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A New Approach for Wireless Communication Systems Based on IDMA Technique

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Abstract—This paper will propose a novel multiple access technology, called OWDM-IDMA (Orthogonal Wavelength-Division Multiplexing-Interleave Division Multiple Access), which is the combination of OWDM (Orthogonal Wavelength-Division Multiplexing) and multiple access schemes IDMA (Interleave Division Multiple Access), in which interleaves are used as the only means for user separation. The IDMA receiver principles for different modulation and OWDM principles are outlined. Simulation example of OWDM-IDMA system is provided to demonstrate the advantages of the OWDM-IDMA scheme in terms of bandwidth by estimating the bit error rate (BER) of system, putting themselves in a real communication.

Index Terms—IDMA, OWDM, CWT, DWT, ESE, DWPT, IDWPT.

I. INTRODUCTION

Since the 1980s, the communications sector known as the telecommunications is growing dramatically thanks to technological advances in several scientific fields. This progress is particularly striking for mobile radio communications with the appearance of different generations of mobile telephony. At the same time, applications that can benefit from this technology have continued to diversify. OWDM (Orthogonal Wavelength-Division Multiplexing) is considered to be promising. IDMA (Interleave-Division Multiple-Access) [1][2] is a special case of random waveform CDMA that is mainly limited by MAI (Multiple Access Interference) and ISI (Inter Symbol Interference); indeed with IDMA, different users are, solely, distinguished by user-specific interleaves. These interleaves can be selected randomly and orthogonality is not essential. Turbo-type iterative MUD (Multi-User Detection) has been extensively studied to mitigate MAI and ISI, and significant progress has been made.

In this contribution, we propose a new multiple access technique, called OWDM-IDMA which is the combination of OWDM and IDMA techniques, this technique can alleviate ISI by the OWDM technique and cancel multiple access interference (MAI) by the IDMA technique. Indeed, through the formalism of wavelets and their application to wavelet packets and filter banks, it is possible to construct orthogonal basis in time and frequency whose properties will develop a

Multicarrier communication system which uses more accurately the radio-electric spectrum.

The system performance is analyzed. A signal-to-noise (SNR) evolution technique is applied to predict the bit-error-rate (BER) performance.

The rest of the paper is organized as follows. In Section 2, we present the transceiver architecture of IDMA. In Section 3, the basics of OWDM are discussed. Afterwards, we present and investigate the performance of our proposed OWDM-IDMA scheme. Finally, we conclude our discourse in Section 6.

II. OVERALL TRANSMITTER AND RECEIVER PRINCIPLE OF IDMA

The technique of multiple access IDMA can allocate the same frequency band to several users while allowing them to transmit simultaneously. IDMA can be regarded as a special case of CDMA where the spreading is done by an arbitrary equal low rate channel code for all users and the separation is done by user-specific interleaves.

A. Transmitter structure

Figure 1 shows the transmitter structure of the multiple access scheme under consideration with K simultaneous users. The input data sequence d_k of user k is encoded basically

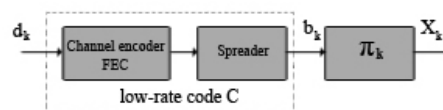


Fig. 1. Transmitter structure for IDMA system

on a low-rate code C , generating a coded sequence $b_k = b_k(j); j = 1, \dots, J$ where J is the frame length (Here, "chip" is used instead of "bit" as the FEC encoding may include spreading or repetition coding.). Then b_k is permuted by an interleaver π_k , producing $X_k = X_k(j)$. The interleavers π_k , are different for different users. We assume that the interleavers are generated independently and randomly. The key principle of IDMA is that the users are solely distinguished

by their interleavers [3]. After chip matched filtering, the received signal from K users can be written as:

$$r(j) = \sum_{k=1}^K h_k(j) * X_k(j) + n(j) \quad j = 1, 2, \dots, J \quad (1)$$

Where $n(j)$ are the samples of a complex AWGN process with variance σ^2 in each dimension, and h_k is the channel coefficient for user- k . The channel coefficients h_k are assumed known a priori at the receiver side.

B. Receiver Structure

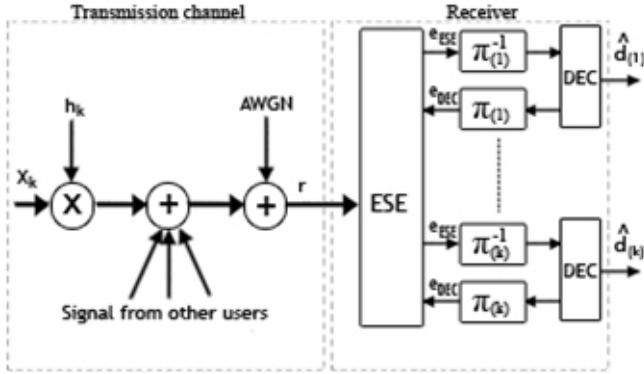


Fig. 2. Receiver structure for IDMA system

The receiver in figure.2 consists of an elementary signal estimator (ESE) and K single-user a posteriori probability (APP) decoders (DECs). The multiple access and coding constraints are considered separately in the ESE and DECs. In the iterative detection process, the ESE and DECs exchange extrinsic information in a turbo-type manner [4][5]. The ESE operation can be carried out in a chip-by-chip manner [6].

C. Chip-by-Chip Detection Algorithm

The chip by chip detection algorithm can be summarized as follows:

Initialization

$$e_{DEC}(x_k(j)) = 0 \quad \forall k, j \quad (2)$$

Iterative process

$$\mu_k(j) = \tanh \frac{e_{DEC}(x_k(j))}{2} \quad \forall k, j \quad (3)$$

$$\vartheta_k(j) = 1 - (\mu_k(j))^2 \quad \forall k, j \quad (4)$$

$$E(r(j)) = \sum_{k=1}^K h_k \mu_k(j) \quad \forall j \quad (5)$$

$$\text{Var}(r(j)) = \sigma_n^2 + \sum_{k=1}^K (h_k)^2 \vartheta_k(j) \quad \forall j \quad (6)$$

$$E(\xi_k(j)) = E(r(j)) - h_k \mu_k(j) \quad \forall k, j \quad (7)$$

$$\text{Var}(\xi_k(j)) = \text{Var}(r(j)) - (h_k)^2 \vartheta_k(j) \quad \forall k, j \quad (8)$$

$$e_{ESE}(x_k(j)) = 2h_k \times \frac{r(j) - E(\xi_k(j))}{\text{Var}(\xi_k(j))} \quad \forall k, j \quad (9)$$

After this last operation, the necessary data information to decode $e_{ESE}(x_k(j))$ is obtained. The decoder then calculates the extrinsic log-likelihood ratios (LLR). Once $e_{DEC}(x_k(j))$ decoding is completed, the calculations of equation 3 in equation 9 are repeated.

III. OVERALL PRINCIPLE OF ORTHOGONAL WAVELET DIVISION MULTIPLEX (OWDM)

The wavelet transform a time function maps into a two dimension function of a (instead of ω - frequency) and τ , where a is called the scale and τ is the translation of the wavelet function along the time axis[7].

A. The Continuous Wavelet Transform

The Continuous Wavelet Transform (CWT) is provided by equation 10, where $S(t)$ is the signal to be analyzed. t is the time. $\psi(t)$ is the mother wavelet or the basis function. And $\frac{1}{\sqrt{a}}(\psi(\frac{t-\tau}{a}))$ is the baby wavelet [8] made by either stretching or compressing the mother wavelet. All the used wavelet functions in the transformation are derived from the mother wavelet through translation (shifting) and scaling (dilation or compression).

$$\text{CWT}(a, \tau) = \frac{1}{\sqrt{a}} \int S(t) \cdot \psi\left(\frac{t-\tau}{a}\right) dt \quad (10)$$

The translation parameter τ relates to the location of the wavelet function as it is shifted through the signal. Thus, it corresponds to the time information in the Wavelet Transform. The scale parameter a is defined as $|1/\text{frequency}|$ and corresponds to frequency information. Scaling either dilates (expands) or compresses a signal.

B. The Discrete Wavelet Transform

The Discrete Wavelet Transform (DWT), which is based on sub-band coding, is found to yield a fast calculation of Wavelet Transform. It is easy to implement and reduce the computation time and the required resources. In the case of DWT, a time-scale representation of the digital signal is obtained by using digital filtering techniques.

The DWT is calculated by successive low pass and high pass filtering of the discrete time-domain signal as shown in figure.3.

In the figure 3, the signal is denoted by the sequence $x[n]$,

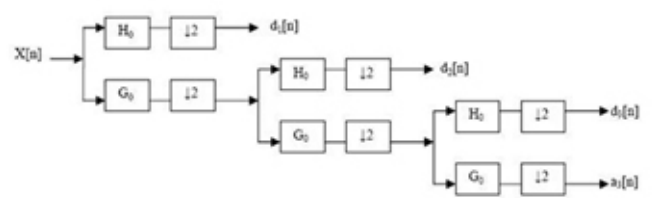


Fig. 3. Three-level wavelet decomposition tree

where n is an integer. The low pass filter is denoted by G_0

while the high pass filter is denoted by H_0 . The $\downarrow 2$ in the figure is the down-sampling function achieved by discarding alternate samples. The maximum number of levels depends on the length of the signal.

Figure 4 shows the reconstruction of the original signal from the wavelet coefficients. Basically, the reconstruction is the reverse process of decomposition. G_0 and H_0 , are exchanged with the synthesis filters G_1 and H_1 , and the $\uparrow 2$ is the zero insertion function (up-sampling).

After reviewing the whole wavelets theory, it is possible to

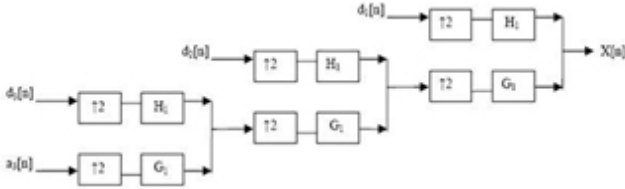


Fig. 4. Three-level wavelet reconstruction tree

define a wavelet functions for Multicarrier modulation. So we can define the principle of Multicarrier modulation using wavelet packets.

The basic principles of Multicarrier modulation using wavelet packets are illustrated in figure.5. At the transmitter side, symbols are transformed from the wavelets domain to time domain by an IDWPT (Inverse Discrete Wavelet Packet Transform); At the reception, the received signal is transformed to time domain by a wavelet DWPT (Discrete Wavelet Packet Transform) [8].

In figure.5, the blocks S and A represent respectively the

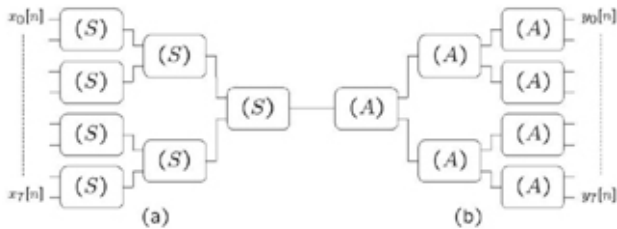


Fig. 5. principle of modulation (a) and demodulation (b) Multicarrier using wavelets

decomposition and reconstruction, also called synthesis.

IV. OWDM-IDMA PRINCIPLES

In this paper, we propose a new technique, called OWDM-IDMA, which is the combination of the OWDM and IDMA techniques. It can alleviate ISI by the OWDM technique and cancel multiple access interference (MAI) by the IDMA technique. Moreover, the use of OWDM technology in this scheme offers better properties. The first ideas of using wavelet transform in communication were made in multidimensional signaling techniques. Wavelet packet waveforms have the property of localization in both frequency and time domains.

Using the time domain localization property of wavelet packet waveforms, a multi-carrier IDMA system based on wavelet packets can be designed to achieve both frequency and time domain diversity.

Figure.6 shows the transmitter/receiver structure of an OWDM-IDMA system with K users.

At the transmitter for user-k, the information data is encoded into a sequence $c_k = \{c_k[m]\}$. Each coded bit c_k is interleaved by a user-specific interleaver π_k , and then the resultant signals, again denoted by $X_k(n)$, are modulated by using IDWPT producing $Y_k(n)$. The received signal equals the sum of the signals received from all transmitters. The received signal from K users can be written as:

$$r(n) = \sum_{k=1}^K h_k(n)Y_k(n) + z(n) \quad (11)$$

with

$$Y_k(n) = \sum_{m=-\infty}^{+\infty} \sum_{l=0}^{M-1} x_k(n)\psi_{m,l}(t) \quad (12)$$

Where h_k is the channel coefficient for user-k, $z(n)$ are samples of an AWGN with variance $\sigma^2 = N_0/2$, $Y_k(n)$ a chip sequence for user k after OWDM modulation, M the number of sub-channels associated with the transmission, and n denotes the transmission time.

As shown in figure.6, the core of the OWDM-IDMA receiver consists of DWPT for demodulation OWDM, an elementary signal estimator (ESE) and K a posteriori probability decoders (APP DECS). After OWDM demodulation by using DWPT, the iterative processes for receiver IDMA can be applied in the receiver signal $r(n)$ to detect the information data of users. Thus, the iterative process does not include the OWDM demodulation. If the number of paths L is large, this structure reduces significantly the calculation complexity of the receiver.

Information provided to the ESE detector is then the same

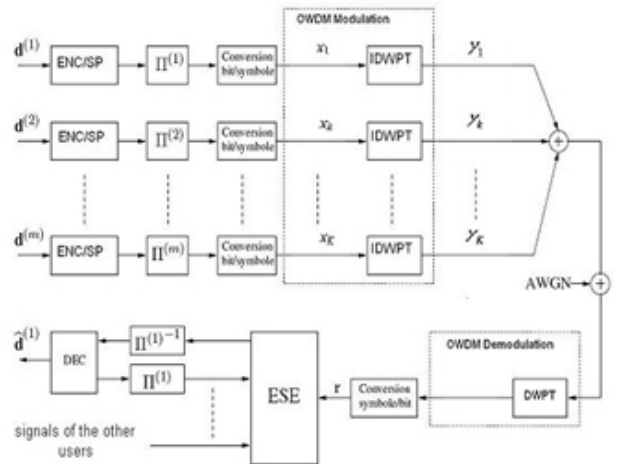


Fig. 6. Transmitter/receiver structure for OWDM-IDMA

kind of IDMA multiuser system on single-path channel. Thus

to retrieve the information from each user, the ESE detector considers only the MAI interferences to allow for removal of the demodulated signal.

V. SIMULATION RESULTS AND DISCUSSION

Simulation was done in Matlab. The simulation results are provided to illustrate the performance of OWDM-IDMA systems. For simplicity, we only consider uncoded systems in AWGN channels. K is the number of simultaneous users in the system.

Figure.7 shows the performances of OWDM-IDMA (with randomly generated interleavers, a common length-16 spreading sequence for all users and 16 Haar wavelets pulses) in AWGN channels.

BPSK modulation is used by all users and the length of the

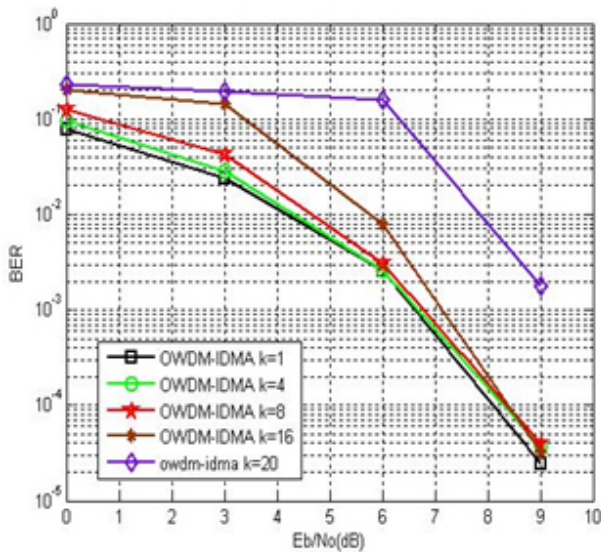


Fig. 7. The simulated performance curves for OWDM-IDMA. In this example, we assume that Information bit length = 3072, iteration number = 10, number of users = 1, 4, 8, 16, 20.

information block is $N = 3072$ bits per user. The lengths of the spreading sequence is $S=16$. Here, the performance gain with OWDM-IDMA is mainly attributed to the use of user-specific interleavers, which greatly facilitates the convergence of iterative MUD.

Simulation results (Figure.7) show that the performance of OWDM-IDMA degrades slightly as K increases. This degradation is caused by the MAI interferences that become critical when the number of users increases.

The results presented in this section allow us to conclude that for a system OWDM-IDMA, the receiver can effectively mitigate the MAI and ISI interferences by treating them separately. The operation of modulation / demodulation can treat interference ISI, while the detector ESE performs interference cancellation MAI. Therefore, the implementation of a corresponding receiver avoids the iterative processing ISI interference, which a priori reduces calculating complexity.

VI. CONCLUSION

In this paper, we have presented the basic principles of OWDM-IDMA. This system has the advantage of being able to dynamically allocate bandwidth for each of the subbands depending on the application (whether it were data for interactive services, video conferencing, audio data, etc) and changing the modulation techniques of each subband to suit the channel.

The main advantage of using OWDM-IDMA relies in the fact that it is a very flexible system which is also simple. In addition, the filter type can be dynamically chosen. It includes low-cost MUD for systems with large numbers of users, robustness and diversity in multipath environment.

In conclusion, OWDM-IDMA appears to be a competitive candidate for future wireless communication systems. We expect that the basic principles can be extended to other applications.

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