Selection of CDMA and OFDM Using DNN in Underwater Acoustic Channels

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Abstract— This paper proposes a selection method to choose a better modulation scheme in a given underwater acoustic communication channel. In this paper, parameters affecting the BER of CDMA and OFDM were calculated from underwater acoustic channels. Deep Neural Network (DNN) with the parameters was utilized to select the better modulation method given an underwater acoustic channel environment. Computer simulations demonstrate the proposed method selects the better modulation scheme by 98.98%.

Keywords—Underwater communication, CDMA, OFDM, Deep Neural Network

I. Introduction

Underwater acoustic (UWA) communication cannot utilize RF waves, but acoustic waveforms with a slow propagation speed. The long delay time of multipath in underwater acoustic channel causes inter-symbol interference (ISI) and frequency selective fading. Water-flow and temperature variation of seawater cause Doppler frequency shift, even though transmitter and receiver are fixed [1]. The ISI and Doppler effect make crucial problems of UWA communication system. Thus, these problems need to be calculated as parameters and are considered when UWA communication system is designed.

Code Division Multiple Access (CDMA) and Orthogonal Frequency Division Multiplexing (OFDM) have been developed to overcome the problems by UWA channels. CDMA utilizes spreading codes that reduces ISI and obtains an array gain. The receiver of CDMA utilizes rake receiver, which obtains time diversity gain. In OFDM system, cyclic prefix(CP) reduces ISI and subcarrier division adopts one-tap equalizer to compensate frequency selective fading.

In general, a large data rate in UWA communications is needed. However, Doppler frequency in CDMA system limits the a time duration of data frame, and RMS delay spread gives restriction to set a frequency space of data. Even though CDMA and OFDM are designed to overcome the UWA channel effects, however, when UWA channel varies and the parameter values exceed the design tolerance of the systems, the BER performance degrades.

In [3], BER performance in CDMA and OFDM were different in a given UWA channels. For a given UWA channel, BER performance of CDMA is better than that of OFDM, and for other channels, vice versa. For a reliable communication in a UWA channel, better modulation scheme needs to be selected. In this paper, we propose a selection method to choose a better modulation scheme by DNN for a given UWA channel. DNN learns the parameters of many UWA channels and selects the better modulation scheme when a UWA channel is given. Computer simulation demonstrates the proposed DNN correctly selects the better modulation scheme by 98.98%.

II. System Model

In this section, CDMA and OFDM systems are explained, and the parameters affecting BER performance are also discussed.

A. CDMA

CDMA utilizes spreading codes that satisfy orthogonality, and reduce ISI, and obtains array gain. The Rake receiver of CDMA equalizes channel distortions, and combines every path of multipath, and obtains array and time diversity gain. For the Doppler effect, pilot intervals are designed according to the coherence time. The pilot length is designed according to maximum excess delay time to correctly estimate UWA channel.

However, if the maximum excess delay time is longer than the designed pilot length, all multi path channels cannot be estimated, and causes a channel estimation error. In this case, Rake receiver cannot fully obtain a time diversity gain. When a coherence time is shorter than the designed pilot interval, the channel estimation error occurs and the BER performance decreases.

B. OFDM

OFDM utilizes orthogonally divided sub-channel by subcarriers. The ISI problem is avoided by CP, and frequency selective fading caused by multi path is compensated with 1-tap equalizer. When OFDM is designed, pilot spacing in frequency subcarrier needs to be within coherence bandwidth, and CP lengths is larger than the maximum excess delay time.

When the coherence bandwidth by RMS delay time of UWA channel is shorter than a designed pilot spacing, a channel estimation error occurs. In addition, the maximum excess delay time of the channel is longer than the designed CP length, ISI occurs and BER performance is degraded.

C. Paramters related to BER performance

As seen above, the parameters related to BER performance are given from the UWA channels. For CDMA system, Doppler frequency and maximum excessive delay time are crucial parameters to BER performance. For OFDM system, maximum excess delay time and RMS delay time are important parameters.

III. Deep Neural Network

This section describes a DNN selecting one of CDMA and OFDM systems to keep better BER performance for the same data rate. The input parameters of DNNs for a given channel are described, and structure of DNN is discussed.

A. *Preprocessing for DNN*

Any variables for the purposed of DNN can be used for the input of the DNN. In our scenario, the UWA channel can be an input. However, when the channels are directly used for the DNN, the processing time will take a long time and convergence may not be guaranteed. Thus, effective parameters containing channel characteristics are calculated and used for the input of DNN. This section describes calculation method of the UWA channel parameters affecting the BER performance of CDMA and OFDM schemes.

The first parameter is SNR, which is expressed by the following equation.

$$SNR(dB) = 10\log_{10}\left(\frac{\int_{T_N}^{T_{S+N}} |r(t)|^2\,dt - \int_{T_0}^{T_N} |r(t)|^2\,dt}{\int_{T_0}^{T_N} |r(t)|^2\,dt}\right) \quad (1)$$

where $r(t)$ denotes the received signal, and T_N denotes the time duration, in which only noise exists, and T_{S+N} denotes the time period in which signal and noise exist simultaneously.

The second parameter of the UWA channel is root mean square (RMS) Doppler frequency, which is shown as below [4],

$$f_{D,rms} = \sqrt{\frac{\int_{f_c - f_{\max}}^{f_c + f_{\max}} (f-\overline{f})^2 \psi_D(f)\,df}{\int_{f_c - f_{\max}}^{f_c + f_{\max}} \psi_D(f)\,df}} \quad (2)$$

where $\psi_D(f)$ denotes the average power of the UWA channel according to frequency, and $\overline{f}$ denotes the average frequency of the Doppler spread, and f_c denotes a carrier frequency, and $f_{\max}$ denotes a maximum Doppler shifted frequency.

The third parameter is RMS delay spread, which is given as below,

$$\tau_{rms} = \sqrt{\frac{\int_0^\infty (\tau-\overline{\tau})^2\, p(\tau)\,d\tau}{\int_0^\infty p(\tau)\,d\tau}} \quad (3)$$

where $p(\tau)$ denotes the power delay profile of the time-varying channel ($h(t,\tau)$), and $\overline{\tau}$ denotes the average of the delay times [4].

The fourth parameter is maximum excess delay, which is a time measured by a time when the channel amplitude has below a threshold. In general, the threshold is determined as a10dB smaller values of the maximum value. The difference between the first time (τ_0) and the last time (τ_k) greater than the threshold, which is given as,

$$Maximum\ Excess\ Delay = \tau_k - \tau_0 \quad (4)$$

Eqs. (1-4) are used as the input parameters of the designed DNN.

B. *Design of DNN*

The design of DNN used in this paper is explained. The number of input parameters of DNN is set to four, and the number of output of DNN is set to three. Since the purpose of DNN is to select one of the two modulation methods, two outputs are used. In addition, one additional output is set when the BER performance is the same. The output values are set as below,

$$\hat{y} = \begin{cases} 0, & if\ \ BER_{CDMA} > BER_{OFDM} \\ 1, & if\ \ BER_{CDMA} < BER_{OFDM} \\ 2, & if\ \ BER_{CDMA} = BER_{OFDM} \end{cases} \quad (5)$$

DNN in this paper is composed of an input layer, an output layer, and two hidden layers. The number of hidden layers and the number of neurons in each layer should be designed in order to improve the selection performance of DNN with four input parameters. However, a design method is not given as a closed form, and but, should be designed through experiments. Fig. 1. is the structure of DNN proposed in this paper.

When the number of input parameters of DNNs is small, the performance of DNN with two hidden layer is expected to be good. As the number of hidden layer increases more, the performance improvement of DNN is getting small [5]. If the number of neurons is large, the overfitting problem occurs. Thus, the number of neurons in the hidden layer is determined according to the size of the input data set [5].

DNN used in this paper utilizes back propagation algorithm with a mini-batch size, and a categorical cross-entropy function because of multiple $\hat{y}$. The activation function of each hidden layer adopts a rectified linear unit (ReLu) function, which prevents the vanishing gradient problem. The activation function of final layer uses a soft-max function to classify the multi labels of $\hat{y}$. The structure used in this paper is shown in Fig. 1.

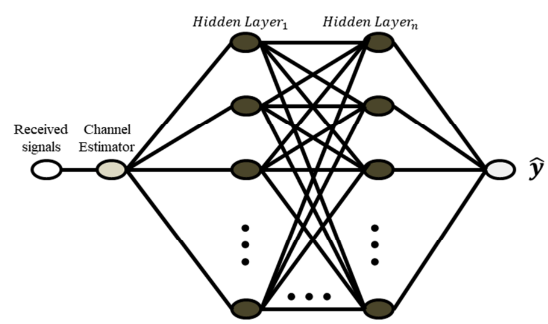

Fig. 1. DNN Structure

IV. SIMULATION RESULTS

In this section, computer simulations were performed using the proposed DNN to select a modulation scheme, which presents better BER performance in UWA channel environments.

The parameters of the transmission frames of CDMA and OFDM are shown in Table 1. The data rates of CDMA and OFDM were set to be similar for fair comparison [3]. Each channel environment was made based on BELLHOP, whose parameters were adopted from actual UWA environments.

The parameters of DNN are shown in Table 2. The number of hidden layers of the proposed DNN is set as two and the number of neurons in hidden layers is set as 64 and 32. The dropout rate to prevent overfitting in the training process is set as 0.3. The mini-batch size is set to 50.

For DNN training set, the number of UWA channels modeled by BELLHOP is 12960. The 20 % of training set was used for validation set.

TABLE I. FRAME PARAMETER OF CDMA AND OFDM

Parameter	**CDMA**	**OFDM**
Modulation	BPSK	
Frame length	6.84sec	6.75sec
Preamble length	250msec	250msec
Guard time	50msec	-
SF	12	-
Cyclic Prefix length	-	26msec
OFDM symbol length	-	102.4msec
Pilot spacing in freq	-	19.5Hz
Pilot spacing in time	-	0sec
Repetition	-	3

TABLE II. PARAMETERS OF DNN

Parameters	**Value**
Number of input parameters	4
Number of hidden layers	2
Number of neurons of hidden layers	64,32
Number of output parameters	3
Activation function of hidden layer	ReLu
Activation function of hidden output layer	Soft-max
Cost function	Categorical-crossentropy
Optimizer Function	SGD
Dropout rate	0.3
Learning rate	0.01
Epoch	30
Batch size	50

TABLE III. RESULT OF SELECTION

Set	**Selection Accuracy**
Training Set	92.46%
Validation Set	98.47%
Test Set	98.98%

The selection results for selection better BER performance scheme are shown in Table 3. The accuracy of selecting a scheme with better BER performance among the two modulation schemes is 92.46%, 98.47% and 98.98%, for training set, validation set, and test set, respectively. The proposed DNN demonstrates 98.98 % of selection accuracy in UWA channel environments.

V. CONCLUSION

We proposed an algorithm selecting a modulation scheme with better BER performance using DNN between CDMA and OFDM in UWA channels. The channel parameters affecting the BER performance of the two schemes are discussed and calculated. In addition, DNN is developed for selecting a modulation scheme that has better BER performance in UWA channels. Computer simulations demonstrate that the proposed DNN has 98.98% accuracy in UWA channels.

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