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Performance evaluation of multi-band OFDM systems for short-haul optical communications

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Performance evaluation of ultra-wide band radio signals based on multi-band (MB) orthogonal frequency division multiplexing (OFDM) system is presented. These systems are very attractive due to their capability to deliver high-speed data streams, their co-existence with the current radio standards and their suitability for transmission in fibre. In this paper, the work is focused on the simulation of both single-input-single-out (SISO) and multiple-input-multiple-output (MIMO) OFDM configuration with transmission over an optical channel model. Different system parameters and transmission strategies are analyzed to estimate the bit-error rate (BER) and packet-error-ratio (PER) performance.

Introduction

Ultrawideband (UWB) is an emerging technology that offers great promises to satisfy the growing demand for high speed and low cost short range wireless networks. Regulated by the Federal Communication Commission in February 2002, the UWB technology operates in the frequency range between 3.1-10.6 GHz frequency band [1], and the power spectral density measured in 1MHz bandwidth must not exceed -41.25dBm. UWB systems support two kinds of modulation techniques: the direct sequence and MB-OFDM UWB technologies. MB-OFDM is preferred over other UWB implementations like impulse-radio UWB [3], or proprietary UWB solution [2] due to the widely commercial availability of low-cost OFDM-based UWB solutions. On the other hand, to enhance the data rates and transmission ranges of UWB system, applying the MIMO scheme has attracted considerable interest [6]. Consequently, the combination of UWB and MIMO technology will become a viable and cost-efficient method to achieve the very high data requirements necessary for future short-range optical communications. In this paper, the MB-OFDM signal was designed as specified in the ECMA-368 standard [2]. The spectrum is divided into 14-sub-bands, each having a bandwidth of 528MHz.We present the simulation of both SISO and MIMO OFDM system with transmission over an optical channel model. Different system choices and parameterization strategies are analyzed to estimate the bit-error-rate (BER) and packet-error-ratio (PER) performance. Both uncoding and coding schemes using Viterbi decoder performance are compared.

Single-Input-Single-Output (SISO) OFDM transceiver

The SISO MB-OFDM transceiver system is shown in Fig. 1, which works in the 3.1-10.6 GHz frequency band. A total 110 subcarriers (100 data carriers and 10 guard carriers) are used per band. In addition, 12 pilot subcarriers that allow for coherent detection bring out a total of 122 subcarriers spaced by 4.125 MHz apart. This system supports from 200-480Mb/s data rates, depending on the choice of encoder and modulator. Unlike the conventional OFDM systems, transmitting all symbols with the same band, the MB-OFDM system is realized using a set of time-frequency codes (TFC) {1 3 2 1 3 2}. Each code corresponds to the centre frequency for the transmission of each OFDM symbol. The information is transmitted using time domain OFDM symbols across three consecutive sub bands in a time-interleaved manner. The corresponding receiver structure is also shown in Fig. 1. After the RF signal is down-converted to baseband and digitized, synchronization is performed and OFDM symbols are demodulated from the OFDM baseband signal. An estimated bit sequence is reconstructed and de-interleaved. Then the sequence is decoded using Viterbi algorithm. Finally, the decoder output is descrambled, yielding an estimated sequence of the transmitted bits.

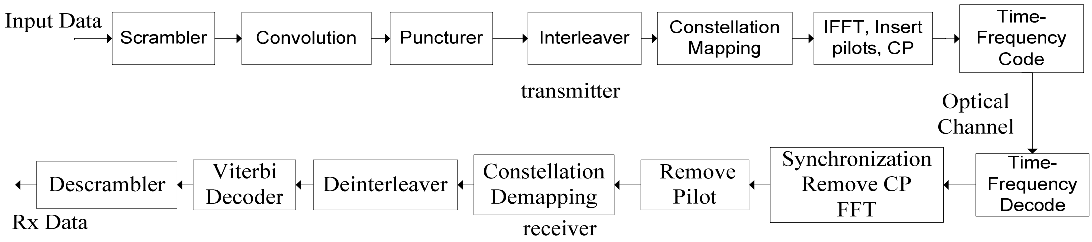

Fig. 1: Multiband OFDM transmission system

Considering an optical communication link, the fibre channel can be modelled as a Gaussian low-pass filter [4-5]. The channel frequency response can thus be expressed as:

$$|H_F(f)|^2 = e^{-\left(\frac{f}{f_0}\right)^2} \text{ with } f_0 = f_{3dB}/\sqrt{\ln 2} \tag{1}$$

where f_{3dB} is the 3-dB channel bandwidth and the phase is constant over the frequency range. The evaluation of the MB-OFDM spectral characteristics was achieved in the three bands within 3,432MHz-4,488MHz. As the transfer function of the system similar to a first order low-pass filter, its frequency behaviour should induce impairments particularly in the upper band. Fig. 2 presents the simulation results of the spectrum mask after transmission through the optical channel model.

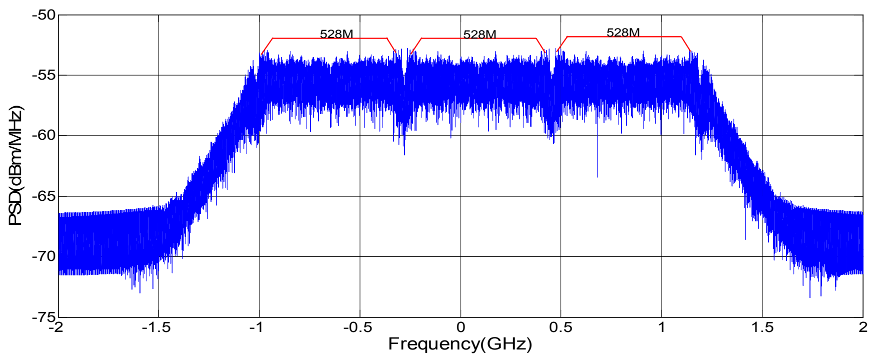

Fig. 2: Transmission of MB-OFDM UWB signal

Multi-Input-Multi-Output (MIMO) OFDM system

In addition, the GHz centre frequency of UWB radio relaxes the requirements on the spacing between antenna array elements. Consequently, the combination of UWB and Multi-Input-Multi-Output (MIMO) technology will become a viable and cost-efficient method to achieve the very high data requirements necessary for future application. We designed a MIMO OFDM system to improve the system robustness, and consequently to increase the system range as shown in Fig. 3. The Alamouti coding scheme[7] (space-time block code) with two transmit and two receive antennas is chosen, since it provides full spatial diversity gain, with no inter-symbol interference and low complexity receivers. The multi-user access is also performed with TFC as in the SISO system. The difference is that frequency hopping from a sub-band to another occurs at the end of each two consecutive symbols, since the Alamouti scheme is applied in space and time per subcarrier.

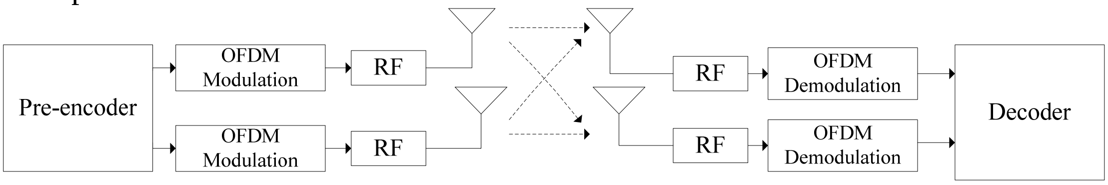

Fig. 3: MIMO-OFDM communication system

At the transmitter, the information is jointly encoded across N_t transmitting antennas, M OFDM subcarriers, and K OFDM blocks. Each block is mapped onto a $KM \times N_t$ pre-codeword matrix:

$$\mathbf{D} = \left[\mathbf{D}_0{}^T \ \mathbf{D}_1{}^T \ \cdots \ \mathbf{D}_{K-1}{}^T \right]^T \tag{2}$$

where $\mathbf{D}_k = \left[\mathbf{d}_1^k \mathbf{d}_2^k \cdots \mathbf{d}_{N_t}^k \right]$. In which $\mathbf{d}_i^k = [d_i^k(0) d_i^k(1) \cdots d_i^k(N-1)]^T$ for $i = 1, 2, ..., N_t$ and $k = 0, 1, 2, ..., N-1$. The symbol $d_i^k(n)$, $n = 0, 1, ..., N-1$, represents the complex symbol to be transmitted over the subcarrier n by the transmitting antenna i during the kth OFDM symbol period. The signal received at the nth subcarrier at receiver antenna j during the kth OFDM symbol duration can be expressed as

$$y_j^k(n) = \sqrt{\frac{E_s}{N_t}} \sum_{i=1}^{N_t} d_i^k(n) h_{ij}^k(n) + z_j^k(n) \tag{3}$$

where $h_{ij}^k(n)$ is the channel impulse response, $z_j^k(n)$ is the zero-mean Gaussian noise, $\sqrt{E_s/N_t}$ guarantees that the average energy per symbol transmitted is E_s.

Simulation

The simulation compares the SISO and MIMO systems performance in terms of uncoded and coded BER, as shown in Fig. 4. We observed for low signal to noise ratio SNR that the uncoded BER showed a better performance than coded BER, due to the architecture complexity of the latter. However, this architecture helps to achieve higher BER performance at higher SNR(>10dB). In coded MB-OFDM system, the performance curve declines sharply when SNR reaches a certain value. Notice that in this region a small change in SNR leads to significant performance improvements. At BER of 10^{-2}, the coding SISO system improves coding gain by 2.5dB. For lower BER, the coding gain can reach 4dB. Secondly, comparisons between SISO and MIMO OFDM systems show that the multi-antenna system yields higher BER performance than the single antenna system. MIMO systems obtain more than 2dB gain than SISO when BER less than 10^{-3}. This means that MIMO system performance is better for low SNR values.

The PER performance is also shown in Fig. 4. The spatial diversity gained from multi-antenna architecture is shown to improve system performance significantly. In addition, it is observed that in comparison with the SISO systems which bring around 6dB coding gain at PER=10^{-1}, the MIMO scheme offers an additional 7dB gain (for

PER=10^{-1}). It is obviously that MIMO system offer 2-3dB SNR gain than SISO when the coded PER less than1.

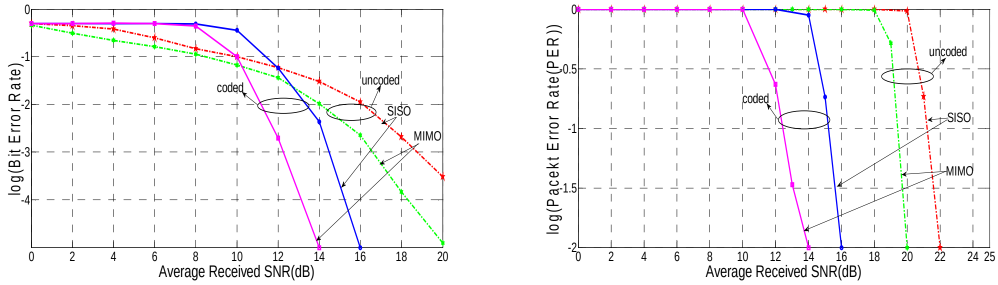

Fig. 4: BER and PER performance of multiband OFDM with various diversity orders.

Conclusion

We have demonstrated by simulation a diversity multi-band OFDM UWB system. Performances of BER and PER of both uncoded and coded systems are presented. The simulation results indicate the feasibility of both SISO and MIMO OFDM configuration when applied in optical channel environment. MIMO systems offer better BER performance than single block system for low SNR values. MIMO systems provide more than 2dB SNR gain for BER $<10^{-3}$ and 2-3dB for PER <1. The physical realisation of an Ultra-Wide Band signal transmission over MMF and POF fibre channel is the future work after completing simulation.

Acknowledgment

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