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실내 비방향성 분산채널에서 다중전송률 광무선 PPM-CDMA 시스템의 성능 분석

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Performance of Multi-rate Optical Wireless PPM-CDMA System over an Indoor Non-directed Diffuse Channel

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요 약

본 논문에서는 실내 비방향성 분산채널에서 비동기 다중전송률 광무선 펄스위치변조기법을 적용한 부호분할다원접속 시스템을 제안한다. 부호분할다원접속을 위한 시그너쳐 시퀀스로는 광직교부호를 사용하고, 비트오류률을 향상시키기 위해 간섭제거기법을 적용한다. PPM-CDMA은 전력효율이 다른 변조기법에 비해 우수하고, 고정된 펄스 구간에 대해 변조레벨을 변화시켜 다중전송률 서비스를 제공하는 데에 용이하다. 본 논문에서 제안한 다중전송률 PPM-CDMA 시스템은 각 전송률에 대해 칩전송률 및 샘플링 시간을 변화시키지 않으므로써 전체 시스템 구조를 단순화할 수 있다.

ABSTRACT

In this paper, an asynchronous multi-rate optical wireless pulse position modulation-code division multiple access (PPM-CDMA) is proposed for an indoor non-directed diffuse channel. As a signature sequence for CDMA, an optical orthogonal code (OOC) is used and an interference cancellation scheme is applied to improve the bit error rate. It is known that the optical PPM-CDMA has advantages due to its power efficiency. Moreover, it provides multi-rate services by varying the modulation level with fixed pulse duration. In the proposed multi-rate PPM-CDMA system with fixed pulse duration, chip rate and sampling time do not change for each transmission rate and this simplifies overall system structure.

I. INTRODUCTION

Recently, an optical wireless channel found applications in an indoor wireless communications [1]. As an optical wireless channel has practically unlimited bandwidth, it accommodates wireless multimedia. As infrared light does not pass through walls, optical wireless communication is robust against interference and eavesdropping. Also, the large size of its detector in comparison with infrared wavelength provides inherent spatial diversity so that infrared links practically are immune to multipath fading. There were studies on optical wireless communication mainly focused on baseband transmission techniques, modulation schemes, and the characterization of an optical wireless channel [1][2].

As a multiple access scheme, code division multiple access (CDMA) is considered for an

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optical wireless system, which was originally proposed for an optical fiber communication system with large bandwidth [3]. CDMA has the advantage of not requiring symbol synchronization or tuneable laser diode with high stability for accurate wavelength control, unlikely to time division multiple access or frequency division multiple access. On-off keying (OOK) is used as a modulation scheme for an optical wireless CDMA system in [4]. While OOK has an advantage of simple implementation for an optical wireless system, pulse position modulation (PPM) has higher power efficiency than OOK. An optical wireless PPM-CDMA system has been proposed over a non-directed diffuse channel [5]. In an optical wireless PPM-CDMA system, successive interference cancellation (SIC) is adopted to mitigate the multiple access interference (MAI) which is originally applied to a radio CDMA system [6].

Multi-rate transmission in a CDMA system was proposed to support multi-media services over mobile radio channel [7]. There are a few methods to implement multi-rate transmission in a direct sequence (DS)/CDMA system : multi-modulation, multi-processing gain, and multi-channel. For a multi-rate DS/CDMA system implemented with any of methods, the interference cancellation technique is applied to reduce bit error rate (BER) degradation [8][9].

In this paper, a multi-rate optical wireless PPM-CDMA system with fixed pulse duration is proposed for an indoor non-directed diffuse channel for which intensity modulation/direct detection is used. In the proposed optical wireless PPM-CDMA system, multi-rate transmission is achieved by varying a modulation level without changing a chip rate at a transmitter and sampling time at a receiver, which simplifies overall system structure. For the proposed multi-rate optical wireless PPM-CDMA system, interference cancellation scheme is applied to reduce BER.

In Section II, a multi-rate PPM-CDMA system is proposed. In Section III, the BER of a PPM-CDMA system is derived for a conventional receiver and a receiver with SIC. In Section IV, numerical results are given. Conclusions are drawn in Section V.

Ⅱ. SYSTEM MODEL

A. Transmitter and Channel

Consider an optical wireless pulse position modulation-code division multiple access (PPM-CDMA) system using an optical orthogonal code (OOC) as a signature sequence for an optical wireless channel. The performance of an optical wireless PPM-CDMA system is extensively studied in [5].

Suppose that there are N users in an optical wireless PPM-CDMA system. Fig. 1 shows the block diagrams of the transmitter and the conventional receiver of the n-th user. The M-ary PPM encoder takes L binary source bits of duration T_b to produce an M-ary symbol of duration T_s with $M=2^L$. A single pulse of duration τ exists in one of M pulse positions. An M-ary symbol of the n-th user at time i is changed into a vector with M coordinates, $\underline{s}_n{}^i = (s_{n,1}{}^i, s_{n,2}{}^i, \cdots s_{n,M}{}^i)$, $i = -\infty, \cdots, -1, 0, 1, \cdots, \infty$. Suppose that $\underline{s}_n{}^i = (0,0,0,\ldots,1,0,0) \triangleq \underline{e}_{l_i}$ where $\underline{e}_{l_i}$ is a unit row vector having zeros at all components except one at the l_i-th component and l_i is a random variable which is equiprobable over $\{1,2,\ldots,M\}$. Then, the PPM encoded waveform of the n-th user is given by

$$s_n(t) = \sum_{i=-\infty}^{\infty} p_\tau(t-(l_i-1)\tau-(i-1)T_s),$$
$$n = 1, 2, \cdots, N, \tag{1}$$

where $p_\tau(t)$ is a rectangular pulse with duration τ.

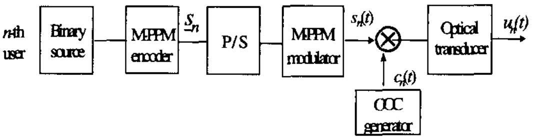

Fig. 1 Block diagram of transmitter for M-PPM-CDMA system

For an optical CDMA system, an optical orthogonal code (OOC) is used as a signature sequence. An $(F, K, \lambda_a, \lambda_c)$ OOC is characterized by length F, weight K, autocorrelation constraint λ_a, and crosscorrelation constraint λ_c [10]. Each PPM pulse has F chips with chip duration T_c, $\tau = FT_c$. Let the signature sequence vector of the n-th user be denoted by $\underline{c}_n = (c_{n,1}, \cdots, c_{n,F})$, $c_{n,j} \in \{0,1\}$, $j = 1,2,\ldots,F$, $n = 1,2,\cdots,N$. Then the signature sequence waveform of the n-th user is given by

$$c_n(t) = \sum_{j=-\infty}^{\infty} c_{n,j}\, p_{T_c}(t-(j-1)T_c), \quad n = 1,2,\cdots,N, \tag{2}$$

where $p_{T_c}(t)$ is a rectangular pulse with duration T_c and $c_{n,j+F} = c_{n,j}$ for any integer j. T_s is integer times T_c, i.e., $T_s = MFT_c$. The transmitted optical signal of the n-th user is given by [5]

$$\begin{aligned} u_n(t) &= \frac{MFP}{K}\, c_n(t)\, s_n(t) \\ &= \frac{MFP}{K} \sum_{j=-\infty}^{\infty} \sum_{i=-\infty}^{\infty} c_{n,j}\, p_{T_c}(t-(j-1)T_c) \\ &\qquad p_\tau(t-(l_i-1)\tau-(i-1)T_s) \end{aligned} \tag{3}$$

where P is the average power of a transmitted optical signal.

Suppose that an optical signal is transmitted over an indoor non-directed diffuse channel. The impulse response of the channel is given by [2]

$$h_n(t) = \sum_{j=-\infty}^{J-1} h_{n,j}\, \delta(t - jT_c - \Delta_n) \tag{4}$$

where $h_{n,j}$ is a channel coefficient of the $j+1$-th path of a signal from the n-th transmitter for the total number of paths J, $\delta(t)$ is the Dirac-delta function, and Δ_n is delay for the signal from the n-th user. Without loss of generality, assume that $0 \le \Delta_n < T_s$ for $n = 1,2,\ldots,N$. Suppose that transmitters are chip asynchronous between users in a PPM-CDMA system, then delay for the signal from the n-th user is given by

$$\Delta_n = (\beta_n + \rho_n)T_c \tag{5}$$

where β_n is a discrete random variable uniformly distributed over $\{0, 1, \cdots, M^* F - 1\}$ for a maximum modulation level M^* and ρ_n is a continuous random variable uniformly distributed over [0, 1). The received signal of the n-th receiver is given by

$$r(t) = \sum_{n=1}^{N} \gamma_n\, u_n(t) * h_n(t) + z(t) \tag{6}$$

where $*$ denotes convolution, γ_n is an attenuation factor for the n-th user and $z(t)$ is an white Gaussian noise with power spectral density $N_0/2$.

B. Multi-rate PPM-CDMA

In Fig. 2, a multi-rate PPM signals are shown with pulse duration fixed. L binary source bits of duration T_b are converted to an M-ary PPM symbol with duration T_s, $M = 2^L$. A PPM symbol has a single pulse of duration τ in one of M pulse positions during T_s, $T_s = 2^L \tau$. By varying the modulation level of PPM with pulse duration fixed, multi-rate transmission is implemented. As the modulation level of PPM increases, power efficiency of PPM increases, while the source bit rate becomes lower for the system with fixed pulse duration. Hence, multi-rate PPM transmission has tradeoff between power efficiency and the high bit rate.

Chip rate is fixed in a multi-rate PPM-CDMA

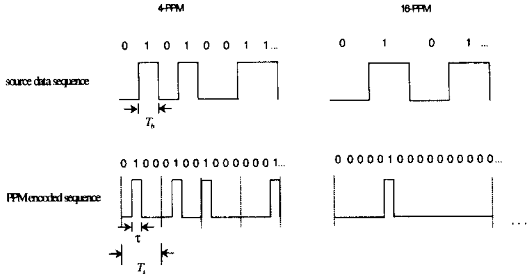

Fig. 2 Multi-rate PPM signals with fixed pulse duration.

system with pulse duration fixed while the level of PPM varies according to the change of a source rate which makes a system structure simple. For a multi-rate PPM-CDMA system with pulse duration fixed, the source bit rate is given by

$$R_{b,M} = \frac{\log_2 M}{MFT_c} \tag{7}$$

where F is OOC length and T_c is chip duration, which is proportional to $\log_2 M/M$ for fixed pulse duration $\tau = FT_c$. For an example, the source bit rate of 4-PPM-CDMA is twice as high as that of 16-PPM-CDMA for the given chip rate.

C. Receiver

Fig. 3 shows the block diagram of the conventional receiver for the n-th user in M-PPM-CDMA system. A received signal is multiplied by the signature sequence of the n-th user, integrated over duration τ, sampled, and serial-to-parallel converted into a received symbol vector $\underline{\mathbf{r}}_n{}^i = (r_{n,1}{}^i, r_{n,2}{}^i, \cdots, r_{n,M}{}^i)$, where i is time index, $i = -\infty, \cdots, -1, 0, 1, \cdots, \infty$. At time index $i = 1$, the m-th component of a received symbol vector for the n-th user is given by

$$r_{n,m}{}^1 = \frac{1}{T_c}\int_{(m-1)\tau}^{m\tau} r(t)\, c_n(t)\, dt \quad m = 1, 2, \ldots, M. \tag{8}$$

Received symbol vectors for the n-th user with different time index are grouped to form a super received symbol vector as follows

$$\tilde{\underline{\mathbf{r}}}_n = (\underline{\mathbf{r}}_n{}^1, \underline{\mathbf{r}}_n{}^2, \ldots, \underline{\mathbf{r}}_n{}^{M^*/M}) \tag{9}$$

where M is PPM level and M^* is the maximum of modulation level in a multi-rate PPM-CDMA system.

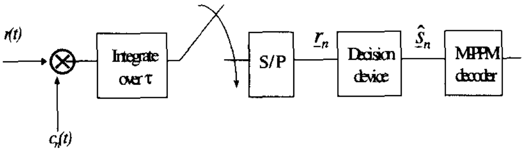

Fig. 3 Block diagram of receiver for M-PPM-CDMA system.

Ⅲ. BIT ERROR RATE

A super received symbol vector consists of a desired signal vector, a self-interference vector, a multi-user interference vector, and a noise vector. A super received symbol vector for the n-th user is given by

$$\tilde{\underline{\mathbf{r}}}_n = \underline{\mathbf{d}}_n + \underline{\mathbf{I}}_{s,n} + \underline{\mathbf{I}}_{c,n} + \underline{\mathbf{z}}_n \tag{10}$$

where $\underline{\mathbf{d}}_n = (\underline{\mathbf{d}}_n{}^1, \underline{\mathbf{d}}_n{}^2, \ldots, \underline{\mathbf{d}}_n{}^{M^*/M})$ is a desired signal vector, $\underline{\mathbf{I}}_{s,n} = (I_{s,n,1}\ I_{s,n,2}\ \ldots\ I_{s,n,M^*})$ is a self-interference vector, $\underline{\mathbf{I}}_{c,n} = (I_{c,n,1}\ I_{c,n,2}\ \ldots\ I_{c,n,M^*})$ is a multi-user interference vector, and $\underline{\mathbf{z}}_n$ is a Gaussian noise vector for the n-th receiver, $\underline{\mathbf{z}}_n = (z_{n,1}\ z_{n,2}\ \ldots\ z_{n,M^*})$, $z_{n,m} = \frac{1}{T_c}\int_{(m-1)\tau}^{m\tau} z(t)c_n(t)\,dt$, and $var[z_{n,m}] = \frac{KN_0}{T_c}$, $m = 1, 2, \ldots, M^*$.

The desired symbol vector of the n-th user at time 1 is given by

$$\begin{aligned}\underline{\mathbf{d}}_n &= K\gamma_n h_{n,0}\left(\frac{FMP}{K}\right)\cdot \\ &\quad (\underline{\mathbf{s}}_n{}^1, \underline{\mathbf{s}}_n{}^2, \ldots, \underline{\mathbf{s}}_n{}^{M^*/M}) \\ &= K\xi_{n,0}\,\tilde{\underline{\mathbf{s}}}_n{}^1\end{aligned} \tag{11}$$

where F is the length of an OOC, K is the weight of the OOC, M is a PPM level, M^* is the maximum of modulation level, P is the average power of a transmitted optical signal, $\xi_{n,0}$ is the instantaneous optical power of the first path of a signal from the n-th user, $\xi_{n,0} = \gamma_n h_{n,0}\left(\frac{FMP}{K}\right)$, and $\tilde{\underline{\mathbf{s}}}_n{}^1$ is a super symbol vector for the n-th user at time 1, $\tilde{\underline{\mathbf{s}}}_n{}^1 = (\underline{\mathbf{s}}_n{}^1, \underline{\mathbf{s}}_n{}^2, \ldots, \underline{\mathbf{s}}_n{}^{M^*/M})$.

Let the signature sequence of the n-th user be denoted by a row vector $\underline{\mathbf{c}}_n = (c_{n,1}, \cdots, c_{n,F})$. Then, an $M^* \times FM^*$ optical orthogonal code matrix for the n-th user is given by

$$\mathbf{C}_n = \begin{bmatrix} \underline{\mathbf{c}}_n & \underline{\mathbf{0}}_n & \cdots & \underline{\mathbf{0}}_n \\ \underline{\mathbf{0}}_n & \underline{\mathbf{c}}_n & \cdots & \underline{\mathbf{0}}_n \\ \vdots & \vdots & \ddots & \vdots \\ \underline{\mathbf{0}}_n & \underline{\mathbf{0}}_n & \cdots & \underline{\mathbf{c}}_n \end{bmatrix} \tag{12}$$

where $\underline{\mathbf{0}}_n$ is a zero row vector with F components.

Let the previous and the current super symbol vectors for the n-th user be denoted by $\underline{\tilde{s}}_n^{-M^*/M+1}=(\underline{s}_n^{-M^*/M+1}, \underline{s}_n^{-M^*/M+2}, \dots, \underline{s}_n^{0})$ and $\underline{\tilde{s}}_n^{1}=(\underline{s}_n^{1}, \underline{s}_n^{2}, \dots, \underline{s}_n^{M^*/M})$, respectively. Then, a self-interference vector for the n-th user is given by

$$\underline{\mathbf{I}}_{s,n}=\sum_{j=1}^{L-1}\xi_{k,j}\ \{\ \underline{\tilde{s}}_n^{-M^*/M+1}\ C'^{(j-MF)}_n + \underline{\tilde{s}}_n^{1}\ C'^{(j)}_n\}\ C_n^T \tag{13}$$

where $\xi_{n,j}$ is the instantaneous optical power of the $j+1$-th path of the n-th user signal and $C'^{(m)}_n$ is the cyclically shifted version of the matrix C_n by m rows downward.

Let a discrete random variable β_l be uniformly distributed over $\{0,1,\cdots,M^*F-1\}$ and a continuous random variable ρ_l be uniformly distributed over [0, 1). Then, a multi-user interference vector for the n-th user is given by

$$\begin{aligned}\underline{\mathbf{I}}_{c,n}= & \sum_{\substack{l=1\\ l\neq n}}^{N}\sum_{j=0}^{L-1}\xi_{l,j}\ \underline{\tilde{s}}_l^{-M^*/M+1}\cdot\\ & [\{\rho_l\ C'^{(j-MF+\beta_l+1)}_l\\ & +(1-\rho_l)\ C'^{(j-MF+\beta_l)}_l\}\\ & +\underline{\tilde{s}}_l^{1}\{\rho_l\ C'^{(j+\beta_l+1)}_l\\ & +(1-\rho_l)\ C'^{(j+\beta_l)}_l\}]\ C_n^T\end{aligned} \tag{14}$$

where $\underline{\tilde{s}}_l^{-M^*/M+1}$ and $\underline{\tilde{s}}_l^{1}$ are the previous and the current super symbol vectors of the l-th user, respectively.

The decision device chooses the largest component out of M components of the received symbol vector to decide which symbol vector was transmitted. A detected PPM symbol vector is decoded into a binary sequence of L bits. Bit error rate (BER) for a conventional receiver of the n-th user is given by [5]

$$P_{b,con,n}=\frac{M/2}{M-1}E\Big[1-\prod_{m=2}^{M}(1$$

$$-Q\Big(\frac{(d_{n,1}+I_{s,n,1}+I_{c,n,1})-(d_{n,m}+I_{s,n,m}+I_{c,n,m})}{\sqrt{2}\sigma}\Big)\Big)\Big] \tag{15}$$

where $d_{n,1}$ and $d_{n,m}$ are the first and the m-th components of the desired signal vector $\underline{d}_n$, respectively, $I_{s,n,1}$ and $I_{s,n,m}$ are the first and the m-th components of $\underline{\mathbf{I}}_{s,n}$, respectively, $I_{c,n,1}$ and $I_{c,n,m}$ are the first and the m-th components of $\underline{\mathbf{I}}_{c,n}$, respectively, $Q(x)=\frac{1}{\sqrt{2\pi}}\int_x^{\infty}e^{-\frac{y^2}{2}}dy$. The expectation is taken over independent and uniformly distributed super symbol vectors $\underline{\tilde{s}}_l^{-M^*/M+1}$ and $\underline{\tilde{s}}_l^{1}$ and random variables β_l and ρ_l, $l=1,2,\dots,N$, $l\neq n$. By symmetry, the BER of a conventional receiver is given by

$$P_{b,con}=P_{b,con,n}. \tag{16}$$

In a receiver with SIC, received symbol vectors are ordered by their power. Then, a multi-user interference vector with the strongest power is estimated and subtracted from the received symbol vector to get a revised symbol vector. From the revised received symbol vector, the signal vector with the second strongest power is estimated and subtracted. This process is repeated until a signal vector with the weakest power is estimated. The estimated interference vector for the n-th user is given by

$$\begin{aligned}\hat{\underline{\mathbf{I}}}_{c,n}= & \sum_{\substack{l=1\\ l\neq n}}^{N}\sum_{j=0}^{L-1}\xi_{l,j}\ \underline{\hat{s}}_l^{-M^*/M+1}\cdot\\ & [\{\hat{\rho}_l\ C'^{(j-MF+\hat{\beta}_l+1)}_l\\ & +(1-\hat{\rho}_l)\ C'^{(j-MF+\hat{\beta}_l)}_l\}\\ & +\underline{\hat{s}}_l^{1}\{\hat{\rho}_l\ C_l^{(j+\hat{\beta}_l+1)}\\ & +(1-\hat{\rho}_l)\ C_l^{(j+\hat{\beta}_l)}\}]\ C_n^T\end{aligned} \tag{17}$$

where $\hat{\beta}_l$ and $\hat{\rho}_l$ are the estimates of β_l and ρ_l, respectively, and $\underline{\hat{s}}_l^{-M^*/M+1}$ and $\underline{\hat{s}}_l^{1}$ are the decision results for the previous and the current super symbol vectors of the l-th user, respectively. From (10), a revised super received symbol vector is given by

$$\begin{aligned}\underline{\tilde{\boldsymbol{r}}}'_n &= \underline{\tilde{\boldsymbol{r}}}_n - \hat{\boldsymbol{I}}_{c,n} \\ &= \underline{\boldsymbol{d}}_n + \underline{\boldsymbol{I}}_{s,n} + \underline{\boldsymbol{I}}_{c,n} - \underline{\hat{\boldsymbol{I}}}_{c,n} + \underline{\boldsymbol{z}}_n \qquad (18) \\ &= \underline{\boldsymbol{\zeta}}_n + \underline{\boldsymbol{z}}_n\end{aligned}$$

where $\underline{\boldsymbol{\zeta}}_n = \underline{\boldsymbol{d}}_n + \underline{\boldsymbol{I}}_{s,n} + \underline{\boldsymbol{I}}_{c,n} - \underline{\hat{\boldsymbol{I}}}_{c,n}$. The decision device chooses the largest component out of the M components of $\underline{\tilde{\boldsymbol{r}}}'_n$ to decide which symbol vector was transmitted. A decided PPM symbol vector is decoded into a binary sequence of L bits. BER for the receiver with SIC of the n-th user is given by [5]

$$P_{b,SIC,n} = \frac{M/2}{M-1} E\left[1 - \prod_{m=2}^{M}\left(1 - Q\left(\frac{\zeta_{n,1} - \zeta_{n,m}}{\sqrt{2}\sigma}\right)\right)\right] \qquad (19)$$

where $\zeta_{n,1}$ and $\zeta_{n,m}$ are the first and the m-th component of the vector $\underline{\boldsymbol{\zeta}}_n$, respectively. Expectation is taken for independent and uniformly distributed super symbol vectors $\underline{\tilde{\boldsymbol{s}}}_l^{-M^*/M+1}$ and $\underline{\tilde{\boldsymbol{s}}}_l^{1}$ and β_l and ρ_l, $l = 1, 2, \ldots, N$ and $l \neq n$. By symmetry, the BER for the receiver with SIC is given by

$$P_{b,SIC} = P_{b,SIC,n}. \qquad (20)$$

Ⅳ. SYSTEM ANALYSIS

Bit error rate (BER) for the proposed multi-rate PPM-CDMA system is computed for a conventional receiver and a receiver with SIC from (15) and (19), respectively. A (43,3,1,1) OOC is used as a signature sequence.

The BER of the multi-rate PPM-CDMA is calculated over a non-directed diffuse channel which has time dispersive characteristic. In Fig. 4, the BER of an M-PPM-CDMA system is shown for single user bound with M= 4, 8 and 16. Fig. 4 shows the BER of the multi-rate PPM-CDMA with transmission rates of M-PPM-CDMA $R_{b,M}$ are like follows : $R_{b,4}$ = 2 Mbps for 4-PPM, $R_{b,8}$ = 1.5 Mbps for 8-PPM, and $R_{b,16}$ = 1 Mbps for 16-PPM. In Fig. 4, it is shown that 16-PPM-CDMA and 8-PPM-CDMA are more efficient in information energy by 3 dB and 1.7 dB than 4-PPM-CDMA, respectively.

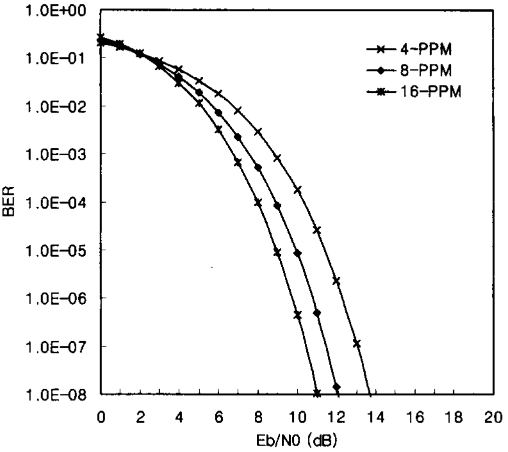

Fig. 4 BER of a multi-rate optical wireless M-PPM-CDMA system with (43,3,1,1) OOC. $N = 1$, $R_{b,4}$ = 2 Mbps, $R_{b,8}$ = 1.5 Mbps, $R_{b,16}$ = 1 Mbps.

Fig. 5 shows the BER of a multi-rate optical wireless M-PPM-CDMA system without interference cancellation which has one 4-PPM user and one 16-PPM user, when $R_{b,4}$=2 Mbps, $R_{b,16}$ =1 Mbps, and the E_b/N_0 of a 4-PPM user is 3 dB larger than that of a 16-PPM user. It is shown that a 4-PPM user achieves smaller BER than a 16-PPM user. In Fig. 5, it is shown that a 16-PPM user requires 2 dB less E_b/N_0 than a

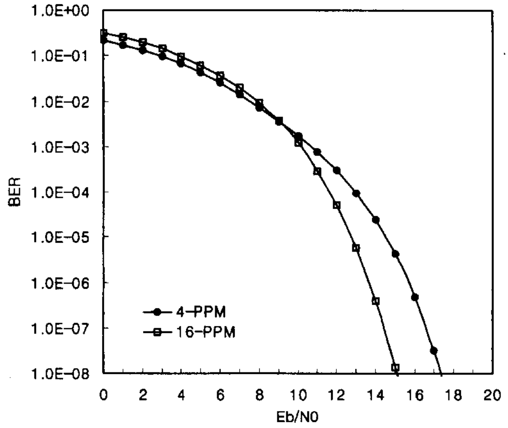

Fig. 5 BER of a multi-rate optical wireless M-PPM-CDMA system with (43,3,1,1) OOC. $N = 2$, $R_{b,4}$ = 2 Mbps, $R_{b,16}$ = 1 Mbps.

4-PPM user to achieve the BER of 10^{-6}. This difference of 2 dB required E_b/N_0 is smaller than the E_b/N_0 efficiency difference of 3 dB, which explains why 4-PPM achieves smaller BER than 16-PPM.

Fig. 6 shows the BER of a multi-rate optical wireless M-PPM-CDMA system with and without interference cancellation which has one 4-PPM and one 8-PPM user, with $R_{b,4}$=2 Mbps for 4-PPM, $R_{b,8}$=1.5 Mbps for 8-PPM, when the E_b/N_0 of a 4-PPM is 1.7 dB larger than that of an 8-PPM. It is shown that a 4-PPM user achieves smaller BER than 8-PPM user. In Fig. 6, it is shown that the 8-PPM user requires 1.5 dB less E_b/N_0 than 4-PPM user for the conventional receiver to achieve the BER of 10^{-6}. This difference of 1.5 dB required E_b/N_0 is smaller than the E_b/N_0 efficiency difference of 1.7 dB, which explains why 4-PPM achieves smaller BER than 8-PPM. It is also shown that a 4-PPM user and an 8-PPM user with a SIC receiver require 3.5 dB and 4 dB less E_b/N_0 than a conventional receiver to achieve the BER of 10^{-6} ,respectively.

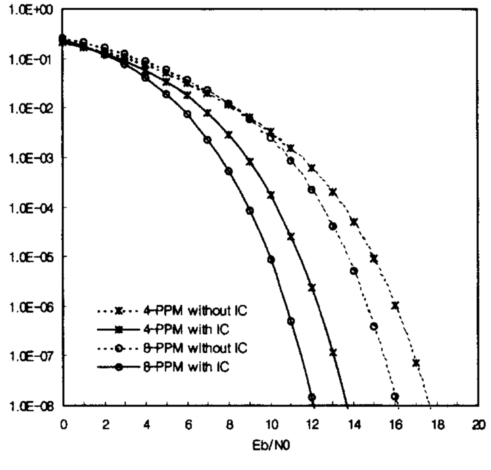

Fig. 6 BER of a multi-rate optical wireless M-PPM-CDMA system with and without interference cancellation. (43,3,1,1) OOC, $N=2$, $R_{b,4}$= 2 Mbps, $R_{b,8}$ = 1.5 Mbps.

Fig. 7 shows the BER of a multi-rate optical wireless M-PPM-CDMA system with and without interference cancellation which has one 4-PPM, one 8-PPM, and one 16-PPM user, when $R_{b,4}$= 2 Mbps, $R_{b,8}$=1.5 Mbps, $R_{b,16}$= 1 Mbps, when E_b/N_0 of a 4-PPM is 1.7 dB and 3 dB larger than those of an 8-PPM and a 16-PPM, respectively. It is shown that BER of a 4-PPM user is severely degraded without interference cancellation, however, significantly improved with interference cancellation. It is also shown that there exists about 4.5 dB E_b/N_0 improvement by SIC for 16-PPM to achieve the BER 10^{-6}.

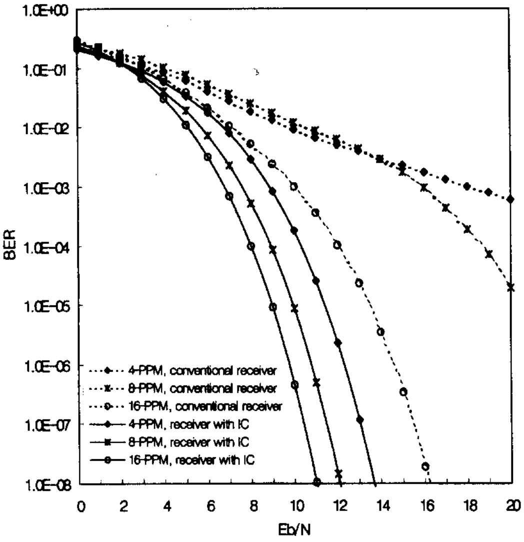

Fig. 7 BER of a multi-rate optical wireless PPM-CDMA system with and without interference cancellation. (43,3,1,1) OOC, $N=3$, $R_{b,4}$= 2 Mbps, $R_{b,8}$ =1.5 Mbps, $R_{b,16}$ = 1 Mbps.

V. CONCLUSION

In this paper, an asynchronous multi-rate optical wireless PPM-CDMA system is proposed for an indoor non-directed diffuse channel. To have multi-rate transmission according to varying source bit rate in a PPM-CDMA system, different PPM levels are used with pulse duration fixed. In the proposed multi-rate PPM-CDMA system with pulse duration fixed, chip rate is fixed while the level of PPM varies according to the change of a source rate which makes a system structure simple. As the modulation level of PPM increases, power efficiency of PPM increases, while the source bit rate becomes lower for the system with fixed pulse duration. Hence, multi-rate PPM transmission has tradeoff between power efficiency and the high bit rate.

To reduce multiple access interference (MAI) in the reverse link, an interference cancellation scheme is adopted. BER is derived for PPM-CDMA systems with a conventional receiver and a receiver with SIC.

It is shown that the system with interference cancellation reduces MAI effectively to achieve a significant BER improvement over the system with a conventional receiver while the latter suffers from MAI.

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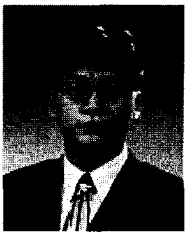

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