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Design and Performance Analysis of an Optical CDMA System for 2-D Perfect Difference Codes Using Shifted Sine

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Abstract— **A Dynamic Optical Code Division Multiple. Access (DOCDMA) communication system for Two Dimensional (2-D) Perfect Difference codes using Shifted Sine Functions (SSFs) is proposed here. The performance analysis for this OCDMA system has been done. This system is modeled and analyzed taking into account Multiple Access Interference (MAI) or Multiuser interference (MUI), Thermal Noise and Phase Induced Intensity (PIIN) noise. The performance of this system is compared to that of a DOCDMA system using SSFs as functional codes, Noncoherent spatial / spectral OCDMA system with 2-D perfect difference codes and OCDMA system for 2-D M-matrices codes. The results show that the proposed system improves the bit error rate (BER) performance for large number of users. Furthermore, it is found that for low values of the effective power for each user, the BER performance improves manifold. So, BER can be kept to very low values for lower power levels and hence, the system is more robust.**

Keywords- Multiple Access Interference or Multiuser Interference (MUI), Optical Code Division Multiple Access (CDMA.), Optical fiber Communication Systems, 2-D perfect difference codes, 2-D M matrices codes, Shifted Sine Functions.

I. INTRODUCTION

Optical Code division multiple access (CDMA) system provide us the advantage of multiple access at a very high speed, since the bandwidth required for transmission is not a major problem.

Many configurations have been proposed for the OCDMA systems in the last two decades. In the early stages of the development of the OCDMA system, the system coded the incoherent pulses in time domain and recovered the data using taped delay lines [1]- [3]. But, special unipolar codes used here does not posses good correlation properties, and hence, systems performance is poor. In general, the performance of the OCDMA system is largely affected by MAI. Coherent systems have also been proposed which can use bipolar codes and eliminate MAI [4]-[9]. But, incoherent systems have gained prominence for their simplicity. Spectral Amplitude Coded (SAC) systems are also a class of system that uses incoherent technique. Though, the MAI can be canceled by using code sequences with fixed in-phase cross correlation, the system still have the PIN as the main parameter limiting the system performance. PIIN is the main source of noise, though some codes have been proposed to suppress it [10]-[16].

In this paper, we propose a novel transceiver structure for the implementation of a DOCDMA system aimed at improving the BER performance at low effective power levels for each user. SSFs [17] have been used as functional codes to modulate the spectral and the spatial codes obtained from 2-D perfect difference codes [18]. SSFs have been used to minimize the number of intersection points and, hence the time limitation decreases both the MAI and PIIN effect on the BER performance. 2-D perfect difference codes have been used because of the inherent MAI cancellation property [18] they posses. Since, the proposed system utilizes the advantage of SSFs and 2-D perfect difference codes, PIIN and MAI effect on the system performance can be minimized.

The rest of this paper is organized as follows. Section II describes the proposed system configuration in detail. The analytic result of the system performance is presented in Section 3. The simulation results are shown in Section 4 and a discussion is given in Section 5. Finally, conclusions are drawn in Section 6.

II. THE PROPOSED OCDMA SYSTEM CONFIGURATION AND DISCRIPTION

The binary data is used to modulate the broadband signal from the light source using ON-OFF keying (OOK) technique. A pulse is sent from the transmitter if the data bit value is “1”; otherwise, no power is transmitted. Therefore, the data is converted to broadband optical pulses. Then, these optical pulses are fed to the two sets of Fiber Bragg Gratings (FBGs) and the splitter for encoding.

Two specific 1-D perfect difference code sequences are chosen to generate each 2-D perfect difference codeword $A_{g,h}$ [19] i.e. X_g and $Y_{h.}$ One of them (1-1) perfect difference code sequences) is taken for spectral encoding and the spatial encoding [18].

Two sets of FBGs and splitters are used to perform spectral and spatial coding, respectively [18].

The encoder uses a fast Tunable Optical Filter (TOF) controlled with an electrical signal representing the functional code i.e. SSF. The spectral and spatial codes are modulated by the functional codes using Optical Multiplier. Signals transmitted from all synchronized users are mixed by star couplers.

At the receiver, the composite signal is decoded by a TOF that is matched to the TOF at the Transmitter end. Since, the TOFs of the decoder are synchronized in time with a phase shift related to the functional code for each one of them, the output of the decoder is therefore the signal that has the same phase shift with some interference noise at the points of intersections with other users. Two optical combiners and two balanced detectors are used in the last stage of each receiver. Two sets of FBGs and two p-i-n photodiodes are used in each of the balanced detector. The FBGs 1-4 of the balanced detectors have the same number of gratings in FBGs 1 and 3 is kept same but contrary to that in FBGs 2 and 4 so as to compensate for the different round trip delays of the matched spectral components.

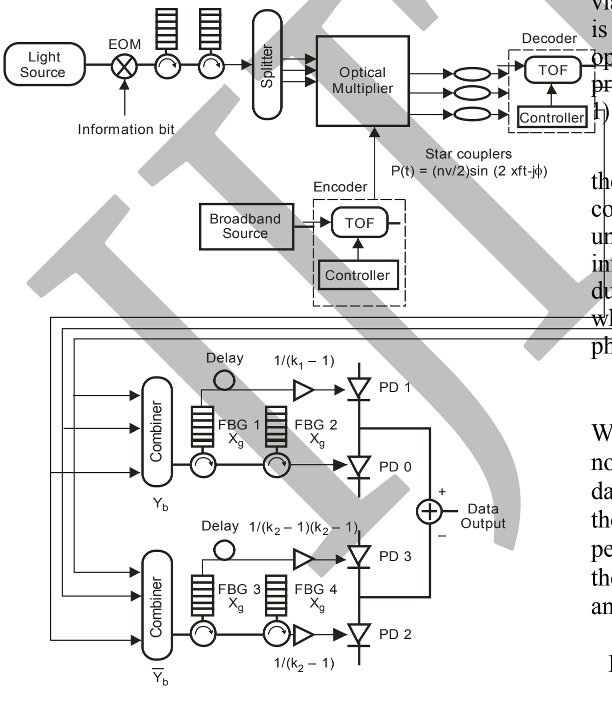

Figure 1. The proposed OCDMA system

The receiver structure of the transceiver (Fig.1) utilizes the MAI cancellation property of the 2-D perfect difference codes a has been explained in [18] and is given as

$$= \begin{cases} k1\,k2 & \text{for } g = 0 \text{ and } h = 0 \\ 0, & \textit{otherwise} \end{cases} \quad (1)$$

Where k_1 and k_2 are the code weights of me spectral and spatial code sequences, respectively, *g* and *h* are the cyclic code shifts of the two code sequences of 1-D perfect .

In order to remove interference caused by the transmitters using different spatial code sequences, the upper branch optical combiner only receives and combines the signals sent from the star couplers matched to "1s"of the spatial code sequence. Then, the received signals are fed to FBG1 of the upper balanced detector. As in transmitter, FBG1 of the upper balanced detector reflects back the spectral components matched to "ls" of the spectral code sequences and filter out the others. The matched portion is fed to the FBG2 of the upper balanced detector for delay compensation and then passed to PD0. The unmatched portion is fed to PD1 via a delay line and a 1/ (k_1-1) optical attenuator. The delays caused by FBGs 1 and 2 are compensated using a delay line. In order to obtain the interference information, the lower branch optical combiner only receives and combines the signals sent from the star couplers matched to "0s" of the spatial code sequence. The signals from the lower combiner are then passed to the FBG3, which can reflect back the spectral components matched to “1s” of the spectral code sequence. The reflected portion is fed to FBG4 for delay compensation and then passed to PD2 via a 1/ (K_2-1) optical attenuator and the other portion is fed to PD3 via a delay line and a 1/ (k_1-1) (K_2-1) optical attenuator. The output current of the receiver is proportional to [$R^{(O)}$(g, h)- $R^{(1)}$(g,h) / (k_l -1)-$R^{(2)}$ (g,h) / (k_2-1) + $R^{(3)}$(g,h)/ (k_l -1) (k_2 -1)][18].

Therefore, due to the MAI cancellation property of the 2-D perfect difference codes, the receiver can completely eliminate the interference from the undesired transmitters and recover the desired information bits. Also, PIIN can be suppressed further due to the use of three optical attenuators in receiver which lower the interference power inputted to the photodiodes.

III. PERFORMANCE ANALYSIS

We consider the PIIN, as well as shot and thermal noises in the photodiodes. The effect of the receiver's dark current is neglected. Since, SSFs are modulating the spectral and spatial codes obtained by the 2-D perfect difference codes using an optical multiplier, the BER can be approximately estimated from [17] and [18] as

$$\text{BER} \approx (0.5\ \text{erfc}\ (\sqrt{\text{SNR}}(k)/2)).(0.5\ \text{erfc}((\sqrt{\text{SNR}}/8)) \quad (2)$$

Where *k* is the no. of simultaneously active users.

IV. SIMULATION RESULT

A MATLAB code has been written to compare the performance of DOCDMA system using SSFs as functional codes, Noncoherent spatial/ Spectral OCDMA system with 2-D perfect difference codes and OCDMA system for 2-D *M*-matrices codes. Parameters used for simulation are as follow:

TABLE I. PARAMETER USED FOR SIMULATION

PD quantum efficiency W =0.6	W =0.6
Spectral width of broadband light source	IX=30nm(i.e. If =3.75 THz)
Wavelength location	1.55µm
Electrical Bandwidth	320 MHz
Receiver Noise Temperature	300K
Receiver load resistor RL	1030Ω

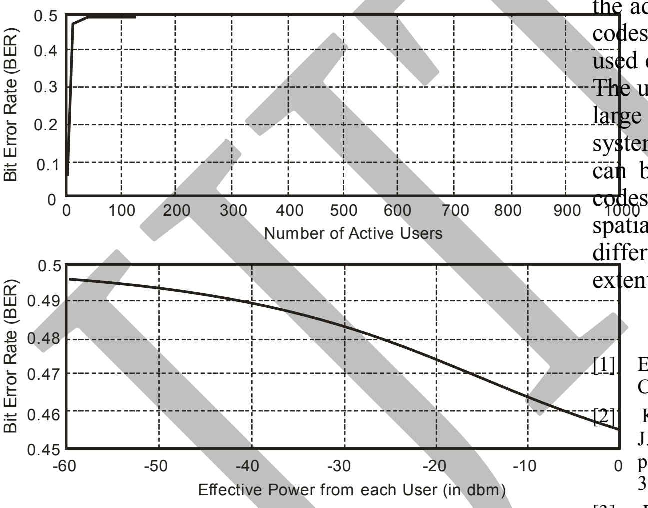

Figure 2. Esimulation results for Noncohrent spatial/spacial OCDMA system 2-D perfect difference code and 2-D M-Matrices code

V. DISCUSSION

From the, simulation results, it can be seen that the BER of the proposed system (Fig.(a)) is much less with respect to the number of users considered, as compared to the other systems i.e. DOCDMA system using SSFs as functional codes (Fig.(b)), Noncoherent spatial/ spectral OCDMA system with 2-D perfect difference codes(Fig. (c)) and OCDMA system for 2-D *M*-matrices (Fig.(d)), which have been considered here for comparison purposes. The BER is close to zero for upto 600 users. Thereafter, the BER increases but not as much as for other systems like the one using 2-D Perfect difference codes. Though, for DOCDMA system using SSFs as functional codes, the BER for number of users above 50(approx.) attains a constant value at 2.5235* 10^{-4}, it is still higher than the lower BER achievable in the proposed system.

When BER estimations are made with respect to the effective source power for each user (in dBm), it can be seen that the BER of the proposed system is close to zero for effective source power for each user upto -20dBm. Thereafter, the BER increases as compared to other systems using SSFs as functional codes and 2-D M-matrices codes. So, BER performance of the system is better for effective source power for each user being less than -20dBm. Hance, BER can be kept low for low power levels. At higher power levels, the interference between the users is main source of noise that limits the system performance. So, better performance of the proposed system for low values of the effective source power would always be advantage.

VI. CONCLUSION

In this paper, we present a novel configuration for OCDMA to improve the BER performance at lower effective power for each user. Here, SSFs have been used to modulate the perfect differnce code and hence the advantages of the SSFs and 2-D perfect difference codes are simultaniously utilized. 2-D perfect codes used can also help to accommodate more no. of users. The use of fast TOFs further helps in the generation of large no. of functional codes. Though, DOCDMA system too employ a fast TOF but more no. of users can be accommodated using 2-D perfect difference codes in the proposed system. The Noncoherent spatial/ spectral OCDMA system with 2-D perfect difference codes cannot minimize the BER upto the extent of the proposed system.

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