sjst.scst.edu.ly
Surman **J**ournal for **S**cience and **T**echnology
ISSN: Online (2790-5721) - Print (2790-5713)
مجلة صرمان للعلوم والتقنية
Vol **8**, No.1. Jan – May. 2026
Pages: 221 ~ 230

A COMPUTER ENGINEERING APPROACH TO MITIGATING BLIND SPOTS CAUSED BY COVERAGE DEFICIENCY IN WIRELESS NETWORKS

Eenas Suwayd, Nizar Ramadan, Adnan Alrammash
Surman College of Since and Technology, Surman, Libya.
*Corresponding author, e-mail: suwayd.e@scst.edu.ly

الملخص

تتكون الشبكات اللاسلكية الآنية (Ad Hoc Networks) من مجموعة من العقد اللاسلكية المتحركة التي تتواصل فيما بينها دون الحاجة إلى بنية تحتية ثابتة أو إدارة مركزية، حيث يمكن لكل عقدة أن تعمل كمرسل أو مستقبل أو عقدة وسيطة لنقل البيانات. وعلى الرغم من المرونة وسهولة النشر التي تتميز بها هذه الشبكات، إلا أنها تواجه العديد من التحديات الناتجة عن طبيعتها اللامركزية واعتمادها على قنوات الاتصال اللاسلكية، مما يؤثر على موثوقية الشبكة وجودة الخدمة. ومن بين هذه التحديات، تمثل النقاط العمياء، وهي المناطق التي تعاني من ضعف أو انعدام التغطية اللاسلكية، مشكلة رئيسية تؤدي إلى انقطاع الاتصال وتدهور أداء الشبكة. تهدف هذه الدراسة إلى تحليل ظاهرة النقاط العمياء في الشبكات اللاسلكية ودراسة تأثيرها على جودة الاتصالات، بالإضافة إلى اقتراح حلول للحد من آثارها. ولتحقيق ذلك، تم تطوير نموذج محاكاة باستخدام برنامج MATLAB يعتمد على نظام إرسال واستقبال بتعديل إزاحة الطور الرباعية (QPSK) لمحاكاة ظروف القنوات اللاسلكية الواقعية، بما في ذلك الضوضاء البيضاء الغاوسية المضافة (AWGN)، وانحراف تردد الحامل، وأخطاء التوقيت. كما تم تضمين تقنيات المزامنة والتعويض المختلفة في المستقبل لتحسين عملية استعادة الإشارة وتقليل تأثير تشوهات القناة. أظهرت نتائج المحاكاة وجود مناطق ذات انخفاض ملحوظ في شدة الإشارة نتيجة لخسائر الانتشار، والتداخل، والعوامل البيئية المختلفة، مما يؤدي إلى ظهور النقاط العمياء وضعف جودة الاتصال. كما بينت النتائج أن استخدام خوارزميات المزامنة المناسبة، وتحسين توزيع العقد، وتطوير استراتيجيات التغطية، يسهم بشكل فعال في الحد من تأثير هذه النقاط وتحسين موثوقية وكفاءة أنظمة الاتصالات اللاسلكية.

الكلمات المفتاحية: الشبكات اللاسلكية، الشبكات الآنية، النقاط العمياء، تعديل إزاحة الطور الرباعية (QPSK)، المحاكاة باستخدام MATLAB، انتشار الإشارة، معدل خطأ البتات.

Abstract

Wireless ad hoc networks consist of a collection of mobile wireless nodes that cooperate to establish communication without relying on fixed infrastructure or centralized administration. In such networks, each node can function as a transmitter, receiver, or intermediate relay. Despite their flexibility and ease of deployment, wireless networks are vulnerable to several challenges arising from their decentralized architecture and reliance on wireless communication channels. One of the most significant issues is the occurrence of blind spots, which are regions experiencing weak or no signal coverage, leading to communication degradation and reduced network performance. This study aims to investigate the characteristics of wireless ad hoc networks, identify the causes and effects of coverage blind spots, and propose possible solutions to mitigate their impact. MATLAB was employed as a simulation platform to model wireless network behavior and analyze signal distribution within the coverage area. The simulation results revealed the existence of regions with significant signal attenuation, influenced by factors such as node locations, propagation characteristics, and environmental conditions. Furthermore, the study demonstrated that optimizing node placement and improving coverage strategies can effectively reduce blind spots and enhance overall network performance.

Keywords: *Wireless Networks, Ad Hoc Networks, Blind Spots, Coverage Optimization, MATLAB Simulation, Signal Propagation.*

Submitted: *28/03/2026* ***Accepted***: *21/05/2026*

1. Introduction

The rapid development of communication technologies over the past few decades has significantly transformed the way information is exchanged and processed. Among these technologies, wireless networks have emerged as one of the most important innovations due to their flexibility, scalability, and ease of deployment. Unlike traditional wired networks, wireless communication systems provide connectivity without requiring physical cables, allowing users and devices to communicate freely within a certain coverage area [1]. As a result, wireless networks have become essential in numerous applications, including home and office networking, industrial automation, healthcare systems, intelligent transportation, disaster recovery, military operations, and Internet of Things (IoT) environments. Wireless networks can generally be classified into several categories, including Wireless Local Area Networks (WLANs), Wireless Sensor Networks (WSNs), Mobile Ad Hoc Networks (MANETs), and cellular communication networks [2-3].

In particular, Mobile Ad Hoc Networks (MANETs) have attracted considerable attention because they operate without fixed infrastructure or centralized management. In such networks, each node acts not only as a source or destination of information but also as an intermediate relay responsible for forwarding packets to neighboring nodes. This decentralized architecture enables rapid deployment and self-organization, making ad hoc networks suitable for environments where conventional communication infrastructure is unavailable or impractical [4].

Despite their numerous advantages, wireless networks face several challenges that affect their reliability and overall performance. Since communication takes place through wireless channels, transmitted signals are exposed to various propagation phenomena, including path loss, fading, shadowing, interference, and multipath effects. Furthermore, physical obstacles such as walls, buildings, vegetation, and terrain irregularities can attenuate radio signals and degrade communication quality. These factors often result in areas with weak or absent signal strength, commonly referred to as blind spots or coverage holes. The presence of blind spots can significantly impair network performance by increasing packet loss, reducing data throughput, causing communication interruptions, and degrading the quality of service experienced by users. Coverage blind spots represent one of the most critical issues in wireless communication systems because they directly influence network availability and connectivity [5].

Their occurrence depends on several parameters, including the transmission power of wireless nodes, node density, antenna characteristics, signal propagation conditions, environmental obstacles, and the spatial distribution of nodes within the coverage area. In densely populated environments, signal interference and multipath propagation may further contribute to the formation of blind spots. Similarly, in sparse networks, insufficient node density may lead to isolated regions that cannot maintain continuous communication. Several approaches have been proposed in the literature to address the problem of coverage holes and improve wireless network performance. These approaches include optimizing node placement, increasing transmission power, deploying additional relay nodes, using directional antennas, implementing cooperative communication techniques, and applying intelligent routing protocols. Recently, advanced optimization techniques and artificial intelligence algorithms have also been employed to enhance coverage efficiency and dynamically adapt network configurations according to changing environmental conditions. Such methods contribute to improving network reliability, extending coverage areas, and reducing communication failures [6-8].

Simulation tools play a crucial role in studying and evaluating the behavior of wireless networks before actual implementation. Among these tools, MATLAB provides a powerful environment for modeling communication systems, implementing algorithms, performing numerical analysis, and visualizing results. MATLAB enables researchers to simulate signal propagation characteristics, analyze network coverage, and evaluate the influence of different parameters on communication performance. Through simulation, regions with insufficient signal strength can be identified, and the effectiveness of proposed solutions can be assessed under various operating conditions.

Therefore, this study focuses on investigating the problem of blind spots caused by insufficient coverage in wireless networks. It aims to analyze the factors responsible for signal degradation and evaluate possible methods for mitigating their effects. MATLAB-based simulations are employed to model wireless network behavior and examine signal distribution across the coverage area. The findings of this research are expected to contribute to improving network reliability, enhancing communication quality, and providing practical solutions for reducing coverage deficiencies in modern wireless communication systems [9].

Wireless networks are susceptible to several performance limitations due to their decentralized nature and dependence on wireless transmission channels. One of the major issues is the presence of blind spots resulting from insufficient signal coverage [10]. These areas experience weak or absent signals, leading to communication failures and reduced quality of service. Consequently, there is a need to investigate the factors contributing to blind spot formation and to develop efficient approaches for minimizing their impact on network performance. The objectives of this study are as follows:

- To provide an overview of wireless networks and their operational principles.
- To investigate the concept and causes of coverage blind spots.
- To analyze the effects of blind spots on network performance.
- To propose suitable methods for mitigating blind spots and improving signal coverage.
- To employ MATLAB simulation for evaluating wireless network coverage and performance.

2. Experimental Setup and Simulation

A. Simulation Environment

To investigate the effect of coverage deficiencies and signal impairments in wireless communication systems, a simulation model was developed using MATLAB R2023a and the Communication Toolbox. MATLAB was selected because of its powerful capabilities in mathematical modeling, algorithm implementation, signal processing, and performance evaluation. The simulation framework enables the analysis of wireless channel behavior under different transmission conditions and provides a graphical representation of signal propagation and degradation. The proposed model employs Quadrature Phase Shift Keying (QPSK) modulation, which is widely used in modern wireless communication systems due to its spectral efficiency and robustness against noise. The simulation incorporates practical channel impairments to emulate real wireless environments and evaluate the ability of the receiver to recover the transmitted information.

B. System Architecture

The implemented communication system consists of four major subsystems:

1. QPSK Transmitter
2. Wireless Channel Model
3. QPSK Receiver
4. Signal Visualization and Performance Evaluation

1) Transmitter: The transmitter generates binary information sequences represented by ASCII characters. A Barker synchronization sequence is inserted to facilitate frame synchronization at the receiver. The binary stream is then modulated using QPSK modulation and shaped by a square-root raised cosine filter to reduce intersymbol interference and improve spectral characteristics.

2) Channel Model: The wireless channel model emulates realistic propagation conditions. Several impairments are introduced to investigate their influence on communication performance, including:

- Additive White Gaussian Noise (AWGN);
- Carrier frequency offset;
- Phase offset;
- Timing drift between transmitter and receiver;
- Signal attenuation due to propagation losses;
- Channel disturbances caused by obstacles and interference sources.

These effects simulate practical wireless environments where coverage holes and signal degradation may occur.

3) Receiver: The receiver reconstructs the original transmitted message through several processing stages.

- Automatic Gain Control (AGC): The AGC stage stabilizes the received signal amplitude and maintains a constant gain level before further signal processing.
- Coarse Frequency Compensation: A correlation-based frequency estimation algorithm is employed to compensate for large carrier frequency offsets. This stage provides an initial frequency correction and facilitates the convergence of subsequent synchronization processes.

- Symbol Timing Recovery: Timing synchronization is performed using a closed-loop symbol synchronizer based on the Gardner Timing Error Detector. This stage compensates for timing deviations introduced by channel delays and clock mismatches.
- Fine Frequency and Phase Synchronization: Residual frequency and phase errors are corrected using a Phase Locked Loop (PLL) implemented through the Carrier Synchronizer block.
- Frame Synchronization: The receiver detects the Barker synchronization sequence and reconstructs fixed-length frames from the received data stream.
- Data Demodulation and Error Detection
- Finally, the synchronized symbols are demodulated and converted back into binary data. The reconstructed message is compared with the original transmitted sequence to calculate the Bit Error Rate (BER).

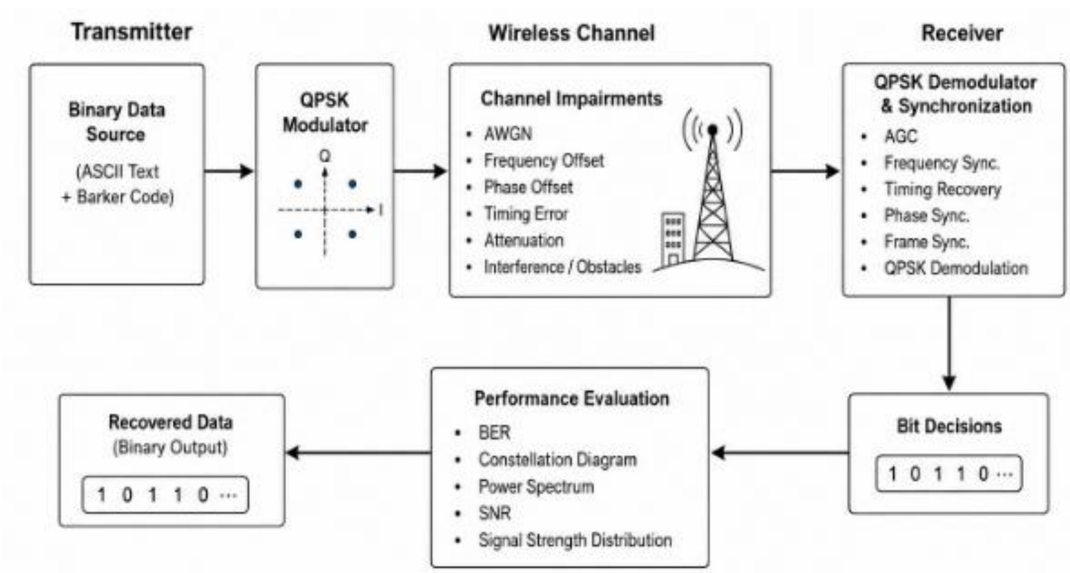

Figure 1: Overall Architecture of the Proposed QPSK-Based Wireless Communication System.

Figure 1 illustrates the simplified architecture of the proposed QPSK-based wireless communication system employed in this study. The system consists of three main components: the transmitter, the wireless channel, and the receiver. At the transmitter, binary information generated from ASCII data and a Barker synchronization sequence is mapped into QPSK symbols before transmission. The transmitted signal propagates through a wireless channel that introduces several impairments, including additive white Gaussian noise (AWGN), frequency offset, phase offset, timing errors, attenuation, and interference caused by obstacles.

These impairments may degrade signal quality and create coverage deficiencies or blind spots. At the receiver, synchronization and demodulation processes are performed to compensate for channel distortions and recover the transmitted information. Finally, the performance of the communication system is evaluated using several metrics, including bit error rate (BER), signal constellation diagrams, power spectrum, signal-to-noise ratio (SNR), and signal strength distribution. This architecture provides a practical framework for analyzing the impact of channel impairments and investigating methods for improving communication reliability and reducing coverage blind spots in wireless networks.

C. Simulation Procedure

The simulation processes one frame at a time. During each iteration, the transmitter generates the modulated signal, which is propagated through the wireless channel model. The receiver then performs synchronization, frequency compensation, and demodulation operations to recover the transmitted information. The simulation workflow can be summarized as follows:

1. Generation of binary data;
2. QPSK modulation;
3. Channel impairment insertion;
4. Signal reception;
5. Timing recovery;
6. Carrier synchronization;
7. Frame synchronization;
8. Data demodulation;
9. BER calculation.

D. Performance Metrics: The communication system performance was evaluated using the following parameters:

- Bit Error Rate (BER);
- Signal constellation diagrams;
- Power spectral density;
- Signal-to-noise ratio (SNR);
- Received signal amplitude distribution;
- Spatial signal strength distribution.

These metrics provide insight into the effects of noise and propagation impairments on system reliability and coverage quality.

3. Results

Several simulation scenarios were conducted to evaluate the behavior of the communication system under different channel conditions.

A. Ideal Transmission Scenario: Under ideal conditions, the received constellation points were concentrated around their theoretical positions, resulting in a low BER and stable signal reception.

B. Noisy Channel Scenario: When Additive White Gaussian Noise was introduced, dispersion of the constellation points increased, causing higher symbol detection errors. Consequently, the BER increased as the signal-to-noise ratio decreased.

C. Signal Attenuation and Coverage Deficiency: The simulation revealed regions with reduced signal intensity caused by attenuation and propagation losses. These regions correspond to coverage holes or blind spots where communication quality deteriorated significantly. Obstructions between transmitter and receiver further intensified signal degradation.

D. Signal Strength Distribution: Spatial analysis of the received signal demonstrated non-uniform coverage characteristics. Strong signal regions were observed near the transmitter, whereas signal power gradually decreased with increasing distance, producing weak coverage zones.

E. Constellation Analysis: Constellation diagrams after timing and frequency synchronization showed that the proposed receiver architecture successfully compensated for channel impairments and improved symbol detection accuracy.

4. Discussion

The performance of the proposed QPSK communication system was evaluated by executing the System Under Test (SUT) script in MATLAB. The simulation was performed under different channel conditions in order to assess the ability of the receiver to compensate for channel impairments and accurately recover the transmitted information. After initializing the system parameters, the transmitter generated QPSK-modulated signals, which were subsequently propagated through a wireless channel affected by additive white Gaussian noise (AWGN), carrier frequency offsets, and timing errors. Upon execution, the receiver performed automatic gain control, coarse and fine frequency compensation, symbol timing recovery, and frame synchronization.

The recovered bit stream was then compared with the transmitted data to determine the communication performance in terms of the Bit Error Rate (BER). The BER values were calculated automatically and used as the primary performance indicator of the implemented system. In addition to the numerical BER measurements, MATLAB provided several graphical outputs for analyzing the signal behavior throughout different stages of the receiver. These graphical results included constellation diagrams of the received signal after the square-root raised cosine receiver filter, after symbol synchronization, and after fine carrier frequency compensation. Furthermore, the power spectrum of the received signal was displayed to illustrate the spectral characteristics of the communication channel.

Figure 2 shows the execution of the MATLAB code and the beginning of the data acquisition process. The generated plots provide a visual representation of the signal quality and demonstrate the effectiveness of the synchronization and compensation algorithms implemented in the receiver.

sjst.scst.edu.ly
Surman **J**ournal for **S**cience and **T**echnology
ISSN: Online (2790-5721) - Print (2790-5713)
مجلة صرمان للعلوم والتقنية
Vol **8**, No.1. Jan – May. 2026
Pages: 221 ~ 230

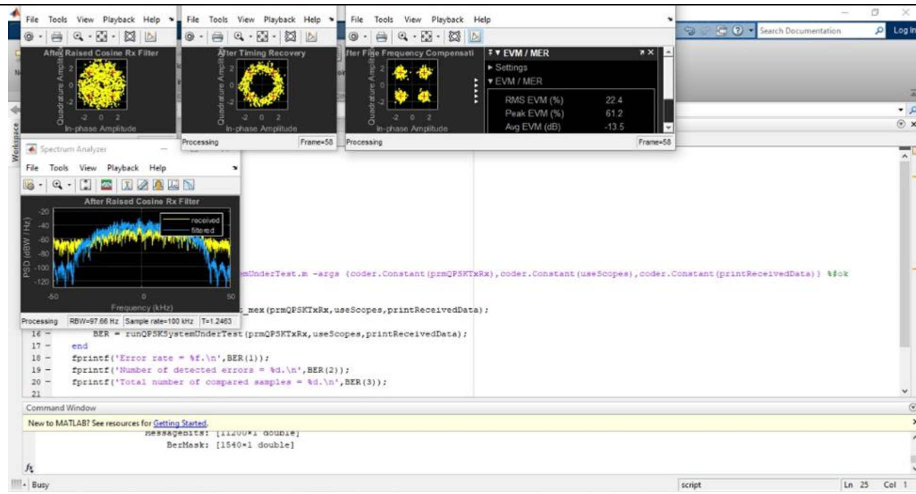

Figure 2: shows the execution of the MATLAB code.

The simulation results indicate that the proposed receiver architecture successfully compensates for channel impairments and restores the transmitted symbols with high accuracy. Under ideal channel conditions, the constellation points remain concentrated around their theoretical positions, resulting in a very low BER. However, when noise and propagation disturbances are introduced, the constellation points become dispersed, leading to increased symbol detection errors and higher BER values. Furthermore, the obtained results reveal the existence of regions with reduced signal strength caused by attenuation and channel disturbances. These regions correspond to coverage deficiencies or blind spots, where communication quality deteriorates significantly. The analysis of signal strength distribution demonstrates that strong signal levels are observed near the transmitter, while the received power gradually decreases with increasing distance and in the presence of obstacles. Such behavior confirms that environmental conditions and propagation effects have a substantial impact on wireless communication performance. Overall, the simulation results demonstrate that the implemented synchronization and compensation techniques effectively improve signal recovery and reduce transmission errors. The obtained BER values and graphical observations validate the proposed model and provide valuable insights into the influence of channel impairments and coverage limitations on the reliability of wireless communication systems. Figures MATLAB execution window showing the simulation process and the beginning of result acquisition. Figure 3(a) Simulation results show network interference. Figure 3(b) Simulation results and signal strength locations.

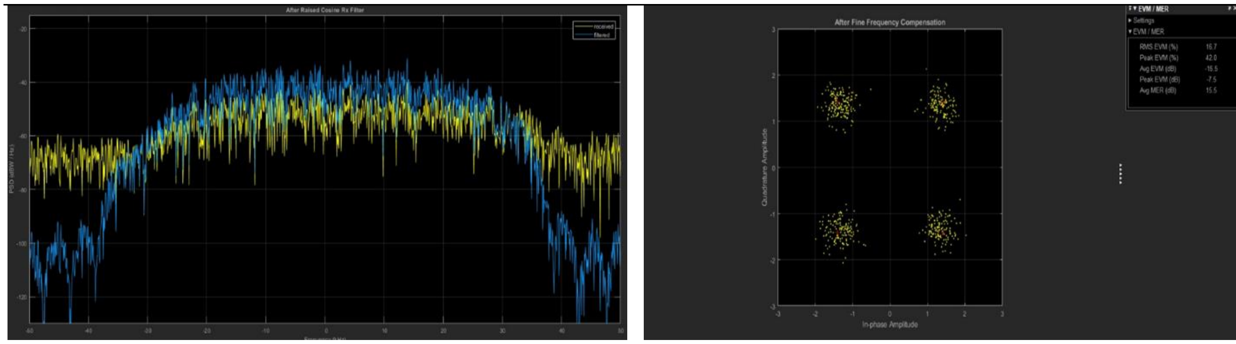

Figure 3: (a) results show network interference. (b): signal strength locations.

The simulation results demonstrate that channel impairments, including noise, timing errors, frequency offsets, and propagation losses, considerably affect wireless communication quality. Coverage blind spots emerge primarily due to signal attenuation and environmental obstacles. The implemented synchronization techniques effectively reduced these effects and improved data recovery performance. Furthermore, the results indicate that increasing transmission power, optimizing node placement, and employing advanced synchronization algorithms can significantly enhance coverage quality and reduce communication failures in wireless networks.

7. Conclusion

This paper presented an experimental investigation of coverage deficiencies and signal impairments in wireless communication systems using a MATLAB-based QPSK transmitter and receiver model. The proposed system was designed to emulate realistic wireless channel conditions by incorporating additive white Gaussian noise (AWGN), carrier frequency offsets, phase shifts, and timing deviations. Several synchronization and compensation techniques, including automatic gain control, coarse and fine frequency synchronization, symbol timing recovery, and frame synchronization, were implemented to improve signal recovery and communication reliability. The simulation results demonstrated that channel impairments have a significant impact on the quality of the received signal and the overall system performance. Under ideal transmission conditions, the constellation points remained close to their theoretical locations, resulting in a low Bit Error Rate (BER). However, the presence of noise, attenuation, and propagation disturbances caused constellation spreading and increased the BER, indicating degradation in communication quality.

Furthermore, the spatial analysis of the received signal revealed the existence of regions with weak signal strength, referred to as coverage blind spots. These regions were mainly caused by propagation losses, environmental obstacles, and interference effects. The results showed that signal power decreases as the distance between the transmitter and receiver increases, leading to non-uniform coverage characteristics. The implemented synchronization algorithms proved effective in mitigating the effects of channel impairments and improving signal detection accuracy. The receiver architecture successfully compensated for frequency and timing offsets, enabling reliable reconstruction of the transmitted data even in the presence of channel disturbances. Overall, the study confirms that wireless communication performance is strongly influenced by channel conditions and signal propagation characteristics. MATLAB simulations provided a useful platform for analyzing signal behavior and evaluating system performance under different operating conditions. The obtained results contribute to a better understanding of coverage deficiencies and their impact on wireless networks.

References

1. T. S. Rappaport, Wireless Communications: Principles and Practice, 2nd ed. Upper Saddle River, NJ, USA: Prentice Hall, 2002.
2. A. Goldsmith, Wireless Communications. Cambridge, U.K.: Cambridge University Press, 2005.
3. S. Haykin and M. Moher, Modern Wireless Communications. Upper Saddle River, NJ, USA: Pearson Education, 2005.
4. J. G. Proakis and M. Salehi, Digital Communications, 5th ed. New York, NY, USA: McGraw-Hill, 2008.
5. T. M. Cover and J. A. Thomas, Elements of Information Theory, 2nd ed. Hoboken, NJ, USA: Wiley, 2006.
6. B. Sklar, “Rayleigh Fading Channels in Mobile Digital Communication Systems—Part I: Characterization,” IEEE Communications Magazine, vol. 35, no. 7, pp. 90–100, Jul. 1997.
7. S. M. Alamouti, “A Simple Transmit Diversity Technique for Wireless Communications,” IEEE Journal on Selected Areas in Communications, vol. 16, no. 8, pp. 1451–1458, Oct. 1998.
8. MathWorks, “QPSK Transmitter and Receiver Example,” Communications Toolbox Documentation, The MathWorks Inc., Natick, MA, USA, 2023.
9. C. E. Perkins, E. M. Royer, S. R. Das, and M. K. Marina, “Performance Comparison of Two On-Demand Routing Protocols for Ad Hoc Networks,” IEEE Personal Communications, vol. 8, no. 1, pp. 16–28, 2001.
10. A. J. Goldsmith and S. B. Wicker, “Design Challenges for Energy-Constrained Ad Hoc Wireless Networks,” IEEE Wireless Communications, vol. 9, no. 4, pp. 8–27, Aug. 2002.