Optik 123 (2012) 941–946

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo

Comparison of LMS-TEQ and DF-TEQ to reduce cyclic prefix length in direct detection optical OFDM system

Mohammad Ghanbarisabagh*, M.Y. Alias, H.A. Abdul-Rashid

Faculty of Engineering, Multimedia University, 63100 Cyberjaya, Selangor, Malaysia

ARTICLE INFO

Article history:
Received 11 January 2011
Accepted 14 June 2011

Keywords:
Optical communications
Optical orthogonal frequency division multiplexing
Single mode fiber
Long haul transmission
Equalizer

ABSTRACT

This paper presents the comparison of using least mean square time-domain equalizer (LMS-TEQ) and decision feedback time-domain equalizer (DF-TEQ) to reduce cyclic prefix (CP) length for direct-detection of optical orthogonal frequency division multiplexing (O-OFDM) over 6960 km of single mode fiber (SMF). Both TEQs are used immediately after the channel. Numerical modeling results show that they can cancel the residual inter symbol interference (ISI) and inter carrier interference (ICI) caused by both the group velocity dispersion (GVD) and the CP length being shorter than the channel impulse response (CIR). Using these TEQs allow the reduction of CP length, and consequently leading to system performance improvement. On the other hand, each of TEQs adds complexity to the system. Therefore, the aim of this paper is to analyze and compare the performance of LMS-TEQ and DF-TEQ while considering different CP length and complexity.

1. Introduction

Orthogonal frequency division multiplexing (OFDM) [1] is a multi-carrier modulation technology that has been proposed for fiber optic communication because it is an effective solution to ISI, when symbol period of each subcarrier is longer than the delay spread caused by GVD [2,3]. It has several advantages including efficient bandwidth usage, transformation of a frequency selective fading channel into a flat fading channel and simplified channel equalization.

In order to avoid the ISI and ICI, OFDM system adds a CP to the waveform [1] in which the end of the waveform block generated by the IFFT is copied and attached to the beginning of the block. If the CP length is sufficiently long, any time shift will not affect the received signal. Therefore, the subcarriers will remain orthogonal. However, the CP wastes transmission capacity, if its length is not optimized [4]. When the CP length is longer than the CIR, ISI can be eliminated. Thus, the effect of delay spread caused by GVD in long-distance SMF leads to frequency selective fading of individual sub-band channels. Fortunately, this fading can easily be cancelled by one-tap frequency-domain equalizer (FEQ) [5]. However, this method will waste the energy within the CP, because the system leads to low energy efficiency. On the other hand, if the CP length is shorter than the CIR, energy wastage is reduced but the system performance will be limited by ISI and ICI [6]. ISI and ICI are a severe degradation factor for the performance of the communications system [7]. Thus, ISI and ICI must be mitigated by equalization.

Lowery [8] reported that the CP overhead can be reduced by using several separate frequency bands to transmit a given data rate. The required CP length is the CP duration of a single band divided by the number of bands. The relative delay between two adjacent bands should equal the CP for each band, and should be calculated from the fiber's dispersion map. However, how can one justify whether CP duration is delayed enough to protect the system from inter band interference (IBI)? According to simulation results, the CP length is only reduced to 6.25% without considering the effect of any noise on the system.

We earlier introduced the use of TEQ in optical OFDM to reduce the CP length to 0.39% [9]. This paper presents the comparison of using LMS-TEQ and DF-TEQ to reduce CP length for direct-detection optical OFDM in SMF. The choice of these algorithms considers the two prominent algorithms in the linear and non-linear family being LMS-TEQ and DF-TEQ, respectively. Both TEQs are used immediately after the channel to reduce size of the CP, and consequently leading to system performance improvement. However, each of TEQs adds complexity to the system. Therefore, the aim of this paper is to analyze and compare the performance of LMS-TEQ and DF-TEQ while considering different CP length and complexity.

2. System model

Fig. 1 shows an optical OFDM transmitter. It is composed of functional blocks for IFFT, CP, digital to analog conversion (D/A), electrical-modulation, optical source and optical-modulation.

* Corresponding author. Tel.: +60 169780260; fax: +60 383183029.
E-mail address: m.ghanbarisabagh@mmu.edu.my (M. Ghanbarisabagh).

0030-4026/$ – see front matter
doi:10.1016/j.ijleo.2011.07.005

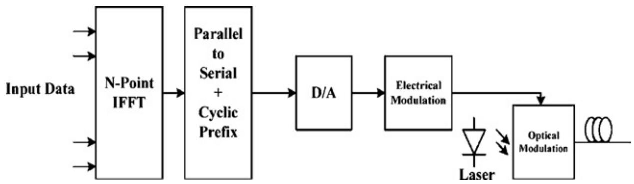

Fig. 1. Block diagram of optical OFDM transmitter.

If $X(p,q)$ denotes the frequency domain data symbol of the p-th sub-band of the q-th OFDM symbol, then the transmitted OFDM symbol in discrete-time domain will be shown as:

$$x(n,q) = \frac{1}{N}\sum_{p=0}^{N-1} X(p,q)\cdot \exp\left(j\frac{2\pi}{N}pn\right) \tag{1}$$

where $x(n,q)$ is an N-point inverse fast fourier transform and n is the time domain index of the OFDM sample.

Then the CP is added to the signal to avoid the ISI provided by the long-distance SMF channel. If $x_g(n,q)$ and g denote the extended OFDM symbol and length of the CP, respectively, it can be written as:

$$x_g(n,q) = \begin{cases} x(n-g+N,q) & 0 \le n \le g-1 \\ x(n-g,q) & g \le n \le N+g-1 \end{cases} \tag{2}$$

After D/A conversion, the components are used to drive the electrical modulator. To provide an optical output power proportional to the electrical drive voltage, the optical modulator is assumed to be linearized. It has been shown that Mach–Zehnder modulators without linearization can be used in O-OFDM [4,10,11]. The modulator output is then coupled into the SMF channel. Receiver Gaussian noise is then added to the channel output, so that the received samples, $y_g(n,q)$ is given by:

$$y_g(n,q) = [x_g(n,q)\cdot h(n)] + z(n,q) \tag{3}$$

where $h(n)$ and $z(n,q)$ are the discrete-time impulse response of the SMF channel and Gaussian noise in the time domain, respectively.

When the CP length is shorter than the CIR, the ISI will not be completely cancelled. The residual ISI reduces the performance of the system. Transformation of Eq. (3) in frequency domain can be written by:

$$Y(p,q) = H(p)\cdot X(p,q) + I(p,q) + Z(p,q) \tag{4}$$

where $I(p,q)$ is the residual ISI and ICI due to the CP length being shorter than the CIR. To overcome this residual ISI and ICI, a TEQ immediately after the channel and a 1-tap FEQ after FFT for each subcarrier are proposed. TEQ can provide multipath diversity. Furthermore, shorter CP length can reduce the energy wastage associated with the CP. Finally, the residual ISI can be cancelled by the CP and one-tap FEQ.

Fig. 2 shows the proposed optical OFDM receiver. The photodiode produces a time-domain waveform proportional to the optical power. From photodiode the waveform goes through the A/D conversion and TEQ subsequently. The proposed TEQ cancels the residual ISI and ICI. Then, CP is removed and the output will be converted to the frequency-domain using an FFT. After FFT each subcarrier is equalized by the 1-tap FEQ to compensate for phase and amplitude distortions due to the optical and electrical paths. The proposed receiver makes a reduction in the energy wastage associated with the CP by using a shorter CP length than the CIR.

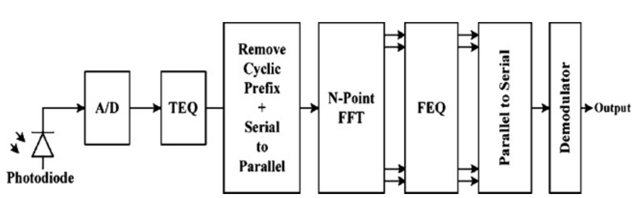

Fig. 2. Block diagram of proposed optical OFDM receiver.

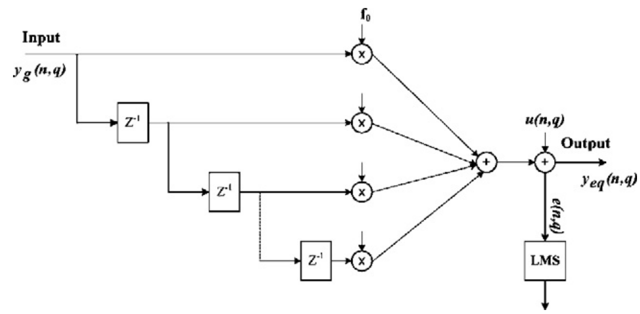

Fig. 3. Structure of LMS-TEQ.

In order to derive the performance of the system, two types of TEQ are used, namely LMS-TEQ and DF-TEQ.

2.1. LMS-TEQ

Fig. 3 illustrates the structure of the LMS-TEQ. It is designed by complex sample-by-sample LMS operations.

It is important to know that the LMS algorithm is a linear adaptive filtering algorithm which belongs to the family of the stochastic gradient algorithms [12]. The stochastic gradient algorithms differ from the steepest descent algorithms in that the gradient is not calculated deterministically. The LMS algorithm has two parts. In the first part, the output of a transversal filter is computed according to the tap inputs and the error term is generated according to the difference between the filter output and the training data. In the second part, the adjustment of the tap weights is done according to the error term.

The LMS algorithm forms a feedback loop by the error term fed back. The filter produces an output and the difference between the output and the training data is obtained. This difference is the estimation error term. The estimation error is given to the adaptation control section. Adaptation control section multiplies the estimation error with the complex conjugate of the input taps and a step size k. The results of the corresponding taps are added to the corresponding filter taps.

Consequently, when the received samples, $y(n,q)$ is applied to the proposed receiver, the TEQ estimates the channel information and determines the tap weights. This adaptive process is given by:

$$f(i,n+1,q) = f(i,n,q) + k\cdot e(n)\cdot w^*[(n-i),q] \tag{5}$$

where k, i, $f(i,n,q)$ and $w(n,q)$ are the step size, $0 \le i \le q-1$, tap weight and received training data of the LMS-TEQ, respectively. The estimated error $e(n,q)$ is given by:

$$e(n,q) = u(n,q) - y_{eq}(n,q) \tag{6}$$

where $u(n,q)$ is the training data. Then, the LMS-TEQ output can be written as:

$$y_{eq} = \sum_{i=0}^{I-1} f(i,n,q)\cdot y_g[(n-i),q] \tag{7}$$

Finally, the residual ISI of $y_{eq}(n,q)$ can be cancelled by the CP and one-tap FEQ.

2.2. DF-TEQ

Fig. 4 illustrates the structure of the DF-TEQ. It is composed of feed-forward and feed-back filters. The input is passed through the