Module

7

Spread Spectrum and Multiple Access Technique

Lesson

38

Introduction to Spread Spectrum Modulation

After reading this lesson, you will learn about

- ***Basic concept of Spread Spectrum Modulation;***
- ***Advantages of Spread Spectrum (SS) Techniques;***
- ***Types of spread spectrum (SS) systems;***
- ***Features of Spreading Codes;***
- ***Applications of Spread Spectrum;***

Introduction

Spread spectrum communication systems are widely used today in a variety of applications for different purposes such as access of same radio spectrum by multiple users (multiple access), anti-jamming capability (so that signal transmission can not be interrupted or blocked by spurious transmission from enemy), interference rejection, secure communications, multi-path protection, etc. However, irrespective of the application, all spread spectrum communication systems satisfy the following criteria-

(i) As the name suggests, bandwidth of the transmitted signal is much greater than that of the message that modulates a carrier.

(ii) The transmission bandwidth is determined by a factor independent of the message bandwidth.

The power spectral density of the modulated signal is very low and usually comparable to background noise and interference at the receiver.

As an illustration, let us consider the DS-SS system shown in **Fig 7.38.1(a) and (b)**. A random spreading code sequence c(t) of chosen length is used to 'spread'(multiply) the modulating signal m(t). Sometimes a high rate pseudo-noise code is used for the purpose of spreading. Each bit of the spreading code is called a 'chip'. Duration of a chip (T_c) is much smaller compared to the duration of an information bit (T). Let us consider binary phase shift keying (BPSK) for modulating a carrier by this spread signal. If m(t) represents a binary information bit sequence and c(t) represents a binary spreading sequence, the 'spreading' or multiplication operation reduces to modulo-2 or ex-or addition. For example, if the modulating signal m(t) is available at the rate of 10 Kbits per second and the spreading code c(t) is generated at the rate of 1 Mbits per second, the spread signal d(t) is generated at the rate of 1 Mega Chips per second. So, the null-to-null main lobe bandwidth of the spread signal is now 2 MHz. We say that bandwidth has been 'spread' by this operation by a factor of hundred. This factor is known as the spreading gain or process gain (PG). The process gain in a practical system is chosen based on the application.

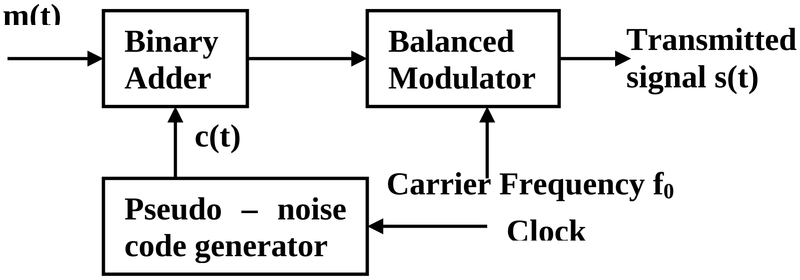

Fig: 7.38.1 (a) *Direct sequence spread spectrum transmitter*

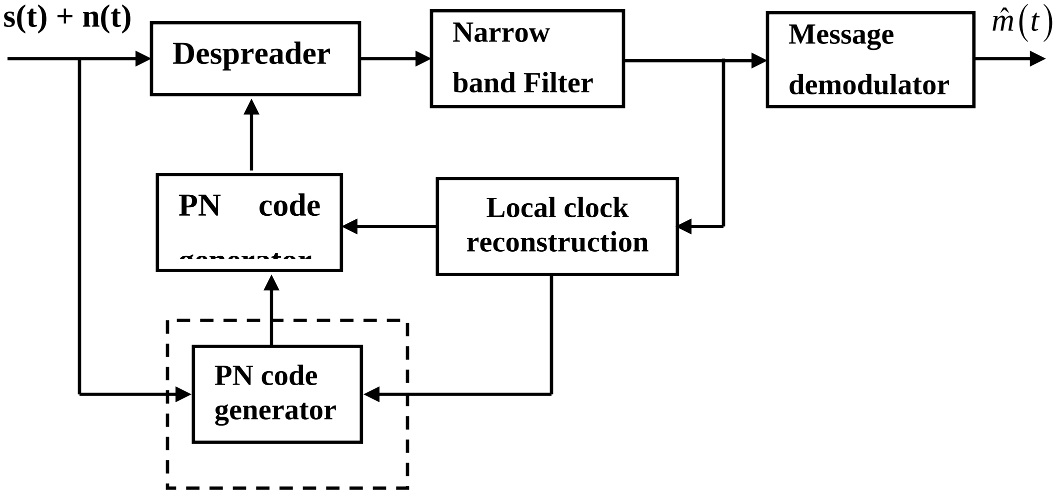

Fig: 7.38.1 (b) *Direct sequence spread spectrum receiver*

On BPSK modulation, the spread signal becomes, s(t) = d(t).coswt. **Fig.7.38.1 (b)** shows the baseband processing operations necessary after carrier demodulation. Note that, at the receiver, the operation of despreading requires the generation of the same spreading code incorrect phase with the incoming code. The pseudo noise (PN) code synchronizing module detects the phase of the incoming code sequence, mixed with the information sequence and aligns the locally generated code sequence appropriately. After this important operation of code alignment (i.e. synchronization) the received signal is 'despread' with the locally constructed spreading code sequence. The dispreading operation results in a narrowband signal, modulated by the information bits only. So, a conventional demodulator may be used to obtain the message signal estimate.

Advantages of Spread Spectrum (SS) Techniques

a) Reduced interference: In SS systems, interference from undesired sources is considerably reduced due to the processing gain of the system.

b) Low susceptibility to multi-path fading: Because of its inherent frequency diversity properties, a spread spectrum system offers resistance to degradation in signal quality due to multi-path fading. This is particularly beneficial for designing mobile communication systems.

c) Co-existence of multiple systems: With proper design of pseudo-random sequences, multiple spread spectrum systems can co-exist.

d) Immunity to jamming: An important feature of spread spectrum is its ability to withstand strong interference, sometimes generated by an enemy to block the communication link. This is one reason for extensive use of the concepts of spectrum spreading in military communications.

Types of SS

Based on the kind of spreading modulation, spread spectrum systems are broadly classified as-

(i) Direct sequence spread spectrum (DS-SS) systems
(ii) Frequency hopping spread spectrum (FH-SS) systems
(iii) Time hopping spread spectrum (TH-SS) systems.
(iv) Hybrid systems

Direct Sequence (DS) Spread Spectrum System (DSSS)

The simplified scheme shown in **Fig. 7.38.1** is of this type. The information signal in DSSS transmission is spread at baseband and then the spread signal is modulated by a carrier in a second stage. Following this approach, the process of modulation is separate from the spreading operation. An important feature of DSSS system is its ability to operate in presence of strong co-channel interference. A popular definition of the processing gain (PG) of a DSSS system is the ratio of the signal bandwidth to the message bandwidth.

A DSSS system can reduce the effects of interference on the transmitted information. An interfering signal may be reduced by a factor which may be as high as the processing gain. That is, a DSSS transmitter can withstand more interference if the length of the PN sequence is increased. The output signal to noise ratio of a DSSS receiver may be expressed as: $(SNR)_o = PG. (SNR)_I$, where $(SNR)_I$ is the signal to noise ratio before the dispreading operation is carried out.

A major disadvantage of a DSSS system is the 'Near-Far effect', illustrated in **Fig.7.38.2**.

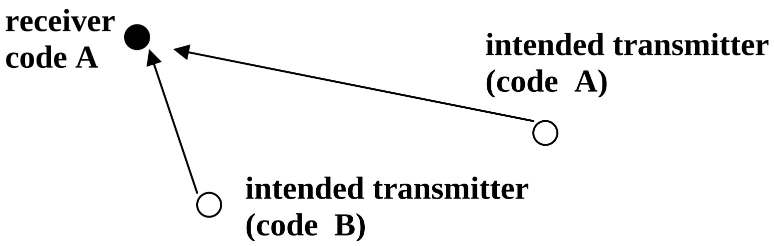

Fig.7.38.2 *Near-far effect*

This effect is prominent when an interfering transmitter is close to the receiver than the intended transmitter. Although the cross-correlation between codes A and B is low, the correlation between the received signal from the interfering transmitter and code A can be higher than the correlation between the received signal from the intended transmitter and code A. So, detection of proper data becomes difficult.

Frequency Hopping Spread Spectrum

Another basic spread spectrum technique is frequency hopping. In a frequency hopping (FH) system, the frequency is constant in each time chip; instead it changes from chip to chip. An example FH signal is shown in **Fig.7.38.3.**

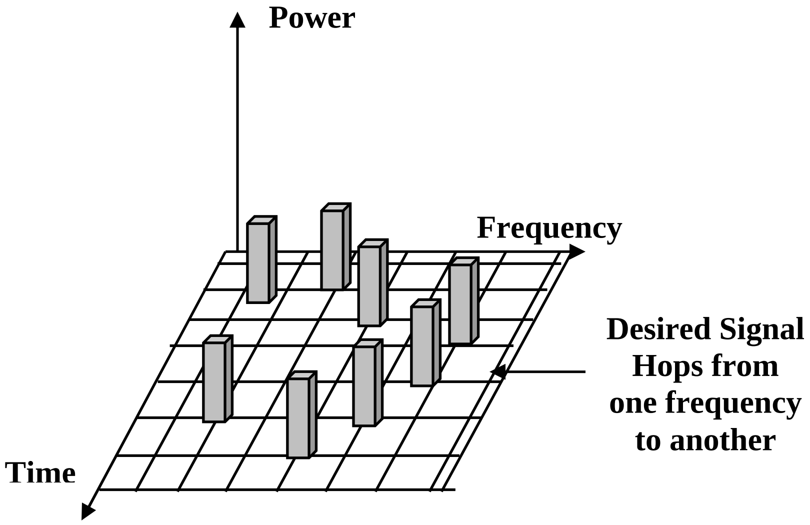

Fig. 7.38.3. *Illustration of the principle of frequency hopping*

Frequency hopping systems can be divided into fast-hop or slow-hop. A fast-hop FH system is the kind in which hopping rate is greater than the message bit rate and in the slow-hop system the hopping rate is smaller than the message bit rate. This differentiation is due to the fact that there is a considerable difference between these two FH types. The FH receiver is usually non-coherent. A typical non-coherent receiver architecture is represented in **Fig.7.38.4.**

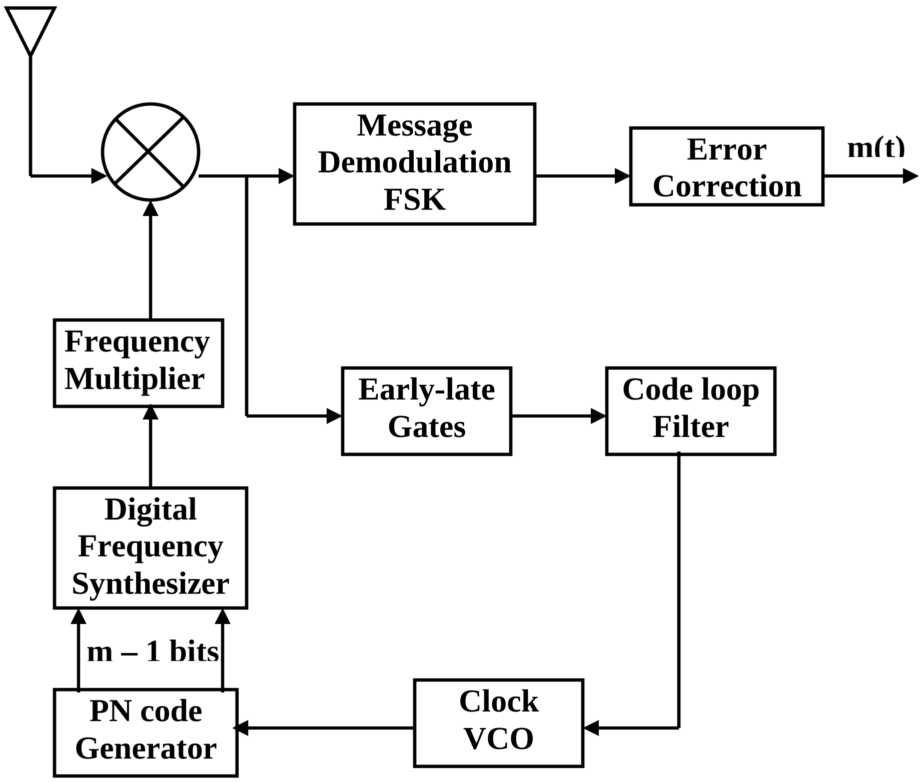

Fig. 7.38.4 *Block diagram of a non-coherent frequency-hopping receiver*

The incoming signal is multiplied by the signal from the PN generator identical to the one at the transmitter. Resulting signal from the mixer is a binary FSK, which is then demodulated in a "regular" way. Error correction is then applied in order to recover the original signal. The timing synchronization is accomplished through the use of early-late gates, which control the clock frequency

Time Hopping

A typical time hopping signal is illustrated in the figure below. It is divided into frames, which in turn are subdivided into M time slots. As the message is transmitted only one time slot in the frame is modulated with information (any modulation). This time slot is chosen using PN generator.

All of the message bits gathered in the previous frame are then transmitted in a burst during the time slot selected by the PN generator. If we let: T_f = frame duration, k = number of message bits in one frame and $T_f = k \times t_m$, then the width of each time slot in a frame is $\frac{T_f}{M}$ and the width of each bit in the time slot is $\frac{T_f}{kM}$ or just $\frac{t_m}{M}$. Thus, the transmitted signal bandwidth is 2M times the message bandwidth.

A typical time hopping receiver is shown in **Fig.7.38.5**. The PN code generator drives an on-off switch in order to accomplish switching at a given time in the frame. The output of this switch is then demodulated appropriately. Each message burst is stored and re-timed to the original message rate in order to recover the information. Time hopping is at times used in conjunction with other spread spectrum modulations such as DS or FH. **Table 7.38.1** presents a brief comparison of major features of various SS schemes.

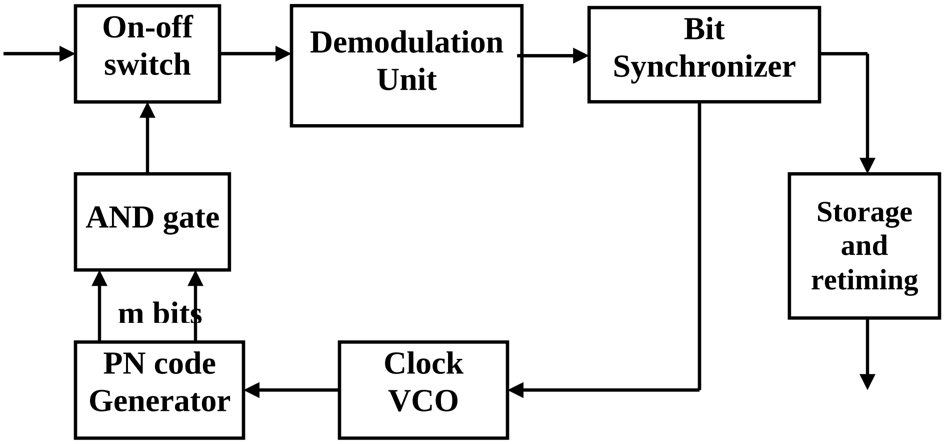

Fig. 7.38.5 *Block diagram of a time hopping receiver*

Spreading Method	Merits	Demerits
Direct Sequence	i) Simpler to implement ii) Low probability of interception iii) Can withstand multi-access interference reasonably well	i) Code acquisition may be difficult ii) Susceptible to Near-Far problem iii) Affected by jamming
Frequency Hopping	i) Less affected by Near-Far problem ii) Better for avoiding jamming iii) Less affected by multi-access interference	i) Needs FEC ii) Frequency acquisition may be difficult
Time Hopping	i) Bandwidth efficient ii) Simpler than FH system	i) Elaborate code acquisition is needed. ii) Needs FEC

Table 7.38.1 *Comparison of features of various spreading techniques*

Hybrid System: DS/(F) FH

The DS/FH Spread Spectrum technique is a combination of direct-sequence and frequency hopping schemes. One data bit is divided over several carrier frequencies (**Fig 7.38.6**).

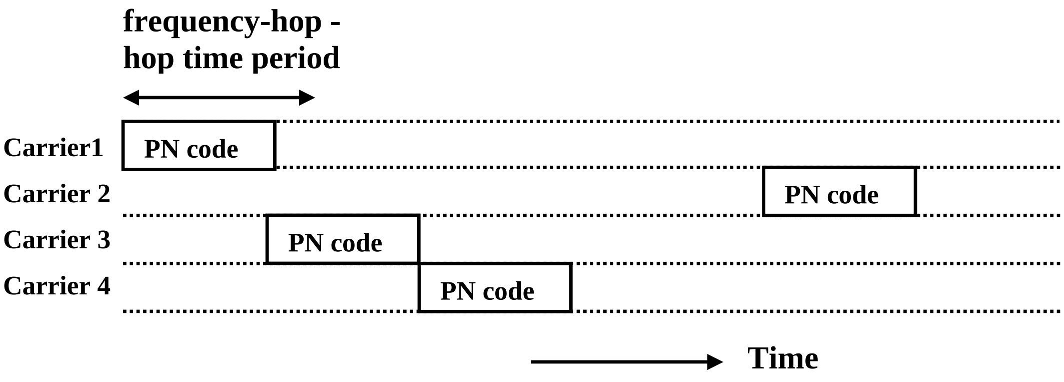

Fig. 7.38.6 *A hybrid DS-FH spreading scheme*

As the FH-sequence and the PN-codes are coupled, a user uses a combination of an FH-sequence and a PN-code.

Features of Spreading Codes

Several spreading codes are popular for use in practical spread spectrum systems. Some of these are Maximal Sequence (m-sequence) length codes, Gold codes, Kasami codes and Barker codes. In this section will be briefly discussed about the m-sequences.

These are longest codes that can be generated by a shift register of a specific length, say, L. An L-stage shift register and a few EX-OR gates can be used to generate an m-sequence of length 2^L -1. **Fig 7.38.7** shows an m-sequence generator using n memory elements, such as flip-flops. If we keep on clocking such a sequence generator, the sequence will repeat, but after 2^L -1 bits. The number of 1-s in the complete sequence and the number of 0-s will differ by one. That is, if L = 8, there will be 128 one-s and 127 zero-s in one complete cycle of the sequence. Further, the auto-correlation of an m-sequence is -1 except for relative shifts of (0 ± 1) chips (**Fig 7.38.8**). This behavior of the auto correlation function is somewhat similar to that of thermal noise as the auto correlation shows the degree of correspondence between the code and its phase-shifted version. Hence, the m-sequences are also known as, pseudo-noise or PN sequences.

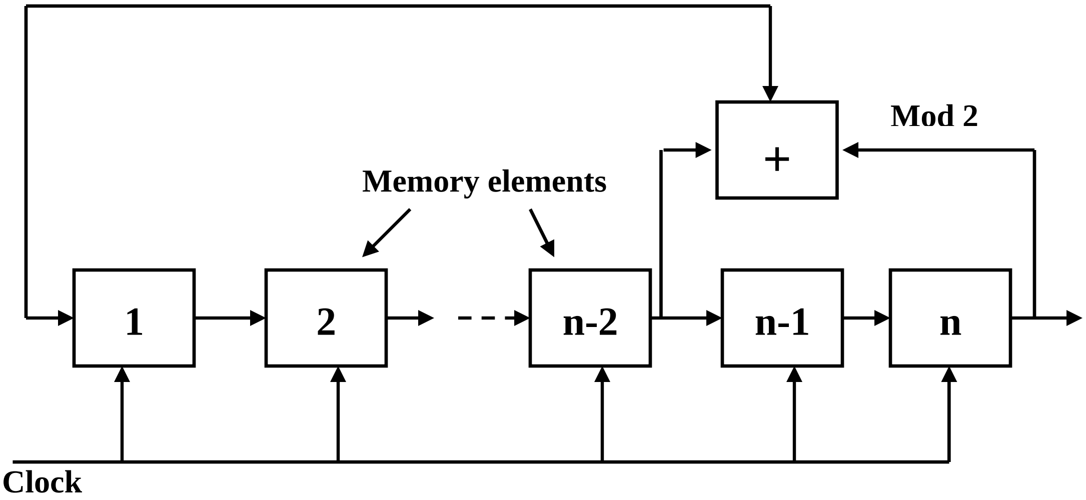

Fig. 7.38. 7 *Maximal length pseudo random sequence generator*

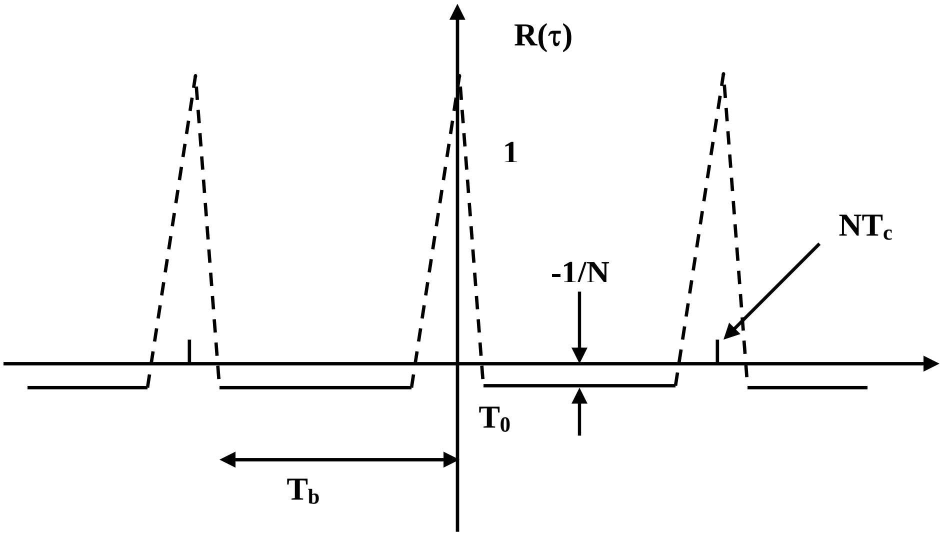

Fig. 7.38. 8 *Autocorrelation function of PN sequence*

Another interesting property of an m-sequence is that, the sequence, when added (modulo-2) with a cyclically shifted version of itself, results in another shifted version of the original sequence. For moderate and large values of L, multiple sequences exist, which are of the same length. The cross correlation of all these codes are studied. All these properties of a PN sequence are useful in the design of a spread spectrum system. Sometimes, to indicate the occurrence of specific patterns of sequences, we define 'run' as a series of ones and zero-s, grouped consecutively. For example, consider a sequence 1011010. We say, the sequence of has three runs of single '0', two runs of single '1' and one run of two ones. In a maximum length sequence of length and 2^L -1, there are exactly $2^{L-(p+2)}$ runs of length 'p' for both of ones and zeros except that there is only one run containing L one-s and one containing (L-1) zero-s. There is no run of zero-s of length L or ones of length (L-1). That is, the number of runs of each length is a decreasing power of two as the run length increases.

It is interesting to note that, multiple m-sequences exist for a particular value of L > 2. The number of available m- sequences is denoted by $\frac{\phi\left(2^L - 1\right)}{L}$. The numerator $\phi\left(2^L - 1\right)$ is known as the Euler number, i.e. the number of positive integers, including 1, that are relatively prime to L and less than (2^L -1). When (2^L -1) itself is a prime number, all positive integers less than this number are relatively prime to it. For example, if L = 5, it is easy to find that the number of possible sequences = $\frac{30}{5}$ = 6.

If the period of an m-sequence is N chips, N = (2^n –1), where 'n' is the number of stages in the code generator. The autocorrelation function of an m-sequence is periodic in nature and it assumes only two values, viz. 1 and (-1/N) when the shift parameter (τ) is an integral multiple of chip duration.

Several properties of PN sequences are used in the design of DS systems. Some features of maximal length pseudo random periodic sequences (m-sequence or PN sequence) are noted below:

a) Over one period of the sequence, the number of '+1' differs from the number of '-1' by exactly one.
b) Also the number of positive runs equals the number of negative runs.
c) Half of the runs of bits in every period of the same sign (i.e. +1 or -1) are of length 1, one fourth of the runs of bits are of length 2, one eighth of the runs of bits are of length 3 and so on. The autocorrelation of a periodic sequence is two-valued.

Applications of Spread Spectrum

A specific example of the use of spread spectrum technology is the North American Code Division Multiple Access (CDMA) Digital Cellular (IS-95) standard. The CDMA employed in this standard uses a spread spectrum signal with 1.23-MHz spreading bandwidth. Since in a CDMA system every user is a source of interference to other users, control of the transmitted power has to be employed (due to near-far problem). Such control is provided by sophisticated algorithms built into control stations.

The standard also recommends use of forward error-correction coding with interleaving, speech activity detection and variable-rate speech encoding. Walsh code is used to provide 64 orthogonal sequences, giving rise to a set of 64 orthogonal ‘code channels’. The spread signal is sent over the air interface with QPSK modulation with Root Raised Cosine (RRC) pulse shaping. Other examples of using spread spectrum technology in commercial applications include satellite communications, wireless LANs based on IEEE 802.11 standard etc.

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