Spread Spectrum Communications

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Abstract:
In telecommunication and radio communication, spread-spectrum techniques are methods by which a signal (e.g. an electrical, electromagnetic, or acoustic signal) generated with a particular bandwidth is deliberately spread in the frequency domain, resulting in a signal with a wider bandwidth. These techniques are used for a variety of reasons, including the establishment of secure communications, increasing resistance to natural interference, noise and jamming, to prevent detection, and to limit power flux density

INTRODUCTION

This is a technique in which a (telecommunication) signal is transmitted on a bandwidth considerably larger than the frequency content of the original information.

Spread-spectrum telecommunications is a signal structuring technique that employs direct sequence, frequency hopping, or a hybrid of these, which can be used for multiple access and/or multiple functions. This technique decreases the potential interference to other receivers while achieving privacy. Spread spectrum generally makes use of a sequential noise-like signal structure to spread the normally narrowband information signal over a relatively wideband (radio) band of frequencies. The receiver correlates the received signals to retrieve the original information signal. Originally there were two motivations: either to resist enemy efforts to jam the communications (anti-jam, or AJ), or to hide the fact that communication was even taking place, sometimes called low probability of intercept (LPI).

Frequency-hopping spread spectrum (FHSS), direct-sequence spread spectrum (DSSS), time-hopping spread spectrum (THSS), chirp spread spectrum (CSS), and combinations of these techniques are forms of spread spectrum. Each of these techniques employs pseudorandom number sequences — created using pseudorandom number generators — to determine and control the spreading pattern of the signal across the allocated bandwidth. Ultra-wideband (UWB) is another modulation technique that accomplishes the same purpose, based on transmitting short duration pulses. Wireless Ethernet standard IEEE 802.11 uses either FHSS or DSSS in its radio interface.

CDMA is a form of Direct Sequence Spread Spectrum communications. 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.

In order to protect the signal, the code used is pseudo-random. It appears random, but is actually deterministic, so that the receiver can reconstruct the code for synchronous detection. This pseudo-random code is also called pseudo-noise (PN).

Theoretical Justification for Spread Spectrum

Spread-spectrum is apparent in the Shannon and Hartley channel-capacity theorem:

$C = B \times \log_2 (1 + S/N)$ (Eq. 1)

In this equation, C is the channel capacity in bits per second (bps), which is the maximum data rate for a theoretical bit-error rate (BER). B is the required channel bandwidth in Hz, and S/N is the signal-to-noise power ratio. To be more explicit, one assumes that C, which represents the amount of information allowed by the communication channel, also represents the desired performance. Bandwidth (B) is the price to be paid, because frequency is a limited resource. The S/N ratio expresses the environmental conditions or the physical characteristics (i.e., obstacles, presence of jammers, interferences, etc.).

There is an elegant interpretation of this equation, applicable for difficult environments, for example, when a low S/N ratio is caused by noise and interference. This approach says that one can maintain or even increase communication performance (high C) by allowing or injecting more bandwidth (high B), even when signal power is below the noise floor. (The equation does not forbid that condition!)

Modify Equation 1 by changing the log base from 2 to e (the Napierian number) and by noting that ln = loge. Therefore:

$C/B = (1/\ln 2) \times \ln(1 + S/N) = 1.443 \times \ln(1 + S/N)$ (Eq. 2)

Applying the MacLaurin series development for

$\ln(1 + x) = x - x^2/2 + x^3/3 - x4/4 + ... + (-1)k+1xk/k + ...$:

$C/B = 1.443 \times (S/N - 1/2 \times (S/N)^2 + 1/3 \times (S/N)^3 - ...)$ (Eq. 3)

S/N is usually low for spread-spectrum applications. (As just mentioned, the signal power density can even be below the noise level.) Assuming a noise level such that S/N << 1, Shannon's expression becomes simply:

$C/B \approx 1.433 \times S/N$ (Eq. 4)

Very roughly:

$C/B \approx S/N$ (Eq. 5)

Or:

$N/S \approx B/C$ (Eq. 6)

To send error-free information for a given noise-to-signal ratio in the channel, therefore, one need only perform the fundamental spread-spectrum signal-spreading operation: increase the transmitted bandwidth. That principle seems simple and evident. Nonetheless, implementation is complex, mainly because spreading the baseband (by a factor that can be several orders of magnitude) forces the electronics to act and react accordingly, which, in turn, makes the spreading and despreading operations necessary.

Benefits of Spread Spectrum

Resistance to Interference and Antijamming Effects

There are many benefits to spread-spectrum technology. Resistance to interference is the most important advantage. Intentional or unintentional interference and jamming signals are rejected because they do not contain the spread-spectrum key. Only the desired signal, which has the key, will be seen at the receiver when the despreading operation is exercised. See Figure 1

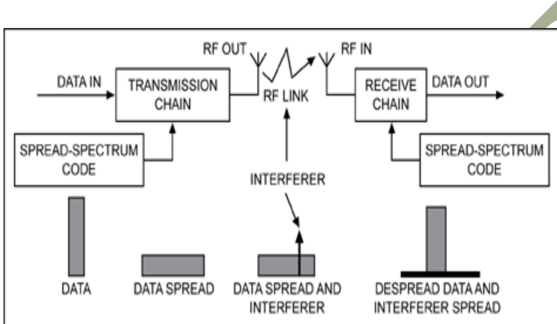

Figure 1. A spread-spectrum communication system. Note that the interferer's energy is spread while the data signal is despread in the receive chain.

You can practically ignore the interference, narrowband or wideband, if it does not include the key used in the despreading operation. That rejection also applies to other spread-spectrum signals that do not have the right key. Thus different spread-spectrum communications can be active simultaneously in the same band, such as CDMA. Note that spread spectrum is a wideband technology, but the reverse is not true: wideband techniques need not involve spread-spectrum technology.

Resistance to Interception

Resistance to interception is the second advantage provided by spread-spectrum techniques. Because nonauthorized listeners do not have the key used to spread the original signal, those listeners cannot decode it. Without the right key, the spread-spectrum signal appears as noise or as an interferer. (Scanning methods can break the code, however, if the key is short.) Even better, signal levels can be below the noise floor, because the spreading operation reduces the spectral density. See Figure 6. (Total energy is the same, but it is widely spread in frequency.) The message is thus made invisible, an effect that is particularly strong with the direct-sequence spread-spectrum (DSSS) technique. (DSSS is discussed in greater detail below.) Other receivers cannot "see" the transmission; they only register a slight increase in the overall noise level!

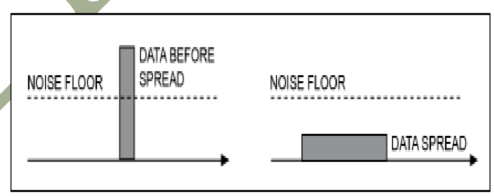

Figure 2. Spread-spectrum signal is buried under the noise level. The receiver cannot "see" the transmission without the right spread-spectrum keys.

CONCLUSION

As spread-spectrum techniques become increasingly popular, electrical engineers outside the field are eager for understandable explanations of the technology. There are books and websites on the subject, but many are hard to understand or describe some aspects while ignoring others (e.g., the DSSS technique with extensive focus on PRN-code generation).

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