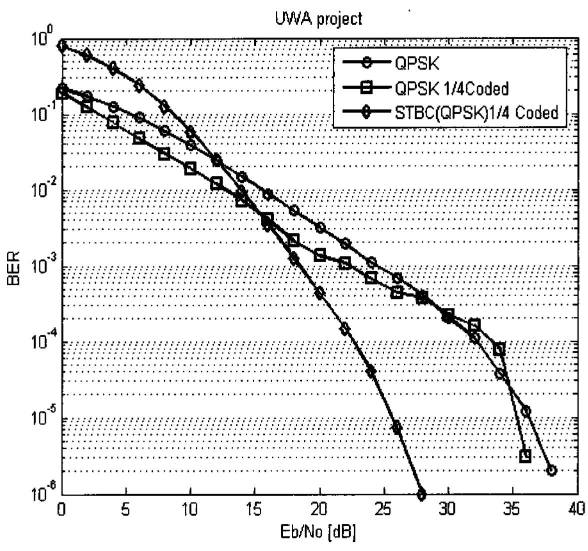


Fig. 9. Result of combined STBC and AMC.

Acknowledgment

This work was supported by the Soongsil University Research Fund.

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[Profile]

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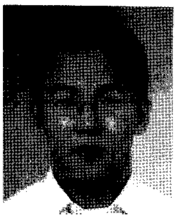

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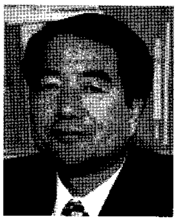

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