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Qusay Jalil Kadhim, Abdullah Al-Husseini and Mohanad Al-Ibadi

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Accuracy Comparison of Hard, Soft, and UnQuantized Decisions across Diverse MIMO Channels and M-QAM Demodulation

[1*]Qusay Jalil Kadhim
Techniques Engineering, Technical Engineering College-Najaf/Al-Furat Al-Awsat Technical University, Iraq

Abdullah Al-Husseini
Avionics Techniques Engineering, Technical Engineering College-Najaf/Al-Furat Al-Awsat Technical University, Iraq

Mohanad Al-Ibadi
Avionics Techniques Engineering, Technical Engineering College-Najaf/Al-Furat Al-Awsat Technical University, Iraq

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Abstract

Purpose: In this paper, hard, soft, and non-quantized Viterbi decision algorithms are examined and compared over multiple-input multiple-output (MIMO), Quadratic amplitude modulation, QAM schemes, and M-ary channels.

Methodology: The proposed system supports the design methodology of a decoding scheme of the LLR algorithm between MIMO and M-ary channels. The proposed system is designed and tested using MATLAB.

Findings: The results provide valuable insights into the balance between computational efficiency and decoding accuracy, which helps in choosing appropriate decision algorithms for specific MIMO and M-QAM communication systems. The results demonstrated different scenarios, including MIMO (2x2), (4x4), and M-ary (4,16, and 32 QAM) technologies.

Unique Contribution to Theory, Practice and Policy: Experimental results show that although non-quantized decisions achieve the highest accuracy, they require significantly more computational resources. Hard decisions provide simpler implementation with lower computational costs but lower accuracy. The soft decision-making method balances performance and complexity and outperforms hard choices regarding bit error rate (BER) in all tested scenarios. It also enhances our understanding of Viterbi decoding in LLR estimation across different connectivity conditions. The scenarios showed that the soft solution is better than the hard solution, as previously known, depending on the conditions. However, from the results obtained using Matlab simulations, the silky solution appears to be the best in terms of the balance between complexity and better performance as the data show.

Keywords: *Bit Error Rates (BER), Convolutional Encoding, Soft-decision, Hard-decision, Log Likelihood Ratio (LLR), Multi Input Multi Output (MIMO), M-QAM*

INTRODUCTION

The demand for data transmission technologies has become very high with the continuous development of wireless communication systems. Multiple input multiple output (MIMO) configurations and advanced modulation schemes such as quadrature amplitude modulation (QAM) have appeared, among the most prominent factors that enable increased efficiency to achieve transmission rates and Enhanced data. On this basis, the accuracy of information retrieval at the receiving end depends on the issue of decryption, as it plays an essential role in this process (El Ouakili, Touati, Kadi, Mehdaoui, & El Alami, 2023).

In (El Ouakili et al., 2023), The researchers demonstrated the effectiveness and efficiency of the hard decision better than the soft decision in conditions far from discussing the type of transmission and without a MIMO channel. He obtained better results by proposing a new algorithm to improve the bit error rate (BER).

The research which was published in 2021, compared the performance of the bit error rate with various types of modulation and with different AWGN and Rayleigh fading channels for different modulation systems. Not to mention the MIMO techniques and the type of coding (Ahmed, Ahmed, & Islam, 2021).

The work of (Cao, Liu, & Hu, 2019), proposed a condensed method to calculate the log-likelihood ratio (LLR) for m-QAM demodulation. The traditional approach to LLR calculation aims to demodulate the m-QAM. System performance and complexity are compared between simplified and traditional techniques. Simulation results show that the simplified approach may significantly reduce computations without impacting system performance.

The analysis of the system performance was discussed for the modulations BPSK, QPSK, M-PSK, D-BPSK, D-QPSK, and with different transmission MIMO channels for the AWGN channel and modification of the fading channel such as the Rayleigh and Rician fading channel. Through the presented research in 2021(Bala, Waliullah, Rahman, Abdullah, & Hossain, 2021).

The study in (Vaigandla, Allanki, Srikanth, Study, & Ijmtst, 2021), demonstrates how the Viterbi Algorithm (VA) for binary Hamming and non-binary Reed-Solomon (RS) block codes increases the Bit Error Rate (BER) by utilizing Channel State Information (CSI). The benefits of CSI-enhanced soft decision decoding diminish in flat fading channels when Doppler spreading to symbol rate ratios decrease. While preserving optimal BER in AWGN channels, the suggested trellis reduction approach makes trellises simpler. However, BER performance marginally deteriorates under flat fading situations with fewer trellises.

The thesis (P. Fertl, Jalden, & Matz, 2012; Peter Fertl, Jaldén, & Matz, 2009), examined in detail and contrasted the roles played by hard and soft demodulators. For non-redundant MIMO-BICM systems. A comparison of concepts from information theory forms the basis of the work. The investigator has gathered signs that the performance of the demodulator cannot be classified as universal. Performance can be greatly affected by the system's operating rate (or similar signal-to-noise ratio). In addition to the comfortable energy results, he also considered outages for the non-comfortable fading scenario. Examining the probability, capacity, and robustness of some demodulators when faulty channels are present. The study's approach highlights issues that have been missed in previously used BER performance comparisons.

Overview of binary and non-binary linear trellis decoding Block codes that utilize the Viterbi algorithm (VA) can be found in (Staphorst & Linde, 2003) on a range of mobile channels. In addition to accounting for channel state information (CSI) in the VA branch metrics computation, both soft and hard resolution decoding are considered. A thorough simulation analysis is presented to verify the effectiveness of VA as a decoder of ML block codes. Simulation results for both soft and hard Decisions are obtained. The Accuracy works in the presence of additive white Gaussian noise (AWGN) and flat fading channel conditions, decoding binary Hamming blocks and non-binary Reed-Solomon (RS) blocks. There is also a comparison between the BER performance of reduced and non-reduced trellises. Additional consideration is provided. Effect of CSI on BER performance for Viterbi decoded line block codes. The study did not discuss the encapsulation method and MIMO technology (Mosleh & Abid, 2013).

The focus on decoding convolutions through the Viterbi algorithm, which is known for its effectiveness, is a pivotal point in the research. Specifically, validation of the hard decision accuracy of Viterbi in likelihood ratio (LLR) demodulation was studied. While adding a new level of complexity to the communications system, the inclusion of M-QAM modulation provides a flexible way to balance signal flexibility and spectral efficiency. Carefully evaluating Viterbi decoding accuracy in different environments is becoming more important as communications technologies advance to maximize system efficiency and ensure reliable data transmission (Ahmed et al., 2021; Babu & Rao, 2011).

This work conducts a comprehensive investigation of the influencing factors associated with achieving a balance between performance and accuracy of the Viterbi soft decision method, paying particular attention to LLR demodulation, different MIMO channel arrangements, and the effect of M-QAM modulation schemes. Through in-depth research and testing, we understand the finer details of Viterbi's decoding accuracy, and the purpose of this study is to highlight how well Viterbi soft Decision technology works in different MIMO channel conditions and the modulation characteristics of M-QAM in LLR demodulation situations. The research results provide useful knowledge that increases the understanding of decoding processes in the complex environment of today's communications networks. The results described and demonstrated in the study can potentially improve the efficiency and reliability of information transmission by influencing the design and improvement of wireless communications networks.

SYSTEM MODEL

Accurate signal demodulation in the face of many obstacles, including noise, interference, and variable channel conditions, is critical for communications systems in general. In this context, the Viterbi Soft decision demodulation technology is vital because it provides flexibility, reliability, and a balance between complexity and accuracy to the system, especially when combined with likelihood ratio (LLR) estimation.

This work aims to validate Viterbi's soft decision demodulation in LLR estimation, especially in cases where multi-input quadratic amplitude modulation (MIMO) and M-ary quadratic amplitude modulation (M-QAM) systems have different channel topologies. The following is a description of the system model used in this research, which is based on the Matlab program shown in Figure 1(Vaigandla et al., 2021) (Wali, Fayadh, & Al_taee, 2018).

Figure 1 explains the sequential block diagram of the communication system. with Convolutional code, M-QAM Modulation, MIMO Fading Channel, Demodulation, and Decoder (P. Fertl et al., 2012; Peter Fertl et al., 2009) (Gupta, Merchant, & Desai, 2018).

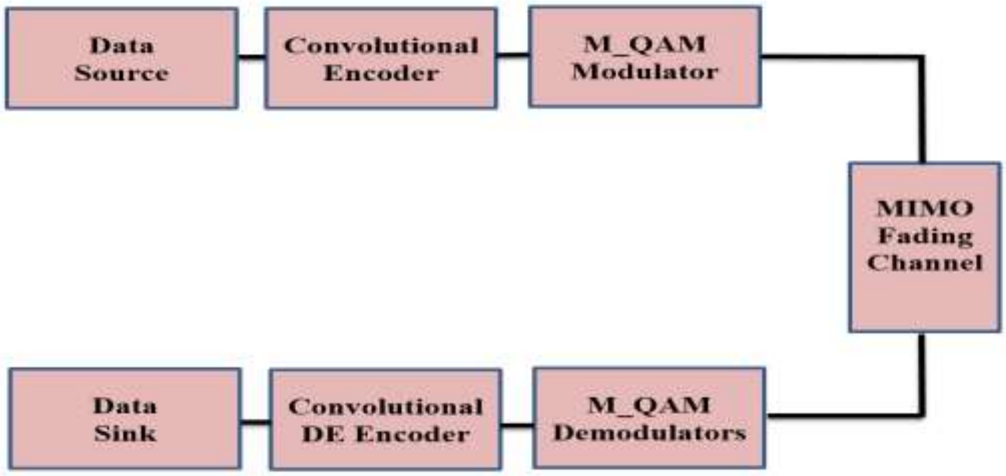

Figure 1: Block Diagram of a Communication System with Convolutional Code & MIMO Channel

The block diagram of a Communication System illustrates the process of digital communication using convolutional coding, M-QAM modulation, and MIMO technology. Data Source, Represents the original data in digital form and is the result of converting the original message (image, text, video, audio). From the experiments and previously published research, errors occur during the communication process, so it provides a Forward Error Correction (FEC) mechanism. It adds redundancy to the data by encoding it using convolutional codes (convolutional encoder). This redundancy helps detect and correct errors during transmission over the noisy channel.

The M-QAM Modulator converts encoded bits into symbols using M-ary Quadrature Amplitude Modulation (M-QAM), indicating the number of distinct amplitude and phase combinations in the constellation diagram, converting binary data into a suitable form for transmission over a physical channel. The MIMO fading channel is the physical medium through which signals propagate, using multiple antennas for improved data rates and reliability, and refers to variations in signal strength due to multipath propagation and environmental factors. These decoders employ methods to rehabilitate the integrity of the original signal. They are M-QAM decoders that restore genuine binary data from channel distortions and noise, ensuring reliable communication over complicated and noisy channels.

After the received signal has been corrected for distortions, it is assigned to the nearest symbol in the M-QAM constellation. The decoder translates the symbol into its binary counterpart, ensuring that the retrieved data roughly aligns with the originally supplied information. Error correction can be utilized to rectify any residual errors, guaranteeing that the recovered data aligns with the original transmitted information as nearly as feasible. The convolutional decoder is an essential element in communication systems, processing incoming bits to correct mistakes induced by noise, interference, or signal deterioration. It generates data redundancy, enabling the decoder to identify and rectify errors. The approach frequently employs techniques such as the Viterbi algorithm, which evaluates the most likely original bit sequence according to the structure of the convolutional code. The decoder reconstructs the original bitstream and

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corrects transmission errors, ensuring precise data recovery and maintaining data integrity across various communication networks. The data sink is an essential communication system component, acting as the ultimate termination location for sent information. It organizes and presents data, including files or video streams, according to the requirements of the receiving system or user. The sink guarantees the accurate reception of information, enabling it to fulfill its intended purpose by delivering the data in a usable manner and finalizing the transmission process (Mahmood Farhan & Fa'aza Abbas, 2013)

AWGN Channel

Additive white Gaussian noise (AWGN) is frequently used to simulate the behavior of noisy real-world communication networks. The design and analysis of communications systems depend heavily on an understanding of the AWGN channel as it provides information on how noise affects signal transmission and reception (Wali et al., 2018) (Rahman, Godder, Singh, Parvin, & Rahman, 2021).

As the broadcast signal moves across the communication channel, noise is added to it. This noise is not related to the original signal and is typically produced by a variety of things, including electrical parts, the surrounding environment, or interference from other signals. This noise has an identical power at every frequency within a certain frequency range, or a flat power spectral density (Rahman et al., 2021).

The AWGN channel's noise follows a Gaussian distribution. The statistical characteristics of Gaussian noise are determined by its mean and standard deviation. Because noise in the AWGN channel causes mistakes and distortions in the sent signals, it lowers the quality and dependability of communication systems. The quality of communication in the presence of noise is determined by the signal-to-noise ratio (SNR), which is the ratio of signal intensity to noise strength (Wali et al., 2018).

Communication systems employ several mitigation strategies to lessen the impact of noise in the AWGN channel. These methods include equalization, modulation schemes, error correction coding, and signal processing algorithms that enhance signal identification and decoding in noisy environments (Rahman et al., 2021).

Real or complex input signals are given a white Gaussian noise introduction using the AWGN Channel block. To create a genuine output signal, real Gaussian noise is applied to actual input signals. Complex output signals are produced by adding complex Gaussian noise to complex input signals. The input signals define this block's sampling time. The AWGN channel model is widely used for studying communication networks. White noise with a fixed spectral density is linearly supplied with a Gaussian noise amplitude. Furthermore, interference, frequency selection, and fading are not taken into consideration. It is still recognized as providing clear mathematical representations (Rahman et al., 2021; Rindani & Bavarva, 2013).

SNR, which measures signal intensity relative to noise, is strongly related to the AWGN channel's effect. Symbol detection accuracy during decoding depends on SNR. SNR is high, channel noise is low, and received symbols are unlikely to stray from their modulation constellation places. Incorrect symbols are less likely. However, with low SNR, noise increases, deviating symbols further from their original places and increasing the likelihood of inaccurate detection and symbol mistakes. SNR and error probability crucially affect system performance. Communication system dependability improves as SNR increases because BER and SER drop. However, noise can dominate the signal at low SNR levels, causing errors and

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system degradation. Designing systems that work at varied SNR levels is crucial. Modulation schemes are also affected by SNR. The numerous constellation points of 64-QAM and 256-QAM make them more noise-sensitive. To reduce errors, these methods need high SNR. Low-order modulation methods like 4-QAM or 16-QAM are more noise-resistant and work better at lower SNRs. To improve performance, communication systems adapt modulation order based on SNR. The Signal-to-Noise Ratio (SNR) is a measure of the strength of a signal relative to the background noise. It is typically expressed in either linear terms or decibels (dB). The SNR equation can be written as in equations (1) and (2) (Bala et al., 2021):

Linear Form:

$$\text{SNR}= \frac{(\text{Power of the signal})}{(\text{Power of the noise})} \tag{1}$$

In Decibels (dB):

$$\text{SNRdB} = 10 * \text{Log}_{10}\left(\frac{(\text{Power of the signal})}{(\text{Power of the noise})}\right) \tag{2}$$

The logarithmic scale (dB) is commonly used because it simplifies calculations when dealing with very large or small values and makes the values easier to interpret.

Relation to Energy per Bit (for Digital Communication):

In digital communication systems, the SNR can also be expressed in terms of energy per bit (E_b) and noise power spectral density (N_0):

$$\frac{E_b}{\boldsymbol{N_o}} = \frac{\textbf{SNR}}{\boldsymbol{R_b}} \tag{3}$$

Here:

E_b: Energy per bit

N_0: Noise power spectral density

R_b: Bit rate

Finally, AWGN channels introduce noise that impacts demodulation and system performance, with SNR determining error rates and modulation scheme efficiency. Communication systems can operate well in noisy situations by recognizing and accounting for SNR (Bala et al., 2021).

Rayleigh Fading Channel

Rayleigh fading is mostly caused by multiple paths of multiplex receivers. For Rayleigh fading channels, there are multipath components that have unpredictable phases and amplitudes. One of the key ideas in wireless communication theory is the Rayleigh vanishing channel, especially concerning cellar and mobile wireless communication systems (Hasan, 2018).

The Rayleigh distribution is often used by mobile radio stations. This statistical model may be used to analyze radio signals and evaluate the effects of propagation conditions. This model may be used to depict the impact of heavily populated metropolitan areas on radio transmissions, as well as the propagation of signals at the troposphere and ionosphere. It is known that the envelopes of sums of Gaussian noise signals in quadrature are governed by Rayleigh distributions (Rindani & Bavarva, 2013).

Rayleigh dispersed signals' time-dependent envelope. When there is a line-of-sight break between the transmitter and the receiver, Rayleigh fading is most advantageous (Hasan, 2018). It represents multipath propagation, which is the process by which signals travel through several pathways to reach the receiver as a result of environmental objects' reflection, diffraction, and scattering (Rindani & Bavarva, 2013).

In a MIMO system, Rayleigh fading is the statistical distribution of the fading process that each distinct channel between the transmitter and the receiver goes through. MIMO systems use multiple antennas at both broadcasters and receivers to provide multiplex gain and spatial diversity. Spatial diversity improves system reliability by taking advantage of the fact that each antenna's fading might differ based on its geographic location from the others. Conversely, gain multiplexing increases the data throughput of the system by utilizing additional spatial dimensions. In multi-antenna MIMO systems with Rayleigh fading, the entire channel array consists of many fading components, one for every pair of antennas.

The result of multiple paths in systems (MIMO) is signal fluctuations, which is what characterizes the phenomenon of Rayleigh fading. Spatial diversity and spatial multiplexing can be used to improve performance. Spatial diversity improves reliability by reducing the probability of simultaneous deep fading across all paths, thereby enhancing the bit error rate (BER) and providing reliable communication in fading channels. Data rates in spatial multicast are improved by transmitting two separate data streams at the same time. Zero-force (ZF) and minimum mean square error (MMSE) techniques are used to decode the transmitted streams by inverting the channel matrix. This allows the system to achieve twice the data rate of a single antenna system under optimal conditions. Spatial variety in Rayleigh fading enhances connection dependability by alleviating deep fading, which is advantageous for substantial signal fluctuations. Spatial multiplexing enhances data speeds in high-throughput applications. MIMO systems achieve optimal performance by consistently alternating between techniques to maintain reliability and efficiency (Jiao et al., 2020; Verma, Mahajan, & Rohila, 2008; Xu et al., 2017).

Convolutional Codes in MIMO Channel

Convolutional codes are extensively employed in communication systems to provide error-correcting capabilities, and they may be utilized in a variety of channel situations, including Multiple Input Multiple Output (MIMO) channels. Convolutional codes have a role in improving data transmission reliability in MIMO systems, which employ many antennas for both sending and receiving (Arevalo, De Lamare, Zu, & Sampaio-Neto, 2014).

The collection of all code words created by a convolutional encoder, which is generally a linear sequential circuit with or without feedback, is referred to as a convolutional code. The coding rate and memory are critical factors of an encoder. The number of delay elements in the encoder circuit determines the memory of a convolutional encoder. A binary convolutional encoder with a rate of “k/n” produces an n-bit word for every k-bit word at the input. A binary convolutional code may be represented as a three-tuple (n, k, and m). This encoder generates n output bits for every k input bit it receives, and its current n outputs are linear combinations of its previous $m \times k$ input bits and its current k input bits. The reason m is termed the memory order of the convolutional code is that it indicates how many prior k-bit input blocks the encoder needs to commit to memory (Yang, Huang, Li, & Ueng, 2014).

The performance assessment of MIMO-OFDM systems emphasizes the analysis of their efficacy under diverse settings. The system's performance is generally evaluated using important metrics including bit error rate (BER) and signal-to-noise ratio (SNR). Evaluations are performed across several channel settings, including Additive White Gaussian Noise (AWGN) channels, to assess the system's ability to preserve signal integrity and transmission accuracy. The performance assessment of MIMO systems emphasizes the analysis of their efficacy under diverse settings. The system's performance is generally evaluated using important metrics including bit error rate (BER) and signal-to-noise ratio (SNR). Evaluations are performed across several channel settings, including Additive White Gaussian Noise (AWGN) channels, to assess the system's ability to preserve signal integrity and transmission accuracy (Bala et al., 2021).

Hard-Decision Viterbi Algorithm

In a convolutional code, the input sequence x is "convoluted" to the encoded sequence c. Sequence r is received and acquired following the transmission of sequence c via a noisy channel. By estimating the maximum likelihood (ML) from the received sequence r, the Viterbi approach maximizes the probability p(r/y) that sequence r is received, conditioned on the estimated code sequence y. Sequence y must belong to the list of allowed coding sequences; it cannot be any arbitrary sequence. Convolutional code in a communication system channel is seen in Figure 2. Less difficult calculations are one of the most important benefits: the difficult judgments resulting from binary options reduce the number of calculations required. Simplicity of implementation: Less complex techniques are usually needed to create difficult decision-making algorithms. There is a dualistic nature in mathematics. The system may find it more difficult to manage inaccurate situations when binary results result in missing data. Making quick decisions in ambiguous or distracted environments may increase the possibility of errors or partial loss of a signal of important information (Ebrahimzadeh Saffar, Alajaji, & Linder, 2009; Jiao et al., 2020; Mosleh & Abid, 2013; Ning, 2019).

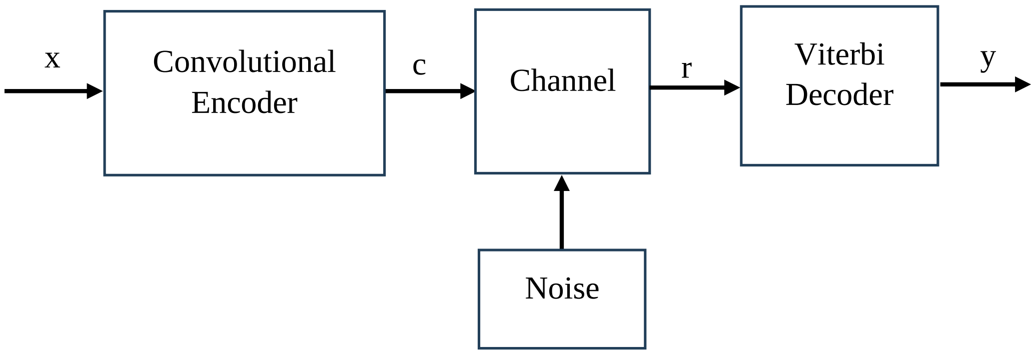

Figure 2: Communication System with Convolutional Code

Soft-Decision Viterbi Algorithm

A soft-decision Viterbi algorithm may be implemented in two broad ways. The first way (way 1) employs the Euclidean distance metric rather than the Hamming distance metric. Multi-bit quantization processes the received bits that are utilized in the Euclidean distance metric (Aubert, Anchora, & Nouvel, 2011).

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The second method (Way 2) uses a correlation measure and further applies multi-bit quantization to the received bits used in the metric. Enhancing resilience to mistakes: Soft decisions provide a probabilistic measure of confidence in a choice, enabling them to manage chaotic circumstances more skillfully (Kang et al., 2014; Li, Zhang, Li, & Ning, 2020).

More detailed information: Soft decision outputs provide a more comprehensive description of the underlying data, facilitating improved adaptation to conditions. These points mentioned above are positives of soft decision. Increased computational complexity: Soft decision-making methods require more advanced algorithms and greater computing power, and these are considered disadvantages. Also, the challenges of implementation may be that putting soft decision systems into practice may be more difficult and require advanced hardware and software solutions. Figure 3 illustrates the block diagram of comparison between the hard and soft decisions. Hard Decision & Soft Decision Paths Computer simulation or analytical methods can be used to quantify the performance of convolutional algorithms. The analytical method relies on the convolutional code's transfer function, which may be acquired from the state diagram (Aubert et al., 2011; Li et al., 2020; Mosleh & Abid, 2013; Staphorst & Linde, 2003).

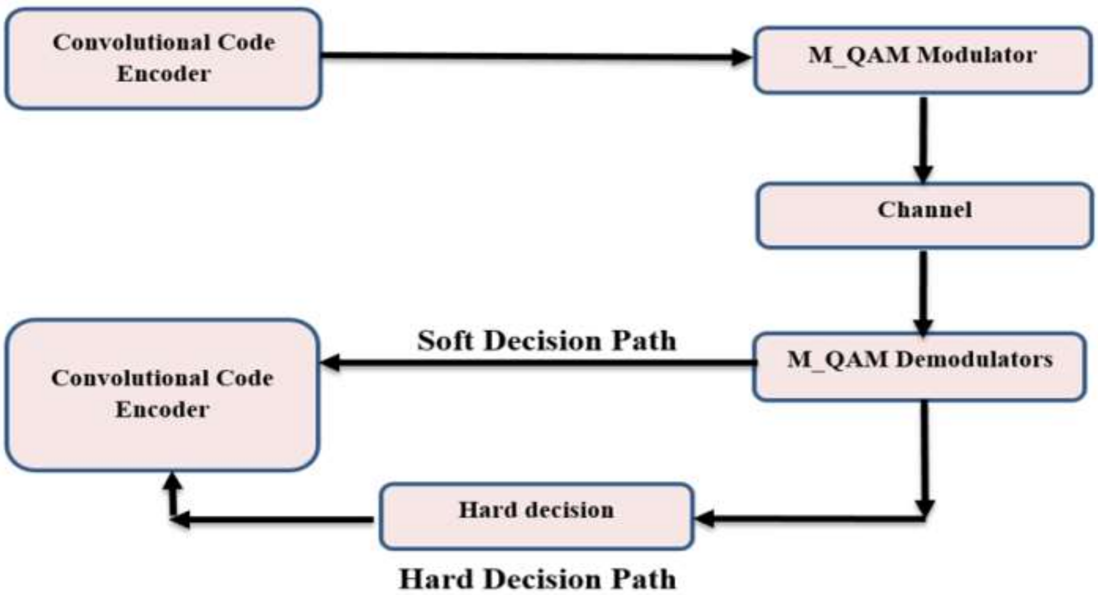

Figure 3: Hard Decision & Soft Decision Path

It is illustrated in the figure (8,9,10 and 11)

RESULTS

The results shown below were obtained through experiments in Matlab. The special environment was also used for communications systems, especially digital signal processing. Which is distinctively available in the program and environment mentioned above, through analysis of the BER standard for: -

- Hard Decision Decoding
- Soft Decision Decoding
- Unquantized Decision Decoding

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In different MIMO channels 2x2 and 4x4 with different M_QAM.

The practice block diagram in Figure 4 refers to the (source, binary Data, Convolutional Encoder, and M-QAM Modulation). Whereas the sequential block diagram in Figure 5 is the MIMO Channel technique. The Figure 6 is the HRAD, SOFT, and UNQUNTIZED DECISION.

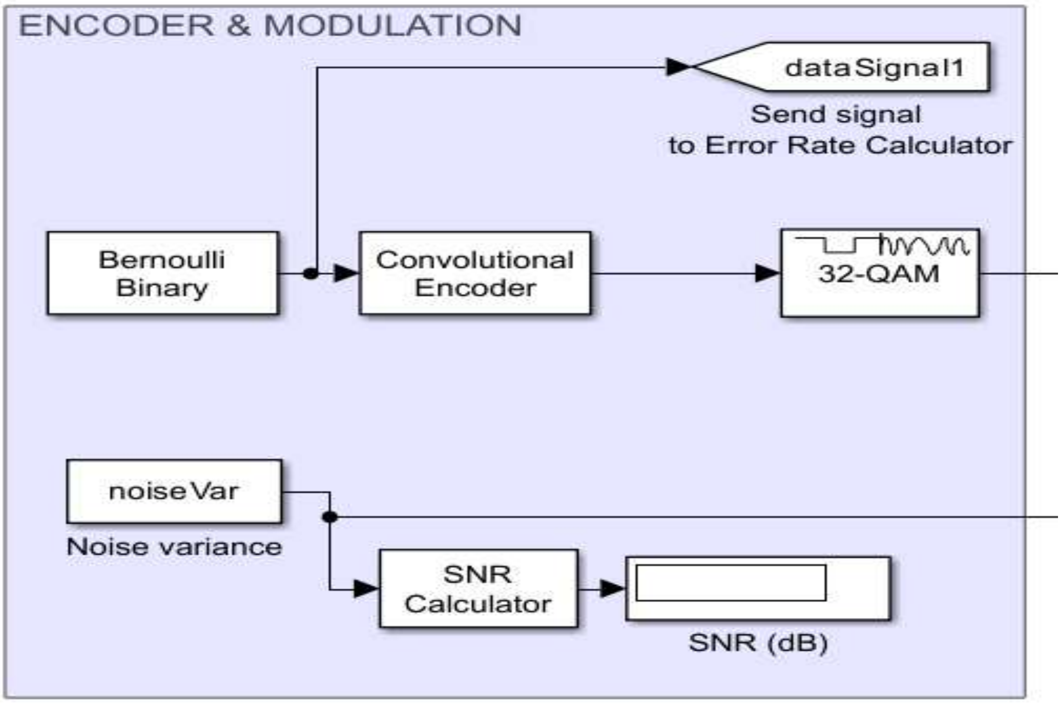

Figure 4: Practical Block (Source, Binary Data, Convolutional Encoder, and M-QAM Modulation)

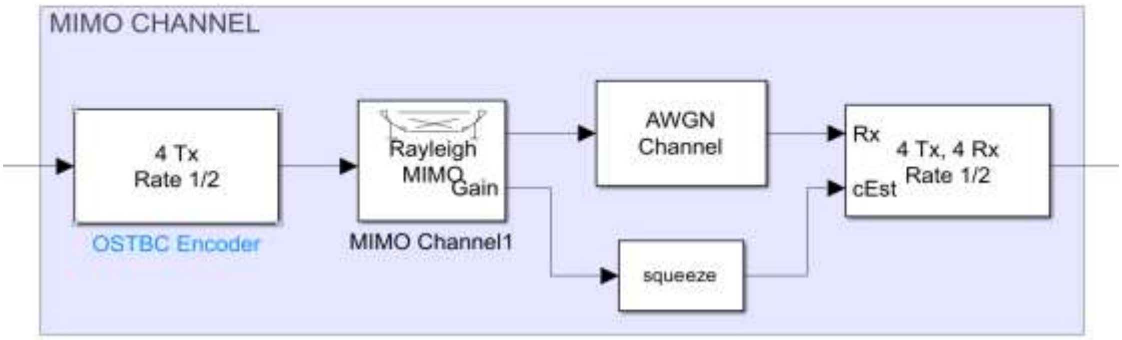

Figure 5: MIMO Channel Technique

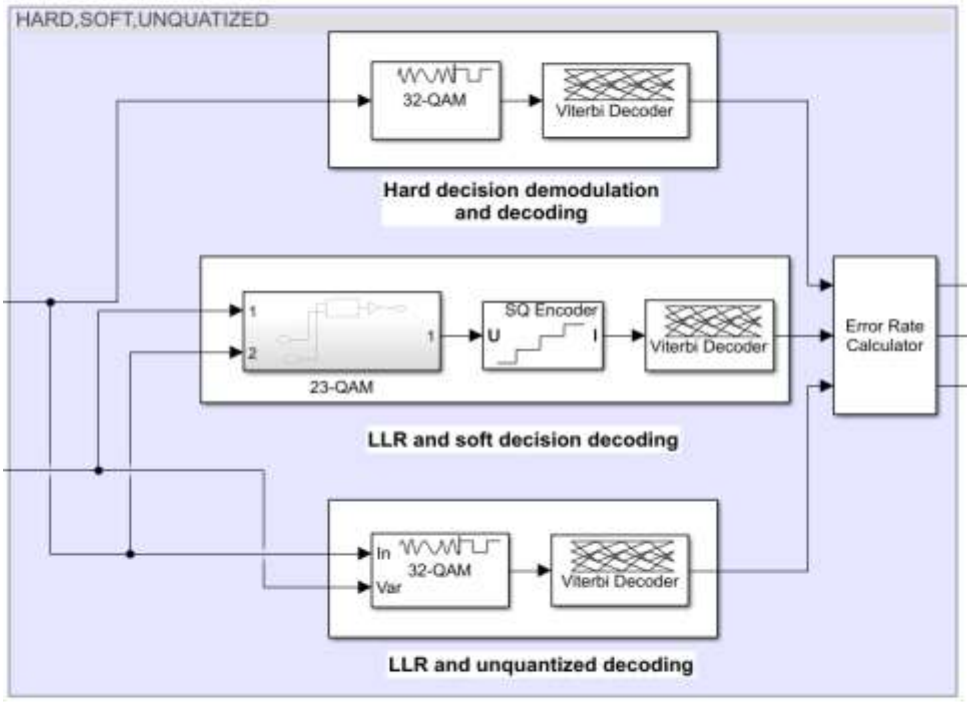

Figure 7: HRAD, SOFT, and UNQUNTIZED DECISION.

The drawings shown in Figures (4), (5), and (6) were implemented in the MATLAB program and with the parameters shown in Table 1.

Table 1: Simulation Parameters for the Baseline

Parameter	**Values**		
M-QAM	**4-QAM**	**16-QAM**	**32-QAM**
Channel model	AWGN Channel	Rayleigh fading Channel	
Number of Antennae	2X2 MIMO Antenna	4X4, MIMO Antenna	
Convolutional Code	Hard Decision Decoding,	Soft Decision Decoding	Unquantized Decision Decoding

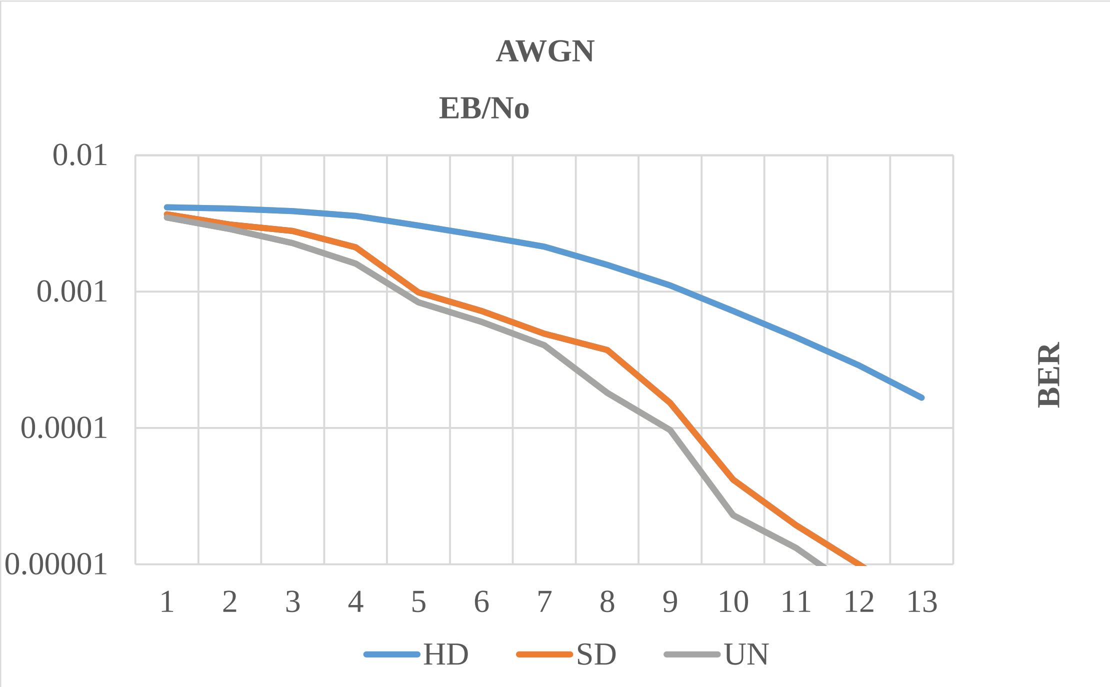

Figure 8: Convolutional Code Detection in AWGN Channel

From the results shown above, it is clear that the (Unquantized Decision Decoding) method is more accurate than all the methods mentioned. But the (Soft Decision Decoding) method represents the closest solution to the (Unquantized Decision Decoding) method and is more balanced than the hard resolution in the AWGN channel with different 16-QAM.

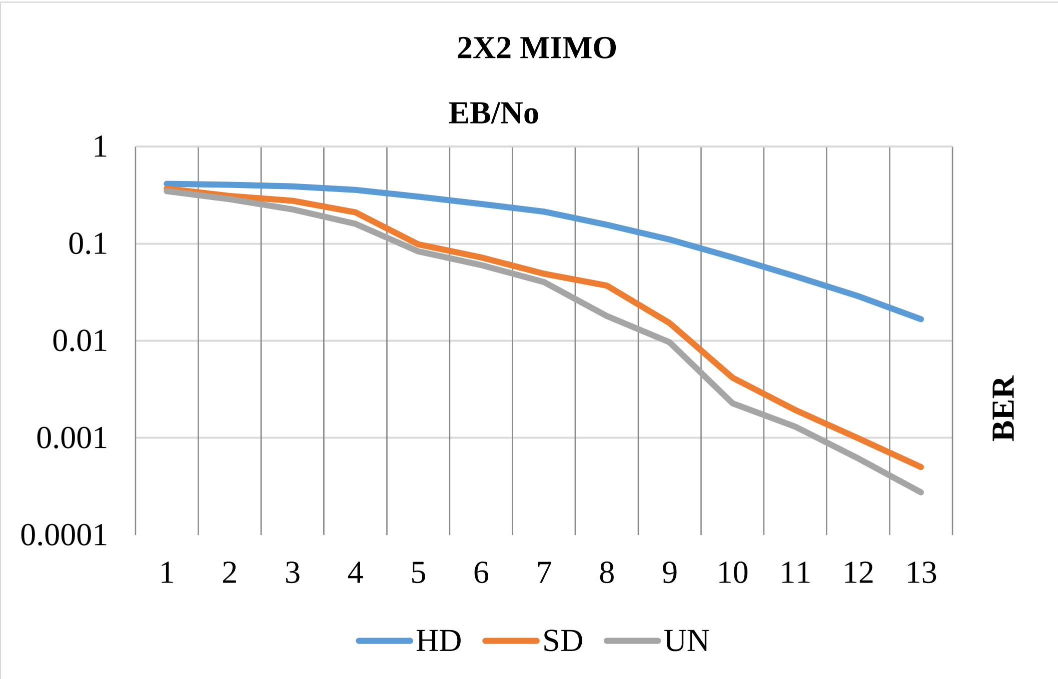

Figure 9: Convolutional Code Detection in MIMO Fading Channel 2x2 16-QAM

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Figure 9 shows the results for 2x2 MIMO fading channels. The result indicates that the value of bit error rate (BER) with increasing power (EB/No) for Soft Decision Decoding is less than the value of "HD" decoding as it is closer to (Unquantized Decision Decoding).

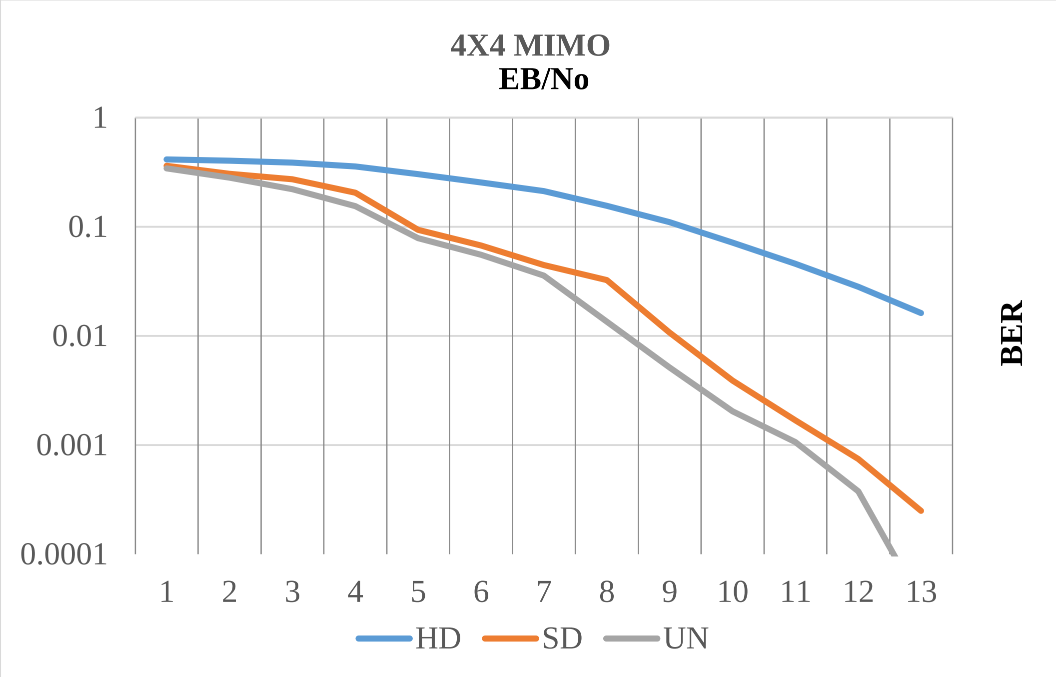

Figure 10: Convolutional Code Detection in MIMO Fading Channel 4x4 16_QAM

Figure 10 displays the results for a 16-QAM channel undergoing fading in a 4x4 MIMO system. The data indicates that the bit error rate (BER) achieved with soft decision-making is more precise than the HDD.

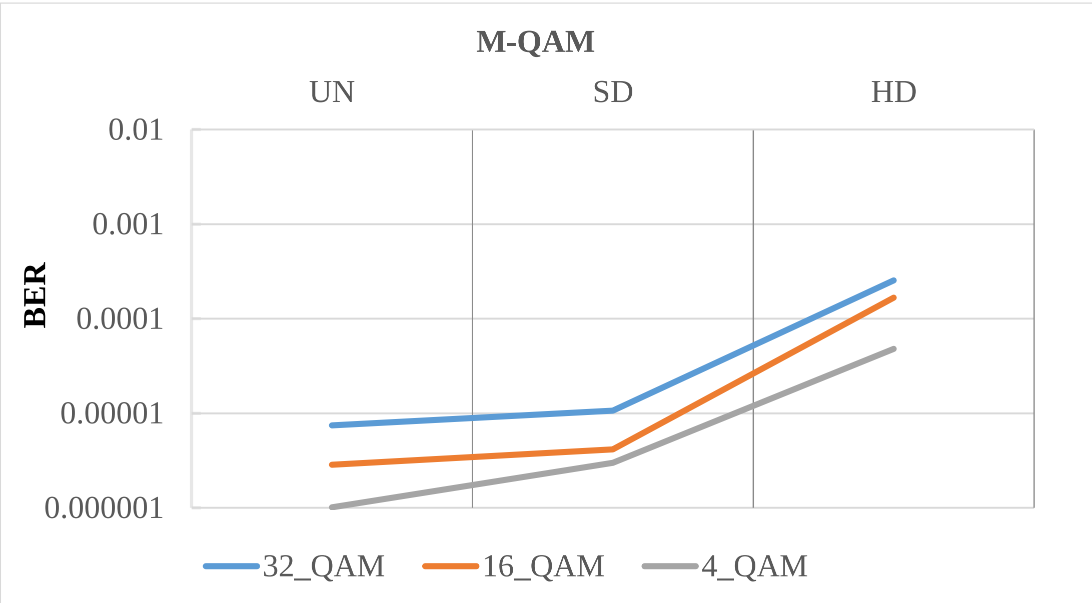

Figure 11: Convolutional Code Detection in AWGN Channel

In other words, by comparing (2x2 MIMO fading channel in different M-QAM), the results appear in Figure 11 which show that soft detection is better than hard detection and is significantly closer to Unquantized.

The above results were obtained through the complete drawing shown in Figure 12 in a MATLAB simulation environment.

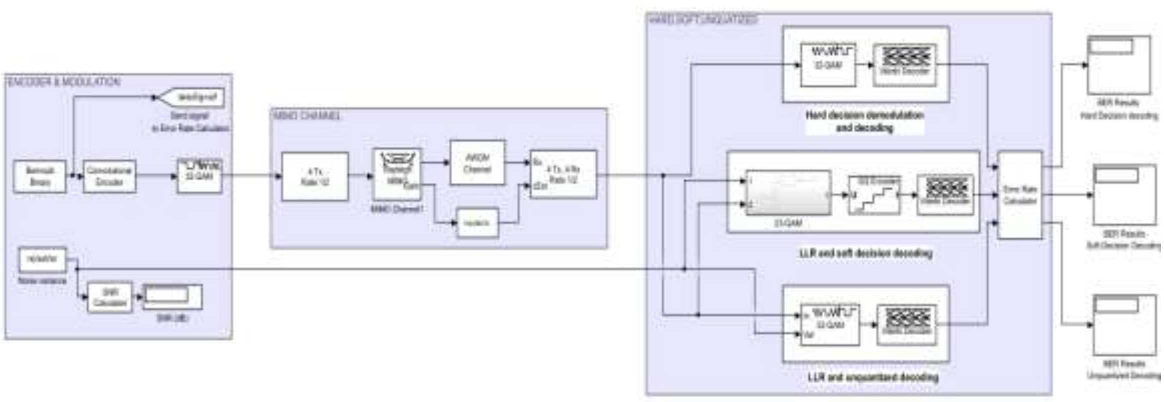

Figure 12: All blocks diagram in MATLAB Simulation

CONCLUSION

This article summarizes the use of hard, soft, and non-quantized Viterbi decision algorithms over MIMO, Quadratic amplitude modulation, QAM schemes, and M-ary channels. The results of the study had beneficial implications for the design and implementation of a wireless communications system. It also adds a state of verification and confirmation to knowledge in the field of communications engineering. The insights derived from this study can confirm the previous information regarding the advantage of a soft decision, as is known. Essentially, validating Viterbi's smooth accuracy and balance in LLR demodulation using different MIMO and M-QAM channel modulation settings has expanded our knowledge of the complex interactions between decoding algorithms, modulation systems, and channel environments. This study provides a foundation for future research and developments in the dynamic field of communications engineering. The experiments mentioned in the above research papers also proved that the accuracy of the soft decision is very close to the non-quantization decision. The study explored modulation techniques, decoding algorithms, and signal processing to improve our understanding of communications systems in a range of challenging situations. Extensive testing and analysis have yielded important insights into how MIMO and QAM configurations affect Viterbi decoding accuracy for soft decisions and balance them with the performance and complexity of both hard and non-quantitative decisions.

REFERENCES

Ahmed, M., Ahmed, M., & Islam, A. (2021). Comparison of Bit Error Rate Performance of Various Digital Modulation Schemes over AWGN and Rayleigh Fading Channels using Simulink. *The International Journal of Ambient Systems and Applications, 9*, 7-16. doi:10.5121/ijasa.2021.9202

Arevalo, L., De Lamare, R., Zu, K., & Sampaio-Neto, R. (2014). *Multi-branch lattice reduction successive interference cancellation detection for multiuser MIMO systems*.

Aubert, S., Anchora, A., & Nouvel, F. (2011, 2011-04-17). *Multi-Level Log-Likelihood Ratio Clipping in a Soft-Decision Near-Maximum Likelihood Detector*. Paper presented at the IARA ICDT 2011, Budapest, Hungary.

Babu, A., & Rao, K. (2011). "Evaluation of BER for AWGN, Rayleigh and Rician Fading Channels under Various Modulation Schemes". *International Journal of Computer Applications, 26*, 23-28. doi:10.5120/3132-4317

Bala, D., Waliullah, G. M., Rahman, Abdullah, M., & Hossain, M. (2021). *Analysis the Performance of MIMO-OFDM for Various Modulation Techniques over AWGN, Rayleigh Fading and Rician Fading Channel*.

Cao, X., Liu, Y., & Hu, D. (2019). Simplified LLR algorithm for m-QAM demodulation. *The Journal of Engineering, 2019*(21), 7370-7375. doi:https://doi.org/10.1049/joe.2019.0634

Ebrahimzadeh Saffar, H., Alajaji, F., & Linder, T. (2009). COVQ for MAP hard-decision demodulated channels. *Communications Letters, IEEE, 13*, 28-30. doi:10.1109/LCOMM.2009.081457

El Ouakili, H., Touati, H., Kadi, A., Mehdaoui, Y., & El Alami, R. (2023). New low-density-parity-check decoding approach based on the hard and soft decisions algorithms. *2023, 13*(2), 8. doi:10.11591/ijece.v13i2.pp1639-1646

Fertl, P., Jalden, J., & Matz, G. (2012). Performance Assessment of MIMO-BICM Demodulators Based on Mutual Information. *IEEE Transactions on Signal Processing, 60*(3), 1366-1382. doi:10.1109/TSP.2011.2177823

Fertl, P., Jaldén, J., & Matz, G. (2009). Performance assessment of MIMO-BICM demodulators based on system capacity. *arXiv preprint arXiv:0903.2711*.

Gupta, K., Merchant, S. N., & Desai, U. B. (2018). Inherence of Hard Decision Fusion in Soft Decision Fusion and a Generalized Radix-2 Multistage Decision Fusion Strategy. *IEEE Access, 6*, 55701-55711. doi:10.1109/ACCESS.2018.2871092

Hasan, A. A. (2018). *Efficient Log Likelihood Ratio Estimation for Polar Codes*: Carleton University.

Jiao, J., Liang, K., Feng, B., Wang, Y., Wu, S., & Zhang, Q. (2020). Joint Channel Estimation and Decoding for Polar Coded SCMA System over Fading Channels. *IEEE Transactions on Cognitive Communications and Networking, PP*, 1-1. doi:10.1109/TCCN.2020.2991425

Kang, I.-W., Lee, Y.-J., Kim, Y., Seo, J., Kim, M., & Kim, H.-N. (2014). Simplified log likelihood ratio calculation in soft ordered successive interference cancellation for multiple-input multiple-output digital video broadcasting-second generation terrestrial receivers. *Communications, IET, 8*, 3280-3289. doi:10.1049/iet-com.2014.0510

Li, Q., Zhang, A., Li, J., & Ning, B. (2020, 15-18 May 2020). *Soft Decision Signal Detection of MIMO System Based on Deep Neural Network.* Paper presented at the 2020 5th International Conference on Computer and Communication Systems (ICCCS).

Mahmood Farhan, M., & Fa'aza Abbas, A. (2013). Log-Likelihood Ratio to Improve Hard DecisionViterbi Algorithm *Engineering and Technology Journal, 31*(9 Part (A) Engineering), 1779-1790.

Mosleh, M., & Abid, D. (2013). Log-Likelihood Ratio to Improve Hard Decision Viterbi Algorithm . *Engineering and Technology Journal, 31*. doi:10.30684/etj.2013.82189

Ning, S. (2019). Improving Resistive RAM Hard and Soft Decision Correctable BERs by Using Improved-LLR and Reset-Check-Reverse-Flag Concatenating LDPC Code. *IEEE Transactions on Circuits and Systems II: Express Briefs, PP*, 1-1. doi:10.1109/TCSII.2019.2960484

Rahman, T., Godder, C., Singh, M., Parvin, & Rahman, M. M. (2021). Performance Comparison of AWGN, Flat Fading and Frequency Selective Fading Channel for Wireless Communication System using 4QPSK.

Rindani, M., & Bavarva, A. (2013). BER PERFORMANCE COMPARISION OF 4X4 EXTENDED ALAMOUTI SCHEME FOR DIFFERENT FADING CHANNELS. *IJAREEIE, 2*, 1074-1081.

Staphorst, L., & Linde, L. P. (2003). On the viterbi decoding of linear block codes. *Transactions of the South African Institute of Electrical Engineers, 94*(4), 29-42.

Vaigandla, K., Allanki, S. R., Srikanth, K., Study, & Ijmtst, E. (2021). Study of Modulation Schemes over a Multipath Fading Channels. *International Journal for Modern Trends in Science and Technology, 7*, 34-39. doi:10.46501/IJMTST0710005

Verma, R., Mahajan, S., & Rohila, V. (2008, 12-14 Dec. 2008). *Classification of MIMO channel models.* Paper presented at the 2008 16th IEEE International Conference on Networks.

Wali, M., Fayadh, R., & Al_taee, D. (2018). Performance of AWGN and fading channels on wireless communication systems using several techniques. *6*.

Xu, C., Sugiura, S., Ng, S. X., Zhang, P., Wang, L., & Hanzo, L. (2017). Two Decades of MIMO Design Tradeoffs and Reduced-Complexity MIMO Detection in Near-Capacity Systems. *IEEE Access, 5*, 18564-18632. doi:10.1109/ACCESS.2017.2707182

Yang, C. H., Huang, T. Y., Li, M. R., & Ueng, Y. L. (2014). A 5.4 $\mu{\rm W}$ Soft-Decision BCH Decoder for Wireless Body Area Networks. *IEEE Transactions on Circuits and Systems I: Regular Papers, 61*(9), 2721-2729. doi:10.1109/TCSI.2014.2312478