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DIRECT MAPPING OVSF-BASED TRANSMISSION SCHEME FOR UNDERWATER ACOUSTIC MULTIMEDIA COMMUNICATION

Chin-Feng Lin
Department of Electrical Engineering, National Taiwan Ocean University, Keelung, Taiwan, R.O.C, lcf1024@mail.ntou.edu.tw

Jiang-Yao Chen
Department of Electrical Engineering, National Taiwan Ocean University, Keelung, Taiwan, R.O.C

Ya-Ju Yu
Department of Electrical Engineering, National Taiwan Ocean University, Keelung, Taiwan, R.O.C

Jung-Ting Yan
Department of Electrical Engineering, National Taiwan Ocean University, Keelung, Taiwan, R.O.C

Shung-Hyung Chang
Department of Microelectronic Engineering, National Kaohsiung Marine University, Kaohsiung, Taiwan, R.O.C.

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DIRECT MAPPING OVSF-BASED TRANSMISSION SCHEME FOR UNDERWATER ACOUSTIC MULTIMEDIA COMMUNICATION

Chin-Feng Lin*, Jiang-Yao Chen*, Ya-Ju Yu*, Jung-Ting Yan*, and Shung-Hyung Chang**

Key words: OVSF, power assignment, underwater acoustic multimedia communication.

ABSTRACT

Underwater communication networks are currently being developed for use in underwater control systems, underwater telemetry systems, and underwater image transmission systems. The transmission bandwidth and transmission rates of an underwater communication system are low, and its transmission delay is high. In this paper, we propose a direct mapping orthogonal variable spreading factor (OVSF)-based transmission system for underwater acoustic multimedia communication. An important feature of this transport architecture is that a power assignment mechanism, an OVSF scheme, a direct mapping strategy, an unequal error protection scheme, and adaptive modulation are employed for transmitting messages that can tolerate various bit error rates. For confirming the effectiveness of this transport architecture, we perform a simulation using measured data of a G.729 audio signal and a JPEG2000 image signal. The simulation results show that the proposed system can achieve maximum transmission data rates or minimum transmission power. In addition, the OVSF-based transport architecture is a feasible platform in underwater acoustic multimedia communication.

I. INTRODUCTION

A major part of the earth's surface is covered by the ocean. Deep oceans are popularly known as inner space. Humans have often enthusiastically explored this inner space in order to gain a better understanding of the underwater world. A popular and interesting area of research is underwater acoustic communication [1-3, 5-6, 8-9, 11, 15-18, 20-21, 24]. At present, underwater acoustic transmission system can be used to issue command/control instructions in underwater systems, to measure transmission data of underwater measurement instruments such as sonar systems, and to transmit underwater images. It is similar to land communication using multiple access schemes. Examples of multiple access schemes include frequency division multiple access (FDMA), time division multiple access (TDMA), spread spectrum technique, and orthogonal frequency division multiplexing (OFDM). However, due to a harsh underwater environment, underwater communication faces some unique problems such as limited bandwidth, high and variable propagation delays, high bit error rates (BER), and severe frequency-selective distortion caused by multipath propagation. Spread spectrum communication is considered as a candidate technique for use in future mobile underwater acoustic networks. Its advantages include efficient use of bandwidth, flexible guard band as compared to that in FDMA, and less stringent synchronization requirements as compared to those in TDMA. In the past, various studies have been conducted to investigate the technologies used in underwater acoustic communication systems. Authors proposed an underwater adaptive-array receiver structure in which direct-sequence code division multiple access (DS-CDMA) and spatial diversity combining are used for achieving reliable low-data rate multiuser communication in an asynchronous shallow-water network [24]. In [5], the authors found that in underwater acoustic networks, the performance of a direct-sequence spread spectrum system is better than frequency-hopping spread-spectrum system in terms of the transmission BER. In [9], the authors use DS-CDMA and multi-carrier CDMA to achieve reliable multiuser communication in asynchronous shallow-water acoustic networks. In DS-CDMA, spread data are transmitted at a single carrier frequency. In contrast, in MC-CDMA, a set of carrier frequencies is used to achieve frequency diversity. In [9], the authors found that for low signal-to-noise ratios (SNRs), the performance of the DS-CDMA system was better than that of the MC-CDMA system and for SNR values higher than 20 dB, the MC-CDMA system outperformed the DS-CDMA system due to the frequency diversity of the former system. In [21], the authors proposed a multichannel detection method and an efficient channel-estimation-based multiuser detection method for wideband underwater acoustic CDMA communication. In

Paper submitted 10/29/08; revised 06/29/09; accepted 06/30/09. Author for correspondence: Chin-Feng Lin (e-mail: lcf1024@mail.ntou.edu.tw).
**Department of Electrical Engineering, National Taiwan Ocean University, Keelung, Taiwan, R.O.C.*
***Department of Microelectronic Engineering, National Kaohsiung Marine University, Kaohsiung, Taiwan, R.O.C.*

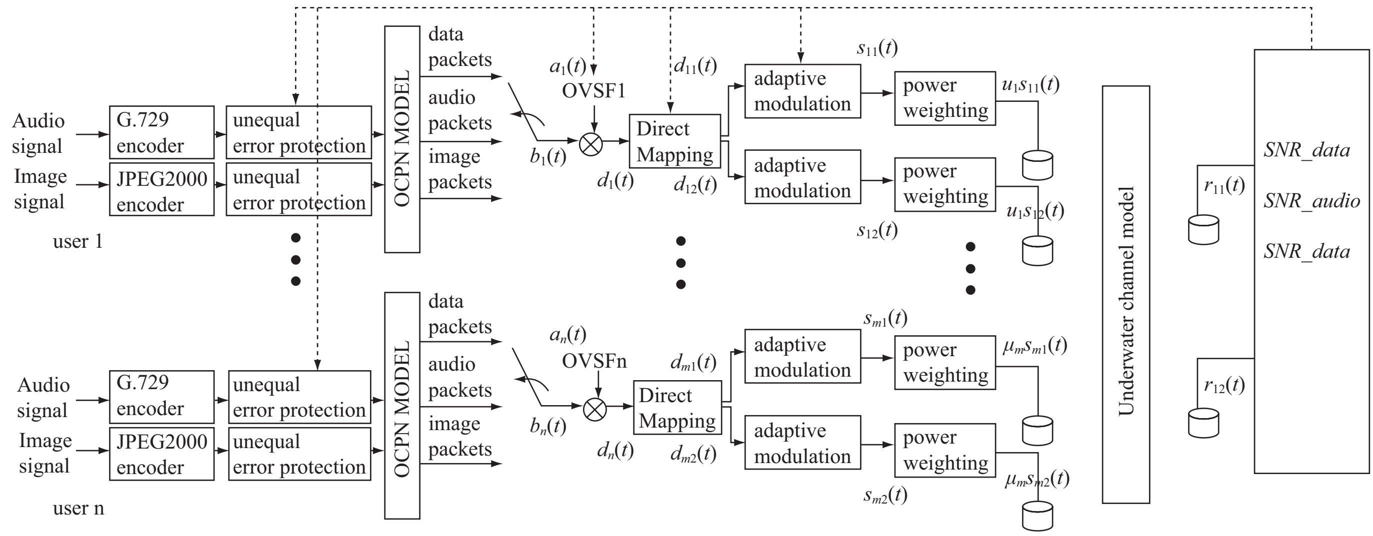

Fig. 1. Proposed OVSF-based underwater acoustic transmission system.

[16], the authors developed a dynamic multiple access protocol for different underwater acoustic network architectures and traffic scenarios; this protocol efficiently shares scarce underwater channel bandwidth by fully leveraging CDMA medium access properties. They also implemented a novel closed-loop distributed algorithm to jointly set the optimal values of transmit power and code length that combat for the near-far effect. In previous studies [4, 10, 11-15], we examined wireless multi-media communication, mobile telemedicine systems, and underwater acoustic multi-media communication. For example, in [15], we studied a single input single output (SISO) OFDM-based transmission scheme for underwater acoustic multimedia communication. Further, in [11], we studied a transmission scheme based on SISO orthogonal variable spreading factor (OVSF) codes for use in underwater acoustic multimedia communication. In this study, we extend this previously work [11], and develop an underwater acoustic multimedia transmission system in which the OVSF, a power assignment mechanism, an adaptive modulation scheme, direct mapping (DM) and an unequal error protection scheme are employed for transmitting messages with low error probability and at low power. We jointly set the transmit power, code length, modulation type, and coding type for underwater multimedia communication and to combat for the near far effect. In addition, we show that the proposed underwater acoustic multimedia communication system can achieve maximum transmission data rates or minimum transmission power.

II. DIRECT MAPPING OVSF-BASED TRANSMISSION SCHEME FOR UNDERWATER ACOUSTIC MULTIMEDIA COMMUNICATION

OVSF-based transmission is one of the various multiple access techniques employed in an underwater acoustic communication system. An advantage of such a system is that it can facilitate robust data transmission. The transmission architecture of the proposed system is shown in Fig. 1. From this figure, we can observe that the proposed system can effectively deal with various types of signals in an underwater environment. When users play multimedia in the receiver of the underwater acoustic communication system, various multimedia objects are synchronized. The time dependent relations among various objects as well as their play throughput and transmission data rates for various objects are estimated. A model called the object-composition Petri-net (OCPN) [25] can describe the temporal relationships among the various aspects of multimedia information, such as its type, size, throughput requirements, and duration for which it is presented in the receiver. Such aspects can then be delivered by the proposed underwater acoustic multimedia communication system. Usually, the quality of service (QoS) requirements for various messages in a multimedia system are different. Here, we assume that the acceptable BERs for audio, and image packets are 10^{-3}, and 10^{-4}, respectively. A 1500 kbits test image signal is compressed by a Joint Photographic Experts Group 2000 (JPEG2000) encoder to produce a 100 kbits image bit stream. Further, a 1330 kbits test audio signal is compressed by a G.729 encoder to produce a 96 kbits audio bit stream. These image, and audio bit streams are introduced in the OCPN model. Two types of packets—image and audio packets—are used in our OVSF-based underwater acoustic communication system for transmitting audio, and image bit streams, respectively. The total number of audio and image channels can easily be estimated by the OCPN model. OVSF codes are applied in spread data to combat channel fading and achieve the required QoS for underwater acoustic multimedia transmission. There is only one code in OVSF with spreading factor 1, and the first OVSF code is 1. The second OVSF code (1, -1) is generated from the first OVSF code, and the spreading factor of the second code is 2. In addition, the *i*th OVSF code C with an spreading factor of 2^{i-1}, and the ith OVSF code set having 2^{i-1} OVSF codes can be generated as

$$C_i = \begin{cases} C_{i-1}C_{i-1} & if \quad x_i = 0 \\ C_{i-1}(-C_{i-1}) & if \quad x_i = 1 \end{cases} \tag{1}$$

In our proposed system, we use the carrier sense multiple access/collision avoidance (CSMA/CA) protocol [7], and the lengths of the OVSF code $c(t)$ are 8, 16, 32, and 64 for various packets. CSMA/CA belongs to a class of protocols called multiple access schemes. In CSMA/CA, a station wanting to transmit data must first listen to the shared channel for a predetermined amount of time so as to check for any activity on the channel. If the channel is sensed as “idle,” that the station is permitted to transmit. If the channel is sensed as “busy,” the station has to defer its transmission. The baseband transmission signal $d_m(t)$ obtained using the mth OVSF code for the mth user is expressed as

$$d_m(t) = a_m(t) b_m(t) \tag{2}$$

Here, $b_m(t)$ is the data signal, which consists of a sequence of rectangular pulses of duration T, for the mth user, and $b_m(t)$ is the mth OVSF spreading sequence for the mth user. The output sequence of $d_m(t)$ is (d_{m1}, d_{m2}, d_{m3}, d_{m4}, …), and then, it is subjected to DM [26]. DM is a transmission mechanism in the IEEE 802.11n standard, and it assigns the sequence (d_{m1}, d_{m2}, d_{m3}, d_{m4}, …) sequence to N parallel units. Further, a serial-to-parallel converter also splits this sequence, d_{m1}, d_{m2}, d_{m3}, d_{m4}, into N branches. Thus, we describe $d_{m1}(t) = d_1(mt)$, m = 1, 3, 5, …, and $d_{m2}(t) = d_1(mt)$, m = 2, 4, 6, …. The first transducer is used to transmit $s_{m1}(t)$, the modulation chip sequence of $d_{m1}(t)$. Similarly, the second transducer is used to transmit $s_{m2}(t)$, the modulation chip sequence of $d_{m2}(t)$. DM can achieve high transmission data rates for underwater acoustic multimedia communication. The received lth hydrophone signal for mth user is expressed *as*

$$\gamma_{ml}(t) = \sum_{n=1}^{N} u_m P S_{mn}(t) * h_{mnl}(t) + n_{ml}(t) \tag{3}$$

Here, constant P is the transmission power of the transmitter; μ_m is the transmission power weighting factor, and $0 < \mu_m \le 1$. Further, h_{il} is the channel impulse response of the ith transducer and lth hydrophones; We assume perfect channel estimation, and $n_{ml}(t)$ is the additive white Gaussian noise (AWGN) for the mth user, obtained by the receiver using the lth hydrophones. L is the total number of hydrophones in the receiver. The SNR obtained by receiver for the mth user is given by

$$SNR_m = \frac{\sum_{l=1}^{L} E\{r_{ml}^2(t)\}}{\sum_{l=1}^{L} E\{n_{ml}^2(t)\}} \tag{4}$$

Thus, the decision on the output is

$$D_m(t) = \sum_{l=1}^{L} r_{ml}(t) a(t) \tag{5}$$

$$\hat{b}_m(t) = dec\{\mathrm{D}_m(t)\}$$

For $D_m(t)$, the receiver makes a decision according to specified thresholds. We summarize our power assignment algorithm as follows:

Step 1: On the basis of the output information of the OCPN model, obtain throughputs of audio and image messages for underwater transmission.
Step 2: Select an appropriate unequal error protection parameter and modulation mode to satisfy the requirements for an underwater system.
Step 3: Assign the transmission power weighting factor μ, $0 < \mu \le 1$, for audio or image packets.
Step 4: Measure the received SNR values in the cases of audio or image packets.
Step 5: If the measured SNR of the received signal is larger than the threshold SNR that can yield the required BER, update the transmission power weighting factor to $\mu = \mu - \Delta$ and go to Step 4. Otherwise, go to Step 6.
Step 6: Increase the transmission power weighting factor to $\mu = \mu + \Delta$. If $\mu > 1$, reselect both the unequal error protection parameter and the modulation mode, and go to Step 3. If $\mu \le 1$, go to Step 4 and repeat the remaining steps.

The value of parameter Δ depends on the variation in channel fading. The greater the variation in channel fading, the larger is the value of Δ. In addition, the smaller the Δ variation, the larger is the amount of power saved. The lengths of the OVSF codes for audio, and video packets—LC_a and LC_v—are 8, 16, 32, and 64. The channel coding rates are obtained using 1/2 (561, 753) and 1/3 (557, 663, 771) convolution codes. The possible length of OVSF codes, modulation type, and channel coding for audio, video, and data packets are (64, 1/2, BPSK), (64, 1/2, QPSK), (32, 1/2, BPSK), (32, 1/2, QPSK), (16, 1/2, BPSK), (16, 1/2, QPSK), (8, 1/2, BPSK), (8, 1/2, QPSK), (64, 1/3, BPSK), (64, 1/3, QPSK), (32, 1/3, BPSK), (32, 1/3, QPSK), (16, 1/3, BPSK), (16, 1/3, QPSK), (8, 1/3, BPSK), and (8, 1/3, QPSK). The initial power for audio, video, and data packets is 1/30, and the maximum power is 1.

III. SIMULATION

We performed a simulation to demonstrate the functionality of the proposed OVSF-based underwater transmission system. In this simulation, we used adaptive modulation, DM, CSMA/CA, OVSF codes, power assignment algorithm, and the unequal error protection scheme. We used the underwater chan-

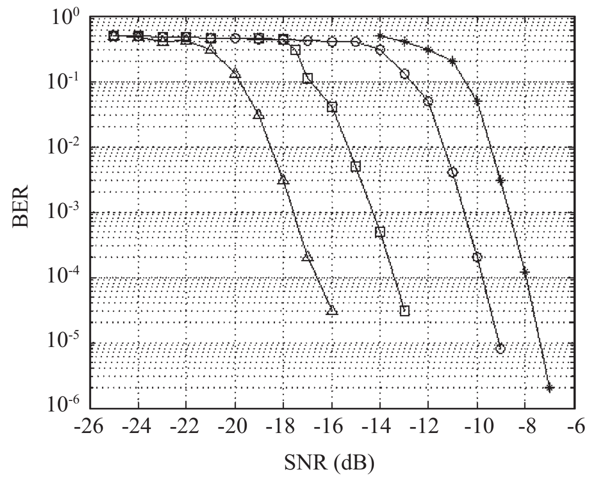

Fig. 2. Bit error rate performance of proposed OVSF-based underwater acoustic transmission system with 1/2 (561, 753) coding and BPSK modulation. (*: spreading factor (SF) = 8, O: spreading factor (SF) = 16, □: spreading factor (SF) = 32, △: spreading factor (SF) = 64)

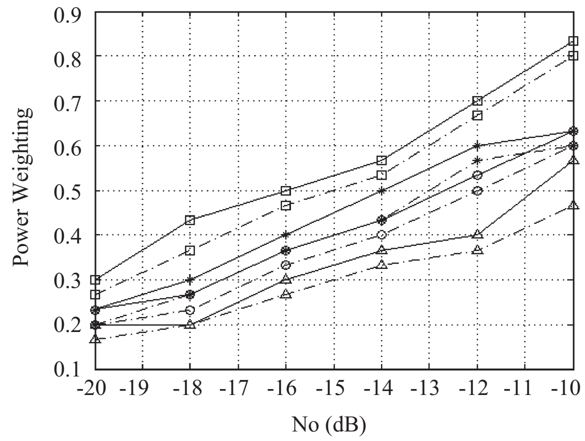

Fig. 3. Transmission power weighting performance of proposed OVSF-based underwater acoustic transmission system with OVSF = 8. (△, dotted line: 1/3 convolution, BPSK, audio; O, dotted line: 1/3 convolution, QPSK, audio; *, dotted line: 1/2 convolution, BPSK, audio; □, dotted line: 1/2 convolution, QPSK, audio; △, line: 1/3 convolution, BPSK, image; O, line: 1/3 convolution, QPSK, image; *, line: 1/2 convolution, BPSK, image; □, line: 1/2 convolution, QPSK, image)

nel model developed by Zhang *et al.* [26] in this simulation. In this model, the transmission range is 1000 m, the frequency of a carrier wave is 11.5 kHz, and the bandwidth is 3.90625 kHz. The transmitter contains two transducers and the receiver contains two hydrophones. The BER performance of the proposed underwater transmission system is shown in Fig. 2. We use BPSK modulation, K = 9 1/2 (561, 753) and 1/3 (557, 663, 771) convolution codes with soft decoding [23], and a 2 × 2 DM strategy for the transmission of audio and image packets. The spreading factor for the OVSF codes are 8, 16, 32, and 64. The greater the length of spreading codes, the lower is the transmission BER. The transmission power weighting for the proposed system in the case of BERs of 10^{-3}, and 10^{-4} for audio and image packets, respectively, under different noise conditions is shown in Fig. 3 as a function of the AWGN (N_o). Here, the length of OVSF code is 8. From Fig. 3, we can observe that the higher the noise, the higher is the transmission power. Further, less restrictions on the transmission BER result in low transmission power. The transmission power weighting of audio signals is smaller than that of image signals. Further, the transmission power weighting of 1/2 convolution codes is larger than that of 1/3 convolution codes. We consider No = -10 dB. The lengths of OVSF codes are 8, 16, 32, and 64. Smaller length of OVSF codes result in low transmission power. Tables 1 and 2 show the descend power and transmission data rates for various lengths of OVSF codes, modulation types, and channel coding types for audio and image signals, respectively. Here, No is -10 dB. The maximum transmission data rates is 976 bits for the bandwidth of 3.90625 kHz, and the maximum descend power is 80%. The descend power is defined as

$$\frac{R_b - R_b \times u_b}{R_b} \times 100\% \qquad (6)$$

Table 1. shows the descend power and transmission data rates for various the length of OVSF codes, modulation types, and channel coding types for audio signals.

the length of OVSF code	modulation	convolution code	transmission data rates (bits)	power weighting	descend power(%)
8	BPSK	1/2	488	18/30	40
8	QPSK	1/2	976	25/30	16.67
8	BPSK	1/3	324	14/30	53.3
8	QPSK	1/3	648	18/30	40
16	BPSK	1/2	244	14/30	53.3
16	QPSK	1/2	488	18/30	40
16	BPSK	1/3	162	11/30	63.3
16	QPSK	1/3	324	14/30	52.72
32	BPSK	1/2	122	9/30	70
32	QPSK	1/2	244	13/30	56.67
32	BPSK	1/3	80	7/30	76.67
32	QPSK	1/3	162	11/30	63.3
64	BPSK	1/2	60	7/30	76.67
64	QPSK	1/2	120	9/30	70
64	BPSK	1/3	40	6/30	80
64	QPSK	1/3	80	7/30	76.67

Where R_b and μ_b are the transmission data rate and the transmission power weighting, respectively, for audio or image signals. From Tables 1 and 2, we observe that the proposed system can achieve maximum transmission data rates or minimum transmission power. Figure 5 shows the performance of a G.729 audio signal in the proposed underwater transmission system with the power assignment mechanism. The mean square error (MSE) of the original and received

Table 2. shows the descend power and transmission data rates for various the length of OVSF codes, modulation types, and channel coding types for image signals.

the length of OVSF code	modulation	convolution code	transmission data rates (bits)	power weighting	descend power(%)
8	BPSK	1/2	488	19/30	36.67
8	QPSK	1/2	976	26/30	13.33
8	BPSK	1/3	324	17/30	43.3
8	QPSK	1/3	648	19/30	36.67
16	BPSK	1/2	244	15/30	50
16	QPSK	1/2	488	19/30	36.67
16	BPSK	1/3	162	12/30	60
16	QPSK	1/3	324	15/30	49.38
32	BPSK	1/2	122	10/30	66.67
32	QPSK	1/2	244	14/30	53.33
32	BPSK	1/3	80	8/30	73.33
32	QPSK	1/3	162	12/30	60
64	BPSK	1/2	60	8/30	73.33
64	QPSK	1/2	120	11/30	63.33
64	BPSK	1/3	40	7/30	76.67
64	QPSK	1/3	80	8/30	73.33

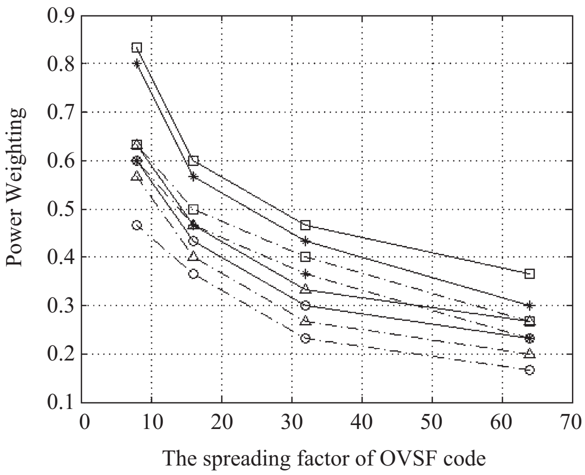

Fig. 4. Transmission power weighting performance of proposed OVSF-based underwater acoustic transmission system with No = -10 dB. (O, dotted line: 1/3 convolution, BPSK, audio; △, dotted line: 1/3 convolution, QPSK, audio; *, dotted line: 1/2 convolution, BPSK, audio; □, dotted line: 1/2 convolution, QPSK, audio; O, line: 1/3 convolution, BPSK, image; △, line: 1/3 convolution, QPSK, image o; *, line: 1/2 convolution, BPSK, image; □, line: 1/2 convolution, QPSK, image)

audio signals is 0.0033. As shown in the figure, the quality of the audio signal is good. Figure 6 shows the received JPEG2000 image when the power assignment algorithm is used. The peak SNR (PSNR) of the received image signal is 42.8 dB. Figure 7 shows the received JPEG2000 image in the case that the power assignment algorithm is not used. From Figs. 6 and 7, we observe that it is feasible to use the proposed

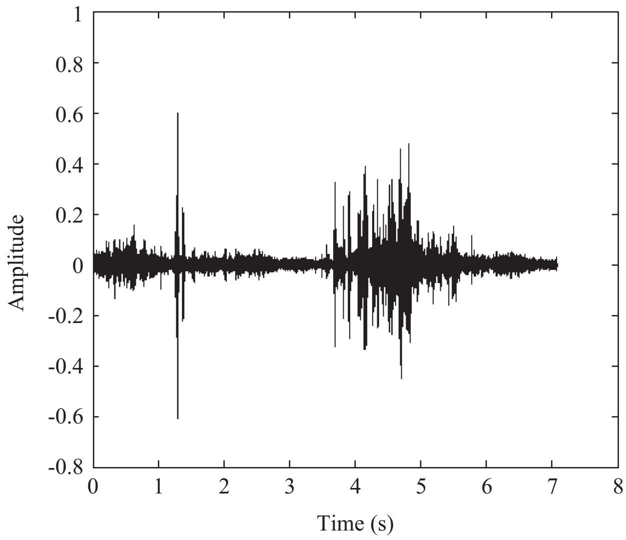

Fig. 5. Received and decoded G.729 audio signals with power assignment mechanism. (MSE = 0.0033)

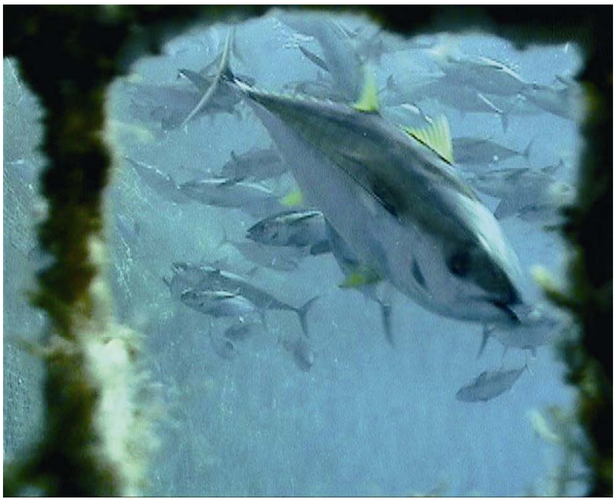

Fig. 6. Received and decoded JPEG2000 image signals using power assignment algorithm. (PSNR = 42.8 dB)

power assignment algorithm is feasible in the underwater acoustic communication system. Further, we can conclude that the proposed system can efficiently transmit audio and image signals.

VI. CONCLUSION

In this paper, we proposed an underwater acoustic multimedia transmission scheme in which the CSMA/CA protocol, OVSF code, DM transmission strategy, a power assignment algorithm, adaptive modulation, and an unequal error protection scheme were employed. We also performed a simulation to demonstrate the functionality of the proposed system; the simulation results were in good agreement with the theoretical discussion. The proposed system can efficiently

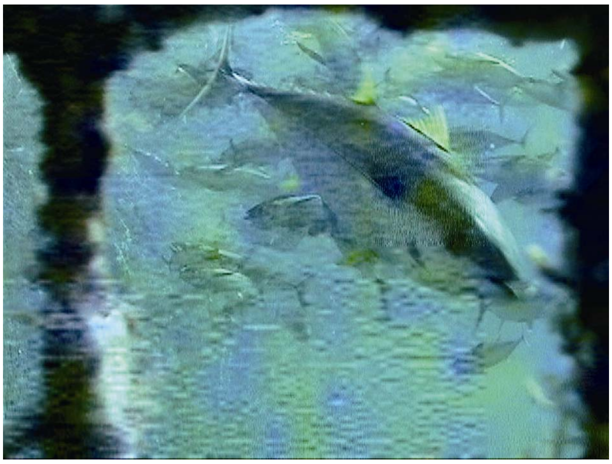

Fig. 7. Received and decoded JPEG2000 image signals without power assignment algorithm. (PSNR = 24.1 dB)

transmit audio and image signals. In addition, it can achieve maximum transmission data rates or minimum transmission power.

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