Journal of Mobile Communication 5 (2): 25-30, 2011
ISSN: 1990-794X

Improving Transmission Rate in Single Mode Fiber Through Code Division Multiple Access Technique

M. Sreedevi and P. Jenopaul
Anna University, Tamilnadu, India

Abstract: Optical fiber is the back bone for all the communication in the modern world. But the full capacity of the fiber is not utilized efficiently. The capacity is in terabit ranges but we are only able to use it in gigabit range. This is because the information amount is get reduced by dispersion. The dispersion in the fiber is mitigated by the CDMA technique. In this study, the importance of Code Division Multiple Access (CDMA) technique in optical domain and its transmission rate improvement is summarized.

Key words: Code Division Multiple Access (CDMA), optical fibers, dispersion, modulation, communication, optical domian

INTRODUCTION

Code Division Multiple Access (CDMA) is a multiple access technique where different users share the same physical medium that is the same frequency band at the same time. The main ingredient of CDMA is the spread spectrum technique which uses high rate signature pulses to enhance the signal bandwidth far beyond what is necessary for a given data rate. In a CDMA system, the different users can be identified and hopefully separated at the receiver by means of their characteristic individual signature pulses (sometimes called the signature waveforms) that is by their individual codes. Now-a-days, the most prominent applications of CDMA are mobile communication systems (Bulow, 2007).

To apply CDMA in a mobile radio environment, specific additional methods are required to be implemented in all these systems. Methods such as power control and soft handover have to be applied to control the interference by other users and to be able to separate the users by their respective codes. Spread spectrum means enhancing the signal bandwidth far beyond what is necessary for a given data rate and thereby reducing the Power Spectral Density (PSD) of the useful signal so that it may even sink below the noise level.

One can imagine that this is a desirable property for military communications because it helps to hide the signal and it makes the signal more robust against intended interference (jamming). Spreading is achieved by a multiplication of the data symbols by a spreading sequence of pseudo random signs. These sequences are called Pseudo Noise (PN) sequences or code signals. Consider a rectangular transmit pulse of length T_S.

$$g(t) = \frac{1}{\sqrt{T_S}}\pi\left(\frac{t}{T_S} - \frac{1}{2}\right) \tag{1}$$

We divide the pulse into N sub rectangles, referred to as chips of length $T_c = T_S/N$ and change the sign of the sub rectangles according to the sign of the pseudorandom spreading sequence. Figure 1 shows the resulting transmit pulse g_k (t) of user number k for N = 8. Here, the spreading sequence for user k is given by (+, −, +, +, −, +, −, −).

When it is convenient, the sign factors shall be appropriately normalized. In practice, smooth pulse shapes (e.g., raised cosine pulses) will be used rather than rectangular ones. For this reason, $N = T_S/T_c$ is called the spreading factor or more precisely, the spreading factor of the signature pulse.

This spreading is due to multiplication by the code sequence. While within the specification documents for CDMA mobile communication systems, the spreading factor is often denoted by SF. We may have different spreading mechanisms that work together, especially in the context of channel coding. It is often not uniquely defined where channel coding ends and where modulation starts and thus, it may be ambiguous to speak of a bit rate after channel coding. We regard it as convenient to define the effective spreading factor by:

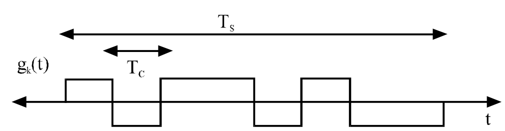

Fig. 1: Signature pulse with N = 8 rectangular chips

Corresponding Author: M. Sreedevi, Anna University, Tamilnadu, India

$$SF_{eff} = \frac{R_{chip}}{R_b} \quad (2)$$

Where:
R_b = Useful bit rate
R_{chip} = $1/T_c$ chip rate

Obviously, this spreading factor is approximately the inverse of the spectral efficiency for a single user. The objective of spreading is a waste of bandwidth for the single user to achieve more robustness against Multiple Access Interference (MAI). It would thus be a contradiction to this objective to use bandwidth-efficient higher-level modulation schemes (Savory, 2008). Any modulation scheme that is more efficient than BPSK would reduce the spreading factor (Spinnler, 2008). Therefore, BPSK and QPSK are used as the basic modulation schemes in most practical communication systems. Nevertheless, higher-order modulation techniques like 8-PSK and 16-QAM also are applied as additional transmission options to offer a high speed packet transfer at good propagation conditions. Furthermore, we point out the special role of channel coding. Channel coding, usually means that higher power efficiency has to be paid by a lower spectral efficiency. Thus, channel coding can be interpreted as an additional spreading mechanism.

In the extreme case, all the spreading can be done by channel coding and the PN sequences serve only for user separation. We can interpret the conventional spreading by a PN sequence as a repetition code combined with the repeated transmit symbols multiplied by a pseudorandom sign. The symbol will be repeated N times at a clock rate increased by the factor $N = T_S/T_c$ and scrambled by a random sign. Equivalently, this is time delay diversity. Because of the time dispersion of the channel, we may get a multipath diversity gain (Fa *et al*., 2009).

RAKE RECEIVER

The name RAKE receiver originates from the fact that there are some similarities to a garden rake is shown in Fig. 2. The receiver consists of a certain number of correlators (called RAKE fingers) correlating the received signal to the used code signal. One of the correlators (the so-called search finger) has the task to determine the propagation delay values τ_i (i = 1, 2, ...) of the most relevant propagation paths. These values are used within the other correlators (fingers) to adjust the exact timing for the respective multipath components (Yang and Hanzo, 2003). By this method, the multipath components can be detected separately (if the codes have a good autocorrelation property); subsequently, they can be

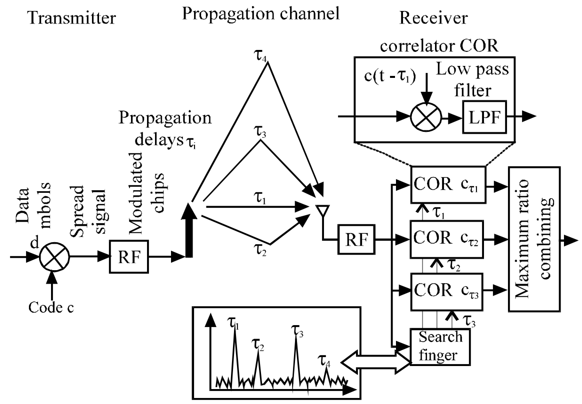

Fig. 2: RAKE receiver

combined by a maximum ratio combiner. It should be noted that multipath components can only be resolved. If their delay difference is higher than about a quarter of the chip duration T_c. Furthermore, the number of RAKE fingers is usually restricted to 4-6 (including the search finger). The CDMA 2000 specification requires for example that there are at least four processing elements (including the search finger). It must be emphasized that spreading by itself does not provide any performance gain in the AWGN channel 1. For a single user, spreading means nothing but choosing a spectrally rather inefficient waveform that smears the spectral power over an SF times higher bandwidth.

Thus for the same signal power, the SNR decreases by a factor of SF. The necessary power per bit rate which equals the energy per bit, E_b does not depend on the pulse shape. We therefore, avoid the popular but misleading word processing gain for the factor SF. Originally for a single user, it is nothing but a waste of bandwidth (Smida *et al*., 2008). We compare, BPSK transmission employing a given pulse shape with a spread spectrum transmission that uses this pulse as a chip pulse and the spectrum will be spread by this factor of SF. Consider for example, BPSK transmission with a Nyquist base and roll-off factor one which occupies a bandwidth of 200 KHz to transmit a bit rate of R_b = 100 Kbits sec^{-1}. For BPSK in an AWGN channel, we need E_b/N_0 = 9.6 dB to achieve a bit error rate. We now compare this system with a spread spectrum system of the same data rate, a spreading factor of SF = 100 and the same roll-off factor for the chip pulse. The performance of a linear modulation scheme does not depend on the pulse shape. Thus, we still need E_b/N_0 = 9.6 dB to achieve a bit error rate that is the power that is needed to transmit a given bit rate of R_b = 100 kbits sec^{-1} is the same. However, the bandwidth has now been increased by a factor of SF and the signal occupies 20 MHz. Because the same signal power is spread over this higher bandwidth, the signal is now completely below the noise and we have SNR = -10.4 dB (Stott, 1998). This fictitious mystery that a signal below the noise level can be completely recovered has its simple explanation in the fact that we have just wasted bandwidth by using a spectrally inefficient pulse shape which does not influence the power efficiency. Thus, the processing gain is just a virtual gain. The reason for using spreading is not this virtual processing gain. A real gain of spreading concerning, the range of data transmission can be achieved in a frequency-selective fading environment. The increased bandwidth of a spread signal provides us with increased frequency diversity as compared to a narrowband FDMA system. Such a frequency diversity can only be exploited if the signaling bandwidth significantly exceeds the correlation frequency (i.e., the coherency bandwidth) of the channel. In that case, we speak of a wideband CDMA system (Armstrong, 2008). Such diversity can also be achieved by increasing the carrier bandwidth by multiplexing different users to a frequency carrier using a time division multiplexing scheme. Comparing the spread spectrum and the TDMA technique at the same signal bandwidth at the same data rate and mean transmission power (energy per transmitted bit), roughly the same performance will result since, the receive E_b/N_0 is the same. Spreading may have an advantage since, it uses a continuous transmission while transmission in time multiplex systems is pulsed. For this reason, sometimes the peak transmission power of systems is limited by regulatory bodies. Obviously at equal peak transmit power, the performance of spread spectrum systems is higher than that of TDMA systems.

AUTO CORRELATION OF CDMA

The most interesting property from the point of view of spread spectrum applications concerns the autocorrelation function. Defining the code sequence c corresponding to an m-sequence by mapping each 0 to +1 and each 1 to −1, the periodic discrete normalized autocorrelation function is given by:

$$\Phi(\nu) = \frac{1}{M}\sum_{\mu=0}^{M-1} c_{\mu} + \nu.c_{\mu} \qquad (3)$$

In an analogous way, one can define the periodic discrete normalized cross-correlation function between two periodic codes c_i and c_j as:

$$\Phi_{i'j}(\nu) = \frac{1}{M}\sum_{\mu=0}^{M-1} c_{i\mu} + \nu.c_{j.\mu} \qquad (4)$$

It can be shown that the autocorrelation function of m-sequences is only two-valued: φ (0) = 1 and φ (ν) = -1/M. Hence, a code given by an m-sequence has for large M nearly an ideal autocorrelation function like a sequence of independent Bernoulli random numbers (Chang, 1966). It should be noted that defining a continuous autocorrelation function instead of a discrete one by using integrals instead of sums, this continuous function is obtained from the discrete one by linear interpolation. These proofs are based on the relation between a linear feedback shift register with coefficients $a_n(n = 0, 1, ..., m)$ and its corresponding generating polynomial which is given by:

$$P(X) = a_m X_m + a_{m-1} X_{m-1} + ... a_1 X + a_0$$

This relationship also allows the classification of those registers that generate m-sequences: a linear feedback shift register of length m produces an m-sequence if and only if the corresponding generating polynomial of degree m is primitive. A polynomial of degree m is called primitive if it is irreducible that is if it cannot be factored and if is a factor of x^M+1, $M = 2^m-1$.

TYPES OF FIBER AND DISPERSION

In general, the optical fibers are clarified into single mode fibers and multimode fibers. In single mode fiber, only one mode of propagation will be present. In multimode fiber, many no of modes are present. Multimode fibers offer several advantages when compared with single mode fibers. After the data has been transmitted from the source and coupled into the optical fiber, it will propagate as an electromagnetic wave according to the Nonlinear Schrodinger Equation (NLSE), the nonlinear wave equation governing the propagation of light in fiber and undergo a number of channel impairments. As shown in Fig. 3, the propagating wave is

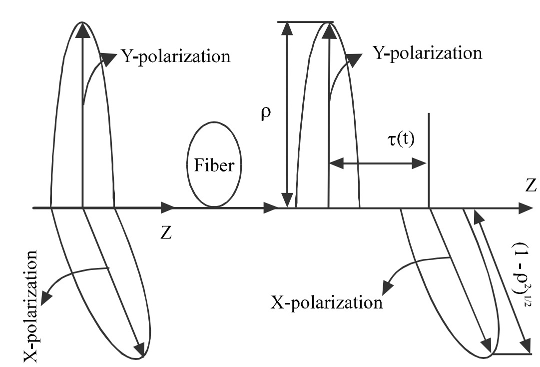

Fig. 3: Single-mode fiber in which a single optical mode is coupled into two axes of polarization

supported by two orthogonal axes of polarization or polarization states within the fiber. The differential group delay experienced by these two modes gives rise to PMD, causing pulse spreading at the output of the detector in the receiver.

In Multimode Fiber (MMF), the transmitted signal will excite a number of propagating which will propagate at mode-dependent velocities. This results in modal dispersion at the where, a single transmitted pulse may spread into a number of adjacent symbol periods depending on the data rate, distance traveled and fiber properties. Single Mode Fiber (SMF) permits only a single optical mode to propagate thereby, enabling greater propagation distances before pulse spreading occurs. Short-reach SMF applications typically employ 1,310 nm wavelengths as this represents the wavelength of minimum dispersion for silica fiber.

Longer reach applications use 1,550 nm wavelengths as this represents the wavelength of minimum loss due to absorption. Though, the 1,550 nm wavelength enables greater transmission distance without amplification, it does so at the cost of necessitating dispersion management at sufficiently high data rates. Long-reach applications may include multiple spans of optical fiber that are periodically amplified using optical amplifiers (Salz and Weinstein, 1969). The noise induced by the optical amplifiers eventually becomes sufficiently large that the data integrity is in jeopardy after the signal passes through a sufficient number of fiber sections.

So due to the dispersion in the fiber segment, the amount of data that is transmitted have being lost, this makes the system performance very weak. The disadvantage of multimode fibers is that they suffer from intermodal dispersion. The next attribute which required attention was dispersion. Signal dispersion a source of Intersymbol Interference (ISI) in which consecutive pulses blend into each other.

Again, it turns out that optical glass fibers have inherently outstanding dispersion properties. As a matter of fact, any particular fiber has a characteristic wavelength for which the dispersion is zero (Peled and Ruiz, 1980). This is typically between 1.27-1.39 m. However as is the case for absorption, long distance transmission can cause dispersion. There are two major contributors to dispersion material and waveguide structure. A waveguide is a device such as a duct, coaxial cable or glass fiber, designed to confine and direct the propagation of electromagnetic waves. In optical fibers, the confinement is achieved by having a region with a larger refractive index. Material dispersion which comes from electronic transitions in the solid is determined as soon as the chemical constituents of the glass have been fixed is shown in Fig. 4. Waveguide dispersion is a function of the geometry of the core or more precisely, how the refractive index in the core and cladding vary in space. This is important because it means that fiber manufacturers have a fair amount of flexibility in modifying the total dispersion of the fiber (Telatar, 1999). Today, there is a plethora of fibers with different dispersion characteristics. However, it is not yet possible to reliably manufacture fibers with zero dispersion for all wavelengths between say 1400-1550 nm. Thus even though, the dispersion can be made as small as 2-4 ps/nm/km over this wavelength region, we still need to worry about dispersion for long-distance networks.

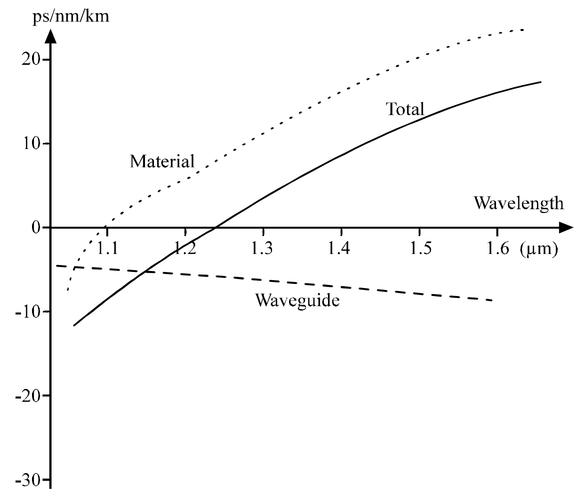

Fig. 4: Dispersion in optical fiber

When considering, the major implementation of optical fiber transmission which involves some form of digital modulation, the dispersion mechanisms within the fiber cause broadening of the transmitted light pulse as they travel along the channel. It is observed that each broadened pulse overlaps with its neighbours, eventually become in distinguishable at the receiver (Foschini and Gans, 1998).

Thus, an increasing number of errors may be encountered on the digital optical channel due to such dispersion. The signal dispersion alone limits, the maximum possible bandwidth attainable with a particular optical fiber. Bit rate or data rate is the number of bits that can be transmitted per second over a channel. It is measured in bit sec^{-1}.

SIMULATION

The simulation is performed by Matlab/simulink. Figure 5 shows the transmitter and receiver section with

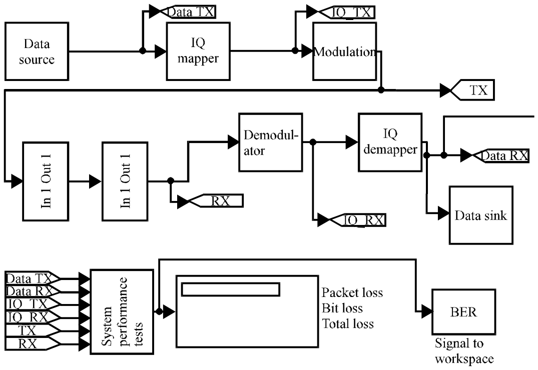

Fig. 5: Optical CDMA simulink model

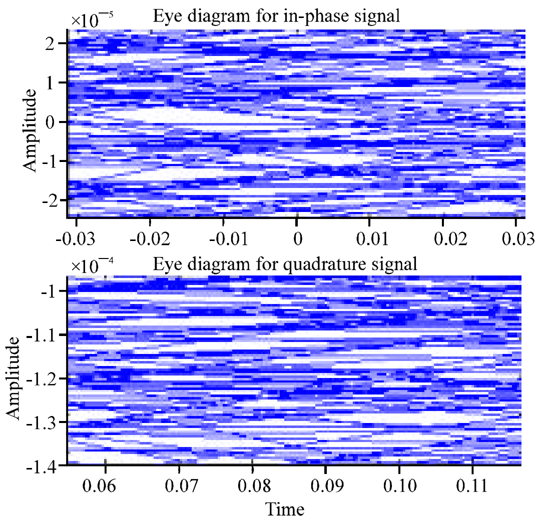

Fig. 6: Eye diagram for a random binary

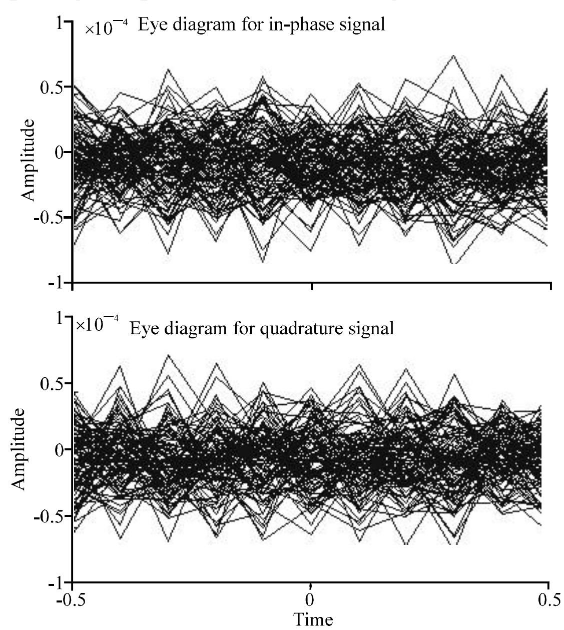

Fig. 7: Eye diagram for a CDMA

the fiber model. The system performance is measured by the spectrum scope and the constellation graph. The serial data is passed through the system, it has been modulated by four Quadrature Amplitude Modulation (QAM).

Then the CDMA has been performed and output is transmitted through the fiber and retrieved in the receiver. The obtained signal has the same of the input parameter so, loss due to dispersion is very minimum and the performance has been increased. So, we can calculate for different modulation schemes. Figure 6 and 7 shows the eye patterns for the random binary and CDMA. It clearly indicates that the eye opening which gives the performance measurement seeking that the performance of CDMA is better compare to the ordinary transmission system and also the transmission rate has been increased.

CONCLUSION

In this study, method of reducing the effect of dispersion is suggested that can increase the data rate. A typical CDMA receiver is described and the roles of the main signal processing blocks explained. A number of forms of CDMA which overcome various incompatibilities in various ways have been developed for variety of optical applications. The CDMA signal is generated and the signal is passed through single mode fiber. The performance of the code division multiplexing in optical domain is analyzed with the help of EYE diagram.

REFERENCES

Armstrong, J., 2008. OFDM: From Copper and Wireless to Optical. Proceedings of the Optical Fiber Communication/National Fiber Optic Engineers Conference, Feb. 24-28, San Diego, California, pp: 1-27.

Bulow, H., 2007. Electronic dispersion compensation. Proceedings of the Optical Fiber Communication/ National Fiber Optic Engineers Conference, Anaheim, CA, March 25-29, Tutorial, OMG5.

Chang, R.W., 1966. Orthogonal frequency multiplex data transmission system. U.S. Patent 3488445, USA.

Fa, R., B.S. Sharif and C.C. Tsimenidis, 2009. Performance analysis for MC-CDMA system in impulsive noise. Proceedings of the Wireless Communications and Networking Conference, (WCN'09), IEEE Publication, pp: 1-5.

Foschini, G.J. and M.J. Gans, 1998. On limits of wireless communications in a fading environment when using multiple antennas. Wireless Personal Commun., 6: 311-335.

Peled, A. and A. Ruiz, 1980. Frequency domain data transmission using reduced computational complexity algorithms. Proceedings of the IEEE International Conference on ICASSP'80 Acoustics, Speech and Signal Processing, April'80, USA., pp: 964-967.

Salz, J. and S.B. Weinstein, 1969. Fourier transform communication system. Proceedings of the 1st ACM symposium on Problems in the Optimization of Data Communications Systems, (PODCS'69), USA., pp: 99-128.

Savory, S.J., 2008. Digital signal processing options in long haul transmission. Proceedings of the Optical Fiber Communication/National Fiber Optic Engineers Conference, Feb. 24-28, San Diego, California, pp: 2508-2510.

Smida, B., S. Affes, K. Jamaoui and P. Mermelstein, 2008. A multicarrier-CDMA space-time receiver with full-interference-suppression capabilities. IEEE Trans. Vehicular Technol., 57: 363-379.

Spinnler, B., 2008. Recent advances on polarization multiplexing. Proceedings of the IEEE/LEOS Summer Topical Meetings, July 21-23, Acapulco, pp: 227-228.

Stott, J.H., 1998. The how and why of COFDM. EBU Technical Review, http://tech.ebu.ch/docs/techreview/trev_278-stott.pdf.

Telatar, E., 1999. Capacity of multi-antenna gaussian channels. Eur. Trans. Telecommun., 10: 585-595.

Yang, L.L. and L. Hanzo, 2003. Multicarrier DS-CDMA: A multiple access scheme for ubiquitous broadband wireless communications. IEEE Commun. Mag., 41: 116-124.