I.Introduction

As the wireless personal communications field has grown over the last few years, the method of communication known as spread spectrum has gained a great deal of prominence. Spread spectrum involves spreading the desired signal over a bandwidth much larger than the minimum bandwidth necessary to send the signal. It was originally developed by the military as a method of communications that is less sensitive to intentional interference or jamming by third parties, but has become very popular in the realm of personal communications recently. Spread spectrum methods can be combined with Code Division Multiple Access (CDMA) methods to create multi-user communications systems with very good interference performance. This paper will cover the details behind the method of Spread Spectrum communications, as well as analyze two main types of Spread Spectrum systems, Direct-Sequence Spread Spectrum (DS-SS) and Frequency-Hopped Spread Spectrum (FH-SS). Finally, a general comparison between the two will be given, trying to indicate the positives and negatives for each with respect to the other, and to indicate when one might system might be preferable over the other.

II. Spread Spectrum

As stated before, spread spectrum systems afford protection against jamming (intentional interference) and interference from other users in the same band as well as noise by “spreading” the signal to be transmitted and performing the reverse “de-spread” operation on the received signal at the receiver. This de-spreading operation in turn spreads those signals which are not properly spread when transmitted, decreasing the effect that spurious signals will have on the desired signal.

Spread Spectrum systems can be thought of as having two general properties: first, they spread the desired signal over a bandwidth much larger than the minimum bandwidth needed to send the signal, and secondly, this spreading is carried out using a pseudorandom noise (PN) sequence. In a general sense, we will see that the increase in bandwidth above the minimum bandwidth in a spread spectrum system can be thought of as applying gain to the desired signal with respect to the undesirable signals. We can now define the processing gain G_P as

$$G_p = \frac{BW_{RF}}{BW_{info}}$$

where BW_{RF} is the bandwidth that the signal has been increased to, and BW_{info} is the minimum bandwidth necessary to transmit the information or data signal. Processing gain can be thought of as the improvement over conventional communication schemes due to the spreading done on the signal. Often, a better measure of this gain is given by the *jamming margin*

$$M_J(dB) = G_P(dB) - SNR_{min} \text{ ,}$$

which indicates the amount of interference protection offered before the signal is corrupted.

The spreading function is achieved through the use of a pseudorandom noise sequence (PN sequence). The data signal is combined with the PN sequence such that each data bit is encoded with several if not all the bits in the PN sequence. In order to achieve the same data rate as was desired before spreading, the new data must be sent at a rate equal to the original rate multiplied by the number of PN sequence bits used to encode each bit of data. This increase in bandwidth is the processing gain, which is a measure of the noise and interference immunity of this method of transmission.

To see how the spreading process helps protect the signal from outside interference, let us look at the types of interference that are possible. The three major types of interference that can arise when using wireless networks are: (1) noise, (2) intentional interference from a jammer or other source trying to disrupt communications, and (3) unintentional interference from other users of the same frequency band. Noise can be considered as background white Gaussian noise (WGN), and can be said to have power spectral density N_0. Since the noise is white, the spreading of the bandwidth does not have much of an effect here. The noise power is constant over the entire bandwidth, so increasing the bandwidth actually lets more noise into the system, which might be seen as detrimental. However, we will see that this is not really a problem.

Intentional interference comes from sources who are actively trying to corrupt the data transmission by sending power transmissions in the same band as the intended transmission. The big difference between intentional interference and noise is that intentional interference is, by its very nature, a finite power signal, since it must be transmitted from a real source. Thus the spreading performed on the data signal allows the signal to “hide” itself in a larger bandwidth, forcing the jamming signal to distribute its power over this new much larger bandwidth, and thus intuitively diminishing the effect that the jamming signal has on the data signal.

The third major source of signal corruption comes from unintentional interference due to other users using the same frequency band, and here, the system uses the PN sequence and the technique of CDMA to combat this type of interference. In a wireless communications network, all the signals propagate through the air by way of electromagnetic waves, thus there is no way to ensure that one user will receive only the signal he or she desires; that user will receive all the signals being sent in that band. By giving each of the signals to be transmitted in the frequency band its own code (CDMA) which is orthogonal to the other codes used in that band, the effect of these other signals will effectively be zero at the receiver (when the receiver correlates the input signal it receives with the code of the transmission it wants to receive, only the desired signal will remain).

The following sections will analyze and derive the specifics of the two major types of spread spectrum systems, Direct Sequence and Frequency Hop. Since the mechanisms by which the above advantages are achieved vary between the two methods, the analysis has been left until those sections.

III. Direct Sequence Spread Spectrum (DS-SS)

Direct Sequence Spread Spectrum (DS-SS) is the most common version of spread spectrum in use today, due to its simplicity and ease of implementation. This method has been adopted by Qualcomm in designing their wireless communications network as well as by the Infopad project here at UC Berkeley. The two major spread spectrum methods differ mainly in the way the encode the data with the PN sequence. In DS-SS, the carrier (data signal) is modulated by the PN code sequence, which is of a much higher frequency than the desired data rate.

Let f be the frequency of the data signal, with appropriate pulse time $T=1/f$. Let the PN sequence be transmitted at a rate f_c, so that the increase in the data rate is f_c/f. The frequency f_c is known as the *chipping rate*, with each individual bit in the modulating sequence known as a *chip*. Thus the width of each pulse in the modulating sequence is T_C, or a *chip time*. The following figure illustrates the two signals, the data signal for one pulse width, and the PN sequence over the same time (since the PN sequence takes values of ±1, the indicated PN sequence also indicates a normalized version of the signal to be transmitted).:

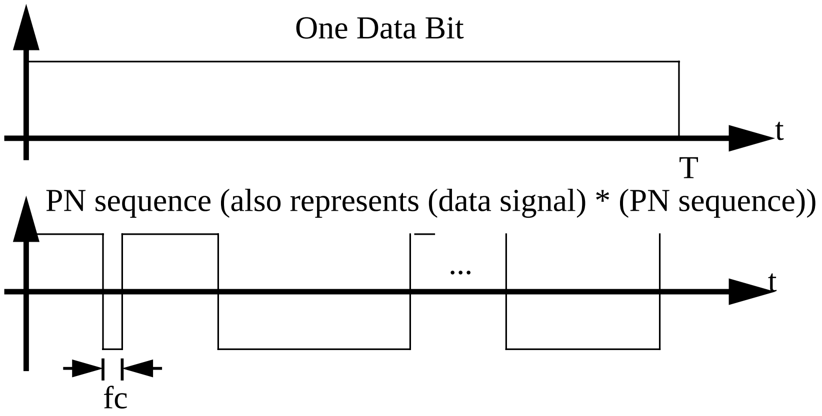

Figure 1. Data Signal and PN Sequence in the Time Domain

As a result, the frequency domain will look something like the diagram shown in Figure 2. Mathematically, the following happens. Let the data signal be $D(t)$, transmitted at frequency f, and let the PN sequence be $PN(t)$, with frequency f_c. So the transmitted signal is

$$S(t) = D(t)PN(t) \quad .$$

The PN sequence is designed such that it has very good autocorrelation properties:

$$R_{PN}(\tau) = \begin{cases} 1, & t = 0, N, 2N \\ -1/N & \text{otherwise} \end{cases}$$

where N is the length of the PN sequence. Therefore, when the signal is correlated with the PN sequence at the receiver, the received signal will be recovered exactly (assuming that there is synchronization between the send and receive PN sequences), i.e.

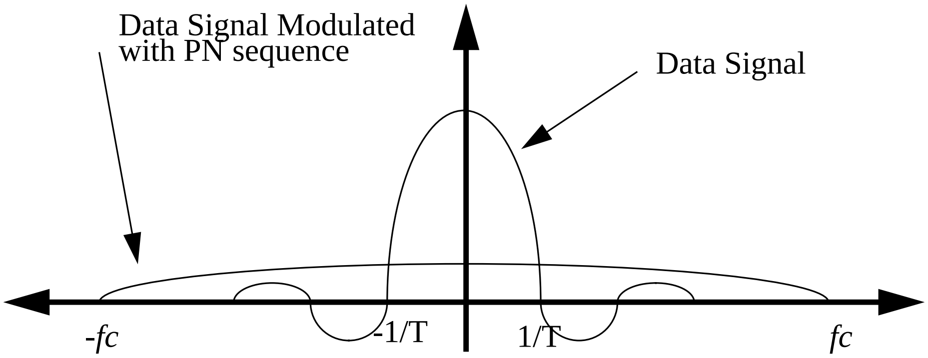

Figure 2. Data Signal and PN seq. modulated signal in frequency domain

$$S(t)PN(t) = D(t)PN(t)PN(t) = D(t)$$

Now, if we allow both noise and a jamming signal *J(t)* with finite power distributed evenly across the frequency band, the received signal at the input to the receiver, *Y(t)*, is

$$Y(t) = D(t)PN(t) + J(t) + N(t) \quad .$$

Now, when the signal is correlated with the PN sequence, the data signal portion of *Y(t)* is de-spread giving us the original *D(t)*. However, the effect of multiplying *J(t)* and *N(t)* with the signal in effect spreads the signal out to have bandwidth f_c, whereas the signal *D(t)* now has returned to its original frequency *f*=1/T. So a filter following the signal correlation can recapture the signal *D(t)* with a reduced amount of jamming power. The jamming power that can pass through the filter is now decreased by a factor f_c/f, which was introduced earlier as the processing gain G_P, i.e. $G_P=(BW_{RF}/BW_{\text{info}})=(f_c/f)$. So we see that the data signal has been made immune to the effect of a malevolent third party jammer. As stated earlier, even though a factor of f_C/f more noise was let into the system by the increased bandwidth, the effect of that noise was also reduced by fc/f due to the processing gain of the system, and thus the effect of WGN has not been increased by this DS-SS system.

CDMA and DS-SS

Now, in order to facilitate a multi-user environment, all that needs to be done is to apply the principle of Code Division Multiple Access (CDMA). In a CDMA system, each user is identified by its own code, and in order to prevent users from interacting with each other, these codes are designed to be orthogonal to each other (the cross-correlation function between any two of these codes is identically zero). In practice, perfect orthogonality is hard to achieve, but assume perfect orthogonality for now, in order to understand the CDMA theory. Now each user's signal is being encoded with not only a PN sequence, but also with its own orthogonal code. Therefore, the transmitted signal $S(t)$ is now

$$S_i(t) = D_i(t)PN(t)C_i(t) = D_i(t)p_i(t) \quad ,$$

where $C_i(t)$ represents the CDMA code of the *i*th user (who has data signal $D_i(t)$), and $p_i(t)$ represents the combination of the PN sequence and the orthogonal code for the *i*th user. Ideally, this allows a large number of users to use the same bandwidth, as now, not only do we have the intentional interference rejection properties detailed above, but we also have now a multi-user interference rejection. Assume that there are now N users in this system, all using the same frequency band. There are therefore N orthogonal codes in use. So the receiver of the *i*th signal receives

$$Y(t) = D_i(t)p(t) + \sum_{k=1, k \neq i}^{N} D_k(t+\theta)p_k(t+\theta) \quad ,$$

where θ is a random delay. When this is correlated with the PN sequence and the *i*th orthogonal code, the result will become zero (the result of the orthogonality), and only the signal due to the desired transmission will remain. The noise and jammer interference was not included here, since those effects were considered earlier, and the multiplication by the orthogonal effect will have no effect on the noise or the jamming signal.

The transmitter and receiver structure for DS-SS are shown in Figure 3. The structure of both the transmitter and receiver are very basic. The transmitter just multiplies the data signal with the PN sequence and the CDMA code, and then modulates this resulting signal up to the carrier frequency, and the receiver just performs the reverse operation and integrates the received signal. However, all this assumes perfect synchronization between transmitter and receiver, and in a highly asynchronous system such as a wireless network, that is no easy task. Therefore, there is a need for the receiver to *acquire*: synchronization with the transmitter, and once that is done, to *track* the signal; otherwise, much of the above analysis is moot. The reader may have noticed that the autocorrelation function of the PN sequence is one only if τ is an integer multiple of the sequence length, i.e. if the two versions of the PN sequence being correlated are exactly in phase, and thus this issue of "acquiring and maintaining lock" must be discussed.

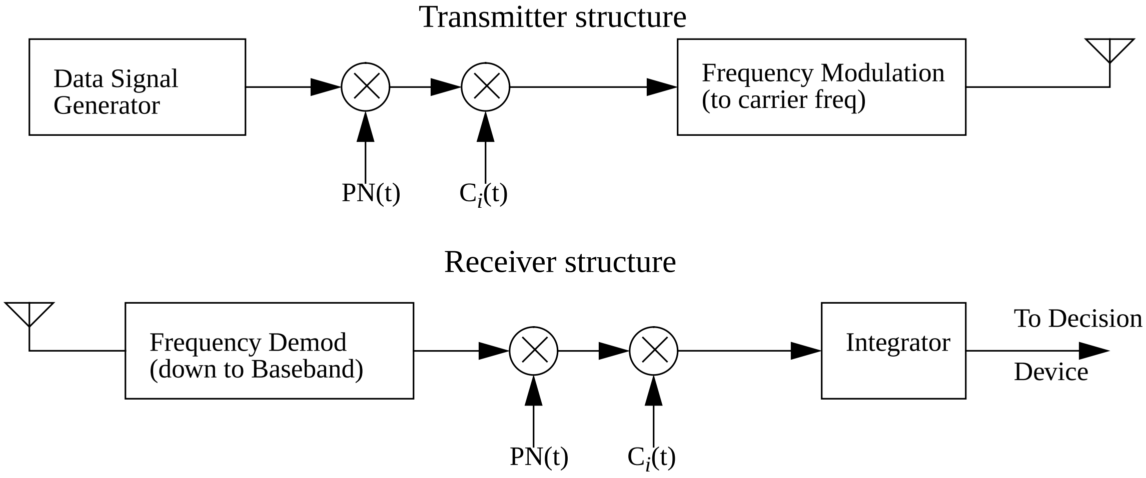

Figure 3. Transmitter and Receiver structure for DS-SS

<u>Basics of Acquisition and Tracking in a DS-SS system</u>

The full theory behind acquisition and tracking are beyond the scope of this paper, but it is necessary to understand the basics, as it is a very crucial part of any spread spectrum system. The first step is to acquire some measure of "coarse lock", whereby an approximation to synchronization is attempted, and then, a finer lock is attempted. For DS-SS, a simple method of acquiring lock is to generate 2N versions of the PN sequence where N is the length of the PN sequence. Each version of the PN sequence will be shifted in time from the next by $T_C/2$. Thus the received signal will be correlated with each of the 2N shifted versions of the PN sequence. After some predetermined period of time L, the receiver selects the sequence with the largest correlation, and this guarantees lock to within $T_C/2$. However, this is a very hardware intensive approach, and can be very expensive. So an alternative is to use fewer correlators, but to have each correlator do multiple correlations (use a combination of serial and parallel methods instead of doing all 2N correlations in parallel). Thus if only N correlators are available, each can do two correlations (so the total length of time necessary to achieve lock within $T_C/2$ would be 2L instead of L). So time for lock and expense can be traded off in order to best fit a particular design. Also, the fineness of the coarse lock can be varied as well. If trying to achieve lock to within $T_C/2$ is too much for a particular design, fewer correlations need to be done.

Once this coarse lock or synchronization has been achieved, the next issue is to track the signal. Inside the tracking system, a PN sequence is generated that is offset from the internal PN sequence by some $\Delta t \leq T_C/2$ (or whatever time step was used to achieve coarse lock). The tracking is done using a feedback loop to control fine adjustments. The input signal is correlated with $PN(t + T_C/2 - \Delta t)$, which is just the PN sequence shifted by some time less than $T_C/2$. Depending on the correlation, the feedback loop will tell the tracking system to either increase or decrease its frequency by some minor amount to achieve a better lock.

Although this just covers the basics of acquisition and tracking, it is important that this point not be overlooked.

III. Frequency-Hopped Spread Spectrum (FH-SS)

Frequency-Hopped Spread Spectrum is the other major type of spread spectrum system in use today. In FH-SS, the signal itself is not spread across the entire large bandwidth; instead the wide bandwidth is divided into N sub-bands, and the signal "hops" from one band to the next in a pseudorandom manner. The center frequency of the signal changes from one hop to the next, changing from one sub-band to another, as shown in Figure 4. As we can see, a large frequency band of width Nf_b centered at F_C has been divided into N sub-bands of width f_b. The bandwidth $f_b$must enough to transmit the data signal D(t), and at a predetermined time interval, the center frequency of the data signal is changed from one sub-band to another in a pseudorandom manner. In the example given in the diagram, the data signal "hops" from band N ($F_C+(N/2)f_b \le f \le F_C+(N/2)f_b$) to band 2 to band N-2, and so on. Usually, the width of each sub-band is set so that the amount of signal that overlaps with adjacent sub-bands is minimal, and is thus approximately the bandwidth of the original data signal.

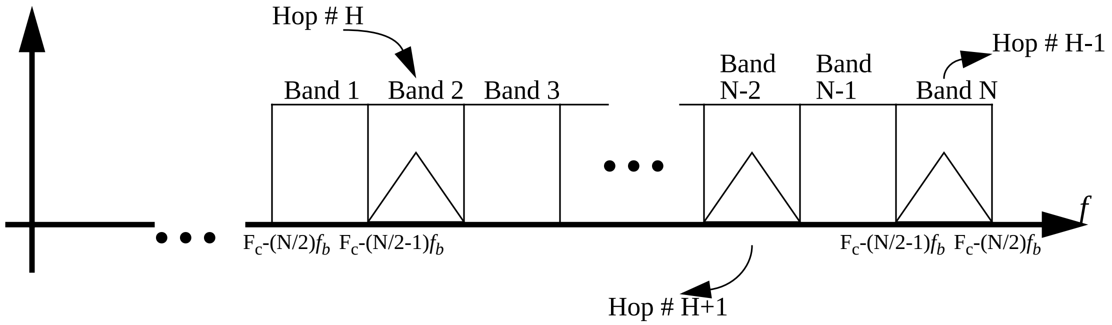

Figure 4. A frequency domain view of FH-SS

Two different kinds of FH-SS are used; slow FH and fast FH. In slow FH-SS, several bits are sent for each hop, so the signal stays in a particular sub-band for a long time relative to the data rate. In fast-SS, the reverse is true. The signal switches sub-bands several times for each bit transmitted, so the signal stays in a sub-band for a very short time relative to the data rate. There are people who say that slow FH is not really a spread spectrum technique, since this does not really spread the system (since the time spent in one sub-band is very large, the corresponding width of the band can be small, thus possibly violating the first tenet of a spread spectrum system, namely that the spread bandwidth must be much greater than the unspread bandwidth). Therefore this paper will deal mainly with fast FH - SS.

In the fast FH case, again, the performance of the system with respect to white Gaussian Noise is not changed, as in the DS-SS case. The noise power seen at the receiver is approximately the same as that in the un-hopped case, since each sub-band is approximately the same size as the original data signal's bandwidth. And just as in the DS-SS case, the effect of a jammer is decreased by the spreading of the signal. Here, if we again assume that the jamming signal *J(t)* is distributed uniformly over the entire band, it is clear that the only portion of the jamming signal that affects the data is the part within the band of width f_b, and thus the jamming signal is reduced by the factor of the processing gain Gp which here is

$$G_P = \frac{BW_{RF}}{BW_{info}} = \frac{N f_b}{f_b} = N.$$

Thus in the frequency hop case, the protection afforded is equal to the number of frequency bands used. However, in this case, the best way for a jammer to disrupt the signal is *NOT* to spread his power equally over the entire band, but to concentrate his power among a few bands. In this case, the jammer is more effective, because he can assuredly disrupt certain bits of data. The probability of a bit being in error is then given by p=J/N, where J is the number of channels selectively jammed, and N is the number of frequencies available to the hopper, which is basically the probability that the jammer "guessed" which frequencies to jam correctly. This can still give high bit error rates (BER). For example, a possible scenario would be where the jammer jams 10 out of a possible 1000 frequencies, giving a highly unacceptable BER of 10^{-2}.

However, fast FH allows us to very simply decrease the BER. If we choose to have a large number of chips per bit (here a chip represents a hop), then we can use a simple majority function to determine what the bit sent was. We are assuming that the number of available hop channels is a good deal larger than the number of channels being jammed (define a successful jamming as when the power of the jamming signal is greater than or equal to that of the data signal). If the simple majority function is being used, then the formula for the error rate becomes

$$P_e = \sum_{x=r}^{c} \binom{c}{r} p^x q^{c-x},$$

where *c* is the number of chips per bit (hops per bit), *r* is the number of chip errors necessary to cause a bit error (for a simple majority function, this is just *c*/2 rounded to the nearest integer), *p* is the probability of 1 bit error (J/N), and *q* is the probability of no error for a chip, or 1-*p*. By just increasing the number of chips per bit from 1 to 3 (thus *r* is 2) for our previous example, we find that the error rate is now

$$P_e = \binom{3}{2}(p^2 - p^3) + \binom{3}{3}p^3 = 3p^2 - 2p^3 = 3 \times 10^{-4} - 2 \times 10^{-6} \approx 3 \times 10^{-4} .$$

Thus by just increasing the hopping rate from once per bit to three times per bit, the bit error rate can be decreased dramatically. So the immunity to jamming provided by spread spectrum works in the FH-SS system as well, even for the clever jammer who tailors his interference to the particular system. The only penalty to be paid here is the increased frequency with which the spread signal must be sent, and with the state of technology today, that is easily surmounted.

The PN sequence is used here to determine the hopping sequence. So in order to transmit the signal, the data signal must be modulated up the center frequency of the band determined by the PN sequence. Therefore, the structure of the transmitter is as shown in Fig 5a. The Data signal is modulated up to the transmit frequency by the frequency produced by the frequency synthesizer, which takes as its input the output of the PN sequence generator (a bandpass filter is also required at the output of the transmitter - it was omitted to simplify the structure). The receiver structure is simply the reverse of the transmitter. The frequency synthesizer demodulates the signal down to an intermediate frequency (or baseband if desired), then the signal is filtered so only the desired data signal is passed through, and finally the signal is decoded. Again, to get multiple users using the same wide frequency band, CDMA techniques must be used.

CDMA and FH-SS

The method of CDMA used in this case is to provide each user with an orthogonal hop sequence (i.e. so no two users occupy the same sub-band at the same time). In this way, multiple users can be accommodated without any chance of them interfering with each other, since ideally only one user will be in a frequency sub-band during a given hop, and thus the receiver, due to its bandpass filter, will be able to isolate the signal it is looking for. Thus the transmitter and receiver structures given in Figure 5 above need only be modified to incorporate an orthogonal code sequence in determining the center frequency of the current hop (i.e. use the orthogonal code combined with the PN sequence as the input to the frequency synthesizer), and the system can support multiple users.

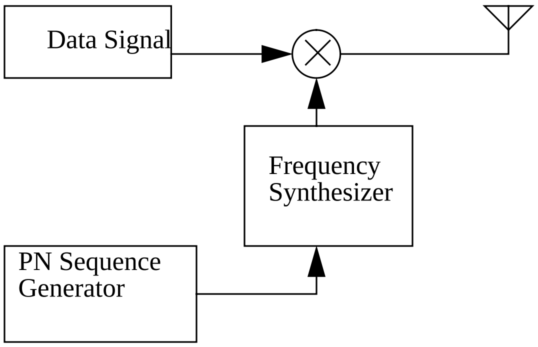

Fig. 5a. Basic FH Transmitter Structure

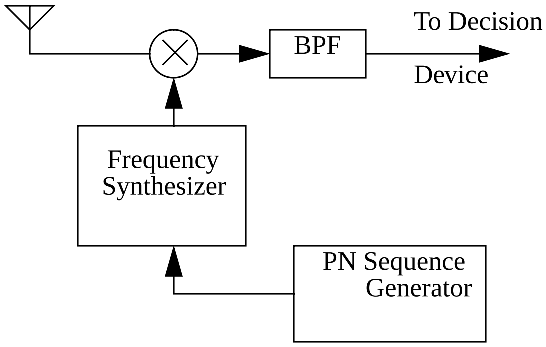

Fig. 5b. Basic FH Receiver Structure

Again, however, the issue of acquisition are an important issue. Especially when the center frequency of the data signal is changing so rapidly, it is necessary to ensure that the correct signal is being decoded.

Basics of Acquisition and Tracking in a FH-SS System

In a FH-SS system, the issue of synchronization is of paramount importance, because the user could easily receive the wrong data signal and treat that as the desired data. A basic (but again hardware-expensive) method for acquiring the signal is to use the structure shown in Figure 6. Here, the incoming signal is sent down N different paths, where N is the number of hop frequencies available. In each path, the incoming signal is multiplied by one of the N frequencies, filtered, squared (to get the power), and then delayed by an amount depending upon the location of that frequency in the hop order. For example, if the sequence is $\{f_1, f_2, ..., f_N\}$, the signal correlated with f_1 will be delayed by N hops, while the signal correlated with f_N will be delayed by one hop. In this way, at any given time T, the input to the summer will be the power of the data signal correlated with the entire hop sequence starting at time T-N. Thus, whenever the value of the output of the summer is greater than a certain threshold, lock has been acquired. If N is large (which is usually the case), we see that this structure can become unnecessarily costly. Again, a trade-off between cost and length of time before lock is acquired can be managed.

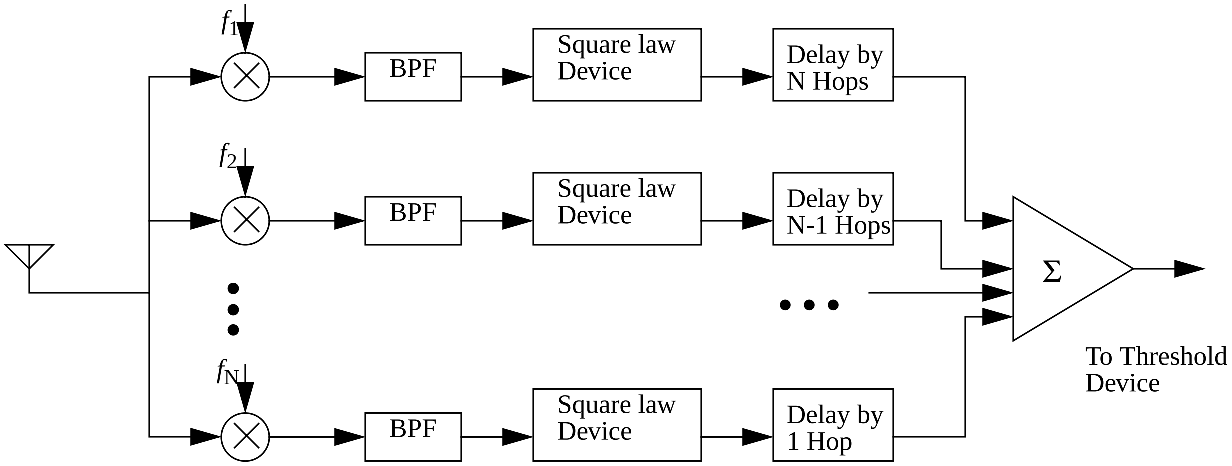

Figure 6. Structure of Synchronizer for FH-SS

Once lock is acquired, tracking the signal involves the use of a corrective feedback loop, just like in DS-SS. The signal is correlated with a frequency offset from the lock frequency by less than the minimum distance guaranteed by the lock acquisition, and depending on the output of that correlator, the frequency is accordingly adjusted. Thus lock is maintained while the signal is being decoded. This is not an inconsequential part of the spread spectrum system, and is very important to ensure that the system works.

This describes the basics behind the FH-SS method of communications. FH-SS, like DS-SS, also provides good interference immunity from both intentional as well as unintentional interference, just as DS-SS does. So what makes one more attractive than the other? The next section deals with the basic advantages and disadvantages of one over the other

IV. A Basic Comparison of Direct Sequence and Frequency Hopped Spread Spectrum Systems

We have seen from the previous two sections that the performance of both Direct Sequence and Frequency Hopped Spread Spectrum systems is comparable. Why then should one be used over the other? Are the two systems so equal that they are equivalent? The answer to the question “Which is better?” is highly dependent on the applications for which the system is being designed.

One big problem with spread spectrum systems is the so-called “near-far” problem. This problem arises when there are multiple transmitters that are geographically separated transmitting in the same band. If receiver *i* is trying to receive the *i*th signal, but transmitter *k* is geographically much closer, receiver *i* will receive signal *k* at a much higher power level than signal *i*. If there is perfect synchronization between all users and all transmitters, the importance of this issue is decreased, because the PN sequence and then the orthogonal code should remove the interference. However, in a real-world situation, where perfect synchronization can never be guaranteed, the near-far problem severely impacts DS-SS systems, whereas FH-SS systems, while impacted, can be designed to overcome this problem. In a DS-SS system, if perfect synchronization is not achieved, then the orthogonality of the *i*th and *k*th signals cannot be guaranteed, and the *k*th signal just appears as finite power noise (it can be considered similar to a jamming signal) at the input of the receiver. Therefore the *k*th signal is reduced by the processing gain of the system; however, in a wireless communication network, the input power can vary up to 3 orders of magnitude, if not more (from 1mW to 1µW is common). If the processing gain of the signal is not large enough to overcome this disparity in power, then the signal is effectively corrupted. So for the case of 3 orders of magnitude difference between the desired and interfering signals, the Processing gain squared (since G_P applies to signal level, and we need to refer this to power) must be greater than 10^3, or in dB,

$$G_P + 6dB > 30dB \rightarrow G_P > 24dB.$$

In today's systems, where the data rates are often high enough that the chip rate is not that much higher than the data rate, this amount of processing gain is by no means assured, and thus DS-SS can suffer greatly from this problem. DS-SS systems have tried to combat this power problem by using a technique called "power-control". The transmitter will adaptively change its transmit power based on the distance to the receiver, so as not to interfere with other transmissions. However, this system is not perfect either. Reducing transmission power increases the vulnerability to corruption due to other sources (such as jammers), and also increases the complexity of the communication between the receiver and transmitter (some sort of constant monitor of distance is needed). Thus this solution is far from perfect.

In FH-SS, the situation is somewhat better. Again, for perfect orthogonality, this is not an issue, just as in DS-SS. However, FH-SS has advantages over DS-SS in a few respects. First of all, the fact that there are N frequency bands decreases the probability of this type of interference, i.e. the *i*th signal and *k*th signal have to overlap, and there is a one in N (or less) chance that they will overlap. In DS-SS, all the received signals are correlated equally, whereas in FH-SS, since the actual data still takes up the same bandwidth as it originally did, a bandpass filter limited to the width of the expected data signal will kill the signals in the N-1 other sub-bands. Thus, in order to cause destructive interference, the *k*th signal must be in the same sub-band as the *i*th signal at the time that the receiver correlates its received signal, which gives at most a one in N chance that interference can occur. Then, even if there is some overlap, but not full overlap, the bandpass filter will again limit the effect of the interfering signal. Finally, if the *k*th signal overlaps enough to interfere with the *i*th signal, the use of error-correction (like the simple majority function described in section III) can dramatically reduce the error probability. Thus we see that in this type of instance, where there are multiple transmitters at vastly differing locales, that FH-SS is preferable.

However, if the designers of the system can guarantee a controlled system, where the distances between different transmitters and a receiver are short (like in an indoor wireless system), then DS-SS definite advantages, most of which come in the implementation side. DS-SS is decidedly easy to implement; the transmitter consists of a few multipliers and modulator, and the receiver consists of correlators - *very* simple. On the other hand, FH-SS systems require very agile frequency synthesizers that must not only be able to switch frequencies very quickly, but the frequencies that the synthesizer must differentiate between are often very small with respect to the absolute operating frequency, i.e. the system may have be fine tunable to 0.5 - 1 MHz while running at absolute frequencies in the 1 GHz+ range! This takes very sophisticated technology and design techniques, and raises the cost of the FH-SS system, which is always a drawback. For example, the Infopad system being designed at Berkeley is using simple DS-SS because of the controlled indoor environment, where there is only one downlink transmitter (from the main server to the portable units) in a given area, and the near-far problem is not an issue. Here we see that the Direct Sequence system is by far the preferable one.

Also, DS-SS systems can easily resolve multipath bounces to their benefit. In most systems, multipath bounces need to be rejected in order to get a clean signal. Because DS-SS uses a PN Sequence for synchronization as well as an orthogonal code to shield the desired signal from other users, it can correlate delayed versions of the desired signal with delayed versions of the PN sequence and orthogonal code sequence, and sum those up with the on-time correlation to get a better value with which to make a decision on the decoded signal.

Overall, the Direct Sequence system seems to be better if any type of control can be exerted over the given design area, but Frequency Hop does have an advantage when no control can be exercised over the range and number of transmitters parameters. However, since most system designs involve some type of control over the environment that the communications system will be operated in, DS-SS is currently the most common spread spectrum technique.

V. Conclusion

This paper has attempted to go through the basics behind the Spread Spectrum system of wireless communication, as well as the basics behind the two major types of spread spectrum systems, Direct Sequence and Frequency Hopped spread spectrum. It was shown that spread spectrum offered protection from outside intentional interference, which is characterized by the *processing gain*, G_P. This processing gain is generally equal to the ratio of the spread (RF) bandwidth to the minimum bandwidth needed to send the signal. The specific ways in which each of these methods achieved the processing gain were discussed, and the benefits of combining each of the spread spectrum techniques with Code Division Multiple Access (CDMA) techniques in order to create multiple-user environments was discussed. Finally, DS-SS and FH-SS systems were compared, and it was shown that Frequency Hopped systems were better for uncontrolled communication channels, where there were multiple users, and the geographic proximity of the transmitter to the receiver could not be guaranteed, whereas the Direct Sequence system was much easier to implement and thus better suited for a controlled system where the transmitter and receiver distance was kept short and controlled. Certainly, as the wireless communications field becomes larger and larger, Spread Spectrum systems will become commonplace, and some of the problems discussed will very likely be solved in the near future.

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