Journal of Marine Science and Technology

Volume 26 | Issue 3 | Article 4

FBMC/LDPC-BASED UNDERWATER TRANSCEIVER ARCHITECTURE FOR VOICE AND IMAGE TRANSMISSION

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Recommended Citation
Lin, Chin-Feng; Hung, Yi-Tai; Lu, Hsun-Wei; Chang, Shun-Hsyung; Parinov, Ivan A; and Shevtsov, Sergey (2018) "FBMC/LDPC-BASED UNDERWATER TRANSCEIVER ARCHITECTURE FOR VOICE AND IMAGE TRANSMISSION," *Journal of Marine Science and Technology*: Vol. 26: Iss. 3, Article 4.
DOI: DOI: 10.6119/JMST.201806_26(3).0004
Available at: https://jmstt.ntou.edu.tw/journal/vol26/iss3/4

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Acknowledgements

The authors acknowledge the support of the grant from The Ministry of Science and Technology of Taiwan, under contract No. MOST 105-2923-E-022-001-MY3, and the valuable comments of the reviewers.

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Journal of Marine Science and Technology, Vol. 26, No. 3, pp. 327-334 (2018)
DOI: 10.6119/JMST.2018.06_(3).0004

FBMC/LDPC-BASED UNDERWATER TRANSCEIVER ARCHITECTURE FOR VOICE AND IMAGE TRANSMISSION

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Key words: filter bank multicarrier, low-density parity-check codes, offset quadrature amplitude modulation, power saving.

ABSTRACT

This paper proposes a filter bank multicarrier (FBMC)-based underwater transmission scheme for voice and image signals. In this scheme, FBMC transmission technology, low-density parity-check (LDPC) channel coding, adaptive binary phase shift keying (BPSK) modulation or offset quadrature amplitude modulation (OQAM), and a power assignment mechanism are integrated into an underwater voice and image transmission system. The bit error rates (BERs) of voice and image signals for underwater transmission are required to be less than 10^{-3}, and 10^{-4}, respectively. The BER performances of the proposed scheme in an underwater acoustic channel were demonstrated through simulations, and the power saving ratios for the underwater transmissions of voice and image signals were explored. The simulation results show that the proposed underwater transmission system can achieve a lower transmission-power consumption or a higher transmission data rates compared to a system without the power assignment mechanism. The results also indicate that the proposed system can be used for advanced underwater signal transmissions.

I. INTRODUCTION

Multicarrier (MC) transmission technology has attracted much attention in the last few decades because it can be used to transmit high data rates. Prashant et al. (2015) demonstrated that MC transmission technology plays an important role in underwater acoustic (UWA) communications, and explores the suitability, Doppler compensation, and diversity schemes of MC transmission for UWA communication. The multipath signal propagation and time variability of the UWA channel have a significant impact on the bit error rate (BER) and data rate performances of the transceiver.

Orthogonal frequency-division multiplexing (OFDM), a type of MC transmission technology, has been the primary transmission scheme for the fourth generation (4G) mobile communication. Behrouz (2011) demonstrated that OFDM yields large side lobes, which result in relatively high intersymbol interference (ISI). Filter bank multicarrier (FBMC) is an advanced modulation scheme that utilizes modulated filter banks at both the transmitter and receiver ends to minimize side lobes and interference. Although FBMC modulation is more complex than OFDM, it has enhanced spectral efficiency of subcarrier signals, and lower intercarrier interference (ICI) compared to OFDM. Kim et al. (2016) described a quadrature amplitude modulation (QAM)-FBMC wave design, which has a superior spectral efficiency, compared to cyclic prefix (CP)-OFDM. FBMC based on offset QAM (FBMC-OQAM) has been considered for use in high speed mobile communications. The features of FBMC radio access technology include low latency, high reliability, and high spectral efficiency. Furthermore, FBMC-OQAM systems have enhanced inter-subcarrier orthogonality. Hamid et al. (2011) demonstrated an FBMC uplink multiuser system using excellent frequency localized filters to achieve a high efficiency without the need for any interference cancellation scheme. The BER performance of FBMC-based multiple access networks is better than that of OFDM-based multiple access networks.

The use of low-density parity-check (LDPC) codes is an advanced error correction method employed to achieve reliable communication. An (n, j, k) LDPC is a code of block length n, in which each column contains a small fixed number, j, of elements equal to 1, and each row contains a small fixed number, k,

Paper submitted 01/31/18; revised 03/19/18; accepted 03/22/18. Author for correspondence: Chin-Feng Lin (e-mail: lcf1024@mail.ntou.edu.tw).
Part of this manuscript appears in the Proceedings of the 2017 International Conference on Physics and Mechanics of New Materials and Their Applications, Jabalpur, India.
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of elements equal to 1, with the code rate defined as (k-j)/k (Gallager, 1962). Gallager demonstrated the influence of code length with target transmission BERs on the computation time and complexity constraints. Brink et al. (2004) studied the performance of irregular LDPC codes with a code rate of 1/2, in a multiple-input multiple-output (MIMO) fading channel using Gray-mapped quadrature phase-shift keying (QPSK) modulation. Optimum design methodologies for the joint iterative decoding, channel, modulator, and detector were illustrated. LDPC codes were introduced into communication systems by Franceschini et al. (2009) after achieving significant insights into the behavior, statistical approach, and graphical representation.

Hanen et al. (2014) investigated the BER performance of FBMC-OQAM and OFDM under nonlinear distortion due to a high-power amplifier, which was simulated by additive white Gaussian noise (AWGN) and Rayleigh fading channels. They presented closed-form expressions for the BER of an FBMC-OQAM transceiver, with the OQAM symbols time staggered by half a symbol period, compared to the QAM symbols. Nissel and Markus (2017) reported on the BER performances of CP-OFDM and FBMC-OQAM in time-selectivity and frequency-selectivity channels. They found that FBMC modulation has superior spectral efficiency with a prototype filter, and other advantages over CP-OFDM include better time-frequency localization and improved BER performance at a high signal to noise ratio (SNR). Kwon et al. (2016) proposed a new channel estimation technology with an iterative interference cancellation algorithm for an FBMC-QAM evolved multimedia broadcast multicast system. They used two different prototype filters to achieve better time-frequency localized properties for even and odd subcarriers. The CP scheme was adopted to combat ISI from adjacent OFDM symbols in CP-OFDM modulation. However, the CP-less FBMC system was found to have higher transmission data rates. Ronald et al. (2017) studied the application of the FBMC modulation scheme for future mobile communications, focusing on performance evaluation. They reported that FBMC modulation communications is characterized by the flexible allocation of available time-frequency resources, ultra-high reliability, and low latency. The features of FBMC-OQAM include maximum symbol density, time and frequency localizations, and independent transmission symbols.

The UWA channel is a time-varying multipath channel with ISI and ICI. Kumar and Mrinal (2016) reviewed various efficient modulation schemes, including OFDM, BPSK, differential phase-shift keying (DPSK), and 16-QAM, to overcome the challenges of UWA communication technology, which include the achievement of a high transmission data rate, low BER, and low latency.

Amini et al. (2015) proposed a design algorithm for the cost function optimization of an FBMC prototype filter for communications in doubly dispersive UWA channels. They found that FBMC performs better than OFDM in such channels because the length of the CP in an OFDM system increases as the duration of the UWA channel impulse response increases; with a long symbol duration, the OFDM UWA system has a significant level of ICI, which leads to a significant degradation in the BER performance. On the other hand, the FBMC UWA system can combat ISI and ICI in time-frequency doubly dispersive UWA channels by using a prototype filter scheme. Mohammud et al. (2016) evaluated the BER performance of the FBMC-OQAM communication scheme in UWA channels and showed that, FBMC-OQAM can provide high transmission data rates, and achieve excellent bandwidth efficiency. Li et al. (2009) introduced a regular LDPC code with a code length of 600, code rate of 1/2, row weight of 6, and column weight of 3, by using log-likelihood ratio belief-propagation decoding algorithm to achieve a transmission BER of 10^{-5} at an SNR of approximately 2.8 dB through an UWA channel. Han et al. (2009) explored the (864,432) LDPC code of an underwater digital speech communication system with a code rate of 1/2, row weight of 6, and column weight of 3. Underwater digital speech was shown to be clear when the SNR is greater than 1.5 dB. Moreover, a direct-mapping orthogonal variable spreading factor (OVSF) transport architecture and an MIMO-OFDM transport architecture were demonstrated for underwater multimedia signals (Lin et al., 2010; Lin et al., 2013). Additionally, Lin et al. (2018) studied an FBMC-based underwater transmission scheme for voice signals.

In this paper, we propose an FBMC-based underwater transmission scheme for voice and image signals. In this scheme, FBMC transmission technology, LDPC channel coding, adaptive BPSK modulation or OQAM, and a power assignment mechanism are integrated into an underwater voice and image transmission system. The remainder of this paper is organized as follows. Section 2 describes the system model of adaptive FBMC-LDPC BPSK and OQAM for underwater voice and image transmission. In Section 3, we present the simulation results. The conclusions of this paper are presented in Section 4.

II. SYSTEM MODEL

Fig. 1 schematically shows the proposed FBMC-LDPC underwater transceiver architecture (UTA) for voice and image transmissions. Packet-by-packet transmission strategies; (2000, 1000) LDPC code encoder with a code rate of 1/2, a row weight of 6, and a column weight of 3; an object-composition petri-net (OCPN) model (Woo et al., 1995); adaptive modulation through BPSK or 4-OQAM; serial-to-parallel and paralel-to-serial schemes; FBMC modulation; and a power assignment mechanism are integrated in the UTA. Table 1 lists the parameters of the proposed UTA scheme. The PHYDYAS FBMC transmission scheme (Bellanger, 2010) is adopted in the proposed UTA with a 64-point inverse fast Fourier transform (IFFT) and two polyphase networks (PPNs).

Voice and image signals were input into an (2000, 1000) LDPC code encoder, and voice and image LDPC bit streams were extracted as outputs. The outputs were then input to the OCPN model, which yield voice and image LDPC packets as outputs for the synchronous playback of underwater voice and image. The voice and image LDPC packets were input into the adaptive BPSK or 4OQAM modulations, which output adaptively modulated voice and image LDPC packets. The adaptively mo-

Table 1. The parameters of the proposed UTA scheme.

FFT size	64
FBMC modulation	PHYDYAS FBMC scheme (Bellanger, 2010)
Channel coding	(2000, 1000) LDPC code encoder with a code rate of 1/2, a row weight of 6, and a column weight of 3
Adaptive modulation	BPSK, 4-OQAM
Power levels	1/30, 2/30, …, 30/30
BER limits for voice transmission	10^{-3}
BER limits for image transmission	10^{-4}

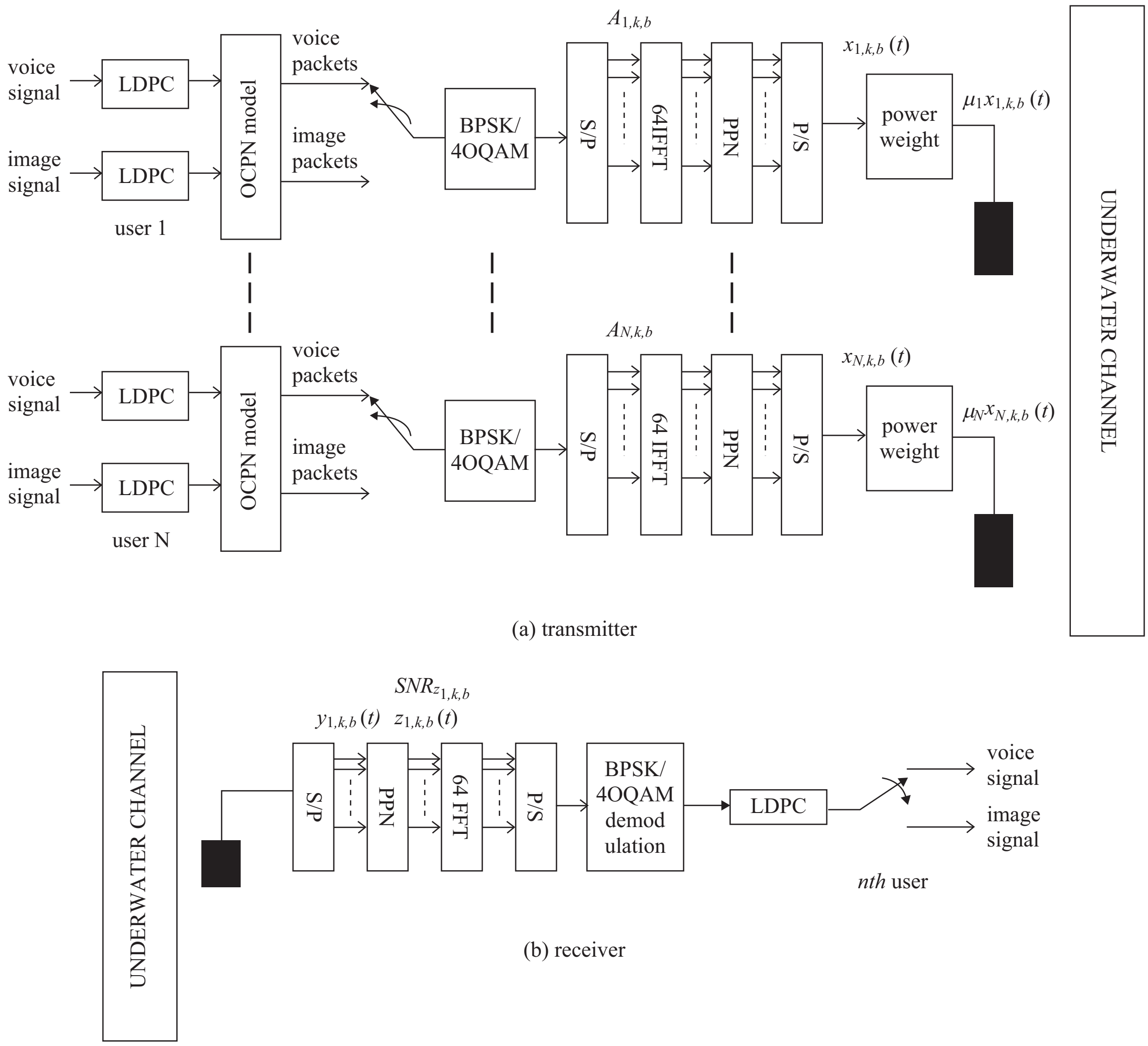

Fig. 1. Proposed FBMC-LDPC based UTA for voice and image transmission.

dulated voice and image LDPC packets were input into the serial-to-parallel mechanism, 64-point IFFT, two PPNs, and parallel-to-serial mechanism, and adaptively modulated voice and image FBMC-LDPC packets were extracted as final outputs. In the proposed UTA scheme, the maximum acceptable transmission BER values for voice, and image packets are assumed to be 10^{-3}, and 10^{-4}, respectively.

We assume that there are L users, M FBMC symbols in an FBMC-LDPC transmission packet, and N sub-carriers in an FBMC symbol for the UTA scheme. The baseband adaptive FBMC transmitted signal is expressed as follows:

$$x_{l,k,b}(t) = \sum_{b=1}^{MN} \sum_{k=0}^{N-1} A_{l,k,b} \phi_{k,b}(t) \quad (1)$$

where $A_{l,k,b}$ is a BPSK or 4-OQAM symbol with a symbol period T for the lth user, transmitted on the kth subcarrier at the instant bT. Let $\phi_{k,b}(t)$ be the time-frequency term of $ptf(t)$ for BPSK modulation, where $ptf(t)$ is the prototype filter impulse response, $\phi_{k,b}(t)$ can be expressed as follows:

$$\phi_{k,b}(t) = ptf(t-bT)e^{j\frac{2\pi}{T}kt} \tag{2}$$

Let $\phi_{k,b}(t)$ be the time-frequency term of $ptf(t)$ for 4-OQAM, which can be expressed as follows:

$$\phi_{k,b}(t) = ptf(t-bT/2)e^{j\frac{2\pi}{T}kt}e^{j\psi_{k,b}} \tag{3}$$

where $\psi_{k,b}$ is the phase term, which is $\frac{\pi}{2}(k+b)-\pi kb$.

Thus, the adaptively modulated FBMC signal using the power assignment mechanism can be expressed as follows:

$$x_{l,k,b}(t) = \sum_{b=1}^{MN}\sum_{k=0}^{N-1}\mu_l A_{l,k,b}\phi_{k,b}(t) \tag{4}$$

where μ_l is the transmission power weighting of the lth user. The received signal is expressed as follows:

$$y_{l,k,b}(t) = x_{l,k,b}(t) * h(t) + w(t) \tag{5}$$

where $h(t)$ is the underwater multipath tap-delay line channel impulse response, $w(t)$ is the additive white Gaussian noise, and '*' is the convolution operation. The signal received through the PPNs is expressed as follows:

$$z_{l,k,b}(t) = y_{l,k,b}(t) * \phi^{*}_{l,k,b}(t) \tag{6}$$

The SNR of the l-th user, $SNR_{Z_{l,k,b}}$, is detected using the double window detection algorithm (Terry and Heiskala, 2002). The proposed power assignment mechanism for the FBMC-LDPC UTA scheme is summarized as follows:

Step 1: According to the output information obtained from the OCPN model, calculate the packet rates for voice, and image underwater transmission.
Step 2: Select the appropriate modulation mode that satisfies the requirements for voice and image transmission over a UWA channel.
Step 3: Assign the initial value of μ_l as 15/30 for voice, and image packets.
Step 4: Measure the received $SNR_{Z_{l,k,b}}$ for voice, and image packets.
Step 5: If the measured $SNR_{Z_{l,k,b}}$ of the received signal exceeds the threshold SNR at which the required BER for voice or image packets is achieved, then update

μ_l as $\mu_l = \mu_l - \Delta$.

If $\mu_l \geq \frac{1}{30}$, go to Step 4; otherwise, go to Step 7.
Step 6: If the measured $SNR_{Z_{l,k,b}}$ of the received signal is less than the threshold SNR at which the required BER for voice, or image packets is achieved, then update μ_l as $\mu_l = \mu_l + \Delta$. If $\mu_l \leq 1$, go to Step 4; otherwise, go to Step 8.
Step 7: Downgrade the modulation mode. If the modulation mode is not 4-OQAM, go to Step 4.
Step 8: Upgrade the modulation mode. If the modulation mode is not BPSK, go to Step 4.

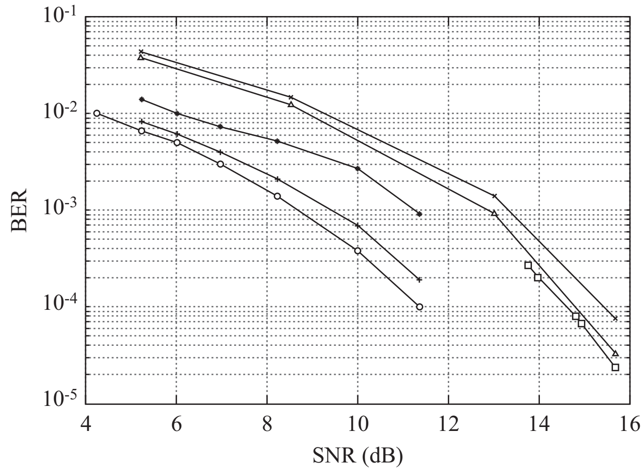

Fig. 2. BER performance of the FBMC-LDPC UTA scheme with a PCE and CEEs of 5% and 10%.

III. SIMULATION RESULTS

We adopted an underwater channel model (Zhang et al., 2008) with a transmission distance of 1 km, carrier central frequency of 11.5 kHz, and underwater channel bandwidth of 3.9 kHz. Fig. 2 shows the BER performance of the FBMC-LDPC UTA scheme with perfect channel estimation (PCE) and channel estimation errors (CEEs) of 5% and 10%. The symbols 'o', '+', '*', '□', '△', and 'x', in Figs. 2-8, respectively, denote BPSK modulation with PCE, BPSK modulation with a CEE of 5%, BPSK modulation with a CEE of 10%, 4-OQAM with PCE, 4-OQAM with a CEE of 5%, and 4-OQAM with a CEE of 10%. The BER performances of BPSK modulation are better than that of 4-OQAM. Furthermore, the BER performances degraded as the CEE increased. The power-saving ratio of the FBMC-LDPC UTA scheme is defined as follows:

$$PS = (1-\mu_l)\times 100\% \tag{7}$$

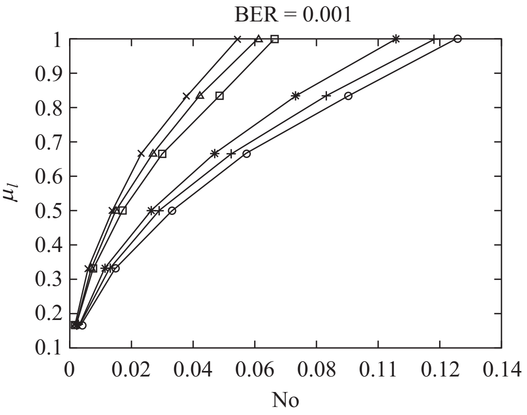

Fig. 3. Transmission power weighting of the FBMC-LDPC UTA scheme with a BER of 10^{-3}, for PCE and CEEs of 5% and 10%.

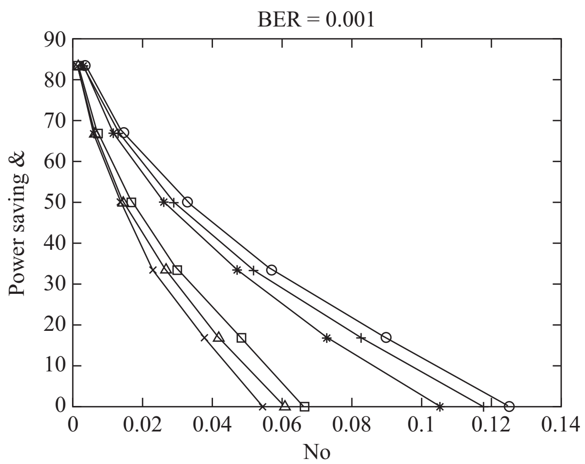

Fig. 4. Power saving ratios of the FBMC-LDPC UTA scheme with a BER of 10^{-3}, for PCE and CEEs of 5% and 10%.

Figs. 3 and 4, show the transmission power weighting and power saving ratios of the FBMC-LDPC UTA scheme with a BER of 10^{-3}, for PCE and the aforementioned CEEs. Figs. 5 and 6, show the transmission power weighting and power saving ratios of the FBMC-LDPC UTA scheme with a BER of 10^{-4}, for PCE and the aforementioned CEEs. The transmission power weighting of OQAM is greater than that of BPSK under BERs of 10^{-3} and 10^{-4}, and the power saving ratio of OQAM is less than that of BPSK under BERs of 10^{-3} and 10^{-4}. As the AWGN increases, the transmission power weighting increases and power saving ratio decreases. As the CEE increases, the transmission power weighting increases and power saving ratio decreases. The MSE of the original and received voice signals is expressed as follows:

$$MSE = \frac{1}{N}\sum_{i=1}^{N}\left(X_i - \hat{X}_i\right)^2 \tag{8}$$

where X_i is the original voice signal, $\hat{X}_i$ is the received voice

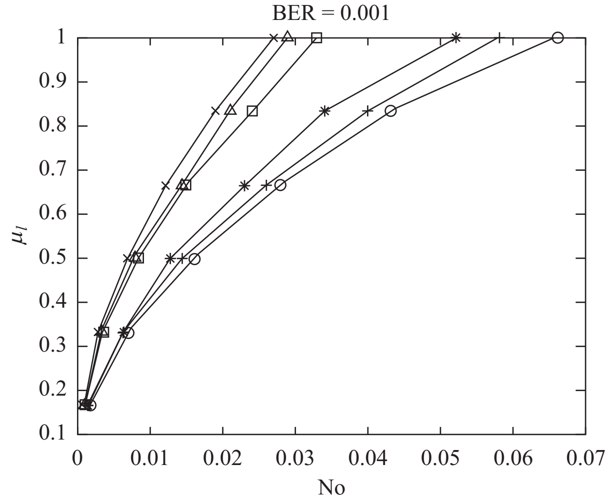

Fig. 5. Transmission power weighting of the FBMC-LDPC UTA scheme with a BER of 10^{-4}, for PCE and CEEs of 5% and 10%.

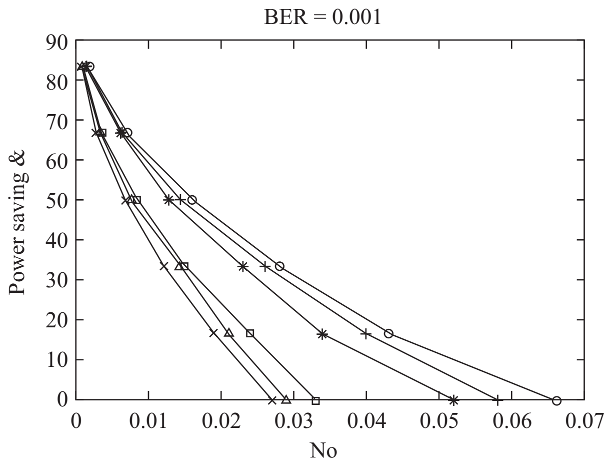

Fig. 6. Power saving ratios of the FBMC-LDPC UTA scheme with a BER of 10^{-4}, for PCE and CEEs of 5% and 10%.

signal, and N is the length of the original voice signal.

Fig. 7 shows the mean square error (MSE) of the original and received voice signals with PCE and the aforementioned CEEs. The image MSE (IMSE) of an $m \times n$ image signal is defined as follows:

$$IMSE = \frac{1}{mn}\sum_{i=0}^{m-1}\sum_{j=0}^{n-1}\left[I(i,j) - K(i,j)\right]^2 \tag{9}$$

where $I(i, j)$ is the matrix containing the pixel values of the original image signal, and $K(i, j)$ is matrix containing the pixel values of the received image signal. The peak SNR (PSNR) (in dB) is defined as follows:

$$PSNR = 10\log_{10}\left(\frac{Max(I(i,j))^2}{IMSE}\right) \tag{10}$$

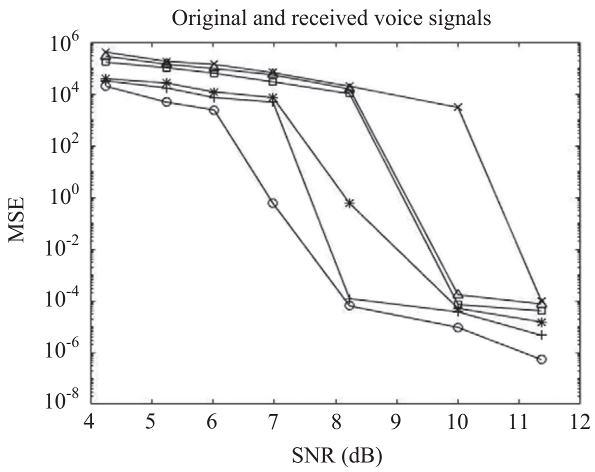

Fig. 7. MSE of original and received voice signals with PCE and CEEs of 5% and 10%.

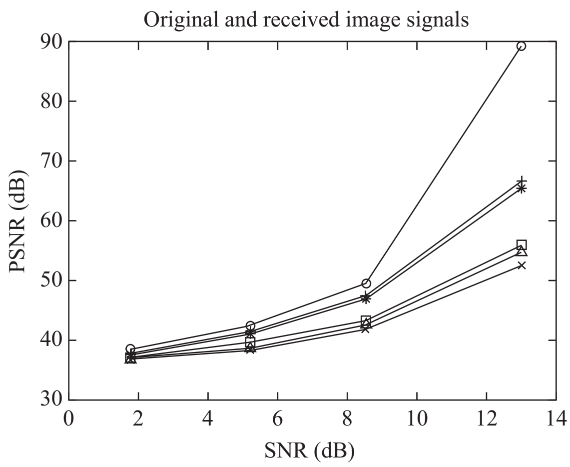

Fig. 8. PSNRs of original and received image signals with PCE and CEEs of 5% and 10%.

Fig. 8 shows the PSNR of the original and received image signals with PCE and the aforementioned CEEs. Figs. 9-11 show the voice signal received using OQAM for BERs of 10^{-1}, 10^{-2}, and 10^{-3}, respectively, with the corresponding MSEs of the original and received voice signals being 1608400, 18795, and 0.00002984, respectively. The CEE in the proposed FBMC-LDPC UTA scheme is 5%. With a BER of 10^{-3}, the MSE of the original and received voice signals is approximately 10^{-5}, the received voice signals are clearly audible and can be used in UWA voice transmission. Figs. 12-15 show the voice signal received using OQAM for BERs of 10^{-1}, 10^{-2}, 10^{-3}, and 10^{-4}, respectively, with the corresponding PSNRs of the received image signals being 36.86 dB, 43.24 dB, 54.77 dB, and 64.68 dB, respectively. The CEE in the proposed FBMC-LDPC UTA scheme is 1%. For a BER value of 10^{-4}, the PSNR of the received underwater image signals is approximately 60 dB; the received image signals are clearly visible, and can be used in UWA image transmission.

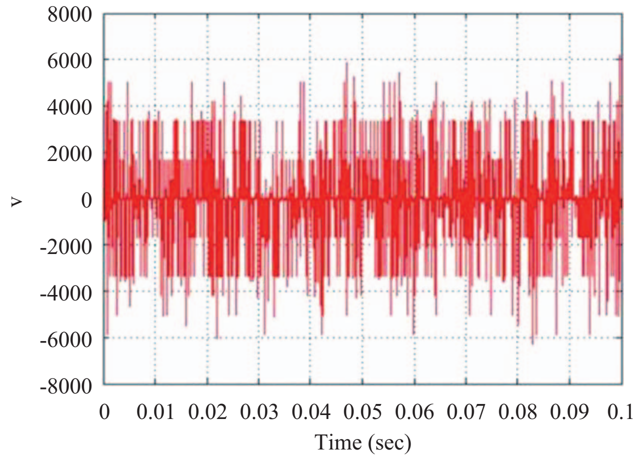

Fig. 9. Voice signal received using 4-OQAM with a CEE of 5%, BER of 10^{-1}, and MSE of 1608400.

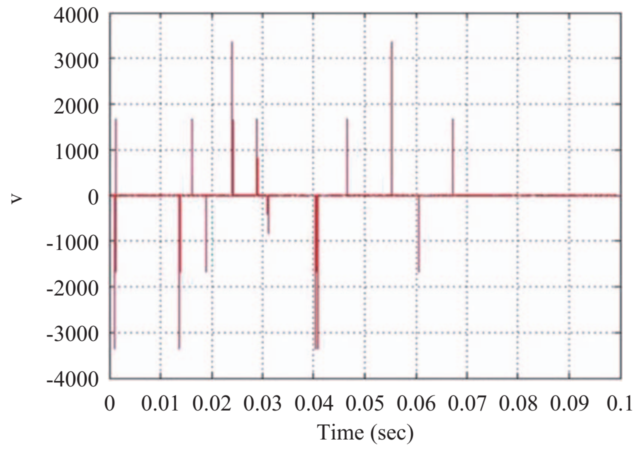

Fig. 10. Voice signal received using 4-OQAM with a CEE of 5%, BER of 10^{-2}, and MSE of 18795.

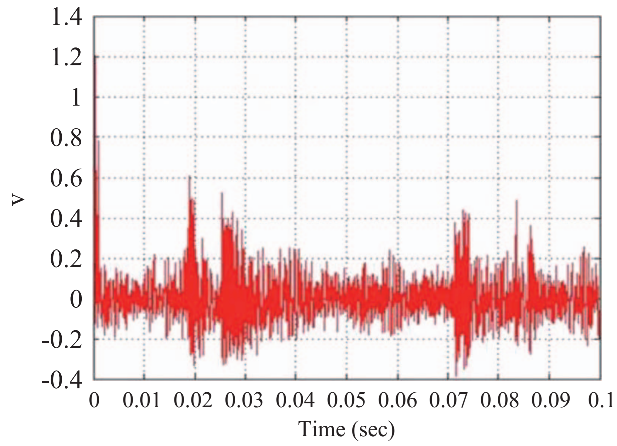

Fig. 11. Voice signal received using 4-OQAM with a CEE of 5%, BER of 10^{-3}, and MSE of 0.00002984.

IV. CONCLUSION

In this paper, an FBMC/LDPC UTA scheme using adaptive

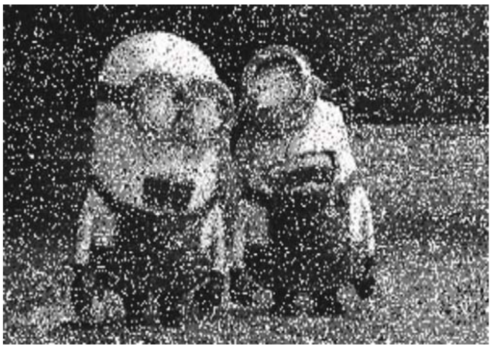

Fig. 12. Image signal received using 4-OQAM with a CEE of 1%, BER of 10^{-1}, and PSNR of 36.86 dB.

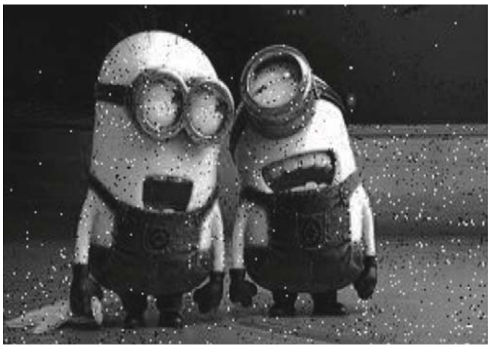

Fig. 13. Image signal received using 4-OQAM with a CEE of 1%, BER of 10^{-2}, and PSNR of 43.24 dB.

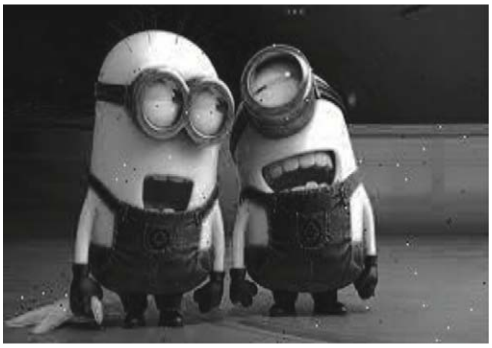

Fig. 14. Image signal received using 4-OQAM with a CEE of 1%, BER of 10^{-3}, and PSNR of 54.77 dB.

BPSK modulation or 4-OQAM, in addition to a power assignment mechanism, was demonstrated to achieve a high quality of service for voice and image signal transmission. The BER performance, transmission power weighting, and power saving ratios for the proposed FBMC/LDPC UTA scheme were explored. Furthermore, the MSE values of the original and received voice signals, and the PSNR values of the received image signals were studied. Simulation results show that the proposed FBMC/LDPC UTA scheme is excellent for the transmission of underwater voice and image signals.

Fig. 15. Image signal received using 4-OQAM with a CEE of 1%, BER of 10^{-4}, and PSNR of 64.68 dB.

ACKNOWLEDGEMENTS

The authors acknowledge the support of the grant from The Ministry of Science and Technology of Taiwan, under contract No. MOST 105-2923-E-022-001-MY3, and the valuable comments of the reviewers.

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