FHSS, DSSS, And Hybrid DS/FH Performance Evaluation For VSAT

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Abstract: The performance of any radio communication system is affected by several factors such as: interference, and jamming caused by some other parallel networks for the purpose of decreasing the performance of a given system. Direct Sequence Spread Spectrum (DSSS), Frequency Hopping Spread Spectrum (FHSS), and a hybrid approach of both techniques DS/FH are proposed to solve the problem. Whereas DSSS generates a sequence of bit and sends them over a fixed data rate and spread the spectrum with a spreading sequence ,FHSS send the data into different channels with variable data rates, and the hybrid DS/FH approach takes advantage of DSSS and uses it in multiple channels. Various modulation techniques which are suitable for Very small aperture terminal VSAT were simulated with each of the mentioned approaches such as Phase Ship Keying PSK, Frequency Shift Keying FSK, and Quadrature Amplitude Modulation QAM to in order to work properly with each technique. The performance of each approach was evaluated in terms of Signal to Noise Ratio vs Bit Error Rate, throughput, delay, and datarate. The results are very close to each other in terms of BER but the best approach was the DSSS. The Hybrid DS/FH needs more power to operate so it best fits the applications with high frequencies. The Hybrid DS/FH approach was the best of the three tested approaches in terms of throughput, delay, and datarate. The FHSS technique was average in all the parameters and had greater delay time due to the delay gap in the hopping process.

Index Terms: Radio communications, Satellite Communications, VSAT, Spread Spectrum techniques, FHSS, DSSS, Hybrid DS/FH

1 INTRODUCTION

The use of satellites in communication systems has become a part of our daily lives. Whether in telecommunications or TV broadcast it is a part of every home, satellites offer multiple features that cannot be found in other means of communication because they cover a large geographical areas, they offer a vast categories of applications such as telecommunications, military, weather and maritime related applications. Their services include GPS and VSATs our main focus is within the VSAT service. VSAT stands for Very Small Aperture Terminal systems; the dish size is small there for they are more convenient for personal use. They are used mainly for private networks offering two-way communication facilities such as Banks, Hotels, Military, and TV broadcast. VSAT operate in the KU-Band from 12 to 18 GHz, the basic structure of a VSAT network consist of a hub station which provides a broadcast facility to all the VSATs in the network and the VSATs themselves which access the satellite in from of a multiple access mode. The hub station is operated by the service provider and it may be shared among a number of users but of course each user organization has exclusive access to its own VSAT network[1]. As the role of satellite communications became an important aspect of many types of communications the interference and jamming became widely applicable in many ways, there are techniques to prevent the interference and jamming such as: Frequency Hopping Spread Spectrum (FHSS) where the signal is broadcast over a seemingly random series of radio frequencies, hopping from frequency to frequency at fixed intervals. A receiver hopping between frequencies in synchronization with the transmitter picks up the message

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telecommunications, private networks, and military applications. Important issues rise in this type of communication, which are the interference and jamming. Where some organizations tries to interfere on military signals or jam TV broadcast for some purposes.

3 THEORETICAL ANALYSIS

A. Very Small Aperture Terminal

VSATs are connected by radio frequency (RF) links via a satellite, with an uplink from the station to the satellite and a downlink from the satellite to the station. The overall link from station to station, sometimes called hop, consists of an uplink and a downlink. A radio frequency link is a modulated carrier conveying information. Basically the satellite receives the uplinked carriers from the transmitting earth stations within the field of view of its receiving antenna, amplifies those carriers, translates their frequency to a lower band in order to avoid possible output/input interference, and transmits the amplified carriers to the stations located within the field of view of its transmitting antenna. Present VSAT networks use geostationary satellites, which are satellites orbiting in the equatorial plane of the earth at an altitude above the earth surface of 35786 km[2].

B. Frequency Hopping Spread Spectrum

FHSS the signal is broadcast over a seemingly random series of radio frequencies, hopping from frequency to frequency at fixed intervals. A receiver, hopping between frequencies in synchronization with the transmitter, picks up the message. Would-be eavesdroppers hear only unintelligible blips. Attempts to jam the signal on one frequency succeed only at knocking out a few bits of it. Typically, there are 2k carrier frequencies forming 2k channels. The spacing between carrier frequencies and hence the width of each channel usually corresponds to the bandwidth of the input signal. The transmitter operates in one channel at a time for a fixed interval; for example, the IEEE 802.11 standard uses a 300-ms interval. During that interval, some number of bits (possibly a fraction of a bit, as discussed subsequently) is transmitted using some encoding scheme. A spreading code dictates the sequence of channels used. Both transmitter and receiver use the same code to tune into a sequence of channels in synchronization. The performance of FHSS is calculated as:

$$\frac{E_b}{N_j} = \frac{E_b W_d}{S_j} \quad (1)$$

Where: Eb : Signal energy, Nj : Jammer noise power density, Wd : Total bandwidth, Sj : Jammer power

If frequency hopping is used, the jammer must jam all 2k frequencies. with a fixed power, this reduces the jamming power in any one frequency band to Sj / 2k . The gain in signal-to-noise ratio, or processing gain is:

$$G_P = 2^k = \frac{W_s}{W_d} \quad (2)$$

Where: Gp : Processing gain, Ws : Total FHSS bandwidth, Wd : Total bandwidth[3].

C. Direct Sequence Spread Spectrum

DSSS With direct sequence spread spectrum (DSSS), each bit in the original signal is represented by multiple bits in the transmitted signal, using a spreading code. The spreading code spreads the signal across a wider frequency band in direct proportion to the number of bits used. Therefore, a 10-bit spreading code spreads the signal across a frequency band that is 10 times greater than a 1-bit spreading code. One technique with direct sequence spread spectrum is to combine the digital information stream with the spreading code bit stream using an exclusive-OR (XOR). The XOR obeys the following rules:

$0 \oplus 0 = 0 \quad 0 \oplus 1 = 1 \quad 1 \oplus 0 = 1 \quad 1 \oplus 1 = 0$

To see how this technique works out in practice, assume that a BPSK modulation scheme is to be used. Rather than represent binary data with 1 and 0, it is more convenient for our purposes to use +1 and –1 to represent the two binary digits. To produce the DSSS signal, we multiply the BPSK signal by c(t), which is the PN sequence taking on values of +1 and –1:

$$s(t) = A\, d(t)c(t)\cos(2\pi f_c t) \quad (3)$$

Where: A: Amplitude of a signal, fc : Carrier frequency, d(t): The discrete function that takes on the value of +1 and -1 for one bit time if the corresponding bit in the bit stream is 0 At the receiver, the incoming signal is multiplied again by c(t). But c(t) × c(t) = 1 and therefore the original signal is recovered. Equation can be interpreted in two ways, leading to two different implementations. The first interpretation is to first multiply d(t) and c(t) together and then perform the BPSK modulation. That is the interpretation we have been discussing. Alternatively, we can first perform the BPSK modulation on the data stream d(t) to generate the data signal sd(t). This signal can then be multiplied by c(t). The performance of this method is calculated as: The jamming signal has the form:

$$s_j(t) = \sqrt{2}s_j \operatorname{Cos}(2\pi f_c t) \quad (4)$$

And the received signal is:

$$s_r(t) = s(t) + s_j(t) + n(t) \quad (5)$$

Where s(t): transmitted signal, sj(t) : jamming signal, n(t) : additive white noise, Sj : jammer signal power
The despreader at the receiver multiplies sr(t) by c(t), so the signal component due to the jamming signal is

$$y_j(t) = \sqrt{2}s_j\, c(t)\cos(2\pi f_c t) \quad (6)$$

Although a number of factors come into play, as an approximation, we can say that the jamming power passed by the filter is

$$S_{jF} = S_j \frac{\left(\frac{2}{T}\right)}{\left(\frac{2}{T_C}\right)} = S_j \left(\frac{T_C}{T}\right) \quad (7)$$

The jamming power has been reduced by a factor of (Tc /T) through the use of spread spectrum. The inverse of this factor is the gain in signal-to-noise ratio:

$$G_p = \frac{T}{T_c} = \frac{R_C}{R} \approx \frac{W_S}{W_d} \quad (8)$$

Where Rc : is the spreading bit rate, R : is the date rate, Wd : is the signal bandwidth, Ws : is the spread spectrum signal bandwidth, Tc : Frequency generation time, T : Bit width[3].

D. Hybrid DS/FH

The advantage in combining two spread spectrum modulation methods is that characteristics can be provided that are not available from a single modulation method. Based on the hopping rate, a hybrid DS/FH system may be classified into hybrid DS/SFH and hybrid DS/FFH systems. Though the modulation complexity has substantially increased in hybrid systems, implementation may not be more difficult than pure DSSS or FHSS systems since a hybrid system can use shorter PN codes and fewer of hopping frequencies. Hybrid DS/FH transmitters are a simple combination of DSSS and FHSS transmitters as shown below. The same PN code generator can be used to provide both the spreading sequence and addressing to a frequency synthesizer. While DSSS and FHSS systems distinguish users by their unique code sequences or hopping patterns, a hybrid user is identified by an address composed of two fields: its PN sequence and hopping pattern. Synchronization between FH and DS code patterns is required. Earlier hybrid systems usually employed DS codes that were much faster than the rate of frequency hopping. For example, a single frequency hop would last for several chips. This should not be confused with slow frequency hopping which has several symbols in one hop[4].

4 SIMULATION AND MODELING

This section shows the procedure to perform the DSSS & FHSS in term of bit error rate (BER) against signal to noise ratio (SNR). Three models are designed for the three techniques consisting of a transmitter component including the code generation and modulation, a channel component using Additive White Gaussian Noise (AWGN), and a receiver component including the de-spreading code and modulation. The simulation tool used is MATLAB/SIMULINK which is a multi-paradigm numerical computing environment and fourth-generation programming language. Developed by MathWorks, MATLAB allows matrix manipulations, plotting of functions and data, implementation of algorithms, creation of user interfaces, and interfacing with programs written in other languages, including C, C++, Java, Fortran and Python[5].

A. Mathematical Model

The theoretical bit error rate (BER) performance of DS-SS & FH-SS for AWGN channel BER as function of the Eb/N0 was determined to be: For DSSS

$$\mathrm{Pe} = \frac{1}{2}\mathrm{erfc}\left(\frac{\sqrt{\mathrm{E_b}}}{\sqrt{\mathrm{JT_c}}}\right) \qquad (9)$$

erfc is given by

$$\mathrm{erfc}\,(x) = \int_{-x}^{x} e^{-\frac{1}{2}}\,dt \qquad (10)$$

Where: Eb : signal to noise ratio, Tc : chip duration, J : jamming power. For the FHSS: While for the FHSS the bit error rate was given by

$$\mathrm{Pe} = 0.333\,\exp(\,(-\mathrm{SNR} \,*\, \mathrm{R_c}) \div 2) \qquad (11)$$

Where: SNR : signal to noise ratio, Rc : chip rate

B. Direct Sequence Spread Spectrum Model

The direct sequence spread spectrum simulation blocks consists of four users, each user has its KSASMI code transmitted via the wireless channel based on Additive White Gaussian Noise to give us the interference of noise to the signal, at the end of the simulation block an error detection calculation block was added to evaluate the system performance for each user.

C. Frequency Hopping Spread Spectrum Model

At the transmitter, the Bernoulli Binary Generator block generates random binary data with symbol width of 1/200s. Then the data feeds into the BFSK Modulator subsystem for baseband modulation. FH Sequence Generator subsystem generates FH sequence, which controls the Frequency Synthesizer subsystem to generate periodic frequency-hopping complex exponential carrier signals. In the FH Modulator subsystem, the output complex exponential carrier signals of the Frequency Synthesizer subsystem and the output complex exponential signals of the BFSK Modulator subsystem are mixed together to generate a real sine wave. The frequency mixed signal is sent to the AWGN Channel. At the receiver, all users receive multi-user mixed signals in AWGN noise. The frequency hopping signals first pass the FH Demodulator subsystem for dehopping, and then pass through the BFSK Demodulator subsystem for nonconherent FSK demodulation. The Error Rate Calculation block is used for calculating the bit error rate, and the Display block shows the result[6].

D. Hybrid DS/FH Model

The concept in this model relays on the structure of transmitting the code in multiple channels with different frequencies to have the system shift find the suitable frequency and transmit on it. A set of block were made to simulate this process and to obtain results, these blocks are the data source generator subsystem to generate a random sequence of bits, the modulation subsystem using QAM modulation, signal transmission subsystem The transmitted signal is furthermore modulated using OFDM "orthogonal frequency division multiplexing" for its ability to allow the spectrum to overlap, By dividing the channel into narrowband flat fading subchannels, OFDM is more resistant to frequency selective fading than single carrier systems are, OFDM was used to represent sending the codes simultaneously on different frequencies. Using adequate channel coding and interleaving one can recover symbols lost due to the frequency selectivity of the channel, demodulation subsystem containing the QAM demodulation and OFDM demodulation, and finally the system calculates the BER, throughput, datarate, and delay.

5 Results and Discussion

The performance of the three proposed techniques is evaluated considering four aspects of evaluation in radio communication systems.

- **BER vs SNR**

Taking into consideration the SNR Average of 18 dB for the Direct Sequence Spread Spectrum using BPSK modulation it was found that the BER reached approximately 10-30 , Note that the SNR is set between 0 and 20 dB. For the Frequency Hopping the BER was approximately 10-19, and the BER of the Hybrid DS/FH was 10-12. While comparing the three simulation results hybrid, FHSS and DSSS systems it was found that all of these techniques are common in the relation of SNR and bit error rate that is while increasing SNR the BER decreases. The hybrid technique needs more power but is it more suitable for applications with high frequencies. The Direct Sequence Spread Spectrum takes advantage over the other two techniques with the lowest Bit Error Rate. The following graph represents the three output results for each.

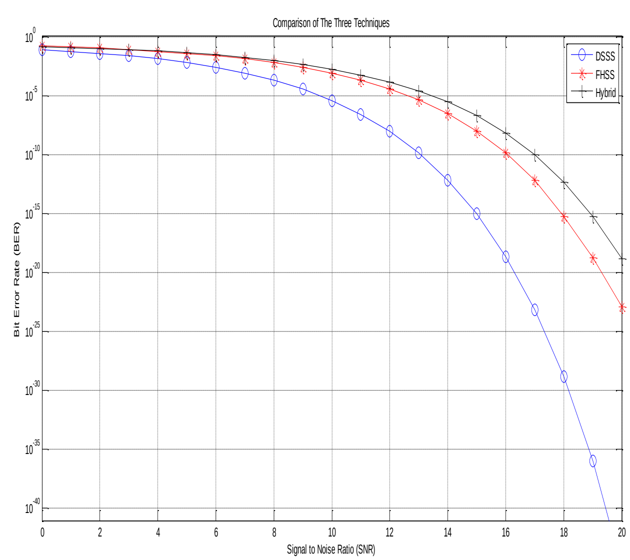

Fig.1 *Comparison of SNR vs. BER for the three techniques*

- **Delay**

The delay time calculations is done to all of the systems based using an equal packet size it was found that the delay time of the FHSS is greater than the DSSS and the

Hybrid Technique because of the delay gap in channel in FHSS. Taking an average transferred bits at 1000 bits the delay time for the Hybrid technique was 100 µs, for the DSSS it was 200 µs, and for the FHSS it was 300 µs because of the delay time gap used in frequency hopping. There for The hybrid technique takes advantage above the other two technique with the lowest delay.

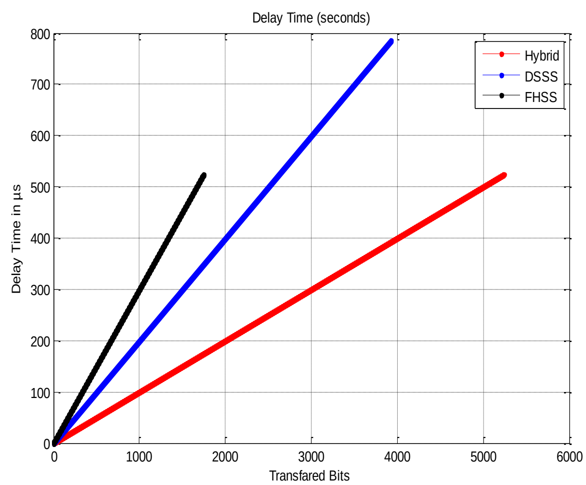

Fig.2 *Comparison of Delay time between DSSS, FHSS, and the Hybrid technique*

- **Throughput**

The throughput calculations is done to all of the systems based using an equal packet size. Taking an average time of 150 seconds the throughput of the Hybrid technique was 45 bits/µs, for the DSSS it was 15 bits/µs, and for the FHSS it was 30 bits/µs. there for the throughput of the Hybrid technique is greater than the FHSS and DSSS because of the delay gap in FHSS.

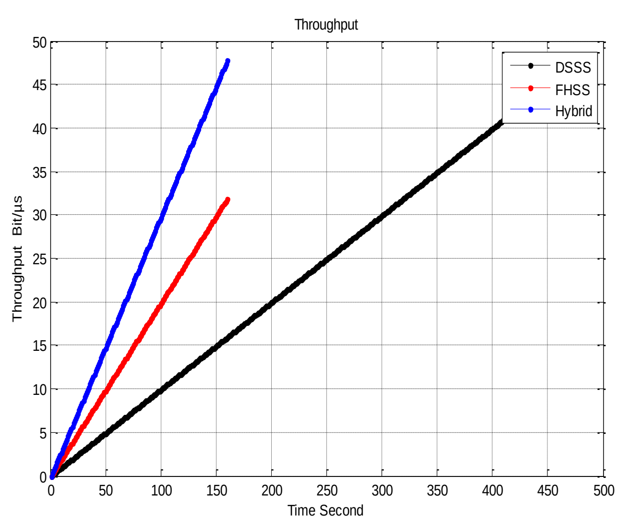

Fig.3 *Throughput comparison between DSSS, FHSS, and the Hybrid Technique*

- **Datarate**

The Datarate calculations is done to all of the systems based using an equal packet size. Taking an average time of 1000 seconds the Datarate of the Hybrid technique was 300 bits/s, for the DSSS it was 200 bits/s, and for the FHSS it was 100 bits/s. there for the Datarate of the Hybrid technique is greater than the FHSS and DSSS because of the delay gap in FHSS

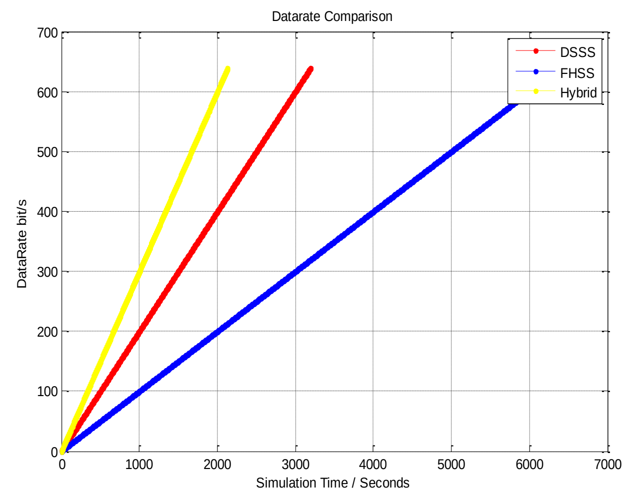

Fig.4 *Datarate comparison between DSSS, FHSS, and the Hybrid Technique*

6 Conclusion and Recommendations

This thesis provides an analytical performance evaluation of the anti jamming anti interference techniques provided, such as Direct Sequence Spread Spectrum, Frequency Hopping Spread Spectrum, and a hybrid approach between these two techniques DS/FH for the purpose of improving the efficiency of today's modern radio communication systems, VSAT in particular. The availability and use of these techniques improved the performance of the system in terms of Bit Error Rate vs Signal to Noise Ratio, throughput, delay, and datarate of the system using various modulation techniques such as: BPSK, BFSK, And QAM all suitable for VSAT systems. Comparing the three approaches together it was found that the DSSS operates better in terms of BER while the Hybrid DS/FH has a better throughput, delay, and datarate. For the future work, it is highly recommended to use these techniques in real time environment, i.e applying them in a real working VSAT system to gain the benefits of the simulated techniques. Also applying these techniques with other types of modulation to cover other applications, high level transport protocol are recommended to have a more accurate results. Finally applying other methods of performance evaluation such as power analysis.

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