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Advanced Engineering Informatics

Elixir Adv. Engg. Info. 61 (2013) 17209-17213

ISSN: 2229-712X

Next Generation CDMA Technology

Irfan Ali[1] and Ankit Agarwal[2]

[1]Department of Electronics and Communication, Jagannath University, Jaipur, India.
[2]Department of Electronics & Communication, SKITM&G, Jaipur, India.

ARTICLE INFO

Article history:
Received: 2 July 2013;
Received in revised form:
14 August 2013;
Accepted: 17 August 2013;

Keywords
OCDMA,
MAI,
OOC,
SNR,
BER.

ABSTRACT

This paper presents the new trends in code division multiple access techniques known as Optical CDMA Technology. I highlight those trends and features that are believed to be essential to the successful introduction of various OCDMA techniques in communication systems and data networks in near future. In particular, i elaborate on enabling technologies that are needed prior to full scale consideration of OCDMA in communication systems. I extend my discussion to various data network. It is believed that OCDMA once fully developed and matured will be an inseparable part of advanced optical communication systems and networks due to its various desirable features and functionalities, in not so distant future. Optical Code Division Multiple Access (OCDMA) is an optical processing system which allows multiple users to share the same bandwidth simultaneously without interfering with each other using unique optical codes. In this paper we present an in depth review on the new trends and the directions taken by the researchers worldwide in Optical Code Division Multiple Access (OCDMA) systems.

Introduction

In order to make full use of the available bandwidth in optical fibres and to satisfy the bandwidth demand in future networks, it is necessary to multiplex low-rate data streams onto optical fibre to accommodate great number of subscribers. There is a need for technologies that allow multiple users to share the same frequency, especially as wireless telecommunications continues to increase in popularity. Currently, there are three common types of multiple access systems:

- Wavelength division multiple access (WDMA)
- Time division multiple access (TDMA)
- Code division multiple access (CDMA)

A. ***WAVELENGTH DIVISION MULTIPLE ACCESS (WDMA)***

In WDMA system, each channel occupies a narrow optical bandwidth (≥100 GHz) around a centre wavelength or frequency. The modulation format and speed at each wavelength can be independent of those of other channels as shown in Figure 1. Arrayed or tuneable lasers will be needed for WDMA applications. Because each channel is transmitted at a different wavelength, they can be selected using an optical filter.

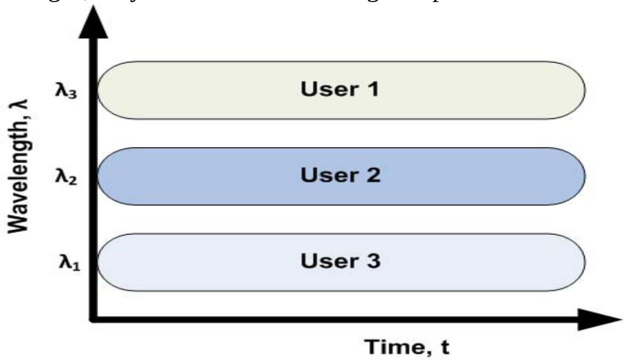

Figure 1- Resource sharing based on WDMA technique

Tuneable filters can be realized using acousto-optics liquid crystal or fibre Bragg grating. To increase the capacity of the fibre link using WDMA we need to use more carriers or wavelengths, and this requires optical amplifiers and filters to operate over extended wavelength ranges. Due to greater number of channels and larger optical power the increased nonlinear effects in fibres causes optical crosstalk such as four wave mixing over wide spectral ranges.

B. ***TIME DIVISION MULTIPLE ACCESS (TDMA)***

In TDMA system, each channel occupies a pre-assigned time slot, which interleaves with the time slots of other channels as shown in Figure 2.

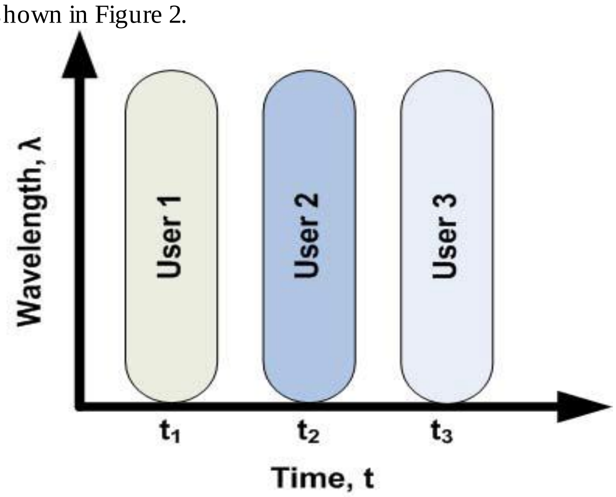

Figure 2 - Resource sharing based on TDMA technique

Synchronous digital hierarchy (SDH) is the current transmission and multiplexing standard for high-speed signals, which is based on time division multiplexing. Optical TDMA (OTDMA) networks can be based on a broadcast topology or incorporate optical switching. In broadcast networks, there is no

Tele:
E-mail addresses: mail2irfan85@gmail.com, ankitsagarwal@gmail.com

routing or switching within the network. Switching occurs only at the periphery of the network by means of tuneable transmitters and receivers. The switch-based networks perform switching functions optically within the network in order to provide packet-switched services at very high bit-rates. OTDMA systems offer a large number of node addresses, however, the performance of OTDMA systems is ultimately limited by the time-serial nature of the technology. OTDMA systems also require strong centralized control to allocate time slots and to manage the network operation.

C. *CODE DIVISION MULTIPLE ACCESS (CDMA)*

CDMA is one of a family of transmission techniques generically called spread spectrum, explained in the following section. In this technique, the network resources are share among users which are assigned a code instead of time slot like TDMA or a wavelength like WDMA. Then, users are capable of accessing the resources using the same channel at the same time, as shown in the Figure 3. The concepts of spread spectrum i.e. CDMA seem to contradict normal intuition, since in most communications systems we try to maximize the amount of useful signal we can fit into a minimal bandwidth. In CDMA we transmit multiple signals over the same frequency band, using the same modulation techniques at the same time. Traditional thinking would suggest that communication would not be possible in this environment.

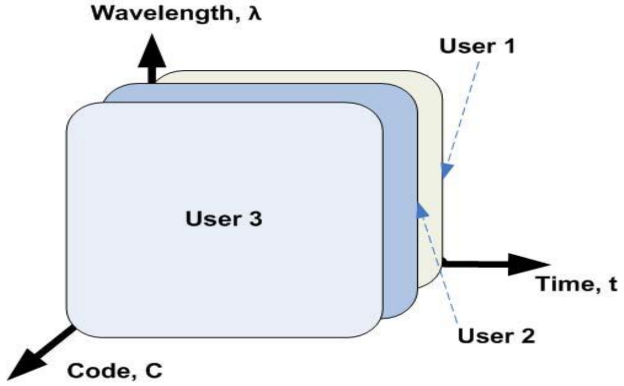

Figure 3 - Resource sharing based on CDMA technique

NEXT GENERATION CDMA TECHNOLOGY

Fiber optics is a particularly popular technology for local area networks. In addition, telephone companies are steadily replacing traditional telephone lines with fiber optic cables. In the future, almost all communications will employ fiber optics. Code Division Multiple Access (CDMA) is a well known scheme for multiplexing communication channels that is based on the method of direct-sequence spread spectrum. In CDMA, every channel is identified by a unique pseudo noise key, whose bandwidth is much larger than that of the input data. Ideally, the key should mimic the correlation properties of white noise and should be as long as possible in order to minimize the interference noise introduced by other channels; thus, a great deal of effort is invested in finding practical keys with good autocorrelation and cross-correlation properties. Optical CDMA is a technology to realize multiplexing transmission and multiple access by coding in the optical domain, which supports multiple simultaneous transmissions in the same time slot and the same frequency. It is another technology of multiplexing and multiple access besides OTDM and WDM and a potentially promising technique for optical networks in the future, and especially, due to its easy access and flexible network structure, it is very applicable to the access network. Now days, OCDMA systems are highly interesting as they offer several sought-after features such as asynchronous access, privacy, secure transmissions, and ability to support variable bit rates and busy traffic and provide high scalability of the optical network. In 1986, Prucnal, Santoro and Fan proposed to realize the fiber-optic LAN by using optical signal processing, and used prime codes to carry out the experiment of electronic encoding and fiber-optic delay line decoding, verifying the feasibility to implement incoherent OCDMA system by encoding in the time domain. In 1988, Weiner, Heritage and Salehi demonstrated how to spread the femto-second optical pulse into pico-second duration pseudo noise bursts. The spread frequency was achieved by encoding the light spectrum into pseudorandom binary phase and then by decoding the spectrum phase encoded to recover the original pulse. They proposed that the coherent ultra-short pulse coding and decoding could be applied to the fast reconfigurable OCDMA communication networks. Both breakthrough studies were milestones for the development of OCDMA. Optical orthogonal codes (OOC) defined by Salehi, Chung, and Wei are a family of (0,1) sequences with desired autocorrelation and cross-correlation properties providing asynchronous multi-access communications with easy synchronization and good performance in OCDMA communication networks.

Optical orthogonal codes

An optical orthogonal code is a family of (0, 1) sequences with good auto and cross-correlation properties. Thumbtack-shaped auto-correlation enables the effective detection of the desired signal and low-profiled cross-correlation makes it easy to reduce interference due to other users and channel noise. The use of optical orthogonal codes enables a large number of asynchronous users to transmit information efficiently and reliably. The lack of a network synchronization requirement increases the flexibility of the system. The codes considered here consist of truly (0,1) sequences and are intended for "unipolar" environments that have no negative components since you either have light, or you don't, while most documented correlation sequences are actually (+1, -1) sequences intended for systems having both positive and negative components. An optical orthogonal code (n, w, λ_a ,λ_c) is a family C of (0, 1) sequences of length *n* and weight *w* which satisfy the following two properties.

1) The Auto-Correlation Property:

$$\sum_{t=0}^{n-1} x_t x_{t+\tau} \leq \lambda_a \qquad (1)$$

for any $x \in C$ and any integer t, 0 < t < n.

2) The Cross-Correlation Property:

$$\sum_{t=0}^{n-1} x_t y_{t+\tau} \leq \lambda_c \qquad (2)$$

for any x ? $y \in C$ and any integer t.

The numbers λ_a and λ_c are called the auto and cross-correlation constraints. The (0, 1) sequences of an optical orthogonal code are called its code words. The number of code words is called the size of the optical orthogonal code. From a practical point of view, a code with a large size is required. A desirable property of a code is that it should be as large as possible i.e. contains as many code words as possible. This is to enable more users to access the channel. When $\lambda_a = \lambda_c = \lambda$, and called optimal OOC. C shows the cardinality of the code sequences i.e. the size of the code which refers to the number of code words contained in the code family. The largest possible size of the set with conditions of (n, w, l) denotes F(n, w, l). By the aid of Johnson bound, it is known that F should satisfy

$$\Phi\ (n, w, \lambda) \leq \frac{(N-1)(N-2)\,......(N-\lambda)}{W(W-1)(W-2)\,.......(W-\lambda)} \quad (3)$$

In case of $\lambda_c = \lambda a = 1$, i.e. strict OOC, it can be shown that the number of codes is upper-bounded by

$$|C| \leq \frac{(N-1)}{W(W-1)} \quad (4)$$

Where ⌊x⌋ denotes the integer portion of the real number x. An example of a strict OOC (13, 3, 1) code set is C= {1100100000000, 1010000100000}. It is clear that the auto-correlation is thus equal to the code-weight of 3, and the nonzero shift auto-correlation and the cross-correlation is less than or equal to one. The same code set can be represented using the set notation of {(1,2,5);(1,3,8)}mod(13), where the elements in the set represent the position of the pulses (i.e. 1s) in the code sequence of code-length 13. The (0, 1) sequences of an optical orthogonal code are called its code words. The number of code words is called the size of the optical orthogonal code. From a practical point of view, a code with a large size is required. A desirable property of a code is that it should be as large as possible i.e. contains as many code words as possible. This is to enable more users to access the channel. An OOC is said to be optimal if it has the maximum cardinality for a given n, w, λ. Optical CDMA extract data with desired code in the presence of all other user's optical pulse sequences, therefore set of code words should be designed to satisfy three fundamental conditions:-

(i) For any codeword the non shifted auto correlation, equal to the hamming weight of the codeword, should be made large as possible, this ensures that the receiver signal is much larger than the background noise in the system.

(ii) For any codeword the shifted auto correlation must be much less than the hamming weight of the codeword. This requirement ensures that the output of correlator receiver will be a small when the receiver is not synchronized with the transmitter and allows OCDMA to operate asynchronously without to operate asynchronously without the need for a global clock signal.

(iii) The cross–correlation between any pair of code words must be small. This property ensures that the each codeword can easily be distinguished from every other address sequence. This makes MAI insignificant compared to the energy contained in the receiver information bit.

In OCDMA many users are transmitting information over a common wide-band optical channel. The target is to design an efficient system, to allow the users to share the common channel. Traditional multiple access techniques such as frequency division multiplexing, time division multiplexing, collision detection or demand assignment require network synchronization at high speed (optical speed), and frequent conversions between the optical domain and the electronic domain. These requirements limit the efficiency of such an optical multiple access system. But if a code division multiple access system with optical orthogonal codes is applied, it simplifies greatly the complexity of the system, and achieves potentially higher transmission efficiency.

OPTICAL CDMA SYSTEM

Although in the Code Division Multiple Access (CDMA) system soft capacity is obtained, the system faces interference in case of two users simultaneously access the communication channel which, in turn, degrades the performance of the CDMA system. Consequently, the main shortcoming of the CDMA system is multiple users' access of the communication channel. For this reason, scientists and researchers are looking at systems that enable transmission without interference. Nevertheless, there are several differences between the electrical and the optical CDMA. The optical CDMA is very important and becoming increasingly popular due to its high available bandwidth and elimination of cross talks. In the OCDMA system, multiple users can access the same channel with help of various coding techniques. In OCDMA, the transmission signal may be subjected to conversion from electrical-to-optical, optical-to-optical or optical-to-electrical signal domain. The OCDMA system consists of five main sections:

1. Data source (i.e., transmitting computer).
2. Optical CDMA encoder.
3. Optical star coupler: Device that accepts one input signal and is able to output to several. At last, using the PN sequence receiver can receive his desired signal. However star coupler has a loss. But this is very poor.
4. The 4th section is the optical CDMA decoder.
5. Data sink (i.e., receiving computer).

The schematic block diagram of an OCDMA communication system is depicted in Figure 1 and 2, for an OCDMA transmitter and for an Optical Correlator Receiver (OCR) with switched sequence inversion keying, respectively. In the OCDMA transmitter, every user preserves different signature codes modulated as binary. Data are actually electrical signals sent to the optical drive which converts the electrical signals into optical signals. The encoded signal is further sent to the star coupler. The star coupler used depends on the topology of the network which can be either a LAN or an access network. In case of a LAN, the star coupler is N:N, while in an access network, the star coupler is 1:N. Further, in OCDMA every user shares the same channel. For this reason, crosstalk which is interference due to multiple accesses is introduced here. In order to reduce this unwanted interference, every user uses various signature sequences. On the other hand, in the OCR with switched sequence inversion keying, an optical switched correlator is used. Consequently, a bipolar reference sequence is correlated directly with the channel's unipolar signature sequence in order to recover the original data . The unipolar-bipolar correlation is practically realized in an optical correlator, by spreading the bipolar reference sequence into two complementary unipolar reference sequences. In addition, the optical correlator provides unipolar switching functions for de-spreading the optical channel signal. The PIN photodiode is also known as the *p-i-n photo-receiver*. Here, *i* is the intrinsic region which is un-doped between the doped regions of *n* and *p*. Finally, the PIN photodiode cancels the de-spreaded signal integrated with the periodic data. This occurs before the detection of the zero threshold voltage.

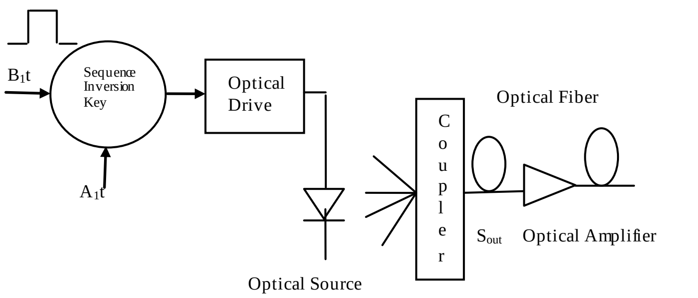

Figure 4: Transmitter of Optical CDMA

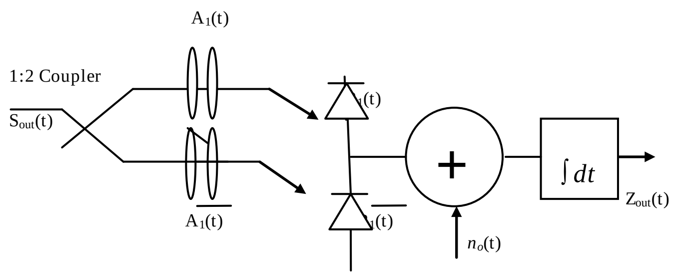

Figure 5: Receiver of Optical CDMA

In the Optical code division multiple access (OCDMA) transmitter, the Sequence Inversion Keying (SIK) modulated signal is passed through the optical drive to a laser diode. Mathematically, the expression for k_{th} users can be written as

$$S_k(t) = \sum_{l=0}^{N-1} P_T \cdot B_k(t) \otimes A_k\left(t - lT_c\right) \qquad (1)$$

In (1), $S_k(t)$ provides information about the transmitted output pulse shape for different users in single mode fiber while l is the period of the chip and P_T is the optical power of the chip. Furthermore, B_k and A_k are the user´s binary signal and signature codes, respectively. The operator ⊗ describes the sequence inversion key modulation, where A_k is transmitted for a”1”, A_k is transmitted for a ”0”, respectively. $S_k(t)$ is transmitted through the single-mode fiber, undergoing dispersion; it gives the output $S'_k(t)$ at the end of the fiber. For the k_{th} user, it is given as

$$S_k'(t) = P_R B_k(t) S_{out}\left(t - lT_c\right) \otimes A_k\left(t - lT_c\right) \qquad (2)$$

Where P_R is the received optical power which is the difference between transmitted power and fiber loss. T_c is the pulse interval, $S_{out}(t)$ stands for the output pulse shape due to fiber chromatic dispersion can be expressed mathematically as [7]

$$S_{out}(t - lTc) = \sum_{l=0}^{N-1} \frac{1}{\sqrt{\pi\gamma}} e^{-i\left(\left(\frac{1}{\gamma}\right)\cdot\left(\frac{t-lTc}{Tc}\right)^2 - \frac{\pi}{4} sgn(\gamma)\right)} \cdot Sinc\left(\frac{t - lTc}{\pi\gamma Tc}\right) \qquad (3)$$

Here, γ indicates the index of chromatic dispersion of the optical fiber which can be expressed mathematically as

$$\gamma = \frac{\lambda^2 D\left(b_c\right)^2 L}{\pi c} \qquad (4)$$

In the equation (4), λ, c, L and D describes wavelength of the optical carrier, velocity of light, length of fiber and coefficient of chromatic dispersion respectively of optical fiber, while the rate of the chip is b_c. The signal is sent to the photo detector and is integrated in the output of the correlator for the i^{th} user which is mathematically expressed as

$$Z_i(t) = \frac{RP_R}{2}\int_0^T \sum_{k=1}^{K}\sum_{l=0}^{N-1} B_k(t) S_{out}(t) \otimes A_k\left(t - lT_c\right)\cdot\left\{A_i\left(t - lT_c\right) - \bar{A}_i\left(t - lT_c\right)\right\}\cdot dt + \int_0^T n_0(t)\, dt \qquad (5)$$

Where R is responsivity of each p-i-n photodiode, K is the number of simultaneous users, $\bar{A}_i(.)$ is the complement of $A_i(.)$ and $n_o(t)$ is the total channel noise at the correlator output. P_R Represents the optical received power given by

$$P_R = P_T - P_f \qquad (6)$$

Where P_T is the transmitted optical power while the loss in the optical fiber is P_f . The bipolar forms of signals presents in correlator output equation (5) are

$A_i(.) = a_i(.)$

$B_k(.) = b_i(.)$

$S_{out}(.) = s_{out}(.)$

$a_i(.) = \{A_i(.) - \bar{A}_i(.)\}$

$B_k(.) \otimes A_k(.) = \{1 + b_k(.)\, a_k(.)\}/2$

$S_{out}(.) = s_{out}(.)$

So reduce the equation (5) by using these bipolar terms as

$$Z_i'(t) = \frac{RP_R}{2}\int_0^T \sum_{k=1}^{K}\sum_{l=0}^{N-1}\left\{\frac{1 + b_k(t - lT_c)a_k(t - lT_c)}{2}\cdot s_{out}(t - lT_c)\cdot a_i(t - lT_c)\right\}\cdot dt + \int_0^T n_0(t)\, dt \qquad (7)$$

Solve the equation (7) as follows

$$Z_i'(t) = \frac{RP_R}{4}\int_0^T \sum_{l=0}^{N-1}\{s_{out}(t - lT_c)a_i(t - lT_c)\}dt + \int_0^T n_0(t)\, dt + \frac{RP_R}{4}\int_0^T \sum_{l=0}^{N-1} s_{out}(t - lT_c)dt + \frac{RP_R}{4}\cdot\int_0^T \sum_{k \neq ik = 1}^{K}\sum_{l=0}^{N-1}\{b_k(t - lT_c)s_{out}(t - lT_c)\cdot a_k(t - lT_c)a_i(t - lT_c)\}dt \qquad (8)$$

The first term in equation (8) is the offset effect, removed by using balanced signature sequence. The second term is the total channel noise at the correlator receiver output. The third term is the in-phase autocorrelation peak signal. The fourth term is the Multiple Access Interference (MAI), which represents the noise occurring in the channel due to multiple accesses of the channel, chromatic dispersion and various noises for the spontaneous signal fluctuations in the receiver. This is described by the variance of the system, denoted as σ^2.The mean of $Z_i'(t)$ is U and the variance of interference σ^2 are given as follows [6]

$$U = \frac{RP_R}{4}\int_0^T \sum_{l=0}^{N-1} s_{out}(t - lT_c)\cdot dt \qquad (9)$$

$$\sigma^2 = U^2\cdot\frac{2(K-1)}{3N} \qquad (10)$$

The Signal-to-Noise Ratio (SNR) at the Optical Correlator Receiver Output can be obtained as

$$SNR = \frac{U^2}{\sigma^2 + N_o} \qquad (11)$$

In equation (11) N_o is the variance of noise, N_{th} is thermal noise of receiver, N_{sh} is shot noise of photo detector, which are given by

$$N_o = N_{th} + N_{sh} \qquad (12)$$

$$N_{th} = \frac{4K_b T_r B_e}{R_L} \qquad (13)$$

$$N_{sh} = \frac{2QK_b RP_r}{4T_r} \qquad (14)$$

Where K_b represents the Boltzmann constant, B_e is the bandwidth of the receiver, the temperature of the receiver is T_r, the charge of the electron is Q, R_L is the resistance of the receiver load, R is Responsivity of each p-i-n photo diode. The Bit Error Rate (BER) at the Optical Correlator Receiver Output can be obtained as

$$\mathrm{BER} = \frac{1}{2}\mathrm{erfc}\left(\frac{\sqrt{SNR}}{\sqrt{2}}\right) \quad (15)$$

CONCLUSION

The goal of increased bandwidth can be fulfilled by extending the optical transparency to the last segment of the network. Therefore, there has been an upsurge interest in the introduction of optical technologies in access networks in order to address these disparities and to cope with the demand of wide-area high bandwidth, due to the increasing commercial use of Internet, private Intranets, electronic commerce, data storage and backup, virtual private networks (VPNs), video conferences, voice over IP and so on. The aim of this paper has been to investigate the use of optical techniques in the next generation CDMA networks, which is growing ever and ever, considering three different aspects: the level of security related to the use of optical code division multiple access techniques in the last segment of the network, the enhancement of network performance thanks to the use of advanced modulation formats and the free space optic technology proposal that is an alternative optical connection that could be a versatile and cost-saving solution, maintaining the bandwidth of fibres. In addition, the overall capacity of the next generation CDMA systems should be greatly enhanced compared to that available in the current first generation CDMA systems, such as IS-95, cdma2000, WCDMA, etc. Obviously, the capacity can be greatly enhanced if the next generation CDMA technology can operate in an interference-free or at least an interference-resistant mode. To make it happen we have to break the myth that a CDMA system is always interference-limited. I have to admit that it is an extremely challenging task to develop next generation CDMA technology.

Reference:

[1] A. J. Vitrebi, CDMA: Principles of Spread Spectrum Communication. Reading, MA: Addison-Wesley, 1995.

[2] Hongxi Yin, David J. Richardson, Optical Code Division Multiple Access Communication Networks: Theory & Applications' Tsinghua University Press, Beijing and Springer-Verlag GmbH Berlin Heidelberg.

[3] J. A. Salehi, "Code division multiple-access techniques in optical fiber networks-Part I: Fundamental principles," IEEE Transactions on Communications, vol. 37, no. 8, pp. 824-833, August1989.

[4] J. A. Salehi, "Emerging Optical Code-Division Multiple Access Communications Systems, " IEEE Network, vol. 3, no. 2, pp. 31-39, Mar. 1989.

[5] L. Tan Cevski, I. Andonovic, M.Tur, J.Budin, "Hybrid wavelength hopping/time spreading code division multilple access systems", iee proc. Optoelectron, vol. 143, no. 3, june 1996, pp. 161-166.

[6] T. O. Farrell and S. I. Lochmann, "Switched correlator receiver architecture for optical CDMA networks with Bipolar capacity", Electron.Lett,vol.31, pp.905-906,May.1995.

[7] E. Forestieri and G. Prati, "Novel optical line codes tolerant to fiber chromatic dispersion", *J. Lightw. Technol.*, vol. 19, no. 11, pp. 1675–1684, Nov. 2001.

[8] J. A. Salehi, C. A. Brackett (1989) Code division multiple-access techniques in optical fiber networks. II. Systems performance analysis. *IEEE Transactions on Communications*,37(8),834–842.

[9] P. Prucnal, M. Santoro, and Ting Fan (1986) Spread spectrum fiber-optic local area network using optical processing. *Journal of LightwaveTechnology*,4(5),547–554.

[10] H.-H. Chen and M. Guizani (2006): *Next Generation Wireless Systems and Networks*, Chichester: John Wiley & Sons.

[11] Hsiao-Hwa Chen (2007): *The Next Generation CDMA Technologies*, John Wiley & Sons.

[12] H. Chung and P. V. Kumar (1990) Optical orthogonal codes—new bounds and an optimal construction. *IEEE Transactions on Information Theory*, 36(4), 866–873.

[13] K. M. Sivalingam and S. Subramanian, (2005): Emerging optical network technologies, Springer Science+Business Media Inc.

[14] R. Prasad, CDMA for wireless personal communications. 1996: Artech House publisher.