Direct Sequence and Frequency Hopping Spread Spectrum Systems, understanding differences between both schemes

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Resumen

En este trabajo se trataran las diferencias entre los sistemas FHSS y DSSS spread spectrum. Estos sistemas son la base en el desarrollo de las nuevas tecnologías inalámbricas. El canal de comunicación y las propiedades de ambos sistemas son importantes para determinar la elección de uno u otro en una particular aplicación. Primero, introduciremos ambos sistemas y posteriormente utilizaremos modelos en simulink para explicar algunas propiedades. Finalmente, compararemos los dos sistemas, FH y DS.

Abstract

In this paper we will discuss differences between FHSS and DSSS spread spectrum systems. New wireless technologies are based in these two systems. The communication channel and the properties of both systems are important to determine the election of one of these systems in a particular application. First, we will introduce both systems and later we will use simulink models to explain some properties. Finally, we will compare the FH and DS spread spectrum systems.

I.- Background

1. Direct Sequence Spread Spectrum (DSSS)

Direct sequence spread spectrum use a spreading signal that comprises a pseudo random sequence of positive and negative pulses at a very high repetition rate (chip rate). The data signal is multiplied by the spreading code, and then modulated at the required carrier frequency. The basic form of the output signal is given by:

\[ s(t) = a(t)d(t)\cos(w_t + \theta) \]  

(1)

Where \( a(t) \) is a sequence of pulses to spread the data, and \( d(t) \) is a sequence of pulses of duration \( T \), that represent the digital data. At the receiver, the spread signal is recovered by applying a “de-spreading” code that is identical to the spreading signal applied at the transmitter. Fig.1 shows a basic scheme for a DSSS system. That spreading signal is called Pseudo Noise code, PN code.

![Fig. 1 Basic Scheme for a DSSS System](image)

The importance of code sequence for the DSSS communications cannot be over emphasized. The type of PN code used, its length, and its chip rate, set bounds on the capability of the system that can only be changed by changing the code.
2. PN Sequence

Pseudo-noise sequences are binary sequences, which exhibit noise like randomness properties. The definition of randomness was studied by Golomb and requires three properties described in [1]. In this class of sequences, there are M-sequences, Gold codes and Kasami sequences.

A spreading code (or PN code) should have a good autocorrelation to make synchronization easier. An adequate autocorrelation function is one that has one main peak and a minimal number (ideally none) of secondary peaks, see Fig. 2.

![Autocorrelation of a M-Sequence](image)

In the CDMA case, it is also important that the degree of correlation between different codes is minimized. Longer pseudorandom code sequences such as Gold, Kasami and Mary code sequences can provide excellent autocorrelation properties and meet cross-correlation requirements. Other types like Walsh-Hadamard codes provide orthogonal sequences. The disadvantage of these sequences is that they assume no time shift. Orthogonality between sequences does not hold when there are time shifts and autocorrelation and cross-correlation requirements would not be satisfied anymore in that case. To analyze a DSSS system we will use a simulink model. This mode will be a simple model to permit compare the result with a FHSS system.

3. Frequency Hopping Spread Spectrum (FHSS)

As we know in DSSS, the spread bandwidth is actually N times the information bandwidth. This suggests another possibility to spread the signal, given by (2);

\[ S_m = A \cos(2\pi f_m t)P_{fb}(t - mT_b) \]  \hspace{1cm} (2)

Where \( f_m \) is chosen from a set of N frequencies. Therefore, the signal “hops” to a new frequency for every bit. This method of spreading the signal is called frequency hopping (FH), and the time during which the frequency \( f_m \) is constant (\( T_b \) in eq. 2) is known as the dwell time. Here in equation (2) there is just one hop interval per bit, but we also can use more frequency for one single bit. Like DS systems, the N hopping frequencies are usually selected according to a periodic pseudo-random sequence (PN code).

In the above equation, the information sequence, \( b_m \), modulates the phase of the signal. The signal is said to be binary phase-shift keyed, and is referred to as a FH/BPSK signal. However, it is more usual to find another FH signal format. That is called M-ary frequency shift keyed (MFSK). That format uses the information sequence and the spreading sequence to jointly determine the frequency of the signal. Equation (3) shows a basic equation for this case

\[ S_m = A \cos(2\pi (v_m + f_m) t)P_{fb}(t - mT_b) \]  \hspace{1cm} (3)

Where the information is encoded, using the frequency \( v_m \). In the simplest form, there are a total of 2N possible frequencies due to the two information frequencies encoding the binary data. In general, there are \( M \geq 2 \) frequencies used to transmit the information. Fig. 3 shows the basic model for a FH spread spectrum system. Notice the way that the PN generator is used here. When the hop duration is equal to more than one information bit interval is called slow hopping (SFH). Conversely, when there are multiple hops per bit is known as fast hopping (FFH).
II Simulink Models

1. Direct Sequence Spread Spectrum (DSSS)

Fig. 7 shows a Simulink model used to investigate some properties. The model uses a pulse generator to trigger every second a data bit from the workspace. Also an AWGN channel was utilized, and a simple detection circuit was implemented. The receiver block integrates and demodulates between every bit interval. We can also add components of multipath delay to the received signal.

The transmitted signal after spreading is shown on Fig. 5. In that case, there were no errors, so the received signal (Fig. 7) is identical to the data. Fig. 6 shows the signal sent to the decision circuit. We observe from Fig. 6 the importance of an adequate time of sampling, because a wrong sampling could yield to bad estimation of the data. Usually in every DSSS scheme there is a block called synchronization. That block is in charge of extracting, from the received spread signal, the correct timing to sampling. For that purpose, a simple sliding correlator can be used to perform synchronization. The correlator tries all of the possible alignment between the PN sequence and the received signal. In Fig. 8, we can compare the difference of the spectrum between the original signal and the DSSS signal. It can be seen from that plot that the original spectrum is less broad than the spread signal.
Fig. 5 Transmitted Signal (Direct Sequence)

Fig. 6 Signal sent to the Decision Circuit

Fig. 7 Data Bits recovered (in this case there are no errors)

Fig. 8 Frequency Spectrum of Data Signal and Spread Spectrum Signal (DSSS)
1.1 Effect of Interferers in DSSS with high power

The DS spread spectrum signal could be interfered by other signals and that could be used to avoid any communication with the user. However, that way of jamming requires signals with high powers compare with the spread spectrum signal. Fig. 9 shows the spectrum of the two interferers with the data signal, and the spectrum of the signal after despreading. For this case, the numbers of errors found were 5 bits. We can also observe from that plot that the interferers modified the original spectrum (Fig.8). However, that problem can be fixed with a bandpass filter if the original bandwidth is known.

![Spread Spectrum of Data with 2 Interferers and Spectrum of Signal Despread in the Receiver](image)

**Fig. 9: Spectrum of Data Signal with Two Interferers and Despread Signal, respectively.**

2. Frequency Hopping Spread Spectrum (FHSS)

Fig. 10 shows the model used to obtain Fig.11. We observe from Fig. 11 that the spectrum of the FHSS system varies between different frequencies. In this particular case, the signal is modeled using two frequencies in the Discrete-Time oscillator and the frequency spectrum is plotted for different times in the same plot. We can observe from Fig.11 that we need to choose adequately the space between frequencies due to small bandwidth between carriers needs a better receivers (and more expensive). However, when the bandwidth assigned to transmit the data signal is limited, the FH systems can utilized instead a DS system because the FH system can use available segments of the frequency band. For the example showed in Fig. 11, it was used two frequencies to hop, 3.5 and 6.5 Hz.

![Basic Simulink Model of a FHSS System](image)

**Fig. 10 Basic Simulink Model of a FHSS System**
III Final comparison between DS and FH systems

It can be shown, based in some examples showed and the theory, that performance of both systems depends of the particular application, the space available in the communication channel, power, and complexity of the receiver. Therefore there is not a single answer about which system is better. However, it could obtain some general conclusions as follow:

1. Power

Both DS and FH reduce the average power spectral density of a signal. Traditional FH signals lower their average power spectral density by hopping over many channels. During any hop, however, an FH signal appears to be a narrow band signal with high spectral density. Conversely, DS has a continuous lower spectral density. In addition, usually DS systems utilize PSK modulation and FH systems use FSK, and FSK is less power efficient than PSK and the probability of error, for a given SNR, is better for PSK.

2. Interference

In DS receivers, the despreading operation multiplies the incoming signal by a local replica of the spreading waveform. This correlates with the desired signal to collapse it to the data bandwidth, while spreading all other signals. After the despread signal is filtered to the data bandwidth, most of the noise is outside this new narrow bandwidth and is discarded. One drawback of DS is that the bandwidth over which the interference is damaging is wider than for a non-spread system. This requires that the channel be spaced wider and well away from high power signals such a broadcast stations. Instead, the FH signal is agile and does not spend much time on any one frequency. When it hits a frequency that has too much interference, the desired signal is lost. In fast enough FH systems, the portion of signal lost may be recovered by spreading the data energy out in time through forward error coding, but only if the FEC spans more than one hop time.

Broadband noise affects both FH and DS similarly, so the system with the better SNR will be more immune. In general, it will be DS systems. Narrowband interference will have a more severe impact on an FH signal than a DS signal if it is on the same channel, but less severe impact if it is on a different channel.
3. Synchronization and Timing

In general, frequency hoping is more difficult to synchronize the receiver to the transmitter because both the time and frequency need to be in tune. The FH system search procedure allows the mobile station to sit on any frequency and wait for a signal or beacon. If this is a bad frequency, it may have to move to another and sit and wait. This is because the FH system has many channels to search and it is not feasible to perform the search in parallel. Instead, DS is self-synchronizing, since it employs a very short code that can be searched with a time-invariant matched filter. In other words, only the timing of the chips needs to be synchronized in this case.

4. Multipath Effects

In DSSS systems, the chipping process generates a high rate transmitted signal. The symbols of this transmitted signal are much shorter/narrow (in time) than the symbols generated by a FHSS system transmitting the same data rate. Obviously, a narrow pulse is more sensitive to delays than a wider pulse and as a result the FHSS system have better chances to be undisturbed by the presence of multipath effect.

In frequency domain, FHSS operates with narrow band signals located around different carrier frequencies. If at a specific moment, the FHSS system is using a carrier frequency significantly faded as a result of multipath, the FHSS receiver could not get enough energy to detect the signal.

IV Bibliography


V. Acknowledgments

Agradecemos a la Dirección de Investigación y Postgrado de la Universidad Católica de Valparaíso por el apoyo que nos permitió desarrollar este trabajo.

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