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ELECTRONIC CHROMATIC DISPERSION COMPENSATION TECHNIQUES WITH FEED FORWARD AND DECISION FEEDBACK ADAPTIVE EQUALIZATION IN OPTICAL COMMUNICATION SYSTEMS

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Abstract

We have examined the electronic dispersion compensation in optical communication systems using adaptive filters equalization. We have used least mean square (LMS), recursive least square (RLS) and fast transverse recursive least square (FTRLS) algorithms for equalization. We have also implemented Feed forward and decision feedback equalizer with these algorithms in optical communication scenerio. Results demonstrates that great reduction in bit error rate and improvement in optical signal to noise ratio might be attained by utilizing FTRLS algorithm.

Index Terms: Chromatic Dispersion, Adaptive Equalization, LMS, RLS, FTRLS.

1. INTRODUCTION

Chromatic dispersion is an important factor in optical communication. A light wave is constituted of different colors or wavelengths. In optical communication systems, different wavelengths arrive at receiver at slightly different times. This makes signal spreading or dispersion. This dispersion reduces the information quality. Sometimes dispersion becomes so severe that it becomes very difficult to retrieve the information. Special attention is required to compensate this chromatic dispersion. Many techniques are in use to reduce the chromatic dispersion. We are here to discuss, some very efficient and simple chromatic dispersion compensation techniques using adaptive equalization. These techniques require some simple signal processing of optical signal and can be implemented easily. Adaptive filters are used for noise cancellation, echo cancellation, equalization etc[1] . In the last decade, the field of adaptive filtering has grown rapidly due to emerging technology for the implementation of the algorithms. However these signal processing techniques have not been properly exploited in optical communication systems. If we implement these signal processing techniques in optical communication systems we can achieve some great reduction in bit error rate and improvement in optical signal to noise ratio.

Adaptive filters provide a method to vary a signal iteratively with respect to a desired signal based on some algorithm. Adaptive filters consist of two basic procedures: filtering and adaptive process [1].

Adaptive filters have a significant role in improving signal integrity and overall system performance in the domain of optical communication. By adaptive filtering, the iterative process adapts the signal with respect to a predefined algorithm continuously. The main purpose is to align the received signal with some predetermined reference signal. This filter can be optimized by means of repetitive adjustment to different situations or settings. Adaptive filtering implies dynamic adjustments that depend on changes of inputs. Channel effects, noise and dispersion are impairments that may cause distortions which adaptive filters are able to effectively mitigate through continuous updating of filter coefficients. This makes it possible for signals being transmitted robustly even in challenging environments where adaptation is important. There are challenges that optical communication systems have to grapple with at any given time or another. One serious challenge is chromatic dispersion that occurs when different wavelengths reach the receiver at slightly different times. Signal quality reduction due to this dispersion leads information loss. All these problems can be solved using adaptive filters as powerful tools. Through equalizing signals and changing their behavior dynamically, we will greatly improve reliability and performance of optical communications systems because it becomes possible now to do so effectively by equalizing signals and altering their behavior dynamically through them now allowing us do such things well resulting into highly reliable communications upon them now whereby doing so improves them so much.

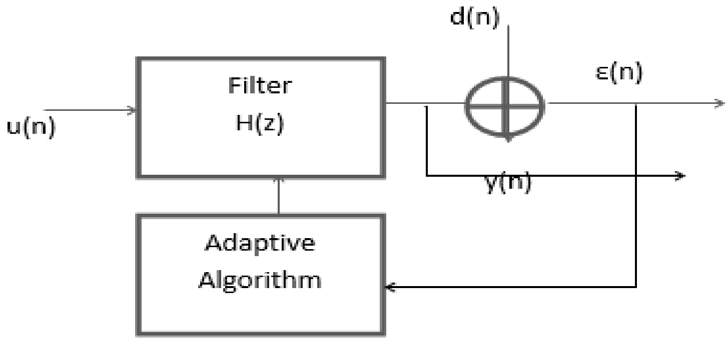

Figure 1

2. ADAPTIVE FILTER ALGORITHMS

A. *Least Mean Square Algorithms*[2]

Least square algorithms, on the other hand, provide minimum squares of mean errors. The difference between the desired signal and the actual signal is called the error signal(fig.1). Filtering includes computing the output of a linear filter in response to an input signal and comparing this output with a desired one to create a possible error between them.

$$\varepsilon(n)=d(n)-y(n) \qquad (1)$$

where y(n) = output signal, d(n)=desired signal ,

ε (n)=error signal, u(n)=input signal.

LMS adaptive process is the filter parameter which automatically adjusts in relation to error estimation.

$$w(n+1)=w(n)+\mu*\varepsilon(n)*u(n) \qquad (2)$$

where μ=step size, w(n)=coefficient vectors.

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B. *Recursive Least Squares (RLS) Algorithm* [2]

The recursive least square algorithm recursively minimizes a cost function based on a weighted linear least square for the input signals, a situation contrary to least mean squares (LMS) where it tries to minimize the mean square error.

Calculate the filter output:

$$y(n)=w(n-1)u(n) \quad (3)$$

Calculate the error signal:

$$\in(n)=d(n)-y(n) \quad (4)$$

Calculate the Kalman gain:

$$K(n)=\frac{\lambda^{-1}p(n-1)u(n)}{1+\lambda^{-1}u^{H}(n)p(n-1)u(n)} \quad (5)$$

Update the cross correlation vector: $p(n)=\lambda^{-1}p(n-1)-\lambda^{-1}K(n)u^{H}(n)p(n-1)$ (6)

Update the coefficient vector of filter:

$$w(n)=w(n-1)+K(n)\varepsilon^{*}(n) \quad (7)$$

where K(n)=kalmain gain vector, λ =forgetting factor, ε=error signal, u(n)=input signal, d(n)=desired signal, p(n)=cross correlation vector, w(n)=coefficient vector.

C. *Fast Transverse Recursive Least Square algorithm* [3]

The future guessing sliding filter calculates the frontward filter weightings so as to minimize the forecast errors (in least squares terms) of the adjacent input samples. The past prediction sliding filter computes previous filters weights that minimizes the forecast error (in least square sense). Gain computation sliding filter recursively determines gain vector for updating forward, backward and joint process estimation filtering weights. In this way, joint-process estimation transversal filter determines its Filters values such that they minimize how inaccurate the predictive signal is from' d(n)'.

D. *Feed Forward Equalization*

Among the most notable obstacles that information faces when it passes through communication channels is the inter-symbol interference (ISI). The damaging effects of ISI can impair signal quality leading to error in data reception. Feed-Forward Equalization (FFE) comes to the rescue; this technique is strong enough to solve these issues and improve performance of a communication system.

Another fascinating aspect of FFE is that it can adapt in real-time. Channel conditions change frequently in dynamic communication environments, such as fading, noise and interference. It quickly changes its equalizations strategies according to new channel status for instance multipath fading or sudden variations. This way, FFE does not compromise continuity even when there are dramatic changes which support consistent performance hence enhancing dependability during data transfer process.

The main idea behind FFE's effectiveness is that it makes use of learning algorithms such as the Least Mean Squares (LMS) algorithm. This is done by continuously adjusting its equalization coefficients with respect to feedback received, hence minimizing bit error rates (BER). This process of adaptive learning ensures that the system can adapt to varied channel conditions leading to optimization of BER and enhanced overall reliability.

What keeps communication systems up and running? The role played by FFE in this area is substantial because it compensates for channel impairments such as dispersion, attenuation, and phase distortion. By keeping the signal quality at optimum levels, FFE guarantees that the system operates within certain bounds. Be it wired or wireless network settings; stability forms the foundation on which effective communication lies.

A Resource-Saving Paradigm In a world where bandwidth is gold, FFE comes out as a means of efficiency booster. By minimizing ISI-induced errors, FFE reduces the need for expensive retransmissions as well as error correcting mechanism. As such it leads to more efficient utilization of available bandwidth and computational resources. For instance, when communication networks are faced with increasing demand for data transfer services, there will be no doubt about how important can be termed as efficiency gains from FFE.

E. *Decision Feedback Equalization*

Decision Feedback Equalization (DFE) is a powerful technique used to mitigate Inter-Symbol Interference (ISI) in communication systems. When symbols overlap and disturb one another, ISI takes place due to channel distortion of the signal. This overlap makes it difficult for the receiver to accurately decode the information. The received signal goes through a feedforward filter (FF), which is similar to a standard equalizer. This filter tries to compensate for the frequency response of the channel and reduce initial ISI. With reference to filtered output, DFE provides an early estimation or decision regarding transmitted symbols. Using the estimated symbols, DFE builds up a replica of previously removed feedforward filtered ISI.

This ISI replica then goes into a separate feedback filter (FB). Subtracting from original filtered signal the resulting FB output cancels out estimated ISI thus leading to cleaner symbol signals with reduced overlapping.

3. SIMULATION SETUP AND RESULTS

The basic simulation set up is shown in fig.3 and fig.4. A 10 Gbps pseudo random binary sequence signal is modulated using mach-zehnder modulator and then transmitted over various fibre length (30km,40km,50km). Signal is amplified in receiver side using erbium doped fibre amplifier (gain=5db). Then signal is detected by PIN photodetector. The detected signal is send into signal processing unit. Here decision feedback equalizer is implemented using adaptive filter algorithm. The DFE feedbacks the weighted sum of past decisions to reduce chromatic dispersion in present signal.

The decision feedback equalization is done using offline signal processing. Different algorithms (LMS,RLS,FTRLS) are implemented in DFE and values for BER and OSNR are taken. We further implemented FFE(Feed Forward Equalizer) in combination with DFE. Results at different fibre length are shown in table 1-3. Results shows that adaptive equalization with FFE-DFE using FTRLS shows best results. Plot of BER vs OSNR is also shown in fig. 5-8.

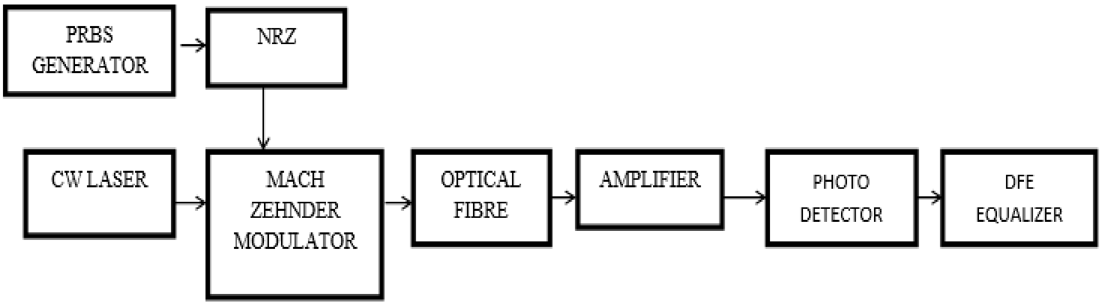

Figure 3: ***Distributed Feedback Equalizer layout***

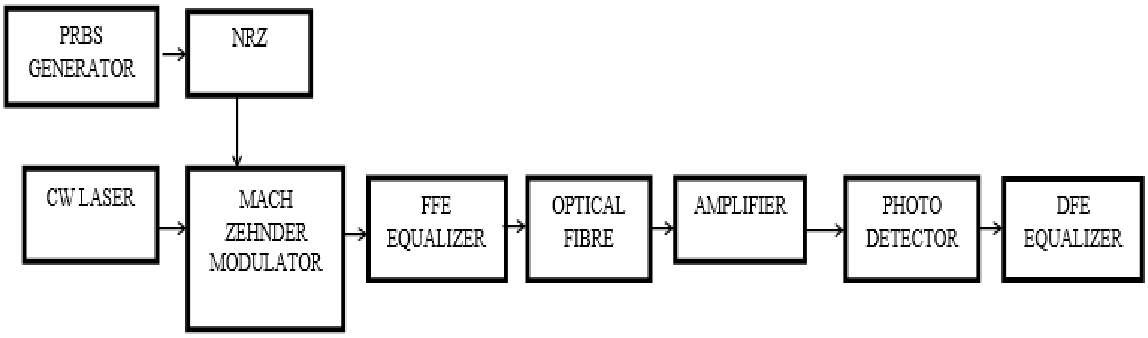

Figure 4: ***Feed Forward Equalizer layout***

Table 1: ***Measurements at 50km***

Layout	BER (without EDFA)	OSNR (without EDFA)	BER (with EDFA)	OSNR (with EDFA)
Direct Design	10e-05	34.073	9.27e-05	34.266
LMS	10e-05	34.108	9.27e-05	34.295
RLS	10e-05	34.125	9.27e-05	34.313
FTRLS	1.81e-05	37.765	1.18e-36	39.532
FFE	10e-05	34.123	9.27e-05	34.299
FFE-DFE (LMS)	10e-05	34.107	9.27e-05	34.276
FFE-DFE (RLS)	10e-05	34.135	9.27e-05	34.322
FFE-DFE (FTRLS)	1.81e-05	37.792	6.39e-37	39.704

Table 2: ***Measurements at 40km***

Layout	BER (without EDFA)	OSNR (without EDFA)	BER (with EDFA)	OSNR (with EDFA)
Direct Design	1.96e-28	37.276	3.87e-29	37.369
LMS	1.96e-28	37.277	3.87e-29	37.367
RLS	1.96e-28	37.299	3.87e-29	37.385
FTRLS	2.91e-68	38.122	1.74e-20	38.468
FFE	1.96e-28	37.282	3.87e-29	37.382
FFE(LMS)-DFE(LMS)	1.96e-28	37.338	3.87e-29	37.434
FFE(LMS)-DFE(RLS)	1.96e-28	37.276	3.87e-29	37.384
FFE(LMS)-DFE(FTRLS)	4.60e-66	38.542	1.57e-27	38.665

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Table 3: *Measurements at 30km*

Layout	BER (without EDFA)	OSNR (without EDFA)	BER(with EDFA)	OSNR (with EDFA)
Direct Design	4.47e-08	35.761	5.01e-08	35.941
LMS	4.47e-08	35.800	5.01e-08	35.981
RLS	4.47e-08	35.803	5.01e-08	35.987
FTRLS	9.09e-13	38.179	3.72e-26	38.998
FFE	4.47e-08	35.800	5.01e-08	36.000
FFE-DFE (LMS)	4.47e-08	35.802	5.01e-08	35.990
FFE-DFE (RLS)	4.47e-08	35.813	5.01e-08	35.997
FFE-DFE (FTRLS)	5.09e-08	38.941	3.58e-20	38.595

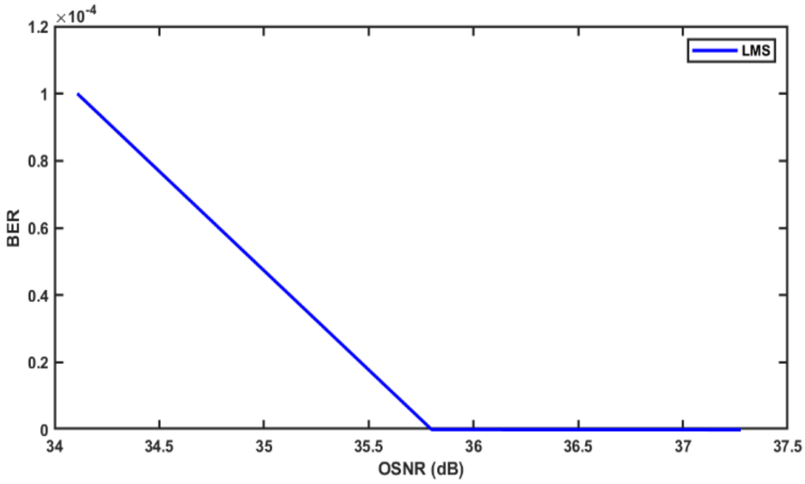

Figure 5: BER vs OSNR for LMS using DFE

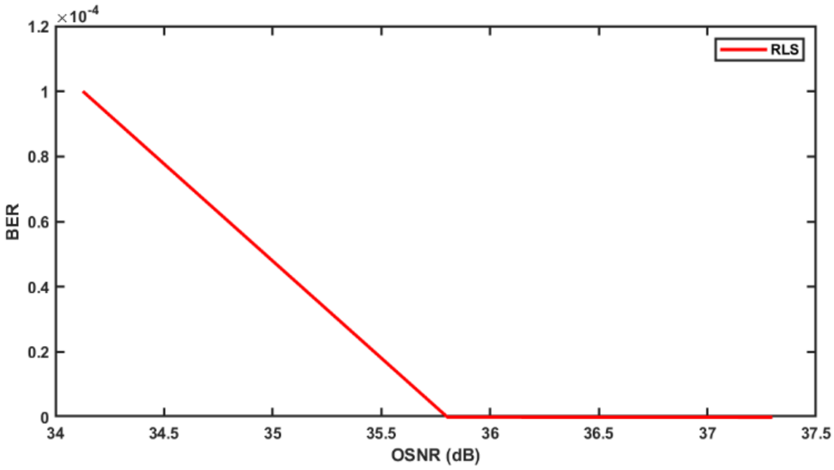

Figure 6: BER vs OSNR for RLS using DFE

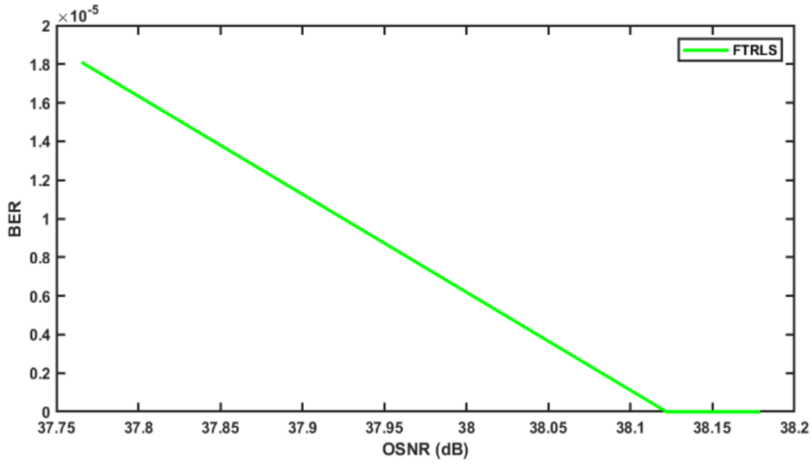

Figure 7: BER vs OSNR for FTRLS using DFE

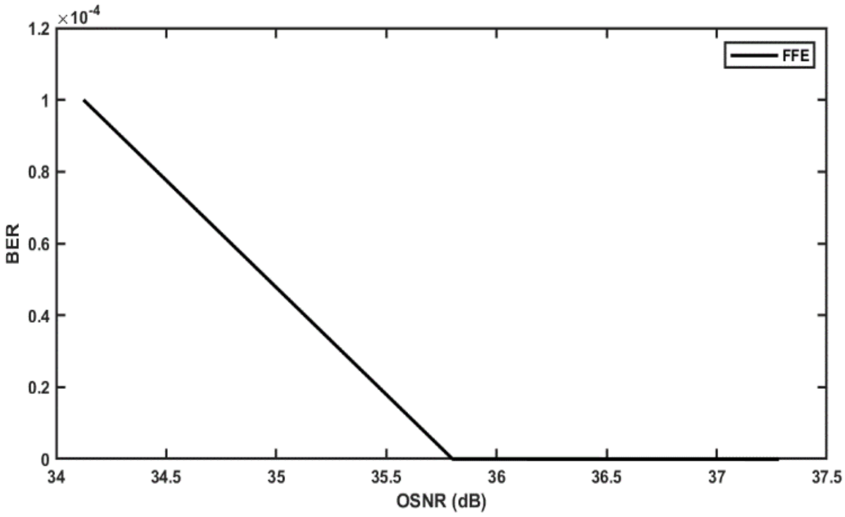

Figure 8: BER vs OSNR for FFE using DFE

Least Mean Square (LMS), Recursive Least Squares (RLS), and Fast Transversal Recursive Least Squares (FTRLS) algorithms were applied to Decision Feedback Equalization (DFE) techniques in order to assess their performance in terms of Bit Error Rate (BER) and Optical Signal-to-Noise Ratio (OSNR) at different fiber lengths. At a fiber length of 50 km, the LMS algorithm attains a BER of 9.27 x 10^{-5} and an OSNR of 34.295 dB at an EDFA gain of 5dB. Similarly, the same BER is maintained by RLS while its OSNR slightly improves to 34.313 dB. In contrast, in FTRLS significant performance enhancements are realized resulting in a BER value as low as 1.18x 10^{-36} and an OSNR of about 38.468 dB, which proves higher values for OSNR but very small values in regard to BER compared with LMS or RLS solutions. Moreover, when embedded within Feed Forward Equalization (FFE) and DFE, the FTRLS algorithm can further push this performance matrix down to a minimally low BER value of 6.39 x 10^{-37} while having an OSNR value hovering around 38.665 dB. Moreover, we have also indicated what the bit error ratio is for both fiber lengths of thirty kilometers as well as that one for forty kilometers that basically confirm adaptive filtering on optical signals using the combination together with adaptive filters that uses FFE - DFE coupled with FTRLS being the most optimal strategy aimed at minimizing bit error rate.

4. CONCLUSION

The fibre length limited by chromatic dispersion is given by:

$$L < \frac{2\pi c}{16 D \lambda^2 B^2}$$

B is bit rate. When D=16 psnm^{-1}km^{-1} and at 2.5 Gbps, L ≈ 500km, whereas it drops to 30 km at 10 Gbps bit rate. In following section we have shown that at 50km, using 10 Gbps bit rate, we can achieve very low bit error rate and high OSNR using adaptive equalization techniques. Chromatic dispersion is a serious issue in long distance fibre communication. Sometimes it makes very difficult to retrieve the transmitted information by receiver. The proposed method is very useful in reducing the bit error rate and enhancing optical signal to noise ratio. Thus we can compensate the chromatic dispersion using these techniques. We also observed that FTRLS technique with FFE-DFE is better than LMS and RLS techniques.

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