Performance Analysis of Higher Order Digital Modulation Techniques for Hybrid Spread Spectrum Systems

Temesgen Tsegaye Liku

A Thesis Submitted to

The Department of Electronics and Communication Engineering

School of Electrical Engineering and Computing

Presented in Partial Fulfillment of the Requirement for the Degree of Master's in Communication Engineering

Office of Graduate Studies

Adama Science and Technology University

June, 2024

Adama, Ethiopia

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APPROVAL PAGE OF M.SC THESIS

We, the advisors of the thesis entitled "**Performance Analysis of Higher Order Digital Modulation Techniques for Hybrid Spread Spectrum Systems**" developed by **Temesgen Tsegaye Liku**, hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

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Co-advisor	Signature	Date

We, the undersigned, members of the Board of Examiners of the thesis by **Temesgen Tsegaye Liku** have read and evaluated the thesis "**Performance Analysis of Higher Order Digital Modulation Techniques for Hybrid Spread Spectrum Systems**" and examined the candidate during open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in Electronics and Communication Engineering.

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DECLARATION

I hereby declare that this Master Thesis entitled "**Performance Analysis of Higher Order Digital Modulation Techniques for Hybrid Spread Spectrum Systems**" is my original work. That is, it has not been submitted for the award of any academic degree, diploma or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation.

Temesgen Tsegaye	___________________	________________
Name of student	Signature	Date

RECOMMENDATION

We, the advisors of this thesis, hereby certify that we have read the revised version of the thesis entitled “**Performance Analysis of Higher Order Digital Modulation Techniques for Hybrid Spread Spectrum Systems**” prepared under our guidance by Temesgen Tsegaye Liku submitted in partial fulfillment of the requirements for the degree of Masters of Science in Communication Engineering. Therefore, we recommend the submission of revised version of the thesis to the department following the applicable procedures.

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ACKNOWLEDGEMENT

First of all, I thank the Almighty God who gave me the strength and ability to complete this thesis successfully. I would like to express my gratitude and appreciation to my Advisor Dr. Rajaveerappa Devadoss for his encouragement, guidance, engagement, constructive criticism and useful suggestions that made this thesis a precious learning experience for me. I am also thankful to my co-advisor Mr. Aga Bayou for his valuable suggestions and continuous support. I would also like to express my special gratitude to the department of Electronics and Communication Engineering (ECE) for giving me the golden opportunity to do this thesis work.

I would like to thank Dr. Tatek Getachew for his advice while I faced challenges on my thesis.

Finally, I would like to thank my families for their endless advice and also I want to express my gratitude to those who directly or indirectly supported me during my thesis.

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LIST OF ACRONYMS AND ABBREVIATIONS

5G	5th Generations
ASK	Amplitude Shift Key
AWGN	Additive White Gaussian Noise
BER	Bit Error Rate
BPSK	Bi-Polar Shift Key
CDMA	Code Division Multiple Access
CFAR	Constant Form Alarm rate
DSSS	Direct Sequence Spread Spectrum
DS/FH	Direct Sequence/Frequency Hoping
DS/FFH	Direct Sequence/Fast Frequency Hoping
DPSK	Differential Phase Shift Keying
DS/FHSK	Direct Sequence/Frequency Hoping shift Key
FFH	Fast Frequency Hopping
FHSS	Frequency Hoping Spread Spectrum
GPS	Geographical Positioning System
HSSS	Hybrid Spread Spectrum System
IEEE	Institute of Electrical and Electronics Engineering
LFSR	Linear Feedback Shift Register
MSINR	Minimum Signal Interference to Noise Ratio
MATLAB	MATrix LABoratory
PAM	Phase Amplitude Modulation
PDF	Probability Density Function
PN	Pseudo Noise
PSA	Power Spectrum Analysis
VSAT	Very Small Aperture Terminal
QAM	Quadrature Amplitude Modulation

Q-factor	Quality Factor
QPSK	Quadrature Phase Shift Key
SNR	Signal-to-Noise Ratio
SINR	Signal-to-Interference-plus-noise ratio
SFH	Slow Frequency Hopping

Abstract

There are two types of digital transmission techniques that give acceptable bit rates and good performance. The first is in satellite communications, where these schemes make efficient use of the limited power available. The second is in mobile wireless, where the schemes make efficient use of the limited bandwidth available for the in-demand service. However, both systems are limited in bandwidth and vulnerable to hostile jamming and radio interference. The novelty of the spread spectrum lies primarily in its wideband, pseudorandom approach to signal transmission, which provides intrinsic benefits such as interference resistance and security. Specific implementations of spread spectrum, such as FHSS and DSSS, add their own innovative techniques to realize these benefits. Furthermore, a hybrid of the two methods can be built to improve processing gain over a single strategy. Compared to traditional narrowband methods, spread spectrum offers a fundamentally different and more robust approach to communication. Hence, the aim of this thesis is to model and simulate the three spread spectrum systems, FFHSS, DSSS, and DS/FFHSS, using Matlab /Simulink software, with Higher M-QAM (16 QAM, 32 QAM, 64 QAM and 128 QAM) modulations and Rayleigh fading channel. The DS/FFHSS system performances were then compared with FHSS, and DSSS based on Bit Error Rate (BER), signal-to-noise ratio (SNR), Q-factor, and received signal power (POWER) metrics. The results revealed that the DS/FFHSS system outperformed the DSSS and FHSS systems at fixed SNR values (0-20 dB) by 74%, 58.5%, and 32.5%, respectively, in BER, SNR, and Q-factor metrics, whereas the values in the received power signal were identical in lower SNRs and differed slightly at higher SNR levels.

Keywords*: Bit Error Rate, Direct Sequence Spread Spectrum, Frequency Hoping Spread Spectrum, Hybrid Spread Spectrum, Quadrature Amplitude Modulation, Signal-to-Noise Ratio.*

CHAPTER ONE

1. INTRODUCTION

1.1 Background of the Study

The need for safe data transfer methods is rising as a result of the amazing developments in the communications industry. Due to the limited bandwidths available in and around the assigned frequency, one of the main issues with narrow-band transmission is unwanted signal interference from the channel as well as interference from users of adjacent frequencies. With spread spectrum technology, a far larger bandwidth is used to transmit data. The origins of spread spectrum can be traced back to military applications during World War II, with its principles and applications expanding significantly in subsequent decades. The concept of spread spectrum was initially developed for secure military communications. The first known implementation was by actress Hedy Lamarr and composer George Antheil during World War II, who invented a frequency-hopping spread spectrum (FHSS) system to prevent the jamming of torpedo guidance signals. This invention laid the groundwork for modern spread spectrum technology.

According to the 2019 International Conference on Intelligent Computing and Control Systems (ICCS), spread spectrum technology is less vulnerable to jamming and purposeful and inadvertent interference that occur during the transmission of digital information. These methods have advantageous characteristics including lessening crosstalk and interference. When using spread spectrum technology, the signal that is broadcast assumes a bandwidth that is far more than what is needed in order to transmit the original data. A third party cannot intercept the message or create interference by broadcasting the signal with a significantly broader bandwidth since the message is now "hidden" in the noise and just the noise spectrum is visible. A spreading code is utilized to achieve this kind of spectrum spreading, and data retrieval at the receiver is accomplished through the usage of a synchronized spreading code.The PN generator generates PN codes at random that are uniformly distributed and unaffected by the input data. There will be a flat spectral density across the spread signal bandwidth as opposed to a single modulation frequency peak. As a result, the signal gets drowned out by noise, protecting the system from outside interference and attacks (2019 International Conference on Intelligent Computing and Control Systems (ICCS)., n.d.).

1.1.1 Principles of Spread Spectrum

Spread spectrum techniques require distributing the sent signal across a wide range of frequencies. There are numerous major concepts and forms of spread spectrum:

- Frequency Hopping Spread Spectrum (FHSS): This approach quickly swaps the carrier frequency between many frequencies across a broad spectral band. The frequency hopping pattern is set by a code that both the transmitter and receiver are familiar with.
- Direct Sequence Spread Spectrum (DSSS): This approach multiplies the data signal by a pseudo-random noise sequence (PN sequence) to spread it across a broader frequency spectrum. The receiver demodulates the signal using the same PN sequence.
- Hybrid distributed Spectrum (HSS): In DS/FHSS, the data stream is distributed first with DSSS and subsequently transmitted using FHSS. This combines the spreading gain.

1.1.2 Significance of spread Spectrum

Spread-spectrum approaches diffuse the signal over a wide frequency range, making it less susceptible to narrowband interference. If interference occurs in a narrow band of the spectrum, its overall impact on the spread signal is lessened. In places with multiple overlapping Wi-Fi networks, spread spectrum lowers interference from neighboring networks, resulting in more stable and reliable connections. Bluetooth devices must perform successfully even when there is interference from other 2.4 GHz devices, such as microwave ovens and cordless phones. When combined with encryption, signals are difficult to intercept and demodulate without knowledge of the spreading code or hopping pattern. This provides an additional layer of protection by disguising the delivered signal. In military communications, spread spectrum encrypts communication lines, making it harder for opponents can intercept or jam transmissions. Satellite communications provide secure links between satellites and ground stations, protecting important data from eavesdropping.

Multipath fading happens when transmitted signals reflect off surfaces, creating several pathways for the signals to travel. Spread spectrum approaches reduce the effects of multipath fading by spreading the signal over a wide frequency range, allowing the receiver to combine numerous signal routes constructively. In cities with many reflective surfaces, the spread spectrum contributes to signal integrity by reducing the impacts of multipath fading and boosting the stability of cellular and Wi-Fi networks. Improves the performance of interior wireless networks that experience multipath reflections from walls and furniture.

Multiple users can share the same frequency band without severe interference, making the spectrum more efficient. This is especially useful in circumstances where spectrum is a restricted resource. Allows several users to share the same frequency band by issuing unique spreading codes, improving the capacity of cellular networks.
Improve communication system reliability by making them more resistant to various types of interference and signal deterioration. This results in higher-quality, more reliable communication links. GPS systems spread the spectrum to guarantee that satellite signals are reliably received, delivering accurate positioning information even in areas with high signal interference. The spread spectrum to maintain stable communication links in crucial conditions, allowing emergency services to communicate effectively.

1.2 Statement of the Problem

The global civilization of the 21st century has been greatly influenced by digital communication technology. It has made the world a better place by connecting people easier and facilitating their everyday lives. Over the time, we have seen huge advancements in communication and due to these there is a rising need for secure data transmission mechanisms. Undesired signal interference from the channel, and also cross-channel users such as those on adjacent frequencies due to densely spaced narrow bandwidths around the assigned frequency is one of main challenges with narrow-band transmission. In response to these problems, a number of spread spectrum technologies have been developed and deployed. Nonetheless, the performances of spread spectrum systems that are currently in use need to be established using multiple methods. This thesis objective is develop in MATLAB Simulation the modeling and anlysis performance of DSSS en FHSS with DS/FFH Hybrid Spread Spectrum using various M higher order modulation schemes(QAM-16, QAM-32, QAM 64, and QAM 128) under Rayleigh Fading channel tone.

1.3 Objectives

1.3.1 General Objectives

The main objective of this thesis is to assess how well a DS/FFH hybrid spread spectrum system performs while employing several higher modulation schemes (QAM-16, QAM-32, QAM-64, and QAM-128) in the presence of Rayleigh fading.

1.3.2 Specific Objectives

The specific objectives of this thesis are:-

1. To model DS/FFH, DSSS and FHSS Spreading Spectrum Systems using MATLAB/Simulink software.
2. To simulate each system using different higher order digital modulation techniques.
3. To analyse the simulation result of BER, Q-factor, SNR, and Power of each system.
4. To compare the performance analysis of DS/FFH system with DSSS and FHSS systems

1.4 Significance of the Study

Depending on their performance, communication systems will produce both excellent and terrible results with varying data rate modulation. Spread spectrum systems function differently depending on data rate modulation. This study had the following significance:

- ➢ By knowing the system's capabilities allows for a safe and dependable communication system for critical government and financial institutions.
- ➢ To carry out further research on the gap between spread spectrum systems
- ➢ It helps to identify the weak system and conduct research on the weakness

1.5 Scope of the Study

The scope of this study was to design a transmission system that models the DS/FFH system and tests the system's SNR, BER, Q-factor, and Power using higher modulation techniques (QAM-16, QAM-32, QAM-64, and QAM-128). Furthermore, the transmission system was tested using MATLAB simulation software.

1.6 Contribution of the Thesis

Direct Sequence/Fast Frequency Hopping (DS/FFH) and Quadrature Amplitude Modulation (QAM) under fading channels add significantly to the existing body of knowledge in wireless communications by addressing the challenges posed by signal fading and interference, both of which are common in real-world settings. Here are the main contributions:

- Robustness to Fading: DS/FFH spreads the signal across a wide frequency band, increasing its resistance to narrowband interference and multipath fading. This spreading strategy ensures that, even if some sections of the signal fade, the sent information remains intact.
- Improved Signal Quality: By altering the amplitude and phase of the carrier signal, QAM makes better use of the available bandwidth and increases data throughput. When paired with DS/FFH, QAM can enable higher-quality signal transmission even

in the face of fading, because the spreading techniques serve to mitigate the impacts of fading.

- Enhanced Spectral Efficiency: By combining DS/FFH with QAM, more bits can be transferred per unit of bandwidth. This is critical for current communication systems that require fast data rates and optimal spectrum utilization.
- Diversity Gain: The use of frequency hopping in DS/FFH introduces frequency diversity, which aids in reducing the negative impacts of fading channels. This increased variety helps to improve the reliability and performance of communication systems.
- Interference Mitigation: DS/FFH approaches effectively reduce both co-channel and adjacent-channel interference. This potential is strengthened when combined with QAM, which allows for faster data throughput while being interference resistant.
- Adaptive Modulation and Coding: Combining DS/FFH with QAM enables adaptive modulation and coding techniques that can dynamically react to changing channel circumstances. This adaptability is crucial for maintaining peak performance in contexts where signal quality varies owing to fading.

1.7 Limitations of the Study

There are several modulation techniques available to improve the capacity and performance of high data rates. However, this thesis only looked at 16-QAM, 32-QAM, 64-QAM, and 128-QAM. Higher order modulation techniques, such as 256-QAM and 1024-QAM, may be necessary to improve system performance.

1.8 Organization of the Thesis

This thesis is divided into five chapters, which are discussed sequentially. The first chapter addresses the introduction sections, which comprise the background, problem statement, objectives, specific objectives, the study's importance, scope, and constraints. The second chapter contains a review of the literature and pertinent publications that explain the hybrid spread spectrum system. Chapter 3 explains the study's approach, which includes modelling and simulating DS/FFHSS system, DSSS system, and FFHSS system with various higher digital modulation techniques and MATLAB/Simulink software. Chapter 4 examines the simulation results and analysis of the hybrid spread spectrum system. Finally, the thesis' conclusion and recommendations are discussed.

CHAPTER TWO

2 LITERATURE REVIEW

2.1 Introduction

Any distributed sensing or information transmission system requires reliable, secure, and cost-effective communications. Aside from its usage in commercial applications, spread spectrum techniques have attracted a lot of interest in military communications in recent years. Although direct-sequence or frequency-hopping commercial off-the-shelf equipment is becoming available for the two lower-frequency ISM bands (915 MHz, 2.45 GHz), it is neither small nor inexpensive. Spread-spectrum systems can be used in a variety of different (military) bands to achieve high data rates while retaining high link integrity (i.e., low error rates) in the presence of severe multipath effects and interfering signals. Furthermore, spread-spectrum systems offer the flexibility of immediate (domestic) license-free operation in four distinct frequency bands (ANUSHA, 2022). New options, such as Wi-Fi local, digital cellular radios, and wide area networks has necessitated research into how to optimally use spread-spectrum systems in these settings. Additional needs include good wireless signal security, particularly for military applications, for which HSS is well-suited (Olama et al., 2011).

2.1.1 Direct Sequence Spread Spectrum (DS-SS)

Due to its high data rate and ease of implementation, Distributed Spread Spectrum is most commonly employed. When the sending and receiving systems are on different wide frequency bands, they can communicate data using the DSSS method. The gadget can send more data at a faster rate because to this wide channel. The signal processing stages on the DSSS system's transmitter and receiver are depicted in Figure 2.1. The way DSSS operates is that the carrier signal modulates the data signal, which is then dispersed using a pseudorandom signal (a spreading signal) whose frequency is higher than the bitrate (or frequency of the data signal). The spreading signal on the transmitter and the carrier signal are multiplied to create the dispreading signal in the receiver. , turning the transmitter's encoding process around. The final step on the receiver is filtering, which removes unwanted signals while preserving the data signal (Bawahab et al., 2018).

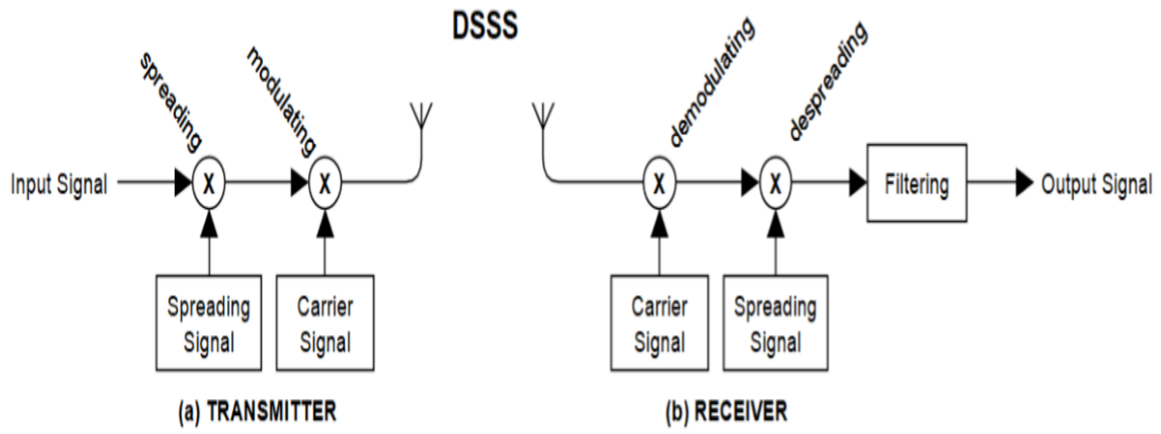

Figure 2-1 Block diagram of DSSS system (Alatabani et al., 2015)

2.1.2 Frequency Hopped Spread Spectrum

The spreading signal's frequency in FHSS will continuously fluctuate or hop at predefined intervals. Based on the spreading frequency series, the transmitter chooses the frequency to be used. The block diagram of the FHSS system's transmitter and receiver is displayed in Figure 2.2. Figure 2.1 highlights the primary distinction between FHSS and DSSS systems. In an FHSS system, the carrier signal modulates the data signal first, and then a spreading signal with a variable frequency is used to spread it out. Only system users are aware of the frequency of a spreading signal, which is chosen from a pre-set range of frequencies. As a result, it is challenging to impede communication if the propagating signal's utilized frequency is unclear.

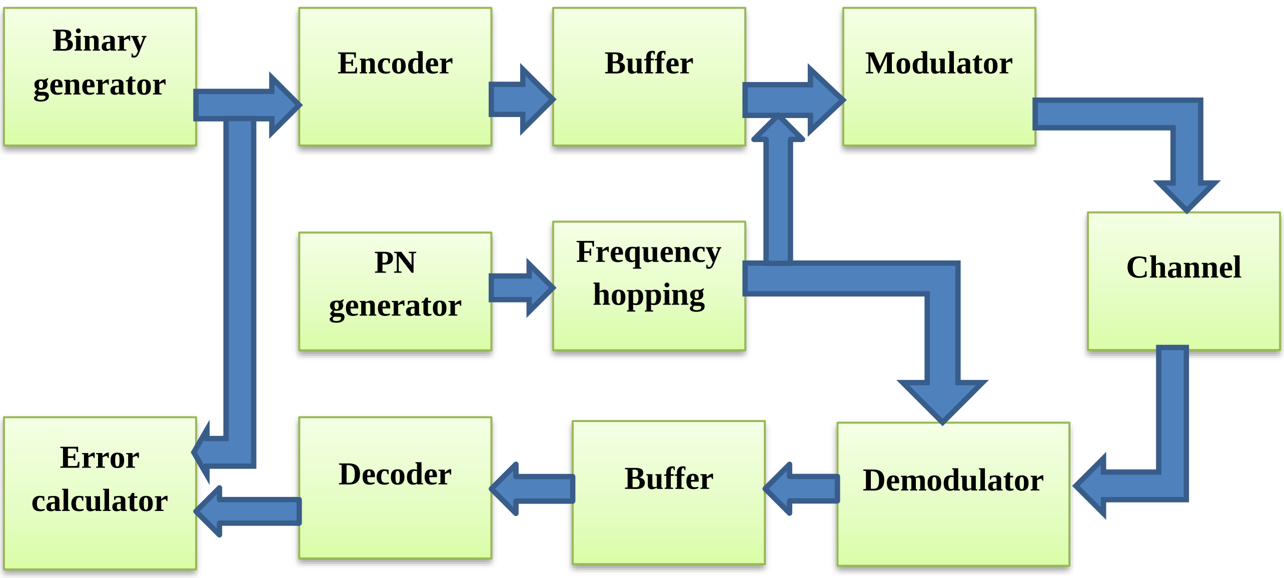

Figure 2-2 Block diagram of FHSS (Zheng et al., 2020)

The baseband signal and the carrier frequency which is produced by the frequency hopping block are mixed in the modulator. Because the PN-sequence generator controls it, the carrier frequency produced by this will be unpredictable. The sum of these two, which is distributed across the whole frequency range, will be the modulated output. The spread spectrum signal is demodulated at the receiver to recover the coded signal. The demodulator needs the same sequence that was used at the transmitting end in order to accomplish this. As a result, the random sequence pattern generators on the transmitter and receiving sides run simultaneously. Following that, the binary information sequence is returned to the receiver's decoder. Both the original input data and the received data are provided to error calculation block to determine the channel's error rate, which is then shown using BER display (Engineering, 2014).

2.1.3 Hybrid Spread Spectrum DS/FH

The direct-spread/frequency-hopping spread spectrum system is created by combining carrier frequency hopping with a direct-sequence spread spectrum system, and its basic operation mechanism is direct-sequence spread spectrum. Thus, system synchronization relies on direct sequence synchronization (Olama et al., 2015). The following is the basic principle of DS/FH hybrid spread spectrum technology, as shown in Figure 2.3.

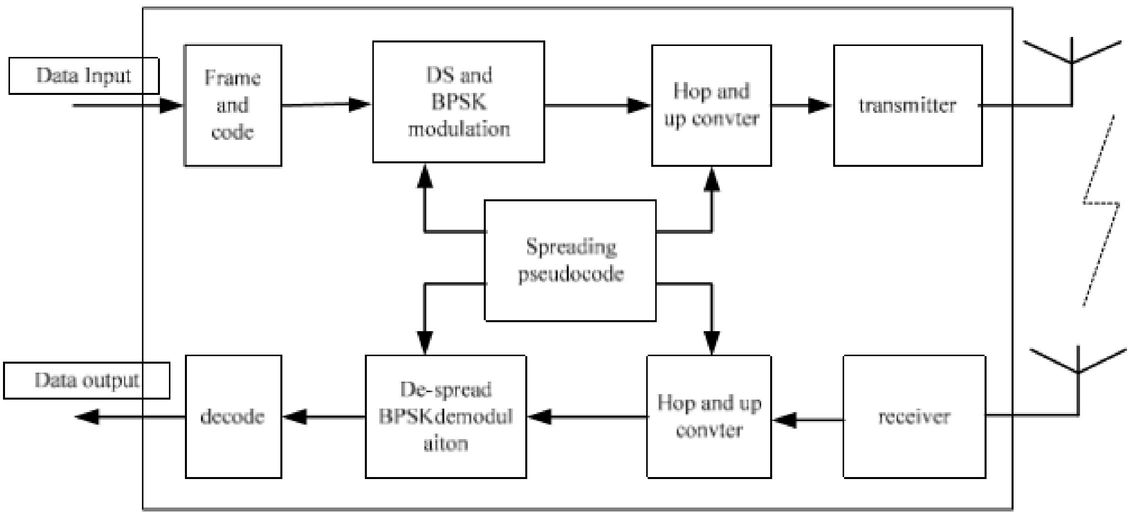

Figure 2-3 Block diagram of DS/FFH system (Lei et al., 2018)

2.1.4 M-ary Quadrature Amplitude Modulation

QAM is a cool that lets you send multiple symbols all at once by putting them together in one symbol. Using single carrier M-ary Quadrature Amplitude modulation has some great benefits like making it easier to assign wavelengths, saving power, being more compact, and allowing real-time implementation. You can use single or multiple in phase quadrature modulators to change a single narrow line width cavity laser into an optical M-ary quadrature signal (Sadinov, 2017).

To get more bits in each symbol, different levels of modulation change the original signal's amplitude and phase. Quadrature Amplitude Modulation (QAM) has two amplitudes that are out-of-phase. 4QAM, 16-QAM, 8-QAM, 64-QAM, 256-QAM, and 1024-QAM give two, three, four, six, eight and ten bits for every symbol (Engineering, 2014).

In order to obtain the final result, the complex symbol gets sent out and split at the receiver using a Quadrature Amplitude Modulation (QAM). According to Shannon's law (it decides the highest possible bit rate that can go through a channel with limited bandwidth despite noise), multi-level optical modulation systems are really good at using the spectrum efficiently even though they're not super tolerant to errors (Luo, Zhang, Ke, Wang, Bu, & An, 2020).

2.1.5 Rayleigh Fading Channels

It is communication channel that has a fading envelope in the shape of a Rayleigh Probability Density Function. It's basically a statistical model that shows us how the environment affects radio signals from wireless devices (Biglieri et al., 1998). In Rayleigh fading channels, the signal's strength fades following the Rayleigh distribution. This happens when there's no clear path between the sender and receiver, no dominant line-of-sight (Journal, n.d.). Rayleigh fading is all about describing how the environment impacts radio signals. It comes into play when there's no direct LOS between the sender and receiver. The signal bounces around, gets diffracted, scattered - creating different paths with varying phase and amplitude (Raju & Reddy, 2016).

2.1.5.1 Key Characteristics of Rayleigh Fading:

1. **Multipath Propagation**: In environments such as urban areas or inside buildings, the transmitted signal encounters numerous obstacles and reflects off surfaces, resulting in multiple copies of the signal arriving at the receiver at slightly different times and phases.

2. **Amplitude Distribution**: The amplitude of the received signal envelope follows a Rayleigh distribution. This is because the received signal is the sum of a large number of scattered signals, and by the central limit theorem, their envelope will follow a Rayleigh distribution.
3. **No Line-of-Sight (NLOS)**: Rayleigh fading assumes there is no direct path between the transmitter and receiver. The received signal is purely due to the sum of the multipath components.

2.1.5.2 Impact on Communication Systems

- **Inter-Symbol Interference (ISI):** Due to multipath propagation, different signal components can arrive at the receiver at different times, causing ISI.
- **Diversity Techniques:** To mitigate Rayleigh fading, diversity techniques such as time, frequency, and spatial diversity are employed. These techniques help in averaging out the deep fades by combining multiple independently faded signals.

2.1.5.3 Applications

- **Cellular Networks:** Rayleigh fading models are extensively used to design and evaluate the performance of cellular networks, especially in urban environments where LOS components are typically blocked.
- **Wireless LANs and MANETs:** These models help in understanding and improving the performance of wireless LANs and mobile ad hoc networks (MANETs) in dynamic and complex propagation environments.

2.2 Related Works

This paper offers the benefits of wideband spread spectrum modulation techniques over narrow band communications and examined a study of such methods with application to secure communications. The two Spread Spectrum methods that are primarily highlighted are FHSS and DSSS. These techniques make for a very safe manner of transmitting data by effectively reducing the power spectrum density of the sent signal. For the aforementioned application, where real-time geographic locations were taken into consideration, both approaches were simulated and analysed using Matlab (2019 International Conference on Intelligent Computing and Control Systems (ICCS)., n.d.).

(Kaittan & Mohammed, 2021).This journal uses the gold sequence as an example because it is thought to be more complex and better for information security than other code sequences (such as pseudo-noise (PN) sequence, barker code, hadamard code, and others).

As a result, it is harder to detect the information sent and can be used for code-division multiple access. Create and apply challenging code to safeguard data in the communication system used here by utilizing MATLAB to transmit a color photo and binary data to ensure that the system is operating correctly with few errors and provides superior information security compared to the other code that is utilized in the spread spectrum direct sequence.

(Zhang, 2021).This work reviews the effects of Direct Sequence spread-spectrum (DSSS), which is based on π/4-DPSK modulation and demodulation technology. The system performance was examined by simulation and comparison. A Rayleigh fading channel is used to transport data from four users in order to simulate 5G communication scenarios. Comparisons of the bit-error rate (BER) and signal to noise ratio (SNR) for both the original signals at the transmitter and the recovered signals at the receiver are used to express the system's performances. The contrast findings show the system's capacity to prevent multi-user interference.

(Ma et al., 2018).This work presents the Simulink simulation paradigm and simulates the DS/HFSK spread spectrum system. According to Ma et al. (2018), the ant correlation interference system outperforms both the pure frequency hopping and direct spread systems.

(Kemdirim Agubor et al., 2021). This literature provides an overview of spread spectrum technology and how it can be used to provide secure digital communication. It's super important in this tech world. We want to make it easy everyone to understand, So, we used simple math and drawings to explain things. Spread spectrum is really secure and used in lots of places, like mobile phones using CDMA. We figured out how to design CDMA systems so they can communicate safely without any interruptions. It's all about code identification and autocorrelation, keeping each user safe from interference.

(Bawahab et al., 2018). This article is all about comparing Direct Sequence Spread Spectrum (DSSS) and Frequency Hopping Spread Spectrum (FHSS) systems. We're looking at how systems handle wideband interference. This interference is kind of like what DSSS and FHSS systems send out. The Bit Error Ratio (BER) helps us see how well these systems are doing. We use simulations and math to figure out which system is better. And guess what? More spreading frequency can actually lower the error rate in some cases. Our research shows that the FHSS system is doing better than the DSSS system.

(Killough et al., n.d.).Here's the scoop on what Oak Ridge National Laboratory has been to. They're working on creating a hardware model of a combo DS/FFH spread-spectrum radio gizmo using just one fancy Field Programmable Gate Array. By cramming everything into that single FPGA, the different parts can chit-chat effortlessly, keeping things in sync like a boss. They've got some test results showing off how well this hybrid DS/FFH system can pick up signals and dodge interference, even when tossing around different settings.

(Kim et al., 2021). in this paper, the authors talk about this easy, dependable, and fast serial time acquisition trick for hybrid direct-sequence and quick frequency hopping packet radio systems. The new method works with both frequency (frequency hopping) and pseudo noise code (direct sequencing). The researcher checks how well this new method performs and proves its accuracy using simulations. When compared to the usual serial search method, this new algorithm is much quicker at getting results but still just as good.

(Ahmadian Yazdi et al., 2021). In this paper, the authors have a really cool way to help HSS systems. They use an adaptive CFAR threshold. This means they find the right threshold by looking at stats and nearby energy levels. They figure out the fastest way to acquire signals if you know how likely you are to them, how likely you are to get a false alarm, and your system's settings. The researchers also talk about finding safe frequency-hopping patterns in their article. They show that this new technique can speed up acquisition time by more than 45% and keep things running smoothly even in unusual without needing new hardware.

(Park et al., 2020). This paper showed that how can make it super to steal information from frequency-hopping transmissions by combining different modulation methods. It also looks at how tough it is to intercept data based on how complicated the interceptor's system is.To prove that blending modulation techniques can beef up security in communication, let's think about mixing BPSK and QPSK modulations randomly in frequency hopping setups. We'll compare this with regular frequency hopping systems that only use BPSK or QPSK schemes. We'll do this by out simple estimates for how tricky it is for an interceptor to crack the code.

Table 2-1 A summary of some related works

Authors	Year	Title	Contribution/ Concept Covered.	Gaps
J. Adv. Res	2020	Analysis, Design and Testing of Frequency Hopping Spread Spectrum Transceiver Model Using MATLAB – Simulink	• This article describes the design and implementation of a Frequency Hopping Spread Spectrum (FHSS) transceiver model in MATLAB-Simulink. • The FHSS transceiver enables secure connection within the communication domain.	The document does not go into detail about the performance gain or how it compares to existing systems.
F. G. A. K. Bawahab, E. Kurniawan, E. Yuniarti, B. Widiyatmoko, and D. Bayuwati	2019	Performance evaluation and mathematical analysis of direct sequence and frequency hopping spread spectrum systems under wideband interference	This article evaluates and compares the performance of Direct Sequence Spread Spectrum (DSSS) and Frequency Hopping Spread Spectrum (FHSS) systems.	The article lacks a comparison between the DS/FHSS system and QAM modulation.
Park et al	2020	Interceptor complexity analysis for mixed BPSK–QPSK modulated frequency hopping spread spectrum systems	Mixing modulation techniques makes it difficult to extract information from frequency hopping signals. The interceptor's computational complexity is used as a parameter to determine the difficulty of interception.	QAM modulation did not provided

CHAPTER THREE

MATERIALS AND METHODS

3 Introduction

In this thesis, we're taking a look at a bunch of different papers and articles from publications like IEEE, Springer, and Elsevier, along with some books on hybrid spread spectrum. We're checking out how the system is modelled, simulated, and analyzed using the technique mentioned in section 3.3 based on the reviewed articles and the problem statement.

3.1 Materials

For all the simulations in this thesis, we used MATLAB/R2018b software tools. MATLAB stands for Matrix LABoratory, which is a cool language meant for technical computation. This software includes technical boxes and Simulink to help with writing algorithms, data analysis, and creating models and applications.

3.2 Simulation Methodology

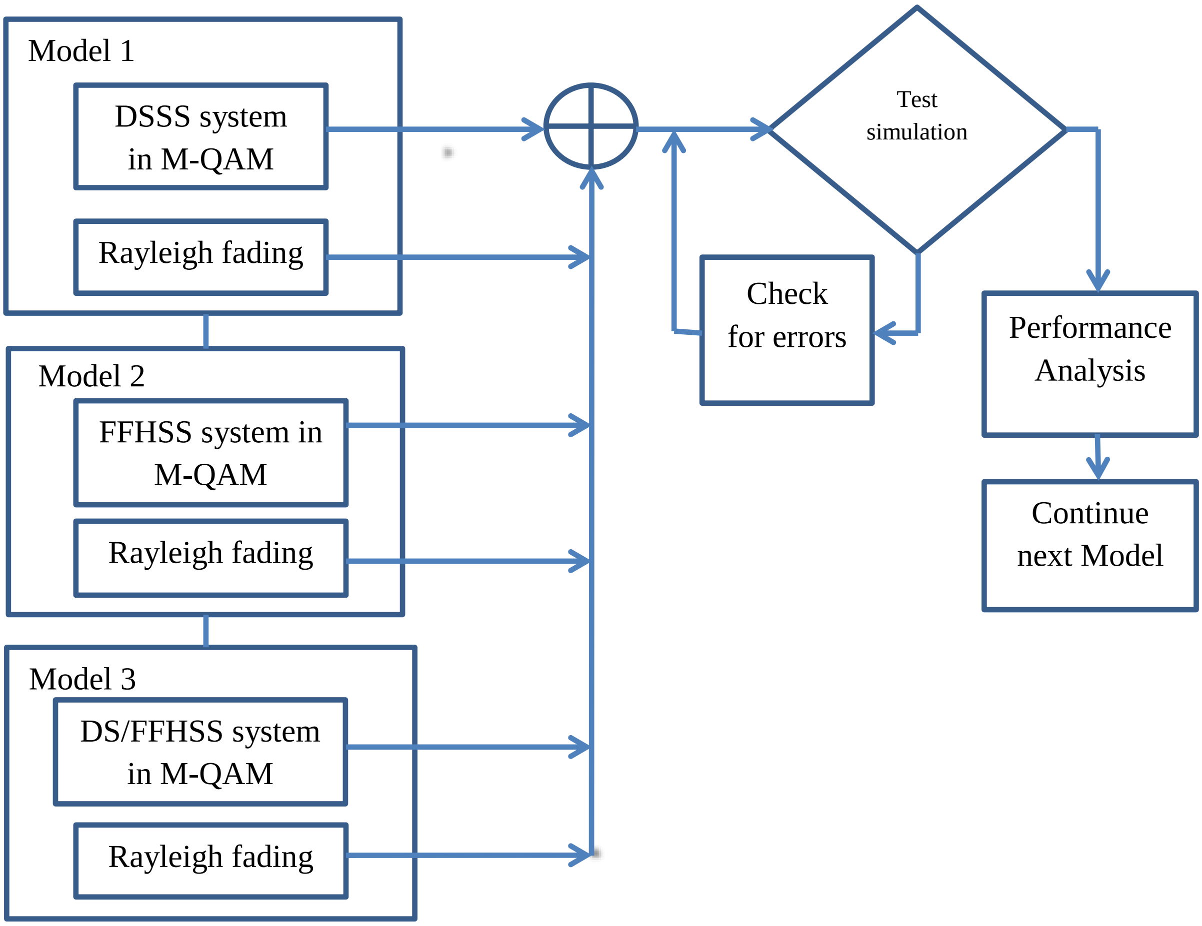

Figure 3-1 Simulation flowchart

3.3 Mathematical Model

3.3.1 PN Spreading Codes

Linear Feedback Shift Registers (LFSRs) are most commonly used to generate PN sequences. An LFSR consists of:

Shift Registers: A succession of flip-flops grouped sequentially.

Feedback Function: A linear function that calculates the register's next state depending on its current state.

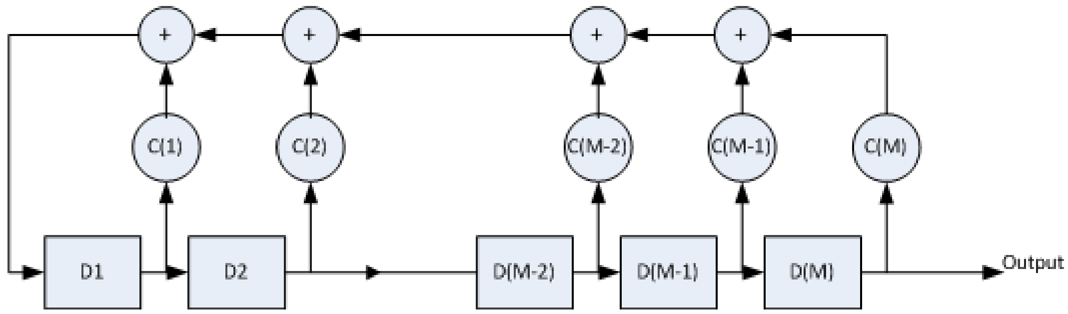

Figure 3-2 PN sequence generation

Mathematical Model

1. **State Vector**: Let the state of the LFSR at time tt be represented by a vector **s**(t):

   $$s(t) = [S_0(t), S_1(t), \ldots, S_{n-1}(t)] \tag{3.1}$$

2. **Next State**: The next state $S(t+1)$ is determined by altering the current state and using the feedback function:

   $$S_0(t+1) = S_{n-1}(t) \tag{3.2}$$

   $$S_1(t+1) = S_{i-1}(t) \;\; for\; i = 1,2,3 \ldots, n-1 \tag{3.3}$$

   $$S_{n-1}(t+1) = \sum_{i=0}^{n-1} C_i\, S_i(t)\; mod2 \tag{3.4}$$

3. **PN Sequence Output**: The output sequence p(t) is normally taken from one of the states, usually the last state.

   $$p(t) = S_{n-t}(t) \tag{3.5}$$

3.3.2 Rayleigh Fading Channel

The Rayleigh fading channel is a statistical model that simulates the influence of a propagation environment on a radio transmission. It is especially useful in situations where there are numerous scatters and no dominant direct path, resulting in the signal's amplitude being modeled as a Rayleigh-distributed random variable.

The Rayleigh fading channel can be expressed mathematically as follows:

$$h(t) = \sum_{n=1}^{N} \alpha_n\, e^{j(2\pi f_{d,n}\, t + \theta_n)} \tag{3.6}$$

where

$h(t)$ is the complex channel gain at time t.

N is the number of multipath components.

α_n is the amplitude of the n-th multipath component, often modelled as Rayleigh distributed.

$f_{d,n}\, t$ is the Doppler shift corresponding to the n-th multipath component.

θ_n is the phase shift of the n-th multipath component, uniformly distributed between 0 and 2π.

In a simplified model, assuming equal amplitude and a homogeneous distribution of phase changes, the channel can be characterized as:

$$\frac{1}{\sqrt{N}}\sum_{n=1}^{N} e^{j(2\pi f_{d,n}t+\theta_n)} \tag{3.7}$$

This model assumes that the multipath components' amplitudes are equal and normalized by one to ensure that the overall power is normalized.

Rayleigh fading is mostly induced by multipath reception. When there is no dominant LOS path, a faded signal is statistically modeled using the Rayleigh distribution. The probability density function (pdf) of the received signal envelope with Rayleigh distribution is as follows:

$$P(\alpha) = \frac{\alpha}{\sigma^2}\exp\left(-\frac{\alpha^2}{2\sigma^2}\right), \quad \alpha \geq 0 \tag{3.8}$$

3.3.3 M-QAM Modulation

M-QAM is commonly utilized in modern communication systems due to its great spectral efficiency. An M-QAM signal can be expressed as:

$$s(t) = I(t)\cos(2\pi f_c t) - Q(t)\sin(2\pi f_c t) \tag{3.9}$$

where

$I(t)$ and $Q(t)$are the in-phase and quadrature components, respectively.

f_c is the carrier frequency.

The in-phase and quadrature components are picked from a defined amplitude range.

3.3.4 BER for QAM

The error probability of the QAM symbol is derived from the error probability of each branch (M-PAM) and is provided by:

$$p_s = 1 - (1 - \frac{2(\sqrt{M}-1)}{\sqrt{M}} Q\left(\sqrt{\frac{3\overline{\gamma}_s}{M-1}}\right))^2 \tag{3.10}$$

The approximations or exact numbers for SER take the following form:

$$P_s \approx \propto_M Q(\sqrt{\beta_{M\gamma_s}}) \tag{3.11}$$

The values of αM and βM vary depending on the approximation and modulation types. The αM and βM values are summarized for common modulations. We can also see that the bit error probability is the same as for SER. It is:

$$P_b(\gamma_b) \approx \bar{\alpha}_M Q(\sqrt{\beta_{M\gamma_b}}) \quad (3.12)$$

where

$\alpha_M = \alpha_M / \log_2 M$ and $\beta_M = \beta_M / \log_2 M$.

Note: γ_s= Es/N0, γ_b= Eb/N0, γ_b= γs $\log_2$ M and $P_b \approx P_s \log_2$ M.

3.3.5 DSSS

The following equation represents the mathematical model of the transmitted signal from the DSSS transmitter.

$$T_d(t) = d(t)p(t)c(t) \quad (3.13)$$

where

$T_d(t)$ is transmitted signal of DSSS system

$d(t)$ is data signal

$p(t)$ is function of the spreading signal

$c(t)$ is function of the carrier signal. The signals d(t), p(t), and c(t) are formulated respectively as follow:

$$d(t) = \sum_{-\infty}^{\infty} d_i \varphi(t - iT_d) \quad (3.14)$$

$$p(t) = \sum_{-\infty}^{\infty} p_i \varphi(t - iT_s) \quad (3.15)$$

$$c(t) = Acos(2\pi f_s t + \theta) \quad (3.16)$$

where

d_i is data series

T_d is data signal period

p_i is pseudo noise series

T_s is spreading signal period

A is carrier signal amplitude

θ is carrier signal phase

f_s is spreading signal frequency

$\varphi\ (t - iT)$ is the delayed impulse unit function.

The delayed impulse unit function $\varphi\ (t - iT)$ is simply given by

$$\varphi(t - iT) = \begin{cases} 1;\ 0\ \le (t - iT) < T \\ 0;\ otherwise \end{cases} \quad (3.17)$$

3.3.6 FHSS

The mathematical equation for the transmitted signal of FHSS is as follows:

$$T_H(t) = d(t)c(t)p(t) \quad (3.18)$$

The data signal d(t) is similar to DSSS's data signal, but the carrier signal c(t) and spreading signal p(t) are distinct as they are formulated by:

$$c(t) = A\cos(2\pi f_d t + \theta) \quad (3.19)$$

$$p(t) = A\cos(2\pi t. h(t) + \theta) \quad (3.20)$$

where

$h(t)$ is data signal frequency

$h(t)$ is hopping frequency given by:

$$h(t) = \sum_{i=-\infty}^{\infty} h_i \varphi(t - iT_d) \quad (3.21)$$

3.3.7 DS/FFHSS

In a hybrid spread spectrum system that combines DS-SS and FH-SS, the transmitted signal is a mixture of the two signals. Mathematically, $S_{hybrid}(t)$ is the sum of the DS-SS and FH-SS signals:

$$\mathrm{S_{hybrid}(t) = T_D(t) + T_H(t)} \quad (3.22)$$

3.3.8 Q-Factor for QAM

The Q-factor, quality factor, is a metric for assessing the performance of a communication system. The Q-factor can be used to evaluate signal quality when using Quadrature Amplitude Modulation (QAM).

For QAM, the Q-factor can be defined using the signal-to-noise ratio (SNR). The relationship between the Q-factor and the BER depends on the modulation scheme and the noise characteristics of the system. However, a common formula for QAM systems, particularly for higher-order QAM, is:

$$Q = \frac{\sqrt{2.SNR}}{\sigma} \quad (3.23)$$

where

SNR is the signal-to-noise ratio.

σ is the standard deviation of the noise.

The Q-factor is often expressed in decibels (dB), given by:

$$Q_{dB} = 20log_{10}(Q) \quad (3.24)$$

3.3.9 Block Diagram of DS/FFHSS system

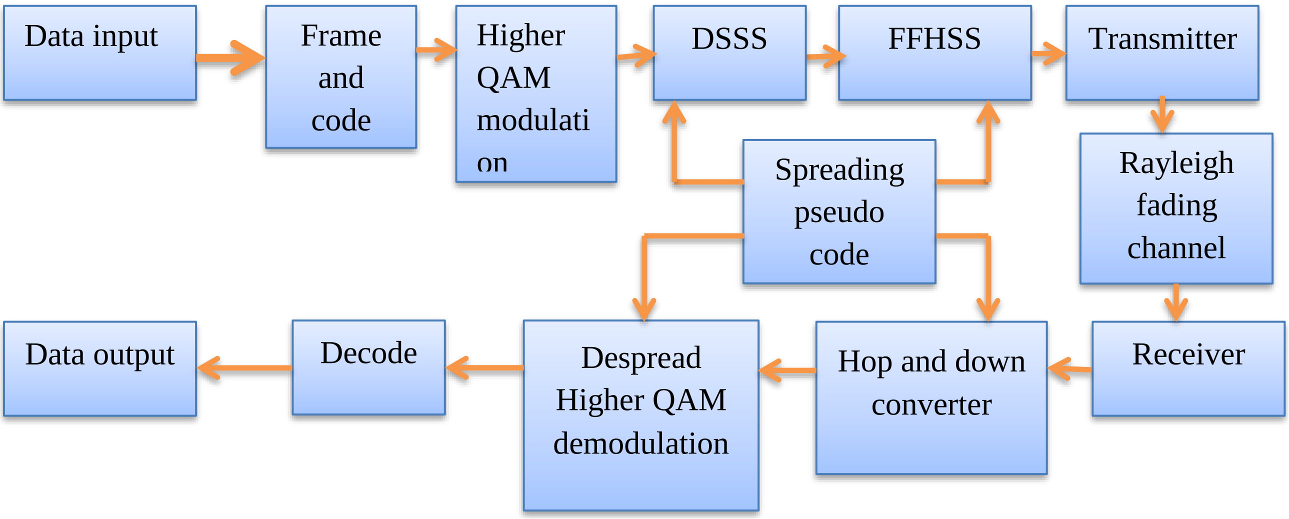

Figure 3-3 Block diagram of Hybrid DS/FFHSS System

3.3.10 Simulink Model of Direct Sequence Spread Spectrum System (DSSS)

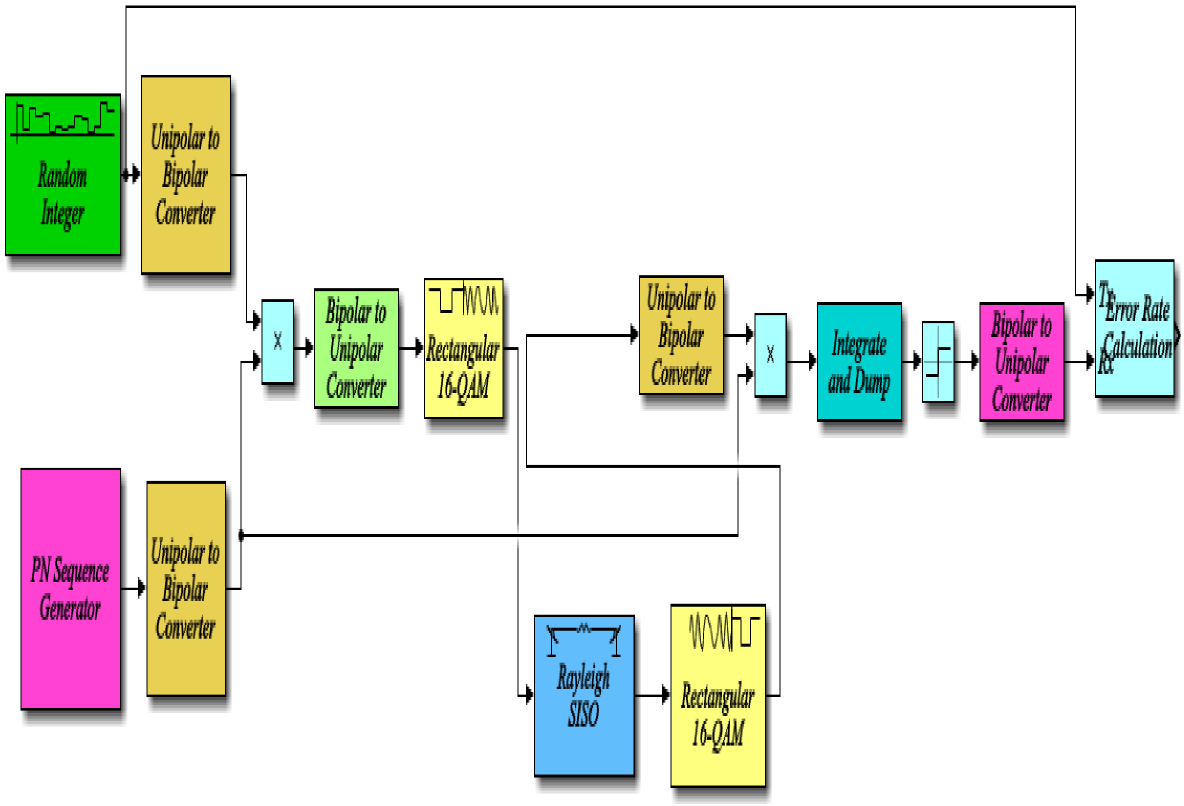

Figure 3-4 Simulink model block diagram of DS spread spectrum communication system

The data source is like a magic number maker from the talking machines. They have this thing called a communications block, which spits out random numbers, either a 0 or 1, really fast - like 1 Kb/sec fast, which they call Tb = 1msec. Inside this magical place are these generators that make sequences out of random binary values using some fancy machine called a linear-feedback shift register. Then, they grab all the info going at 1 kb/s and mix it up in a modul-2 adder alongside one of those sequences to make spreading data. This data then goes into a QAM modulator that changes the regular numbers into funny bipolar ones with twisty phases. The whole shebang gets sent out through this Rayleigh fading channel. If the sender picks the right code, the receiver can understand everything coming through once it's demodulated by the QAM demodulator.

3.3.11 Simulink Model of Frequency Hopping Spread Spectrum System (FHSS)

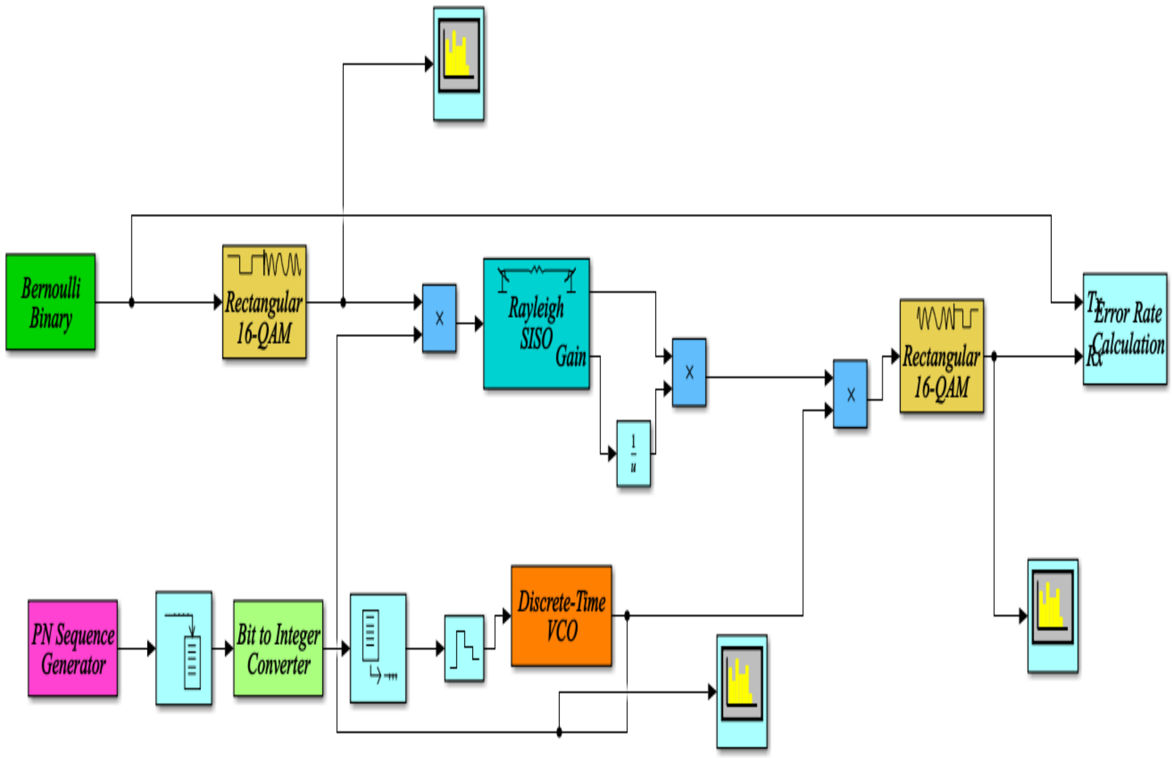

Figure 3-5 Simulink model block diagram of FH spread spectrum communication system

The Bernoulli binary generator generates binary values (ones and zeros) based on the Bernoulli equation. To make transmission easier, the binary generator's output is encoded with a cyclic encoder and converted to a frame of binary 1's and 0s. The binary values are modulated with QAM, which uses the carriers as a frequency hopping signal, then supplied via a Rayleigh fading channel. The transmitter's output is retrieved using an FFT scope.

3.3.12 Simulink Model of Hybrid spread spectrum system (DS/FFHSS)

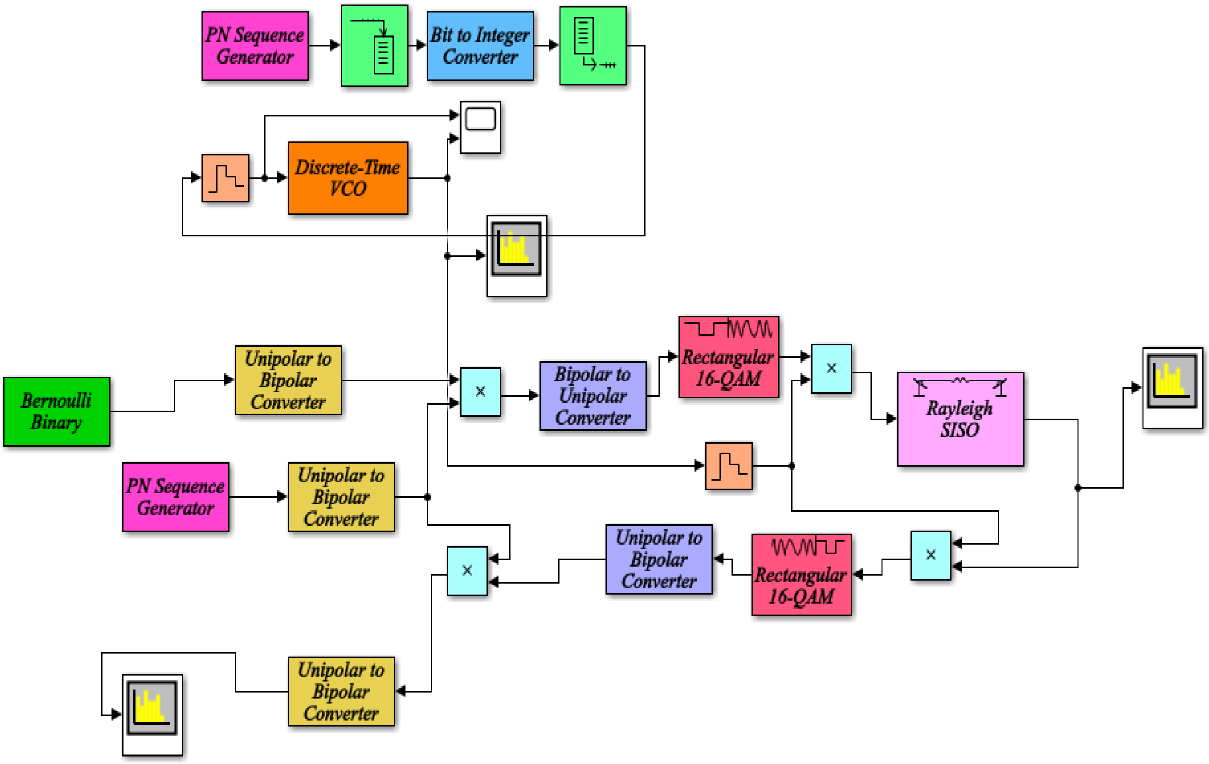

Figure 3-6 Simulink model block diagram of DS/FFHSS hybrid spread spectrum communication system

The simulation system's signal source is the Random integer generator, which produces a binary random signal. Spreading and dispersing: A PN sequence generator generates a 15-bit m-sequence to spread and disperse the source signal. Modulation and demodulation should be performed using separate QAM modulation modules. Following transmission over the channel, the spread spectrum wideband signal is modulated with varied QAM and demodulated using coherent demodulation. Channels: Rayleigh fading . The module allows for signal power and signal-to-noise ratio changes.

CHAPTER FOUR

4 RESULTS AND DISCUSSION

In this chapter, we will utilize MATLAB simulation to evaluate the performance of the DS/FFHSS with various higher modulation schemes (QAM-16, QAM-32, QAM-64, and QAM-128) in a Rayleigh fading channel. We will also compare DS/FFHSS performance to that of the DSSS and FHSS systems.

The performance metrics are:

1. Bit-Error Rate (BER)
2. Q factor
3. Signal power and
4. Signal to Noise Ratio (SNR)

The major parameters used for simulation in this thesis are provided below.

Table 4-1 Simulation parameters

Simulation Parameters	**Type and values**
Number of bits	$1.0752*1e^6$
Modulation type	QAM
Modulation order	16-QAM,32- QAM,64- QAM, and128- QAM
Range of SNR values in dB	0:2:20
spreading factor	16
Number of frequency hopps	10

4.1 Bit Error Rate (BER) Performance Analysis

4.1.1 Performance Analysis of BER Direct Sequence Spread Spectrum System Using Different Higher Modulation Scheme

BER for various SNRs in the simulation were calculated and finally analyzed the performance of the direct sequence spread spectrum system. Figure (4.1) shows the Bit Error Rate (BER) performance in the Rayleigh fading channel vs. the signal to noise ratio (Eb/No) for 8QAM-DSSS, 16QAM-DSSS, 32QAM-DSSS, 64QAM-DSSS, 128QAM-DSSS, and 256QAM-DSSS. The Eb/No ratio were increased as the BER value decreased. In contrast, as the order of the modulation scheme grows, the bit error rate increases.

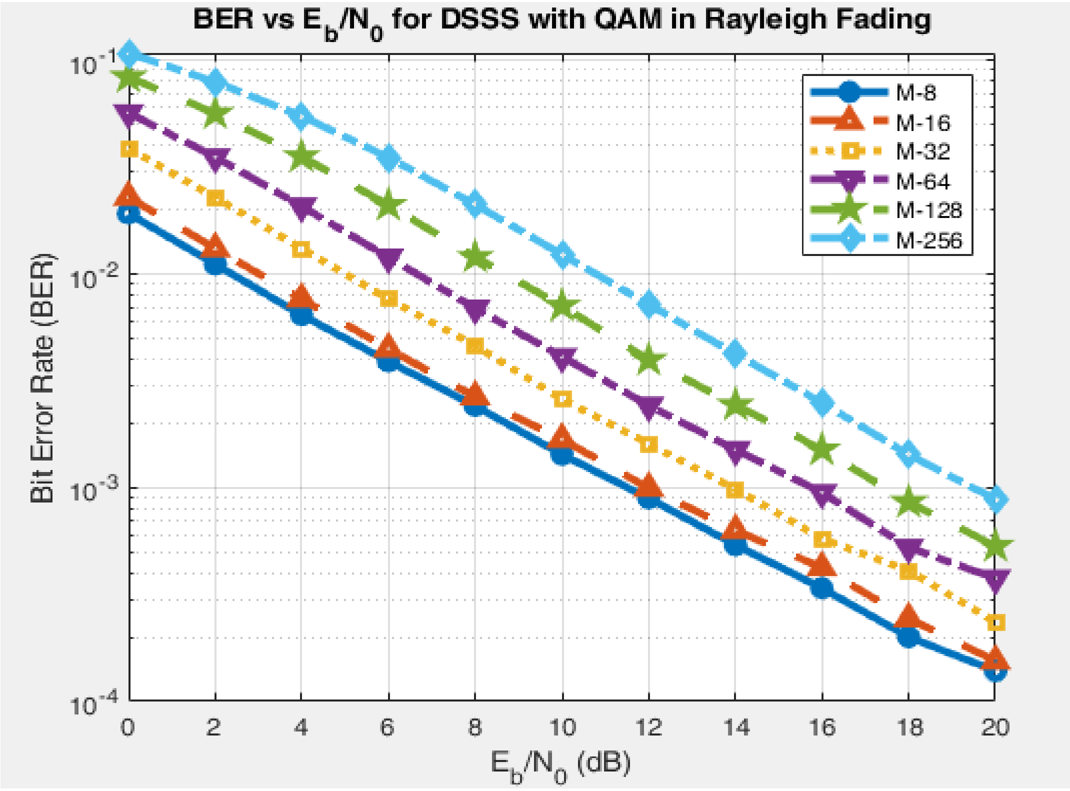

Figure 4-1 BER vs. Eb/No Performance Analysis of DSSS using different QAM modulation scheme

4.1.2 Performance Analysis of BER Frequency Hopping Spread Spectrum System Using Different Higher Modulation Scheme

BER for various SNRs in the simulation were calculated and finally analyzed the performance of the frequency hopping spread spectrum system. Figure (4.2) shows the Bit Error Rate (BER) performance in the Rayleigh fading channel vs. the signal to noise ratio (Eb/No) for 8QAM-FHSS, 16QAM-FHSS, 32QAM-FHSS, 64QAM-FHSS, 128QAM-FHSS, and 256QAM-FHSS.The Eb/No ratio grew as the BER value declined. In contrast, as the order of modulation scheme grows the BER increases.

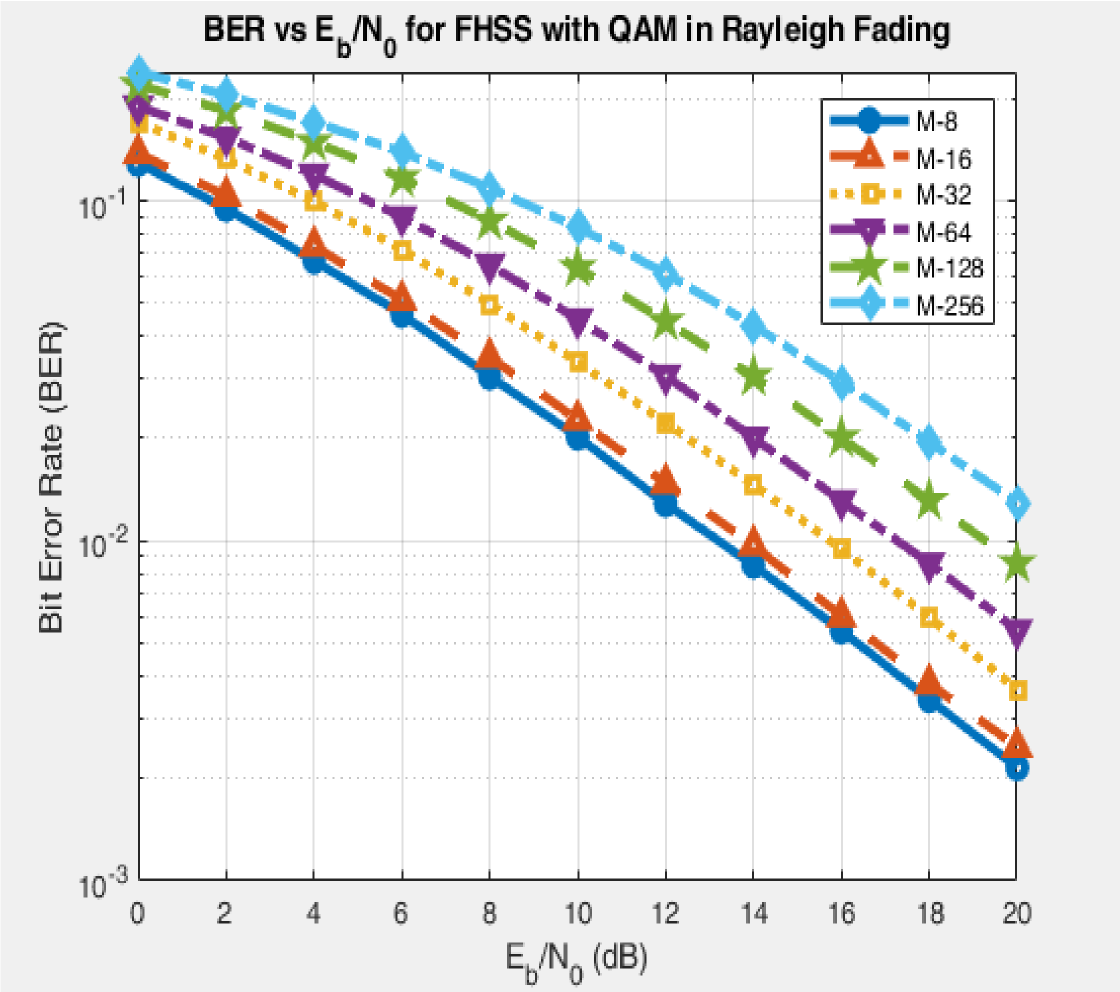

Figure 4-2 BER vs. Eb/No Performance Analysis of FHSS using different QAM modulation scheme

4.1.3 Performance Analysis of BER DS/FFHSS Using Different Higher Modulation Scheme

BER for various SNRs in the simulations were calculated and then evaluated the hybrid spread spectrum system's performance. Figure (4.3) shows the Bit Error Rate (Eb/No) performance in the Rayleigh fading channel vs. the signal to noise ratio (Eb/No) for 8QAM-DS/FFHSS, 16QAM-DS/FFHSS, 32QAM-DS/FFHSS, 64QAM-DS/FFHSS, 128QAM-DS/FFHSS, and 256QAM-DS/FFHSS.

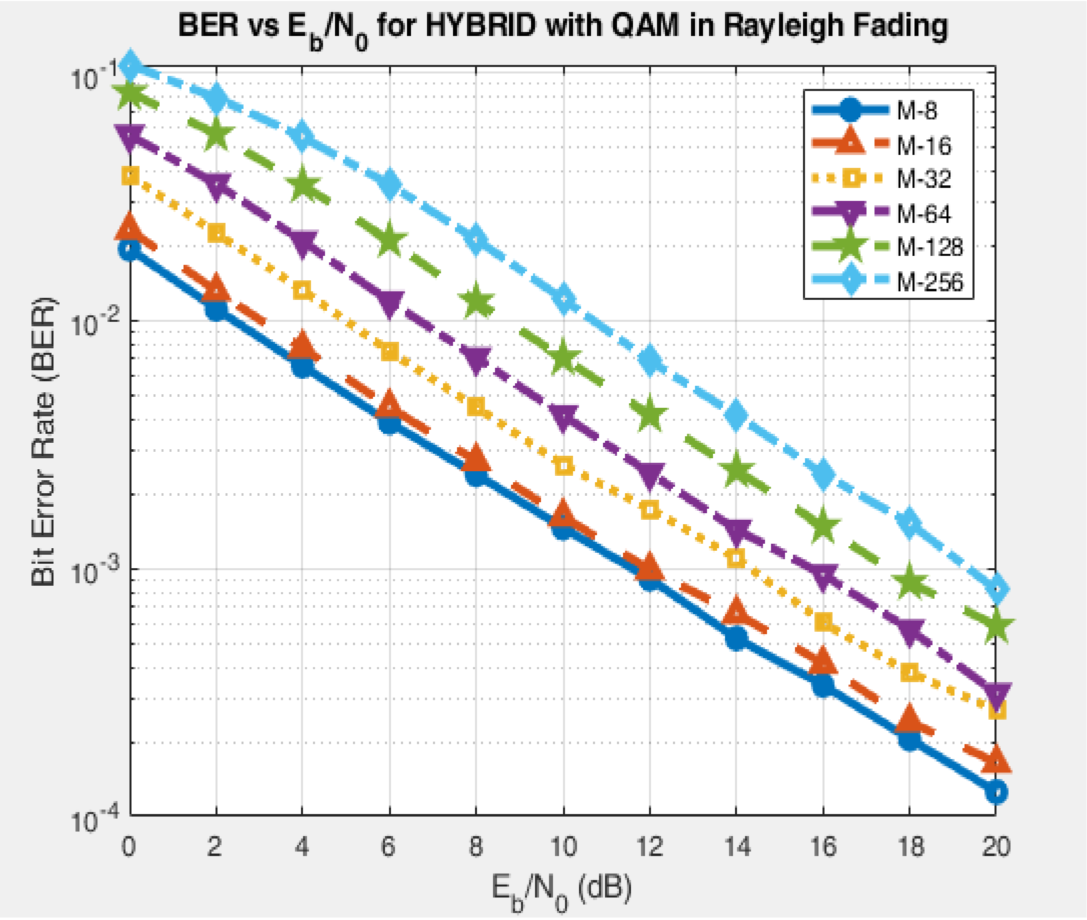

Figure 4-3 BER vs. E_b/N_o Performance Analysis of DS/FFHSS using different QAM modulation scheme

Figure 4.3 shows that the signal-to-noise ratio grew as the BER value decreased. In contrast, the bit error rate value grew as the modulation scheme order grew.

4.1.3.1 BER Comparison of DSSS, FHSS and DS/FFHSS Systems Using 16-QAM Modulation

This section compares the BER performance of three different spread spectrum techniques: DSSS, FHSS, and HYBRID. Figure (4.4) shows the Bit Error Rate (BER) performance of the 16QAM-DSSS, 16QAM-FHSS, and 16QAM-DS/FFHSS systems in the Rayleigh fading channel as a function of signal-to-noise ratio.

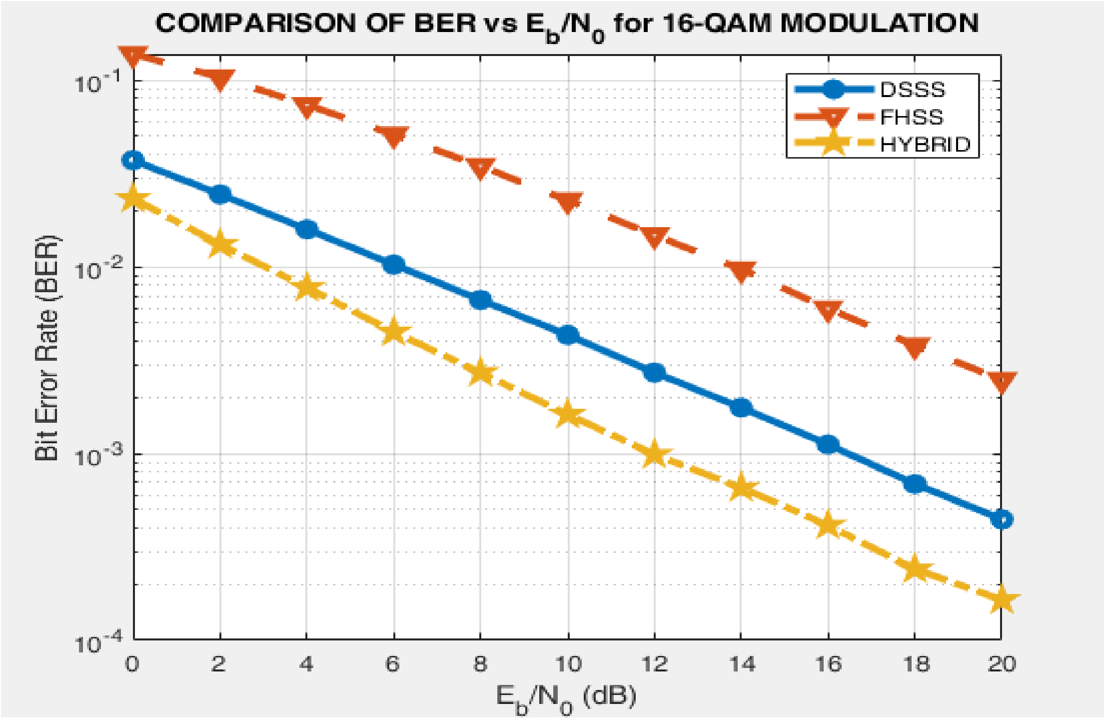

Figure 4-4 BER Comparison of DSSS, FHSS and DS/FFHSS Systems Using 16-QAM Modulation

4.1.3.2 BER Comparison of DSSS, FHSS and DS/FFHSS Systems Using 32-QAM Modulation

Figure (4.5) shows the Bit Error Rate (BER) performance of the 32QAM-DSSS, 32QAM-FHSS, and 32QAM-HSS systems in the Rayleigh fading channel as a function of signal to noise ratio (Eb/No).

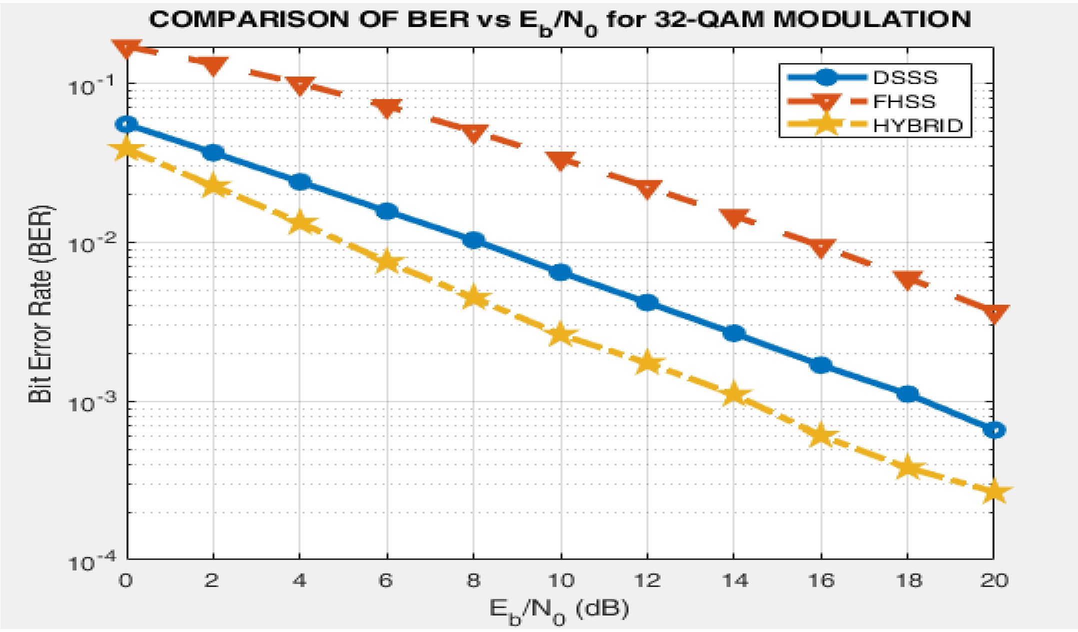

Figure 4-5 BER Comparison of DSSS, FHSS and DS/FFHSS Systems Using 32-QAM Modulation

4.1.3.3 BER Comparison of DSSS, FHSS and DS/FFHSS Systems Using 64-QAM Modulation

Figure (4.6) shows the Bit Error Rate (BER) performance of the 64QAM-DSSS, 64QAM-FHSS, and 64QAM-DS/FFHSS systems in the Rayleigh fading channel as a function of signal to noise ratio (Eb/No).

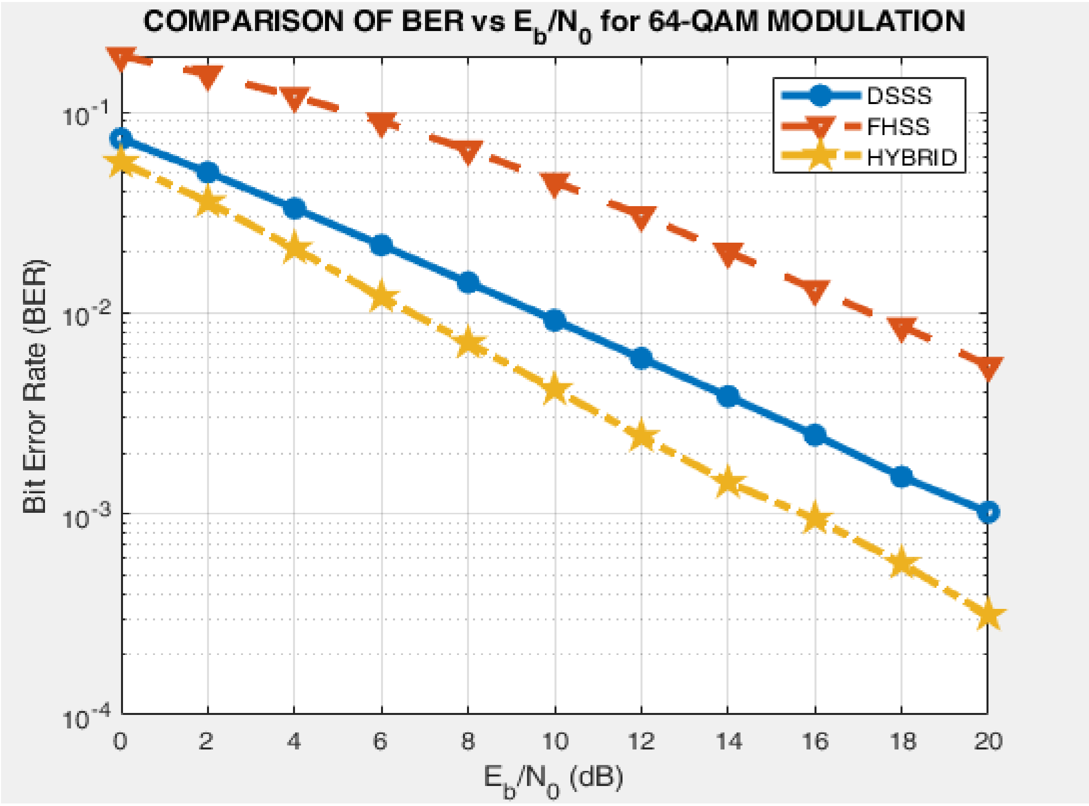

Figure 4-6 BER Comparison of DSSS, FHSS and DS/FFHSS Systems Using 64-QAM Modulation

4.1.3.4 BER Comparison of DSSS, FHSS and DS/FFHSS Systems Using 128-QAM Modulation

Figure (4.7) shows the Bit Error Rate (BER) performance of the 128QAM-DSSS, 128QAM-FHSS, and 128QAM-DS/FFHSS systems in the Rayleigh fading channel as a function of signal to noise ratio (Eb/No).

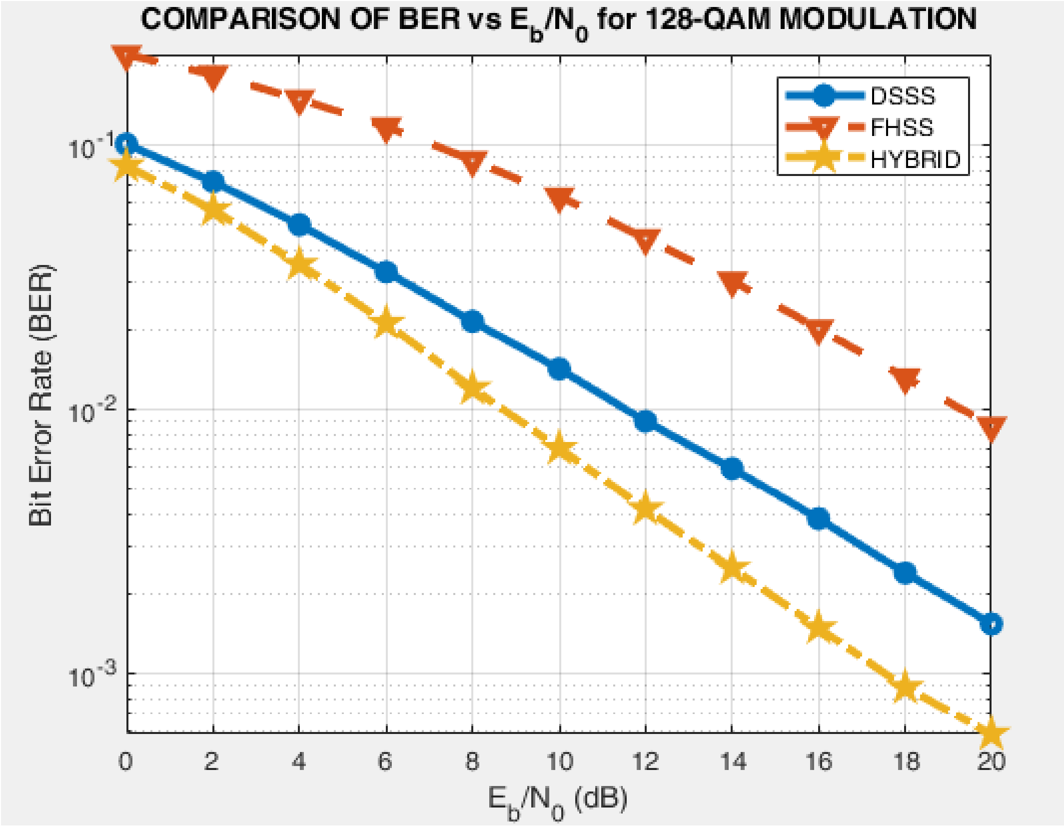

Figure 4-7 BER Comparison of DSSS, FHSS and DS/FFHSS Systems Using 128-QAM Modulation

Table 4-2 BER performance of DSS, DS/FFHSS and FHSS

QAM	DSSS	FHSS	DS/FFHSS
M=16	0.0096	0.0418	0.0050
M=32	0.0144	0.0558	0.0085
M=64	0.0197	0.0673	0.0129
M=128	0.0286	0.0852	0.0204

The figures and table show the three systems' BER performance in various QAM modulations. The DS/FFHSS spread-spectrum system outperformed the other two systems.

4.2 Signal to Noise Ratio (SNR) Performance Analysis

4.2.1 Performance Analysis of BER vs. SNR Direct Sequence Spread Spectrum System Using Different Higher Modulation Scheme

BER vs. SNR were simulated for various SNRs and then evaluated the performance of the direct sequence spread spectrum system. Figure (4.8) depicts the BER performance against signal to noise ratio (SNR) for 8QAM-DSSS, 16QAM-DSSS, 32QAM-DSSS, 64QAM-DSSS, 128QAM-DSSS, and 256QAM-DSSS in the Rayleigh fading channel.

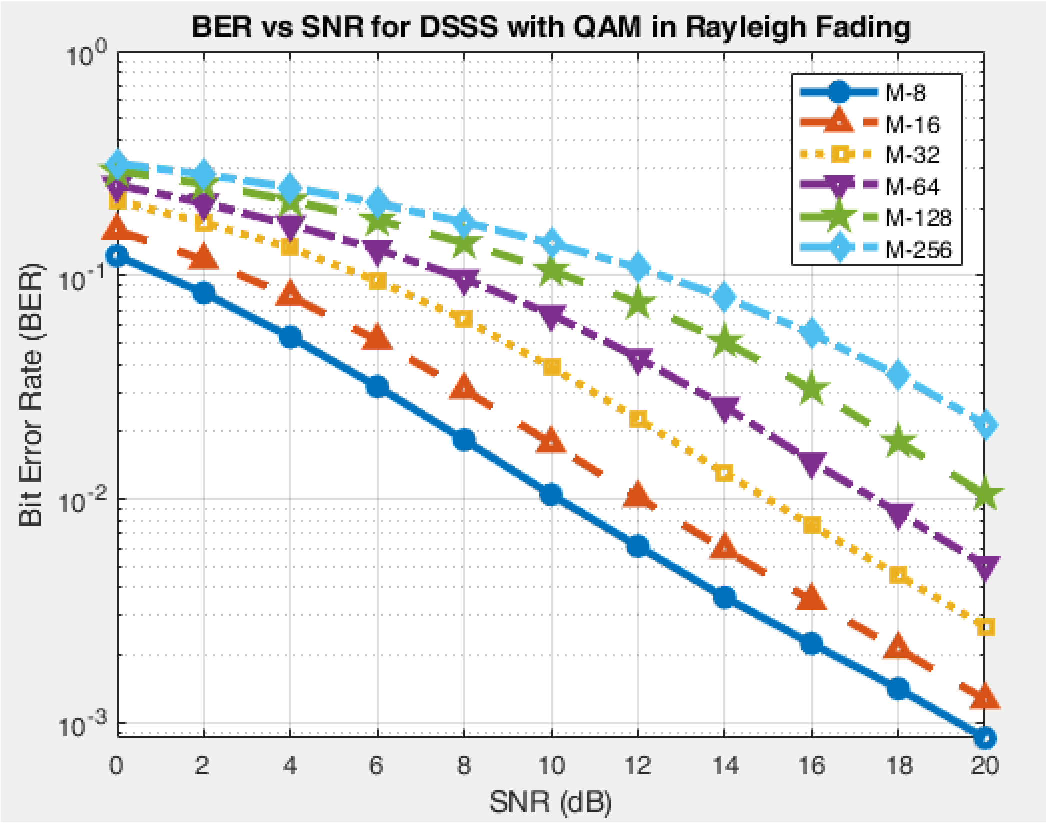

Figure 4-8 BER vs. SNR Performance Analysis of DSSS using different QAM modulation scheme

The error rate grows with the amount of bits in a symbol (M), from 8 to 256. The BER findings were minimized by employing a predetermined range of SNR values. All modulated signals passing through the Rayleigh fading channel behave the same way.

4.2.2 Performance Analysis of BER vs. SNR Frequency Hopping Spread Spectrum System Using Different Higher Modulation Scheme

BER vs. SNR were simulated for various SNRs were simulated and analyzed to determine the performance of a frequency hopping spread spectrum system. Figure (4.9) depicts the Q-factor performance against signal to noise ratio (SNR) for 8QAM-FHSS, 16QAM-FHSS, 32QAM-FHSS, 64QAM-FHSS, 128QAM-FHSS, and 256QAM-FHSS in the Rayleigh fading channel.

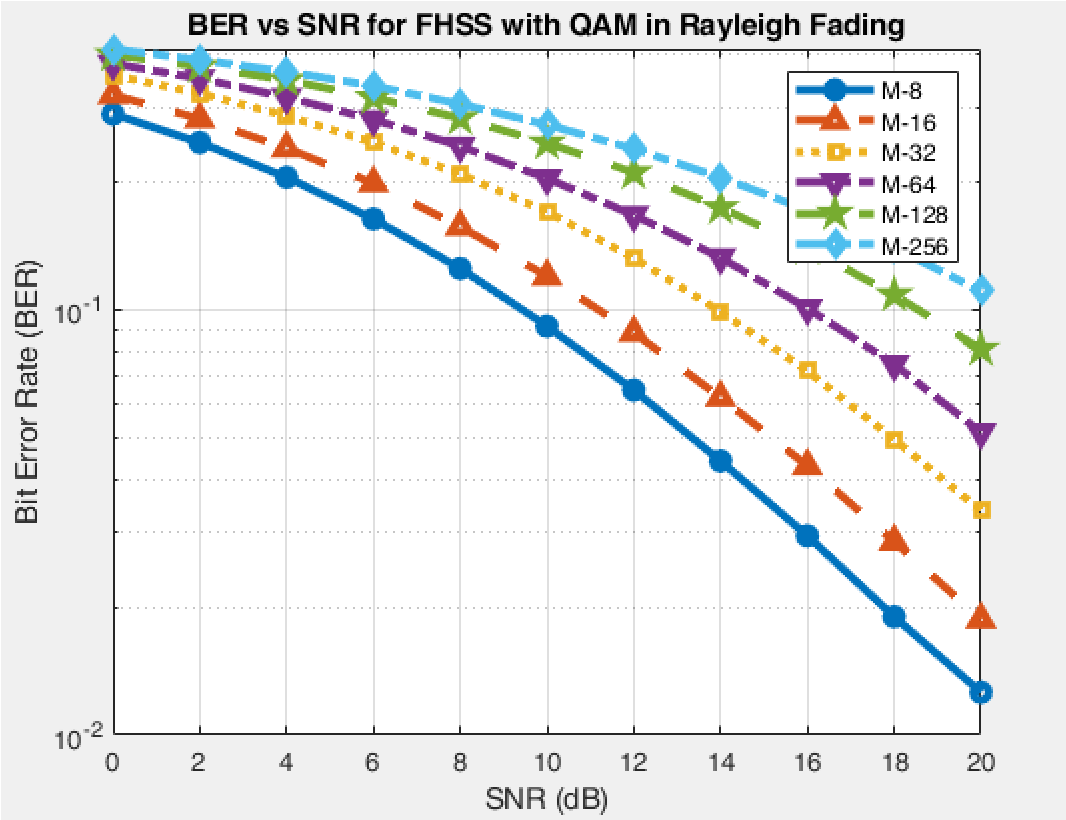

Figure 4-9 BER vs. SNR Performance Analysis of FHSS using different QAM modulation scheme

The error rate grows with the amount of bits in a symbol (M), from 8 to 256. The BER findings were minimized by employing a predetermined range of SNR values. All modulated signals passing through the Rayleigh fading channel behave the same way.

4.2.3 Performance Analysis of BER vs. SNR DS/FFHSS Using Different Higher Modulation Scheme

BER vs. SNR were simulated for various SNRs and then evaluated the performance of the hybrid spread spectrum system. Figure (4.10) depicts the Bit Error Rate (BER) performance versus signal to noise ratio (SNR) of 8QAM-DS/FFHSS, 16QAM-DS/FFHSS, 32QAM-DS/FFHSS, 64QAM-DS/FFHSS, 128QAM-DS/FFHSS, and 256QAM-DS/FFHSS in the Rayleigh fading channel.

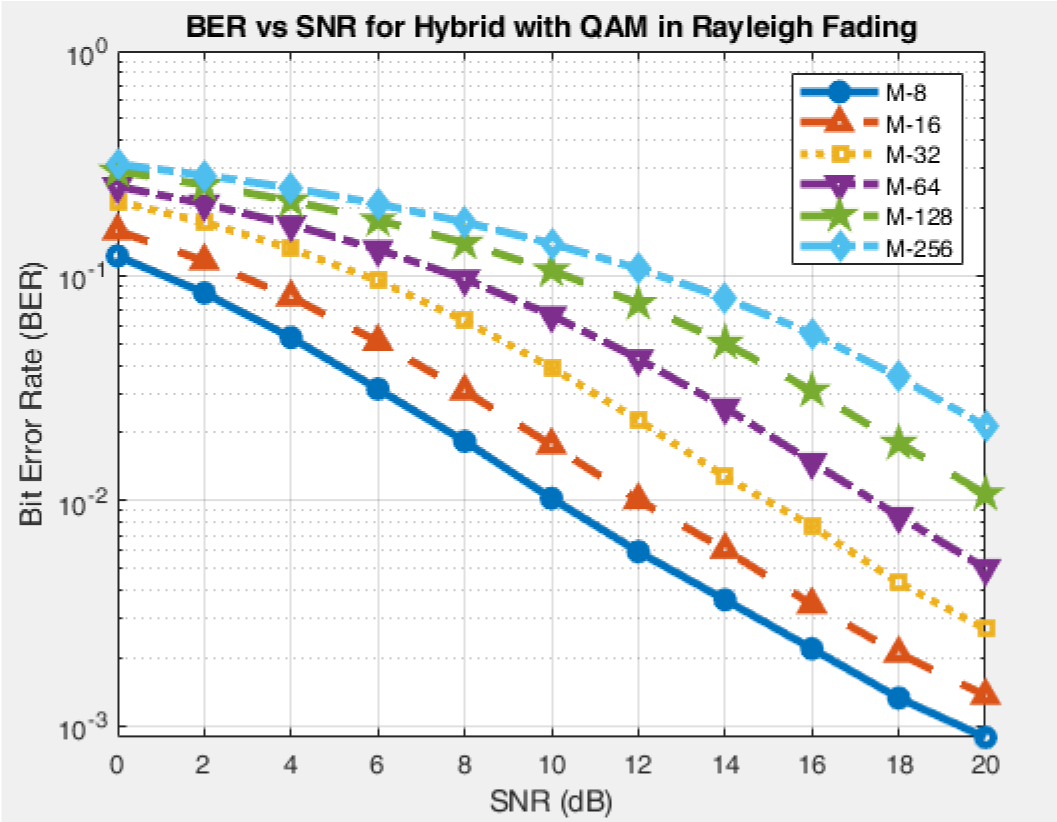

Figure 4-10 BER vs. SNR for DS/FFHSS with QAM in Rayleigh fading channel

The error rate grows with the amount of bits in a symbol (M), from 8 to 256. The BER findings were minimized by employing a predetermined range of SNR values. All modulated signals passing through the Rayleigh fading channel behave the same way.

4.2.3.1 SNR Comparison of DSSS, FHSS and DS/FFHSS Systems Using 16-QAM Modulation

This section compares the SNR performance of three different spread spectrum techniques: DSSS, FHSS, and DS/FFHSS. Figure (4.11) plots the Bit Error Rate (BER) vs. SNR performance of the 16QAM-DSSS, 16QAM-FHSS, and 16QAM-DS/FFHSS systems in the Rayleigh fading channel as a function of signal to noise ratio (Eb/No).

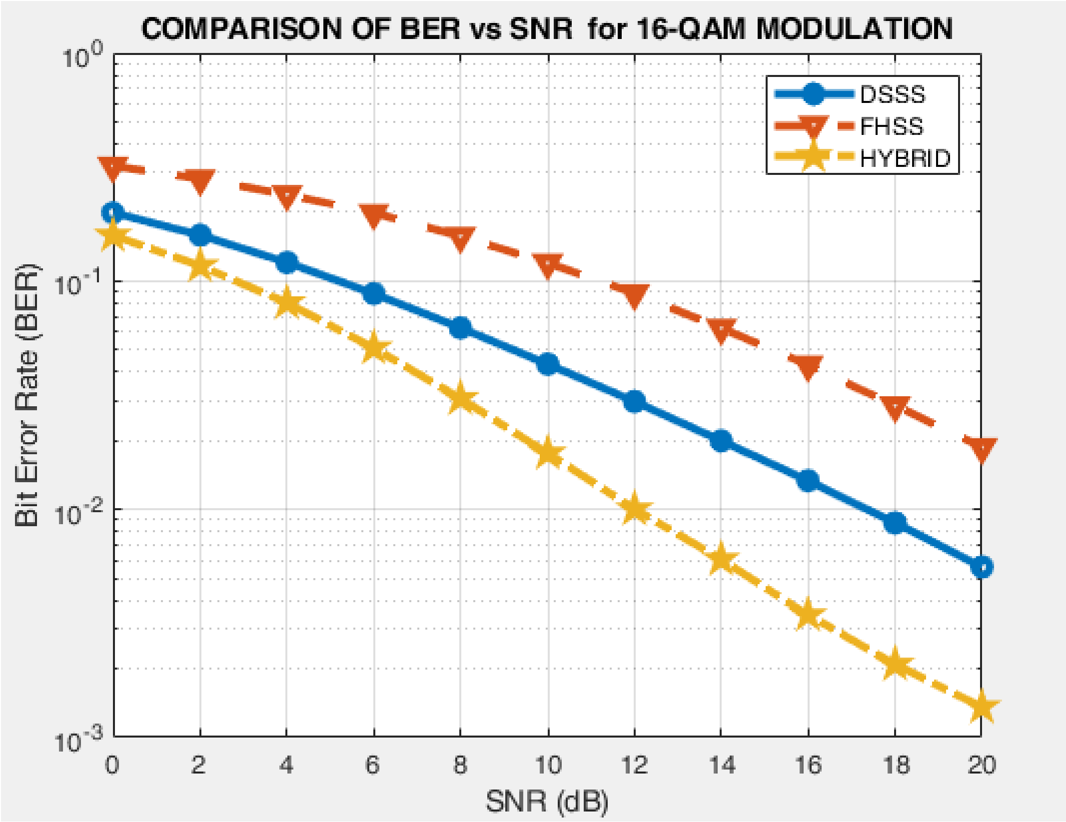

Figure 4-11 SNR Comparison of DSSS, FHSS and DS/FFHSS systems using 16-QAM modulation

4.2.3.2 SNR Comparison of DSSS, FHSS and DS/FFHSS Systems Using 32-QAM Modulation

This section compares the SNR performance of three different spread spectrum techniques: DSSS, FHSS, and DS/FFHSS. Figure (4.12) plots the Bit Error Rate (BER) vs. SNR performance of the 32QAM-DSSS, 32QAM-FHSS, and 32QAM-DS/FFHSS systems in the Rayleigh fading channel as a function of signal to noise ratio (Eb/No).

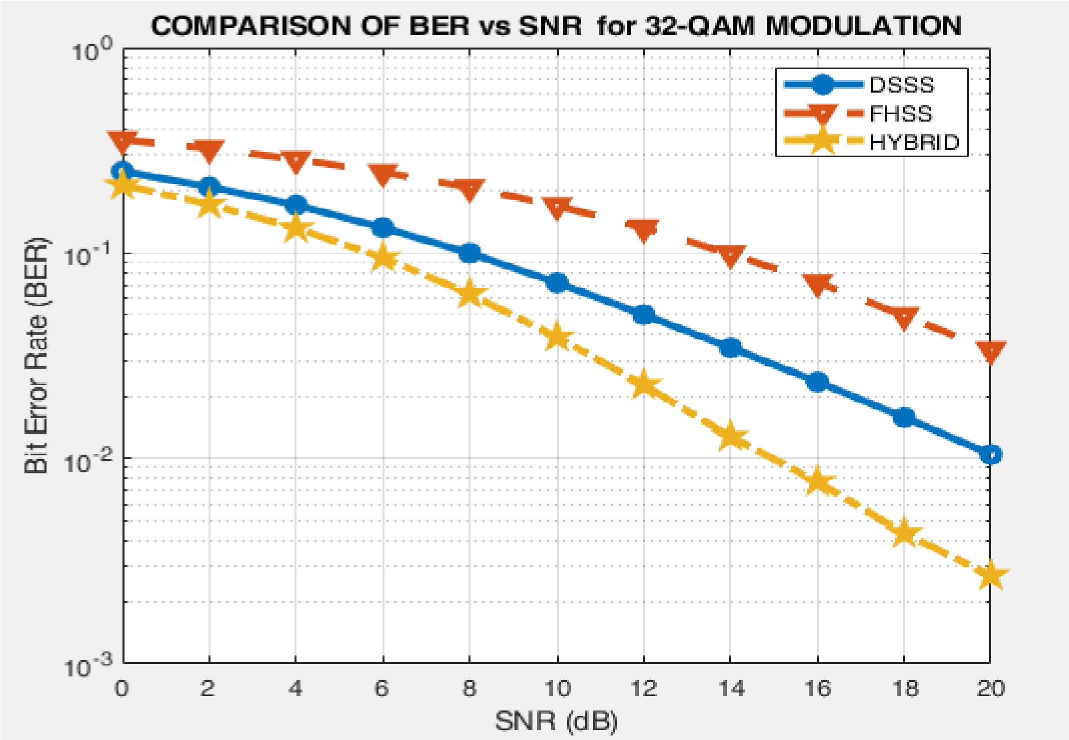

Figure 4-12 SNR Comparison of DSSS, FHSS and DS/FFHSS systems using 32-QAM modulation

4.2.3.3 SNR Comparison of DSSS, FHSS and DS/FFHSS Systems Using 64-QAM Modulation

This section compares the SNR performance of three different spread spectrum techniques: DSSS, FHSS, and DS/FFHSS. Figure (4.13) shows the Bit Error Rate (BER) vs. SNR performance of the 64QAM-DSSS, 64QAM-FHSS, and 64QAM-DS/FFHSS systems in the Rayleigh fading channel as a function of signal to noise ratio (Eb/No).

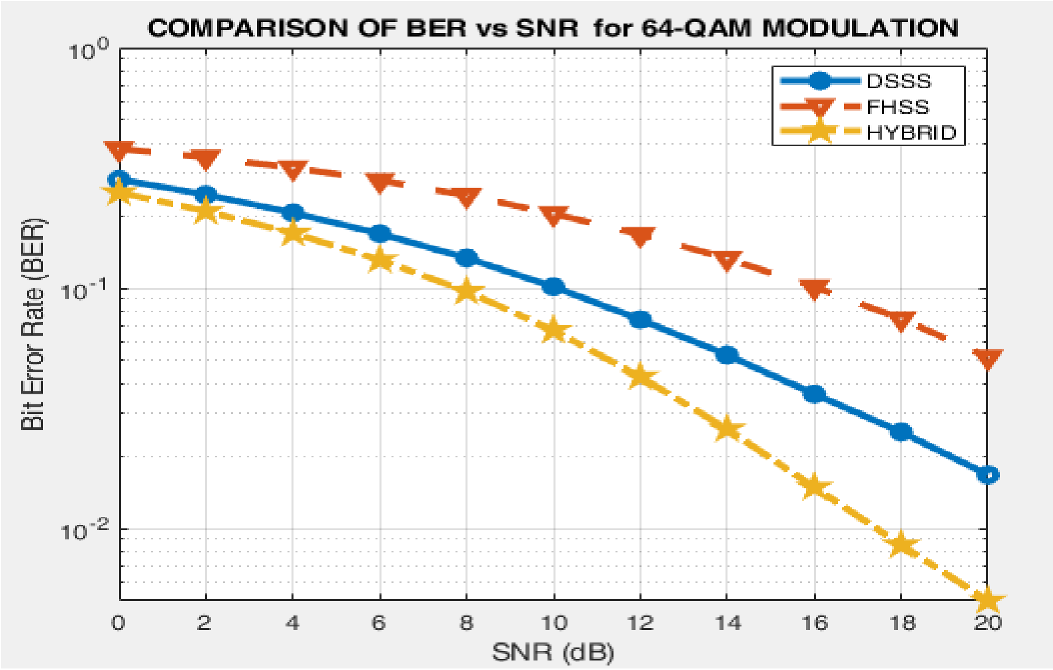

Figure 4-13 SNR Comparison of DSSS, FHSS and DS/FFHSS systems using 64-QAM modulation

4.2.3.4 SNR Comparison of DSSS, FHSS and DS/FFHSS Systems Using 128-QAM Modulation

This section compares the SNR performance of three different spread spectrum techniques: DSSS, FHSS, and HYBRID. Figure (4.14) shows the Bit Error Rate (BER) vs SNR performance of the 128QAM-DSSS, 128QAM-FHSS, and 128QAM-DS/FFHSS systems in the Rayleigh fading channel as a function of signal to noise ratio.

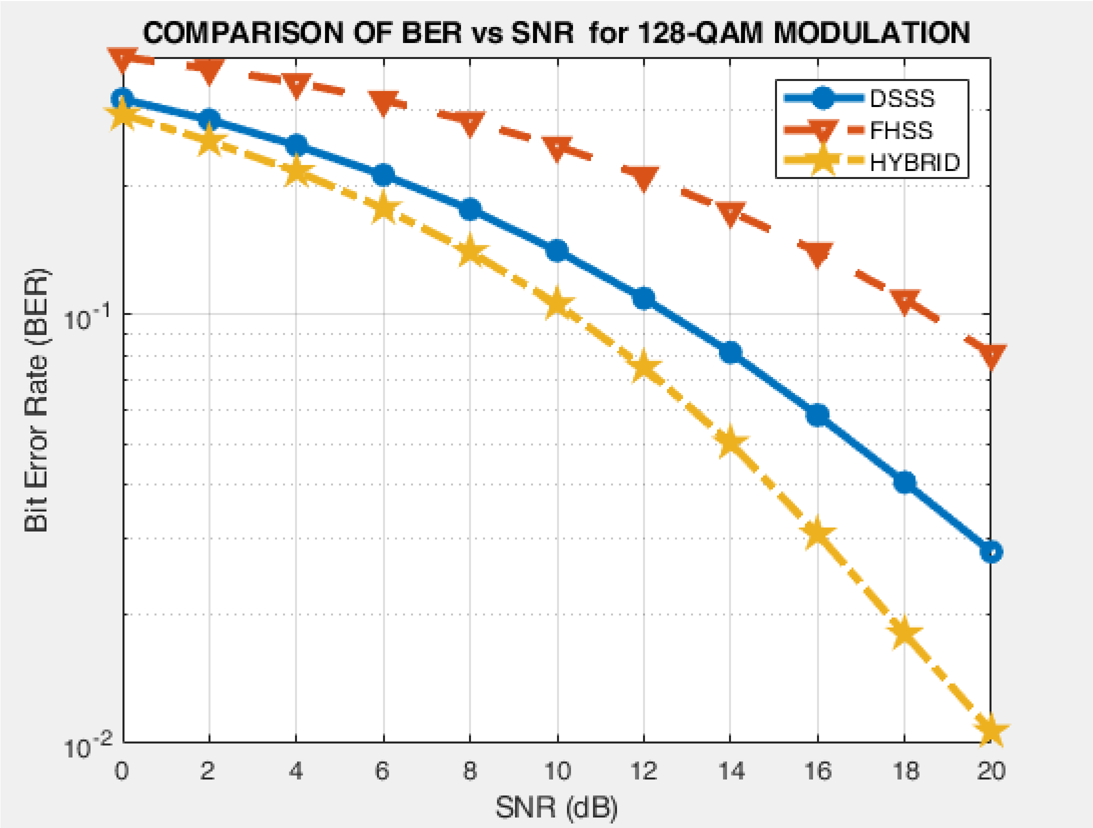

Figure 4-14 SNR Comparison of DSSS, FHSS and DS/FFHSS systems using 128-QAM modulation

Table 4-3 BER vs. SNR performance of DSSS, FHSS, DS/FFHSS

QAM	DSSS	FHSS	DS/FFHSS
M=16	0.0680	0.1416	0.0434
M=32	0.0973	0.1799	0.0687
M=64	0.1219	0.2092	0.0928
M=128	0.1542	0.2438	0.1245

The figures and table show the BER vs. SNR performance of the three systems in various QAM modulation schemes. The DS/FFH spread-spectrum system outperformed the other two systems.

4.3 Performance Analysis of Q-Factor

4.3.1 Performance Analysis of Q-Factor Direct Sequence Spread Spectrum System Using Different Higher Modulation Scheme

Q-factors were simulated for various SNRs and then evaluated the performance of the direct sequence spread spectrum system. Figure 4.15 depicts the Q-factor performance against signal to noise ratio (SNR) of 8QAM-DSSS, 16QAM-DSSS, 32QAM-DSSS, 64QAM-DSSS, 128QAM-DSSS, and 256QAM-DSSS in the Rayleigh fading channel.

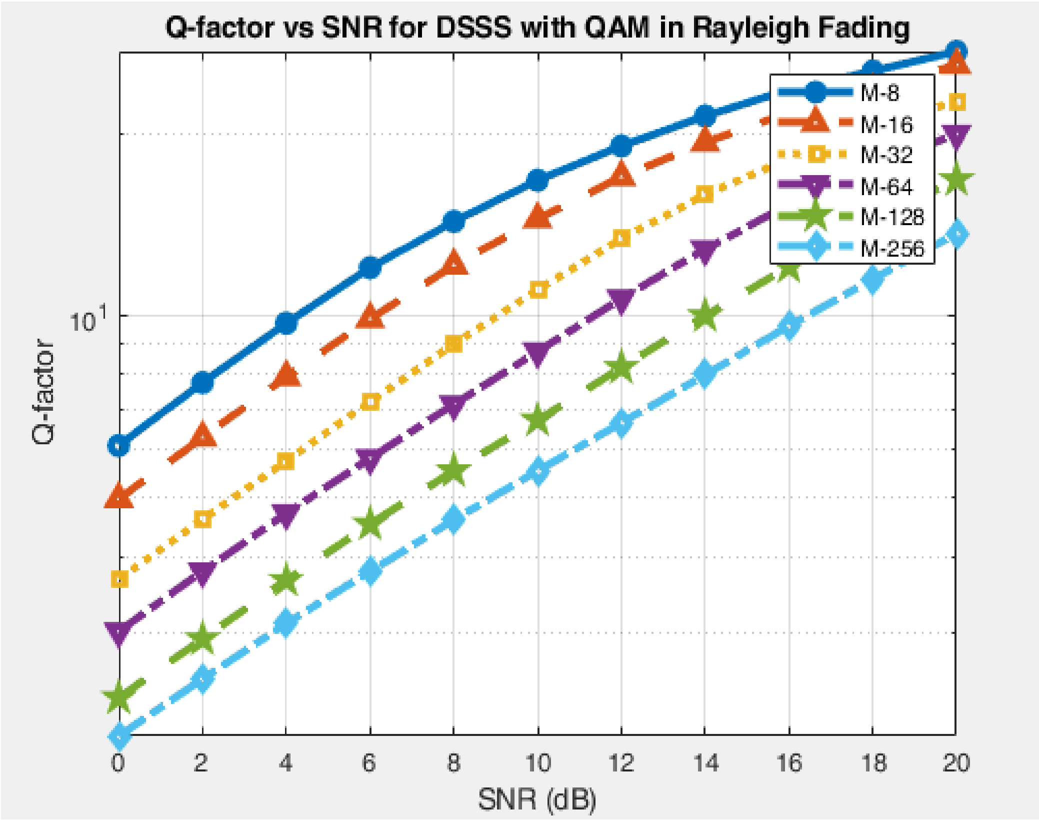

Figure 4-15 Q-factor Performance Analysis of DSSS using different QAM modulation scheme

4.3.2 Performance Analysis of Q-Factor Frequency Hopping Spread Spectrum System Using Different Higher Modulation Scheme

In the simulation, computed the Q-factor for various SNRs and then examined the performance of the frequency hopping spread spectrum system. Figure 4.16 depicts the Q-factor performance against signal to noise ratio (SNR) of 8QAM-FHSS, 16QAM-FHSS, 32QAM-FHSS, 64QAM-FHSS, 128QAM-FHSS, and 256QAM-FHSS in the Rayleigh fading channel.

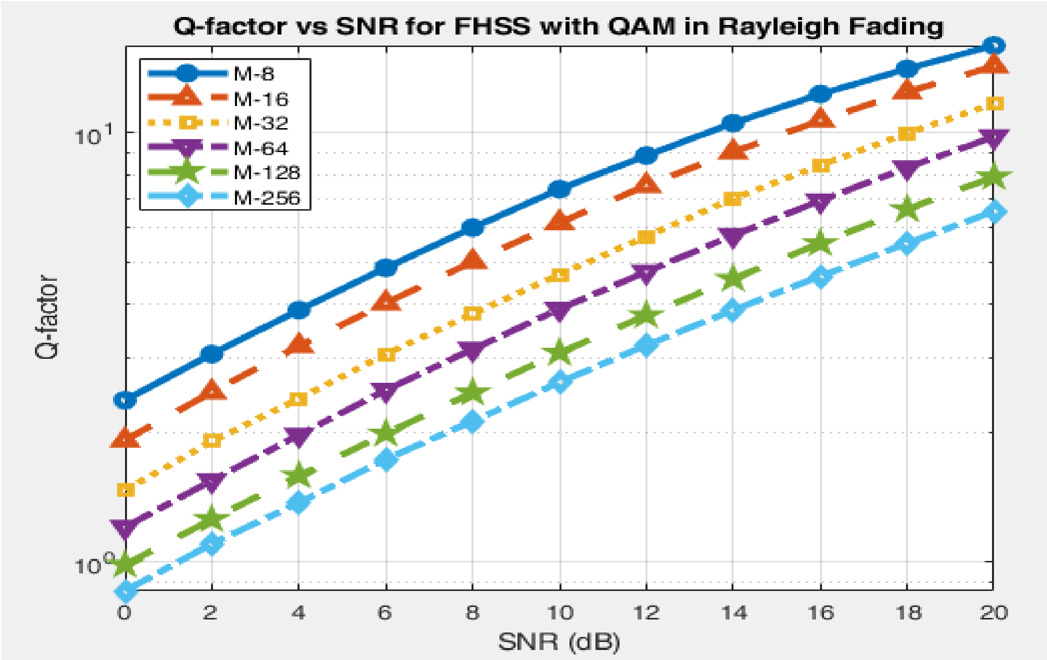

Figure 4-16 Q-Factor Performance Analysis of FHSS using different QAM modulation scheme

4.3.3 Performance Analysis of Q-Factor DS/FFH Spread Spectrum System Using Different Higher Modulation Scheme

In the simulation, computed the Q-factor for various SNRs and then examined the performance of the hybrid spread spectrum system. Figure (4.17) depicts the Q-factor performance against signal to noise ratio (SNR) for 8QAM-DS/FFHSS, 16QAM-DS/FFHSS, 32QAM-DS/FFHSS, 64QAM-DS/FFHSS, 128QAM-DS/FFHSS, and 256QAM-DS/FFHSS in the Rayleigh fading channel.

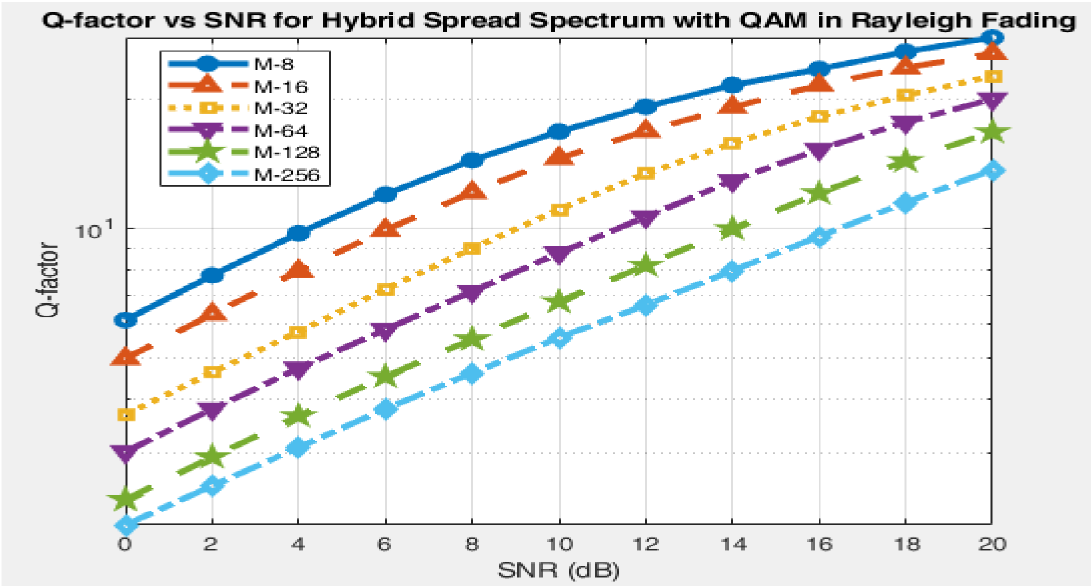

Figure 4-17 Q-Factor performance of DS/FFH spread spectrum using different higher modulation scheme

The Q-factor decreases as the amount of M, or the number of bits in a symbol, grows, namely from 8 to 256. The behavior of every modulated signal going through the Rayleigh fading channel is same.

4.3.3.1 Q-factor Comparison of DSSS, FHSS and DS/FFHSS Systems Using 16-QAM Modulation

This section compares the Q-factor performance of various spread spectrum techniques, including DSSS, FHSS, and DS/FFHSS. Figure (4.18) shows the Q-factor and SNR performance of the 16QAM-DSSS, 16QAM-FHSS, and 16QAM-DS/FFHSS systems in the Rayleigh fading channel as a function of signal to noise ratio (SNR).

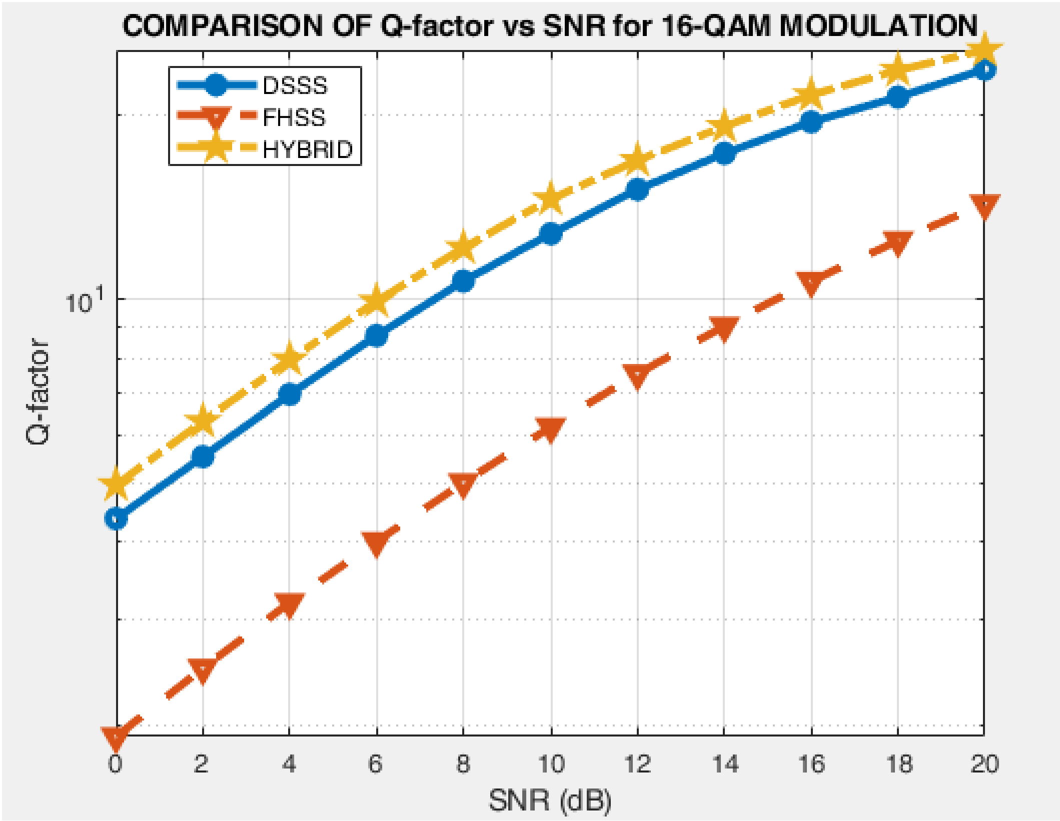

Figure 4-18 Q-factor Comparison of DSSS, FHSS and DS/FFHSS systems using 16-QAM modulation

4.3.3.2 Q-factor Comparison of DSSS, FHSS and DS/FFHSS Systems Using 32-QAM Modulation

This section compares the Q-factor performance of various spread spectrum techniques, including DSSS, FHSS, and DS/FFHSS. Figure (4.19) shows the Q-factor and SNR performance of the 32QAM-DSSS, 32QAM-FHSS, and 32QAM-DS/FFHSS systems in the Rayleigh fading channel as a function of signal to noise ratio (SNR).

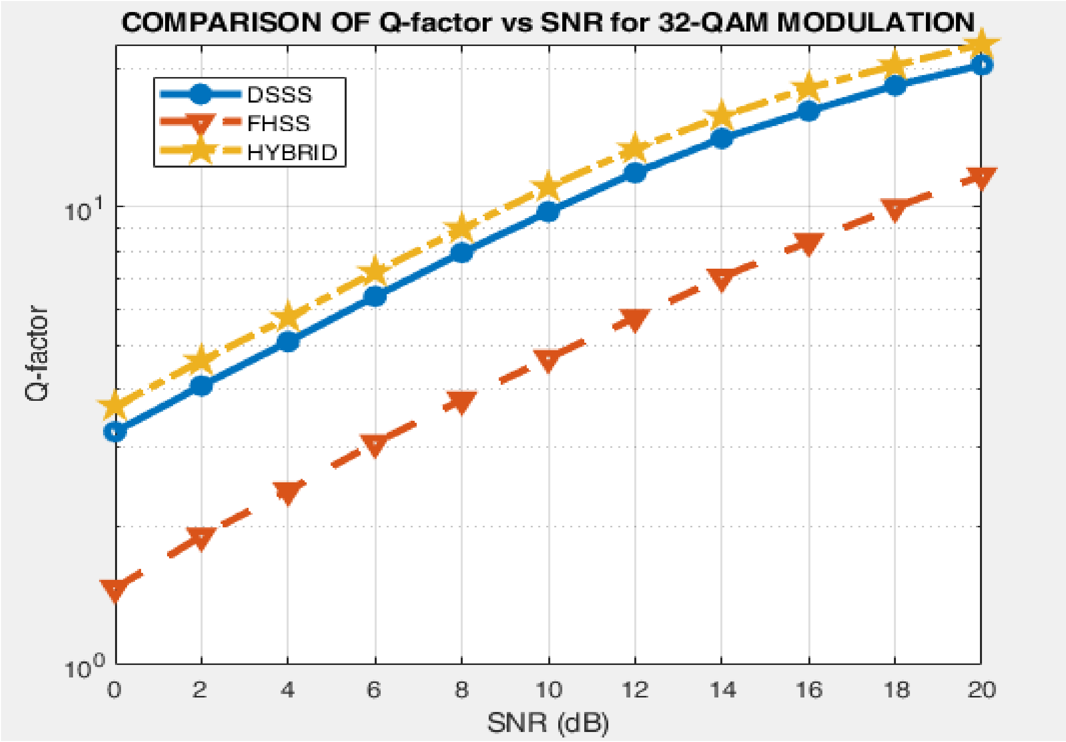

Figure 4-19 Q-factor Comparison of DSSS, FHSS and DS/FFHSS systems using 32-QAM modulation

4.3.3.3 Q-factor Comparison of DSSS, FHSS and DS/FFHSS Systems Using 64-QAM Modulation

This section compares the Q-factor performance of various spread spectrum techniques, including DSSS, FHSS, and HYBRID. Figure (4.20) shows the Q-factor and SNR performance of the 64QAM-DSSS, 64QAM-FHSS, and 64QAM-DS/FFHSS systems in the Rayleigh fading channel as a function of signal to noise ratio.

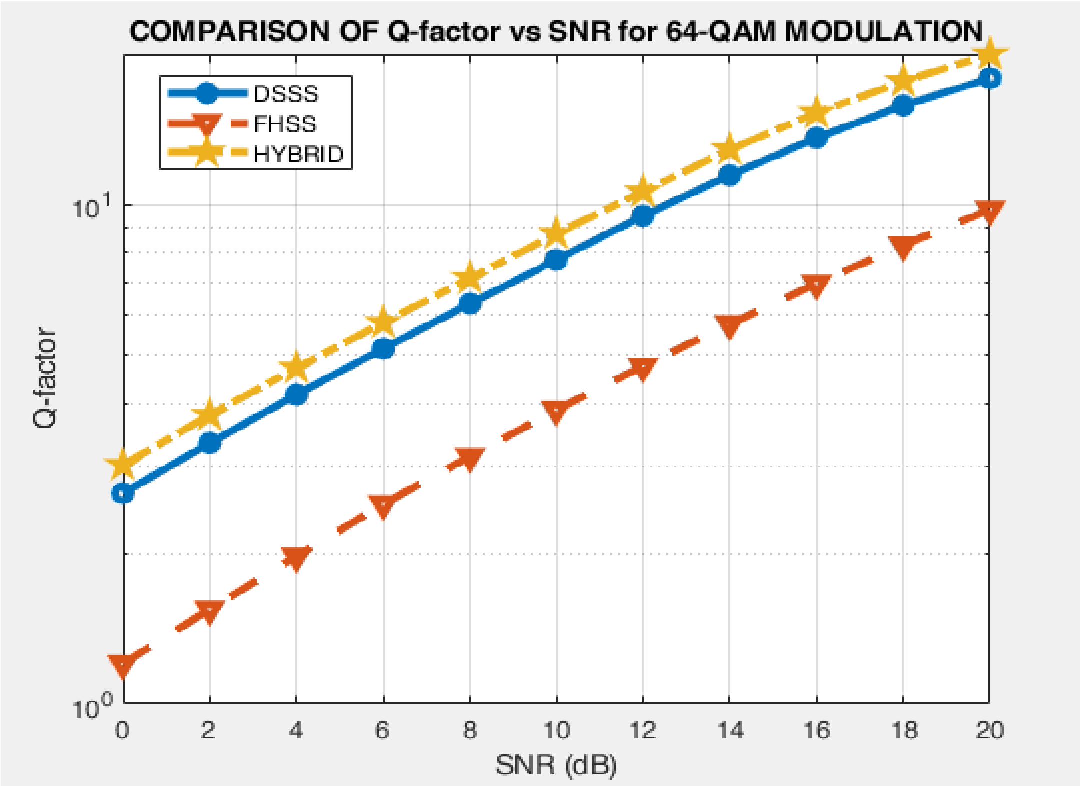

Figure 4-20 Q-factor Comparison of DSSS, FHSS and DS/FFHSS systems using 64-QAM modulation

4.3.3.4 Q-factor Comparison of DSSS, FHSS and DS/FFHSS Systems Using 128-QAM Modulation

This section compares the Q-factor performance of various spread spectrum techniques, including DSSS, FHSS, and HYBRID. Figure (4.21) shows the Q-factor and SNR performance of the 64QAM-DSSS, 64QAM-FHSS, and 64QAM-DS/FFHSS systems in the Rayleigh fading channel as a function of signal to noise ratio (SNR).

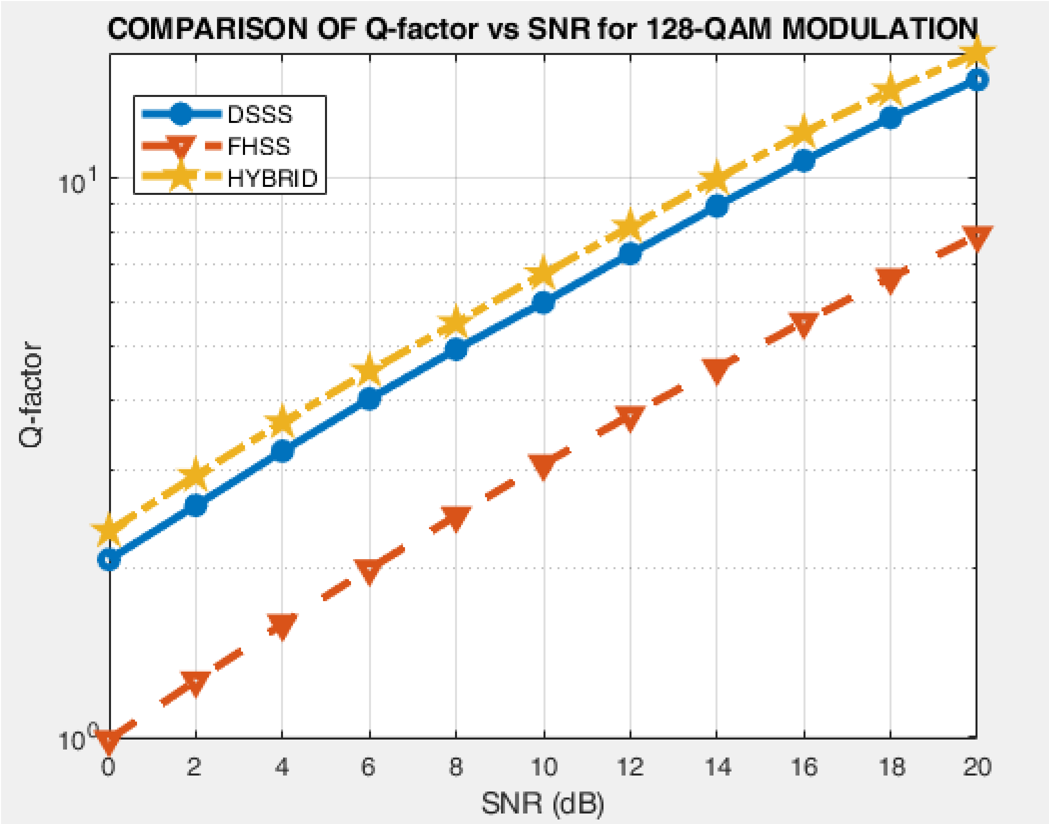

Figure 4-21 Q-factor Comparison of DSSS, FHSS and DS/FFHSS systems using 128-QAM modulation

Table 4-4 Q-factor performance of DSSS, FHSS, DS/FFHSS

M-QAM	DSSS	FHSS	DS/FFHSS
M=16	13.2478	6.9934	14.8188
M=32	10.7039	5.4724	12.0331
M=64	8.8896	4.5273	9.9695
M=128	7.0671	3.6168	7.9254

The figures and table show the three systems' Q-factor performance in various QAM modulations. The DS/FFH spread-spectrum system outperformed the other two systems.

4.4 Performance Analysis of Signal Power

4.4.1 Performance Analysis of signal power Direct Sequence Spread Spectrum System Using Different Higher Modulation Scheme

Q-factor were simulated for various SNRs in the simulation and then evaluated the hybrid spread spectrum system's performance. Figure (4.22) plots signal power performance in the

Rayleigh fading channel against signal to noise ratio (SNR) for 8QAM-DSSS, 16QAM-HSS, 32QAM-DSSS, 64QAM-DSSS, 128QAM-DSSS, and 256QAM-DSSS.

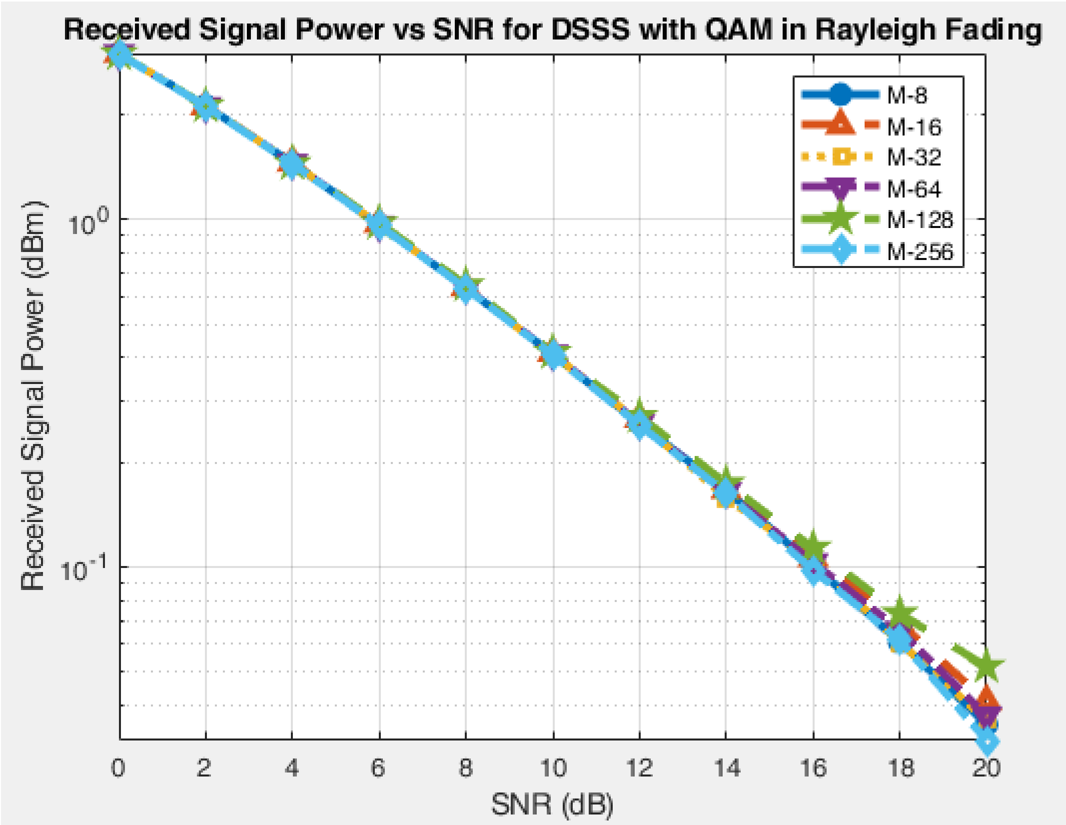

Figure 4-22 Signal power Performance Analysis of DSSS using different QAM modulation scheme

4.4.2 Performance Analysis of signal power Frequency Hopping Sequence Spread Spectrum System Using Different Higher Modulation Scheme

Q-factor were simulated for various SNRs in the simulation and then evaluated the hybrid spread spectrum system's performance. Figure (4.23) plots signal power performance in the Rayleigh fading channel versus signal to noise ratio (SNR) for 8QAM-FHSS, 16QAM-FHSS, 32QAM-FHSS, 64QAM-FHSS, 128QAM-FHSS, and 256QAM-FHSS.

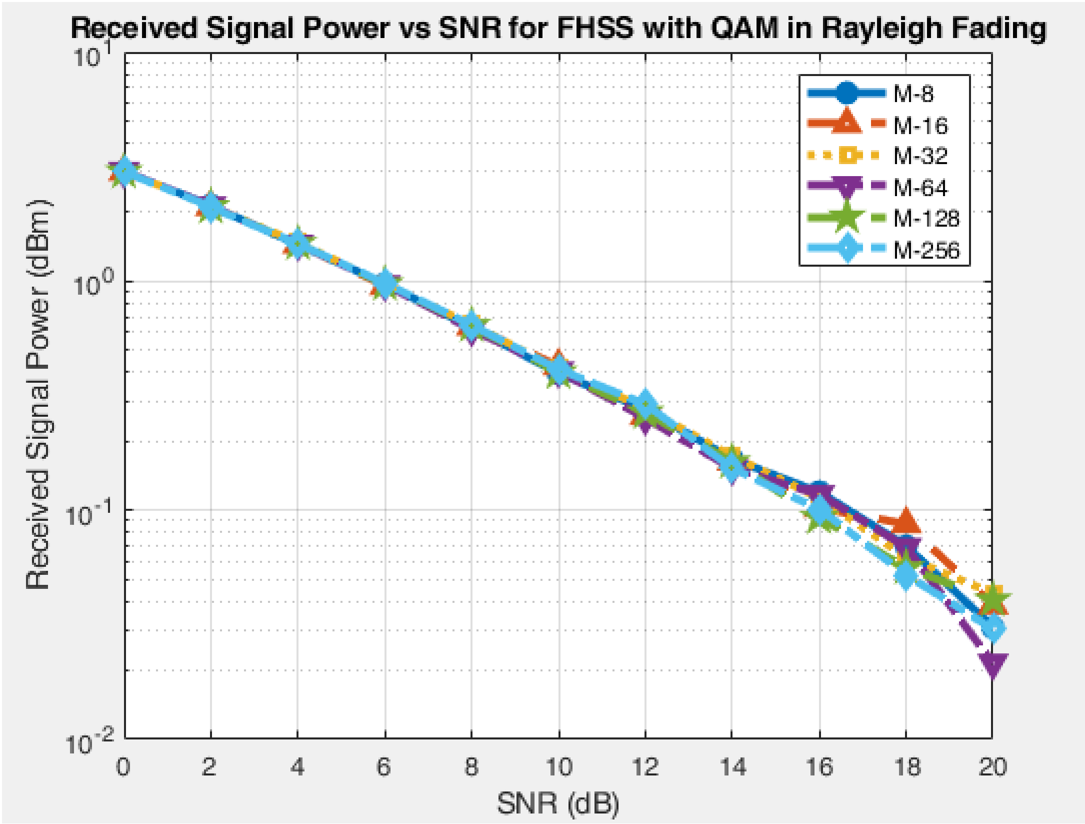

Figure 4-23 Signal power Performance Analysis of FHSS using different QAM modulation scheme

4.4.3 Performance Analysis of signal power DS/FFH Spread Spectrum System Using Different Higher Modulation Scheme

Q-factor were simulated for various SNRs in the simulation and then evaluated the hybrid spread spectrum system's performance. Figure (4.24) plots signal power performance in the Rayleigh fading channel against signal to noise ratio (SNR) for 8QAM-DS/FFHSS, 16QAM-DS/FFHSS, 32QAM-DS/FFHSS, 64QAM-DS/FFHSS, 128QAM-DS/FFHSS, and 256QAM-DS/FFHSS.

The signal to noise ratio will increase as the Signal power value decrease.

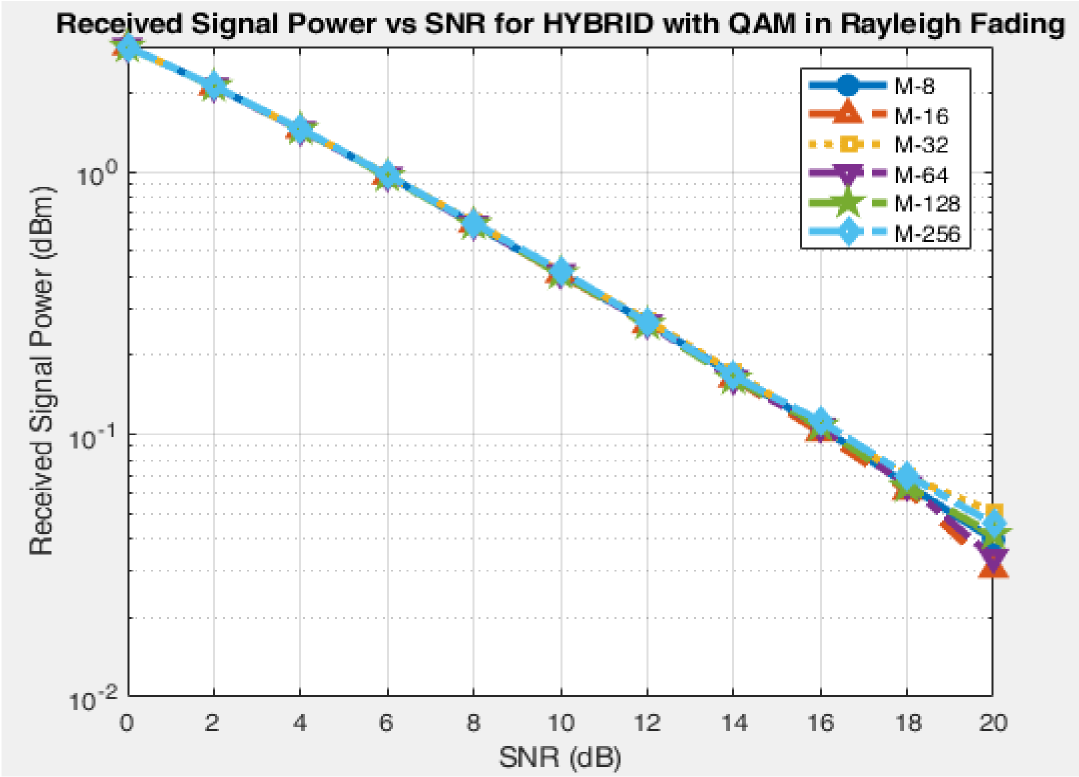

Figure 4-24 Signal power performance of DS/FFH spread spectrum using different higher modulation scheme

When the SNR increases, from 0dB to 20dB, the signal power drops. All modulated signals going via the Rayleigh fading channel exhibit the same behavior.

4.4.3.1 Signal Power Comparison of DSSS, FHSS and DS/FFHSS Systems Using 16-QAM Modulation

This section compares the signal power performance of various spread spectrum techniques, including DSSS, FHSS, and DS/FFHSS. Figure (4.25) shows the signal power and SNR performance of the 16QAM-DSSS, 16QAM-FHSS, and 16QAM-DS/FFHSS systems in the Rayleigh fading channel as a function of SNR.

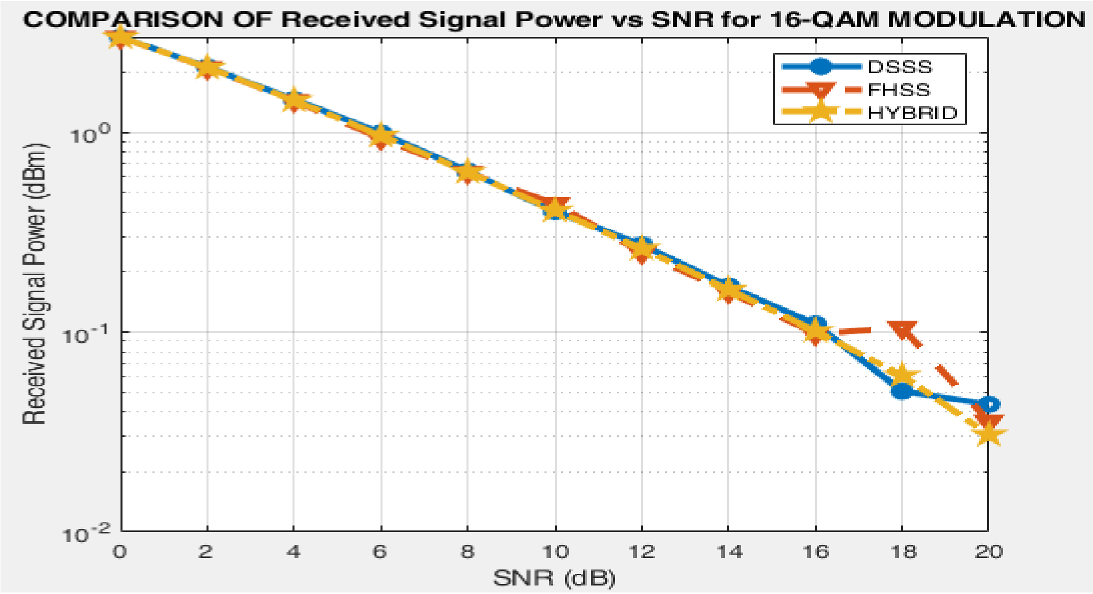

Figure 4-25 Signal power Comparison of DSSS, FHSS and DS/FFHSS systems using 16-QAM modulation

4.4.3.2 Signal Power Comparison of DSSS, FHSS and DS/FFHSS Systems Using 32-QAM Modulation

This section compares the signal power performance of various spread spectrum techniques, including DSSS, FHSS, and DS/FFHSS. Figure (4.26) shows the signal power and SNR performance of the 32QAM-DSSS, 32QAM-FHSS, and 32QAM-DS/FFHSS systems in the Rayleigh fading channel as a function of signal to noise ratio.

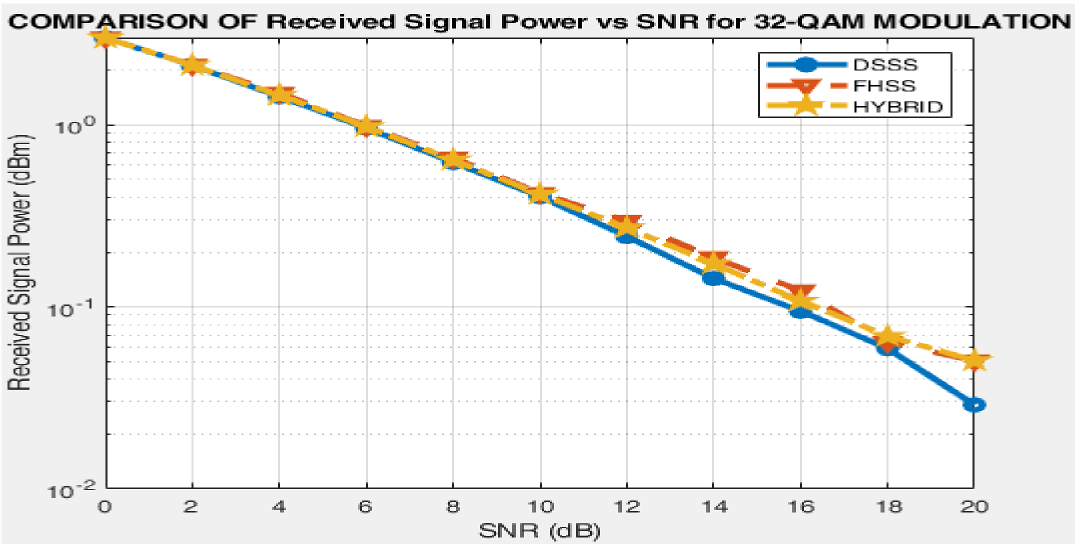

Figure 4-26 Signal power Comparison of DSSS, FHSS and DS/FFHSS systems using 32-QAM modulation

4.4.3.3 Signal Power Comparison of DSSS, FHSS and DS/FFHSS Systems Using 64-QAM Modulation

This section compares the signal power performance of various spread spectrum techniques, including DSSS, FHSS, and HYBRID. Figure (4.27) shows the signal power and SNR performance of the 64QAM-DSSS, 64QAM-FHSS, and 64QAM-DS/FFHSS systems in the Rayleigh fading channel as a function of SNR.

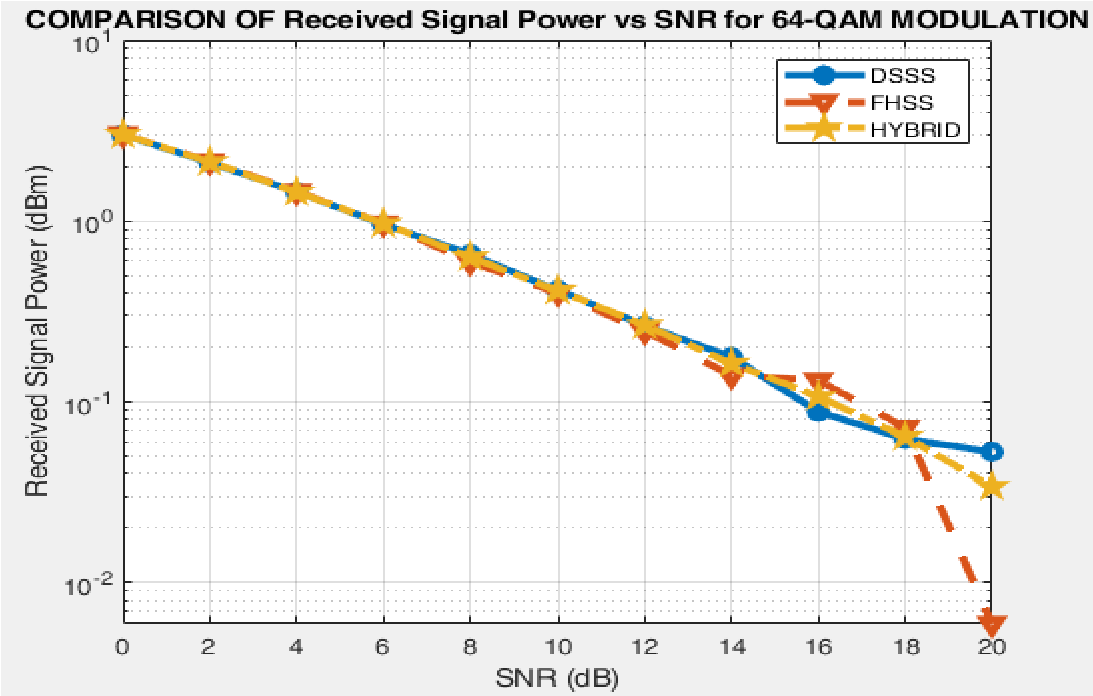

Figure 4-27 Signal power Comparison of DSSS, FHSS and DS/FFHSS systems using 64-QAM modulation

4.4.3.4 Signal Power Comparison of DSSS, FHSS and DS/FFHSS Systems Using 128-QAM Modulation

This section compares the signal power performance of various spread spectrum techniques, including DSSS, FHSS, and DS/FFHSS. Figure (4.28) shows the signal power and SNR performance of the 16QAM-DSSS, 16QAM-FHSS, and 16QAM-DS/FFHSS systems in the Rayleigh fading channel as a function of SNR.

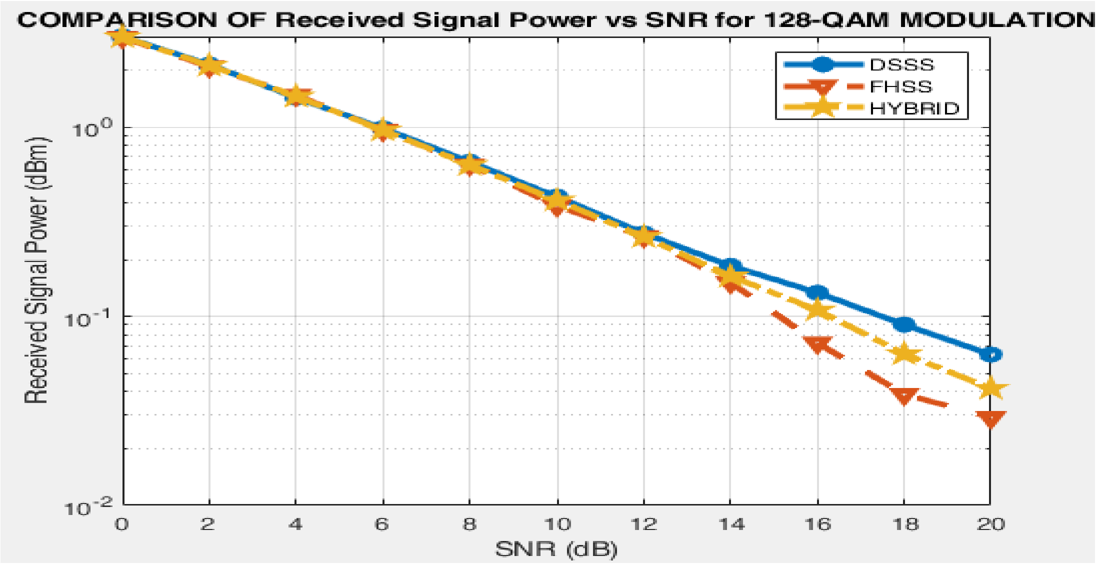

Figure 4-28 Signal power Comparison of DSSS, FHSS and DS/FFHSS systems using 128-QAM modulation

Table 4-5 the power performance of DSSS, FHSS, DS/FFHSS

M-QAM	DSSS	FHSS	DS/FFHSS
M=16	0.8505	0.8482	0.8502
M=32	0.8426	0.8476	0.8374
M=64	0.8438	0.8428	0.8507
M=128	0.8441	0.8428	0.8416

The results from the graphs and table show that there is no difference in signal power performance at lower SNRs, while there are some differences at higher SNR levels. The received signal power is not stable at increasing SNRs.

CHAPTER FIVE

5 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

In this thesis, three spread spectrum systems, DSSS, DS/FFHSS and FHSS, were modeled using Matlab /Simulink software. The modeled spread spectrum systems were then simulated using Rayleigh fading and different QAM modulation schemes, namely 16 QAM, 32 QAM, 64 QAM and 128 QAM. The DS/FFHSS system performance were then compared with the other systems as well as with different QAM modulation schemes employing BER, SNR, Q-factor and POWER metrics for performance evaluation.

The results showed that DS/FFHSS system performance improved by 64% and 84% in BER metrics when compared to DSSS and FHSS systems. When comparing the DS/FFHSS system to the DSSS and FHSS systems, the SNR performance increased by 38% and 79%, respectively. The Q-factor measurements showed that the DS/FFHSS system outperformed the DSSS and FHSS systems by 11% and 54%, respectively, while in the received power signal the values were identical in lower SNRs and there were some differences at higher SNR levels. Similarly, when the level of modulation increased, the performance of DS/FFHSS decreased by 9% of BER, 79% of Q-factor and 1% of SNR.

In general, DS/FFHSS has revealed enhanced performance than FHSS, and DSSS based on the abovementioned metrics.

5.2 Recommendation

This thesis were evaluated and compared the performance of the hybrid spread spectrum system to that of other systems using a distinct QAM modulation in a Rayleigh-fading channel. In the future, it is advised to assess the system's maximum performance by include additional features such as extra fading channels, performance measures, and higher QAM modulation techniques.

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