code sequence $C_x = (C_{x0}, C_{x1}, C_{x2}\ldots, C_{xj}\ldots C_{x(N-1)})$ according to [4,5,18]

$$c_{i,k} = 1, k = s_{i,j} + jp \quad (4)$$

The mapping of prime sequence *S,* into code sequence *C,* following equation (4) with *P = 5* is also shown in Table I. The number of binary 1's per code sequence is *P.* The cross-correlation function at chip position '*j'* for any pair of code sequences C_x, and C_y can be found from the discrete state-time position cross-correlation function

$$\theta_{C_xC_y}(j\tau) = \sum_{i=0}^{p^2-1} C_x(i\tau).C_y(\tau - j\tau) \; 0 \le \left(p^2 - 1\right) \quad (5)$$

where *x,* y, ***i,*** and *j* are integers, and *r* is the chip width. The number of coincidences of 1's for all shifted versions of any two code sequences is either one or two (the function is at most 1 for code sequence C_O with any other code sequence, but is at most 2 for any other code sequence pair), so that the Cross-correlation peak is at most 2. Furthermore, by setting *x* = y in equation (3), it can easily be shown that the autocorrelation peak is *P* .

The signal-to-noise ratio (SNR) is given by the ratio of the autocorrelation peak squared to the variance of the amplitude of the interference. The average variance of the cross-correlation amplitude, computed using all possible code sequences for several values of *P,* was found to be approximately 0.29 . This value is independent of *N* since the number of coincidences of 1's is independent of *P.*

TABLE1
Prime sequences S_X and CDMA code sequences C_X for GF (5)

x	i 0 1 2 3 4	Se qu	Code Sequences
0	0 0 0 0 0	S_0	C_0=10000 10000 10000 10000 10000
1	0 1 2 3 4	S_1	C_1=10000 01000 00100 00010 00001
2	0 2 4 1 3	S_2	C_2=10000 00100 00001 01000 00010
3	0 3 1 4 2	S_3	C_3=10000 00010 01000 00001 00100
4	0 4 3 2 1	S_4	C_4=10000 00001 00010 00100 01000

The SNR for the code sequences can then be approximated by

$$SNR \approx \frac{p^2}{0.29(K-1)} \quad (6)$$

From equation (6), the SNR is directly proportional to the number of chips per code sequence. For a given number of chips, the SNR decreases gradually as the number of simultaneous user's increases. A degradation of the SNR implies an increase in the probability of error, i.e., the more the users accessing the network at a given time, the system performance is degaded. The probability of error $P_{e|G}$ (to emphasize the Gaussian approximation) as a function of the SNR is given by

$$P_{\in|G} = \varphi\left(\frac{-\sqrt{SNR}}{2}\right) = \varphi\left(\frac{-p}{\sqrt{1.16(K-1)}}\right) \quad (7)$$

Where $\Theta(x) = \frac{1}{\sqrt{2\pi}}\int_{-\infty}^{x} e^{\frac{-y^2}{2}} dy$ is the unit normal cumulative distribution function. This approximation is valid for large values of *K* where,by the central limit theorem, the interference component approaches a Gaussian distribution [7].

4. Implementation Detail

MATLAB is a high-level technical computing language and interactive environment for algorithm development, data visualization, data analysis, and numeric computation. So MATLAB is adopted in this paper for the simulation of wireless optical CDMA system using prime codes

4.1 Transmitter side

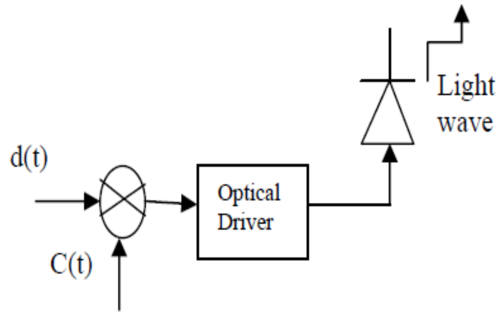


Fig 4 Wireless OCDMA transmitter employing Prime codes

In the wireless optical transmitter prime code is generated by using equation (4). Fig 4 describes the transmitter system. The data signal from the user is convoluted with the prime code generated. These signals which are electrical in nature have been converted into optical signals with the help of LED. The optical signals that are generated from the LED passes through the wireless medium [3, 8]. During the electrical to optical conversion two modulation schemes are efficiently carried out Employing OOK improves the bandwidth efficiency while PPM improves the power efficiency and it is more robust when the transmission power is low[3]. To simplify and evaluate the channel path loss, it is assumed that both transmitter and receiver are pointed straight upward and transmitter emits a Lambertain pattern [9]. IM/DD is used for the transmission of optical signals.

4.2 Channel Model

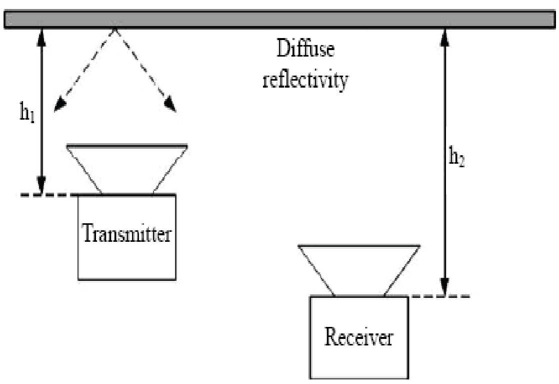


Fig 5 Wireless Diffuse Channel Optical Communication System

Wireless optical system is deeply affected by the channel that is used for propagation. In order to avoid the pointing and shadowing problems, diffuse links are used. The optical power that is transmitted is assumed to be reflected by the surface of the room. One of the important parameters that affect the characteristics of the Infrared system is the channel path loss. It is the DC-gain (H_0) of the channel transfer function. It can be expressed as

$$P_r = H_0 P_t \qquad (8)$$

Diffused channel does not exhibit fading. This is due characteristics the fact that the receive photodiode integrates the optical intensity field over an area of millions of square wavelengths, and hence no change in the channel response is noted if the photodiode is moved a distance on the order of a wavelength [19, 20].

4.2 Receiver side

Simple correlator is the most propounded structure for OCDMA systems [10,11]. Fig 5 describes the receiver system. The optical signals are converted into electrical signals by using the photo detector. Since square law is applied for the photo detector multipath fading is reduced. The signal at the output of the photo detector is sampled by an analog to digital converter.

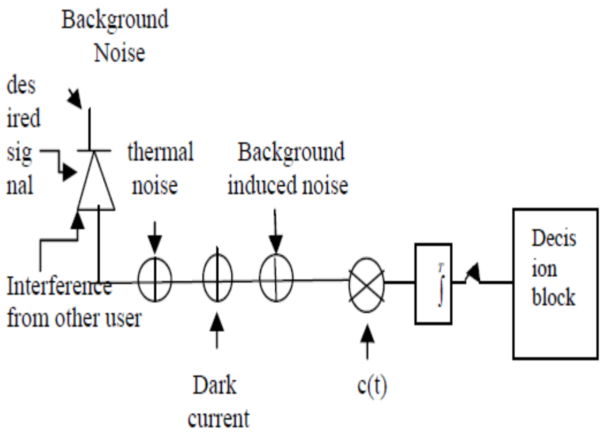


Fig 5 Wireless OCDMA receiver employing Prime codes

The received signal is divided into v branches and then delayed to accumulate the marked chips in the optical correlator. At the receiver all the weighted chips of the desired sequences are summed to form a decision variable. This decision variable is compared to threshold to detect the data bit 1 or 0. Or else it can be stated as follows. The buffer after the A/D operation saves and reset it at the end of the bit time. After the bit duration the correlation value is compared with an optimum threshold to the accumulated value which is saved in the buffer.

5. BER Analysis on Transmission Power

5.1. OOK Modulation Scheme:

Since correlation receiver model is used the level of interference is much lesser when compared to the hard-limiters. Considering M interfering users, the BER of desired user's detected information can be expressed as [12]

$$P_E = \sum_{l=0}^{M} \binom{M}{l} q^l (1-q)^{M-l} P_E(l) \quad (9)$$

The value of $P_E(l)$ can be obtained by averaging the conditional probability $P_E(l/\rho)$ with respect to ρ

$$P_E(l) = \int_{\rho} P_E(l/\rho) f_p(\rho) d\rho \quad (10)$$

The distribution of all the users in the cell is Uniform. Therefore $f(\rho) = 2\rho / r_{cell}^2$. Here r_{cell} is the Radius of the cell. So that integration of $f(\rho)$ over ρ becomes 1.

$$P_E(l/\rho) = 0.5 * Q\left(\frac{Th - \bar{R}_0}{\sigma R_0}\right) + 0.5 * Q\left(\frac{\bar{R}_1 - Th}{\sigma R_1}\right) \quad (11)$$

So the mean and the variance of received photon count can be expressed as

$$\bar{R}_j = Km_r j + Km_b Km_d + \sum_{i=1}^{l} m_i \quad (12a)$$

$$\sigma_{R_j}^2 = \bar{R}_j + K\sigma_T^2 \quad (12b)$$

The final decision variable is Gaussian variable with mean and variance equal to the sum of mean and variances of each variable.m_r is the mean received photon count of the desired user, m_b is mean photon count of the ambient light noise,.$\sigma_T{}^2$ is the variance of the electron count produced by the thermal circuit noise.m_d represents photo detector dark current noise.

$$m_d = \frac{i_d T_c}{e}, \quad m_i = \frac{2\eta P_{r,i}}{Kh\nu R_b} \quad (13)$$

$P_{r,i}$ is the power that base station receives from the *i*th user and can be expressed as $P_{r,i} = H_0(\rho_i) p_t$. R_b is transmitter bit rate and T_c is the chip duration in seconds.

5.2 BPPM Scheme

For the case of BPPM bit '0' should be considered for the interference pattern. The bit error probability can be obtained by using [12]

$$P_E = \sum_{l_0=0}^{M} \sum_{l_1=0}^{M-l_0} \frac{M!}{l_0! l_1! (M - l_0 - l_1)!} \times q^{l_0+l_1} (1-2q)^{M-l_0-l_1 P_E(l_{0,}l_1)} \quad (14)$$

Here l_0 and l_1 are the users causing interference by sending the information bit '0' and '1' respectively among M users.

$P_E(l_{0,}l_1)$ can be obtained from [3,12].

$$m_x = -Km_r - \sum_{i=1}^{l_0} m_i + \sum_{i=l_0+1}^{l_0+l_1} m_i \quad \_\_\_\_\_\_\_\_ (15)$$

Table 2
System Parameters

GF(p)	Prime code Length	25
W	Prime code weight	5
N	Active users number	4
n_s	Sample power chip	4
H	Photodetector quantum efficiency	0.8
Λ	Optical wavelength	880nm
I_b	Ambient light irradiance on the photodetector	100μW/cm^2
i_d	Photodetector dark current	10nA
A_d	Photodetector area	1cm^2

$$\sigma_x^2 = Km_r + \sum_{i=l_0+1}^{l_0+l_1} m_i + \sum_{i=l_0+1}^{l_0+l_1} m_i + 2K(m_b + m_d + \sigma_T^2) \quad (16)$$

x is a random variable with mean and variance as stated in the equation 15,16. We assume same bit rate for both modulation schemes so that both of them use equal amount of system resources. Threshold adjustment is not needed since correlation receivers are used.

6. Simulation Results

MATLAB is a high-level technical computing language and interactive environment for algorithm development, data visualization, data analysis, and numeric computation. So MATLAB is adopted in this paper for the simulation of wireless optical CDMA system using prime codes.

Analytical evaluations are done for the system designed. Various parameters that affect the efficiency of the system is noted and analyzed. The parameters considered are transmission power, signal to noise ratio and number of users. Table 2 shows about the other parameters that are reviewed in the system.

The BER analysis of optical CDMA is based on a Gaussian approximation and leads to the result

$$P_{e|G}(k,p) = \phi\left(\frac{-p}{\sqrt{k-1}}\right) \qquad (17)$$

With $\phi(x) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{x} e^{-\frac{-y^2}{2}} dy$

Where p is the prime number used to design the particular prime code and k is the number of simultaneous users [13, 14]

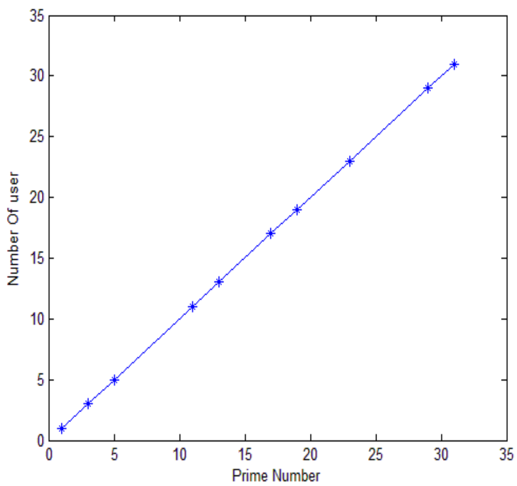


Fig 6 Prime Number Vs Number of User

The graph (Fig 6) clearly depicts that the prime number P is directly proportional to the number of simultaneous users. Comparing CDMA with synchronous CDMA, CDMA achieves the very good probability of error P_e less than or equal to 10^{-9}. In ideal case, for synchronous CDMA K=P-1.

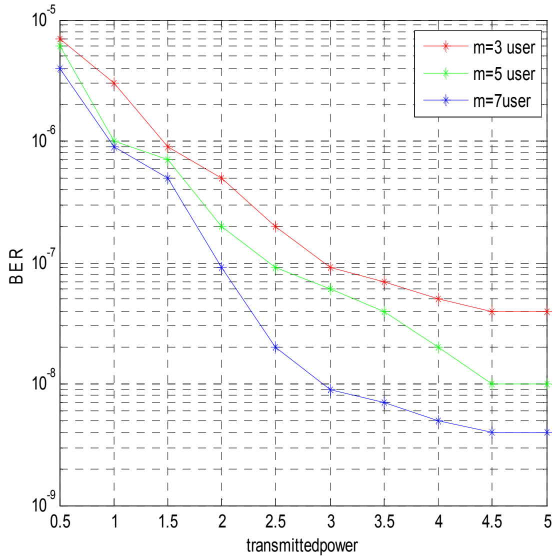
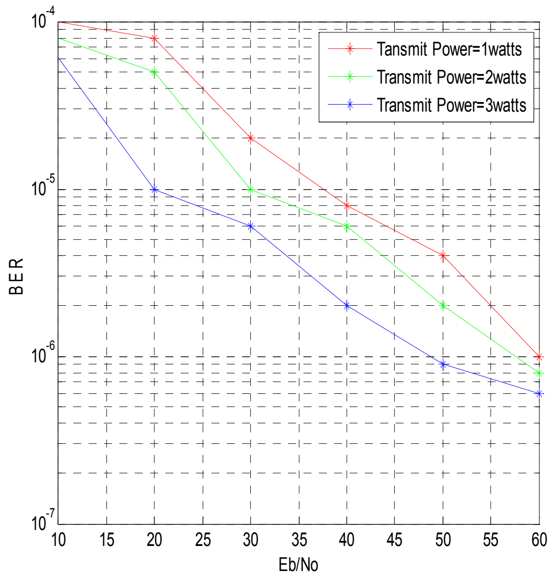


Fig 7 Transmission Power Vs Bit Error Rate

It is clear from Fig 7, that increase in interfering users degrade the system performance. This degradation increases the multi access interference. Apparently increasing the transmission power alone will not improve the efficiency. The range of BER will also be bigger for higher number of interfering users. The amount of noise lower when BPPM scheme is used. Cell radius is another Factor that affects the bit error rate.



.

Fig 8 Eb/No Vs Bit Error Rate

Fig 8, shows the relationship between signal to noise ratio and BER. The BER simulations were performed by transmitting a large number of frames in parallel. Multipath considerations, transmission power are taken into account. The transmitted power is varied accordingly with the Eb/N0 value and the BER is calculated. By increasing the value of Eb/N0, better BER is achieved. By using the power control algorithm and by choosing an optimal power value, BER performance can be improved.

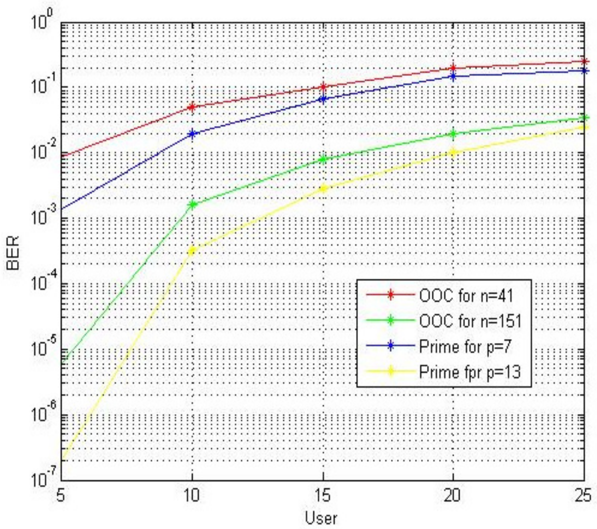


Fig 9 Error probabilities versus number of simultaneous users for prime code and OOC of similar code length

The most important parameter dealing with the system performance is the number of simultaneous users. The error probabilities of prime code with p={7,13} and (41,3,1,1), (41,4,1,2) (151,4,1,1) and (151, 5,1,2) OOCs are plotted against the number of simultaneous users K. The OOCs are chosen such that the code lengths are similar to those of prime code. In general, the performance improves as p, n or w increases but as K decreases. The graph clearly depicts that the Prime code performs better because of heavier code weight.

6. Conclusion

In this paper we have analyzed the performance of wireless optical CDMA LAN without any control on the transmission power. The system uses Prime code with minimum auto- and cross- correlation as an implementation of optical CDMA concept. Both OOK and PPM modulations are employed. In wireless infrared medium path loss is a main issue and therefore power control becomes a main concern. Though multipath fading don't occur in wireless optical systems, channel path loss is a major issue. This can be avoided by employing an optimal power control algorithm.

7. References

[1].Gao Yan, Wu Min, Du Weifeng, Performance Research of Modulation for Optical Wireless Communication System, *Journal Of Networks*, Vol. 6, No. 8, August 2011.

[2] Hu Zm, Tang Jx, Digital pulse interval modulation for atmospheric, *Optical wireless communication*, 26(3), 2005, pp.76 -77.

[3].S.Khazraei M.R. Pakravan A. Aminzadeh-Gohari, Analysis of power control for indoor optical wireless code-division multiple access networks using on–off keying and binary pulse position modulation, *IET Commun.*, Vol. 4, Issue 16, 2010, pp. 1919–1933.

[4] Wing C.Kwong , Paul R.Prucnal, Ultrafast All-optical code division multiple access (CDMA) fiber-optic networks, *Computer Networks and ISDN Systems* 26,1994, pp.1063-1086

[5]G.C. Yang and W.C.Kwong ,Performance Analysis of optical CDMA with prime codes, *Electronics Letters,* Vol 31 No.7, 30th March 1995.

[6]. Naser Tarhuni, M. Elmusrati, and T. Korhonen, Nonlinear Power Control for Asynchronous Fiber-optic CDMA Networks, *IEEE International conference on Comm. ICC,* Volume 6, June 2006, pp. 2782 – 2786.

[7] R.Kanmani, Dr.K.Sankaranarayanan, Using prime code analysis of power control for indoor wireless optical CDMA network, *IJETSE*, Vol.5, No.2, December 2011.

[8] Sina Zahed ,Jawad A.Salehi and Masoumeh Nasiri-Kenari, A Photon Counting Approach to the Performance Analysis of Indoors Wireless Infrared CDMA Networks, *Iran Telecom Research center (IRTC),* Tehran, Iran.

[9] Amir Aminzadeh-Gohari, M.R.Pakravan , Analysis of Power Control for Indoor Wireless Infrared CDMA Communication, *IEEE International Performance, computing and communications conference*, April *2006,* pp. 10-12.

[10]. Babak M.Ghaffari Mehdi D.Matinfar Jawad A. Saheli, Wireless Optical CDMA LAN: Digital Design Concepts, *IEEE Transactions on Commun,* Vol.56, No12, December 2008.

[11].Ghaffari, B.M. Matinfar, M.D. Salehi, J.A, Wireless optical CDMA LAN: digital implementation analysis , *IEEE Journal on Selected Areas in Communications,* Vol 27*,* Issue 9, December 2009.

[12]. Azizoglu,M., Salehi,J.A;Li,Y, Optical CDMA via temporal codes, *IEEE Transactions on Communication,* Vol 40, Issue 7, July 1992, pp. 1162-1170.

[13]Stephen B.Alexander , *Optical Communication Receiver Design*, SPIE Tutorial Text in Optical Engineering -Vol TT22, IEE Telecommunication Series -Vol 37.

[14] Helmut Walle Ulrich Killat, Combinatorial BER analysis of Synchronous Optical CDMA with Prime Sequence, *IEEE transaction on Commun.,* vol.43, No 12, December 1995

[15] Stephen Z.Phinter, Xavier N.Fernando, Estimation and Equalization Of Fiber-Wireless Uplink for Multiuser CDMA 4G Networks, *IEEE Transactions on Communication*, Vol 58, June 2010, pp. 1803-1813.

[16] IrDA standards can be obtained at http://www.irda.org

[17] Paul R.Prucnal *Optical Code division multiple access : fundamentals and applications*, CRC Taylor and Francis, 2006.

[18] G.C Yang,Wing C.Kwong , *Prime Codes with applications to CDMA optical and wireless networks*, Artech House, 2002.

[19] Steve Hranilovic, *Wireless Optical Communication System*, Springer ,2005.

[20] Fahim A.Umrani, Salah Obaya, Application Of Perfect Difference Codes in Wireless Infrared Systems, *Int.J.Communications,Network and System Sciences* ,vol 3,2010, pp.674-678

Ms.R.Kanmani is Assistant Professor in Department of Information Technology, Sri Krishna College of Technology, Coimbatore, India. She received her B.E degree from Bharathiar University, Tamilnadu, India in 2000. She received her M.E degrees from Anna University, Chennai, Tamilnadu, India in 2005. Her research interests are CDMA, Optical CDMA, wireless optical CDMA. She is a member of ACM.

K.Sankaranarayanan, born on 15.06.1952, completed his B.E.(Electronics and Communication Engineering) in 1975, and M.E.(Applied Electronics) in 1978 from P.S.G.College of Technology, Coimbatore under University of Madras. He did his Ph.D. (Biomedical Digital Signal Processing and medical Expert System) in1996 from P.S.G.College of Technology, Coimbatore under Bharathiar University. His areas of interest include Digital Signal Processing, Computer Networking, Network Security, Biomedical Electronics, Neural Networks and their applications, and Opto Electronics.He has more than 32 years of teaching experience and worked in various Government and self financing Engineering colleges. At present he is working as DEAN at EASA College of Engineering and Technology, Coimbatore, Tamil Nadu, India.

F.Infant Princy is pursuing her Bachelor Of Engineering in Information Technology. Her area of interests includes Computer Networking, Wireless Networks, Optical Communications. She is a member of Computer Society of India.