HIGH SPEED REAL-TIME UNDERWATER ACOUSTIC SPEECH COMMUNICATION WITH ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING

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In the complex underwater acoustic (UWA) channel, the channel characteristics of multipath interference, time-varying, bandwidth limitation, and transmission delay have great effects on the real time UWA speech communication. This paper combines Orthogonal Frequency Division Multiplexing (OFDM) communication technology with Multi-Band Excitation (MBE) speech compression coding technology. With high-speed DSP device, algorithms of speech compression and decompression, modulation, coding, equalization and anti-Doppler, are being used to design a set of digital UWA speech communication system. This system realized a kind of real time wireless speech communication on submersibles or divers. The paper firstly introduces OFDM communication technology and MBE voice compression technology, then the hardware and software structure of the system are mentioned. Finally, the paper verifies the performance of the system through a lake experiment.

Keyword: Underwater Acoustic Speech Communication; Underwater mobile phone; OFDM; Speech Compression

1. Introduction

Among various forms of communication, the speech communication is a very important and the most straightforward way of communication\textsuperscript{1}. As the radio waves can only transmit tens of meters underwater, sound is the only known information carrier which can remotely transmit underwater. Now, the underwater acoustic communication is not limited to solve the problem of military applications, in many non-military fields. Especially in many fields such as underwater inspection and maintenance, seabed oil and gas development, marine environmental monitoring, underwater archaeology, diving tourism and other fields, acoustic communication has been used in kinds of commercial and civil application\textsuperscript{2-4}. Divers equipped with underwater acoustic communication system can talk freely, anxiety will be reduced, and working efficiency will be relatively high\textsuperscript{5-6}. Thus, the study of underwater acoustic speech communication technology has very important practical significance and application value\textsuperscript{7-8}.

By using high-speed digital signal processor as the core processor of system, this paper combines Orthogonal Frequency Division Multiplexing (OFDM) communication technology with Multi...
Band Excitation (MBE) speech compression coding technology. The present work achieves a long-distance wireless transmission of speech signals over underwater acoustic channel by using OFDM and MBE technology. In this paper, we solve the problem of signal transmission caused by multi-path propagation and Doppler frequency shift, and design a real-time digital underwater acoustic speech communication system, we call it ‘underwater interphone’, achieve the function of communication among submersible vehicle, divers and shore base.

First, the paper introduces OFDM communication technology and MBE voice compression technology, then the hardware and software structure of the system are mentioned. Finally, the paper verifies the performance of the system through a lake experiment.

2. Principle of OFDM

In OFDM modulation system, high speed data flow is transferred through many sub-carriers as a parallel way. Each sub-channel has a relatively low data rate and a specific carrier frequency which is orthogonal to each other. Data symbols are transmitted on multiple subcarriers at the same time.\(^1\), \(^9\).

The data rate on each subcarrier is 1/N of the single carrier transmission system with the same data rate, symbol during time of each sub-carrier corresponding increase N times. This way allows data transfer in a high speed, as well as data symbol duration is much larger than the channel delay spread. So that, the complex channel equalization can be simplified.

Using orthogonal multi-carrier transmission, overlapping between the sub-carriers is allowed. Inter-carrier interference can be zero, so that the bandwidth of system is well used\(^1\), \(^0\). Such orthogonal multi-carrier transmission signal may be expressed as:

\[
x(t) = \sum_{k=0}^{N-1} X(k) \exp(j2\pi f_k t)g_r(t)
\]  

Wherein, \(g_r(t) = \begin{cases} 1, & 0 \leq t \leq T \\ 0, & \text{other} \end{cases} \) is the transmission waveform for the symbol, \(X(k)\) is the symbol transmitted on the \(k\)-th sub-carrier, \(f_k\) is the frequency of the \(k\)-th sub-carrier, \(N\) is the total number of carriers, they satisfy the following orthogonal relationship within the symbol transmission time \(T\):

\[
\int_0^T \exp(j2\pi f_k t) \exp(-j2\pi f_l t)dt = 0, \forall k \neq l
\]  

Obviously, when \(f_k = \frac{k}{T}, k = 0,\ldots,N - 1\), the reciprocal of the subcarrier interval is the symbol duration, they satisfy the above orthogonal relation, Eq. (1). At the receiving terminal, using a plurality of orthogonal demodulation groups to demodulate the transmission signal, without considering the effects of the channel, the received signal can be:

\[
\hat{Y}(k') = \frac{1}{T} \int_0^T x(t) \exp(-j2\pi k't)dt = X(k'), \ k' = 0, \ldots., N - 1
\]  

Fig. 1 shows the block diagram of the OFDM system.

3. MBE Speech Compression

Underwater acoustic channel is a complex time-varying channel. Multi-path and frequency selective fading severely affect the transmission characteristics of underwater acoustic signal, limit
the bandwidth of the signal. Bandwidth of high-quality voice signal is much larger than that of long-range underwater acoustic channel. Signal must be compressed in the real-time communications. Modern low-rate speech coding method is designed to provide coding system with high quality, low rate, good robustness and proper coding delay.

![Block diagram of the OFDM system.](image)

Figure 1. Block diagram of the OFDM system.

This system adopts the advanced MBE encoding algorithm for speech coding, which is suitable for underwater acoustic voice communications. This method not only has the ability to synthesize a better voice than other phonetic vocoder in rate of 2.4kbps ~ 4.8kbps, but also has a good naturalness and noise tolerance. This algorithm adjusts the compression ratio by decoding properties and channel response, adjusts the parameters of encode and decode, makes sure of good voice quality through underwater acoustic channel. Fig. 2 shows the basic principle of MBE algorithm.

![Basic principle of MBE.](image)

Figure 2. Basic principle of MBE.

According to harmonic frequency, MBE algorithm divides voice into several sub-bands. Each band of signals will be judged by voiced (V) or unvoiced (U), then encode separately. At the decoder side, according to coding format, the system firstly extracts the parameters. Then, it finds the V/U judge bit, and synthesizes the voice into speech using different driver signal of voiced or unvoiced.
MBE algorithm essentially belongs to parameter coding technology, it does not require a voice close to the original speech waveform as much as possible, but requires a good voice quality.

4. The System Structure

![Figure 3. Block diagram of speech communication system.](image)

As shown in Fig. 3, the voice communication system can be divided into two parts: the speech signal processing unit (SSP) and the underwater acoustic communication unit (UAC). SSP unit completes speech signal sampling, encoding, decoding and speech synthesis functions. UAC completes digital signal processing, OFDM modulation and demodulation and channel equalization functions.

![Figure 4. Workflow of listening state and transmission state.](image)
This system has two work state: listening state and transmission state. System comes into listening state after initialization. As shown in Fig. 4(a), when the system is in the listening state, UAC unit receives acoustic signals in the water. If a sync-signal is detected, a start of communication is considered, then the OFDM signal after the synchronization data packets are demodulated. SSP unit decodes the packet, and the voice plays from speaker.

Listening state and transmission state switch through a button, when voice need to be sent, the system first stops detecting the sync-signal, and turns into the transmission state, as shown in Fig. 4(b). At this moment, the SSP unit will code the voice signal into packages, and complete the channel code and modulation by the UAC unit. Finally, a header, an end and the sync-signal will be added into each data packages, form frames of OFDM underwater acoustic signal. The signal is transmitted to water by power amplifier.

5. Lake Experiment

We test the half-duplex real-time speech communication by two devices in the lake experiment. Signal bandwidth is 8~12 KHz, source level is 177dB. Average depth of experiment are approximates 80meters. The depth of transmitter and receiver are both 10meters. Test result is shown in Table 1.

<table>
<thead>
<tr>
<th>Distance/m</th>
<th>Code Rate/kbps</th>
<th>Communication Rate /kbps</th>
<th>Forward Error Correction /bps</th>
<th>Error/%</th>
</tr>
</thead>
<tbody>
<tr>
<td>600</td>
<td>3.6</td>
<td>3.82</td>
<td>1150</td>
<td>3</td>
</tr>
<tr>
<td>2100</td>
<td>2.7</td>
<td>2.98</td>
<td>250</td>
<td>5</td>
</tr>
<tr>
<td>3100</td>
<td>2.4</td>
<td>2.59</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>4100</td>
<td>2.4</td>
<td>2.59</td>
<td>0</td>
<td>2</td>
</tr>
</tbody>
</table>

Fig. 5 is the channel impulse response when the range between two devices is 4100m. Time difference between direct sound and multipath is about 2ms. At this point, voice performance is excellent, voice is clear and quality, characteristic of human tone can be distinguished.
A long-time voice communication was tested when the range between two nodes reached 4100 m. Fig. 6 shows the voice waveform of transmitting and receiving.

![Voice waveform of transmitting (a) and receiving (b).](image)

**Figure 6.** Voice waveform of transmitting (a) and receiving (b).

### 6. Conclusion

The system combines MBE voice compression technology with OFDM digital modulation technology. High-speed DSP devices is used as the implementation platform of voice compression and underwater acoustic communication. It realized a real-time continuous voice call among the shore, submarine, diver and surface ships. Working in the half-duplex wireless way, the system can improve the utilization of underwater acoustic channel and avoid issues such as wired communication cable winding. This research has a widely usage in underwater inspection and maintenance, subsea oil and gas development, monitoring the marine environment, underwater archeology, diving tourism and other commercial or civil application.

The results of lake experiment show that the design of this system can implement real-time duplex speech communication. Communication range exceeds 4 km. The system has high fidelity voice quality and strong ability in anti-doppler.

### REFERENCES


