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A Novel TDD Multicarrier System Using Pre-Equalizer in Downlink*

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Abstract: In this paper, a time division duplex (TDD) multicarrier system based on Nyquist filter bank is proposed for wireless broadband communications. In this system a novel two-tap pre-equalizer is adopted to effectively suppress the inter-symbol interference (ISI). Studies show that the system has almost the same frequency spectrum efficiency as the orthogonal frequency division multiplexing (OFDM) system. Simulation results show that the proposed system outperforms the conventional OFDM system with one-tap maximum likelihood equalizer (MLE) in low signal-to-noise ratio (SNR) and is quite robust to carrier frequency offset.

Key words: multicarrier system, OFDM system, TDD, Nyquist filter bank, pre-equalizer

Recently multicarrier techniques have drawn a lot of interests for high data rate wireless multimedia services[1,2]. Among these techniques orthogonal frequency division multiplexing (OFDM) is a desirable technique. However, such a system is very sensitive to frequency offset[2]. Generally, for given communication links, subcarrier bandwidths of OFDM system are already determined. Thus the robustness against frequency offset of such a system will only depend on advanced algorithms.

In this paper a novel TDD multicarrier system is proposed which uses Nyquist filter bank to separate each subcarrier bandwidth. The system can choose the parameters such as the bandwidth and the subcarrier number more flexibly than conventional OFDM system. No guard interval is required and fast algorithm is also provided. As a result, the performance of the system is superior to that of the conventional OFDM system without the increase of the complexity. Besides, the system is robust to frequency offset.

In TDD mode, multicarrier system can exploit the reciprocity of the channel between downlink and uplink, and the channel equalization function can be moved from mobile to base station in the forward link, which will greatly reduce the mobile complexity.

This paper is organized as follows. Section 1 presents the system model. In section 2, a stabilized pre-equalizer is described. Section 3 shows the coherent detection scheme. And the simulation results are shown in section 4. Finally, conclusions are given in section 5.

1 System Model

The transmitter of the multicarrier system based on Nyquist filter bank in downlink is shown in Fig.1, in which input information sequence $d(t)$ with duration T_d is first serial-to-parallel converted to M lower rate streams $d_0(t) \cdots d_{M-1}(t)$ with duration $T = MT_d$. To suppress the inter-symbol interference (ISI), the output sequence feeds to a multi-channel pre-equalizer, whose parameters are determined by the estimated channel parameters of the adjacent uplink frame. Then the data symbol in each subcarrier is modulated with Nyquist filters for baseband pulse shaping. Thus the bandwidth of adjacent subcarrier does not overlap.

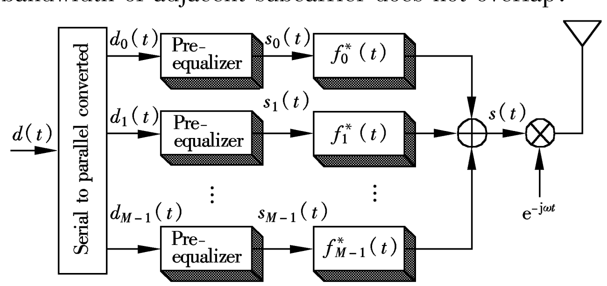

Fig.1 Transmitter structure of the proposed system

The modulation function of the m-th subcarrier can be described as

$$f_m(t) = f(t)\exp\left(-\mathrm{j}\frac{2\pi m(1+\alpha)t}{T}\right)$$

$$0 \leqslant m \leqslant M-1;\ 0 \leqslant \alpha \leqslant 1.0 \qquad (1)$$

where $f(t)$ is Nyquist filter with the roll off factor α; and m is subcarrier number.

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The frequency spectrum efficiency of the proposed system is $1/(1+\alpha)$. Generally α can be chosen as 0.25. So the frequency efficiency of the proposed system is approximately equal to that of conventional OFDM system, which is generally 80% considering the insertion of guard interval[1].

The complex equivalent low-pass transmitted signal can be written as

$$s(t) = \sum_{n=-\infty}^{+\infty} \sum_{m=0}^{M-1} s_m(n) f_m^*(t - nT_s) \tag{2}$$

where $s_m(n)$ is the pre-equalized data of the m-th subcarrier, and $T_s = T/(1+\alpha)$, T_s is the symbol duration of each subcarrier corresponding to the minimum orthogonal interval.

For this multicarrier system, the channel is subject to frequency selective fading. $h(t,\tau)$ is assumed as a wide sense stationary uncorrelated scattering (WSSUS) channel with L received paths in the complex equivalent low-pass time variant impulse response and can be described as[3]

$$h(t,\tau) = \sum_{l=0}^{L-1} g_l(t)\delta(\tau - \tau_l) \tag{3}$$

where t and τ are the time and delay, respectively; $\delta(\cdot)$ is the Dirac delta function; $g_l(t)$ is the l-th path gain which is independent complex Gaussian random process. Assuming that the path gain keeps constant for several frames, the channel can be simplified to the following equation:

$$h(t) = \sum_{l=0}^{L-1} g_l \delta(t - \tau_l) \tag{4}$$

The received signal can be written as

$$r(t) = \sum_{n=-\infty}^{+\infty} \sum_{m=0}^{M-1} s_m(n) f_m^*(t - nT_s) \otimes h(t,\tau) + n(t) \tag{5}$$

Then the received signal can be written as

$$r(t) = \sum_{n=-\infty}^{+\infty} \sum_{m=0}^{M-1} \sum_{l=0}^{L-1} g_l s_m(n) \cdot f_m^*(t - nT_s - \tau_l) + n(t) \tag{6}$$

where $n(t)$ is Gaussian white noise with zero mean and two-sided power spectral density of N_0.

2 Two-Tap Pre-Equalizer

The proposed system based on Nyquist filter bank doesn't require guard interval since the frequency response of adjacent subcarrier is non-overlapping. Then the number of subcarriers for this system can be chosen flexibly compared to OFDM system. To reduce the sensitivity to frequency offset, the bandwidth of subcarrier is chosen close or equal to coherent bandwidth. Then the ISI of each subcarrier is dispersed only to the adjacent symbol. A two-tap pre-equalizer is used in the transmitter to suppress ISI interference, the structure of which in each subcarrier is illustrated in Fig.2. The equalizer transfer function is given as

$$H(Z) = \frac{1}{h_{m,0} + h_{m,1} Z^{-1}} \tag{7}$$

where $h_{m,0}$ and $h_{m,1}$ are the 1st and 2nd equivalent paths of the m-th subcarrier, respectively.

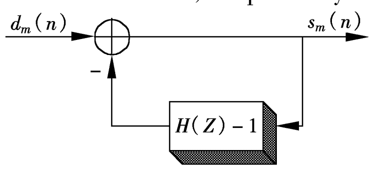

Fig.2 Pre-equalizer of sub-carrier

A discrete-time system is bounded-input bounded-output stable if all the roots of $H(Z)$ lie within the unit circle of the z-plane. There are three cases of roots.

Case 1 $|h_{m,0}| > |h_{m,1}|$

The root is well inside the unit circle in the z-plane, so the system is minimum-phase and causal and stable. The feedback filter function is given as $D(Z) = h_{m,0} + h_{m,1} Z^{-1}$. Then the signal pre-equalized can be written as

$$s_m(n) = (A_m d_m(n) - h_{m,1} s_m(n-1))/h_{m,0} \tag{8}$$

Case 2 $|h_{m,0}| < |h_{m,1}|$

The root is outside the unit circle in the z-plane, so the system is unstable. Due to the particularity of the communication system, several frames of data can be stored and the system can be a non-causal one. Then the feedback filter function becomes $D(Z) = h_{m,0} + h_{m,1} Z$. This system is stable. Then the signal pre-equalized can be written as

$$s_m(n-1) = (A_m d_m(n) - h_{m,0} s_m(n))/h_{m,1} \tag{9}$$

Case 3 $|h_{m,0}| = |h_{m,1}|$

The root is a critical one (on the unit circle) and will cause instability. Then the new set coefficients can be calculated by using radial scaling of the roots[4]. This is a trade-off between equalization accuracy and stability. The feedback filter function can be written as

$$D(Z) = \overline{D}(\lambda^{-1} Z) = h_{m,0} + \lambda h_{m,1} Z^{-1} \quad 0 < \lambda < 1 \tag{10}$$

This system is stable and causal. The signal pre-equalized can be written as

$$s_m(n) = (A_m d_m(n) - \lambda h_{m,1} s_m(n-1))/h_{m,0} \tag{11}$$

3 Coherent Detection

The received data of the m-th subcarrier after the coherent detector can be written as

$$y_m(n) = \sum_{i=0}^{1} s_m(n-i)\sum_{l=0}^{L-1} g_l \cdot \int_{-\infty}^{+\infty} f_m^*(t-(n-i)T_s-\tau_l) f_m(t-nT_s) \cdot \mathrm{d}t + I_m(n) + \eta_m(n) = d_m(n) + I_m(n) + \eta_m(n) \tag{12}$$

$$\eta_m(n) = \int_{-\infty}^{+\infty} n(t) f_m(t-nT_s)\mathrm{d}t \tag{13}$$

$$I_m(n) = \sum_{i=0}^{1}\sum_{\substack{m_1=0 \\ m_1\neq m}}^{M-1} s_{m_1}(n-i)\sum_{l=0}^{L-1} g_l \cdot \int_{-\infty}^{+\infty} f_{m_1}^*(t-(n-i)T_s-\tau_l) f_m(t-nT_s)\mathrm{d}t \tag{14}$$

The subcarrier frequency response can be estimated from the multipath channel estimated in the uplink by the following equation.

$$h_{m,i} = \sum_{l=0}^{L-1} g_l \int_{-\infty}^{+\infty} f_m^*(t-(n-i)T_s-\tau_l) \cdot f_m(t-nT_s)\mathrm{d}t \tag{15}$$

The interference mainly depends on the cross correlation coefficients of the filter bank of different subcarrier. Since the frequency spectrum correlation of the carriers that are adjacent is below − 30 dB and that of the carriers that are not adjacent is below − 60 dB, the interference I_m is very small. And η_m is Gaussian white noise with zero mean and two-sided power spectral density of N_0. The equation shows that the two-tap pre-equalizer can effectively suppress the ISI.

4 Simulation Results

The carrier frequency is 1.9 GHz and the system bandwidth is 20 MHz. The mobile speed is 3 km/h and the modulation scheme is QPSK. The multipath fading channel is a typical ITU-R M.1225 pedestrian channel model. The rolloff factor is 0.22. Other parameters of the system is shown in Tab.1.

Tab.1 Parameters comparison of the simulation

Parameters	OFDM(MLE)	Proposed OFDM (Pre-equalizer)
Number of carriers	64	32
Subcarrier equalizer	One-tap MLE	Two-taps ORC
Symbols per frame	80	160
CP	16	0

Fig.3 shows the bit error rate (BER) of various systems with different signal-to-noise ratio (SNR). From the figure, the proposed system with two-tap pre-equalizer performs better in low SNR than the OFDM system with one-tap MLE equalization. The combining scheme is the orthogonal restoring combining (ORC). In Fig.4, BER of different systems with frequency offset is compared. The performance of OFDM system with MLE equalizer degrades greatly with the increase of the frequency offset while the proposed system is robust to the frequency offset.

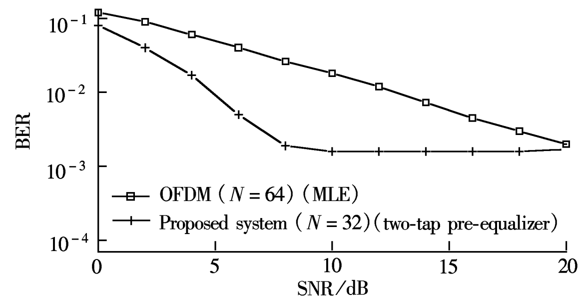

Fig.3 Comparison of BER with different SNR

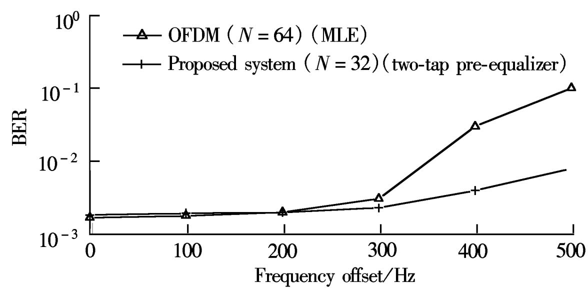

Fig.4 BER performance comparison with different frequency offset

5 Conclusions

In this paper, a novel TDD Nyquist based OFDM system is proposed. The proposed system based on the Nyquist filter bank uses a two-tap IIR filter in the transmitter to suppress the ISI and can avoid the error propagation. It is found that the system has the same frequency efficiency as that of the conventional OFDM system[1]. Simulation results show that without increasing the computation complexity the proposed system has two advantages over conventional OFDM system. ① The number of subcarriers can be chosen flexibly so that the system can perform well with high frequency offset; ② The system outperforms OFDM system with one-tap MLE equalizer in low SNR.

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一种使用预均衡器的下行链路多载波系统的研究

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摘　要　提出了一个在无线宽带系统中的基于 Nyquist 滤波器的时分复用多载波系统.在这个系统中,采用两抽头的预均衡器可以有效地抑制符号间干扰.研究表明该系统有着和正交频分多址复用系统同样的频谱利用率.仿真结果表明该系统在低信噪比下性能明显优于传统的 OFDM 系统.并且该系统对于载波频偏有一定的鲁棒性.

关键词　多载波系统,OFDM 系统,时分复用,Nyquist 滤波器,预均衡器

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