An OFDM-based Transmission Scheme for Underwater Acoustic Multimedia

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Abstract: - In this paper, we propose an orthogonal frequency division multiplexing–based (OFDM-based) underwater acoustic multimedia system. An essential feature of this system is that it offers greater power and schemes with significant error protection for the transmission of sensor data information requiring a higher quality of service (QoS). To realize maximum resource utilization or minimum total transmission power, we also include an adaptive modulation strategy into the system. The proposed underwater acoustic multimedia system employs high power, low speed modulation, and schemes providing significant error protection for the transmission of sensor data messages requiring a stringent bit-error rate (BER). In contrast, low power, high speed modulation, and less capable error protection schemes are provided for messages that can tolerate a high BER. A simulation was carried out to verify the functionality of the proposed system in a practical underwater acoustic multimedia scenario.

Key-Words: - underwater multimedia, acoustic, OFDM, QoS, power assignment, unequal error protection, adaptive modulation.

1 Introduction

An underwater acoustic communication scheme is an interesting research topic [1–12, 19, 20]. There are various multiple access schemes, such as frequency division multiple access (FDMA), time division multiple access (TDMA), code division multiple access (CDMA), and orthogonal frequency division multiplexing (OFDM). These schemes work similarly to a cellular system or wireless local area network (WLAN) in land. The performance of mobile

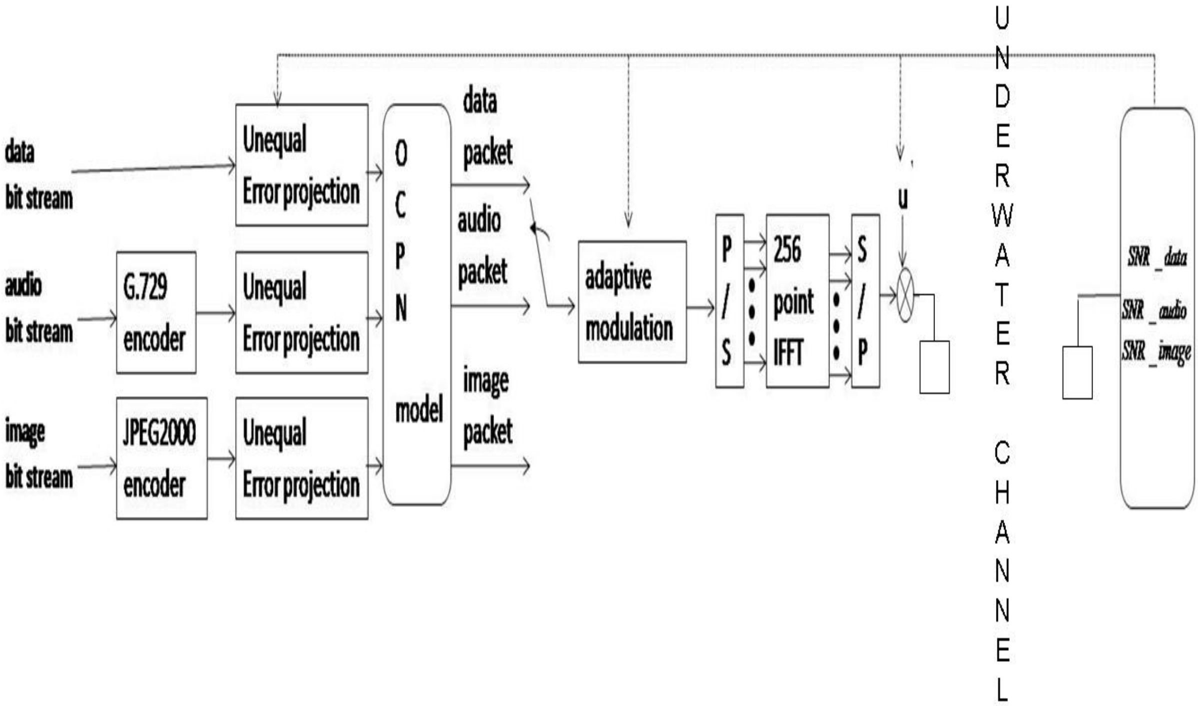

Figure 1 The proposed OFDM-based transmission scheme for underwater acoustic multimedia.

telemedicine transmission schemes that adopt multi-code code division multiple access (CDMA), wideband CDMA, orthogonal frequency division multiplexing (OFDM), or direct-sequence ultra-wideband (DS UWB) techniques has been scrupulously studied in our earlier work [13–17, 21, 24]. As well as unequal error protection, power assignment mechanism, and adaptive modulation are applied in land mobile communication. In addition, we have proposed an OFDM-based as well as an OVSF-based (orthogonal variable spreading factor) transmission architecture with unequal error protection, power assignment mechanism, and adaptive modulation for underwater acoustic multimedia communication [10-12]. Research in underwater communication commonly includes the investigation of design challenges such as low communication bandwidth, large propagation delay, and high error probability. In [10,11], we discussed an OFDM-based underwater acoustic transmission scheme for image and audio signals transmission. In this paper, we study the transmission performance of sensor data, audio, and image signals in the proposed multimedia communication system. An essential feature of this scheme is that higher power is allocated to information requiring a higher quality of service (QoS). To achieve maximum resource utilization, or minimum total transmission power, we also incorporate unequal error protection and adaptive modulation techniques into the proposed power assignment scheme. Specifically, we employ high power, low level modulation, and a high-level error-protection scheme for sensor messages that require a stringent bit error rate (BER). In contrast, low power, high speed modulation, and less capable error protection schemes are provided for messages that can tolerate a high BER. For a practical underwater acoustic communication scenario, a simulation was carried out to verify the proper functionality of the proposed scheme.

2.An OFDM-based Transmission Scheme for Underwater Acoustic Multimedia

A sketch of the proposed OFDM-based underwater acoustic communication system is depicted in Fig. 1. From this figure we can see that the system under consideration can deal with various types of signals, such as (i) G.729 audio signals, (ii) JPEG2000 image signal, and (iii) data signals. Note that processing the pre-orchestrated multimedia information requires the synchronous playback of time-dependent multimedia data based upon some pre-specified temporal relations. For this purpose, a patient needs a model where temporal constraints, among various data objects that must be observed at the time of playback, can be specified. A well-known model that fits this requirement is known as the object-composition petri-net (OCPN) model [23]. Usually, the QoS requirements for various messages in a underwater acoustic multimedia system are different. Here, we assume that the acceptable bit error rates (BERs) for data, audio, and image packets are 10^{-5} , 10^{-3} , and 10^{-4} respectively [10–12]. For this purpose, it is assumed that the system can perform at unequal power levels, as illustrated in Fig. 1. To satisfy the differentiated QoS, we adopt power assignment strategies and different transmission techniques for different types of packets. Specifically, we impart high transmission power and low level modulation to data packets requiring a low BER. In contrast, low transmission power and high level modulation are used for the transmission of audio and image packets that can tolerate a less stringent BER. Assume that there are *M* OFDM symbols in an OFDM transmission packet and *N* sub-carriers in an OFDM symbol. Furthermore, it is assumed that each packet can be modulated independently. Let $S_{n,k}$ denote the complex modulated symbol transmitted in the *n*-th OFDM symbol over the *k*-th sub-carrier before the IFFT for the considered OFDM block. The transmitted signal after the IFFT can then be represented as:

$$s_{n,k} = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} S_{n,k} \mu e^{j2\pi k/N} \qquad (1)$$

where μ is the transmission power weighting factor and $1/30 \le \mu \le 1$. If the underwater channel impulse response is denoted by h_l , the received signal can be expressed as :

$$y_{n,k} = h_l * s_{n,k} + n_{n,k} \qquad (2)$$

where □ denotes convolution and $n_{n,k}$ is the additive white noise of the channel. Thus, the received signal after the FFT $R_{n,k}$ can be written as:

$$R_{n,k} = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} y_{n,k} e^{-j2\pi k/N} \qquad (3)$$

If the sub-carrier spacing Δf is chosen to be much smaller than the coherence bandwidth and the symbol duration *T* is much smaller than the coherence time of the channel, then the radio channel transfer function $H(f,t)$ can be considered constant within the bandwidth Δf of each sub-carrier and the duration *T* of each symbol $S_{n,k}$. As a result, $R_{n,k}$ can be obtained as:

$$R_{n,k} = H_{n,k} S_{n,k} + N_{n,k} \qquad (4)$$

To calculate $R_{n,k}$ from (4), we need to perform channel estimation to obtain the estimated channel transfer function $\hat{H}_{n,k}$. The decision on the output is:

$$D_{n,k}^{c} = \frac{R_{n,k}}{\hat{H}_{n,k}} = S_{n,k} + \frac{N_{n,k}}{H_{n,k}} \qquad (5)$$

$$\hat{S}_{n,k} = dec\{D_{n,k}^{C}\}$$

For $D_{n,k,l}^{c}$, the receiver makes a decision according to the specified thresholds. We summarize our power assignment algorithm below:

Step 1: Based upon the output information of the OCPN, obtain throughputs of data, audio, and image messages for transmissions.

Step 2: Select appropriate unequal error protection and suitable modulation modes to fulfil the requirements for transmission through an underwater acoustic communication network.

Step 3: Assign an original transmission power weighting μ , where $0 < \mu \leq 1$, for data, audio, or image packets.

Step 4: Measure the received SNR for data, audio, or image packets.

Step 5: If the measured SNR of the received signal is larger than the threshold SNR for the required BER, update the transmission power weighting to $\mu = \mu - \Delta$ and return to Step 4. Otherwise, go to Step 6.

Step 6: Increase the transmission power weighting to $\mu = \mu + \Delta$. If $\mu > 1$, re-select the unequal error protection as well as the mode of modulation and go to Step 3. If $\mu \leq 1$, go to Step 4 and repeat the remaining steps.

The parameter Δ depends upon the variation in channel fading. The greater the variation in channel fading, the larger the value of Δ. In addition, the smaller the Δ variation, the larger the power conservation is. The rates of channel coding are obtained using 1/2 (561, 753) and 1/3 (557, 663, 771) convolution codes [22]. The possible modulation type and channel coding for audio, image, and data packets are (1/2, BPSK), (1/2, QPSK), (1/3, BPSK), and (1/3, QPSK). The initial power for audio, image, and data packets is 1/30, and the maximum power is 1.

3. Simulation Results

We performed a simulation to demonstrate the functionality of the proposed OFDM-based underwater transmission system. In the simulation, we used adaptive modulation, power assignment algorithm, and the unequal error protection scheme. Yang's underwater channel model [18] was adopted in this simulation. In the channel model, the transmission range is 10 km with a depth of 100 m, which includes a sediment rock bed at a depth of 40m; the sonic speed is 1572 m/s, with the source end situated in water at a depth of 35 m; further, there are 15 vertical line array receiving terminals, each deployed at a depth of 5 m; the frequency of a carrier wave is 750 Hz, and the bandwidth is 250 Hz. The BER performance of the proposed underwater transmission system is shown in figure 2. We use BPSK modulation, K=9 1/2 (561, 753) and 1/3 (557, 663, 771) convolution codes with soft decoding. In figure 2, we can also observe the performances of 1/2 (561, 753) convolution channel coding with soft decoding, and 1/3 (557, 663, 771) convolution channel coding with soft decoding in the case of BPSK and QPSK modulation. Channel coding can mitigate the noise fading of the proposed OFDM-based underwater acoustic transmission system. The greater the length of spreading codes, the lower is the transmission BER. The transmission power weighting under different noise conditions for the proposed system for BERs of 10^{-3}, 10^{-4}, and 10^{-5} for audio, image, and data packets, respectively, is shown in figure 3 as a function of N_o, which is adaptive white Gaussian noise. From figure 3, we can observe that higher the noise, the higher is the transmission power. Further, less restrictions on transmission BER result in low transmission power. Figure 4 shows the transmission audio performance of the proposed OFDM-based underwater acoustic multimedia scheme with power assignment. The BER is 10^{-3} and mean square error MSE is 7.69×10^{-4} . Figure 5 shows the transmission audio performance of the proposed OFDM-based underwater acoustic multimedia scheme without power assignment. Figure 6 show the transmission image performance of the proposed OFDM-based system without power assignment. Figure 7 show the transmission image performance of the proposed OFDM-based system with power assignment. The BER is 10^{-4} and PSNR is 31.1 dB. From these figures, we see that the audio and image signals in underwater environment are clear. Table I and II show the descend power

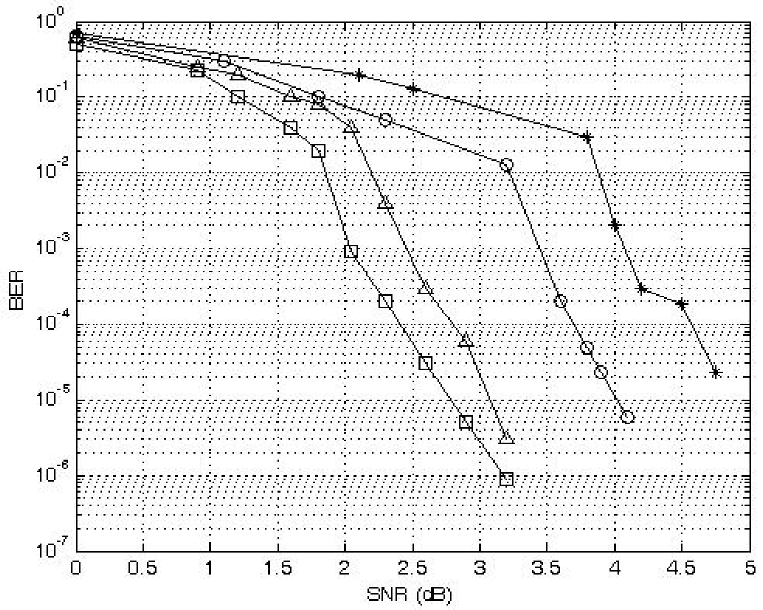

Figure 2 Bit error rate performance of proposed OFDM-based underwater acoustic transmission system. (*:QPSK with channel estimation and 1/2 (561,753) coding; o:QPSK with channel estimation and 1/3 (557, 663, 771) coding; Δ:BPSK with channel estimation and 1/2 (561,753) coding; □:BPSK with channel estimation and 1/3 (557, 663, 771) coding)

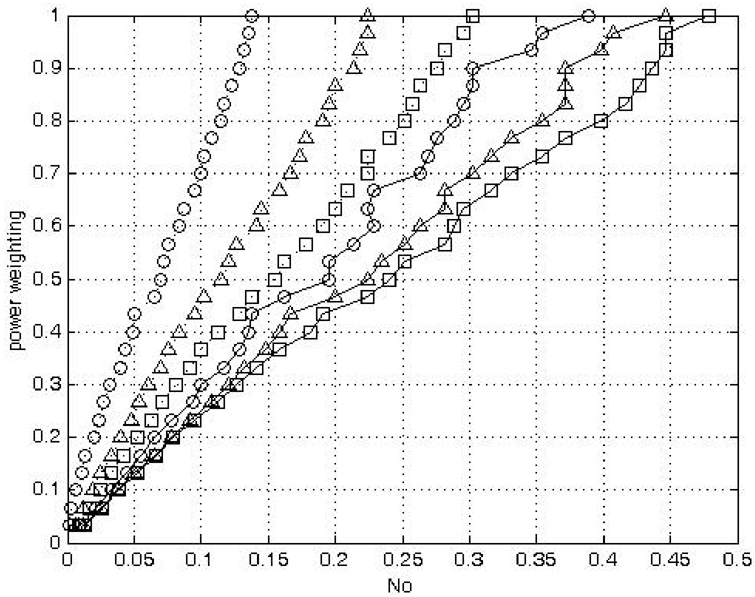

Figure 3 Transmission power weighting under different noise conditions. (□-line: BPSK with channel estimation, 1/2 (561,753) coding, and 10^{-3}; Δ-line: BPSK with channel estimation, 1/2 (561,753) coding, and 10^{-4};o-line: BPSK with channel estimation, 1/2 (561,753) coding, and 10^{-5};□- dotted line: QPSK with channel estimation, 1/2 (561,753) coding, and 10^{-3}; Δ- dotted line: QPSK with channel estimation, 1/2 (561,753) coding, and 10^{-4} ;o- dotted line: QPSK with channel estimation, 1/2 (561,753) coding, and 10^{-5})

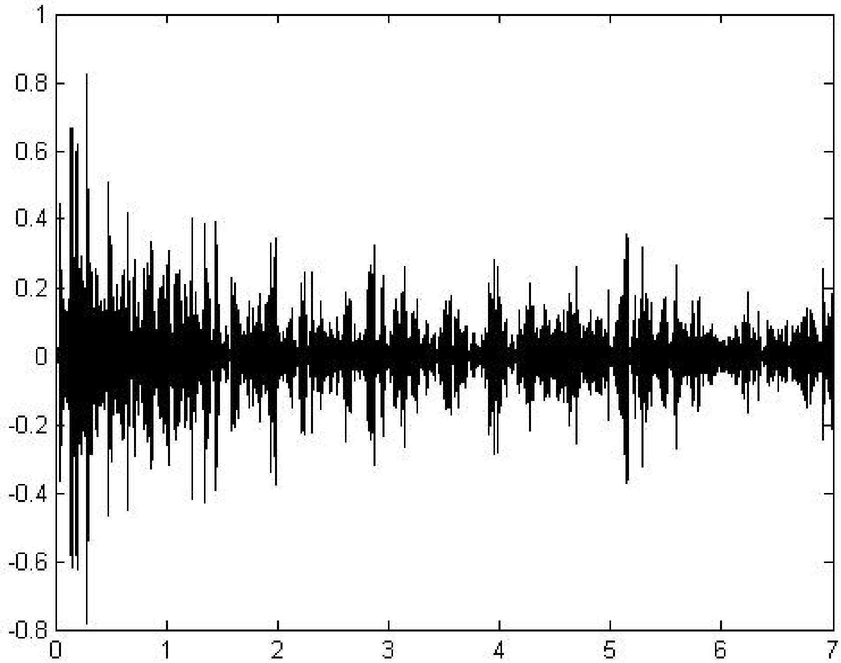

Figure 4 The transmission audio performance of the proposed OFDM-based underwater acoustic multimedia transmission with power assignment. (MSE= 7.69×10^{-4})

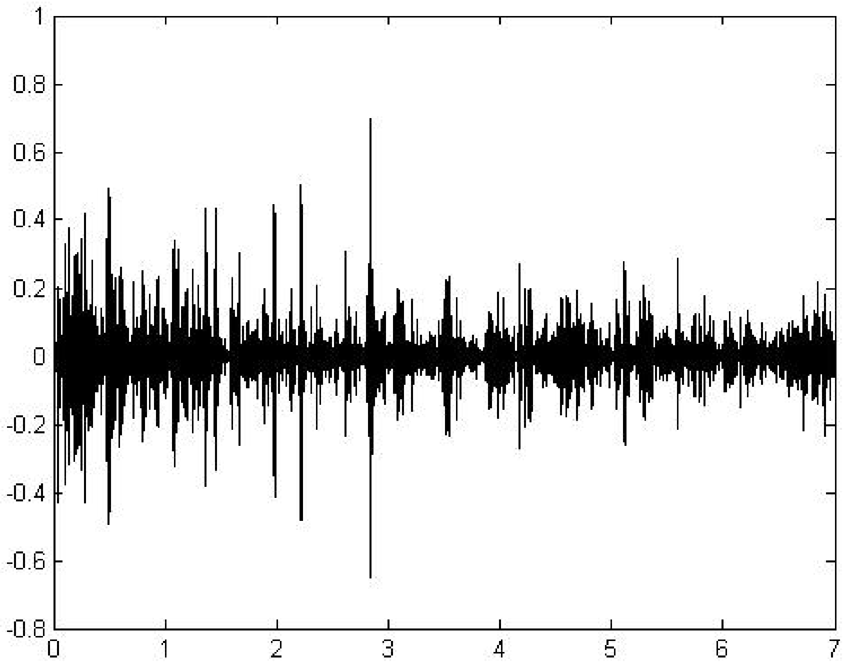

Figure 5 The transmission audio performance of the proposed OFDM-based underwater acoustic multimedia transmission without power assignment. (MSE=0.32)

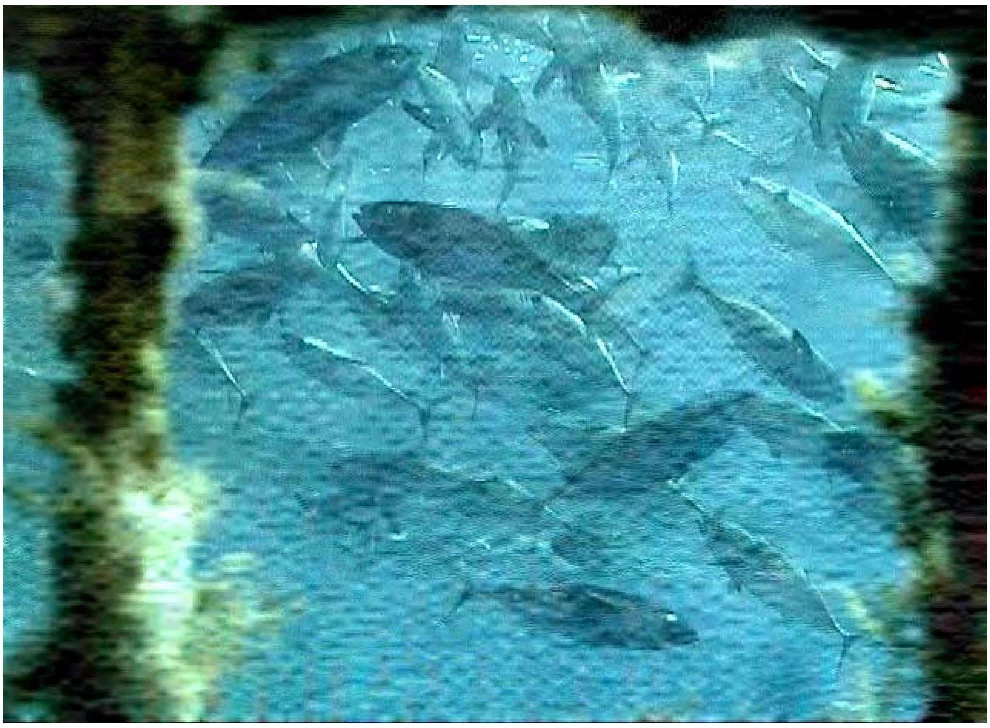

Figure 6 The transmission image performance of the proposed OFDM-based underwater acoustic multimedia transmission scheme without power assignment. (PSNR= 20.7 dB .)

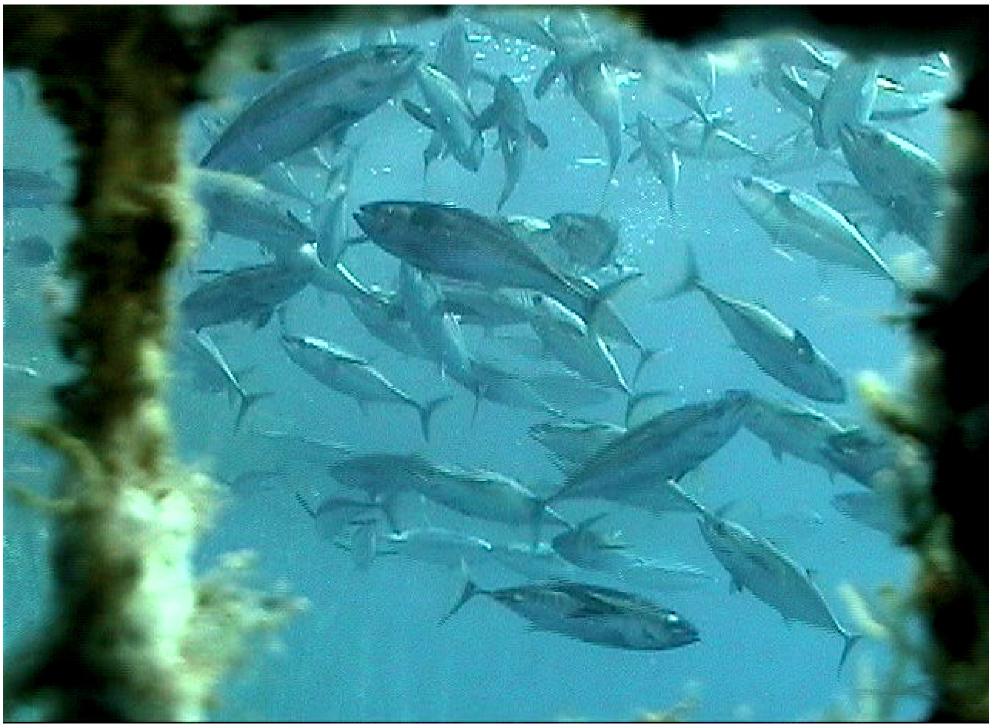

Figure 7 The transmission image performance of the proposed OFDM-based underwater acoustic multimedia system. (PSNR= 31.1 dB)

Table I Transmission power and adaptive Gaussian noise (No) in the proposed underwater acoustic OFDM-based transmission scheme with 1/2 (561,753) convolution coding and soft decoding.

No (variance, dB)	BPSK BER=10^(-3) audio	BPSK BER=10^(-4) image	BPSK BER=10^(-5) data	Descend Power (%)	QPSK BER=10^(-3) audio	QPSK BER=10^(-4) image	QPSK BER=10^(-5) data	Descend Power (%)
-1.11	5/30	6/30	7/30	80	9/30	10/30	11/30	66.67
-1	7/30	8/30	9/30	73.33	11/30	12/30	13/30	60
-0.9	9/30	10/30	11/30	66.67	13/30	14/30	15/30	53.33
-0.8	11/30	12/30	13/30	60	16/30	17/30	18/30	43.33
-0.7	13/30	14/30	15/30	53.33	19/30	20/30	21/30	33.33
-0.6	16/30	17/30	18/30	43.33	24/30	26/30	27/30	14.44

Table II Transmission power and adaptive Gaussian noise (No) in the proposed underwater acoustic OFDM-based transmission scheme with 1/3 (557, 663, 771) convolution coding and soft decoding.

No (variance, dB)	BPSK BER=10^(-3) audio	BPSK BER=10^(-4) image	BPSK BER=10^(-5) data	Descend Power (%)	QPSK BER=10^(-3) audio	QPSK BER=10^(-4) image	QPSK BER=10^(-5) data	Descend Power (%)
-1.11	4/30	5/30	6/30	83.33	7/30	8/30	9/30	73.33
-1	6/30	7/30	8/30	76.67	8/30	9/30	10/30	70
-0.9	7/30	8/30	9/30	73.33	10/30	11/30	12/30	63.33
-0.8	8/30	9/30	10/30	70	12/30	13/30	14/30	56.67
-0.7	10/30	11/30	12/30	63.33	15/30	16/30	17/30	46.67
-0.6	13/30	14/30	15/30	53.33	20/30	22/30	23/30	27.78

ratio for transmission power weighting and adaptive Gaussian noise in underwater environment with BPSK and QPSK modulation. We assume the transmission rates for audio, image, and data signals are the same in BPSK and QPSK modulation, respectively. The reference transmission powers without power assignment mechanism are 1, 1, 1 for audio, image, and data signals, respectively. From the simulation results shown in Table I, it can be observed that when the power weighting factors are 5/30, 6/30, and 7/30 for the audio, image, and data packets, respectively, the obtainable corresponding descend power is 80% in No=-1.11 dB. The larger the adaptive Gaussian noise, the larger the transmission power weighting is. The transmission power weighting of QPSK modulation is larger than the transmission power weighting of BPSK modulation. In addition, the transmission power weighting of 1/3 (557, 663, 771) convolution coding is smaller than the transmission power weighting of 1/2 (561,753) convolution channel coding. From above discussions, we observe that the proposed power assignment algorithm is feasible in the underwater acoustic communication system. Therefore, we can conclude that the proposed system can efficiently transmit audio and image signals. In addition, it can achieve maximum transmission data rates or minimum transmission power.

4. Conclusion

In this paper, we proposed an OFDM-based underwater acoustic multimedia transmission. Power assignment mechanism, adaptive modulation, OFDM scheme, and unequal error protection are adopted in the system. In addition, the proposed underwater acoustic multimedia system employs high power, low speed modulation, and schemes providing significant error protection for the transmission of sensor data messages requiring a stringent bit-error rate (BER). In contrast, low power, high speed modulation, and less capable error protection schemes are provided for messages that can tolerate a high BER. The simulation results show that the proposed scheme is a feasible underwater multimedia transmission system. In addition, it can achieve maximum transmission data rates or minimum transmission power.

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References

[1] A. Vine, ‘Present and prospective needs of submersibles for underwater telecommunication,’ *Present and Future Civil Uses of Underwater Sound,* NAS Book, 1970.

[2] A. B. Baggeroer,‘Acoustic Telemetry-An Overview,’ *IEEE J. Oceanic Eng.* OE-9(4), 1984, pp.229-235.

[3] M. Stojanovic, ‘Recent Advances in High-Speed Underwater Acoustic Communications,’ *IEEE J. Oceanic Eng.* 21(2), 1996, pp.125-136.

[4] D. B. Kilfoyle and A. B. Baggeroer, ‘The State of the Art in Underwater Acoustic Telemetry ,’ *IEEE J. Oceanic Eng.* 25(1), , 2000, pp.4-27.

[5] E. M. Sozer, M. Stojanovic and John G. Proakis., ‘Underwater Acoustic networks,’ *IEEE J. Oceanic Eng.* 25(1), ,2000, pp.72-83.

[6] John G. proakis, E. M. Sozer, J. A. Rice, and M. Stojanovic, ‘Shallow Water Acoustic Networks,’ *IEEE Communications Magazine,* 11, 2001, pp.114-119.

[7] J. H. Cui, J. Kong, M. Gerla, and S. Zhou, ‘The Challenges of Building Scalable Mobile Underwater Wireless Sensor Networks for Aquatic Applications,’ *IEEE Network,* 2006, pp.12-18.

[8] M. Chitre, S. Shahabudeen, L. Freitag, and M. Stojanovic, ‘Recent Advances in Underwater Acoustic Communications & Networking,’ *Ocean’08.*

[9] F. S. Lu, C. H. Tseng, and B. C. Wu, "Design and Implementation of An All-Digital Real-Time Underwater Acoustic Transceiver Using Digital Signal Processors," *Journal of Marine Science and Technology*, 16(1), 2008, pp. 34–43.

[10] C. F. Lin, Z. X. Shi, and S. H. Chang,' A Power Assignment Mechanism for OFDM-based Underwater Acoustic Communication System,' appear in *Proceedings of IEEE the 11th International Conference on Advanced Communication Technique 2008, Korea.*

[11] C. F. Lin, C. H. Shih, C. P. Chen, S. W. Leu, C. H. Tseng, H. S. Hung, F. S. Lu, S. H. Chang, 'An OFDM-based Underwater Acoustic Multimedia System', appear in *WSEAS Books(Proceeding of 9th WSEAS Int. Conf. on Multimedia Systems & Signal Processing 2009, China), invited paper*.

[12] C. F. Lin, S. H. Chang, J. Y. Chen, and J. T. Yan, "A Power Assignment Mechanism for Underwater Wireless Multimedia," *Ocean'08.*

[13] C. F. Lin, J. Y. Chen, R. H. Shiu, and S. H. Chang, "A Ka Band WCDMA-based LEO Transport Architecture in Mobile Telemedicine," *Telemedicine in the 21st Century,* edited by Lucia Martinez and Carla Gomez, Nova Science Publishers, Inc, USA, 2008 3rd Quarter.(invited book chapter)

[14] C. F. Lin and C. Y. Li, "A DS UWB Transmission System for Wireless Telemedicine," *WSEAS Transactions on Systems, July, 2008, pp.578-588.*

[15] C. F. Lin, and K. T. Chang," A Power Assignment Mechanism in Ka Band OFDM-based Multi-satellites Mobile Telemedicine," *J. of Medical and Biological Engineering,* 28(1), 2008, pp.17-22.

[16] C. F. Lin, W. T. Chang, H. W. Lee, and S. I. Hung, "Downlink Power Control in Multi-Code CDMA Mobile Medicine System," *Medical & Biological Engineering & Computing*, vol.44, 2006, pp.437-444.

[17] C. F. Lin, C. H. Chung, Z. L. Chen, C. J. Song, and Z. X. Wang, "A Chaos-based Unequal Encryption Mechanism in Wireless Telemedicine with Error Decryption, " *WSEAS Transactions on Systems, Feb, 2008,* pp.49-55.

[18] T. C. Yang, "Temporal Resolutions of Time-Reversal and Passive-Phase Conjugation for Underwater Acoustic Communications," *IEEE Journal of Oceanic Engineering*, Vol. 28, pp. 229–245 (2003).

[19] J. Garus, 'Fuzzy Control of Motion of Underwater Robotic Vehicle,' *6th WSEAS CIMMSC 2007*, pp.192-197.

[20] R. Soheilifar and J. Rasekhi (2008), 'A Computer Simulation of Underwater Sound Propagation Based on the Method of Parabolic Equations,' *WSEAS ACC,* pp.91-97.

[21] J. Terry and J. Heiskala (2002):, *OFDM Wireless LANs: A Theoretical and Practical Guide, Indianapolis*, Indiana: Sams Publishing, pp.51-53.

[22] Technical Specification Group Radio Access Network; multiplexing and channel coding (FDD), Release 6, 2005.

[23] M. Woo, N. Prabhu and A. Ghafoor, "Dynamic resource allocation for multimedia services in mobile communication environments," *IEEE J. Sel. Areas Commun.*, 13: 913-922, 1995.

[24] H. Liu, T. Zhang, Y. Zhou," A Novel Iterative Channel Estimation Algorithm for OFDM Systems," *WSEAS Transactions on Communications*, 2006, pp.1309-1313.