Analysis of Indoor Wireless Infrared Optical CDMA LAN Using Prime Codes

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Abstract:-In wireless optical system, CDMA suits well for high bit rate systems where good security is needed and mobility is not important. It would be economical when compared to radio frequency band and much safer since there is no electromagnetic effect. Infrared systems are used for its widest bandwidth and are not affected by radio transmission. The advantage of the prime code and the security issues in choosing the coding technique is noted. Prime codes would be much better than optical orthogonal code because of its heavier code weight. The error probability of prime codes and OOC is compared in infrared wireless OCDMA network. The bit error probabilities of Optical CDMA system using prime sequence codes are analyzed. We employ OOK and PPM as the modulation schemes and derive the bit error probability of the systems. The transmission power versus BER and number of user versus BER for various signals is calculated and the results are analyzed.

Key-Words: - CDMA-Code Division Multiple Accesses *OOC* –Optical Orthogonal Code, *OCDMA*-optical CDMA, Prime Codes, wireless infrared, OOK-On Off Keying, BPPM -Binary Pulse Position Modulation

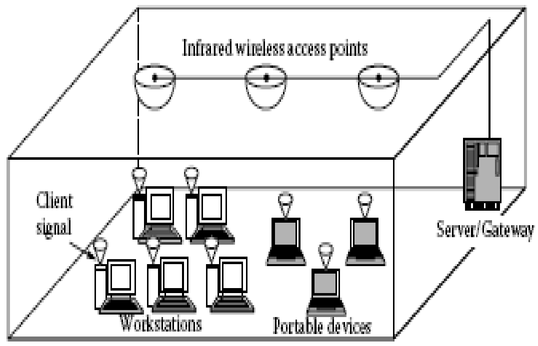
1. Introduction

Optical code-division multiple-access (OCDMA) is receiving increasing attention due to its potential for enhanced information security, simplified and decentralized network control, improved spectral efficiency, and increased flexibility in the granularity of bandwidth that can be provisioned. Since, optical CDMA systems should be pragmatic; the coding technique used should be efficient. Wireless systems improve the bandwidth competence when compared to wired scenario. Optical wireless communication has many advantages over RF wireless or wired communication.

An optical wireless communication system is [1]:

- Quickly-deployable: Optical wireless communication can be quickly setup, torn down or reconfigured.
- Supporting high-data-rates: The available bandwidth is extremely large and the supportable data rate is ultra-high.
- Cost-effective: Optical wireless communication operates in license-free spectrum band, and does not
- require trenching streets or eying down fibers or wires.
- Secure: Laser light directly points to the receiver, and obviates the opportunity of eavesdrops.

So with the increasing of information communication, optical wireless communication has emerged as a viable technology for next generation indoor and outdoor broadband wireless applications. Applications range from short-range wireless communication links providing network access to portable computers, to last-mile links bridging gaps between end users and existing fiber optic communications backbones, and even laser communications in outer-space links. Indoor optical wireless communication is also called wireless infrared communication, while outdoor optical wireless communication is commonly known as free space optical (FSO) communication [1-20].
Fig 1 describes free space LAN within building. Expansion of network bandwidth resources and improvement of communication flows have become important issue. In OCDMA, different users whose signals may be overlapped both in time and frequency share a common communications medium; multiple-access is achieved by assigning unlike minimally interfering code sequences to different transmitters, which must subsequently be detected in the presence



. **Fig 1 Free Optical Space LAN within a building**

of multiple access interference (MAI) from other users. The important advantage of the optical CDMA is that the users can transmit completely independently; no coordination with other users is required. Two particularly important mathematical properties of OCDMA codes for both communication performance and security are their auto-correlation and cross-correlation functions. Spreading sequences are selected with the features of maximum autocorrelation and minimum cross-correlation in order to optimize the differentiation between correct signal and interference. An important type of coding scheme is optical orthogonal code. Since the code weight is lower, its efficiency in encoding and decoding gets decreased. A better coding scheme with higher code weight is analyzed. The drawbacks of OOC are that when noise effects are considered, the performance can be two orders of magnitude worse than that of the ideal case. Performance degradation of OOC systems will be severe if synchronization is not maintained. In order to increase the scalability in the network, prime codes scheme is implemented. Fig 2 describes the basic wireless optical System.LED is used for electro-optical converter and Photo detector is used for Optical-Electro converter [1, 19].

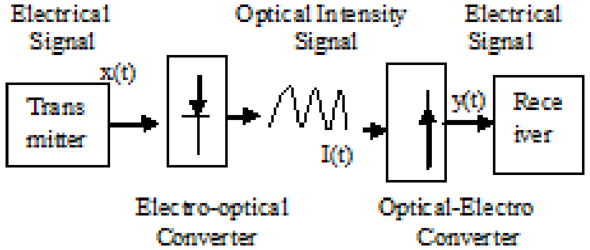


Fig 2 Basic Wirelesses Optical System

Section 2 discusses about the wireless optical CDMA system model. Analysis of prime codes and their properties is studied in section 3. Section 4 deals with the implementation of prime codes in wireless optical CDMA. The discussion about the numerical results is made in section 5.

2. Wireless Optical CDMA Systems

Implementing a coherent fiber optic system is difficult. It is even more difficult to implement a coherent optical wireless system because the phase of the local oscillator light should be adjusted to the phase of the free space signal. Because of this practical systems are non coherent (Intensity Modulated / Direct Detection IM/DD) systems [17,19]. The output light power can be easily modulated in by varying injection current, since optical output power increases linearly with the injection current. This type of modulation is referred to as direct modulation. Implementing lens and optical waveguide structures for optical signature coding and for correlating the received signal with the desired signature code are also difficult. So they are usually performed electrically. The signature code can be used directly to modulate the intensity the laser or LED transmitter (On-Off-Keying, OOK) or subcarrier modulation may be used. Pulse position modulation (PPM) or Binary Phase Shift Keying (PSK) are often used as the modulation method [1,3]. In the subcarrier modulation the intensity of the transmitter is varied on a radio frequency. This subcarrier is modulated by the chip values. Because the wireless system does not suffer from the material dispersion the channel bandwidth is not limited. So a high spreading factor can be used and high bit rates can be achieved. Unlike in a fiber optic system the relation between optical output power *X(t)* from the laser or LED and the output current *Y(t)* of the photo detector is linear in the wireless optical system. So a linear baseband model can be used:

$$Y(t) = R.X(t) * h(t)+ N(t) \qquad (1)$$

Where R is the detector responsitivity (A/W)
h(t) is the impulse response of the channel.
N(t) is the noise caused by the background light and reflections.
By using this model the following signal to noise ratio is obtained.

$$SNR = \frac{R^2 \ . \ P^2}{R_b . \ N_0} \qquad (2)$$

where R_b = bit rate
P = average received optical power.
When *P* decreases SNR decreases relative to P^2. This limits the achievable distance *d* and sets a requirement

to the average power efficiency of the used multiple access method, The AWGN channel model can be used because there is no fast fading in the wireless optical systems. The minimums of the received signal locate about a wavelength apart from each other but they do not affect the received power because typical detector areas are millions of square wavelengths. The multipath distortion causes inter symbol interference but *N(t)* can be assumed to be dominated by a white Gaussian component having double-sided power spectral density N_0.

In intensity modulation system, each user information source modulates the laser diode directly or indirectly using an external modulator. The optical signal is encoded optically in an encoder that maps each bit into a very high rate (i.e. code-length x data-rate) optical sequences. The encoded light wave from all active users is broadcasted in the network by a star coupler. The star coupler can be a passive or active device. The Fig 3 describes wireless optical CDMA system. The optical decoder or matched filter at the receiving node is matched to the transmitting node giving a high correlation peak that is detected by the photo-detector. Other users using the same network at the same time but with different codes give rise to MAI. This MAI can be high enough to make the LAN useless if the code used in the network does not satisfy specific cross-correlation properties.

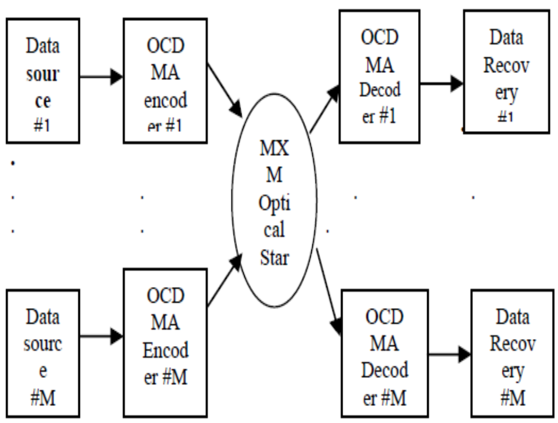


Fig 3 Wireless Optical CDMA system

The photo-detector detects the power of the optical signal but not the instantaneous phase variations of the optical signal. Thus, only incoherent signal processing techniques can be used to process the signature sequences composed of only ones and zeros restricting the type of codes that can be used in incoherent OCDMA systems. In coherent OCDMA, the phase information of the optical carrier is crucial for the de-spreading process. However, the performance of the coherent scheme is much better than incoherent one since the receivers are more signal-to-noise ratio (SNR) sensitive.

3. Prime Codes Generation

In a CDMA system, each data bit '1' is encoded into a waveform s *(n),* consisting of a code sequence (or signature sequence) of *N* chips, which represents the destination address of that bit. Data bits '0' are not encoded. Each receiver correlates its own address *f (n)* with the received signal *s (n).* The receiver output r *(n) is*

$$\mathrm{r\ (n)} = \sum_{k=1}^{N} s(k) f(k-n) \qquad (3)$$

If the signal has arrived at the correct destination, then *s (n) = f (n),* and equation (3) represents an autocorrelation function. If the signal has arrived at an incorrect destination, then *s (n) # f (n)* and equation (1) represents a cross-correlation function. At each receiver, it is necessary to maximize the autocorrelation function and minimize the cross-correlation function in order to optimize the discrimination between the correct (destination address) signal and the interference (all other signals). Many classes of binary signature sequences that are suitable for CDMA have been studied . In most of these codes, a strong autocorrelation peak and zero cross-correlation function can be obtained through bipolar (-1, +1) sequences.

Starting with the Galois field *GF (P)* = {0, 1, *j*, *P*-1}, a prime sequence $S_x = (S_{x0}, S_{x1}, S_{x2} \ldots, S_{xj}, \ldots S_{x(P-1)})$ is constructed by multiplying every element *j* of *GF(P)* by *x,* also an element of *GF(P),* modulo *P* (for a view of Galois fields, see [3]) *P* distinct prime sequences can thus be obtained. Therefore, *p* codeword, each of weight *p* and length p^2**,** with cross correlation values no greater than 2 are generated. When there are *M* users transmitting simultaneously, the total interference at a given receiver is the superposition of the cross correlation functions created by the remaining *M-1* interferers, which are assumed to be uncorrelated and have an identical cross correlation variance *0.02.*

An example for *P = 5* is given in Table 1**.** Each prime sequence S_x is then mapped into a binary code sequence $C_x = (C_{x0}, C_{x1}, C_{x2}\ldots, C_{xj}\ldots C_{x(N-1)})$ according to [4,5,18]

$$c_{i,k} = 1, k = s_{i,j} + jp \tag{4}$$

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

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

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	Sequ	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

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

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

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

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

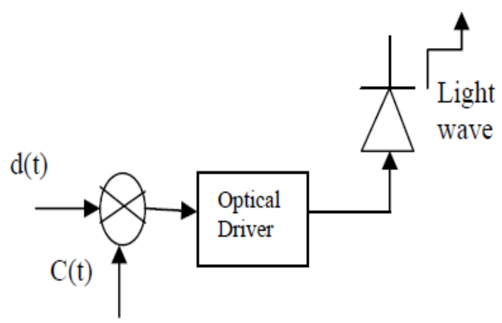


Fig 4 Wireless OCDMA transmitter employing Prime codes

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

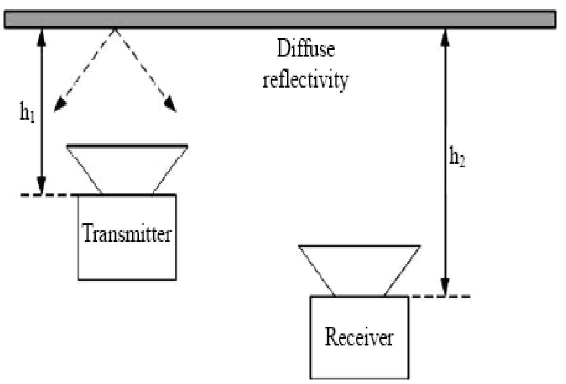


Fig 5 Wireless Diffuse Channel Optical Communication System

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

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

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.

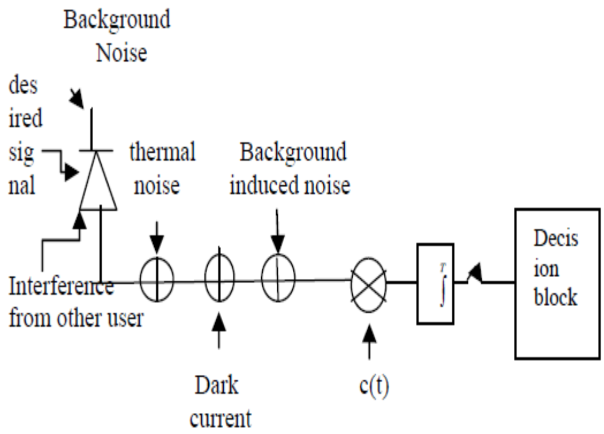


Fig 5 Wireless OCDMA receiver employing Prime codes

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.

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

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

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

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

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

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

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]

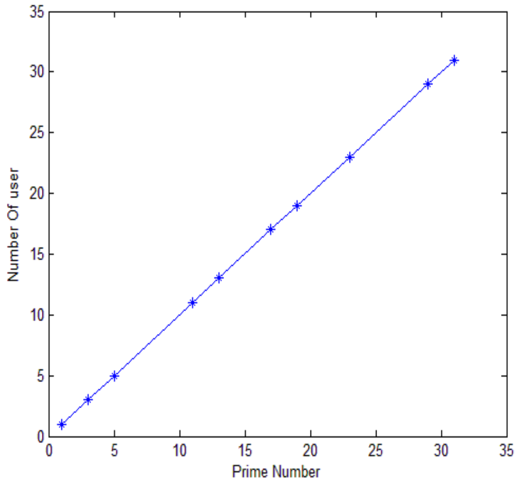


Fig 6 Prime Number Vs Number of User

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.

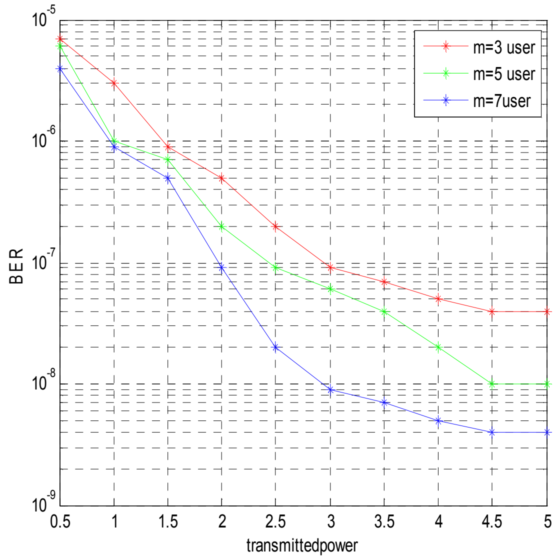


Fig 7 Transmission Power Vs Bit Error Rate

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.

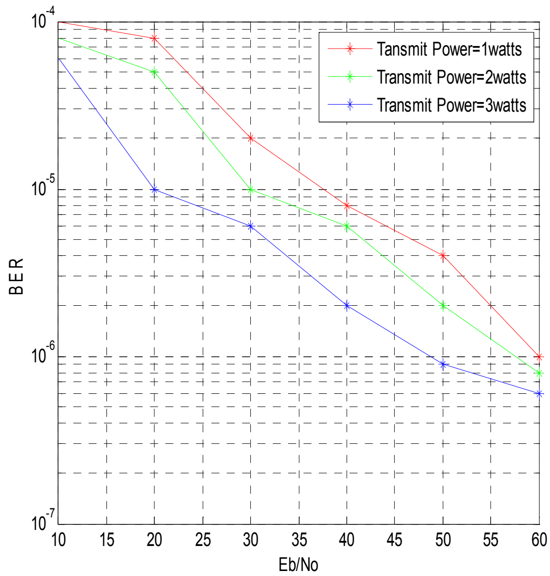


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Fig 8 Eb/No Vs Bit Error Rate

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.

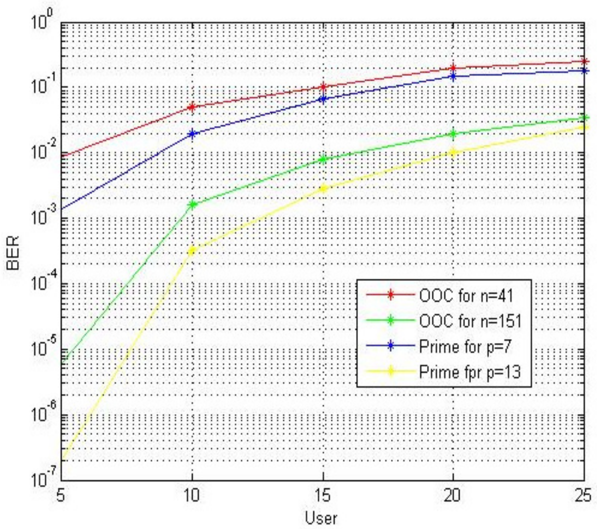

Fig 9 Error probabilities versus number of simultaneous users for prime code and OOC of similar code length

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.

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