Performance Evaluation of Multi Carrier Modulation Techniques for HF Frequency Selective Fading Channel

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Abstract - Multipath fading in HF channels causes time-delay spread that limits the maximum symbol rate, and frequency selective fading that attenuates some frequency bands compared to others. Multi-carrier modulation techniques, Multi-carrier ASK (MCASK) and Multi-carrier PSK (MCPSK), can be used to ensure reliability of transmission and high data transmission rate. The bit-error rate (BER) performance is compared between single frequency modulation such as Amplitude Shift-Keying (ASK) or Phase Shift-Keying (PSK) and the m ulti-carrier modulation in the presence o f additive white Gaussian noise and a combination of multipath fading and additive white Gaussian noise. On the average, the BER performance is better for the multi-carrier modulation compared to the single carrier modulation under multipath fading conditions.

1.0 Introduction

The HF spectrum is still widely used by the maritime industry, military and foreign services despite the availability of satellite communication services [8]. Multipath fading is the result if the variation in the ionosphere causes time-delay spread and frequency selective fading [2]. Time-delay spread limits the maximum symbol rate to 100 bauds while frequency selective fading results attenuation in some frequency ranges. Some techniques were presented to overcome this problem based on conventional digital modulation techniques [3][5]. However, this paper proposes the use of multi-carrier modulation [1][4] based on the ASK and PSK and compare their p erformance with conventional single sub-carrier modulation techniques in the presence of noise and frequency selective fading.

2.0 Channel Model

The received signal within a symbol duration T_b is

$$x(t) = h(t) * (s(t) + w(t)) \quad t_0 \le t \le t_0 + T_b \qquad (1)$$

where $s(t)$ is the true signal, $h(t)$ is the channel impulse response, $w(t)$ is the interference due to additive white Gaussian noise with zero mean and noise power σ_w^2 and * denotes the convolution process. The frequency selective channel is characterized by a channel impulse response

$$h(t) = \delta(t) + \delta(t - T_d) \qquad (2)$$

where T_d is the differential path delay with 2 ms delay. The channel model is known as the Watterson Gaussian scatter HF ionospheric channel model and the setting chosen is under poor condition [9].

3.0 Theory

The digital modulation technique relevant to this paper is ASK and PSK. Detection can be performed using coherent or noncoherent detection.

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3.1 Single Carrier Modulation

This is the most basic form of digital modulation and the detection method for PSK and ASK

3.1.1 Single Carrier PSK

If *x(t)* is the received signal, then the output receiver *y(t)* is [7]

$$y(t) = \int_0^{Tb} x(t)[x_1(t) - x_0(t)]dt \qquad 0 < t < T_b \qquad (3)$$

where $x_0(t)$ and $x_1(t)$ are the reference signal used at the receiver. By sampling *y(t)* at intervals nT_b , the detection is performed as follows

$$y(n) = +ve \text{ then binary bit "1" is detected}$$
$$= -ve \text{ then binary bit "0" is detected} \qquad (4)$$

The BER for PSK is

$$BER = Q\left(\sqrt{\frac{A^2T_b}{2\sigma_W^2}}\right) \qquad (5)$$

where *Q( )* denotes for Q function

$$Q(x) = \frac{1}{\sqrt{2\pi}}\int_x^{\infty} \exp\left(-\frac{z^2}{2}\right)dz \qquad (6)$$

Signal-to-noise ratio (*SNR*) in decibels for PSK is as follows

$$SNR\,(dB) = 10\log\left(\frac{A^2T_b}{2\sigma_W^2}\right) \qquad (7)$$

3.1.2 Single Carrier ASK

If the received signal is *x(t)* and the output of the receiver *y(t)* is [7]

$$y(t) = \int_0^{Tb} x(t)[x_1(t)]dt \qquad 0 < t < T_b \qquad (8)$$

By sampling *y(t)* at intervals nT_b, the detection is performed as follows

$$y(n) > y_{thd} \text{ then binary bit "1" is detected}$$
$$y(n) < y_{thd} \text{ then binary bit "0" is detected} \qquad (9)$$

where *thd* stands for threshold value. The BER for ASK is

$$BER = Q\left(\sqrt{\frac{A^2T_b}{8\sigma_w^2}}\right) \qquad (10)$$

SNR in decibels for ASK is the same as SNR for PSK as shown in Equation (7).

3.2 Multi Carrier Modulation

A multi carrier modulation is a type of modulation, where the frequency band of the channel is subdivided into a number of sub-carriers and information is transmitted on each of the sub-carriers [6]. The difference between multi carrier modulation and single carrier modulation is that for the same baud rate, multi carrier modulation is capable in transmitting more data compared to single carrier modulation.

3.2.1 Implementation Methodology

Process executed in transmitter side:-

1. Serial to parallel conversion.
2. Conjugate symmetry in frequency domain.
3. Perform IFFT.
4. IF and RF processing.

Process executed in receiver side:-

1. RF and IF processing.
2. Perform FFT.
3. Detect sequence from frequency domain.
4. Parallel to serial conversion.

3.2.2 MCPSK and MCASK Coding

The difference between MCPSK and MCASK is in the encoding method. For example, the data in MCPSK encoded for a discrete frequency k_0 is

$$X(k_0) = -NA \qquad \text{binary bit "0"}$$
$$X(k_0) = +NA \qquad \text{binary bit "1"} \qquad (11)$$

where N is number of samples within a symbol duration and A represents the amplitude. For MCASK, data encoded for frequency k_0 is

$$X(k_0) = 0 \qquad \text{binary bit "0"}$$
$$X(k_0) = +NA \qquad \text{binary bit "1"} \qquad (12)$$

3.2.3 MCPSK and MCASK BER Performance

The BER performance for multi-carrier modulation is the same as conventional single carrier digital modulation. Eventhough data is transmitted over many sub-carriers, the detection process for multi-carrier modulation is performed one sub-carrier at a time. Thus, the average BER per sub-carrier for MCPSK and MCASK is described in Equation (5) and (10) respectively.

4.0 Results

In general, the BER performance for single carrier PSK is better than single carrier ASK by about 6 dB. This is based on the SNR for a given BER performance of 10^{-3}. Theoretically and also by simulation, this is also true for MCPSK and MCASK evaluated for 4,8 and 16 sub-carriers. The BER performance for ASK, PSK, MCASK and MCPSK with 16 sub-carriers are shown in Figure 1.

MCPSK requires coherent detection while the detection of data in MCASK can be performed using power spectrum. The reduction in performance for MCASK in terms of the BER is about 5 dB, but this is at the advantage of having a simpler system since carrier recovery and phase synchronization is not required.

Simulation result for MCASK and MCPSK 16 sub-carriers are shown in Figure 2. Detection process for both MCASK and MCPSK is performed using FFT. Detection for MCASK can also be done by employing power spectrum detection method (*PSD*). Separation between FFT detection method and PSD method is only about 2 dB.

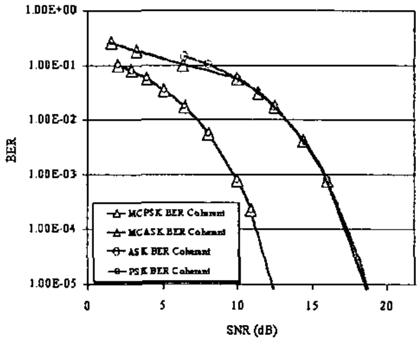

Figure 1 - Theoretical BER value for single carrier and multi carrier

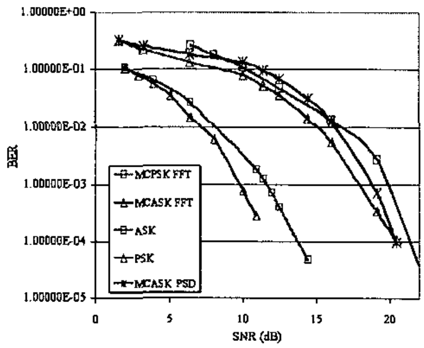

Figure 2 - Simulation result without frequency selective fading

In the presence of frequency selective fading, however, multi carrier modulation clearly performs better than single carrier. This is because certain frequency components are attenuated when frequency selective fading occurs. Since multi carrier modulation method transmits data over more than one carrier, the probability of data loss is less compared to single carrier modulation method.

Figure 3 shows the effect of frequency selective fading for ASK, PSK, MCASK and MCPSK. For ASK and PSK, the sub-carrier frequency is chosen at 250 Hz where the effect of frequency selective fading is at its worst.

Simulation result for 4 and 8 sub-carriers is not shown in this paper. The performance is almost the same with the MCASK and MCPSK 16 sub-carriers respectively.

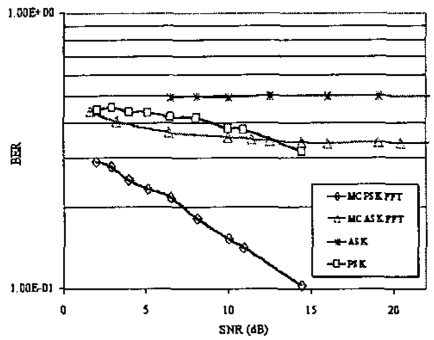

Figure 3 - Effect of Frequency Selective Fading

5.0 Conclusions

Multi carrier modulation method proofs to be the suitable modulation method because of its capability to achieve high data transfer rate and also because of its high performance in a frequency selective fading channel. In this paper the BER performance using coherent detection and FFT is compared in the frequency selective fading channel. In general, the BER performance for multi carrier modulation is better compared to single carrier modulation. BER performance for multi carrier modulation method decreases as the SNR increase, whereas BER performance for single carrier does not improve eventhough SNR increases.

6.0 References

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