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基于DCO-OFDM的帧内信号时域调整技术研究

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摘 要:在传统OFDM系统中,OFDM码元在信道特性不佳时可能会超出保护间隔并严重影响相邻码元,从而造成码间干扰和载波间干扰.针对此类干扰,在高速非相干光OFDM通信系统中,提出了一种基于直流偏置光OFDM的帧内信号时域调整方案.该方案运用傅里叶变换的基本性质,通过简单的频域子信道预处理,便可以将直流偏置光OFDM时域信号进行帧内交叉性时序搬移,使信号能量从码元边缘部分集中到中间部分.数值模拟表明,该方案能显著降低因码元超出保护间隔而引起的码间干扰和载波间干扰,从而有效改善系统的误码率性能.对于某些通过减小保护间隔来提高信息传输有效性的光OFDM系统,该方案也具有很大意义.

关键词:非相干光通信;直流偏置光OFDM;保护间隔;帧内信号时域调整;码间干扰
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Analysis of Time Domain Reshuffling Based on DC-biased Optical OFDM

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Abstract: In conventional OFDM system, an OFDM symbol will exceeds its guard interval (GI) and seriously interfere with its neighboring symbols when channel characteristic is unsatisfactory. This will cause inter-symbol interference (ISI) and inter-carrier interference (ICI). In high-speed incoherent optical OFDM communication system, a novel time domain reshuffling method for mitigating ISI and ICI based on DCO-OFDM was proposed. This scheme utilized the properties of Fourier Transform. By simple pre-processing subcarrier channels in frequncy domain, sampling sequence of a DCO-OFDM symbol in time domain was exchanged interactively. Thus signal energy was centralized in the central part of a symbol. Numerical simulation indicates that ISI and ICI is significantly reduced and system BER performance is improved effectively due to signal surpassing the GI. In optical OFDM systems with insufficient GI for the popurse of higher information transmission efficiency, the reshuffling scheme also has a great value.

Key words: Incoherent optical communication; DC-biased OFDM; Guard interval; Time domain reshuffling; Inter-symbol interference
OCIS Codes: 060.4510; 060.4080; 200.4960; 200.3050

0 Introduction

Orthogonal Frequency Division Multiplexing (OFDM) is widely applied in many new and emerging high-speed wired and wireless communication systems because it allows high-speed data transmission across a

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dispersive channel[1-2]. Compared with conventional scheme of single carrier modulation, OFDM is a parallel transmission technology which uses multi-carrier broadband modulation scheme, and it offers many excellent advantages such as high spectral efficiency and superior capability against the fading[3-4]. Recent researches have shown that OFDM is also a promising technology in optical communication[5-6]. In optical fiber communication, OFDM can help to reduce the impact of fiber dispersion and polarization mode dispersion[7-8]. And in optical wireless communication, OFDM is also an effective solution to Inter-Symbol Interference (ISI) caused by multi-path effect[9]. Apart from the nature of multi-carrier modulation itself, the widespread use of optical OFDM can be mainly attributed to Guard Interval (GI) in OFDM symbols.

In OFDM signals, Cyclic Prefix (CP) is usually adopted as GI to resist ISI and Inter-Carrier Interference (ICI)[4]. However, system efficiency will be sacrificed if CP is too long. So some shorter GI methods are emerging to reduce the transmit redundancy[10-11]. But in some scenarios, i. e., multi-path propagation or channel dispersion, signals may still surpass the GI. Part of signal energy especially from both sides of an OFDM symbol will be lost, leading to severe ISI and ICI[12-13]. Therefore, it is necessary to reduce the energy in the margin part of OFDM symbols. At the present time, DC-biased optical OFDM (DCO-OFDM) is one kind of intensity modulation OFDM in optical communication[14-15]. Because of high spectral efficiency, simple system structure and low cost, it is investigated and used extensively[16]. In DCO-OFDM, if all subcarriers are assumed to be allocated with equal power, it can be found in the time domain that most energy distributes in margin part of symbols instead of middle part. This results from the different range of sampling points of Discrete Fourier Transform (DFT) in OFDM and that of Fourier Transform (FT) for continuous signal.

In this paper, starting from inverse Fourier Transform (IFT), we propose a time domain reshuffling method for DCO-OFDM which can be simply achieved by pre-processing subcarrier channels. This scheme can centralize the signal energy OFDM in the central part of a symbol and reduce the aforementioned ISI and ICI. Then a comparison of sampling waveform with and without the reshuffling scheme is analyzed. Finally the BER performance improvement in a back-to-back system is investigated.

1 Time domain reshuffling scheme

In OFDM, signals are transmitted in parallel on a number of subcarriers at different orthogonal frequencies. The transmitter uses an Inverse Fast Fourier Transform (IFFT) to generate a sampled waveform[1]

$$f(n)=\frac{1}{N}\sum_{n=0}^{N-1}F(k)\exp\left(\frac{\mathrm{j}2\pi kn}{N}\right) \tag{1}$$

where $F(k)$ is the complex number representing the constellation point on the kth subcarrier of a given symbol, $f(n)$ is the baseband time domain samples for $F(k)$ and N is the size of IFFT. In general, $F(k)$ and $f(n)$ are complex. However, in incoherent optical systems, signals must be mapped to light intensity which is positive. Thus the bipolar OFDM signal has to be converted into unipolar form suitable for intensity modulation. DCO-OFDM in which a DC bias is added to the bipolar signal has been developed[14]. The information stream is first parsed into a block of complex data symbols. Then complex symbols are primarily drawn from QAM/PSK constellations. After that, these complex symbols are mapped according to the following vector[15]

$$\{S_k\}_{k=0}^{2N-1}=[0\{X_k\}_{k=1}^{N-1}0\{X_k^*\}_{k=N-1}^{1}] \tag{2}$$

where $(\cdot)^*$ denotes the complex conjugate.

However, the IFT denoted by $f(t)$ of spectral density function $F(\omega)$ can be written as

$$f(t)=\frac{1}{2\pi}\int_{-\infty}^{\infty}F(\omega)\exp(\mathrm{j}\omega t)\mathrm{d}\omega \tag{3}$$

where

$$F(\omega)=\int_{-\infty}^{\infty}f(t)\exp(-\mathrm{j}\omega t)\mathrm{d}t \tag{4}$$

If $F(\omega)$ is sampled by $2N+1$ points with the interval of $2\pi/T$ denoted by $F(k)$, where $k=-N,-N+1,\cdots N$, then

$$f(n)=\frac{1}{2N}\sum_{k=-N}^{N}F(k)\mathrm{e}^{\mathrm{j}\pi nk/N}\quad n=-N,-N+1,\cdots N \tag{5}$$

According to the mapping expression of DCO-OFDM in (2), $F(k)$ should be the following expression

$$\{F_k\}_{k=-N}^{N-1}=[0\quad\{X_k\}_{k=-N+1}^{-1}\quad 0\quad\{X_k^*\}_{k=-1}^{-N+1}] \tag{6}$$

So based on (5) we can get

$$f(n)=\frac{1}{2N}\sum_{k=-N+1}^{-1}X(k)\mathrm{e}^{\mathrm{j}\pi nk/N}+\frac{1}{2N}\sum_{k=1}^{N-1}X^*(-k)\mathrm{e}^{\mathrm{j}\pi nk/N} \tag{7}$$

where $f(N)$ is assumed negligible. If a variable substitution of $k'=k+N$ is made, then $f(n)$ should be

$$\begin{aligned}f(n)=&\frac{1}{2N}(-1)^n\sum_{k'=1}^{N-1}X(k'-N)\mathrm{e}^{\mathrm{j}\pi nk'/N}+\\&\frac{1}{2N}(-1)^n\sum_{k'=N+1}^{2N-1}X^*(-k'+N)\mathrm{e}^{\mathrm{j}\frac{\pi}{N}nk'}\end{aligned} \tag{8}$$

Similarly, in order to change the range of n, $n'=n+N$ should be made, then

$$\begin{aligned}f(n')=&\frac{1}{2N}(-1)^{n'}\sum_{k'=1}^{N-1}(-1)^{k'}X(k'-N)\mathrm{e}^{\mathrm{j}\pi n'k'/N}+\\&\frac{1}{2N}(-1)^{n'}\sum_{k'=N+1}^{2N-1}(-1)^{k'}X^*(-k'+N)\mathrm{e}^{\mathrm{j}\pi n'k'/N}\end{aligned} \tag{9}$$

Obviously, $f(n)$ can be further written as follow

$$f(n)=\frac{1}{2N}(-1)^n\sum_{k=0}^{2N-1}(-1)^kF(k-N)\mathrm{e}^{\mathrm{j}\pi nk/N} \tag{10}$$

Compared Eq. (10) with Eq. (1), it can be shown that frequency signals should make a transformation before taking IFFT, so as to transmit discrete time domain function $f(t)$ as in Eq. (3). Such a procedure should be done again in the OFDM receiver before taking FFT. By these procedures, the resultant time domain OFDM signal is equivalently exchanging its first and second half which can be represented as

$$\begin{cases} f_r(n)=f(n+N) \\ f_r(n+N)=f(n) \end{cases}, n=0,1,\cdots,N-1 \qquad (11)$$

where $f_r(t)$ donates time domain signal after transformation. Thus we call this scheme as time domain reshuffling method.

Flow chart of the scheme of DCO-OFDM in transmitter is shown in Fig. 1(a). The complex data symbols denoted by $X(k)(k=1,\cdots N-1)$ are mapped into $\{S_k\}_{k=0}^{2N-1}$. After that odd terms $S(2m+1)(m=0,1,\cdots,N-1)$ are set to multiply (-1) and even terms are unchanged. So the new sequence $\{C_k\}_{k=0}^{2N-1}$ in Fig. 1(a) is obtained. The expression after $2N$-point IFFT is denoted by $\{f'_n\}_{n=0}^{2N-1}$. In the end, odd terms $f'(2r+1)(r=0,1,\cdots N-1)$ are multiplied by (-1) and even terms are unchanged as well. Similarly, we can recover the original signal in the receiver by reversed procedures shown in Fig. 1(b).

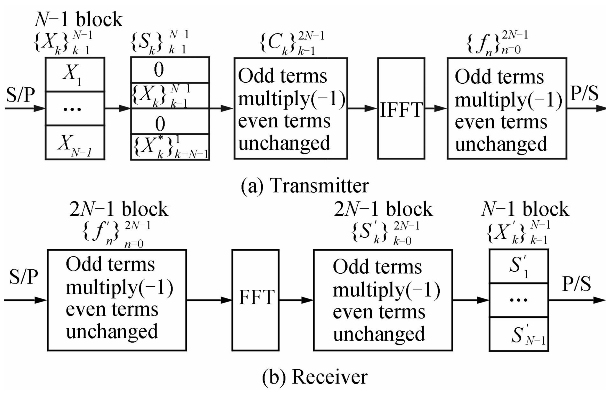

Fig. 1 Flow chart of time domain reshuffling of DCO-OFDM

Actually, at the both sides of an OFDM time frame, all subcarrier channels have a greater possibility to synchronize and sum up a high peak power. However, all subcarrier channels in the center of an OFDM time frame is more likely out of synchronization and the resultant instantaneous power is small. This will be demonstrated in the following part. By considering making more subcarrier channels synchronized in the center of an OFDM time frame while the resultant instantaneous power minimal at the both end, the data stream should be processed before taking IFFT. For a DCO-OFDM signal the time domain reshuffling method is as simple as only changing sign of each odd subcarrier channel, while even subcarrier channels kept unchanged.

2 Simulation results

In OFDM, when all subcarriers are summed up at the same phase, the time domain peak power is N times the average power, where N is the number of subcarrier. The Peak-to-Average Ratio (PAR) can reach $10\log_{10}N$. For example, when N is 256, the PAR is 24 dB. Fig. 2(a) shows the time domain waveform of a DCO-OFDM when all subcarriers are modulated by the same initial phase. The number of subcarrier and IFFT size are both 32 and BPSK is adopt. Fig. 2(b) shows the waveform after the reshuffling applied. Obviously in Fig. 2, time domain reshuffling as proposed makes signal energy centralized in the central part of an OFDM symbol.

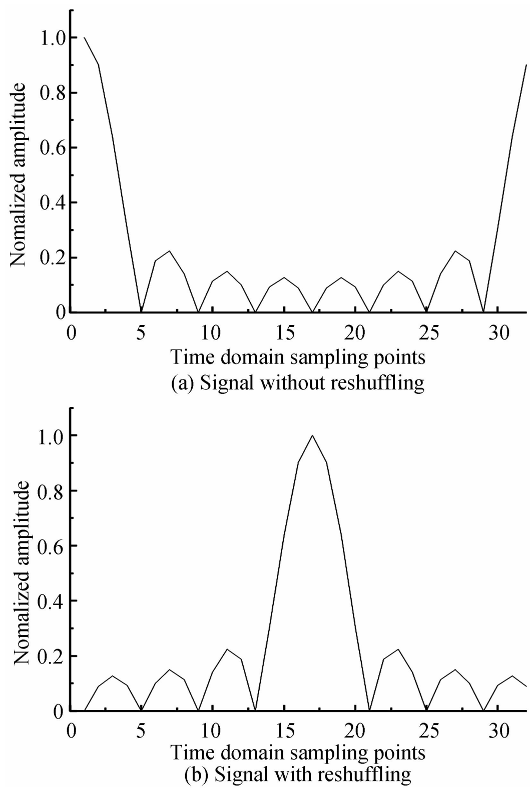

Fig. 2 Comparison when all subcarriers synchronize

We take the pseudo-random sequence and adopt QPSK as subcarriers modulation. Fig. 3(a) shows a time domain symbol of conventional DCO-OFDM after 256 points IFFT while Fig. 3(b) shows the waveform after the reshuffling applied.

In Fig. 3, the differences with and without reshuffling is not very distinct and not all symbols are like this where energy centralize in the middle part. Although Fig. 2 is an extreme circumstance, because frequency domain signal can be seen as the superposition of numerous rectangular waves of each subcarrier, the time domain waveform still has more probabilities to synchronize and centralize in both sides if we put a signal in an OFDM frame. When signal surpasses GI, it will lost much energy. Thus by reshuffling, the mount of signal energy surpassing the GI can be reduced by reshuffling significantly. Accordingly, the system transmission performance can be estimated to suffer less interference than the conventional one, especially in systems suffering from severe multi-path effect.

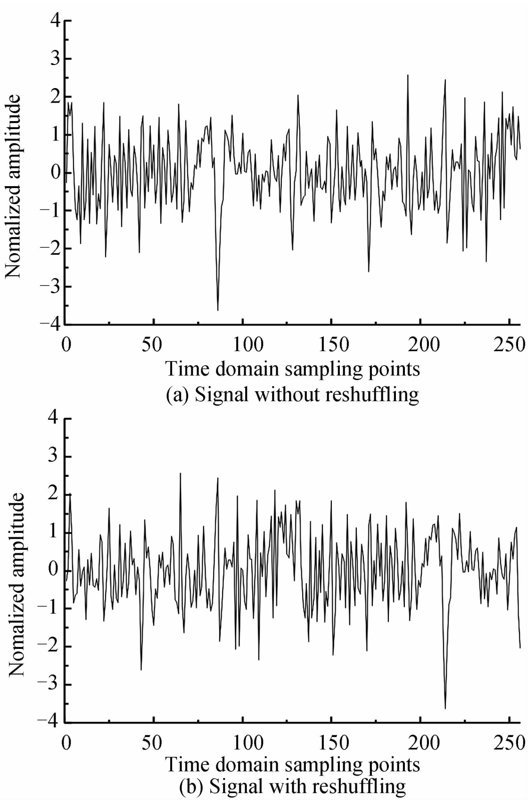

Fig. 3. Comparison of 256 points IFFT

Fig. 4 shows performance comparison for OFDM signals with and without reshuffling in a back-to-back transmission system, based on the assumption of additive white Gaussian receiver noise. The walk-off part out of an OFDM frame in the whole duration is denoted by ratio s in Fig. 4. The respective value of the lost signal is considered as zero in FFT calculation for simulation. The GI is approximately chosen to be one eighth of symbol length.

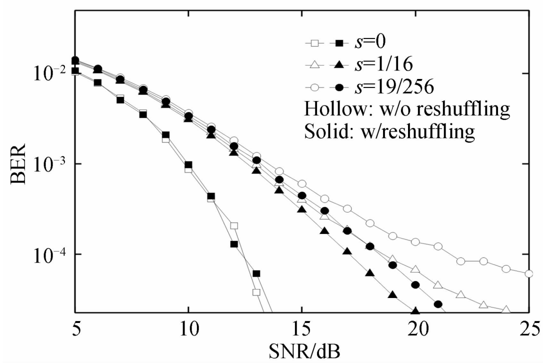

Fig. 4. BER performance comparison of DCO-OFDM system adopting zero-padding

From Fig. 4, it is shown that the one with reshuffling exhibits better system performance than the conventional one with the same walk-off part. Similarly, the more walk-off part is, the more improvement there will be. When the lost part of a signal is large enough, the BER will approach a nonzero value without reshuffling while error free transmission can be realized with reshuffling. For simplicity, details of ISI and ICI improvement between OFDM frames will be discussed elsewhere.

3 Conclusions

In summary, a time domain reshuffling method of DC-biased OFDM in incoherent optical system has been proposed in this paper. When signal of OFDM surpasses GI which is used to resist ISI and ICI, it will lead to loss of partial signal energy. Through time domain reshuffling method, we rearrange a conventional DCO-OFDM signal whose energy focuses on both sides to the one whose energy centralized in the middle part. So ISI and ICI between neighboring symbols will be expected to be reduced significantly. Simulation results have shown the comparison in the cases where time domain reshuffling is used or not. The method is attractive because it only modifies data part in frame structure of OFDM based on simple mathematical calculation, rather than buffering and exchanging the long data block sequences. This will also contribute to shorter GI methods in the future optical OFDM system. In the extended research, we will discuss the performance comparison in actual optical fiber communication system.

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