CODE DIVISION MULTIPLE ACCESS

Spread spectrum and CDMA are up-to-date technologies widely used in operational radar, navigation and telecommunication systems and playing a dominant role in the philosophy of the forthcoming generations of systems and networks. 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.

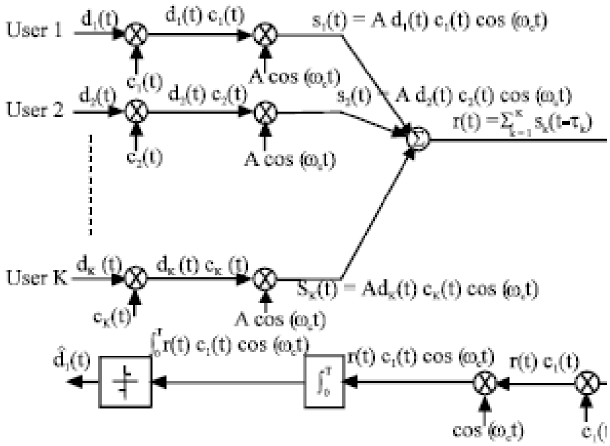
Classifications of CDMA Schemes:

CDMA can be classified according to the modulation method used to obtain the spread spectrum signal into four major techniques: DS-CDMA, FH-CDMA, TH-CDMA and hybrid CDMA.

3.4.1 DS-CDMA:

Now-a-days, DS modulation has been used for many commercial communication systems (almost all 3G mobile cellular systems use DS-CDMA as their prime multiple access air-link architecture) and measurement instruments. It is reasonable to expect that DS modulation will continue to be a familiar form of spreading modulation scheme in the years to come due to its unique and desirable features. Characteristic of DS spreading modulation is just exactly that modulation of a carrier by a code sequence. The use of DS-CDMA can effectively enhance overall bandwidth efficiency compared with traditional multiple access schemes such as FDMA (Frequency Division Multiple Access) and TDMA (Time Division Multiple Access). Spectrum is extremely expensive; it has to be purchased from various governmental licensing authorities at auction and sometimes those auctions have involved billions of US dollars (or equivalent monetary value in other currencies). It represents a considerable investment by a service carrier. Therefore, the bandwidth efficiency of a communication technology will be a primary concern for any network operator. The right selection of a suitable multiple access schemes to provide multi-user services is of ultimate importance. DSCDMA-based mobile cellular carries more calls than TDMA-based technologies. Generally speaking, CDMA will carry between 2 and 3 times as many calls simultaneously as TDMA in the same amount of bandwidth. The major advantage of CDMA is its capability for dynamic allocation of bandwidth. To understand this, it is important to realize that in this context in CDMA, bandwidth refers to the ability of any user to get data from one end to the other. It does not refer to the amount of spectrum used by the user because in CDMA every terminal uses the entire spectrum of its carrier whenever it is transmitting or receiving. On the other hand, TDMA works by taking a channel with a fixed bandwidth and dividing it into several time slots. Any given mobile terminal is then given the ability to use one or more of the slots on an ongoing basis if it is in a call.

DS-CDMA's system model: The block diagram of simple asynchronous DS-CDMA modem in a noiseless channel is shown in figure. This system supports K users each transmitting its own information. The users are identified by $k = 1, 2, 3, ..., K$. This modulation scheme is used in Binary Phase Shift Keying (BPSK).



Block diagram of a simple asychronous DS CDMA system

Each user's data signal is denoted by $d_k(t)$ and each user is assigned a unique pseudo-random code also known as a spreading code denoted by $C_k(t)$.

There are two classes of spreading codes in general, binary and complex. For simplicity, the following discussion considers only binary codes. Each spreading code consists of Q pulses, commonly known as chips. Here, the wanted signal is the signal of user k = 1 and all the other (K-1) signals are considered to be interfering signals. At the DS-CDMA transmitter of user k is 1st multiplied by the spreading code $c_k(t)$. This causes the spectrum of the information signal to be spread across the allocated bandwidth. Next, the signal is modulated onto its carrier before it is transmitted. The transmitted signal is given by:

$$S_k(t) = A\, d_k(t)\, c_k(t)\cos(w_c t) \quad (1.25)$$

where, w_c is the carrier frequency in rad sec^{-1} and A is the amplitude of the carrier signal. At the DS-CDMA receiver, the composite of all the K user signal is received, consisting of the transmitted signal from user 1 and the other (K-1) interfering signals. Ignoring the noise, the received signal is given by:

$$r(t) = \sum_{k=1}^{k} S_k(t-\tau_k) \quad (1.26)$$

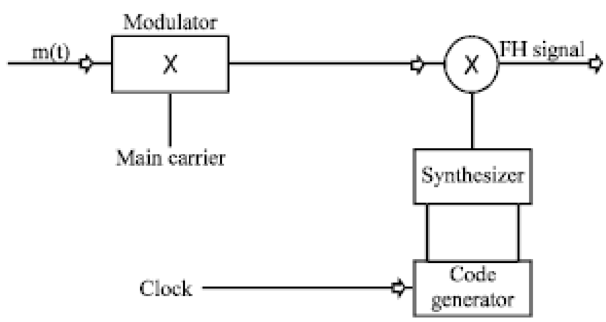
where, T_k is the propagation delay from the transmitter to the receiver of the kth user.

3.4.2 FH-CDMA:

After having discussed the issues on DS-CDMA techniques, let's look at Frequency-hopping (FH) CDMA. Compared to the DS-CDMA technique, the FH-CDMA technique is a relatively less widely used CDMA scheme in real applications. The reason for its less wide acceptance is owing to several factors. First, the FH technique requires a very accurate reference clock in the whole wireless system which uses the FH-CDMA technique for user separation. This accurate network-wide reference clock is very costly to implement using currently available digital technology.

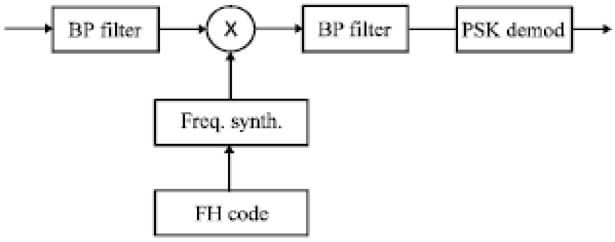
Maybe in the future, the situation will be different with the advancement in micro-electronics technologies. Second, the hardware to implement an FH-CDMA is still much too complex compared to DS-CDMA under the same maximum data transmission rate constraint. Therefore, system designers still prefer DS-CDMA to FH-CDMA for most commercial wireless applications. In Frequency Hopping CDMA (FHCDMA), the transmission bandwidth is divided into frequency sub-bands where the bandwidth of each sub-band is equal to the bandwidth of the information signal. A pseudo-random code is then used to select the sub-band in which the information signal is transmitted and this sub-band changes periodically according to the code. There are two sub-categories of FH-CDMA: Fast frequency hopping where one complete or a fraction of the data symbol is transmitted within the duration between carrier hops. Consequently for a binary system, the frequency hopping rate may exceed the data bit rate. Slow frequency hopping system, >1 symbol is transmitted in the interim time between frequency hops.

Usually, an FH system must have a code generator and a synthesizer which is capable of generating the corresponding frequencies according to the code generator. As stated earlier, the difficult part of developing an FH system is to design a fast-settling synthesizer with a sufficiently large number of carrier frequencies. Theoretically speaking, the output instantaneous frequency the synthesizer generates must be a single frequency. This is one of the reasons why an FH system is very difficult and costly to implement. In particular, the synthesizer in a fast-hopping, FH system has to work by switching from one frequency to another in a very fast and stable way, especially when the data rate is very high. However, a practical system may produce an output spectrum which can be a composite of the desired frequency, sidebands generated by hopping, as well as some other spurious frequencies generated as by-products. Figure shows a conceptual block diagram of an FH transmitter. The receiver of the FH system is given in. The FH-CDMA transmitter shown in figure, consists of the following basic blocks, a data modulator, a mixer (denoted simply by a multiplier), an FH pattern code generator, a synthesizer and an antenna.



Basic FH modulator

The hopping rate is a very important parameter in an FH-CDMA system which will determine if it is a fast-hopping or a slow-hopping FH system. At the FH-CDMA receiver as shown in figure, the received signal should first go through a band pass filter which will be used to reject the image of the carrier frequency produced in the mixer. For the same purpose, the code generator will produce a replica of the sequence used by the transmitter and will yield an FH pattern which should be exactly the same as that used in the transmitter in the output of the synthesizer.

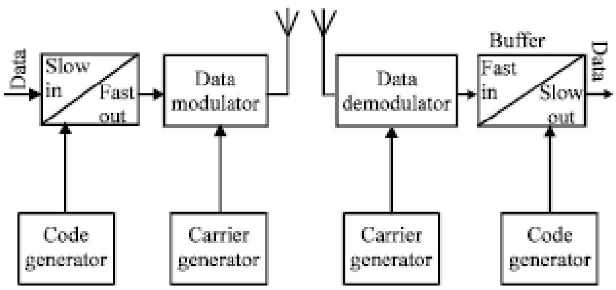


Basic FH receiver

The locally generated FH pattern will be mixed with the received signal to produce a narrowband data-modulated signal with a fixed carrier frequency which should be equal to the intermediate frequency (IF) ω_I. The output IF signal will be demodulated by a PSK demodulator to recover the transmitted data information. Ideally, the spectrum generated from an FH system should be perfectly rectangular with spectral lines distributed evenly in every predetermined frequency channel. The transmitter should also be designed to send the same amount of power in each frequency. Otherwise, the detection efficiency on different frequencies will be different causing decision errors at a receiver. As shown in figure, the received frequency-hopping signal is mixed with a locally generated replica which is offset by a fixed amount (which is equal to a carrier frequency suitable for the reception process at the receiver, ω_I) such that the output from the mixer in the receiver will produce a constant difference frequency or ω_I if transmitter and receiver code sequences are synchronous. Signal that is not a replica of the local reference is spread by multiplication with the local reference and is never restored into its original narrowband waveform. The bandwidth of an undesired signal after multiplication with the local reference is approximately equal to the bandwidth before dispreading.

3.4.3 TH-CDMA:

The 3rd CDMA technique, TH-CDMA is found to be much less widely used than the previous two mainly due to its implementation difficulties and hardware cost associated with its transmitter which should provide an extremely high dynamic range and very high switching speed.



Block diagram of a TH-CDMA transmitter and receiver

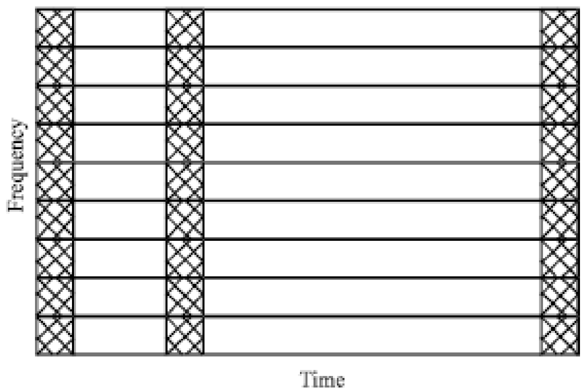
The TH technique in fact, works in a very similar way as a digital modulation scheme called Pulse Position Modulation (PPM). The TH-SS (Time Hopping Spread Spectrum) technologies are not as popular as the other two spread spectrum techniques, i.e., the DS-SS (Direct Sequence Spread Spectrum) and FH-SS (Frequency Hopping

Spread Spectrum) techniques. The main reason is implementation difficulties, especially for the pulse generator which is the core of a TH-SS system and should be able to produce a train of very narrow impulses with its width being at an order of nano sec. The pulse generator should also provide very good timing accuracy such that the PPM can be effectively applied to code different SS sequences for multiple accesses. The TH-SS technique seldom works independently in an SS system (except for the case of an Ultra-wideband (UWB) system, a technology developed based on the TH technique). Instead, it works with some other SS modulation schemes in particular the FH technique which has been discussed in the previous study to result in a time-frequency hopping SS scheme.

TH-CDMA's system model:

In the TH-CDMA system, a pseudo-noise sequence defines the transmission moments, rather than the transmission frequency as FH does. The data signal in time-hopping CDMA is transmitted in rapid bursts at time intervals determined by the code assigned to the user. The time axis is divided into frames and each frame is divided into M, time slots. During each frame, the user will transmit in one of the M time slot which of the M time slots is transmitted depends on the code signal assigned to the user. Since, a user transmits all of its data in one instead of M, time slots, the frequency it needs for its transmission has increased by a factor M.A. block diagram of a TH-CDMA system is shown in figure.

figure shows the time-frequency plot of the TH-CDMA system which clarified that TH-CDMA uses the whole wideband spectrum for short periods instead of parts of the spectrum all of the time.



Time frequecny plot of the TH-CDMA

3.4.4 Hybrid CDMA:

The increasing demand for high data rate transmission for newly evolving wireless communications systems (3G, beyond 3G and 4) has challenged the researchers to exploit new modulation, diversity and coding techniques to overcome the limited natural wireless resources: frequency and power. There are many different types of hybrid CDMA schemes which can be formed by various combinations of DS, FH and TH, together with Multi-carrier (MC) and Multi-tone (MT) techniques.