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# AN ANALYSIS OF SYNCHRONOUS COHERENT OPTICAL CODE DIVISION MULTIPLE ACCESS (OCDMA) NETWORK

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## *Declaration*

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## *Abstract*

*An Analysis of a Synchronous Coherent Optical Code Division Multiple Access Networks (OCDMA) is accomplished by analyzing various CDMA code sequences. The entire essential signal processing which include, switching, add/drop, multiplexing/ de-multiplexing, amplification and synchronization are performed in the optical domain. Among the many multi-access techniques that have been introduced, optical code division multiple access is believed to be the most robust as the speed and scale of information processing elements grow and the number of nodes reach the order of hundreds to thousands. Recent advances in optical devices and their ubiquitous use in the future all optical networks, in particular in Optical Code Division Multiple Access (OCDMA), have been the main thrust behind a vast number of research activities. These could prove to be essential for successful all OCDMA system, and one such application is optical synchronization, which will be dealt later in detail in forthcoming chapters. These are modified and implemented for all optical networks, in OCDMA systems. These include m-sequences, Gold codes, Prime sequences and Modified prime code sequences. A simulation model of an OCDMA network for the analysis and performance of these sequences is developed and analyzed. From these studies it has been shown that for a large number of simultaneous users in the network, Modified Prime codes give the best system performance. Also, for a coherent system, bipolar codes have a significantly better performance. The hardware technology used in the implementation of an OCDMA system is studied. It includes the transmitter structures and receivers with various modifications that can be implemented. The synchronous and asynchronous techniques, coherent and non-coherent with electrical or optical processing are examined for CDMA.*

*Keywords:* Optical code division multiple access (OCDMA), Cross correlation, Autocorrelation, Coherent Correlation Detection, Match filter, *pseudo noise* (PN) sequence, Hardware of OCDMA and Power Spectral density.

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## *1.Introduction*

The Code Division Multiple Access (CDMA) is a radically new concept in wireless communications. It has gained widespread international acceptance by cellular radio system operators as an upgrade that will dramatically increase both their system capacity and the service quality. It has likewise been chosen for deployment by the majority of the winners of the United States Personal Communications System (PCS) spectrum auctions. It may seem, however, mysterious for those who aren't familiar with it. This site is provided in an effort to dispel some of the mystery and to disseminate at least a basic level of knowledge about the technology. The use of CDMA for civilian mobile radio applications is novel. It was proposed the erotically in the late 1940's, but the practical application in the civilian marketplace did not take place until 40 years later. Commercial applications became possible because of two evolutionary developments. One was the availability of very low cost, high density digital integrated circuits, which reduce the size, weight, and cost of the subscriber stations to an acceptably low level. The other was the realization that optimal multiple access communication requires that all user stations regulate their transmitter powers to the lowest that will achieve adequate signal quality. Since the advent of the mid 80.s, single-mode fiber-optic media were believed to become the main highways of future telecommunications networks for transporting high-quality high-volume multipurpose information. Hence the need for an all optical multi-accessing network became urgent. An all-optical multi-access network is a collection of multiple nodes where the interconnection among various nodes is via single mode optical fibers. The CDMA is a method of allowing multiple users on the same communication channel using same bandwidth. These users are given distinct orthogonal codes, which can be transmitted at the same time, using the same channel and the entire available frequency spectrum available. The data for multiple users are multiplexed synchronously or asynchronously. Among various optical CDMA techniques used to date, fiber-optic CDMA using optical orthogonal codes (OOC), and their possible variations, have received much attention due to their simple structure and compatibility with intensity modulation/direct-detection fiber-optic transmission systems. Commercially introduced in 1995, CDMA quickly became one of the world's fastest growing wireless technologies. In 1999, the International Telecommunications Union selected CDMA as the industry standard for new "third-generation" (3G) wireless systems. Many leading wireless carriers are now building or upgrading to 3G CDMA networks in order to provide more capacity for voice traffic, along with high-speed data capabilities.

The structure of a typical OCDMA network is shown in the figure (1)

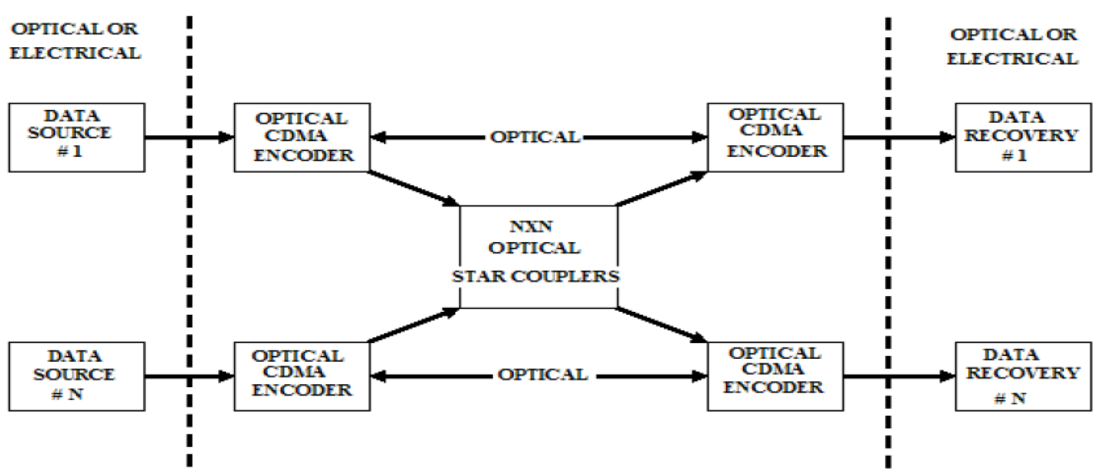



**Fig. 1 Schematic diagrams of an optical code division multiple access (OCDMA) communication system.**

## *2. Spread Spectrum System*

In general, Spread Spectrum communications is distinguished by three key elements:

1. The signal occupies a bandwidth much greater than that which is necessary to send the information. This results in many benefits, such as immunity to interference and jamming and multi-user access, which we'll discuss later on.
2. The bandwidth is spread by means of a code which is independent of the data. The independence of the code distinguishes this from standard modulation schemes in which the data modulation will always spread the spectrum somewhat.
3. The receiver synchronizes to the code to recover the data. The use of an independent code and synchronous reception allows multiple users to access the same frequency band at the same time.

The bandwidth expansion or spreading is done with the help of a pseudorandom code sequence at a very high data rate. This also follows that, the demodulator should have the same pseudorandom code sequence in order to de-modulate or obtain the information signal at the receiver. This pseudorandom code is useful for multiple users in the network, since each user can be assigned an independent code sequence. These CDMA codes are orthogonal codes and are unique from each other. Two functions, *a(t)* and *b(t)* are said to be orthogonal with respect to each other over the interval $x<t<y$ , if, they satisfy the equation

$$\int_x^y a(t)^* \, b(t) = 0 \qquad \text{……………………………………………………………………..(1)}$$

Equation (1) is used to test the orthogonality of functions. This zero result implies that the functions are .independent. of each other. With any large network of users, if the spreading sequences are all orthogonal, then it would allow many users to use the same frequency range and this would not cause interference. Hence, systems utilizing this method of transmission are called *code division multiple access* (CDMA) systems. Large redundancy inherent in spread spectrum signals is required to overcome the severe levels of interference in transmission of digital information over radio and satellite channels.

The spread spectrum signals are used for:

1. Combating or suppressing the detrimental effects of interference due to jamming, interference arising from other users in the channel, and self interference due to multipath propagation.
2. Hiding a signal and transmitting it at a low power level, thus making it difficult to be detected in the presence of background noise by an unintended listener and achieving message privacy.

## *3.Spread Spectrum Techniques*

There are four main ways to spread a signal. The main techniques used are *Direct Sequence Spread Spectrum* and *Frequency Hopping Spread Spectrum*. In addition to these, there are hybrid formats, such as *Chirp* and *Time Hopping*. But the latter two are not as popular. They are mainly restricted for military use.

For spread spectrum three types of modulation are used. These are *phase shift keying* (PSK), *frequency shift keying* (FSK) and *on off keying* (OOK). PSK is used where a phase coherence can be maintained between the transmitted signal and received signal. FSK is generally used where such phase coherence cannot be maintained mainly due to time varying effects on the communication link, and OOK is generally used for optical CDMA.

### *3.1 Direct Sequence Spread Spectrum (DSSS)*

In spread spectrum systems, the spreading code is called *pseudo noise* (PN) sequence, which consists of periodic coded sequence of 1.s and 0.s. The binary bit stream is designed to appear random with approximately equal number of 1.s and 0.s. This binary sequence can be generated at the receiver and the transmitter and receiver must be synchronized. The bit rate for these sequences is much higher than the bit rate of the message sequence to be transmitted. This will increase the bandwidth of the modulated message signal by a factor N, called the processing gain. Direct Sequence Spread Spectrum shown as given below.

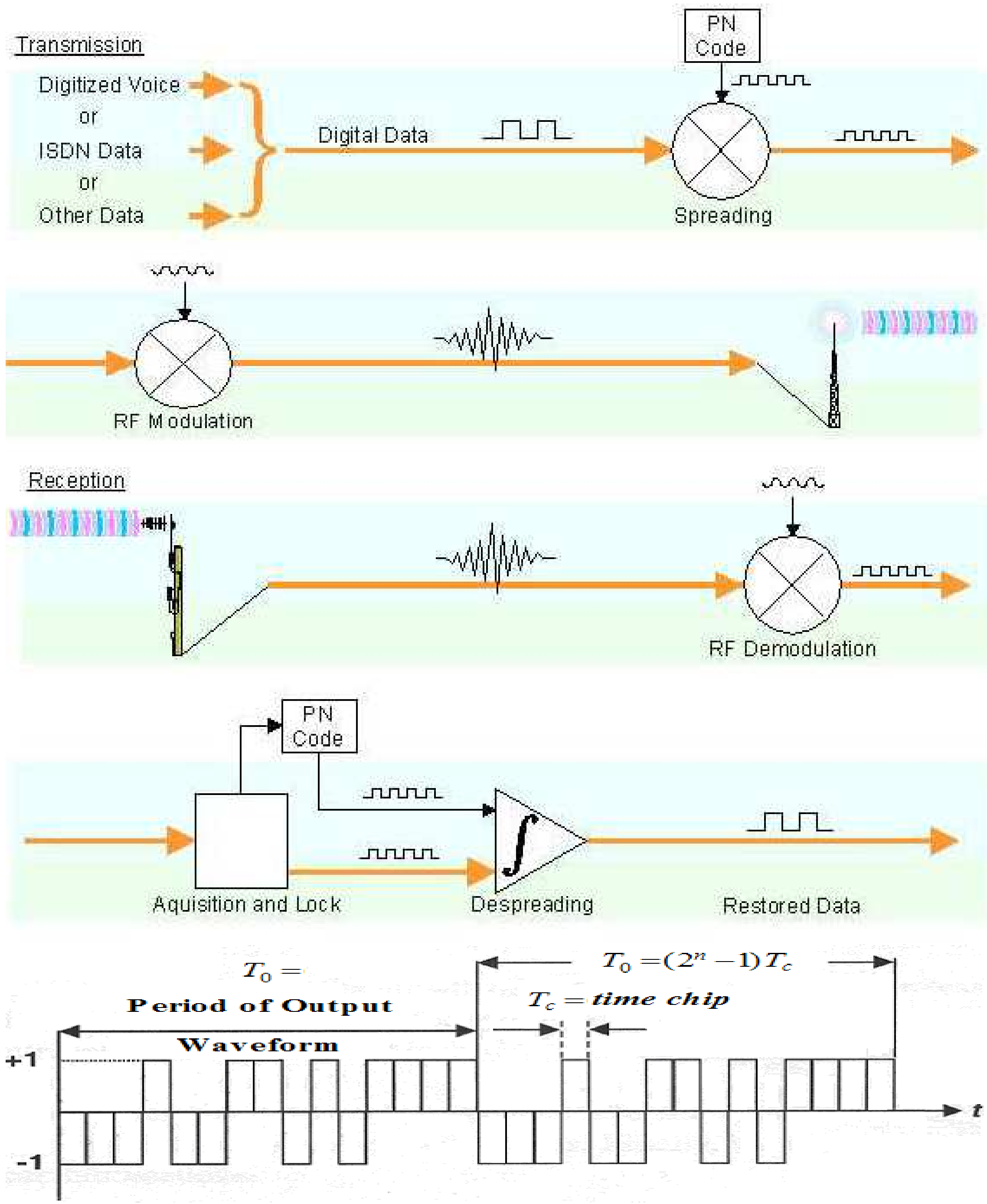
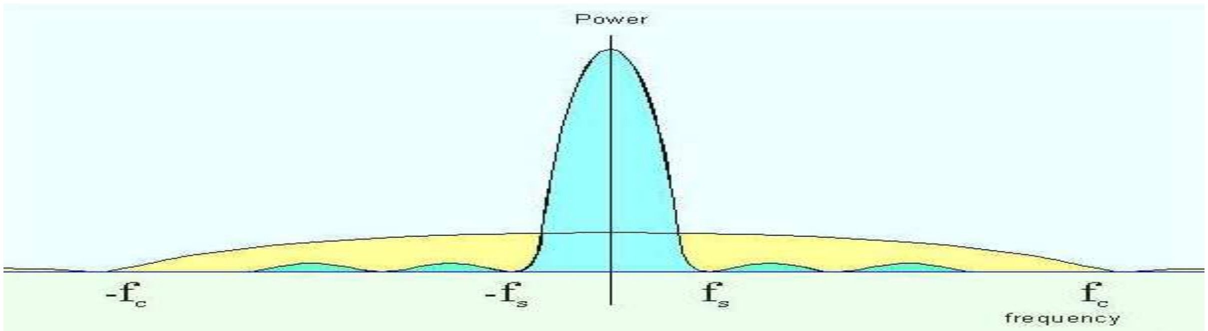



**Fig.2 Direct Sequence Spread Spectrum**

### *3.2 Frequency Hopping Spread Spectrum*

Another form of spread spectrum is called *Frequency Hopping Spread Spectrum.* Here the carrier frequency of the signal is altered many times, in a pseudo andom fashion. The result is an increase in the effective bandwidth of the signal over time.



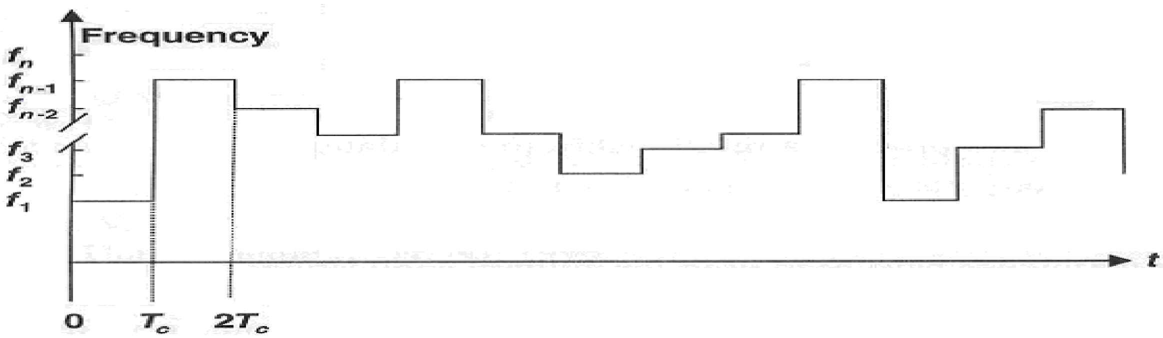




**Fig. 3 Frequency Hopping Sequence Spread Spectrum**

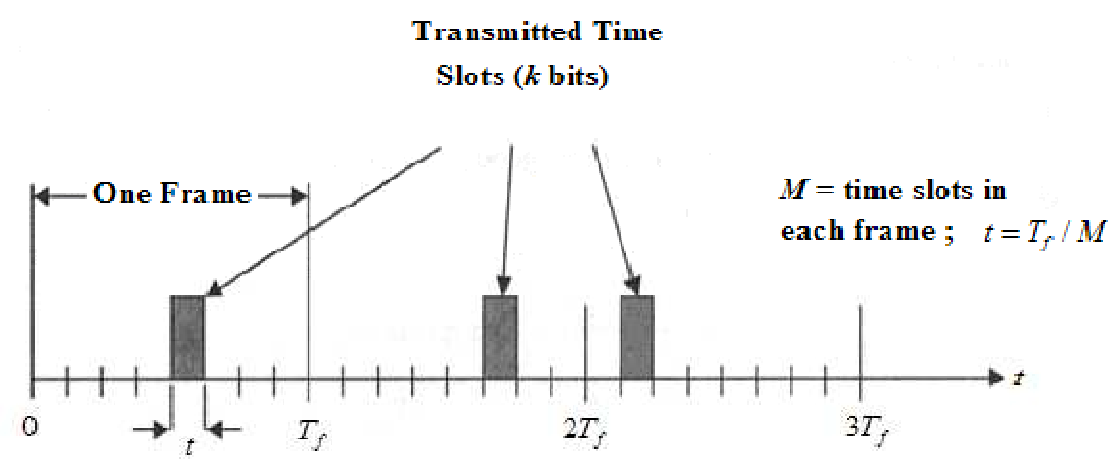



**Fig.4 Time Hopping Sequence Spread Spectrum**

In this scheme, the FSK signal is generated and the frequency of this signal is shifted by an amount that is determined by a PN code. At the receiver the frequency synthesized is controlled by an identical PN sequence, to generate a spreading sequence similar to the sequence used at the receiver.

In addition to the above mentioned spreading techniques, we also have ***Chirp*** and ***Time Hopping*** along with some other ***Hybrid*** systems.

***Chirp*** . This method employs a carrier that is swept over a range of frequencies. At the beginning of each transmitted pulse, the carrier frequency is modulated, causing an additional spreading of the carrier.
The primary application of this method is in radar systems where the uniqueness of each part of the spread spectrum system increases time resolution allowing accurate measurement of the time a signal takes to return.
***Time Hopping*** . In time hopping systems the period of the duty cycle of the pulsed RF carrier varied in a pseudo random manner. This is also mainly a military application.
***Hybrid Systems*** . Hybrid systems employ a combination of two or more of theabove methods. Typically, hybrid systems combine the best of two or more of these spread spectrum systems.

### *4. Coherent And Incoherent System*

An Optical communication receiver can be divided into 2 major categories: direct detection and coherent detection systems.

- In direct detection (DD) systems the optical signal is processed by an optical front end. The front end is composed of primarily passive devices, such as, lenses, directional couplers, polarizers, etc. The signal is then detected by a photodiode or a group of diodes. Direct detection systems are by far the simplest configurations.

  In DD systems, at the transmitter the information signal is intensity modulated to produce a series of optical pulses. While at the receiver the received signal is detected by a photodiode, which converts the optical signal into an electric baseband signal. The information, which is coded into optical energy, can be retrieved. A DD or Incoherent system is shown in figure 5.
- In coherent optical systems the optical signal from the fiber is mixed with a signal generated by a laser (optical local oscillator). The mixing operation translates the received optical signal, using heterodyne detection, resulting in a baseband signal followed by a standard electronic receiver to process the signal. This is shown in figure 6.

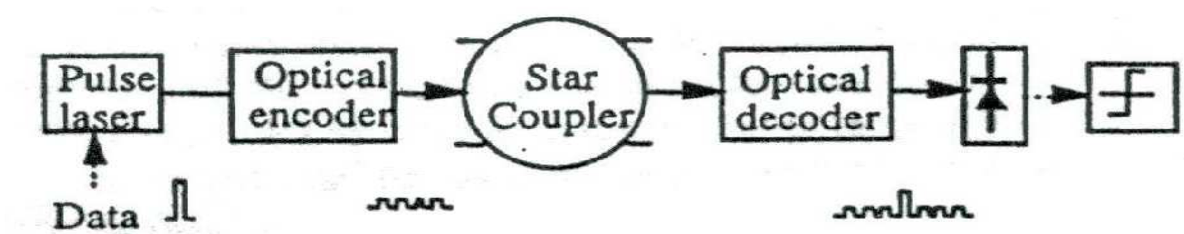



**Fig.5 Incoherent OCDMA**

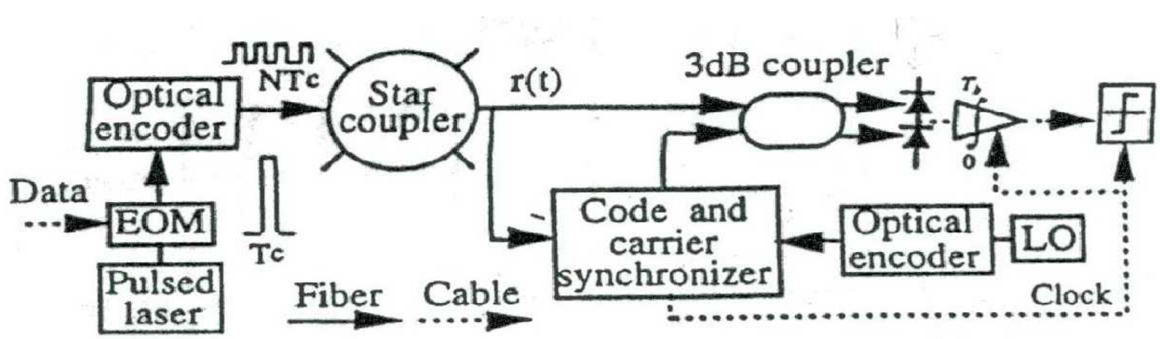



**Fig.6 Coherent OCDMA**

## *5.Auto Correlation and Cross Correlation*

Typically a correlation circuit consists of a mixer and a low pass filter. The Correlation can be defined as the measurement of how much two signals are alike. It is a measurement of the similarity of two signals. Correlation is used for detecting spread spectrum signals. However autocorrelation refers to the degree of correspondence between a sequence and a phase shifted replica of itself.

In a direct sequence spread spectrum system correlation is used to identify a signal that has been coded with a PN sequence. The low pass filter handles averaging and removing noise which is outside the bandwidth of information signals I. Essentially the two incoming signals are multiplied together (in a mixer) and the product will be checked. The average value from the mixer will result in the average likeness of the two signals. After mixing, the interference signals are spread out (since they resemble noise) while the desired signal is de-spread to its narrow band. As mentioned before, typical autocorrelation plots show the number of agreements minus the number of disagreements for the overall length of the sequences being compared. If c(r) is a periodic: pulse waveform representing a PN sequence, we refer to each fundamental pulse as a PN sequence symbol or chip.[2] The normalized autocorrelation function is expressed as follows;

$$R_x(\tau) = \frac{1}{T_o}[\textit{number of agreements} - \textit{number of disagreements}] \quad (2)$$

$T_o = 2^m - 1$ chips.

The Agreement and Disagreement with reference sequences are as given below.

| Shift | Sequence | Agreement (A) | Disagreement (D) | A – D |
|---|---|---|---|---|
| 1 | 0111001 | 3 | 4 | –1 |
| 2 | 1011100 | 3 | 4 | –1 |
| 3 | 0101110 | 3 | 4 | –1 |
| 4 | 0010111 | 3 | 4 | –1 |
| 5 | 1001011 | 3 | 4 | –1 |
| 6 | 1100101 | 3 | 4 | –1 |
| 0 | 1110010 | 7 | 0 | 7 |

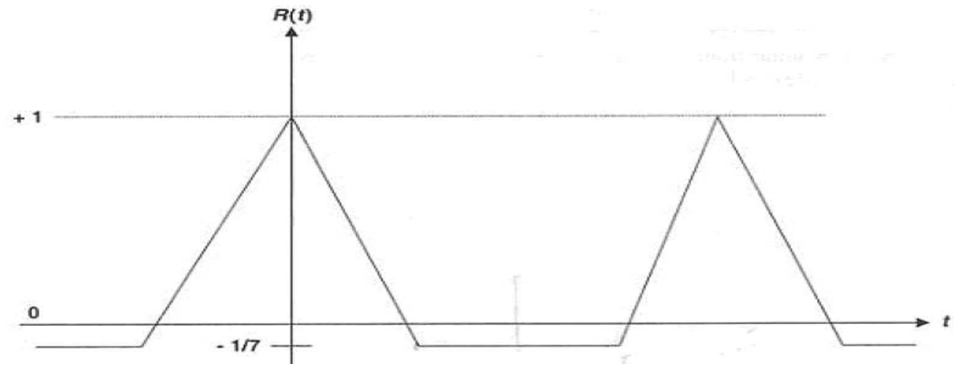



**Fig.7 Auto correlation of a three stage linear feedback shift register**

The normalized autocorrelation function ivv(x) of a periodic waveform ***x(t)*** with period *T0* is given as:

$$R_x(\tau) = \frac{1}{R_x(0)} \frac{1}{T_0} \int_{-T_0/2}^{T_0/2} x(t)x(t+\tau)dt \qquad for \quad -\infty < \tau > \infty \qquad (3)$$

Where,

$$R_x(0) = \frac{1}{T_0} \int_{-T_o/2}^{T_o/2} x^2(t)dt$$

The cross correlation function between two signals ***x(t)*** and ***z(t),*** is defined as the con elation between two different dsns Is *x(t)* and *s(t)* and is given by,

$$R_c(\tau) = \int_{-T_0/2}^{T_0/2} x(t)z(t+\tau)dt \qquad for \quad -\infty < \tau > \infty \qquad (4)$$

We have focused 011 the performance analysis of an OCDMA network using certain sequence codes as mentioned before in previous chapters of this thesis, hi order to achieve this, certain PN codes ate generated and analyzed. The codes that have heen studied for this purpose are *ui-sequences*. *Gold codes*, *Prime code* and *Modified Prime-**Codes.***

*6. Coherent Correlation Detection*

In a coherent correlation detection, multiplying the incoming signal with the designated user code, which is generated chip by-chip, carries out coherent correlation detection. The product of the multiplication is then integrated over the code length.

The incoming signal $C_k^{(t)}$ and the local code $C_1^{(t)}$ can be represented with the cross-correlation function,

$$\int_0^{T_b} c_1(t)c_k(t-\tau)dt = T_c\theta_{k,l}(m) + (\tau - mT_c)\lfloor \theta_{k,l}(m+1) - \theta_{k,l}(m) \rfloor \qquad (5)$$

Where $\tau$ is the code phase shift between the incoming signal and the local code,

$m = \lfloor \tau / T_c \rfloor$.

$$\theta_{k,l}(m) = \sum_{j=0}^{N-1} c_j^{(k)} c_{j+m}^{1} \qquad (6)$$

With $\lfloor \tau / T_c \rfloor$ defined as the largest integer less than or equal to $\tau / T_c$, $\theta_{k,l}(m)$ is the discrete periodic cross-correlation function $\theta_1(m)$, at $k$=1, represents the periodic auto-correlation function.

The two primary correlation conditions needed for a multi-user system like CDMA are,

- The autocorrelation function between the codes and its time shifted code should be low compared to the autocorrelation peak value.
- The cross correlation function between two codes in the set should be low compared to the autocorrelation peak value.

### *7.Hardware Description of OCDMA System*

An Optical fiber networking is one of the main solution path to meet the growing demands of the information society with respect to the provision of a range of telecommunication services. The most desirable aspect of the OCDMA is the huge bandwidth inherent with single mode optical fiber transmission. A single mode optical fiber can support transmission capacity in the range of Terabits per second. Optical multiplexing techniques have to be employed to exploit full system transmission capacity. Code division multiple access (CDMA) is a multiple access scheme that is adopted in local area networks (LAN) so that the users in the network can access the same network channel without delay or scheduling but with high transmission security. CDMA is one technique that simultaneously, asynchronously or synchronously, multiplexes multiple users in the same frequency band and timeslot through unique signature codes.

In the above Fig. 1 shows a typical fiber optic CDMA network. Each information source provides am information bit for a laser based optical OOK modulator, every T second. Pulses generated by optical OOK modulator have duration ***Tc=*** T/F, where F is CDMA code length or processing gain of the network. In an optical CDMA encoder, energy of pulse generated gets split into K (code weight) equal parts. Each part undergoes a specified delay and then recombines to form the CDMA code pattern at the output of a CDMA
encoder. This process is performed using optical couplers and optical tapped delay lilies. We assume the OOC codes with minimum auto and cross correlation is assigned to each user's encoder .

In the diagram shown. N is the maximum number of active users of the network and by **Nmax** the maximum number of allowable users. This means that **Nmax** is the size of the star coupler, Under conditions of minimum auto and cross correlation, **Nmax** is limited to **(F-1 )/K (K-l).**

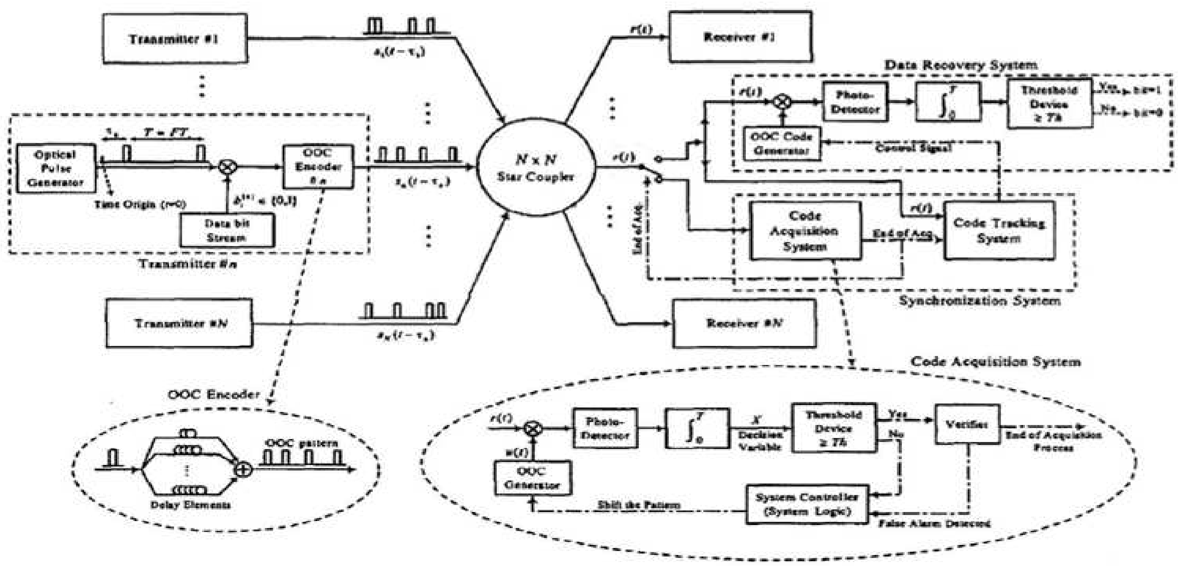


*Fig.8 Optical Orthogonal Codes CDMA Networks*

The star coupler distributes the signal equally from each input port to its A7ma;. Output ports. At the receiver the desired signal along with the interference from all other N-l users will be received. The receiver has to be able to decide which bit of the desired user has been sent. Bit Error Rate performance of the receiver is highly affected by the architecture of CDMA decoder.

*8. Match Filter*

In an OCDMA match filter is an important parameter for optimization analysis. A general matched filter is illustrated in the figure below.

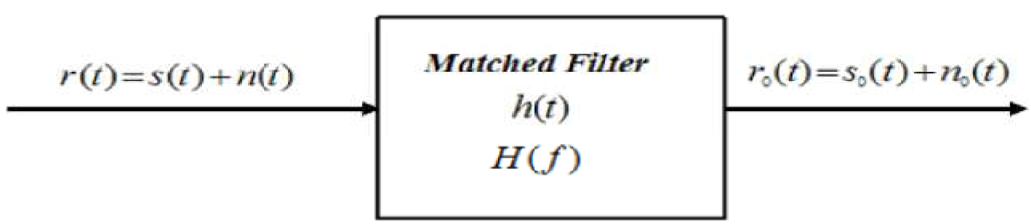



***Fig.9 Match Filter***

Let the input be denoted by s (t) and the output signal by S(0). Similar notation is used for noise. This filter is used in applications where the signal may or may not be present. Firstly, the signal is assumed to be tune limited between the intervals (0, T) and is zero otherwise. The Power Spectral Density (PSD) of the additive input noise ***n(t)*** will also be known. In order to determine the filter characteristics such that the instantaneous output signal power is maximized at $t_0$ we need to find the filter impulse response ***h(t),*** such that the signal to noise ratio will be maximum at $t = t_0$.

$$\left(\frac{S}{N}\right)=\frac{s_o^2(t)}{n_o^2(t)} \tag{7}$$

And the transfer function of the matched filter is given by

$$H(f)=K\frac{S^*(f)}{P_n(f)}e^{-j\omega t_o} \tag{8}$$

where $S(f)=F[s(t)]$ is the Fourier transform of the input signal $s(t)$ of duration T seconds. $P_n(f)$ is the PSD of the input noise, $t_o$ is the sampling time when $(S/N)_{out}$ is evaluated, and K is an arbitrary real non zero constant.

The output is given by,

$$s_0(t_0)=\int_{-\infty}^{\infty} H(f)S(f)e^{j\omega t_0}df \tag{9}$$

The average power of output noise is,

$$n_o^2(t)=R_{n_0}(0)=\int_{-\infty}^{\infty}|H(f)|^2 P_n(f)df \tag{10}$$

The signal to noise ratio at the output is given by,

$$\left(\frac{S}{N}\right)_{out}=\frac{|s_0(t_0)|^2}{n_0^2(t)}=\frac{\left|\int_{-\infty}^{\infty} H(f)S(f)e^{j\omega t_0}df\right|^2}{\int_{-\infty}^{\infty}|H(f)|^2 P_n(f)df} \tag{11}$$

Using the Schwarz inequality , we obtain,

$$\left(\frac{S}{N}\right)_{out}\le\frac{\int_{-\infty}^{\infty}|H(f)|^2 P_n(f)df\int_{-\infty}^{\infty}\frac{|S(f)|^2}{P_n(f)}df}{\int_{-\infty}^{\infty}|H(f)|^2 P_n(f)df} \tag{12}$$

Since $P_n(f)$ is a non negative real function. Hence,

$$\left(\frac{S}{N}\right)_{out}\le\int_{-\infty}^{\infty}\frac{|S(f)|^2}{P_n(f)}df \tag{13}$$

*9.Prime Sequence Codes*

The typical receiver output in a CDMA system is shown in the equation (14) below. Where each data bit is encoded into the waveform *s(n)*, which consists of a signature sequence of N chips. This signature sequence represents the destination address of that bit. Individual receivers correlate their own address *a(n)* with the received signal *s(n)*.

The resulting output *q(n)* is:

$$q(n) = \sum_{k=1}^{N} s(k)a(k-n)$$

**…………………………………………………….*(14)***

If *s(n)*= *a(n)* then the signal has arrived at the correct receiver, and the equation (14) represents an autocorrelation function. The probability of error can be calculated with respect to the number of users on a system, with the use of the signal to noise ratio. From the auto correlation and cross correlation analysis the signal to noise ratio for these types of sequences can be approximated by

$$SNR \cong \frac{P^2}{0.29(K-1)}$$

…………………………………………………….(15)

Here *K* is the number of users transmitting simultaneously. In this equation the SNR is directly proportional to the square of the number of chips (P) per code sequence. It is also true from the equation that, for a given chip length for a code sequence, the signal to noise ratio decreases as the number of simultaneous users, *K* increases. Hence it can be said that, larger the number of users in the network, at a given time, the poorer the system performance. This degradation in the SNR leads to an increase in the probability of error.

The probability of error P*e* /*G* , assuming Gaussian distributed interference, is given by the

$$P_{e/G} = Q\left(\frac{-\sqrt{SNR}}{2}\right) = Q\left(\frac{-P}{\sqrt{1.16(K-1)}}\right)$$

**………………………………..…*(16)***

where $Q(x) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{x} e \frac{-y^2}{2} dy$ is the cumulative distribution function. The above approximation is valid for large values of K where, by the central limit theorem, the interference component approaches a Gaussian distribution.

Table Mapping of $S_x$ and $C_x$ for $P = 5$

| *Group* | *i* | | |
|---|---|---|---|
| *x* | *0 1 2 3 4* | *sequences* | *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 |

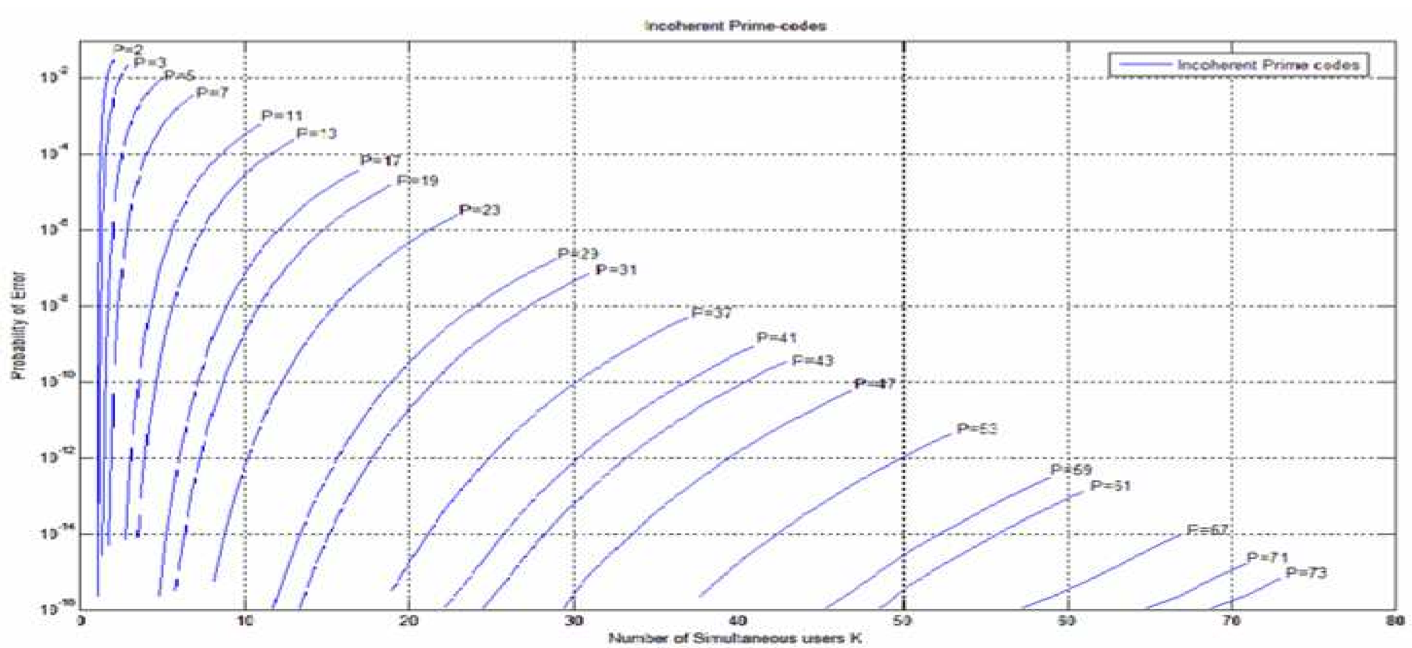



***Fig.9Probability of error Vs Number of simulation user for Prime codes ( In coherent detection scheme) for P=7 to P73***

## *10. Conclusion*

The primary task of this paper has been to study and analyze the different spreading code sequences in a fiber optic CDMA Local Area Network. For this purpose we designed and simulated an OCDMA Local Area Network using certain spreading code sequences. The code sequences we considered for our evaluation are *m* .sequences, Gold sequences, prime sequences and modified prime codes. The performance of these codes and their probabilities or error versus the number of users are evaluated from simulation and plotted. These are shown in the figures in the previous chapters. We analyzed, both coherent OCDMA and incoherent OCDMA. In a CDMA system, we have a transmitter and a receiver. In the receiver, information is retrieved using Matched filter detection (MFD) and Coherent Correlation detection (CCD). There is a need for a lot of future research work to be performed on OCDMA systems, particularly in the area of development and implementation of all optical systems. The coding and other simulations were performed using Matlab. However, future research work can be carried out using better software tools and simulation software such as coding using Visual C++, or even maybe more advanced versions of Matlab.

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