A MODIFIED MULTI-FREQUENCY CDMA FOR UNDERWATER REMOTE OPERATED VEHICLES USED IN SHALLOW WATER

Eric T.M. Law, L.F. Yeung and R.S. Bradbeer
Department of Electronic Engineering, City University of Hong Kong
Tat Chee Avenue, Kowloon
Hong Kong SAR

ABSTRACT

A modified wave-shaping technique used in multi-frequency Code Division Multiplex Access (MF-CDMA) scheme for data transmission between fast moving mobile underwater vehicles is proposed. Ultrasound is the main carrier used in this environment. The use of spreading code enables a frequency diversity (FD) scheme to be implemented over a Multi-Frequency-Shift-Keying (MFSK) framework in order to reduce the multipath fading problem. The scheme is simple to implement and effective, and the modified wave-shaping technique can reduce the interference between subcarriers.

KEY WORDS

Multi-Frequency modulation, Wave-shaping, Underwater communication

1. INTRODUCTION

The non-coherent MFSK technique is a robust modulations technique used extensively in underwater communications, especially in a fast changing, large phase uncertainty, and Doppler shift underwater environment [1]. By converting a data stream into a set of M parallel digitally modulated carrier frequencies $\{f_i\}$ with narrow frequency spacing Δf , data can be transmitted at a lower rate with longer duty cycle. In typical, modulation and demodulation scheme are usually implemented via Inverse Discrete Fourier Transform (IDFT) and Discrete Fourier Transform (DFT) respectively. This type of technique trades time with longer cycle time per bit, so as to increase the signal energy in order to improve the signal to noise ratio (SNR). For fast changing channels, relatively short with respect to data duty cycle, this method works successfully by averaging out this short term drop-off. However, it still suffers from the severe multipath fading problems. In this paper, a modified MF-CDMA system is proposed. The MF-CDMA system is a combination of CDMA [5] and multi-frequency modulation techniques that enables FD to minimise the multipath fading. Each data symbol is spreading into all subcarriers via Walsh code for FD purpose. Also, it can maintain the channel throughput. Furthermore, a wave-shaping technique is used to minimise the interference between adjacent subcarriers by reducing the subcarrier's bandwidth.

Fading in a shallow water channel: In a shallow water channel, the frequency selective multipath fading is one of the problems affecting the data rate and distance of communication. Common practices in tackling the fading problem are time-reversal [2], spatial diversity [3], adaptive channel identification and equalisation [4]. However, the ultrasound speed in water (typically at 1500m/sec) is relatively slow compared to EM waves; the channel identification would not be able to cope with the fast changes in the channel characteristics created by the fast moving vehicle. For moderate vehicle speed, we can shorten the frame size to get closer to the channel characteristic. But the expansion of header-to-data ratio will lower the overall data throughput. A simple and effective FD scheme commonly used to solve multipath fading between the same symbols is 4 to 2 channel coding [6]. This coding provides a relative immunity to channel fading, but the channel throughput is halved. Recently, Interleave-Division-Multiple-Access (IDMA) [7] can reduce the operation cost of channel identification by predicting the channel characteristic with a set of distributed pilots. However, in a very fast channel variation, these common schemes may not compensate for the problem when the carrier signal level drops below the noise floor.

In this paper, section 1 describes the conventional multicarrier modulation system. Then section 2 shows the MF-CDMA system with wave-shaping scheme. Finally, simulation results are presented in section 3.

1. CONVENTIONAL MULTI-FREQUENCY MODULATION

Multi-Frequency modulation (MFM) divides a channel into a set of parallel independent subchannels [8]. The SNR of each subchannel is measured and a suitable number of bits is then assigned to each channel. There are two reasons for choosing MFM in the system. According to [9], the MFM signal can be processed in a receiver without the enhancement of noise or interference that is caused by linear equalisation of a single-carrier signal. Another is that the long symbol time used in MFM produces a much greater immunity to impulse noise and fast fades. According to [9] [10], the input data is Mf_s b/s. They are grouped into blocks of M bits at block (symbol) rate of f_s . Therefore $f_{c,n} = n\Delta f$ for $n = n_1$ to n_2 and $M = \sum_{n=n_1}^{n_2} m_n$ where $N_c = n_2 - n_1 + 1$, $f_{c,n}$ is carrier frequency, Δf is frequency separation and N_c is number of carriers.

Typically, the modulation and demodulation techniques used are IDFT and DFT. IDFT and DFT are well-known efficient algorithms and significantly reduce the complexity of implementing the modulation and demodulation functions. The benefit in system implementation using IFFT and FFT are mentioned in [8] [11]. However, the resulting signalling filters have relatively large overlapping sidelobes (-13dB), and this causes a deviation from the ideal multicarrier scheme of independent carriers.

The discrete complex multicarrier modulation signal [12] can be represented for n^{th} sample by:

$$s(nT) = \frac{1}{N}\sum_{k=0}^{N-1} A_k e^{j(2n\pi f_k T + \phi_k)} \qquad (1)$$

The sampling frequency is $1/T$ and the period of one data symbol is $2NT$ with inter-modulation frequency domain. The frequency, f_k , is given by $f_k = f_0 + k\Delta f$ where f_0 is the lowest frequency of the signal spectrum and $\Delta f = 1/NT$ is the frequency separation between carriers.

2. THE MF-CDMA SYSTEM WITH WAVE-SHAPING TECHNIQUE

A MF-CDMA system spreads the original data stream using a Walsh code, and then modulates into different subcarriers for each chips, i.e., spreading in the frequency domain [5]. Let the Walsh code $\mathbf{c}_i = [c_{i,1}, c_{i,2}, \cdots, c_{i,N}]^T$ be the spreading code of the ith bit and $S \in \Re^N$ be the symbol, where $S = \{\alpha_1, \alpha_2, \ldots, \alpha_N\}$ and $\alpha_i \in \{1, -1\}$ represents the i^th^ data bit. For each bit α_i , it is spread into N chips by Walsh code and then N chips are mapped to N frequency components. The resulting chips are expressed as $\mathbf{v}_i = [\alpha_i c_{i,1}, \alpha_i c_{i,2}, \ldots, \alpha_i c_{i,N}]$. The transmission of a symbol can be synthesised similarly to the MFM mode as follows

$$s(t) = \sum_{i=1}^{N} \mathbf{v}_i \boldsymbol{\psi}(t) \qquad (2)$$

where $\boldsymbol{\psi}(t) = [\psi_1(t), \psi_2(t), \ldots, \psi_N(t)]^T$, $\psi_i(t) = w(t) \cdot A^i \varphi^i$ and $\varphi^i(t) = e^{j(2\pi f^i t + \phi^i)}$. A^i determines the amplitude of the function φ^i , f^i is the carrier frequency, ϕ^i is the phase and $w(t)$ is a Gaussian windowing function defined by $w(t) = \frac{1}{\sqrt{2\pi}\sigma} e^{-(t-m_t)^2/2\sigma^2}$. Note that the $\psi_i(t)$ is similar to MFM signal; here its envelope is Gaussian shaped instead of zero-one switching. Therefore, the required bandwidth is lower, which is an advantage when driving band-limited ultrasound transducers.

The Gaussian function is used to minimise the interference between adjacent carriers. Also, we can introduce a modified envelope which is the sum of sine waves with different lengths of time. The shape of the modified envelope is similar to a Gaussian envelope shown in Fig. 1. The black dotted rectangles show different time frames of the sine wave.

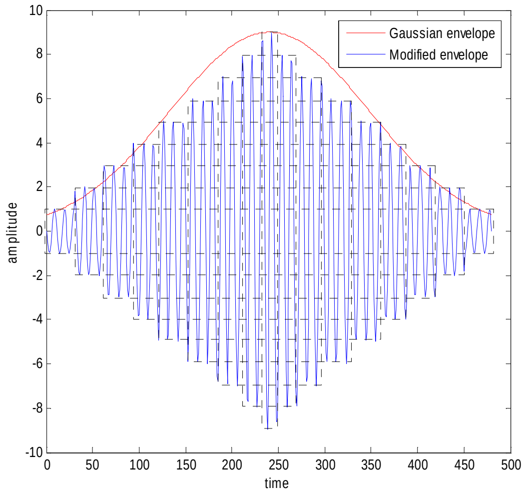

Fig. 1: The Gaussian envelope and modified shape envelope

The function of modified envelope is

$$g_i(t) = \sum_{b=1}^{Z} \sin(2\pi f^i t_b) \qquad (3)$$

where t_b is the time from $(\frac{T}{2} - \frac{T}{2^b})$ to $(\frac{T}{2} + \frac{T}{2^b})$, T is the symbol time with $0 \le t \le T$, Z is the number of precision. The modified envelope is orthogonal to its function so that $\langle g_i(t), g_j(t) \rangle \approx 0$ if $i \ne j$. This can reduce the interference between successive carriers.

Let the impulse responses of a simplified multipath channel be modelled by

$$h(\tau_d; t) = \sum_{d=1}^{L} \beta^d(t)\delta(t - \tau_d) \qquad (4)$$

where $\beta^d(t)$ is the d^{th} multipath factors and τ_d is its delay time. There are L multipaths and with relative delay τ_d each. In addition to multipath signals and noise, the received signal becomes

$$y(t)=\sum_{i=1}^{N}\mathbf{v}_i\mathbf{G}(t)+\sum_{d=1}^{L}\sum_{i=1}^{N}\mathbf{v}_i\mathbf{G}(t-\tau_d)\cdot\beta^d\,\hat{u}(t-\tau_d)+\eta(t) \quad (5)$$

where $\mathbf{G}(t)=[g_1(t),g_2(t),\ldots,g_N(t)]^T$, $\eta(t)$ is the received noise and $\hat{u}(t)$ is unit step function.

Let θ_i be the projection of $y(t)$ onto $g_i(t)$ over the closed interval $[p,q]$,

$$\theta_i=\langle y(t),g_i(t)\rangle\equiv\int_p^q y(t)g_i(t)dt \quad (6)$$

Let $\overline{\eta}_i=\langle\eta(t),g_i(t)\rangle$ and $\mathbf{r}_i(\tau_d)=\langle\mathbf{G}(t-\tau_d)\cdot\hat{u}(t-\tau_d),g_i(t)\rangle$.

For $\tau_d=0$, we have

$$\begin{aligned}\theta_i&=\langle y(t),g_i(t)\rangle\\&=\mathbf{v}_1\mathbf{r}_i(0)+\mathbf{v}_2\mathbf{r}_i(0)+\cdots+\mathbf{v}_N\mathbf{r}_i(0)+\overline{\eta}_i\end{aligned} \quad (7)$$

The matrix form of (7) is

$$\begin{bmatrix}\theta_1\\\theta_2\\\vdots\\\theta_N\end{bmatrix}=\begin{bmatrix}\mathbf{r}_1(0)&\mathbf{r}_1(0)&\cdots&\mathbf{r}_1(0)\\\mathbf{r}_2(0)&\mathbf{r}_2(0)&\cdots&\mathbf{r}_2(0)\\\vdots&\vdots&\ddots&\vdots\\\mathbf{r}_N(0)&\mathbf{r}_N(0)&\cdots&\mathbf{r}_N(0)\end{bmatrix}_{NxN}\begin{bmatrix}\mathbf{v}_1\\\mathbf{v}_2\\\vdots\\\mathbf{v}_N\end{bmatrix}+\begin{bmatrix}\overline{\eta}_1\\\overline{\eta}_2\\\vdots\\\overline{\eta}_N\end{bmatrix} \text{ or}$$

$$\boldsymbol{\theta}=\mathbf{R}(0)\mathbf{V}+\overline{\boldsymbol{\eta}} \quad (8)$$

where $\mathbf{V}=[\mathbf{v}_1,\ldots,\mathbf{v}_N]^T$.

In general, we have

$$\boldsymbol{\theta}=\mathbf{R}(0)\mathbf{V}+\sum_{d=1}^{L}\beta^d\cdot\mathbf{R}(\tau_d)\mathbf{V}+\overline{\boldsymbol{\eta}} \quad (9)$$

If $\mathbf{R}(0)$ and $\mathbf{R}(\tau_d)$ are full rank, then the data bit can be estimated by $\overline{\alpha}_i=sign((\mathbf{R}^{-1}(0)\boldsymbol{\theta})^T\cdot\mathbf{c}_i)$.

3. SIMULATION RESULTS

In the following example, we choose $N=64$, $f_0=43kHz$, $\Delta f=400Hz$. The test channel has two multipath with delay time $2ms$ and $5ms$ with attenuation -7dB and -12dB respectively. A MF-CDMA scheme is chosen with Walsh code in length 64. Fig. 2 shows the BER performance with different modulation schemes using a Gaussian envelope, a modified envelope and/or Walsh code. The suffixes 'MFM', 'WMFM' and 'GWMFM' represent the systems using conventional multi-frequency modulation; multi-frequency modulation with Gaussian envelope; and multi-frequency modulation with modified envelope respectively. The suffixes 'CMFM', 'CWMFM' and 'CGWMFM' are using Walsh code for FD scheme and with the systems using conventional multi-frequency modulation; multi-frequency modulation with Gaussian envelope; and multi-frequency modulation with modified envelope respectively. In Fig. 2, it shows that the system using modified wave-shaping technique in MF-CDMA algorithm has better Bit-Error-Rate (BER) performance than the conventional MFM system. This is because the bandwidth interference is reduced in using modified envelope, and the spreading code spreads the information to all subcarriers that can reduce the multipath fading problem. Because of the approximation error of the modified envelope to Gaussian envelope, the BER performances of the systems with modified envelope are slightly degraded compared to the systems using the Gaussian envelope.

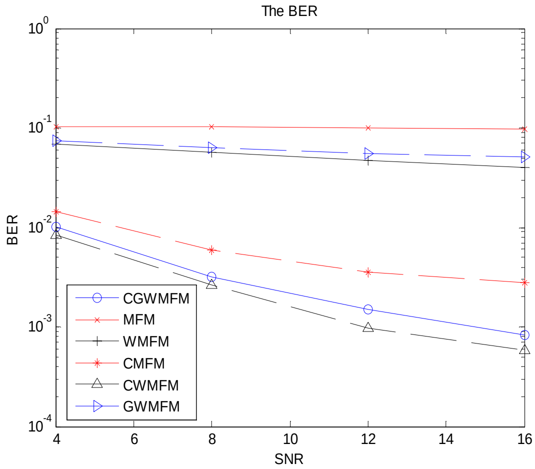

Fig.2. The BER of different modulation

4. CONCLUSION

A modified wave-shaping scheme MF-CDMA underwater acoustic system is described in this paper. In a conventional MFM system, the error rate gets worse with the multipath fading problem. However the MF-CDMA system with modified wave-shaping technique can minimise the fading without reducing channel throughput.

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