

Performance Improvement in Optical CDMA System Under The Presence of Beat Noise Using a Cancellation Method

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Abstract: This paper presents performance improvement in optical CDMA system under the presence of beat noise using a cancellation technique. Optical fibers and atmospheric optical communications have been proposed the connection between base stations and central station. The optical signal beat noise is due to interference between lightwave, many optical waves are simultaneously incident on each receiver photodiode. Since the photodiode acts as a square-law detector, beat noise can occur in the receiver. While A two-stage cancellation technique is analyzed and verified via simulation employed here because of its system simplicity. By using the random ingredients of all user signals are estimated, the beat noise is rebuilt and removed from the intended signal. In addition to cancellation technique cancel the inherent multiuser interference (MUI) in CDMA system and nonlinear distortion (NLD) in optical system. It is performed at the receiver of the central station where the random ingredients of all user signals are estimated and the MUI and the NLD are rebuilt and removed from the received signal. The validity of the cancellation technique is theoretically analyzed and shown by numerical results. The increasing of capacity in two stage cancellation are obtained.

Keywords: Optical CDMA, beat noise, multiuser interference(MUI), nonlinear distortion(NLD)

1. INTRODUCTION

Code division multiple access (CDMA) application for microcellular mobile radio system has been proposed [1],[2]. It is well known that CDMA has the advantages in terms of the large user capacity, the effective utilization of frequency and immunity to multipath fading. In microcellular system, a great number of base stations (BSs) are required where compared with conventional system. For low cost and simplicity, optical fibers and atmospheric optical communications have been proposed as connecting between BSs and central base station (CBS) [3]. Here, each BS consists of a laser diode and a photodiode is employed out an electric-to-optical converter for the signals from CBS to mobile station (MS) and an optical-to-electric converter for the signal from MS to CBS.

The capacity of CDMA scheme is directly limited by the inherent multiuser interference (MUI) of CDMA signals. Since the MUI is not completely random, to fully exploit the CDMA capacity, many studies have been carried out on receiver structures that are capable of canceling the MUI [4]. By using a multiuser and multi-stage detection in the receiver, the random ingredients of all user signals are estimated, and the MUI is rebuilt and removed from the intended use signal [7]. Meanwhile, multiple signals via optical link may cause a severe nonlinear distortion (NLD) stemming from the limited region where laser diode can be linearly modulated by the injected current signal. Hence, in addition to MUI, the capacity of microcellular radio CDMA system using optical link is reduced by NLD. A conventional method to minimize the NLD is realized by optimizing the modulation index.

The optical signal beat noise is due to interference between lightwave, many optical waves are simultaneously incident on each receiver photodiode [8]. Since the photodiode acts as a square-law detector, beat noise can occur in the receiver. The beat noise in contrast to the foregoing additive shot noise, has a multiplicative character.

A cancellation technique for microcellular CDMA system using optical link. A two-stage cancellation technique which is analyzed in and verified via simulation is employed here because of its system simplicity. In asynchronous CDMA a desired data bit is disturbed by the interference from two bits from all other users. By a multiuser and multi-stage detection, a first stage cancellation is used to effectively remove half the

interference power from the first bits of all other users. With the good performance of the first stage, one more stage is enough to remove the remaind interference. Differing from the previous studies, here the cancellation technique is first used to cancel both the MUI and the NLD. The nonlinearity of optical link by a memoryless third-order polynomial, the system performance is theoretically analyzed and the numerical results are given. It is shown that using only the MUI cancellation is not sufficient for CDMA signals in a nonlinear channel. The best system performances are obtained by selecting an optimal modulation index after the cancellation of the MUI and NLD.

2. MICROCELLULAR OPTICAL CDMA

The block diagram of microcellular radio CDMA system in optical link is shown in Fig. 1. There are a total K users in the cell and the k th transmitter generates data signal, $d_k(t)$ at a rate of $1/T_b$ and spreading signal, $c_k(t)$ at a rate of $1/T_c$. The ratio of T_b/T_c is the system processing gain, N . The transmitted signal of each mobile station using a binary phase shift keying (BPSK) as

$$s_k(t) = d_k(t - \tau_k) c_k(t - \tau_k) \cos(\omega t + \phi_k) \quad (1)$$

where ω is the angular frequency, and τ_k is the k th user's transmitter time delay. Moreover, we set $\tau_k \in [0, T)$ for all k and ϕ_k its phase offset uniformly distributed in $[0, 2\pi)$.

The nonlinearity of laser diode (NLD) can be represented by the third-order polynomial [5]

$$P(t) = P_o [1 + S(t) + A_2 S^2(t) + A_3 S^3(t)], \quad (2)$$

where

$$S(t) = m \sum_{k=1}^K s_k(t) \quad (3)$$

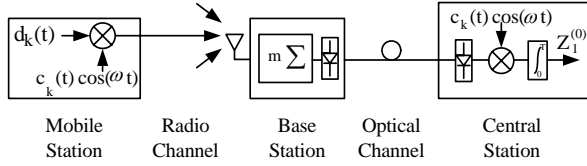


Fig.1 Microcellular Optical CDMA

Where $P(t)$ is the output optical power modulated by the current signal S , P_o is the transmitted average optical power, m is the modulation index and A_2 and A_3 are the constants. For an ideal laser diode (LD), A_2 (the 2nd order Intermodulation Distortion (IMD)) and A_3 (the 3rd order IMD) are zero. For a practical NLD, A_2 and A_3 are non-zero, rather, A_2 induces the zero and double frequency components, and A_3 induces the common and triple frequency components. Since in the case of CDMA, the harmonic of 3rd order intermodulation term influences the system performance, thus A_2 is disregarded, simplifying Eq. (2)

The optical output of the laser diode is sent to a CBS via an optical channel that may be an optical fiber. At the CBS, the optical signal is converted to a photo-current by a photodiode. Ignoring the optical power loss of the optical channel, the photo-current is represented as

$$i(t) = \eta P(t) + n_{op}(t) \quad (4)$$

where η is the photodiode responsivity, and $n_{op}(t)$ is the optical device noise consisting of relative intensity noise of laser diode, I_{LD} , shot noise, I_{shot} , and thermal circuit noise, I_{th} , and is modeled as a zero-mean Gaussian random variable with the power spectral density function (pdf)

$$N_{op} = \langle I_{LD}^2 \rangle + \langle I_{shot}^2 \rangle + \langle I_{th}^2 \rangle + \langle I_{beat}^2 \rangle, \quad (5)$$

where the nonlinear effect, at the transmitter, LD output has intensity fluctuation and also at the receiver, there are shot noise and thermal circuit noise being presented by [6]

We assume in our investigation that all light sources are semiconductor lasers which have identical Gaussian distribution in the long term due to frequency uncertainties and instabilities. Beat noise power at the receiver output assessed by considering the following observations. The optical beat noise power is given by [8]

$$\langle I_{beat}^2 \rangle = \frac{(\eta R_{PD})^2 W}{2\sigma\sqrt{\pi}} \left(2(K-1)P_w P_l + (K-1)(K-2)P_l^2 \right) \quad (6)$$

where W is the signal bandwidth, η is the photodiode responsivity, R_{PD} is the transimpedance of amplifier, P_o is the optical power at the receiver, the intending user contributes average optical power $P_w = P_o/4$ whereas each interfering user contributes average optical power of $P_l = P_o/8$ [8].

To demodulate the received signals, the signature code

replica of the intended user is locally generated at the receiver. It is assumed that the user one is intended at the receiver. With an idea of carrier phase and the code phase, the local carrier and code are multiplied to the photo-current and the output integrated over one bit duration to produce a signal for threshold comparison as

$$Z_1^{(0)} = \int_0^T i(t) c_1(t) \cos(\omega t) dt \quad (7)$$

3. WITHOUT CANCELLATION TECHNIQUE

The third-order term of NLD for the k th mobile stations sum of signal. Using the following relationship

$$\begin{aligned} \left[\sum_{k=1}^K x_k \right]^3 &= \sum_{k=1}^K x_k^3 + 3x_1^2 \sum_{k=2}^K x_k + 3x_1 \sum_{k=2}^K x_k^2 \\ &+ 3 \sum_{\substack{j=2k=2 \\ k \neq j}}^K \sum_{k=2}^K x_j^2 x_k + 3x_1 \sum_{\substack{j=2k=2 \\ k \neq j}}^K \sum_{k=2}^K x_j x_k \\ &+ \sum_{\substack{j=2 \\ j=2k=2 \\ j \neq i \neq j}}^K \sum_{k=2}^K \sum_{k=2}^K x_i x_j x_k \end{aligned} \quad (8)$$

Since the zero frequency, the double frequency and triple frequency components can be eliminated from the signal component, $Z_1^{(0)}$ can be represented as

$$Z_1^{(0)} = D_1 + \sum_{i=1}^6 I_i + N_{op} \quad (9)$$

The desired signal D_1 as

$$D_1 = \frac{\eta m P_o T}{2} d_o^{(i)} \quad (10)$$

The interference I_i ($i=1,2,\dots,6$) are represented in [7]. The average signal-to-noise ratio (SNR) as

$$SNR = \frac{1}{4} (\eta m P_o)^2 / \left[\sum_{i=1}^6 \langle I_i^2 \rangle / T^2 + N_{op} W \right] \quad (11)$$

where

$$\langle I_1^2 \rangle = \frac{(\eta P_o T)^2}{4} \left[\frac{A_3 m^3 (6K-3)}{4} \right]^2 \quad (12a)$$

$$\langle I_2^2 \rangle = \frac{(\eta P_o T)^2 (K-1)}{8} \left[\frac{A_3 m^3}{4} \right]^2 \quad (12b)$$

$$\langle I_3^2 \rangle = \frac{(\eta P_o T)^2}{24N^3} \left[m + \frac{6KA_3 m^3}{4} \right]^2 \sum_{k=2}^K r_{k,1} \quad (12c)$$

$$\langle I_4^2 \rangle = \frac{3(\eta P_o T)^2 (K-2)}{8N^3} \left(\frac{3A_3 m^3}{4} \right)^2 \sum_{k=2}^K r_{k,1} \quad (12d)$$

$$\langle I_5^2 \rangle = \frac{15(\eta P_o T)^2}{8N^4} \left(\frac{A_3 m^3}{4} \right) \sum_{j=2}^K \sum_{\substack{k=2 \\ \neq j}}^K r_{j,k} \quad (12e)$$

$$\langle I_6^2 \rangle = \frac{3(\eta P_o T)^2}{80N^5} \left(\frac{A_3 m^3}{4} \right)^2 \sum_{i=2}^K \sum_{\substack{j=2 \\ \neq i}}^K \sum_{\substack{k=2 \\ \neq i, j}}^K r_{i,j,k} \quad (12f)$$

With the discrete autocorrelation function of the k th user, as the number of the users is large, Gaussian assumption can be used for the interference according to central limit theorem. Hence, the error probability is given by

$$P_b(0) = Q\left(\sqrt{SNR_o}\right) \quad (13)$$

where "0" denotes the without cancellation, and

$$Q(x) = \frac{1}{\sqrt{2\pi}} \int_x^{\infty} e^{-t^2/2} dt, x \geq 0 \quad (14)$$

4. CANCELLATION TECHNIQUE

The desired data bits are disturbed by the interference from two bits from all other users [7]. The interference can be rebuilt and removed from the decision statistic of the user before the threshold comparison. In Fig. 2, the cancellation scheme of the multiuser and two-stage detection using in the paper are shown.

4.1 First-stage cancellation

For multiuser detection, the carrier phase and code phase of all users are known. The first-stage cancellation as shown in Fig. 2 rebuilds the interference due to $\{d_{-1}^{(k)}\} (k \neq 1)$ and removes it from $Z_1^{(0)}$. It is defined the first-stage estimates as

$$\hat{d}_{-1}^k = x_k d_{-1}^{(k)}, \quad (15)$$

where

$$x_k = \begin{cases} 1 & \text{with probability } 1 - P_b(1) \\ -1 & \text{with probability } P_b(1) \end{cases} \quad (16)$$

For $x_k = 1$, $\hat{d}_{-1}^{(k)} = d_{-1}^{(k)}$, the first-stage detection of the k th user is correct with a probability, $1 - P_b(1)$. Using the first-stage estimates $\hat{d}_{-1}^{(k)}$ as shown in Fig. 2, the interference of I_3 and I_4 in (12) are modified to be

$$\langle \hat{I}_3^2 \rangle = \frac{1}{2} [1 + 4P_b(1)] \langle I_3^2 \rangle \quad (17a)$$

$$\langle \hat{I}_4^2 \rangle = \frac{1}{2} [1 + 4P_b(1)] \langle I_4^2 \rangle \quad (17b)$$

where $\langle \hat{I}_i^2 \rangle = \langle I_i^2 \rangle$ for $i = 1, 2, 5$ and 6 .

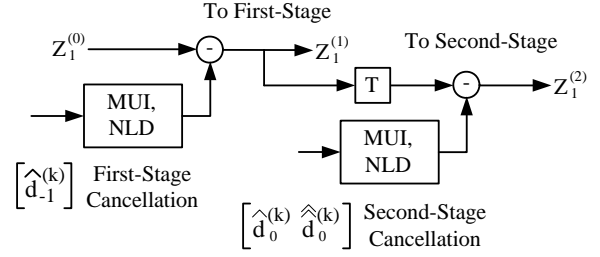


Fig.2 Block diagram of two stage cancellation for Optical CDMA

4.2 Second-stage cancellation

The second-stage for the bits $\{d_{-1}^{(k)}\}$ as shown in Fig. 2, the second-stage estimates, $\{\hat{d}_{-1}^{(k)}\}$ can be written as

$$\hat{d}_{-1}^{(k)} = y_k d_{-1}^{(k)}, \quad (18)$$

Where

$$y_k = \begin{cases} 1 & \text{with probability } 1 - P_b(2) \\ -1 & \text{with probability } P_b(2) \end{cases} \quad (19)$$

In (19) $P_b(2)$ is the error probability obtained from the second-stage cancellation. Using $\hat{d}_{-1}^{(k)}$, $\hat{d}_0^{(k)}$ the interference is rebuilt as the second-stage cancellation in Fig. 2. The interference terms are given as

$$\langle \tilde{I}_1^2 \rangle = 2P_b(1) \langle I_1^2 \rangle \quad (20a)$$

$$\langle \tilde{I}_2^2 \rangle = 2P_b(1) \langle I_2^2 \rangle \quad (20b)$$

$$\langle \tilde{I}_3^2 \rangle = 2[P_b(1) + P_b(2)] \langle I_3^2 \rangle \quad (20c)$$

$$\langle \tilde{I}_4^2 \rangle = 2[P_b(1) + P_b(2)] \langle I_4^2 \rangle \quad (20d)$$

where $\langle \tilde{I}_i^2 \rangle = \langle I_i^2 \rangle$ for $i = 5$ and 6 .

5. NUMERICAL RESULTS

In this section, we present the curves to compare the results of no cancellation, the first-stage cancellation and second-stage cancellation system. The parameters of the laser diode with a RIN intensity noise of -150 dB/Hz and output power of 2 mW have been chosen. The photodiode sensitivity is 0.8 mA/mW and the photodiode thermal noise is 5 pA/ $\sqrt{\text{Hz}}$, trans-impedance of amplifier $R_{PD} = 600\Omega$ for beat-noise. The processing gain is 127 is used for CDMA signal. Fig. 3 shows the error probability versus the modulation index m . The total number of users K is 20 and the received average optical power P_o is -40 dBm. For optimal modulation index

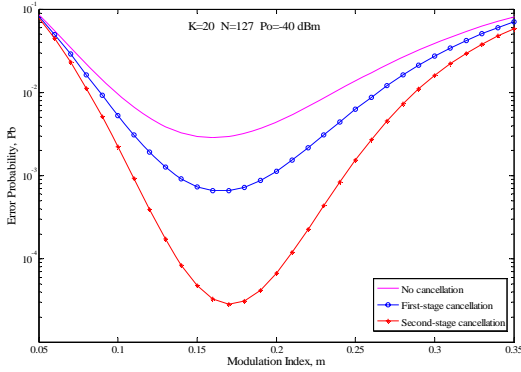


Fig.3 Error probability versus modulation index

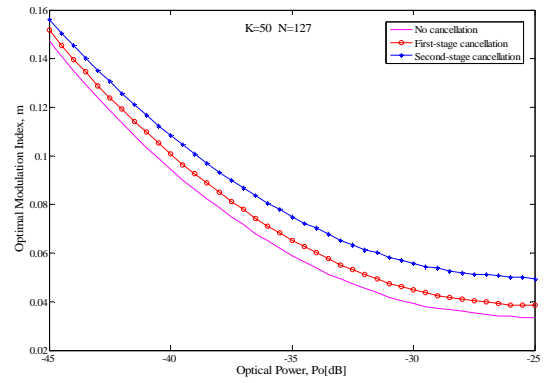


Fig.6 Optimal modulation index versus optical power

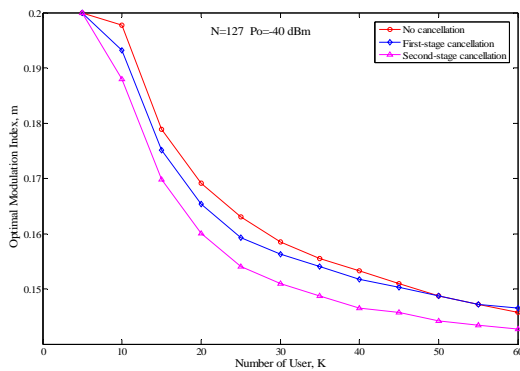


Fig.4 Optimal modulation index versus the number

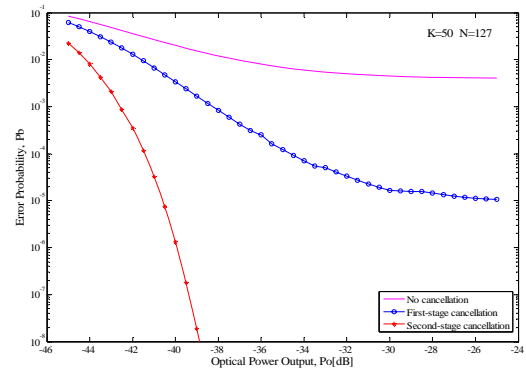


Fig.7 Error probability versus the optical power with optimal modulation index

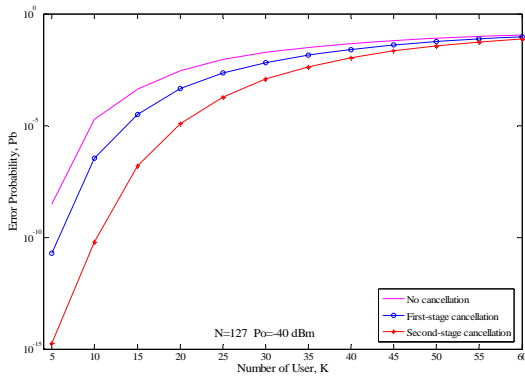


Fig.5 Error probability versus the number of the users with optimal modulation index

equal to 0.17, the minimal error probability for no cancellation first-stage and second-stage cancellation are 5×10^{-3} , 9×10^{-4} and 5×10^{-9} , respectively. Higher and lower optimal modulation index value degrades the performance. The significant improvement of the performance is obtained by the use of the cancellation technique. Fig. 4 shows the relation of optimal modulation index and number of users. The larger number of user needs a small modulation index to reduce the nonlinear effect. For $K = 40$ case, the optimal modulation index is 0.14 that is smaller than 0.17 for $K = 20$ shown in Fig. 3.

Fig.5 shows the error probability as the number of users with an optimal modulation index. At the same error probability, the number of users increases largely by using the second-stage cancellation. For threshold error probability 10^{-3} gives number of users $K = 35$ for second-stage cancellation which greater than no cancellation gives number of users $K = 20$. Fig. 6 shows the relation of received optimal modulation index and optical power. The larger received optical power needs a small modulation index. Fig. 7 shows the error probability as the received optical power, the curves of no cancellation and the first-stage cancellation become flat as the optical power increase. It is also because of the effect of the MUI.

6. CONCLUSIONS

Two stage cancellation techniques is introduced into analysis of cancel beat noise to improved performance. Beat noise that occurs in the passband of receiver by consider amount of beat noise in a non-coherent system. It is performed at the receiver of the central station where the random ingredients of all user signals are estimated. This cancellation technique can cancel the inherent multiuser interference (MUI) in CDMA system and nonlinear distortion (NLD) in optical system. The validity of the system has been analyzed theoretically and shown by the numerical results. The second-stage cancellation offers performance greater than no cancellation about 10^{-2} of error probability for users. In case of LD nonlinearity it is necessary to select an optimal modulation

index that provides a minimum error probability. Optimal modulation index relate to the number of users and received optical power. While the larger number of user and received optical power needs a small modulation index. The results are useful for system design and performance analysis

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