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Hybrid SCM SAC-OCDMA System Employing New Optical Spectral Amplitude Direct Decoding Detection Technique

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Abstract: In this research, a hybrid subcarrier multiplexed spectral-amplitude-coding optical code-division-multiple-access (SCM SAC-OCDMA) system is proposed for the purpose of combining the advantages of both techniques. SAC-OCDMA is employed because of its ability to eliminate the Multiple Access Interference (MAI) when code sequences with fixed in-phase cross correlation are used. In order to enhance the channel data rate of the OCDMA systems, the SCM technique is used. As a result, the hybrid system is robust against interference and is much more spectrally efficient. The system utilizes double weight (DW) code that has a weight W equal to two, code length N equal to six and cross correlation λ equal to 1. A simple and new detection technique called optical spectral amplitude direct decoding is proposed. Based on the theory and experimental simulation results obtained, the new proposed detection technique provides a better performance than the conventional balanced detection technique.

Key words: Hybrid SCM SAC-OCDMA, multi access interference, optical spectral amplitude direct decoding, subtraction detection technique

INTRODUCTION

The basic concept of SCM is borrowed from the microwave communication technology, which employs multiple microwave carriers for transmission of multiple channels over coaxial cable or free space. The total bandwidth is limited well below 1 GHz when coaxial cables are used to transmit the multi-channel microwave signals. However, if the multi-channel microwave signal is transmitted optically by using optical fibers, the signal bandwidth can easily exceed 10 GHz for a single optical carrier.

In an SCM system, the information signals are modulated onto different electrical carriers at radio or microwave frequencies and combined. The resulting signals are then used to intensity modulate an optical carrier. At the receiver end, the optical signal is converted back to an electrical current by a photodetector. The particular signals can then be demultiplexed and demodulated using conventional methods. The attractive feature of SCM is the independence of the different channels. This allows for great flexibility in the choice of modulation schemes. In addition to being flexible, the current SCM technology is also cost effective as it provides a way to take advantage of the multi-gigahertz bandwidth of the fiber optics using well-established microwave techniques for which components are matured and commercially available (Laurencio *et al*., 2005). Furthermore it is less expensive than the corresponding Wavelength Division Multiplexing (WDM) technology (Thomas and Bala, 1999).

Optical CDMA systems have received more attention because CDMA allows many users share the same transmission medium asynchronously by assigning a specific code sequence to every user. However, Multi Access Interference (MAI) is the main factor of performance degradation in optical CDMA. Thus, the SAC-OCDMA system employing code sequences fixed in-phase cross correlation was proposed as it can eliminate MAI by using balanced detection or also known as complementary subtraction detection technique (Xu, 2004; Djordjevic, 2004). Modified quadratic congruence codes (Wei and Ghafari-Shiraz, 2002), M-sequence codes (Yang *et al*., 2004) and double weight codes (Aljunid, 2004) are some of the codes that have been developed for SAC-OCDMA system. Hence, a new and simple detection technique named optical spectral amplitude direct decoding detection technique is proposed, capable of canceling MAI to further suppress phase-induced intensity noise (PIIN). It is shown in this

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research that the technique provides a significantly better performance than the complementary subtraction detection technique, which in turns allows for longer transmission distance or higher data rate or a larger number of users. Furthermore, this new technique has reduced the receiver complexity. The studies were carried out using a hybrid SCM SAC-OCDMA system. This hybrid system is proposed for the purpose of combining the advantages of both techniques.

THE DESIGN OF SCM SAC-OCDMA SYSTEM

Figure 1 illustrates the block diagram of the system. The data signals multiply with the assigned subcarrier signals and then modulated the signals with a distinct codeword using the Optical External Modulator (OEM). The received optical signals are decoded and converted to electrical signals, which then are filtered and demodulated accordingly to recover the original data. The data are protected by the difference in either the codes or the subcarrier frequencies. Each filter only corresponds to the desired data tuned to its center frequency and with a matching code. Other signals are rejected. Therefore the hybrid scheme is robust against interference and is more spectrally efficient.

SAC-OCDMA detection techniques: Basically there are two detection techniques for OCDMA, namely coherent and incoherent (Huang, 2000). Incoherent system consists of unipolar sequences in the signature code whereas coherent system uses bipolar codewords. Incoherent detection has a less hardware complexity compared to coherent detection because it does not need phase synchronization. In this study, the incoherent detection technique is used. Many researches such as Xu (2004) and Huang and Yang (2002) have used complementary subtraction detection technique at the receiver side to recover the original signal. The complementary subtraction and optical spectral amplitude direct decoding detection techniques will be discussed in the following sub-sections.

Complementary subtraction detection technique: The implementation of complementary subtraction detection technique is shown in Fig. 2. The Fig. 2 shows two different sequences X = (0110) and Y = (1100) are modulated with data and sent to multiplexer. The received signal in Receiver is divided into two complementary branches of spectral chips. These two branches of spectral signals are sent to a subtractor that computes the correlation difference.

In this technique, it is important to ensure that the total optical powers received by both photodiodes are balanced so that the subtraction of the unwanted overlapping channels can be completely done. This is not very easy to achieve considering the imperfect and non-uniform responses of the components used particularly in varying environmental conditions. Another weakness of the existing scheme is that, even if MAI can be totally cancelled, the effect of PIIN remains. PIIN induced in the system employing codes that have in-phase cross correlation equal to one will severely degrade the system performance.

The complementary subtraction technique was first proposed by Kavehrad and Zaccarin (1995). The cross-correlation is defined as:

$$\theta_{XY}(k) = \sum_{i=0}^{N-1} x_i y_{i+k} \tag{1}$$

where X and Y are the two OCDMA code sequences. The complementary of sequence (X) is given by ($\bar{X}$) whose elements are obtained from (X) by $\bar{x}_I = 1 - x_i$. Let X = 0011 and Y = 0110 and therefore $\bar{X}$ = 1100. The periodic cross-correlation sequence between ($\bar{X}$) and (Y) is similar to Eq. (1) and is expressed as:

$$\theta_{\bar{X}Y}(k) = \sum_{i=0}^{N-1} \bar{x}_i y_{i+k} \tag{2}$$

The sequences required are as:

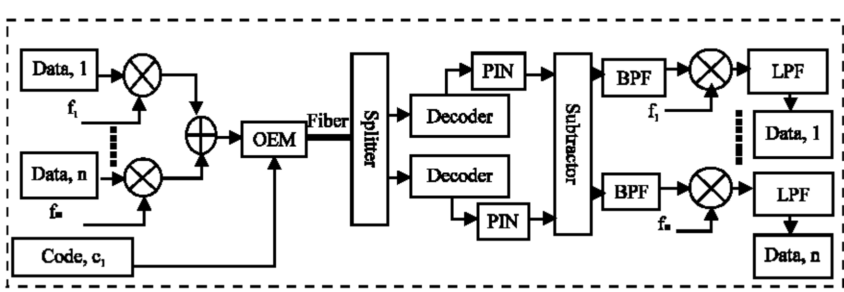

Fig. 1: A block diagram for one code of hybrid SCM SAC-OCDMA system using balanced detection technique

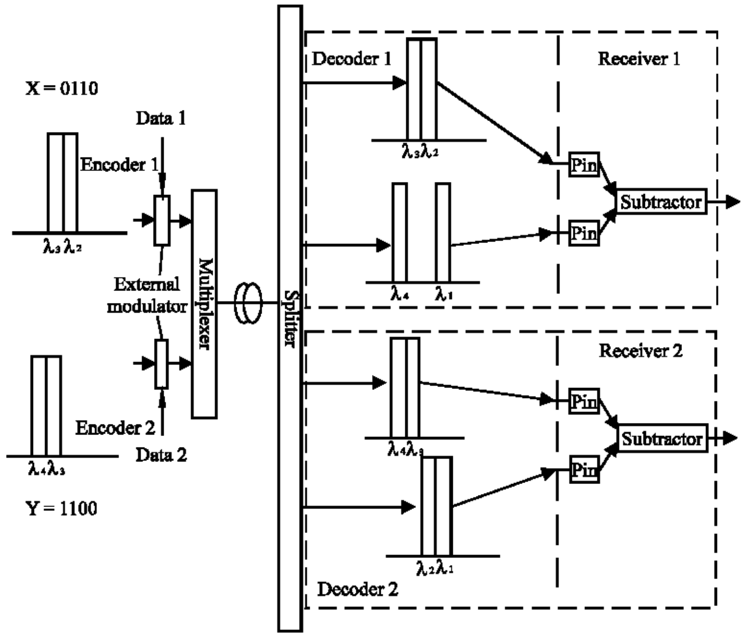

Fig. 2: Complementary subtraction detection technique for SAC-OCDMA system

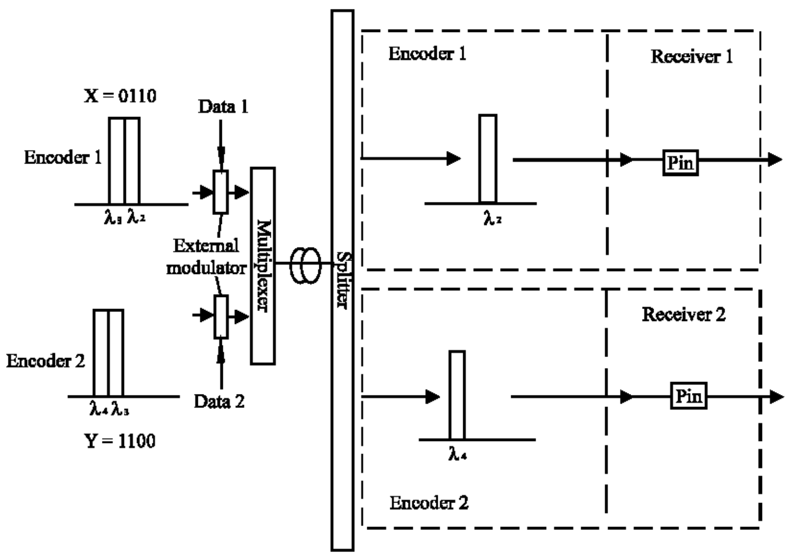

Fig. 3: Optical spectral amplitude direct decoding detection technique for SAC-OCDMA system

$$\theta_{XY}(k) = \theta_{\overline{X}Y}(k) \quad (3)$$

At the receiver, the photodetectors will detect the two complementary inputs which will be fed to the subtractor whose cross-correlation output, Z can be expressed as:

$$Z_{Complementary} = \theta_{XY}(k) - \theta_{\overline{X}Y}(k) = 0 \quad (4)$$

There is no more signal from other users in the intended channel when $Z_{Complementary} = 0$.

Optical spectral amplitude direct decoding detection technique: Figure 3 depicts the implementation of spectral amplitude direct decoding technique for OCDMA system. The property of spectral amplitude direct decoding technique is entirely different from complementary subtraction. Only two filters are required for the decoders, each for λ_2 and λ_4. MAI and PIIN are not existed since the subtraction detection technique at the electrical side is not needed in this detection technique. The intended signal spectral chips in the optical domain are filtered using the corresponding decoder. It is possible because the code properties possess one uncorrelated signal chip that contains the information for each of the users. Consequently, this will improve the system performance.

Nevertheless, this technique is only applicable to codes, which the spectral chips are not overlapped with other spectral chips of the other channel, i.e., a minimum of one clean chip in every code sequence. Many of the reported codes such as modified quadratic congruence, Modified Frequency Hopping (MFH) (Wei and Ghafouri-Shiraz, 2002) and MDW have this property.

As described above, the optical spectral amplitude direct decoding requires less number of optical filters in the decoder compared to the complementary subtraction detection technique. Figure 2 shows that the complementary subtraction detection technique requires three optical filters in the optical domain for decoder 1. A filter with the bandwidth twice the chip width for λ_2 and λ_3 and two separate filters for λ_1 and λ_4. Whereas for optical spectral amplitude direct decoding t echnique as shown in Fig. 3, only one filter is needed for decoder 1 which is for λ_2.

EXPERIMENTAL SIMULATION RESULTS AND DISCUSSION

OptiSystem Ver. 4.1 was used to evaluate the performance of the hybrid system. The simulation was carried out for DW code family with weight equal to 2 for four SCM channels. The bit rate of each channel is 155 Mbps (STM-1). Table 1 shows the DW code with weight equal to 2, code words equal to 4 and code length equal to 6. The advantages of DW code are easy and efficient code constructions, simple encoder-decoder design, existence for every natural number n, ideal cross correlation and high signal-to-noise ratio (SNR). The detailed of DW code families' construction and performances are explained in Aljunid (2004).

The ITU-T G.652 standard single mode optical fiber without any amplifier is employed for the transmission. The subcarrier frequencies are set at ≥ 2 times bit rate and equal channel spacing of 310 MHz. The spectral width of each chip was 0.8 nm. The attenuation and dispersion were set at 0.25 dB km^{-1} and 18 ps/nm km, respectively. The nonlinear effects were activated and specified according to the typical industry values to simulate the real environment as close as possible. The performances of the system are characterized by referring to the signal-to-noise ratio (SNR) and eye pattern for the complementary and optical spectral amplitude direct decoding detection techniques.

Table 1: DW code with weight = 2 and 4 code words

K_{th}	C_6	C_5	C_4	C_3	C_2	C_1
1	0	0	0	0	1	1
2	0	0	0	1	1	0
3	0	1	1	0	0	0
4	1	1	0	0	0	0

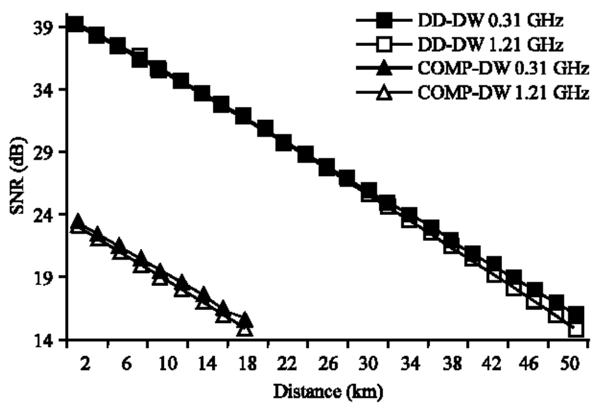

Fig. 4: SNR vs distance for SCM SAC-OCDMA systems using complementary and optical spectral amplitude direct decoding detection technique for DW

Figure 4 shows the SNR performance carried out against the transmission distance taken at the lowest and highest subcarrier frequencies, 0.31 and 1.21 GHz, respectively. It can be seen that SNR decreases with the transmission distance. The dispersion and attenuation are increased as the optical fiber length increases, thus decreasing the SNR. The results for the SCM SAC-OCDMA system using optical spectral amplitude direct decoding shows better SNR compared to the complementary subtraction technique. The performance for complementary subtraction technique is simulated only up to 18 km because the system cannot support longer distance at acceptable SNR. Taking the SNR threshold of 20 dB, the system using complementary subtraction technique could perform sufficiently well only up to approximately 10 km and optical spectral amplitude direct decoding technique up to approximately 44 km.

Figure 5 shows the effect of transmitted input power on the system performance taken at the lowest and highest subcarrier frequencies, 0.31 and 1.21 GHz, respectively for the system with the optical fiber length set at 10 km. As expected the system performance for both techniques increases as the transmitted input power increases. However the SNR for the system using complementary subtraction is lower than the system using

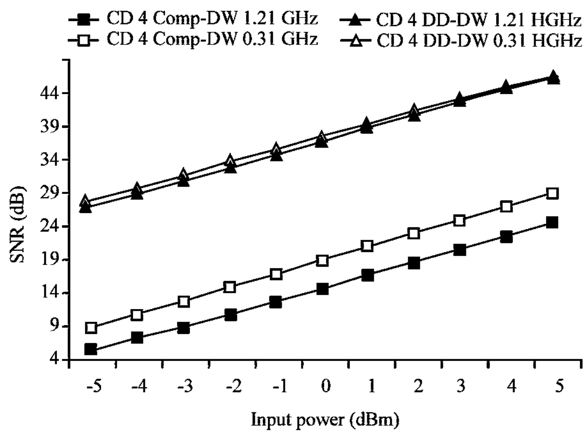

Fig. 5: SNR vs optical input power for SCM SAC-OCDMA systems using complementary subtraction and optical spectral amplitude direct decoding detection technique for DW

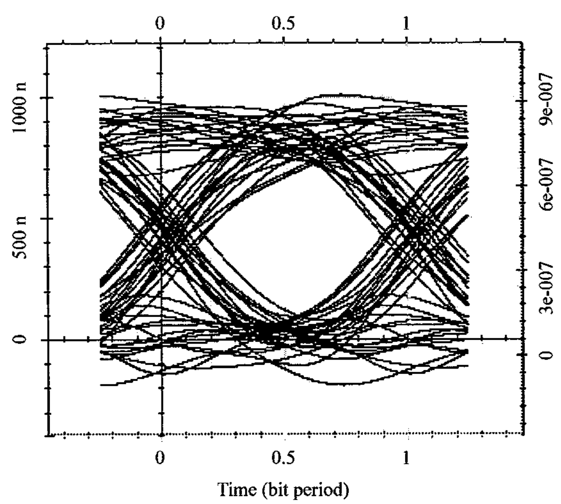

Fig. 6: Eye diagram taken at the fourth code word with complementary subtraction detection technique, subcarrier frequency of 0.61GHz

spectral amplitude direct decoding. Taking the SNR threshold of 20 dB, the system with spectral amplitude direct decoding could perform sufficiently well even when the transmitted power is at -5 dBm whereas for the complementary subtraction the transmitted power should set at 1 dBm or higher.

Figure 6 and 7 show the results for the SCM SAC-OCDMA with distance of optical fiber set at 14 km using complementary subtraction and optical spectral amplitude direct decoding detection techniques, respectively. The eye patterns show that the system using optical spectral amplitude direct decoding detection technique gave a better performance. The BER for complementary

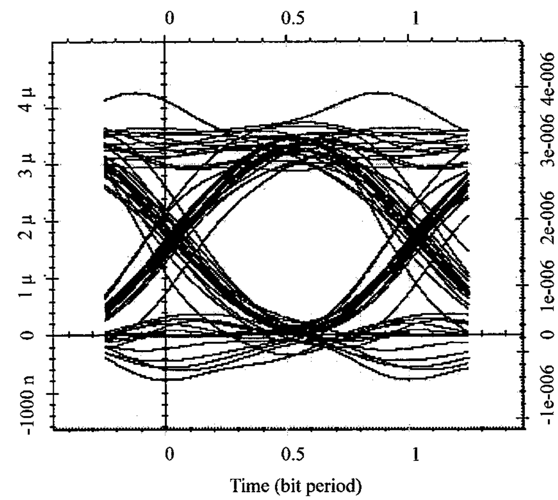

Fig. 7: Eye diagram taken at the fourth code word with optical spectral amplitude direct decoding technique, subcarrier frequency of 0.61GHz

subtraction and optical spectral amplitude direct decoding technique were 10^{-10} and 10^{-22}, respectively.

The effect of MAI causes PIIN and for the OCDMA system using complementary subtraction detection technique, subtractors are used to eliminate the noises imposed by the interference. However, there is no effect of MAI in the system using spectral amplitude direct decoding technique because there is no cross correlation take place as subtractor are not needed in order to recover the original signal. The performance of the SCM SAC-OCDMA system is improved significantly by using the optical spectral amplitude direct decoding technique because less number of filters is required in the decoder. Hence, the overall hybrid SCM SAC-OCDMA system cost, complexity as well as total power loss is reduced and this improves the system performance.

CONCLUSIONS

A new optical spectral amplitude direct decoding detection technique has been proposed. The performance of the hybrid SCM SAC-OCDMA system with the new optical spectral amplitude direct decoding technique using DW code family has been presented. The results of the experimental simulation have proved that the new optical spectral amplitude direct decoding technique provides a better performance than the complementary subtraction technique. The performance of the system improved significantly because the total power loss is reduced as optical spectral amplitude direct decoding technique requires less number of filters in the decoder.

REFERENCES

Aljunid, S.A., 2004. A new family of optical code sequences for spectral-amplitude-coding optical CDMA systems. IEEE Photonic Technol. Let., 1: 2383-2385.

Djordjevic, I.B., 2004. Multi-weight unipolar codes for multimedia spectral-amplitude-coding optical CDMA systems. IEEE Commun. Lett., 8: 259-261.

Huang, W., 2000. Coherent optical CDMA (OCDMA) systems used for high capacity optical fiber networks system description, OTDMA comparison and OCDMA/WDMA networking. IEEE J. Lightwave Technol., 18: 765-778.

Huang, J.F. and C.C. Yang, 2002. Reductions of multiple-access interference in fiber-grating-based optical CDMA network. IEEE Trans. Commun., 50: 1680-1682.

Kavehrad, M. and D. Zaccarin, 1995. Optical code-division-multiplexed systems based on spectral encoding of noncoherent sources. IEEE J. Lightwave Technol., 13: 534 -545.

Laurencio, P., S.O. Simoes and M.C.R. Meideiros, 2005. Simulation of intermodulation distortion in fiber-radio links employing OSSB. EUROCON 2005. Proceeding on The International Conference on Computer as a Tool, Belgrade, Serbia and Montenegro November 21-24, 2: 1365-1368.

Thomas, T.E. and K. Bala, 1999. Multiwavelength Optical Networks: A Layered Approach, Addison Wesley Longman.

Wei, Z. and H. Ghafouri-Shiraz, 2002. Proposal of a novel code for spectral amplitude coding optical CDMA systems. IEEE Photonic Technol. Lett., 14: 414-416.

Xu, L., 2004. Multiple Access Interference (MAI) noise reduction in A 2D optical CDMA system using ultrafast optical thresholding. In Proceeding of the 17th Annual Meeting of the IEEE Lasers and Electro-Optics Society, 2004, Nov. 8-9, 2: 591-592.

Yang, C.C., J.F. Huang and S.P. Tseng, 2004. Optical CDMA network codecs structured with M-sequence codes over waveguide-grating routers. IEEE Photonics Technol. Lett., 19: 641-643.