An optical CDMA system based on chaotic sequences*

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In this paper, a coherent asynchronous optical code division multiple access (OCDMA) system is proposed, whose encoder/decoder is an all-optical generator. This all-optical generator can generate analog and bipolar chaotic sequences satisfying the logistic maps. The formula of bit error rate (BER) is derived, and the relationship of BER and the number of simultaneous transmissions is analyzed. Due to the good property of correlation, this coherent OCDMA system based on these bipolar chaotic sequences can support a large number of simultaneous users, which shows that these chaotic sequences are suitable for asynchronous OCDMA system.
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Chaotic systems have a very sensitive dependence on their initial conditions, and chaotic signals are broadband, noise-like but deterministic. This makes it easy to generate numerous uncorrelated and random-like chaotic sequences. These properties make the chaotic sequences very useful for spread spectrum applications, and chaotic sequences provide the code division multiple access (CDMA) system with more security features than the conventional binary sequences. Various methods for designing chaotic sequences have been proposed to improve the capacity and security of CDMA system[1-7]. Optical CDMA (OCDMA) is an important technology of optical communication[8,9]. How to generate chaotic sequences and apply them into optical CDMA system is an interesting and new research topic. Ref.[10] designed an all-optical generator of chaotic sequences and introduced a non-coherent OCDMA system based on this generator. But the capacity of this system is small, because the generated chaotic sequence is unipolar. We have designed a chaotic sequence generator which can generate analog chaotic sequences for satisfying the logistic maps[11]. In this paper, we design an OCDMA system whose encoder is the all-optical generator described in Ref.[11]. The performance of this OCDMA system is analyzed in terms of bit error rate (BER).

The Mach-Zehnder interferometer (MZI) shown in Fig.1 can modulate the input electric field. If the arm lengths are some special values, the output of the MZI can have a profile in cosine function of phase shift. This makes it possible to design a chaotic sequence generator by utilizing MZIs[11]. The generator composed of N MZIs with phase shifters and fiber-optic delay lines is shown in Fig.2. The coupler divides the coherent pulse into N pulses equally, and launches them into each MZI. The electric fields of E_1, E_2, $\cdots$, E_N output from different MZIs can satisfy the logistic map.

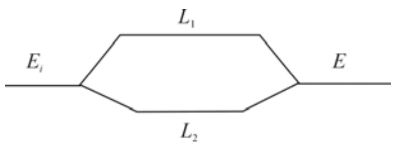

Fig.1 Schematic diagram of the MZI

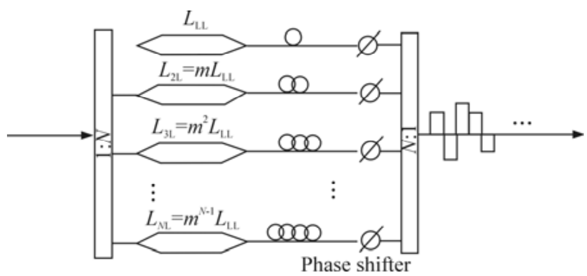

Fig.2 The generator of chaotic sequences composed of MZIs, phase shifter and fiber-optic delay lines

We propose a coherent OCDMA system based on this generator of chaotic sequences which can be used as the encoder of the OCDMA system. To simplify the analysis, the noises, such as shot and thermal circuit noise, are not considered, and Gaussian hypothesis is made on the multiple access interference (MAI).

The transmitter consists of a coherent pulse laser, a data modulator and a generator of chaotic sequences. The laser emits the optical pulses with width of T_c and interval of T_b. The pulse stream from the laser is phase-

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modulated by the data. The data of the kth user is

$$d_k(t)=\sum_{i=-\infty}^{\infty}d_i^{(k)}p_{T_b}(t-iT_b)\,, \tag{1}$$

where the information data bits $\{d_i^{(k)}\}$ take on values of {-1, 1} with equal probability. The modulated signal is encoded via the generator to produce an optical bipolar chaotic sequence which is analog. The output of the kth encoder is

$$y_k(t)=\sqrt{\frac{2P_0}{N}}d_k(t)C_k(t)\exp[\mathrm{j}(wt+\varphi_k)]\,, \tag{2}$$

where P_0 is the optical pulse power, N is the length of the chaotic sequence, w is the optical angular frequency, and φ_k is the optical carrier phase which is uniformly distributed within [0, 2π]. $C_k(t)$ is the chaotic sequence of the kth user, which can be expressed as

$$C_k(t)=\sum_{n=1}^{N}c_n^{(k)}(t-nT_c)\,, \tag{3}$$

where $c_n^{(k)}$ is the code element which can be represented by

$$c_n^{(k)}=\cos\frac{2\pi nm^{n-1}L_1^{(k)}}{\lambda}\,, \tag{4}$$

where $L_1^{(k)}$ is the arm length of the first MZI in the kth encoder.

The optical signals from the simultaneous users are multiplexed in a star coupler. At the receiver, the signal is coherently detected through homodyne correlation detection (HCD) proposed by Ref.[12]. The received optical signal is correlated with an optical pulse code locally generated by a pulsed local oscillator (LO) in tandem with an encoder representative of the selected user. The resultant correlation signal in the electrical domain is integrated over a bit duration and discriminated by a threshold device. The advantages of this receiver architecture are that the detection in the chip duration is avoided and the chip duration is only limited by the optical pulse width of available light sources. The received signal of the first user is

$$r(t)=\sqrt{\frac{2P_0}{N}}\sum_{k=1}^{K}d_k(t-\tau_k)c_k(t-\tau_k)\exp[\mathrm{j}(\omega t+\varphi_k)]\,, \tag{5}$$

where K is the number of simultaneous users, τ_k is the access delay uniformly distributed in [0, T_b], and φ_k is the optical carrier phase uniformly distributed in [0, 2π]. For the first user, φ_1 and τ_1 can be assumed as zero.

The locally generated code of the first user is[11]

$$L_1(t)=\frac{\sqrt{2P_L}}{\sqrt{N}}c_1(t)\exp(\mathrm{j}\omega t)\,, \tag{6}$$

where P_L is the optical pulse power. The received signal is correlated and integrated in [0, T_b] by an integrator. The output of the integrator is

$$Z_1=\frac{2\eta\sqrt{P_0P_L}}{N}\times\left\{Td_{1,0}+\cos\varphi_k\sum_{k=2}^{K}\left[d_{k,-1}R_{k1}(\tau_k)+d_{k,0}\overline{R_{k1}(\tau_k)}\right]\right\}\,, \tag{7}$$

where $R_{k1}(\tau_k)=\int_0^{\tau_k}c_k(t-\tau_k+T)c_1(t)\mathrm{d}t$, $\overline{R_{k1}(\tau_k)}=\int_{\tau_k}^{T}c_k\times(t-\tau_k)c_1(t)\mathrm{d}t$, $d_{1,0}$ is the data bit of the first number in interval [0, T_b], and $d_{k,-1}$ and $d_{k,0}$ are the data bits of the kth user in intervals [$-T_b$, 0] and [0, T_b], respectively. The useful signal is $\frac{2\eta\sqrt{P_0P_L}}{N}Td_{1,0}$ whose energy is $\frac{4T^2\eta^2P_0P_L}{N^2}$. The MAI has a zero mean and a variance as[13]

$$\sigma=\frac{4T^2\eta^2P_0P_L}{6N^5}\left(\sum_{k=2}^{K}r_{k1}\right). \tag{8}$$

We can obtain

$$SNR=\left\{\frac{1}{6N^3}\sum_{k=2}^{K}r_{k1}\right\}^{-\frac{1}{2}}\,, \tag{9}$$

$$p_e=Q(SNR)\,. \tag{10}$$

Fig.3 shows the curves of BER versus the number K of simultaneous transmissions for chaotic sequences with lengths of 60, 100, 200 and 400 for m=2 and m=3.

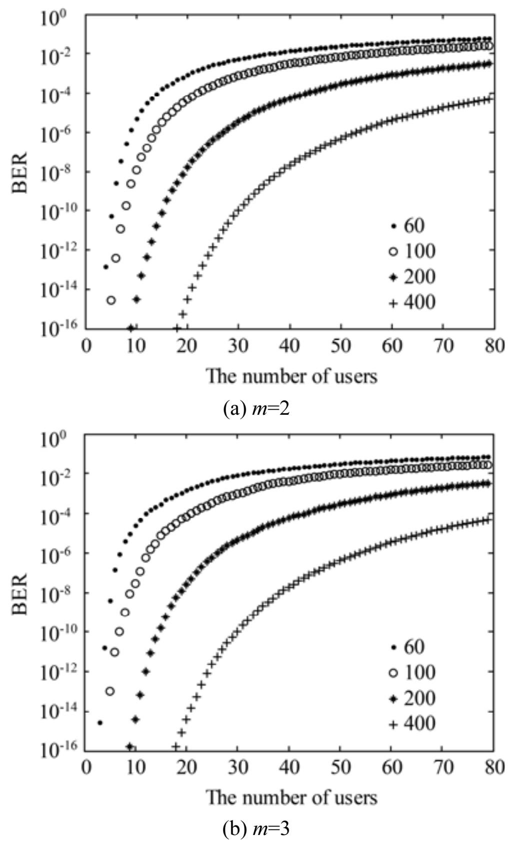

Fig.3 BER as a function of the number of simultaneous users for chaotic sequences with lengths of 60, 100, 200 and 400

Due to the good property of correlation, these bipolar chaotic sequences can support a large number of simultaneous users. The ratio of the number of the simultaneous users to the code length is approximately 10% at BER of 10^{-9}, which is close to the value when Gold sequences are employed[12].

Chaotic systems are very sensitive to the change of their initial conditions, which makes it easy to generate numerous chaotic sequences and enhance the security of transmission. Using MZIs combining phase shifters and fiber-optic delay lines, we design a passive generator which can generate analog chaotic sequences satisfying the logistic maps. The generator can be used as an encoder in an OCDMA system based on chaotic sequences. The performance of this OCDMA system is analyzed in terms of BER. The results of BER show that these chaotic sequences are suitable for asynchronous OCDMA system due to the good property of correlation.

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