Modeling and Performance Analysis of DSSS Techniques in 5G Wireless Systems

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Abstract: In modern wireless communication systems, the Direct Sequence Spread Spectrum (DSSS) technique plays a pivotal role in improving signal robustness and resistance to interference. DSSS is a type of spread spectrum modulation technique where the bandwidth of the transmitted signal is significantly greater than that of the original message. The expansion of the bandwidth is achieved through spreading the signal with a pseudo-random noise (PN) sequence, which is essential for both spreading and de-spreading processes. The maximal length PN sequence (m-sequence) is widely used due to its optimal properties for spread spectrum communication. In the context of 5G wireless systems, DSSS can provide enhanced spectral efficiency, secure communication, and robustness against interference. The performance of DSSS in 5G systems is closely tied to the quality of the PN sequence and its ability to mitigate interference, noise, and multipath fading. This study focuses on modeling the DSSS technique and evaluating its performance in 5G networks, with particular emphasis on signal robustness, interference management, and spectral efficiency. The results will demonstrate the potential benefits of integrating DSSS into next-generation 5G wireless systems.

1 INTRODUCTION

The development of 5G technology marks a significant leap in communication systems, offering faster data rates, lower latency, and the ability to connect a vast number of devices. However, these advancements bring new challenges, particularly in managing interference, ensuring signal robustness, and optimizing spectral efficiency. In dense 5G environments, where signals are prone to interference and fading, techniques like Direct Sequence Spread Spectrum (DSSS) can play a critical role.

DSSS spreads the transmitted signal across a wider bandwidth using a pseudo-random noise sequence, enhancing security and resilience against interference. This approach makes the signal more robust, reducing the impact of noise and jamming. In 5G networks, where efficient spectrum usage and interference management are key, DSSS offers a promising solution for improving overall performance.

This study aims to model and analyze the performance of DSSS techniques in 5G wireless systems, focusing on critical metrics such as signal robustness, spectral efficiency, and interference management. By exploring the integration of DSSS in 5G, this research seeks to highlight its potential to enhance the reliability and efficiency of next-generation wireless networks..

2 MULTIPLE ACCESS TECHNIQUE

Multiple access technique where many users or local stations can uses the communication channel at the same period of time or nearly so despite the fact originate from different locations. A multiple access method is a definition of how the radio spectrum is split into channels and how the channels are allocated to the many users of the system. Since there are different users transmitted over the same channel, a method must be established so that individual users will not disrupt one another.

There are three basic types of multiple access technique

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A. Multiple Access via Frequency Division (FDMA)
B. Multiple Access with Time Division (TDMA)
C. Multiple Access over Spread Spectrum (SS-MA)
   - Direct sequence spread spectrum (DSSS)
   - Frequency-hopped spread spectrum (FHSS)

2.1 Multiple Access via Frequency Division (FDMA)

FDMA assigns each user a distinct frequency band or channel for communication. These separate frequency bands are made available to users seeking communication services, ensuring that no other user can use the same frequency band during its assigned time. As a result, when an FDMA channel is not in use, it becomes idle and cannot be used by other users to expand or share capacity. This exclusivity enables for continuous communication, but it might result in inefficiencies in spectrum utilization when channels are empty. To successfully tune in and receive broadcast signals, the receiver just has to know the allotted frequency.

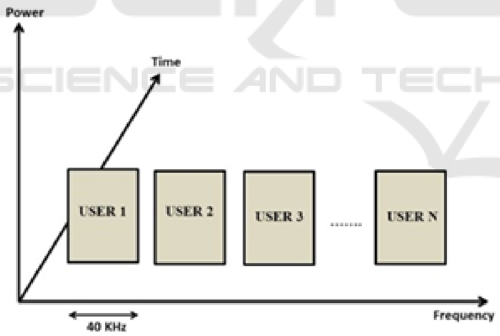

Figure 1: FDMA System Blocks.

2.2 Multiple Access with Time Division (TDMA)

TDMA enables multiple users to share the same frequency bandwidth, but only for specific time slots. Each user transmits during their assigned time, which prevents overlap. If transmissions do overlap, it causes co-channel interference. Precise clock synchronization is essential to ensure that each user transmits in their designated time slot, maintaining effective communication and minimizing interference.

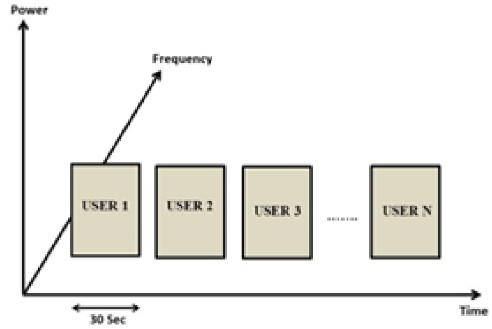

Figure 2: TDMA System Blocks.

2.3 Spread Spectrum Multiple Access

Spectrum uses signals with a transmission bandwidth that exceeds the minimum needed RF bandwidth. A pseudo-noise (PN) sequence converts a narrowband signal into a wideband signal, increasing immunity to multipath interference. Although SSMA is not particularly bandwidth-efficient for a single user, it does allow numerous users to share the same spread spectrum bandwidth without interfering. This feature makes spread spectrum systems especially efficient in multi-user scenarios, which appeals to wireless system designers. Spread spectrum multiple access techniques are classified into two types: frequency hopping (FH-MA) and direct sequence (DS-MA), often known as code division (CDMA).

2.4 Direct Sequence Spread Spectrum

Direct Sequence Spread Spectrum involves a transmitter and receiver system as illustrated in Figure (3). In the transmitter, the baseband data signal m(t) m(t) m(t) is spread using a pseudo-noise (PN) sequence c(t), resulting in a spread signal s(t).

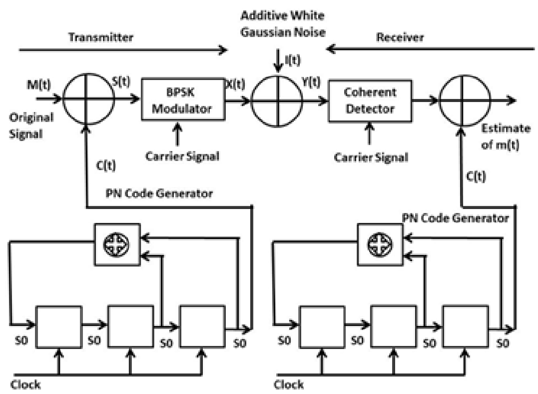

Figure 3: DSSS System Blocks

This spread signal is modulated using binary shift keying (BPSK), resulting sending of signal x(t), which is a binary direct sequence phase shift keying signal (DS/BPSK).

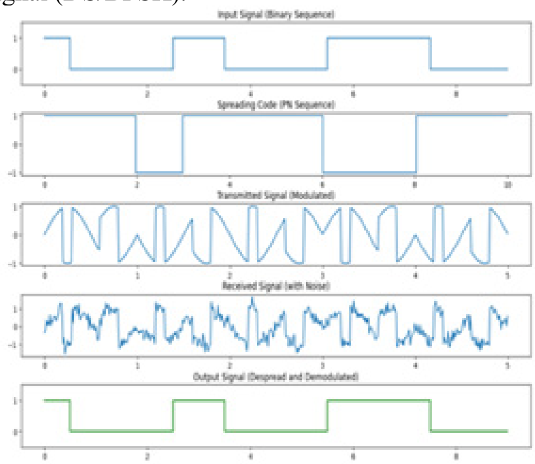

Figure 4: DSSS Signal with PN Code.

At the receiver, the transmitted signal is demodulated using a coherent detector and then multiplied by the same PN code c(t). This multiplication effectively removes the PN code from the received signal, restoring the original data signal d(t). It's noteworthy that the spreading operation performed in the transmitter is mirrored by the de-spreading operation in the receiver, allowing for accurate recovery of the original signal.

3 PERFORMANCE EVALUATION PARAMETERS OF DSSS IN 5G

Direct Sequence Spread Spectrum (DSSS) in 5G wireless systems, performance evaluation is based on several critical parameters. Bit Error Rate measures the accuracy of data transmission, indicating how often bits are incorrectly received. Signal-to-Noise Ratio reflects the clarity of the signal, comparing signal power to background noise. Processing gain shows how effectively the spread spectrum improves resilience against interference. Spectral efficiency evaluates the efficient use of bandwidth, while latency and throughput determine speed and system capacity.

Additionally, delay spread is a crucial parameter, representing the time difference between the arrival of the direct signal and reflected signals, which affects signal clarity. Jamming resistance, another vital factor, evaluates DSSS's ability to maintain communication in the presence of intentional interference, which we will discuss further in the paper. These parameters together help assess DSSS's reliability, robustness, and performance in 5G environments.

3.1 BER and SNR

Bit-Error-Rate is a critical performance metric for evaluating Direct-Sequence-Spectrum systems in 5G wireless networks, which require high reliability and low latency for applications like autonomous vehicles and remote healthcare. The BER is defined as the ratio of incorrectly received bits (Ne) to total transmitted bits (Nt)

$$BER = \frac{Ne}{Nt} \tag{1}$$

DSSS enhances signal robustness by spreading data over a wider bandwidth, which significantly reduces the BER. The processing gain (G) of a DSSS system can be expressed as:

$$G = \frac{Bs}{Bd} \tag{2}$$

Where Bs is the bandwidth of the spread signal and Bd is the bandwidth of the original data signal. Higher processing gain leads to improved SNR, which in turn lowers the BER. The relationship between SNR (γ) and BER for Binary Phase Shift Keying (BPSK) is approximated by:

$$BER = \frac{1}{2}.erfc(\gamma) \tag{3}$$

where erfc(γ) is the complementary error function. As SNR increases, BER decreases, demonstrating DSSS's effectiveness in challenging environments.

SNR is defined as the ratio of received signal power (Ps) to noise power (Pn):

$$\gamma = \frac{Ps}{Pn} \tag{4}$$

In DSSS, processing gain enhances effective SNR by combating interference and multipath fading, essential for reliable 5G communication among numerous connected devices. The use of pseudo-noise (PN) sequences allows DSSS to handle co-channel interference effectively, maintaining low BER.

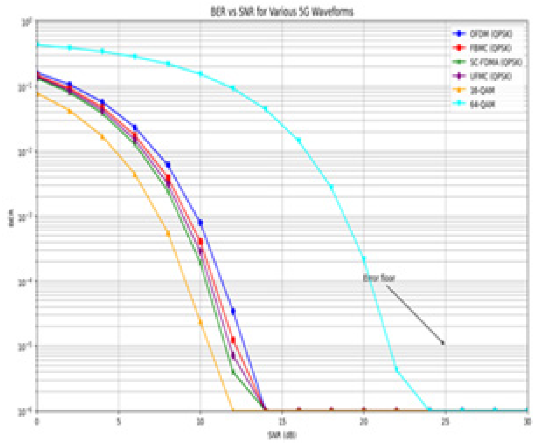

Figure 5: BER Vs. SNR Various 5G Waveforms Testing

The graph depicts the Signal-to-Noise Ratio (SNR) against Bit Error (BER) for various 5G waveforms such as OFDM, FBMC, SC-FDMA, UFMC, 16-QAM, and 64-QAM.

Curves are quite close, showing a gradual decrease in BER with increasing SNR, dropping to below 10^{-4} around 12^{-15} dB SNR.

3.2 Delay Spread

Delay spread is a critical parameter in 5G wireless communications, particularly in systems using Direct Sequence Spread Spectrum (DSSS) techniques. It refers to the time dispersion of multipath signals as they arrive at the receiver, caused by reflections and scattering from various obstacles in the environment. In urban environments, for example, delay spreads can range from 50 to 200 nanoseconds (ns), while in more complex environments, such as dense urban areas, it may exceed 1 microsecond (µs). In 5G, where high data rates (up to 10 Gbps) and low latency (as low as 1 ms) are essential for applications like autonomous vehicles and remote healthcare, significant delay spread can lead to inter-symbol interference (ISI), where overlapping delayed signals interfere with one another, resulting in data errors.

$$Trms = \sqrt{\frac{\sum_{i=1}^{N} |h(ti)|2.(ti = Tmean)2}{\sum_{i=1}^{N} |h(ti)|2}} \quad (5)$$

To quantify delay spread, the Root Mean Square (RMS) delay spread can be calculated using the following equation:

Where:
- Trms is the RMS delay spread.
- h(ti) is the impulse response of the channel at time ti
  - Tmean is the mean delay, calculated as Tmean
  - N is the number of multipath components

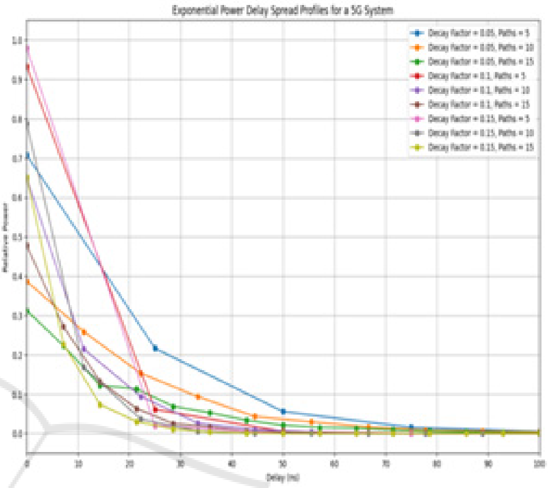

Figure 6: Power Delay Spread Profiles of 5G Tech

The graph shows Exponential Power Delay Spread Profiles for a 5G system, comparing how the signal's relative power decreases over time (in nanoseconds) for various decay factors (0.05, 0.1, and 0.15) and number of paths (5, 10, and 15).

- Higher decay factors lead to faster drops in power.
- Increasing the number of paths (multipath components) also accelerates the power decay.

For example, a decay factor of 0.05 with 5 paths shows a slower decline in signal strength, while a decay factor of 0.15 with 15 paths results in rapid decay within the first 20 ns. This highlights how the environment affects signal fading in 5G networks.

3.3 Jamming

Because 5G networks are made to Communication designed for many low-data IoT devices, Eenhanced-mobile-broadband, and Highly reliable low-□delay communication, jamming becomes an even more serious problem. To evaluate the effect of jammers on 5G, performance metrics like Packet Send Ratio (PSR) and Packet Delivery Ratio (PDR) are crucial.

3.3.1. Packet Send Ratio (PSR) in 5G:

In 5G, PSR remains an important metric to evaluate how successfully data packets are transmitted by the sender. As 5G supports high-bandwidth and low-latency applications, a jammer that targets the high-frequency bands (such as millimeter waves) or causes congestion in lower-frequency bands can drastically reduce PSR. The massive device connectivity in 5G networks also increases the likelihood of interference, where a jammer can reduce PSR by causing collisions and overwhelming the network with noise, especially in dense environments with numerous IOT devices.

3.3.2. Packet Delivery Ratio (PDR) in 5G:

With 5G's promise of reliable communication, especially in mission-critical applications like autonomous vehicles, smart factories, or healthcare, a jammer's effect on PDR can have serious consequences. A low PDR indicates interference at the receiver, preventing devices from receiving packets reliably.

In 5G, where latency-sensitive applications require near-instant data delivery, a jammer can exploit vulnerabilities in beam forming, massive MIMO, or the use of small cells to create localized disruptions. A reduced PDR in 5G could lead to service outages, delay-sensitive failures, or even safety risks in critical applications.

3.3.3. Packet Delivery Ratio (PDR) in 5G:

5G networks, with their multi-access edge computing (MEC) and network slicing technologies, can detect jammers more efficiently using real-time monitoring of PSR, PDR, signal strength, and carrier sensing time. These parameters can be used to identify abnormal distributions caused by jammers, particularly through advanced techniques like machine learning that can identify and adapt to new jammer strategies.

4 LITERATURE RIVIEW

Table 1: Study of 5G based on DSSS Systems.

Ref. No	work	System Design/Technology Used	Comparative Parameters
Adrian et al. (Adrian et al. 2004) – IEEE Journal	"BER of No coherent Unbalanced DQPSK in DSSS"	• Conventional Demodulator: Needs coherence. • Non-Coherent Demodulator: Tolerates cross-talk. • Focus: BER model. • Finding: Minimal BER impact from noise.	• No coherent Demodulation: ~5dB loss at low SNR. • BER: Affected by I/Q cross-correlation. • Simulation: Matches theory at high SNR.
Behrouz et al.(Behrouz et al. 2020) - IEEE 3rd 5GWF	"CP-DSSS for 5G"	• CPDSSS: Coexists with OFDM. • Comparison: CPDSSS vs. OFDM. • Channel Model: Similar to CP-SCM. • Symbol Rate: ≤ bandwidth.	• Operates at low SINR (-10 dB). • Low data rates (<100 kbps). • PAPR < 4 db. • Similar to CP-SCM • Reduces interference. • Secondary channel for 5G NR...
Hongling et al. (Li, Pei et al. 2010)– ICITIS	"DSSS with Jamming"	• Focus: DSSS with jamming. • Conclusion: BER affected by SNR, JSR, PN sequence, and frequency/phase.\ • Key Point: Longer PN sequence doesn't enhance performance with optimal jamming.	• DSSS with single-tone jamming. • BER depends on SNR, JSR, PN sequence, and frequency/phase difference. • Synchronization disruption is a key tactic in jamming. • Optimal JSR limits BER increase.
Xianbin et al. (Xianbin et al. 2011)- ICEMI	"Fast Acquisition in LEO DSSS"	• Focus: High dynamic spread spectrum signals (>100 KHz Doppler shifts) in LEO satellites. • Method: Fast acquisition using FFT.	• DSSS in LEO faces 100 KHz Doppler shifts. • FFT-based method for fast signal acquisition. • Implemented with FPGA+DSP for faster speed and detection...
Harshali et	"Compressed	• Focus: DSSS transmission with compression.	• SNR Improvement – +6 dB at low SNR.

al.(Harshali et al 2015) - ICSTM	DSSS Transmission"	• Signals: Text, binary, speech, and images. • Techniques: Huffman compression and Discrete Cosine Transform.	• BER Reduction – 0.001 at 10 db. • Compression Ratio – 3:1 with Huffman
Ahmed et al.(Ahmed et al., 2017) - IEEE	"ML Time Delay in 5G MIMO DSSS"	• Focus: Two ML TDE methods for multi-carrier DSSS in 5G MIMO. • First TDE: EM method with initialization. • Second TDE: IS method without initialization.	• 0 Gbps data rate • 50% faster with IS method • Handles 1 μs delay spread • 20% better delay accuracy
Faouzi et al.(Faouzi et al., 2016) - ICREMT	"ML Time Delay in 5G DSSS MIMO"	• Focus: TDE from SC/MC DSSS in 5G with multiple antennas. • Results: EM for large observations; IS for short records.	• CRLB: 1.2 ms accuracy. • EM TDE: Effective for 1000+ samples. • IS TDE: Best for <100 samples. • Robustness: >95% accuracy with correlations.
Zhang et al (Zhang et al. 2012) - ICCECT	"PN Sequence Estimation for Weak DSSS"	• Focus: PN sequence period estimation in low SNR DSSS signals. • Method: Wavelet decomposition and power spectrum reprocessing.	• BER: 10^{-6} in AWGN • Bandwidth Expansion: 10-20x • Multipath Tolerance: 50%
Sanjay et al. (Sanjay et al, 2017) CMS	"Spread Spectrum Modulation Performance"	• Focus: Wireless communication advancements. • Solution: Spread spectrum communication. • Results: DSSS-BPSK offers better BER.	• Anti-Jamming: 30dB • Security: Low Probability of Intercept
Mohammed et al.(Mohammed et al., 2023) Alexandria Engineering Journal	"6G Technology: Requirements and Challenges"	• Improvements: Enhances 5G limitations. • Applications: Supports 3D communications and XR/VR. • Requirements: Ultra-low latency and extreme speed	• Latency: Ultra-low (sub-millisecond) • Data Rate: 100x increase (compared to 5G) • Connection Density: 10^6 devices/km²
Astha et al. (Astha et al, 2013) CAC2S	"Spread Spectrum Performance Analysis"	• Analyzes wireless communication performance. • Increases bandwidth and jamming resistance. • Originated in military; now used for analog and digital data.	• Processing Gain (PG): 10 dB to 60 dB. • Bandwidth Expansion: Up to 100 xs.
Adam et al. (Adam et al., 2000)- The University of Texas at Austin	"DS Spread Spectrum"	• Purpose: Ensures secure radar and communications. • Advantages: Security, selective addressing, and interference rejection. • Limitations: Trade-offs required; not all benefits can be used at once.	• Signal Power Density: Lower than narrowband, measured in watts per hertz (W/Hz). • Traffic Growth: 55% per year
Azita et al.(Azita et al, 2020) - IJECE	"eDSSS for SINR Mitigation in LTE-Wi-Fi"	• Issue: LTE data demand increased Wi-Fi offloading. • Challenge: Wi-Fi interference at 2.4 GHz with LTE.	• 4.69% SINR improvement for MUEs. • 17.94% SINR improvement for WUEs. • Optimized chip rate coefficient (α = 0.2).

		• Solution: Enhanced DSSS. • Result: α = 0.2 improved SINR by 4.69% for Mobile Users, 17.94% for Wi-Fi Users.	• Reduced co-channel interference.
Dayana et al (Dayana et al., 2019)-IJECE	"Modified IOTA for 5G Cognitive Radio"	• Issue: Spectrum scarcity. • Solution: Cognitive radio (CR) for spectrum sensing. • Focus: Spectrum sensing in multi-carrier systems. • Result: UFMC-based CR outperforms OFDM in efficiency and data rates.	• Data Rate: 20% improvement. • Spectral Efficiency: 15% better. • Complexity: 10% lower. • SNR: 5 dB improvement. • Latency: 30% faster.
Taeho et al. (Taeho et al, 2013) - JCSE	"Security in DSSS Signals"	• Challenge: Security issues from the broadcast nature of communication. • Countermeasure: DSSS technology to combat jamming. • Enhancements: Keyless DSSS and watermarked DSSS for better security • Innovation: Adaptive DSSS	• Jamming Resistance: Requires 100x stronger signal to jam. • Interference Rejection: 20 dB improvement in SNR. • Privacy: 256-chip spread sequence for privacy. • Usage: Adopted in IEEE 802.11 (Wi-Fi) and IEEE 802.15.4.

5 CONCLUSIONS

The study of Direct Sequence Spread Spectrum (DSSS) techniques in 5G wireless systems demonstrates their critical role in enhancing signal robustness and managing interference. DSSS effectively expands the bandwidth of transmitted signals using pseudo-random noise (PN) sequences, providing improved spectral efficiency and secure communication. The analysis highlights key performance metrics, such as Bit-Error Rate and Signal-to-Noise Ratio.

For instance, the processing gain (G) of DSSS can be expressed as the ratio of the bandwidth of the spread signal (Bs) to that of the original data signal (Bd). In practical scenarios, if Bs=20MHz and Bd=1 the processing gain GGG would be 20, leading to a significant reduction in the BER, potentially achieving values as low as 10−6 under optimal conditions. The SNR is critical for the performance of DSSS, with an ideal scenario yielding an SNR of γ=15dB, which translates to a BER of approximately 1.3×10−5 for Binary Phase Shift Keying (BPSK) modulation.

Additionally, the examination of delay spread emphasizes the importance of addressing inter-symbol interference for maintaining data integrity in high-speed applications. For example, in urban environments, the Root Mean Square (RMS) delay spread can be as high as 200ns , while in more complex environments, it may exceed 1μs, potentially causing severe ISI.

Overall, the integration of DSSS into next-generation 5G networks presents significant potential for improving communication reliability, efficiency, and security, making it a valuable technique for meeting the demands of modern wireless communications.

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