OFDM MODULATION AND ADAPTIVE EQUALIZATION FOR UNDERWATER COMMUNICATIONS

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Transmission performances of a shallow underwater channel are limited due to multiple reflections of sound waves off the bottom and water surface, and to the non-stationarity caused mainly by water surface movement. In traditional narrowband telecommunication modems complex Decision Feedback Equalizers are used for minimizing the influence of intersymbol interferences caused by multipath propagation of sound waves. The article proposes adapting OFDM modulation and adaptive equalization based on Kalman filtration techniques for use in underwater communications system. The OFDM modulation is used in wideband ADSL telecommunication modems. The Kalman filtration algorithm is used for time-varying processes identification. The techniques were tested in simulation environment with promising results.

INTRODUCTION

In underwater communications the acoustic wave signal is transmitted by a time-varying medium. Multiple reflections of sound waves off the bottom and moving water surface cause intersymbol interferences. Nowadays telecommunications offer few techniques for eliminating this effect. In the receivers of conventional telecommunication modems, decision feedback equalizers based on adaptive filters are employed. The weakness of these equalizers is their complexity. In ADSL (Asymmetric Digital Subscriber Line) modems the wideband Orthogonal Frequency Division Multiplexing modulation technique is used, which is spectrally efficient and intersymbol interferences resistant [5]. The adaptive equalizers in the ADSL receivers are simpler than the DFE devices in the conventional modems.

The article proposes the application of the OFDM modulation and the adaptive equalization in an underwater communication system. A short characteristic of the shallow underwater channel is presented (section 1). The ideas of the OFDM modulation (section 2) and the adaptive equalization (section 3) are described. The techniques were implemented and tested in simulation environment. The results of the simulations are discussed in section 4.

1. SHALLOW UNDERWATER CHANNEL

A unique feature of underwater communication is that the acoustic wave signal is transmitted by a time-varying medium. Because of absorption the channel is band-limited. The majority of underwater communication systems operate below 30 kHz. The maximum range and transmission rate are functions of channel physics.

In shallow water the fluctuations of the transmitted signal are caused mainly by multiple reflections of sound waves off the bottom and water surface. The reflected signal paths reach the receiver with different delays. The interferences between the signal paths cause the transmitted signal to fade. The non-stationarity of the channel is caused mainly by water surface movement and the transmitter and receiver relative movement.

In case of interferences caused by a few strong reflections, the non-stationary channel is described by n-element impulse response, whose coefficients vary periodically:

$$h_k(t) \cong \sum_{i=0}^{m} \gamma_{ki} e^{j\omega_i t} , \qquad k = 0,\dots,n \tag{1}$$

where γ_{ki} denotes weights of sinusoids, $\omega_0 = 0$ and ω_i, $i = 1,\dots,m$ are Doppler pulsations. The propriety of this model has been proved in [3].

The underwater channel non-stationarity is also caused by random phenomena, which can be described as a stochastic process.

2. OFDM MODULATION

The Orthogonal Frequency Division Multiplexing is a modulation technique used in wideband ADSL telecommunication modems. The technique splits the signal into several narrowband channels at different mutually orthogonal frequencies. The original data stream is divided into N parallel data sub-streams. Each of the sub-streams modulates its own carrier frequency. The OFDM modulator (Fig.1) consists of N QAM modulators and a DFT processor. The QAM modulation is realized in narrowband sub-channels, where the transmission rates are relatively low, so there is no need to apply complex filters and equalizers in the receiver.

In each sampling interval N baseband QAM symbols represent a sequence of discrete spectrum samples. The DFT processor computes the inverse Fourier transform of each QAM symbols sequence. The result is interpreted as discrete time signal samples. The discrete time signal computed this way is equal to the signal obtained by passband QAM modulation of N carrier frequencies.

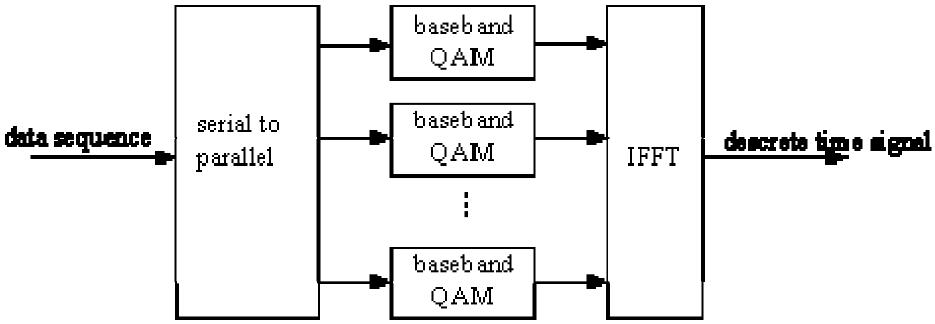

Fig.1 Diagram of the OFDM modulator

3. ADAPTIVE EQUALIZATION

The adaptive equalizer presented in the article realizes two functions. The first one is the inverse channel impulse response identification. The second one is the transmitted signal estimation based on the identified impulse response.

The received signal is described by the equation:

$$y(t) = h(t) * x(t) + w(t) \tag{2}$$

where $h(t)$ is the impulse response of the non-stationary channel, $x(t)$ is the transmitted signal and $w(t)$ denotes the process noise.

The problem of identification is to find the inverse impulse response of the channel:

$$g(t) = h(t)^{-1} \tag{3}$$

The identification of the process $g(t)$ is possible thanks to transmission of a training sequence $x_t(t)$ known to the receiver:

$$x_t(t) = g(t) * y_t(t) + w(t) \tag{4}$$

where $y_t(t)$ is the received training signal.

Adaptative Kalman filtering algorithm is applied to solve the problem of identification [2], [4]. The Kalman filtering algorithm assumes a stochastic model of process parameters changes. In this case the process is the inverse impulse response $g(t)$ of the channel. As the result of computations an estimate $\hat{g}(t)$ of inverse impulse response $g(t)$ is obtained.

The problem of signal estimation consists in filtration of the received signal $y(t)$ with the use of the computed estimate $\hat{g}(t)$:

$$\hat{x}(t) = \hat{g}(t) * y(t) \tag{5}$$

4. SIMULATION MODEL

The usefulness of proposed OFDM modulation and adaptive equalization techniques in underwater communication system was examined. The simulation of digital signal transmission was performed in the Simulink computing environment of the Mathworks. A diagram of the transmission model is presented in Fig. 2. The parameters of the simulation system are presented in Table 1.

The training sequence, used by the adaptive equalizer, is transmitted before each frame of data. Its length is equal to the length of the data frame.

The simulated OFDM modulator consists of 30 QAM-4 baseband modulators and an IFFT block. Its structure meets the specification given by Proakis in [1]. The spectrum of the OFDM signal is shown in Fig. 4.

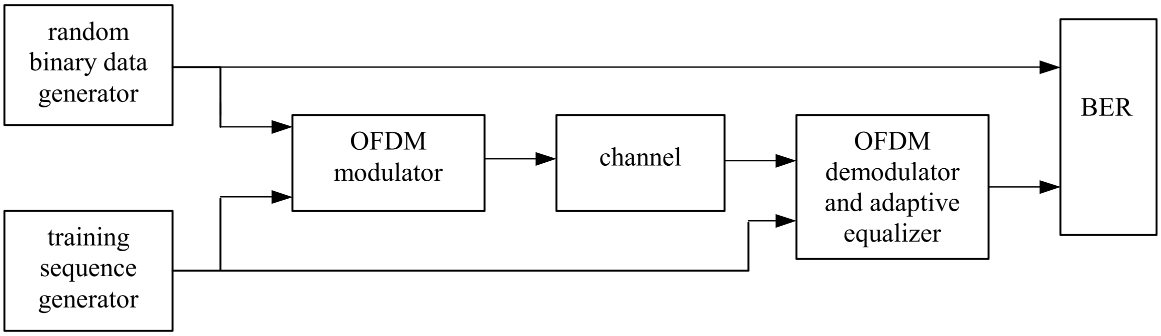

Fig.2 Diagram of the transmission system model.

Tab.1 Parameters of simulation

parameter	**value**
Modulating signal	Pseudorandom binary signal
Band of tranmistted signal	$50kHz$
Data transmission rate	$8kbit/s$
Trasmitted frame length	$180bits$
Maximum Doppler shift in channel	$20Hz$
Signal to Noise ratio	$28dB$

The channel model consists of three independent blocks (Fig.3). The first one is the multipath Rayleigh fading channel block from the Simulink Communicaion Blockset library. The block simulates the time-varying multipath channel with Doppler shift. The rate of time-variation is equal to the rate of signal frames transmission. The second block is an FIR filter with 8 randomly varying taps. Changes of taps are 200 times slower than the rate of signal frames transmission. The last element of the channel model is the Additive White Gaussian Noise block. The spectrum of the signal after transmission through the channel is shown in Fig.5.

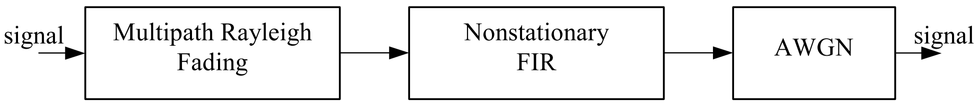

Fig.3 Diagram of the channel model.

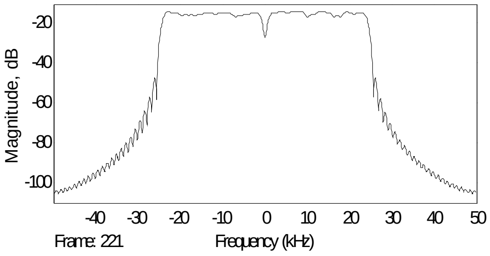

Fig.4 Spectrum of tranmistted signal.

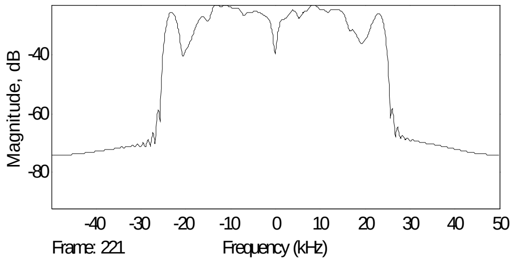

Fig.5 Spectrum of received signal.

The adaptive equalizer is modeled as a bank of 30 sub-systems shown in Fig.6. Each subsystem consists of Kalman filter and FIR filter. Each Kalman filter identifies the inverse impulse response of narrowband subchannel related with one carrier frequency. The received signal is convolved with the computed estimate of the inverse impulse response by the FIR filter. QAM constellations of the received signal before and after equalization are shown in Fig.7 and Fig.8. respectively. It’s evident that the correct detection of QAM symbols without signal equalizing is not possible. The bit error rate (BER) equals 0,5. The application of adaptive equalizer reduces the BER to 0,011.

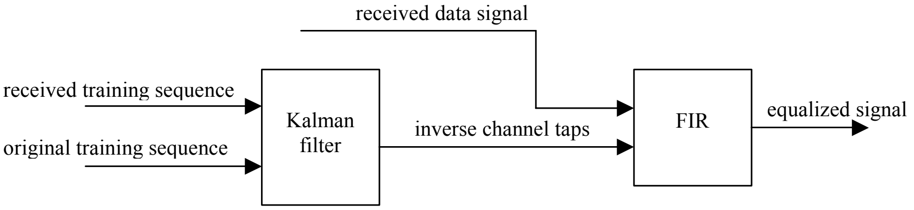

Fig.6 Diagram of the adaptive equalizer element.

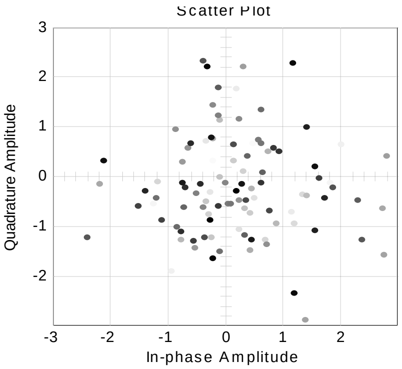

Fig.7 Received signal constellation

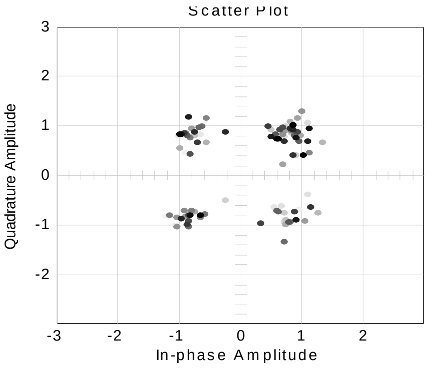

Fig.8 Received signal constellation at the equalizer output

The simulation tests have shown, that the transmission bit error rate strongly depends on the channel maximum Doppler shift (multipath Rayleigh fading channel block). The results of the tests are shown in fig. 9. Other parameters of the non-stationary channel (number of coefficients, rate of change) have also significant influence on the BER, but it can be corrected by changing the Kalman filters parameters.

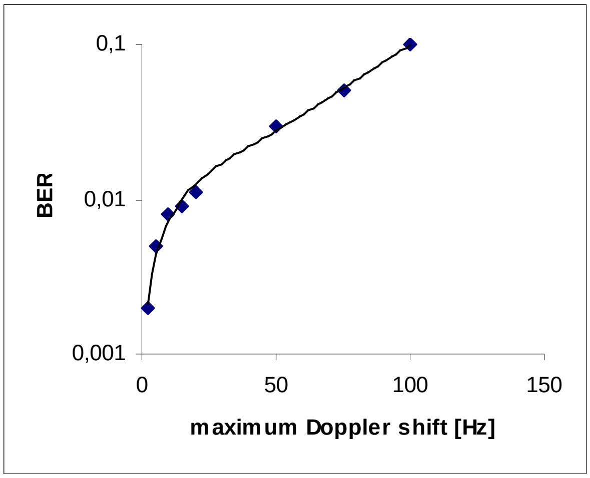

Fig.9 BER dependence on Doppler shift in the channel

5. CONSLUSION

The OFDM modulation and the Kalman adaptive equalization techniques proposed for use in a non-stationary multipath underwater channel were tested in a simulation environment. The promising results suggest that the described techniques are worthwhile to be tested in natural environment. The optimal solution would be the application of the DFT processor for the OFDM realization and the parallel processing architecture-based device for the adaptive equalizer implementation.

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