

# Evaluation of coherent homodyne and heterodyne optical CDMA structures

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**Abstract** This paper evaluates the coherent optical code-division multiple-access (OCDMA) techniques and examines the overall system performance in terms of signal-to-noise ratio (SNR) penalty as a function of simultaneous users accommodated to maintain an appropriate value of the bit-error rate (BER) for homodyne and heterodyne detections. As spreading codes, the proposed structures are utilizing a recently introduced prime code family hereby referred to as double-padded modified prime code (DPMPC). As a coherent modulation, binary phase-shift keying (BPSK) format is deployed. In homodyne detection, two different phase modulations are studied including either an external phase-modulator or injection-locking methods. The phase limitation and the performance for two methods plus multiple-access interferences (MAI) and receiver noise in a shot-noise limited regime are investigated. In heterodyne detection, BER analysis of the system based on only external phase modulator is examined. It is found that by maintaining  $BER = 10^{-9}$ , this system can accommodate an increased number of simultaneous users to compare with systems which employ conventional bipolar codes.

**Keywords** Coherent OCDMA · Injection-locking · Limited phase excursion · Multiple access interference · Prime code family

## 1 Introduction

The huge bandwidth and extremely low propagation loss offered by fiber optics can be effectively exploited only in a multi-channel context, i.e. by grouping several simultaneous transmissions on the same physical link. In a network framework, this goal can be achieved

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through the use of multiple access techniques such as code-division multiple-access (CDMA). Coherent time spreading optical CDMA (OCDMA) as an access protocol that takes advantage of the excess bandwidth in single-mode fiber optic (SMF) has attracted a lot of attention because of the superior performance over incoherent schemes (Wang et al. 2005). It maps low-rate electrical or optical signals into high-rate optical sequences to achieve simultaneously random multiple access on a common frequency band. The most commonly used modulation format in OCDMA is on-off keying (OOK) with power detection. In a coherent OOK-OCDMA system, the most severe issues are the coherent signal interferences (SI) as well as incoherent multiple access interference (MAI) (Wang et al. 2005). Moreover, by changing the number of active users, a dynamic threshold level setting is required to maintain a wider power margin in receiver setup. Also, the OOK-OCDMA is vulnerable in terms of interception that could be easily broken by simple power detection even without any knowledge of the code (Wang et al. 2006).

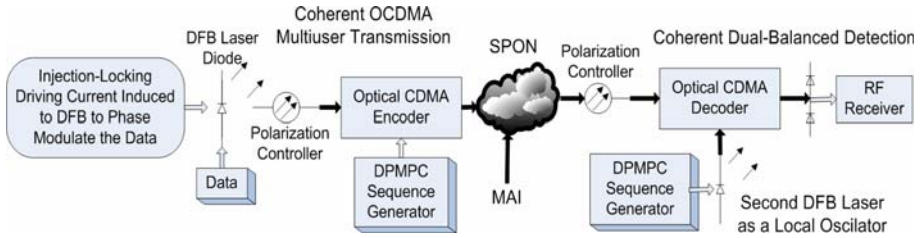
In this study unipolar signaling in terms of optical signature sequences are considered. Double-padded modified prime code (DPMPC) has been extensively introduced and applied to incoherent pulse position modulation (PPM) OCDMA (Karbassian and Ghafouri-Shiraz 2007b,c), frequency shift keying (FSK) OCDMA (Karbassian and Ghafouri-Shiraz 2008a,b) and coherent PSK-OCDMA (Karbassian and Ghafouri-Shiraz 2008c; Karbassian et al. 2007; Karbassian and Ghafouri-Shiraz 2007a). DPMPC has  $P$  groups, each of which has  $P$  sequence codes, thus the total number of available sequences is  $P^2$ . The code-length and weight of each code become  $(P^2 + 2P)$  and  $(P + 2)$  respectively. The in-phase correlation function ( $C_{mn}$ ) for any pair of codes  $m$  and  $n$  at synchronization time ( $T$ ) is given by Karbassian and Ghafouri-Shiraz (2007b):

$$C_{mn} = \begin{cases} P + 2, & \text{if } m = n \text{ Auto} - C_{mn} \\ 0, & \text{if } m \neq n, m \text{ and } n \text{ share the same group} \\ 1, & \text{if } m \neq n, m \text{ and } n \text{ are from different groups} \end{cases} \quad (1)$$

where  $m, n \in \{1, 2, \dots, P^2\}$ . As observable, it enjoys very flexible number of sequences and code-lengths as well as low cross-correlation peaks as compared with the conventional bipolar codes (e.g. Gold codes (Wang et al. 2005, 2006; Benedetto and Olmo 1991; Ayadi and Rusch 1997)).

The system capacity using prime codes is limited by the maximum achievable bit-rate of the electronic circuitry generating the pseudo-noise sequences. We settle on a maximum attainable chip-rate of 10 Gchip/s and a desired bit-rate of 100s of Mbps, leading to a limit in the length of the spreading sequences in the order of hundreds of chips per bit. As Gold sequences are  $N = 2^n - 1$  chips long, with  $n$  being an odd integer, we have limited the results to  $n = 9$ , i.e. a maximum length of 511, whereas with DPMPC there are two further steps where  $P$  equals 23 and 29 with achievable code-lengths ( $N = P^2 + 2P$ ) of 575 and 899, respectively in that they increase system security and capacity.

In the analysis, the system signal-to-noise ratio (SNR) of OCDMA using DPMPC sequences and two different phase modulation methods with homodyne detection are investigated. First method is utilizing Mach-Zehnder interferometer (MZI) as an external phase modulator. The practical feasibility of the MZI modulator and an acceptable number of interferers that can be tolerated by the system was investigated in Gnauck (2003). Second method is utilizing a distributed feedback (DFB) laser diode which modulates the signal's phase through its modulated driver current, so-called injection-locking method. The performance penalty imposed on the system as a result of the limited phase excursion of  $\pm 0.42\pi$  introduced in Ayadi and Rusch (1997) is also evaluated. For the heterodyne structure, only external modulator (i.e. MZI) is evaluated.



**Fig. 1** Transceiver structure of coherent homodyne OCDMA network based on injection-locking phase modulation method of DFB laser diode

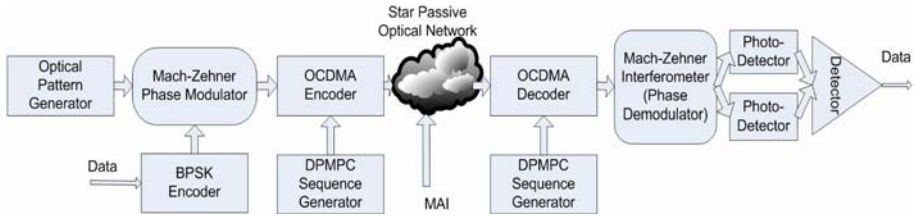
This paper is organized as follows. Coherent homodyne OCDMA structure is modeled in next section including two different phase modulation method analyses and their discussion of results in systems SNRs. Section 3 describes coherent heterodyne OCDMA structure with external phase modulator including the analysis obtaining the system bit-error rate (BER). The study is concluded finally.

## 2 Structure of coherent homodyne OCDMA

In coherent OCDMA system, a high quality reference laser is centrally located and each user uses this reference for injection-locking of inexpensive DFB lasers to act as a source for transmission and also serve as the local oscillator for coherent homodyne detection. Figure 1 illustrates such a system in network concept. The phase is modulated by controlling the injection current to the DFB laser. In this case, data is phase modulated by assigned DPMPC sequence and transmitted over the network. At the receiver a DFB laser is slaved to the reference laser, phase modulated by the original sequence and then combined coherently with the received OCDMA signal. Since the same wavelength source is used for transmission and reception we have homodyne detection. The coherently mixed optical signals are incident on a dual-balanced detector whose electrical output conserves phase information. The possible bipolar electrical signal is integrated over a bit interval and the result compared with a threshold forming the final bit estimation. When phase modulation is achieved by an external modulator as shown in Fig. 2, chip-rate can range to the maximum of 10 Gchip/s; in contrast, the injection current adjusted to achieve phase modulation has the maximum chip-rate of the order of 1 Gchip/s due to the limited phase excursion (Ayadi and Rusch 1997). This reduction in chip-rate may be justified to avoid the expense of an external modulator. As mentioned before, the use of an external MZI modulator for this application was also verified experimentally in Gnauck (2003). Here, at the intended receiver, another MZI is used to demodulate the received signal using the same DPMPC sequence used for encoding at the transmitter in Fig. 2. The optical phase modulator could be followed by a Fabry-Perot optical filter that rejects unwanted crosstalk originating from the MAI outside the filter bandwidth. The optical output of the filter consists of the intended signal and residual MAI.

### 2.1 External phase modulation analysis (with MZI)

Figure 2 shows that for conserving information contained in the phase of the optical carrier, coherent detection is used whereby a local optical source is coherently combined with the received information-bearing signal. In homodyne detection the local oscillator is at the carrier wavelength and the output electrical signal is at baseband. To eliminate the direct current



**Fig. 2** Transceiver structure of coherent homodyne OCDMA network based on MZI as an external phase modulator

(dc) component in this baseband signal a dual-balanced detector is used. Obviously, using a local oscillator with much greater power than the total received signal results in a shot-noise limited regime where dark current and receiver thermal noise are negligible.

Now, the first step is to examine the equations that govern the electrical output of a dual-balanced detector in a system. Let  $K$  denote the number of simultaneous active users and  $S_i(t - \tau_i)$  be the signature sequence of user  $i$ . Let  $\tau_i$  be the relative time-delay between users  $i$  and the desired user (e.g. user #1). At any instant of time  $t$ ,  $C_i(t)$  denotes the piecewise-constant function which is the product of the bit value and the sequence value of user  $i$  at time  $t$ . The initial phase offset of user  $i$  is  $\theta_i$ , a random variable uniformly distributed over the interval  $(0, 2\pi)$ . The received signal, with carrier angular frequency  $\omega_c$ , in phasor format is given by:

$$S = \hat{S} \sum_{i=1}^K e^{j(\omega_c t + C_i(t) \cdot \pi/2 + \pi/2 + \theta_i)} \tag{2}$$

The local oscillator will be modulated by the spreading sequence of the desired user,  $S_1(t)$ . The phasor format of the local oscillator signal is then given by:

$$L = \hat{L} \sum_{i=1}^K e^{j(\omega_c t + S_1(t) \cdot \pi/2 + \pi/2 + \theta_{LO})} \tag{3}$$

The output of the dual-balance detector is hence:

$$\begin{aligned} \frac{2\eta e}{h\nu} Re[LS] &= \frac{2\eta e}{h\nu} \hat{L} \hat{S} \sum_{i=1}^K \cos [(S_1(t) - C_i(t)) \cdot \pi/2 + \theta_{LO} - \theta_i] \\ &= \frac{2\eta e}{h\nu} \hat{L} \hat{S} \sum_{i=1}^K S_1(t) \cdot C_i(t) \cdot \cos(\theta_{LO} - \theta_i) \end{aligned} \tag{4}$$

where  $\eta$  is the photo-detectors quantum efficiency,  $h$  is Planck’s constant,  $e$  is the fundamental charge of an electron, and  $\nu$  is the employed optical frequency. Note that we assume the local oscillator tracks the phase of the desired user, so without loss of generality we use  $\theta_{LO} = \theta_1 = 0$ . The output of the detector, (4), is integrated over a bit interval, leading to the following statistic (Ayadi and Rusch 1997):

$$\begin{aligned}
 S_{out} &= \frac{2\eta e}{h\nu} \hat{L} \hat{S} \sum_{i=1}^K \int_0^T S_1(t) \cdot C_i(t) dt + \sqrt{N_0} \int_0^T n(t) dt \\
 &= \frac{2\eta e}{h\nu} \hat{L} \hat{S} \cdot b_0^i \cdot T + \sqrt{\frac{\eta e^2 T}{h\nu}} \hat{L} \cdot n \\
 &\quad + \frac{2\eta e}{h\nu} \hat{L} \hat{S} \sum_{i=2}^K \left[ b_{-1}^i \cdot R_{i,1}(\tau_i) + b_0^i \cdot \hat{R}_{i,1}(\tau_i) \right] \cdot \cos \theta_i
 \end{aligned} \tag{5}$$

where  $b_0^i$  represents the information bit being detected and  $b_{-1}^i$  is the overlapping previous bit of user  $i$ , and  $b_0^i$  is the overlapping following bit of user  $i$ . The continuous-time partial cross-correlation functions are denoted by  $R_{i,j}(\tau)$  and  $\hat{R}_{i,j}(\tau)$ . The noise  $n(t)$  in (5) is assumed a Gaussian random variable with zero mean and unit variance; all data bits are independent and equiprobable, and the delays are also independent and uniformly distributed over a bit interval. The first term in (5) is due to the desired user, while the second term is additive white Gaussian noise, and the third is the MAI.

For further analysis, the MAI has been assumed to have a Gaussian distribution. The variance of each term in the MAI sums has been shown in [Ayadi and Rusch \(1997\)](#) that approximately equals  $T^2/3N$ , where  $N$  is the code-length ( $2T^2/3N$  corresponds to the correlation and  $1/2$  is due to the phase offset). Hence, the SNR is given by:

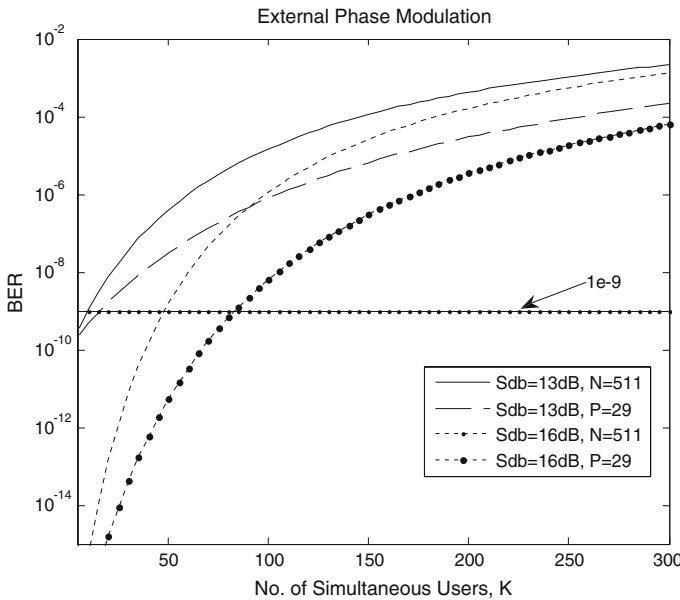
$$SNR = \frac{\left(\frac{2\eta e}{h\nu}\right)^2 \hat{L}^2 \cdot \hat{S}^2 \cdot T^2}{\left(\frac{2\eta e}{h\nu}\right)^2 \hat{L}^2 \cdot \hat{S}^2 \cdot T^2 \cdot \frac{K-1}{3N} + \frac{\eta e^2 T}{h\nu} \cdot \hat{L}^2} = \frac{1}{\frac{K-1}{3N} + \frac{h\nu}{4\eta \hat{S}^2 T}} \tag{6}$$

Note that  $4\eta \hat{S}^2 T/h\nu$  is the single-user SNR, that shows the SNR is equal to it if the MAI is zero ( $K = 1$ ). Since we have BPSK signaling in Gaussian noise, the BER can be calculated directly from the accomplished SNR.

Figure 3 clearly explains the system behavior versus the number of simultaneous active users ( $K$ ) and compares DPMPC of  $P = 29$  and Gold-sequences of  $N = 511$  as discussed in [Benedetto and Olmo \(1991\)](#), [Ayadi and Rusch \(1997\)](#). Figure 3 shows the higher the single-user SNR (shown as  $S_{db}$  in the graphs) the lower the BER achieved. By comparing these two codes, it is noticeable that DPMPC increases the system capacity in terms of accommodating more simultaneous active users, up to two times more. For example, following the  $S_{db}$  of 16 dB in Fig. 3, the system employed DPMPC tolerates maximum of 82 (10% of full-load in case of  $P = 29$ ) simultaneous users having  $BER = 10^{-9}$  while the system employed Gold-sequences tolerates 42 simultaneous users.

### 2.2 Injection-locking phase modulation (with DFB)

As presented in Fig. 1, the injection current of DFB laser diode is modulated to accomplish PSK signaling at the transmitter, with phase excursion limited to  $\pm 0.42\pi$  and modulation speed no greater than 1 Gchip/s ([Benedetto and Olmo 1991](#); [Ayadi and Rusch 1997](#)). At the receiver we demodulate via injection-locking of the local oscillator which is another DFB shown in Fig. 1, however as it is no longer possible to track the desired user’s initial phase offset by injection-locking, another tracking method is assumed to be used in that  $\theta_1 = \theta_{LO}$  is still zero. By writing  $\pm 0.42\pi = \pm \pi/2 \mp 0.08\pi$ , the data and local oscillator signals are therefore given as the following forms:



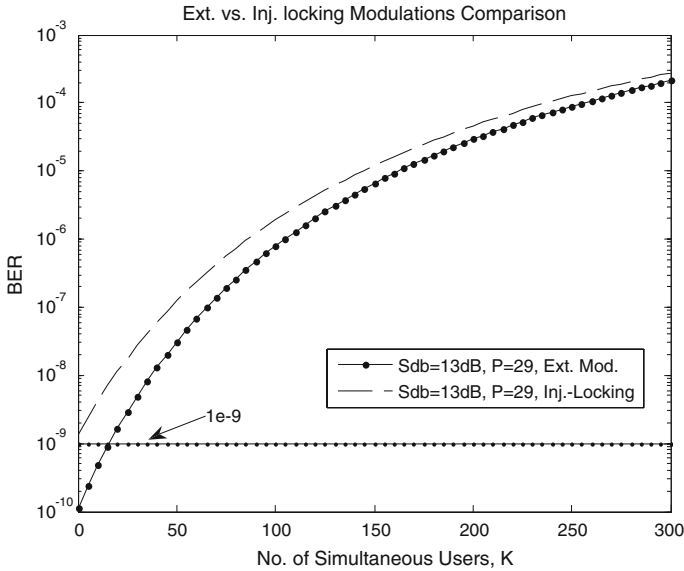
**Fig. 3** BER performance of externally phase modulated (with MZI) coherent homodyne OCDMA system versus number of simultaneous users,  $K$

$$\begin{aligned}
 S &= \hat{S} \sum_{i=1}^K e^{j(\omega_c t + C_i(t) \cdot (\pi/2 - 0.08\pi) + \pi/2 + \theta_i)} \\
 &= \hat{S} \sum_{i=1}^K e^{j(\omega_c t + \pi/2 \cdot C_i(t) + \pi/2 + \theta_i)} \cdot e^{j0.08\pi C_i(t)} \tag{7}
 \end{aligned}$$

$$L = \hat{L} \sum_{i=1}^K e^{j(\omega_c t + S_1(t) \cdot \pi/2 + \pi/2)} \cdot e^{j0.08\pi \cdot S_1(t)} \tag{8}$$

By calculating the same way as in previous subsection, the output of the dual-balanced detector under this condition contains two new terms as compared with (5) due to the phase limitation. The first term is going to be constant in time, and for the purposes of our analysis, this can be estimated and subtracted with no error. The last term involves the weighted-sum of the difference of two codes. The weighted-sum is bounded by the sum over the pseudo-codes, which in turn is negligible compared with the main signal term in the output as the code-length becomes arbitrarily larger than the number of active users ( $N \gg K$ ). Therefore, by approximating the output with the main term alone plus noise by integrating over a bit interval, the output signal is thus obtained. By using the same Gaussian approximation for the MAI, the SNR is then achieved as follows:

$$\begin{aligned}
 SNR &= \frac{\left(\frac{2\eta e}{h\nu} \cos^2 0.08\pi\right)^2 \hat{L}^2 \cdot \hat{S}^2 \cdot T^2}{\left(\frac{2\eta e}{h\nu} \cos^2 0.08\pi\right)^2 \hat{L}^2 \cdot \hat{S}^2 \cdot T^2 \cdot \frac{K-1}{3N} + \frac{\eta e^2 T}{h\nu} \cdot \hat{L}^2} \\
 &= \frac{1}{\frac{K-1}{3N} + \frac{h\nu}{4\eta \hat{S}^2 T \cos^4 0.08\pi}} \tag{9}
 \end{aligned}$$



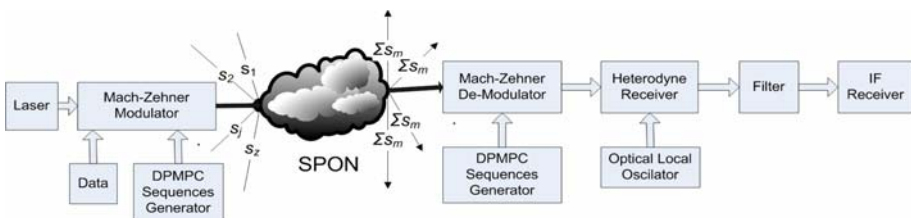
**Fig. 4** BER performance comparison of two different phase modulation methods on coherent homodyne OCDMA systems versus number of simultaneous users,  $K$

By comparing (6) and (9), it is noticed that the only difference is the cosine term which causes 0.6dB degradation. While this is analogous to each single user expecting a power-loss of twice, since the limitation applies to modulator and demodulator, then the degradation dually equals 1.2 dB ( $20 \log \theta$ , where  $\theta$  is the phase limitation).

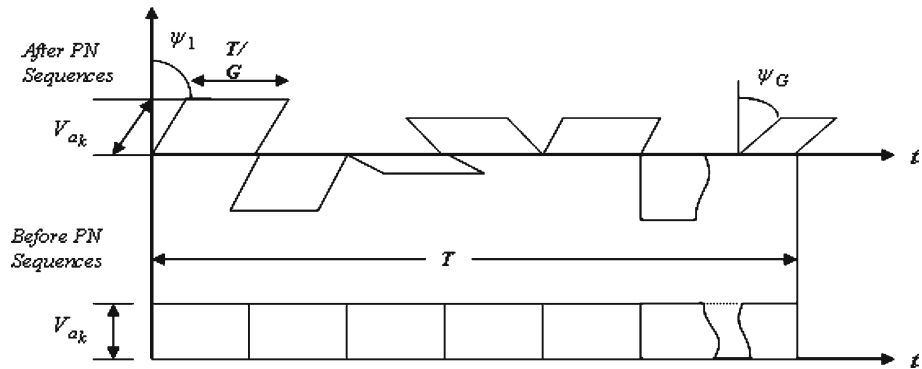
The behavior of these two systems is analyzed and shown in Fig. 4 in terms of  $K$ , where  $Sdb$  and  $P$  are set to 13 dB and 29 respectively. The external modulation indicates remarkably enhanced performance, particularly at the lower number of simultaneous active users.

### 3 Structure of coherent heterodyne OCDMA

As a reference configuration, we consider a star passive optical network (SPON) with  $Z$  transmitters and  $Z$  receivers employing a coherent BPSK modulation scheme with heterodyne detection as shown in Fig. 5. Each incoming bit is encoded by means of a DPMP sequence, acting as the address of the destination.



**Fig. 5** Transceiver structure of coherent heterodyne OCDMA network with MZI phase modulator



**Fig. 6** Pseudorandom rotation of the modulating signal's phase during each chip interval in a unit energy pulse

Let  $x_i$  be the DPMPC sequence identifying the  $i$ th receiver and each '1' or '0' symbol forming the DPMPC sequence called 'chips'. The following rule is applied in the BPSK scheme: Either  $x_i$  or  $\bar{x}_i$  is transmitted, depending on whether a '1' or a '0' data bit is to be sent, where  $\bar{x}_i$  is derived from  $x_i$  by inverting each chip in the sequence.

The signals from all the transmitters are then summed up and broadcasted to every receiver (multiplexed). The receivers perform a correlation between the received signal and their own address code; all the signals except the properly encoded one will be decoded as interfering signals, while the latter will give rise to a correlation peak. Hence, several simultaneous transmissions addressed to different receivers are made possible. Because the periodic cross-correlation between DPMPC sequences in different groups is not zero (but it is as low as '1') (Karbassian and Ghafouri-Shiraz 2007b), the interfering signals will reduce the noise margin of the receivers.

The spreading and de-spreading operations can be performed directly on the optical domain by means of a lithium-niobate crystal phase modulator (Benedetto and Olmo 1991), driven by the incoming data and the address sequence. After the de-spreading, the signal is heterodyne-detected and processed for the decision according to the chosen modulation scheme.

Because of the spreading, the maximum achievable bit-rate is limited by the speed of the electronic circuitry which generates the prime code sequences. If we pose the limit of 10Gchip/s to the chip-rate and want to keep the bit-rate sufficiently high (hundreds of Mbps), we are limited to spreading sequences having lengths in the order of hundreds as discussed before.

As presented in Fig. 6, the spreading is taken to be the form of a pseudorandom rotation of the modulating signal's phase during each chip interval  $T_c$  according to the DPMPC sequence associated with the intended receiver (user). The receiver de-spreads the received signal using the exact DPMPC sequence by subtracting the same phase pattern used in the spreading process. After de-spreading, it is as if no spreading had been done. For proper de-spreading the address sequence used in the receiver must be synchronized with the one used in the transmitter. This synchronization is one of the tasks to be performed by the call-start-up procedure, together with carrier-frequency acquisition. These are also challenging functions; however, we will not discuss them here in that the focus is on the key issue of the performance of an ongoing call under the assumption that other users are actively engaged in a call.

### 3.1 Outline of heterodyne analysis

By using a semi-analytical method as in [Benedetto and Olmo \(1991\)](#), the final results are obtained. In the following the main guidelines for the BPSK modulation is outlined.

Let us assume the  $l$ th signal is from the intended user. As the signal is heterodyne detected, thus the receiver output after multiplication contains both an unwanted optical signal and the required intermediate frequency (IF) signal which is selected through the filter. As aforementioned, using a local oscillator with greater power than the total received signal results in a shot-noise limited regime where dark current and receiver thermal noise are negligible. The IF signal level is proportional to the phase shift of the incoming signal, the higher the difference in phase between the two states the higher will be the difference between the two output voltage levels from the receiver. Decisions are taken by the IF receiver on the basis of the IF signal level achieved from the following variable  $Z(T)$  ([Benedetto and Olmo 1991](#)):

$$Z(T) = \frac{R}{2N} \left[ N \cdot d_l + \sum_{i=1, i \neq l}^K d_i \cdot X_{li} \right] + n_B(T) \tag{10}$$

where  $K$  is the number of simultaneous active users,  $N$  is the sequence code-length,  $d_i$  is the  $i$ th transmitter data bit,  $R$  is a constant relating to the photo-detector responsivity,  $n_B(T)$  is the sampled baseband Gaussian noise process and  $X_{li}$  is a random variable representing the cross-correlation between the DPMP sequences used by the  $i$ th and  $l$ th transmitters. We define the new random variable,  $W$ , as:

$$W = \sum_{i=1, i \neq l}^K d_i \cdot X_{li} \tag{11}$$

Its probability density function (PDF) can be obtained from the independent values of random variable  $X_{li}$ . The in-phase cross-correlation value as introduced in (1) is either *zero* or *one* depending on whether the codes are in the same group or from the different groups. Obviously, the *zero* value does not cause the interference due to perfectly orthogonal sequences, while the *one* value causes the interference which is only among intended user and  $(P^2 - P)$  users from the different groups (i.e.  $P^2$  whole sequences and  $P$  sequences from the same group of intended user which are orthogonal). As, the cross-correlation values are uniformly distributed among interfering users, thus the PDF of  $w$ , realization of  $X_{li}$ , is:

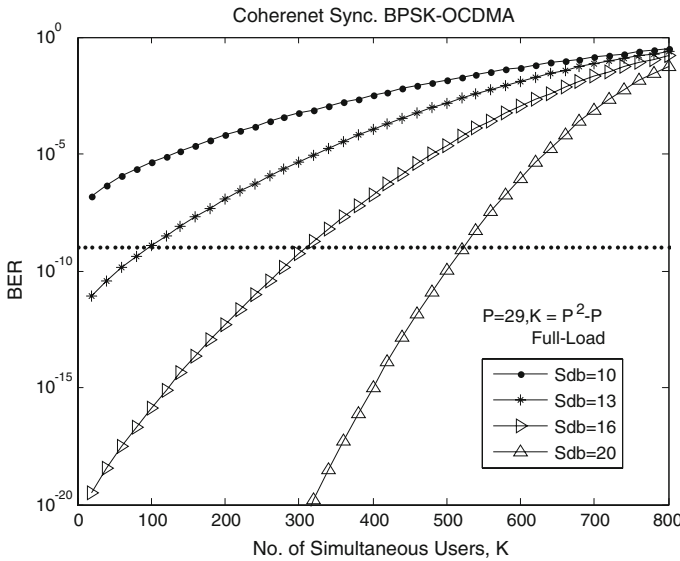
$$P(w = i) = \frac{i}{P^2 - P} \tag{12}$$

where  $P(w = i)$  is the probability that  $w$  assumes the value  $i$  (number of actively involved users in transmission). Based on the knowledge of the PDF of  $w$ , representing the interference, after some calculations based on the modulation scheme, the following expression for the BER, conditioned to a number of simultaneous transmissions  $K$ , can be obtained:

$$BER_K = \frac{1}{2} \sum_{i=0}^{w_m} \text{erfc} \left[ \frac{N - i}{N} \cdot \sqrt{r} \right] \cdot P(w = i) \tag{13}$$

where  $w_m$ , is the largest value assumed by the random variable  $w$  that depends on  $K$  and denotes the interference,  $r$  is the single-user SNR as follows:

$$r = \frac{E_b}{N_0} = \frac{\eta P_s}{2h\nu B_{IF}} \tag{14}$$



**Fig. 7** BER performance of coherent heterodyne OCDMA system versus number of simultaneous users,  $K$

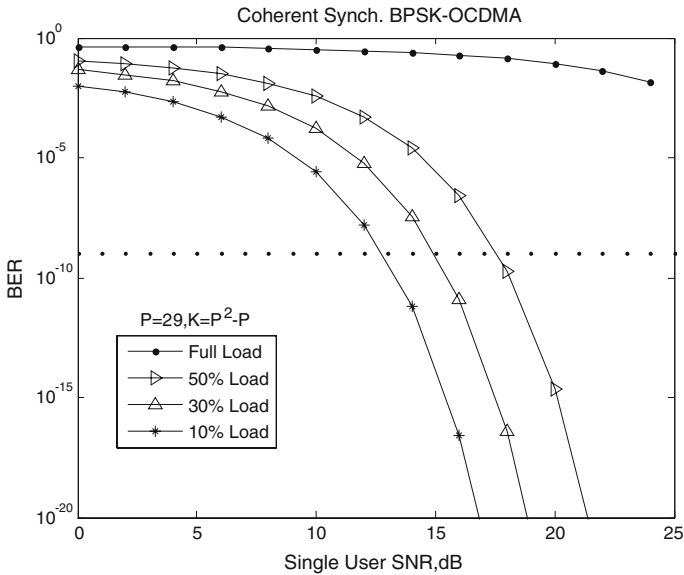
where  $E_b$  is energy per bit,  $N_0$  is noise power,  $\eta$  is the photo-detector quantum efficiency,  $P_s$  is the received signal power,  $h$  is the Planck constant,  $\nu$  is the employed optical frequency and  $B_{IF}$  is the IF frequency bandwidth.

The performance (i.e. BER) of this structure is illustrated in Fig. 7 versus the number of simultaneous users  $K$ , for the prime number  $P = 29$ . The system performs under a different number of users from non-interference ( $K = 1$ ) to full-load interference ( $K = P^2 - P = 812$ ), taking into account various  $r$  (shown as  $S_{db}$  in the graphs) of 10, 13, 16 and 20 dB. As can be observed, the higher  $r$  the lower BER achieved. Figure 7 explains when  $r$  is 13 or 16 dB, the maximum number of simultaneous users in which the system  $BER = 10^{-9}$  is  $K_c = 101$  (12.5% of total simultaneous users) or  $K_c = 304$  (37.5% of total simultaneous users), respectively. It indicates that by maintaining  $BER = 10^{-9}$ , the system can accommodate an increased number of simultaneous users as compared with other systems using bipolar Gold-family codes discussed in Benedetto and Olmo (1991), Ayadi and Rusch (1997). This critical value ( $K_c$ ) depends on  $r$  and can be obtained by setting  $BER = 10^{-9}$ .

Figure 8 shows the system BER variation versus  $r$  with  $K$  as a given parameter. As expected, again the higher  $r$  the more enhanced performance is obtained. In this analysis  $K$  changes from 10% to full-load for  $P = 29$ . As Fig. 8 indicates, to maintain  $BER = 10^{-9}$ ,  $r$  should be 13 dB (for 10% load), 16 dB (for 30% load) or 18 dB (for 50% load).

### 4 Conclusion

Different architectures of coherent OCDMA with the network perspective have been analyzed regarding homodyne and heterodyne detections. The BER performance of structures deployed unipolar spreading codes (DPMP) is investigated with the effects of the multi-user interferences. This paper also presented SNR of coherent homodyne OCDMA systems using either external or injection-locking phase modulation methods by assuming Gaussian distributed multiple co-channel interferences. Thus, employing DPMP outperforms



**Fig. 8** BER performance of coherent heterodyne OCDMA system versus single-user SNR,  $r$

the conventional bipolar sequences in terms of more flexible code-lengths and the increased number of accommodated active users. The limited phase excursion causes (i) separate phase tracking, (ii) a dc value needed estimation and removal and (iii) degradation in BER equivalent to the signal loss of 1.2 dB. However this loss is small in comparison with the MAI penalty for multiple simultaneous users.

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