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Biomimetic FSK Underwater Communications using Dolphin Whistle

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1. Introduction

Ultrasonic signals motivated from dolphin sound have been utilized for underwater acoustic communications. If a transmit signal precisely mimics dolphin signal patterns, it confuses other users with dolphin sound, and securely transmits information to a specific user. Such biomimetic communication researches have been emerged.

Dolphin whistle sound shows frequency sweeped pattern[1)]. Chirp spread spectrum(CSS) was firstly studied for a biomimetic communication method[2)]. To transmit digital information, this method divides a dolphine whistle into many small time slots with a time duration, and up- or down-sweeped chirp signals are allocated to contain binary information[2)]. However, the fact that CSS has lower BER performance than frequency shift keying(FSK) is known [3)].

In this paper, we propose a biomimetic FSK communication method based on the dolphin whistle in underwater communications. Computer simulations and lake experiments demonstrate that BER performance of the proposed method shows better than that of CSS.

2. Biomimetic FSK communication scheme

The length of whistle is from several hundered milliseconds to few seconds long, and its frequency bands vary from several tens of Hz to several hundereds of kHz, along to species[1)]. To measure the time-frequency pattern of the dolphin whistle, short time Fourier transform(STFT) can be utilized. STFT of the dolphin whistle with a time length T can obtained as **Eq.).**

$$W[k\times\tau, f_k] = \sum_{t=1}^{N} w[t]\ h(t-k\times\tau)e^{-2j\pi t f/N} \quad (1)$$

where $w[t]$ denotes the dolphin whistle, $h(t)$ denotes a short-time window with a length of L, N denotes a size of FFT, τ denotes a time slot for digital symbol, and f_K denotes a frequency at $k\times\tau$. From **Eq. 1**, frequency components which will be used for micmicking dolphin whistle pattern can be measured as $f_1, f_2, \dots f_k, \dots, f_K$ at $k\times\tau$. **Fig. 1** dicpicts the spectrogram of the dolphin whistle sound obtained from **Eq. 1**.

As mentioned above, the conventional CSS transmits binary bits by modulating up- or down-chirp signal in τ. To improve BER performance, this paper proposes a biomimetic FSK method of UWA communication.

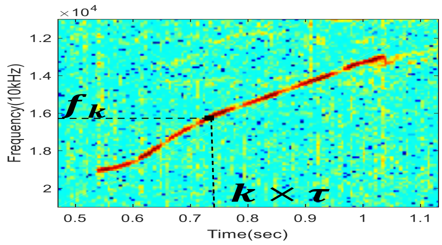


Fig. 1. Dolphin whistle sound spectrogram

FSK is a frequency shifting scheme in τ to allocate the binary information [4)]. Since the slot time τ and the bandwidth of the conventional CSS symbol are restricted, up- or down-chirp symbols of CSS are quasi-orthogonal, which degrades BER performance. However, FSK scheme preserves orthogonality among symbols, and presents better BER performance than that of that of CSS[3)].

FSK mimicking dolphin whistle can be designed as follows. Firstly, determine a FSK symbol length τ and secondly, make the frequency modulation of the *k*th symbol with f_k. Note that f_k varies with time. Then, the biomimetic FSK pattern are closely equal to the dolphin whistle. Biomimetic FSK which mimics the dolphin whistle can be expressed by **Eq. 2**.

$$s(t) = \begin{cases} cos\{2\pi(f_k - f_{FSK}/2)t\},\ bit{:}\,0 \\ cos\{2\pi(f_k + f_{FSK}/2)t\},\ bit{:}\,1 \end{cases} \quad (2)$$

In order to keep the orthogonalization of each symbol in FSK scheme, $f_{FSK} \geq 1/T_{FSK}$ should be held. A spectrogram example of FSK signal obtained from **Fig. 1** is shown in **Fig. 2**.

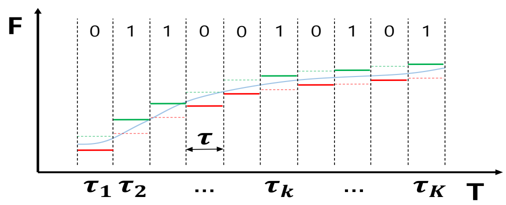


Fig. 2. Dolphin whistle biomimetic FSK underwater communication signal

As seen in **Fig. 2**, FSK mimicking the dolphin whistle can be considered as fast hopping(FH) FSK which hops at every frequency f_k. In FH-FSK, channel estimation is very difficult, because each symbol has a different carrier frequency and no room for pilot to estimate the channel. Thus, non-coherent detection is utilized in FH-FSK reciever, too. If receiver knows the time-frequency characteristic, i.e., τ and f_k, of the transmitted signal, received signal can be detected using a conventional FSK demodulation method after dehopping the received signal to baseband.

3. Experiments and results

Computer simulations and practical lake experiments were performed to evaluate and compare BER performance of the proposed method with that of the conventional CSS. To mimic the dolphin whistle, the signal pattern in **Fig. 1** was utilized. The whistle length T was 0.5sec and its frequency varied from 12.5 kHz to 19.5kHz.

For computer simulation, underwater channel was generated by Bell-hop. For fair BER performance comparison, FSK and CSS symbol lengths were equal to 10msec, and the bandwidths were set to 300Hz and 600Hz. **Fig. 4** displays BERs of the biomimetic CSS and FSK. **Fig. 4** shows that BER performance of the proposed biomimetic FSK are better than that of CSS at the same EbNo.

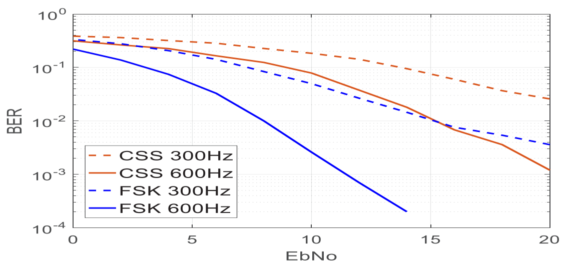
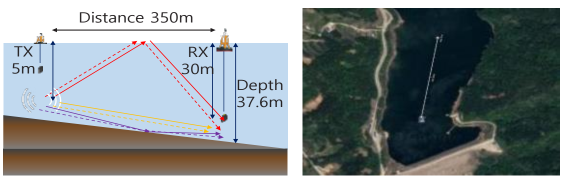


Fig. 4. BER simulation results

Practical experiments were also performed on May 28, 2018 at Kyungcheon lake (36°45`27.6"N 128°18`40.5"N) in South Korea. The same transmitted signals used in computer simulations were executed, and BERs of two methods were measured. **Fig. 5** presents experimental parameters and environments of lake tests.



(a) (b)

Fig. 5. Experimental configuration (a), site (b)

The distance between a transmitter and a receiver was about 350m, the depths of the transmitter and the receiver were 5m and 30m, respectively, and the depth of water was 37.5m. Sampling frequency was 192 kHz.

Fig. 6 depicts the spectrogram of the transmitted signal (a) and the received signal (b).

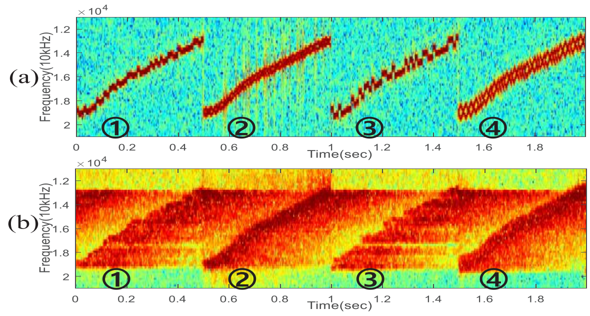


Fig. 6. Experimental transmitted signal(a) Received signal(b)

In **Fig. 6,** signal ① and ② are biomimetic FSK and CSS signals with 300Hz bandwidth, and signal ③ and ④ are FSK and CSS signal with 600Hz bandwidth.

Table I shows the BER results of FSK and CSS by the lake experiments.

Table. 1. Experimental BER result

Modulation	300Hz	600Hz
FSK	0.043	0.042
CSS	0.080	0.074

In **Table 1**, BERs of the proposed method demonstrates 47% and 44% of those of CSS at 300Hz and 600Hz bandwidth, respectively. For all cases, the proposed biomimetic FSK provides about half of BER rate of the conventional CSS scheme.

4. Conclusion

This paper proposes a biomimetic FSK communication method based on the dolphin whistle. Computer simulations and practical lake experiments exhibit that BER performance of the proposed method is always better than that of the conventional CSS.

Acknowledgment

This work was supported by the Agency for Defense Development, South Korea, under Grant UD170022DD.

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