Database Based Phase Noise Compensation in CO-OFDM Transmission

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ABSTRACT

In this paper, a new approach of establishing database to estimate phase noise due to chromatic dispersion is proposed. The database can be used to compensate phase shift without using any pilot carriers, which results in high spectral efficiency and low BER. Time variability, temperature and aging effects of channel are introduced in order to ensure the suitability of the database for stable long term performance. The proposal is confirmed by simulation using matlab.

Key words: Orthogonal Frequency Division Multiplexing (OFDM), Phase Estimation, Chromatic Dispersion (CD).

1. INTRODUCTION

It is important to investigate the optical phase noise impact due to fiber linear and nonlinear effects and establish the optimal approach to estimate the phase evolution of OFDM signals in order to ascertain its suitability for optical transmission. Many dispersion compensation techniques have been proposed and demonstrated. Pilot aided and data aided proposals have already proved themselves as successful phase estimation methods. Adaptive tracking scheme that reduces the effect of laser phase noise and consequently relaxes the laser linewidth requirement has been proposed [1]. The impact of system nonlinearity on the OFDM symbol can be moderated by partially filling the OFDM spectrum, or assigning zero values to particular OFDM subcarrier [2]. As a result gathered spurious components generated by fiber nonlinearity, four wave mixing will be located in the unfilled (zero) subcarriers, which will have no impact on the filled (data) subcarriers. Method of dividing the subcarriers in groups and allocating different pilot for different groups is also presented. A common problem with bandwidth requirement is associated with all these methods.

Here in this paper we have investigated phase shift due to different subcarrier frequencies considering chromatic dispersion and finally established a database to compensate the phase noise. As it does not require any pilot carriers, it will eventually relax the bandwidth requirement. And if the database is perfectly acquired including time variability and aging effects of fiber channel it will show drastic improvement in the BER performance also.

2. THEORETICAL BACKGROUND

Due to fiber linear and nonlinear effects received CO-OFDM symbols will be affected by phase noise. We want to find out the optimum way to improve the BER performance as well as bandwidth efficient. To implement our proposed concept which is described in the next section it is important to know the dependency of this phase noise on different subcarrier frequencies and channel characteristics. Now if $h'_{ki}$ is the frequency response of the fiber including chromatic dispersion, PMD and PDL effects, it can be expressed as [3]:

$$h'_{ki} = e^{j\Phi_{Dki}} \prod_{p=1}^{M} \exp \{-(1/2 \cdot j \cdot \frac{\pi}{2 f_{p} f_{k}} + \frac{1}{2} \cdot \alpha_p) \cdot \sigma \}$$

$$\Phi_{Dki} = \pi \cdot c \cdot D \cdot \frac{f_{k}^2}{f_{LD}^2} \ldots (1)$$

Where, $\Phi_{Dki}$ is the phase shift due to the chromatic dispersion, $f_k$ is the frequency for the $kth$ subcarrier, $D$ is the total chromatic dispersion assuming quadratic dependence on frequency, $f_{LD}$ is the centre frequency of the transmit/receive laser. Here we see the phase shift due to channel characteristics has a relation with subcarrier frequency.
frequency. Phase shift due to Chromatic Dispersion has a quadratic relation with subcarrier frequency. So, if we want to estimate phase noise we need to concentrate on this subcarrier frequency where phase shift due to CD will be less in initial subcarriers and will increase quadratically with the increment of subcarrier frequency.

3. PROPOSED CONCEPT

Phase estimation using pilot carriers is already an established method. In our previous works we showed that, dividing the subcarriers in groups and allocating different pilot for different groups gives better result in terms of BER than considering the pilot carriers over all subcarriers. But still bandwidth requirement is not relaxed. Here we propose to build up a database which will be used to compensate the noise without any pilot carriers. We already found, phase shift due to CD has a quadratic relation with subcarrier frequency. As it will be known how many subcarriers are used in the CO-OFDM transmission, we can predict the phase noise associated with each of the subcarrier frequency and generate the database which can be stored in the receiving side to compensate the noise.

Due to interaction in the non linear optical medium there will be introduction of undesired photons known as four wave mixing. The more the interactions the more interference will occur resulting in a high BER. Suppose we are using four subcarriers in an OFDM symbol. There will have sixteen possible combinations of phases with these four subcarriers. Now if we can find out the phase responses of these sixteen combinations we can take necessary actions in the receiver to eliminate the noise. But practically the no. of subcarriers will be large. Suppose for 128 subcarriers there will be huge no. of combinations. Still it will not be a problem as the estimation of phase response has to be done once and this will be stored in a database for further use. This will be highly bandwidth efficient as there is no need of pilot carriers or carriers for partial filling. There may be a simple approach to estimate the phase noise. In case of a Wide Area Network (WAN) system where several routers are involved, if we use all the subcarriers as pilot once and estimate the phase change then this can be stored in the servers associated with the routers and will be used later. Necessary actions can be taken when actual information carrying sub carriers reach the router. Because it already knows from which router its coming and what is the phase noise associated with this.

4. SIMULATION RESULTS AND DISCUSSION

We applied matlab simulation to a 1000 km CO-OFDM transmission with QPSK modulated 512 subcarriers. The acquired traces are processed according to the theory and proposal in section 2 & 3. The simulation can be divided into three parts. In the first part relation between CD and subcarrier frequency is presented. Next the phase shift due to CD is removed using database. Lastly, comparison in BER performance between the concept of database and previously proposed pilot carrier is discussed.

Part A: Increment in subcarrier frequency will increase phase shift due to chromatic dispersion which is obvious from Figure 1 where chromatic dispersion has been considered as 16 ps/nm-km. It explains, to achieve same BER, SNR has to be increased in high frequency subcarriers and vice versa. For example, to achieve 10^-4 BER, 17 dB SNR is required for the 1st subcarrier, where in case of 500th subcarrier, to achieve the same BER, 22 dB SNR is required.

![Figure 1: BER Vs SNR for different subcarrier frequencies. It explains increment in subcarrier frequency will increase phase shift due to Chromatic Dispersion.](image-url)
Figure 2(a): BER Vs SNR without compensating CD, after removing CD applying database and without considering CD. We achieve sufficient improvement in BER with this approach of implementing database to estimate phase shift.

Figure 2(b): Constellation Diagram with Chromatic Dispersion. Due to phase shift the points have been scattered.

Part B: Due to the presence of CD, BER will be high. If CD is not considered, BER will be much less compared to the previous, which is reflected in figure 2(a). It shows 11dB SNR is required to achieve $10^{-4}$ BER without CD but 18 dB is required if CD is considered. Now to remove the phase noise caused by CD, we established a database. The phase shift associated with the different subcarrier frequencies was included in it. Necessary information to avoid the noise was taken from the database without using any pilot carriers. The simulation result shows the BER graph is quite similar if the phase shift due to CD is not considered and if it is compensated using database. Figure 2(b) is the constellation diagram with CD noise. And figure 2(c) is the same constellation diagram after compensating the noise with our proposed concept. Minimized scattering reflects the improvement in phase estimation clearly.

Part C: Here we have compared the suitability of phase estimation between our proposed concept and a previous concept of using pilot carriers. We see a better BER performance using database than pilot carriers. For example, figure 3 shows 12 dB SNR is required to achieve $10^{-4}$ BER, but the same BER is achieved by 11dB of SNR. Again it will be bandwidth efficient as there is no requirement of sending any pilot carriers. So compensation using a proper database will be better in BER performance and bandwidth requirement.
Figure 2(c): Constellation Diagram After removing Chromatic Dispersion. It reflects the improvement in phase estimation as the scattering has been minimized.

Figure 3: BER Vs SNR without compensating CD, after removing CD using pilot, after removing CD applying database and without considering CD. This new method of implementing database is showing better performance compared to pilot carriers.

5. TIME VARIABILITY, TEMPERATURE AND AGEING EFFECTS OF FIBER CHANNEL

To enable higher stability, reconfigurability, and flexibility in a self-managed optical network it is obvious to observe time variability, temperature and ageing effects. This scenario is quite challenging for higher capacity systems, since network paths are not static and channel-degrading effects can change with temperature, component drift, aging, and fiber plant maintenance [6]. Basic changes, such as temperature changes, component aging, and plant maintenance, will all have an effect on the physical properties that impact the integrity of data channels. CD is significantly more important for ≥ 40-Gbit/s systems than for lower-rate systems as its effect increases with the square of the bit-rate increase. Due to repair and maintenance, the link length or fiber type itself may change. Moreover, CD has a temperature dependence that causes a change in net link dispersion. Again the exposure of an optical fiber to hydrogen has the potential to change the fiber’s performance in several ways. Hydrogen ageing which arises due to the absorption of light by various species in glass results in a finite attenuation increase over the remaining service life of the fiber [7]. Regarding the impact of hydrogen ageing on reduced or low water peak fiber, strict attention needs to be paid while establishing the database in order to ensure stable long term performance.
6. CONCLUSION

SNR of 12dB is required to achieve 10^-4 BER if conventional method of pilot carrier is used to estimate the phase shift where 11dB is enough to achieve the same BER implementing our proposed method. The constellation diagram is still scattered as other dispersion and non linear effects are not compensated here. Again the time variability, temperature and aging effects are discussed but not included in the simulation. Method to minimize these effects will be focused in our future works.

REFERENCE

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