Optical Overlapping PPM-CDMA Systems With Novel Two-Dimensional Optical Codes

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***Abstract*-Utilizing the hybrid-coding method on both existing two-dimensional (2D) codes and one-dimensional (1D) optical orthogonal codes (OOCs), novel 2D optical codes are systematically constructed, and applied to optical code-division multiple-access (CDMA) systems with the use of overlapping pulse position modulation (OPPM) technique in this paper. The novel optical OPPM-CDMA system not only can enhance the system confidentiality, compared to the traditional optical CDMA system adopting on-off keying (OOK) technique, but also can further improve the transmission data rate and spectral efficiency due to utilizing OPPM technique instead of the PPM technique.**

I. Introduction

With the growing demands of transmission rate and bandwidth for the information and communication technology (ICT) application services, such as internet of things (IoT), big data and cloud computing [1], it is the inevitable development tendency that the future novel communication systems and networks must be able to support the higher transmission rate and larger bandwidth efficiently. The optical network not only has already become the backbone network which can support the transmission requirements of wireless communications in recent years, but also has become a promising candidate of the future broadband communications and networks, due to its several appealing features, such as the high transmission rate, long transmission distance, good data confidentiality and less susceptibility to electromagnetic interference [2].

Recently, many researchers proposed many novel optical code constructions successively for optical code-division multiple-access (CDMA) systems by considering three main design parameters simultaneously, including system performance, number of simultaneous users, and number of subscribers [2]-[7]. In addition to the three design parameters, the coding modulation technique is another important technique to improve the system complexity, data transmission confidentiality, data transmission rate and spectral efficiency [2]. In general, on-off keying (OOK) [3], [7], pulse position modulation (PPM) [8] and overlapping PPM (OPPM) [9], [10] techniques are the main coding modulation techniques which are widely used in optical CDMA systems, in order to meet the system designs and transmission requirements, besides both techniques of multicode keying (MK) [4] and multiple code (MC) [2].

In this paper, novel two-dimensional (2D) optical codes are systematically constructed by using the hybrid-coding method on both existing 2D carrier-hopping prime codes (CHPCs) [2] and one-dimensional (1D) optical orthogonal codes (OOCs) [3]. Moreover, this paper also further proposes a novel optical CDMA system with the use of both proposed 2D optical codes and OPPM technique to enhance the system confidentiality, instead of the use of the traditional OOK technique. Unlike the latter, the former can mainly avoid an intruder using the simple energy detection method to decide whether the transmitted data bits are bit ones or bit zeros directly [2], [4]. In addition to the system confidentiality, the proposed optical OPPM-CDMA system can also improve the transmission data rate and spectral efficiency significantly by using the overlapping index r efficiently [9], [10] due to utilizing OPPM technique instead of the PPM technique.

II. Construction of Novel Two-Dimensional Optical Codes

This section mainly introduces how to construct the proposed novel 2D optical codes by using the existing 2D CHPCs [2] and hybrid-coding method [2], [3]. Moreover, a brief review of both techniques is also given as follows.

A. Carrier-hopping prime codes

Each code matrix $C_{i_1,i_2,\ldots,i_k}$ of 2D CHPCs with code cardinality $\Phi_{\mathrm{CHPC}} = p_1 p_2 \cdots p_k$, number of available wavelengths $L = p_1$, length $N = p_1 p_2 \cdots p_k$, weight w, maximum autocorrelation sidelobe $\lambda_a = 0$ and maximum cross-correlation value $\lambda_c = 1$ can be represented with the ordered pairs as follows [2].

$$\begin{aligned} C_{i_1,i_2,\ldots,i_k} = \{&[(0,0),(1,1\otimes_{p_1} i_1 + (1\otimes_{p_2} i_2)p_1 + \cdots \\ &+ (1\otimes_{p_k} i_k)p_1 p_2 \cdots p_{k-1}), \\ &(2,2\otimes_{p_1} i_1 + (2\otimes_{p_2} i_2)p_1 + \cdots \\ &+ (2\otimes_{p_k} i_k)p_1 p_2 \cdots p_{k-1}),\cdots, \\ &((p-1),(p-1)\otimes_{p_1} i_1 + ((p-1)\otimes_{p_2} i_2)p_1 + \cdots \\ &+ ((p-1)\otimes_{p_k} i_k)p_1 p_2 \cdots p_{k-1})]: \\ &i_1 = \{0,1,\ldots,p_1-1\}, i_2 = \{0,1,\ldots,p_2-1\}, \ldots, \\ &i_k = \{0,1,\ldots,p_k-1\}\} \end{aligned} \quad (1)$$

where "$\otimes_{p_k}$" represents the multiplication modulo p_k, and each ordered pair (i, j) means code matrix $C_{i_1,i_2,\ldots,i_k}$ transmits the wavelength λ_i at time slot t_j [2].

B. Hybrid-coding method

The proposed novel 2D optical codes are mainly constructed by using the hybrid-coding method [2], [3] which simultaneously combines the existing 2D CHPCs with code cardinality Φ_{CHPC} [2] and the traditional 1D OOCs with code cardinality Φ_{OOC}, length n, weight w, and $\lambda_a = \lambda_c = 1$ [3]. The main design concept of the novel 2D optical codes is that the 1D OOC code sequence is used to determine whether the wavelength of each transmitted pulse of the original 2D CHPC

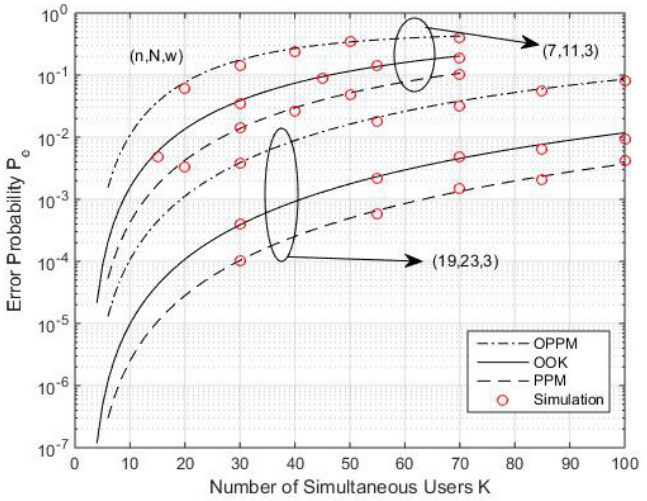

Fig. 1. Hard-limiting error probabilities of optical OOK-, PPM- and OPPM-CDMA systems using the proposed 2D optical codes with the number of available wavelengths L=n={7,19}, length N={11,23}, weight w=3 and the parameter m=4 of PPM and OPPM techniques.

code matrix should be removed or not. Thus, the overall cardinality of the resulting novel 2D optical codes, based on the above-mentioned coding construction algorithm, is $\Phi_{\mathrm{ALL}} = n \cdot \Phi_{\mathrm{OOC}} \cdot \Phi_{\mathrm{CHPC}}$.

III. Numerical Examples and Comparisons

Figure 1 illustrates the hard-limiting error probabilities of optical OOK-, PPM-, and OPPM-CDMA systems using the proposed 2D optical codes with the number of available wavelengths L= n= {7, 19}, length N={11, 23}, weight w=3, and the parameter m=4 of PPM and OPPM techniques as a function of the number of simultaneous users K. When K increases, the system performance will be degraded on the contrary. It is because that there are more interferers that result in the effect of multiple-access interference (MAI) in these optical CDMA systems with the use of three kinds of coding modulation techniques, respectively. Furthermore, the system performance will improve as the parameter n or N increases. It is because that the hit probabilities between any two code matrices will be reduced as n or N increases, no matter which coding modulation technique is used.

Also as shown in the figure, the performance of optical OPPM-CDMA system is the worst one among these three optical CDMA systems. It is because that there are the extra interferences caused by the symbol transmission of the same user in the optical OPPM-CDMA system, besides the interferences caused by different users (i.e., the effect of MAI), compared to the optical OOK- and PPM-CDMA systems. That is, the optical OPPM-CDMA system mainly provides the higher data transmission rate and spectral efficiency at the expense of system performance, compared to the optical PPM-CDMA system, and supports the better data transmission confidentiality, compared to the optical OOK-CDMA system, respectively. Moreover, the simulation results (i.e., marked in circles) of the performance of these three optical CDMA systems are also provided and matched closely with the theoretical results, thus it can validate the accuracy of our theoretical analysis in this paper.

IV. Conclusion

This paper constructed novel 2D optical codes systematically by using the hybrid-coding method on both existing 2D CHPCs and 1D OOCs, and applied to optical OPPM-CDMA system. It was showed that the novel optical OPPM-CDMA system not only enhanced the data transmission confidentiality, compared to the traditional optical CDMA system with the use of OOK technique, but also further supported the better data transmission rate and spectral efficiency at the expense of the performance by utilizing OPPM technique instead of the PPM technique to allow the overlap between any two adjacent PPM frames.

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