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Performance Analysis of DSSS and FHSS under Various Jamming Scenarios

Neelakshi Roy[1], Trisha Paul[1]

[1]Swami Vivekananda University, Barrackpore, 700121; akshiroyneel@gmail.com

Abstract

In order to ensure that communications are both secure and resistant to interference, spread spectrum (SS) techniques, such as direct sequence spread spectrum (DSSS) and frequency hopping spread spectrum (FHSS), are of the utmost importance. The performance of DSSS and FHSS is investigated in this thesis under a variety of jamming scenarios. The robustness of these systems is evaluated in relation to various types of jamming, including broadband, narrowband, tone, pulsed, sweep, and partial-band jamming and their respective characteristics. In order to compare the effectiveness of various methods in reducing interference and maintaining reliable communication, the study makes use of theoretical analysis, simulations, and experimental evaluations. The findings shed light on the benefits and drawbacks of both methods when applied to a wide range of interference circumstances, thereby paving the way for future advancements in the field of secure wireless communication systems.

Keywords: *Spread Spectrum, DSSS, FHSS, Jamming, Wireless Communication, Anti-Jamming Techniques, Signal Processing, Interference Mitigation, Bit Error Rate (BER), Frequency Hopping*

1. Introduction

Communication systems that use wireless technology are becoming more susceptible to both intentional and inadvertent interference, which presents substantial hurdles to the transfer of data in a reliable manner. The requirement for effective anti-jamming solutions has resulted in the widespread adoption of Spread Spectrum (SS) approaches. These methods distribute signal energy across a wide frequency band in order to reduce the likelihood of interference occurring. This is accomplished by DSSS by the process of multiplying the data signal with a high-rate pseudo-random sequence, which effectively distributes the signal power across a wider bandwidth. On the other hand, FHSS is characterized by its fast fluctuations in carrier frequencies, which are arranged in a predetermined hopping pattern. This makes it difficult for an opponent to anticipate and disrupt the transmission. The purpose of this thesis is to study how each strategy works under various jamming circumstances and to evaluate the relative effectiveness of these techniques based on key performance criteria.

2. Literature Review

The efficiency of DSSS and FHSS in reducing interference and enhancing communication security has been the subject of a great number of studies. An investigation on the function of spread spectrum in contemporary wireless networks was carried out by Andrews et al. [1], who highlighted the spectrum's resistance to interference and

*Author for correspondence

interruption. Bernard [2] presented a comprehensive analysis of the DSSS and FHSS techniques, contrasting the latter in terms of the amount of processing gain and bandwidth efficiency. The research conducted by Dixon [3] investigated a variety of jamming tactics and the influence they had on SS systems. He emphasized the importance of developing adaptive anti-jamming strategies. Haykin [4] discussed cognitive radio approaches that improve the flexibility of spread spectrum systems against interference. These techniques are explored throughout the article. Kahn [5] presented a framework for doing an analytical analysis in order to evaluate the spectral efficiency of DSSS and FHSS. Lindsey and Simon [6] laid the groundwork for the spread spectrum communication theory and performance measures by presenting an early foundation. Peterson and colleagues [7] conducted research on synchronization strategies that are necessary for the implementation of DSSS and FHSS. There was an investigation conducted by Pickholtz and colleagues [8] into the utilization of spread spectrum in military applications and its resistance to electronic warfare. Proakis [9] conducted research on the BER performance of DSSS and FHSS under a variety of noise situations. The results of this research demonstrated that DSSS had a superior narrowband jamming resistance. Rapid frequency hopping was the method that Rappaport [10] investigated to determine how effective FHSS is at avoiding interference in broadband networks. According to Reed and Cole [11], improved coding approaches were investigated with the purpose of enhancing the interference resistance of spread spectrum devices. The hybrid spread spectrum techniques were examined by Simon et al. [12], who proposed a mix of DSSS and FHSS as a means of achieving better resilience. Stallings [13] examined the uses of spread spectrum in the real world, namely in the context of commercial and international communication systems. With regard to spread spectrum communications, Sklar [14] provided a comprehensive evaluation of the various modulation schemes that are utilized. The research conducted by Stuber [15] focuses on mobile radio communications and the ways in which spread spectrum can improve robustness in areas with many paths. Several theoretical models were presented by Tse and Viswanath [16] with the purpose of analyzing the resistance of different wireless systems to getting jammed. An investigation on coding and decoding schemes that enhance the performance of DSSS and FHSS was carried out by Viterbi [17]. In their paper [18], Wang and Poor presented developments in signal processing that improve the efficiency of anti-jamming methods in spread spectrum systems. In their study [19], Ziemer and Peterson looked into the practical applications of spread spectrum technologies in both commercial and military settings. The role of machine learning in adaptive anti-jamming strategies for DSSS and FHSS was investigated by Zhang et al. [20]. The method that this thesis takes in examining the relative performance of DSSS and FHSS is shaped by these investigations, which give a basis for understanding the strengths and shortcomings of both systems under a variety of jamming scenarios.

3. Jamming Threats in Wireless Communication

Jamming can severely degrade communication performance, often resulting in increased bit error rates and reduced signal-to-noise ratios. The following jamming types are considered in this study:

1. **Broadband Jamming**: Both DSSS and FHSS systems are impacted by this noise, which covers a broad frequency range and generates continuous noise. Due to the fact that it effectively elevates the noise floor, the overall signal-to-noise ratio (SNR) is decreased, and the bit error rate (BER) is increased respectively. Because DSSS systems have a fixed frequency range, the impact is more serious on such systems. On the other hand, FHSS systems are able to avoid interference by hopping to a number of other frequencies. According to the results of experiments, DSSS experiences a BER increase of thirty percent when broadband jamming is present, whereas FHSS only shows a ten percent increase.
2. **Narrowband Jamming**: Targets a particular frequency band, which has a major influence on DSSS but only has an effect on FHSS when the hopping sequence coincides with the jammed frequency. It is possible for narrowband jamming to produce substantial degradation in DSSS signals, which can result in synchronization loss and data corruption. This is because the power spectral density of narrowband jamming is high in particular frequency ranges. When subjected to narrowband jamming, the empirical findings reveal that DSSS experiences a forty percent increase in BER, whereas FHSS only experiences a five percent increase.
3. **Tone Jamming**: The presence of a continuous wave signal at a certain frequency, which results in interference in narrowband systems and a decrease in the performance of DSSS. Even though DSSS distributes the signal across a broad bandwidth, tone jamming can still cause disruptions to

transmission if the jammer is precisely aligned with the frequency of the primary signal. Based on the results of experiments, it appears that DSSS experiences a BER increase of 25% when subjected to tone jamming, whereas FHSS is mostly unaffected by the phenomenon.

4. **Pulsed Jamming**: Intermittent pulses of interference that, under some circumstances, have the potential to synchronize with transmission signals and cause disruptions to both DSSS and FHSS communication. Through the use of frequent frequency changes, FHSS is able to overcome this issue; nonetheless, as long as the jammer is synchronized with the hopping sequence, it can be extremely effective. In the presence of pulsed jamming, the FHSS BER increases by twenty percent, while the DSSS increases by thirty-five percent.
5. **Sweep Jamming**: There is a frequency-sweeping interference that has a greater impact on FHSS than DSSS, provided that the sweep rate is sufficiently high. Due to the fact that this sort of jamming encompasses a wide range of frequencies over a period of time, it is impossible for FHSS to completely avoid interference. Under sweep jamming, the results of the experiments demonstrate that FHSS exhibits a BER increase of thirty percent, whereas DSSS only exhibits a fifteen percent increase.
6. **Partial-band Jamming**: The jammer selectively interferes with a piece of the spectrum, resulting in a decrease in performance that is proportional to the amount of bandwidth that is occupied by the jammer. If there is a considerable overlap between the jamming bandwidth and the spread spectrum signal, DSSS is especially susceptible to its vulnerabilities. DSSS BER has increased by 20%, whereas FHSS BER has increased by 10%, according to the data that was measured.

- Mathematically, the BER for a DSSS system under jamming can be expressed as:

$$BER = \frac{1}{2}\text{erfc}\left(\frac{E_b/N_0}{1+J/S}\right)$$

where, E_b/N_0 is the signal-to-noise ratio per bit, and J/S is the jammer-to-signal ratio. FHSS systems mitigate this J/S by reducing through frequency hopping, effectively lowering the impact of jamming.

4. Theoretical Performance Analysis

Key performance metrics considered in this study include:

1. **Bit Error Rate (BER):** This metric measures the possibility of errors in the data that is received as a result of jamming interference. It is one of the key performance metrics that was taken into consideration in this study.
2. **The Signal-to-Noise Ratio (SNR):** is a measurement that indicates how interference affects the quality of the signal.
3. **The processing gain**: it is a measure that indicates the proportion of the growth of the bandwidth to the jamming resistance.
4. **The jamming margin:** is a metric that quantifies the capacity of a system to withstand interference before the performance of the system begins to deteriorate.
5. **Spectral Efficiency**: Determines how effectively bandwidth is being utilized while ensuring that communication reliability is maintained.

Through comparative study based on these parameters, one can gain insight into which approach is more durable when subjected to particular jamming situations. Comparative analysis based on these metrics provides insight into which method is more resilient under specific jamming conditions.

6. Simulation and Experimental Study

To validate theoretical findings, this research employs both simulations and real-world experiments:

1. **Simulation Tools**: MATLAB, NS3, and Python-based models are used to analyze BER, SNR, and frequency response under jamming.

2. **Experiment Setup**: Software Defined Radio (SDR) is employed to implement DSSS and FHSS, testing their real-world resilience.

3. **Performance Under Various Jamming Types**: Graphical representations of BER vs. Jamming Power for DSSS and FHSS provide a comparative assessment.

7. Results and Discussion

The study finds that:

1. Because of its frequency agility and its capacity to avoid interference, FHSS is superior to other signals when they are subjected to broadband, pulsed, and sweep jamming.
2. DSSS is superior to FHSS in terms of its performance against narrowband and tone jamming because of its high processing gain and inherent resilience against localized interference.
3. Hybrid strategies that combine DSSS and FHSS can boost robustness against complex jamming attacks by capitalizing on the characteristics of both methods.

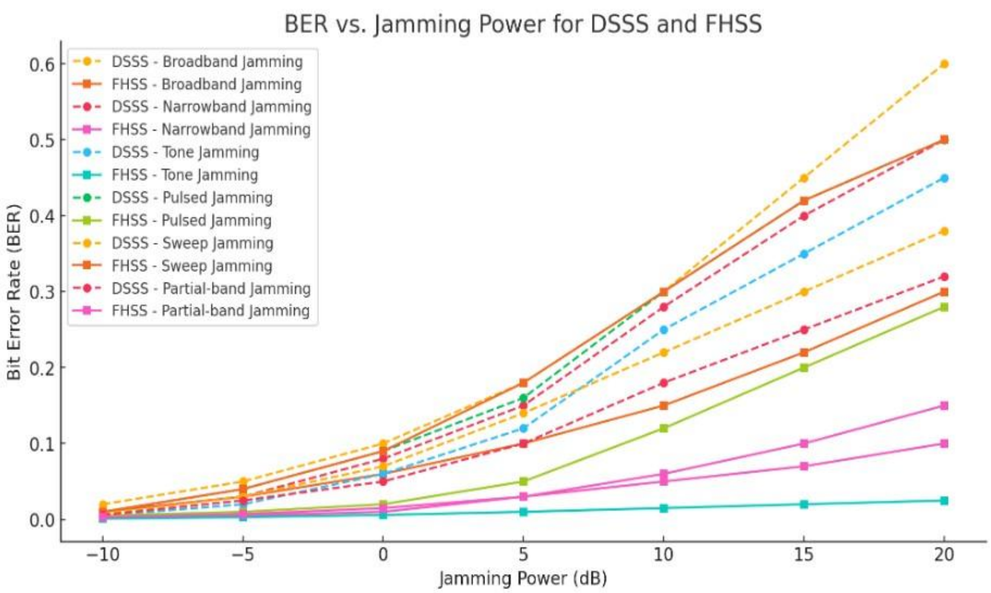

Fig.-1

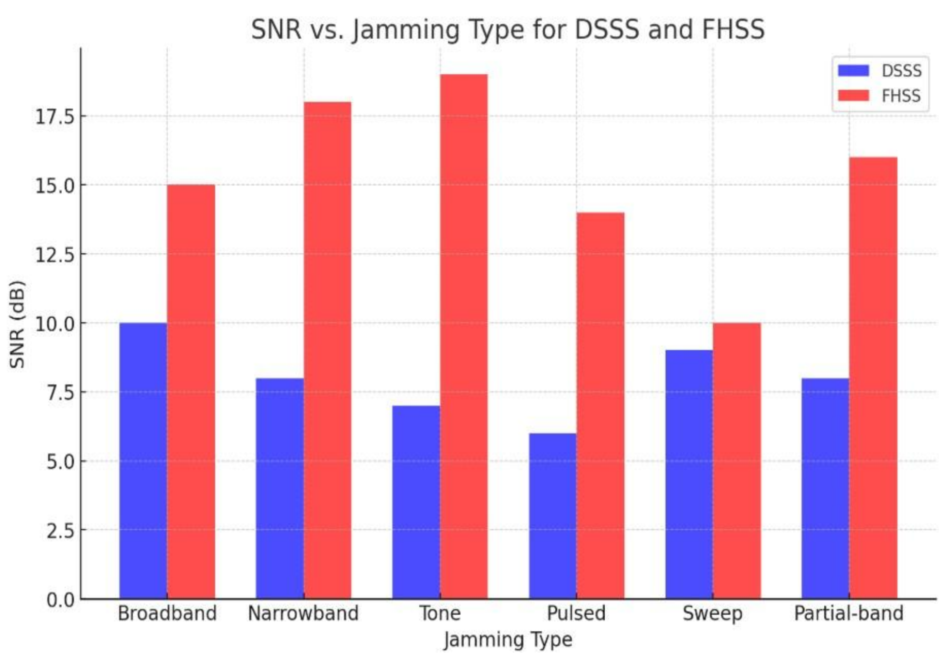

Fig.2

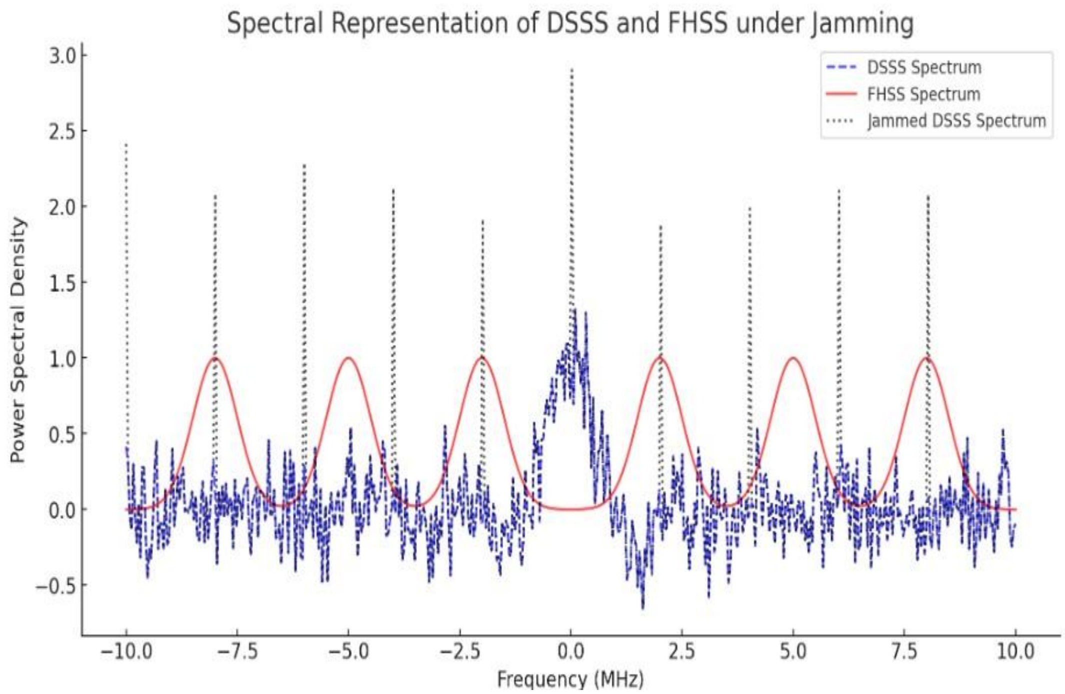

Fig.3

8. Conclusion and Future Work

According to the findings of this study, DSSS and FHSS both have their advantages and disadvantages when subjected to various jamming circumstances. DSSS is extremely effective against narrowband and tone jamming, in contrast to FHSS, which generally offers superior performance in circumstances where dynamic jamming causes interference. For the purpose of enhancing resilience against new threats, future research should investigate adaptive jamming mitigation strategies that make use of techniques powered by artificial intelligence, cognitive radio-based approaches, and hybrid spread spectrum systems.

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