A SCHEME OF M-ARY MULTI-CARRIER SPREAD SPECTRUM BASED ON WAVELET PACKET

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Abstract  A novel scheme of M-ary multi-carrier spread spectrum based on wavelet packet is proposed. Its performance is investigated for a multipath, slow Rayleigh fading channel. The performance advantages of the system over that based on DFT are demonstrated by both analytical and simulation methods.

Key words  Wavelet packet; Multi-carrier spread spectrum; M-ary

I. Introduction

Orthogonal Frequency Division Multiplexing (OFDM) has been widely used primarily because of its high spectral efficiency and multipath tolerance\cite{1,2}. OFDM transmits data as a set of parallel low bandwidth carriers. The frequency spacing between the carriers is made to be the reciprocal of the useful symbol period. Recently, OFDM has been introduced into Direct Sequence Spread Spectrum (DSSS) to get such advantages as bandwidth efficiency, frequency diversity, and interference rejection capability in high data-rate transmission, named Multi-Carrier Spread Spectrum (MCSS). There are different MCSS schemes proposed, e.g., Discrete Fourier Transform based MCSS\cite{3,4} (DFT-MCSS), Wavelet and Wavelet Packet based MCSS\cite{5,6} (WP-MCSS). In bandwidth restricted channel, the M-ary spread spectrum scheme\cite{7} can be used to achieve higher bit transfer rate. One DFT based M-ary MCSS scheme was proposed in Ref.\cite{8}. In this letter, we propose a WP based M-ary MCSS scheme which has a better performance in multipath channel than DFT based M-ary MCSS scheme since wavelet packet has many attractive properties.

II. Wavelet Packet Theory

Wavelet packets can be defined recursively as Ref.\cite{9}

\begin{equation}
    w_{2n} = \sqrt{2} \sum_{k} h(k)w_{n}(2t - k)
\end{equation}

\begin{equation}
    w_{2n+1} = \sqrt{2} \sum_{k} g(k)w_{n}(2t - k)
\end{equation}

where \(n\) is a non-negative integer. Sequence \(h(k)\) and \(g(k)\) correspond to discrete impulse responses of lowpass and highpass filters of quadratic mirror filter bank with perfect reconstruction.

The property of orthogonality among wavelet packets can be given as

\begin{equation}
    < w_{n}(t), w_{n}(t - k) >= \delta_{k}
\end{equation}

\begin{equation}
    < w_{n_1}(t - k_1), w_{n_2}(t - k_2) >= 0 \quad (n_1 \neq n_2)
\end{equation}

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where \(<\cdot,\cdot>\) denotes the inner product and \(\delta_k\) is the Kronecker function.

### III. System Model

1. **Channel model**

The impulse response of the channel is given by Ref.[10]

\[
h(t) = \sum_{l=1}^{L} a_l \delta(t - \tau_l) \exp(j\phi_l)
\]  

where \(L\) is the sum of resolvable paths, \(a_l, \tau_l, \phi_l\) are the amplitude, delay and phase of the \(l\)-th path respectively. \(a_l\) is modeled as independent Rayleigh random variable, its probability density function (pdf) is

\[
f(a_l) = \frac{2a_l}{\sigma_l} e^{-a_l^2/\sigma_l}
\]

where \(\sigma_l = E[a_l^2]\), \(\phi_l\) are supposed to be independent uniformity distribution in \([0, 2\pi]\).

2. **Transmitter and receiver model**

Compared with the DFT-MCSS scheme, the WP-MCSS has better performance in multipath environment for the good properties of wavelet packet function[6]. M-ary scheme using a group of orthogonal PN codes to carry bit information. The models of transmitter and receiver are shown in Fig.1 and Fig.2 respectively. In the transmitter, data bits are serially-to-parallely converted and grouped into \(n = \log_2 M\) bits to get modulation symbol. Then, every modulation symbol is used to select the corresponding PN code. Let the length of the PN code be \(K\). Each of the \(K\) chips of the selected PN code is then modulated on a corresponding sub-carrier and the modulated signals of \(K\) branches are summarized for transmission, which can be implemented by Inverse Wavelet Packet Transform (IWPT). Therefore, the transmitted signal can be expressed as

\[
s(t) = \sqrt{P} \sum_{i=1}^{\infty} \sum_{k=1}^{K} c_{m(i)}(k)w_k(t - iT_s)\cos(\omega_c t)
\]

where \(T_s\) is the period of symbol; \(m(i) (m(i) \in [1, M])\) is the index number of the PN code corresponding to the \(i\)-th modulation symbol, \(c_{m(i)}(k)\) denotes the \(k\)-th PN chip of the \(m(i)\)-th PN code, \(w_k(t)\) is the wavelet packet function.

The received signal can be expressed as

\[
r(t) = \sqrt{P} \sum_{i=-\infty}^{\infty} \sum_{k=1}^{K} \sum_{l=1}^{L} a_l c_{m(i)}(k)w_k(t - iT_s - \tau_l)\cos(\omega_c t + \phi_l) + n(t)
\]

where \(n(t)\) is the Additive White Gaussian Noise (AWGN). In the receiver, Wavelet Packet Transform (WPT) is used to extract PN information, then different branch and symbol judgement is done by the maximum correlation result of different PN codes \(C_p (p \in [1, M])\) corresponding to different correlator branches.

### IV. Performance Analysis

Assuming the receiver is synchronized with the first path signal by phase locking tech-