FOREX Publication
Open Access | Rapid and quality publishing

International Journal of
Electrical and Electronics Research (IJEER)
Research Article | Volume 12, Issue 2 | Pages 375-382 | e-ISSN: 2347-470X

Rate 5/6 TCM Code Having 64 States with 64 QAM for Fading Channel

Raj Kumar Goswami[1], Swathi Nambari[2], Srinivasa Rao Kandula[3], P. Pavithra Roy[4] and A.H. Sharief[5]

[1]Department of ECE, Gayatri Vidya Parishad College of Engineering for Women, Visakhapatnam, A.P, India, rajkumargoswami@gmail.com
[2]Department of ECE, Anil Neerukonda Institute of Technology and Sciences, Visakhapatnam A.P., India, swathiyadav23@gmail.com
[3,4,5]Department of ECE, Dhanekula Institute of Engineering and Technology, Vijayawada, A.P., India, ksrinivas.ece@gmail.com

***Correspondence:** rajkumargoswami@gmail.com

ABSTRACT- Trellis Coded Modulation (TCM) is powerful technique employed in digital communication systems to improve the reliability and efficiency of data transmission. TCM combines error control coding and modulation schemes to achieve superior performance in challenging channel conditions. In TCM, information bits are encoded using a trellis encoder, which generates a sequence of encoded symbols. These symbols are then mapped onto a modulation scheme, such as Quadrature Amplitude Modulation (QAM) or Phase Shift Keying (PSK), to create the modulated signal. At the receiver, the received signal is demodulated and decoded using a trellis decoder, which employs maximum likelihood decoding to recover the original information bits. The trellis structure allows for efficient error correction and makes TCM particularly suitable for channels with fading, noise, and other impairments. TCM has been widely used in various communication standards and applications to enhance data transmission reliability and spectral efficiency. TCM is a coding technique that merges coding and modulation to attain substantial coding gain without compromising bandwidth efficiency. The emergence of TCM occurred in the late 1970s, and ever since, it has found extensive utilization in various contemporary information transmission systems. In this paper, a new methodology is introduced for the design of a 64-state rate 5/6 TCM code optimized for fading channels. The outcomes obtained from the study are remarkably encouraging, demonstrating coding gain of around 10 dB in comparison to uncoded 32 PSK. This substantial gain plays a pivotal role in boosting data rates, especially in situations where bandwidth-limited channels are involved

General Terms: Forward Error Correction, Data Communication
Keywords: TCM, Convolutional Coding, QAM, PSK, Fading Channel, Maximum Likelihood Decoding.

ARTICLE INFORMATION

Author(s): Raj Kumar Goswami, Swathi Nambari, Srinivasa Rao Kandula, P. Pavithra Roya and A.H. Sharief;

Received: 24/07/23; **Accepted**: 01/02/24; **Published**: 30/04/2024;
E- ISSN: 2347-470X;
Paper Id: IJEER230715;
Citation: 10.37391/IJEER.120207
Webpage-link: https://ijeer.forexjournal.co.in/archive/volume-12/ijeer-120207.html

crossref member
CROSSREF.ORG
THE CITATION LINKING BACKBONE

1. INTRODUCTION

Concept of employing error correction coding in conjunction with compatible modulation technique has been widely recognized and adopted for a significant duration. In fact, the idea of utilizing multilevel modulation of symbols encoded with convolutional codes was already established before the advent of Trellis Coded Modulation (TCM) [1-2]. When expanding signal set for providing the desired redundancy, it is important to note that it also results in a reduction in distance between signal points, assuming mean energy remains constant. Phenomenon is visually depicted in *figure 1*, showcasing the effect of signal set expansion on the spacing between signal points.

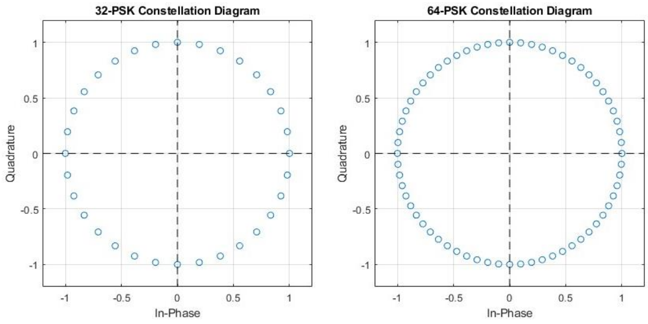

Fig. 1 Reduction in distance post expansion of signal points

Expanding signal set can lead to a decrease in distance between signal points, which in turn may result in an increased error rate. To address this issue, TCM coding techniques are utilized. It is an effective coding technique that attains coding gain without compromising bandwidth. TCM enables robust and efficient communication at high data rates, even in scenarios where bandwidth is limited. The unique characteristic of TCM makes it highly appealing for mobile radio communications, where spectrum and power resources are limited and valuable. Fundamental innovation of TCM resides in the notion of considering convolutional encoding and modulation as a unified and integrated operation, rather than separate entities. By adopting this integrated approach, transmission system achieves enhanced performance and efficiency. TCM undertakes the combination of modulation and convolutional coding scheme to strive for superior noise immunity compared to uncoded transmission, resulting in improved robustness against disturbances and noise [3-4]. This achievement is accomplished without requiring signal bandwidth expansion or an increase in transmitted power. TCM provides a well-balanced approach to enhance system performance in the presence of noise. The evaluation of TCM scheme's performance is typically quantified by measuring the coding gain attained in comparison to an uncoded signal. The coding gain serves as a metric to evaluate the extent of system performance improvement offered by TCM, highlighting its capability to mitigate channel noise and enhance communication reliability [5-8].

When designing a TCM scheme, special attention is paid to enhance the minimum free distance by establishing a connection between the modulation scheme and the trellis structure. This careful consideration aims to optimize the overall performance and reliability of the TCM system. This ensures that the TCM scheme effectively maximizes the separation between transmitted symbols, consequently enhancing the code's error correction capabilities. By strategically increasing the distance between symbols, the TCM scheme strengthens its ability to detect and correct errors, leading to improved overall performance and reliability. In TCM, the mapping of symbols from the encoder output to the modulator involves a nontrivial process. It does not simply entail a direct mapping. Instead, the signal constellation is divided into distinct signal sets, and the symbols are mapped accordingly within these sets. This strategic mapping approach allows for efficient utilization of the signal space and optimizes the performance of the TCM system. The partitioning of the signal constellation in TCM facilitates efficient encoding and modulation, leading to improved error correction capabilities and overall performance. In TCM, the selection of the signal set is determined by the encoder output, while an additional systematic input is utilized to choose the specific symbol within the selected signal set. This combination of encoding, modulation, and systematic selection enables effective utilization of the signal space, contributing to the enhanced performance of TCM. By incorporating the dual process of signal set selection and symbol mapping, an optimized encoding and modulation scheme is achieved in TCM. This approach enables efficient error correction and maximizes the overall system performance. The performance of TCM is significantly impacted by the various methods employed for symbol selection, as they directly influence the system's robustness and capacity to mitigate errors. The selection methods for symbols play pivotal role towards determining the overall performance along with efficiency of TCM scheme. These methods directly impact the scheme's capability to combat noise and achieve reliable communication. The careful choice of symbol selection methods significantly contributes to the system's robustness, error correction capabilities, and overall reliability.

Among the various types of errors in convolutional codes, pairwise error stands out as one of the most significant. Pairwise error arises when the decoder mistakenly selects a sequence that differs from the one originally transmitted by the transmitter. This specific error type has significant implications for the overall decoding accuracy and reliability of the system. Pairwise errors in convolutional codes typically originate from incorrect state transitions within the decoding process. To tackle this challenge, it is crucial to allocate constellation points in a manner that maximizes the Euclidean distance between them for divergent and emergent branches. This approach effectively reduces pairwise errors by enhancing the distinguishability between different state transitions, consequently improving the overall decoding performance, and minimizing the error rate. By strategically designing the constellation points, the system benefits from increased reliability and robustness in decoding convolutional codes. Through strategic assignment of constellation points to divergent and emergent branches based on their Euclidean distance, the modulation and convolutional encoder are effectively merged. This integration ensures that the encoding process incorporates the characteristics of the modulation scheme, leading to an optimized system that maximizes the separation between signal points and enhances the error correction capabilities. By harmoniously combining modulation and encoding, the system achieves improved performance and robustness in transmitting and decoding data. Within TCM, the detection process adopts a soft decision approach rather than a hard decision approach. Unlike binary decision-making on the received signal, soft decision decoding takes into account the likelihood of various symbol values, considering the effects of noise and channel conditions. By considering these factors, soft decision decoding enables more informed and accurate symbol detection, enhancing the overall performance and reliability of the TCM system. By employing a soft decision decoding approach, the system achieves more accurate and robust decoding, especially in scenarios where the received signal is affected by noise or interference. Utilizing hard-decision demodulation before decoding in a coded scheme leads to an irretrievable loss of information, consequently impairing the SNR. Hard-decision demodulation involves making binary decisions on received symbols, disregarding valuable information about reliability or confidence of those symbols. In contrast, soft decision decoding retains and utilizes this additional information, leading to improved decoding performance and higher SNR in the TCM system.

The loss of information through hard-decision demodulation can adversely affect the overall system performance, diminishing the ability to effectively correct errors and potentially resulting in decreased decoding accuracy. When employing the maximum likelihood criterion in soft-decision decoding on a fading channel, the optimal sequence decoder's decision rule relies on calculating the Euclidean distance. This distance measure plays a crucial role in determining the most likely sequence, enabling more reliable and accurate decoding in challenging channel conditions. The decoder chooses the sequence with the highest likelihood by evaluating the calculated Euclidean distances between the received symbols and the potential transmitted symbols. Through the consideration of Euclidean distance, the soft-decision decoder accurately determines the most probable transmitted sequence, accounting for the influence of fading and noise on the received signal. This approach enables robust decoding by effectively mitigating the effects of channel impairments, resulting in improved system performance and reliable communication. In essence, the optimal decoder chooses the code sequence that displays the closest proximity to received sequence in accordance with Euclidean distance. By incorporating Euclidean distance metric, decoder accurately identifies the transmitted sequence that is highly probable, considering the impact of fading, noise, and other channel impairments. This utilization of the Euclidean distance metric allows for effective recognition of the most likely transmitted sequence, leading to enhanced decoding performance and improved resilience against various channel conditions. Through the integration of TCM with a suitably deep interleave, substantial coding gains can be attained, particularly in fading channels, when compared to uncoded schemes. However, adhering to proper design criterion [4,9,10,11,12] is crucial when constructing code. Combination of TCM and interleaving strengthens the system's resilience against fading, effectively mitigating the impact of fading-induced errors and enhancing overall performance. This integration ensures improved error correction capabilities and robustness, leading to reliable communication even in challenging fading environments [13].

This paper introduces a novel methodology for designing a 64 -state rate 5/6 Trellis Coded Modulation (TCM) code specifically tailored for optimal performance in fading channels. The results derived from the study present highly encouraging outcomes, revealing a significant coding gain of approximately 10 decibels (dB) when compared to the uncoded 32-PSK scheme. This noteworthy gain is pivotal in enhancing data rates, particularly in scenarios characterized by bandwidth limitations. The implications of this achievement are crucial, as the substantial coding gain not only signifies the effectiveness of the proposed TCM code but also points to its potential in elevating communication performance in challenging environments. This paper contributes to the advancement of communication technologies, especially in situations where reliable data transmission is essential, by demonstrating the efficiency of the newly introduced TCM code in optimizing communication over fading channels. Sections of this paper have been organized in the following manner. *Section 2* offers concise overview of System Model, highlighting its essential elements and functionality. *Section 3* introduces the proposed design approach and outlines the systematic rules for creating an optimal code tailored specifically for the rate 5/6, 64-state, 64-QAM TCM scheme in fading channels. This section details the strategies and considerations involved in designing the code to ensure optimal performance in challenging channel conditions. This section delves into the design methodology, offering comprehensive insights that facilitate the creation of an efficient and effective code specifically tailored for the given system parameters. *Section 4* provides an in-depth explanation of the code construction process, presenting a step-by-step guide on how the code is systematically built. The section elucidates the key considerations and techniques involved, empowering the reader with a clear understanding of the code construction procedure. Subsequently, *section 5* centers on the performance analysis of the proposed code, thoroughly examining its efficacy under diverse conditions. Moving forward to *section 6*, the results obtained from simulations are presented, and the corresponding conclusions derived from these findings are discussed. This section provides a comprehensive summary of the attained results, highlighting their significance and implications for both the proposed code and the overall system. The discussion encompasses the strengths, limitations, and potential areas for further improvement based on the simulation outcomes.

2. SYSTEM MODEL

Figure 2 presents a generalized block diagram showcasing the implementation of a TCM scheme [5] in fading channel. The scheme starts with input bits that undergo encoding by trellis encoder, resulting in a sequence of signals $s_l = (s_1, s_2 \dots s_l)$, Each signal represents a k dimensional vector selected from M-QAM signal set, wherein present time index is denoted by i. This block diagram illustrates the comprehensive information flow and signal processing within the TCM scheme, emphasizing the crucial encoding and modulation stages. It provides a visual representation of the overall operation and highlights the key components involved in the TCM process. Through the utilization of complex notation, every signal within the TCM scheme can be denoted as point in complex plane. This representation offers a convenient means to visualize and analyze the signals. Moreover, the coded signals can undergo interleaving, a procedure in which they are rearranged to distribute and mitigate bursts of errors. Interleaving plays a crucial role in enhancing the system's error correction capabilities and improving performance of TCM scheme in presence of channel impairments. It ensures a more robust and reliable transmission by effectively dispersing the impact of errors, leading to improved decoding accuracy and overall system resilience. Before modulation and transmission over the channel, it is essential to implement pulse shaping on the signal to mitigate Inter Symbol Interference (ISI). Pulse shaping techniques ensure that the transmitted signal is appropriately molded in the time domain, thereby reducing the likelihood of symbol overlap, and minimizing ISI effects. However, during the transmission process, the signal inevitably encounters additive white Gaussian noise, which is inherent to the channel. This noise component introduces randomness and impacts the overall quality of the received signal, leading to potential degradation in performance.

At the receiver end, the received signal undergoes demodulation and quantization to facilitate the subsequent decoding process.

Furthermore, a channel estimator can be utilized to estimate the channel gain, offering valuable insights into the prevailing channel conditions. This channel gain estimation plays a crucial role in decoding process, enhancing performance of coded system. By incorporating channel gain estimation, the decoder can adapt its decoding strategy to effectively accommodate the fluctuating channel conditions. This adaptive approach improves the overall system performance and reliability by enabling the decoder to make informed decisions based on the estimated channel gain, thus mitigating the adverse effects of varying channel conditions, and optimizing the decoding accuracy. The sequence $r_l = (r_1, r_2, \ldots, r_l)$ is utilized as the input for the TCM decoder, where Maximum Likelihood (ML) decoding is performed. Through ML decoding techniques, the TCM decoder strives to identify the most probable transmitted sequence by analyzing the received sequence of symbols. By assessing the likelihood of various transmitted sequences, the decoder aims to faithfully reconstruct the original transmitted data, effectively correcting any errors that might have occurred during the transmission process. The ML decoding approach ensures a robust and accurate recovery of the transmitted information by leveraging statistical analysis and probability estimation to determine the optimal sequence that aligns with the received symbols.

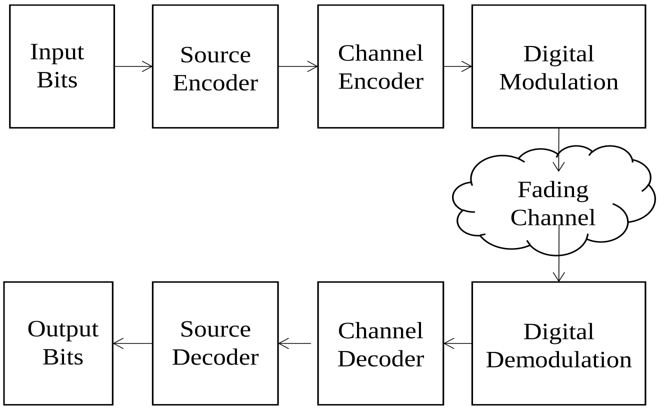

Fig. 2 System block diagram

System's discrete-time model depicted in *figure 2* has been presented in *figure 3*. Model offers a depiction of received signal at time index *i* and mathematically expressed as follows:

$$r_i = c_i . s_i + n_i \qquad (1)$$

Complex Gaussian noise indicated by n_i has zero mean and $N_0/2$ variance. Similarly, *ci* represents complex channel gain, having complex Gaussian process with variance of σ^2_c.

c_i can also be written as

$$c_i = a_i \cdot e^{j\phi_i} \qquad (2)$$

here a_i indicates the amplitude and ϕ_i phase.

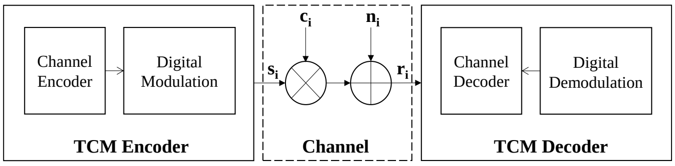

Fig. 3 Discrete time model of System

Undertaking coherent detection at receiver, phase shift caused by channel gets compensated. Consequently, *equation (1)* can be simplified as follows:

$$r_i = a_i s_i + n_i \qquad (3)$$

here a_i indicates the amplitude of noise.

3. DESIGN

Set of formulated rules are discussed in this section, which are employed in design and construction of rate 5/6, 64-state TCM coding scheme specifically optimized for fading channels. Rules proposed, serve as essential guidelines, enabling the effective design of TCM codes that exhibit high performance and robustness, even in the presence of channel impairments induced by fading. These rules have been derived by extending the guidelines proposed in previous studies for 4-state, rate 2/3 TCM codes designed in respect of fading channels [5]. By leveraging these existing principles, the formulated rules presented in this study offer a comprehensive framework for designing rate 5/6, 64-state TCM codes that are specifically tailored to effectively tackle the challenges posed by fading channels. Ungerboeck utilized heuristic methods to design rate 2/3 having 8-state, 8PSK TCM scheme, specifically tailored to optimize performance in fading channels [5,13]. Through careful optimization of TCM parameters, Ungerboeck successfully developed a coding scheme that significantly improves performance and robustness in fading channel environments.

This paper presents a comprehensive set of guidelines for designing 64-state, 64-QAM TCM schemes that are specifically optimized to mitigate the impact of fading channels. These guidelines offer valuable insights and recommendations for designing TCM schemes that effectively overcome the challenges posed by fading, ensuring reliable and efficient communication in fading channel scenarios. The proposed guidelines serve as a valuable resource for researchers and practitioners working on the design and implementation of TCM schemes in fading environments.

A 64 x 64 matrix is employed to represent the signals corresponding to transitions between states in consecutive stages within the TCM scheme. Each element in the matrix corresponds to the signal connected with path going out from state i at stage k to state j at stage k+1. This matrix serves as a valuable tool, providing a comprehensive representation of signal relationships and transitions within the TCM scheme. It facilitates the analysis and design of the system by offering insights into the signal dynamics and aiding in the optimization of the TCM scheme. Moreover, within matrix, elements of i^{th} row represent signals connected with paths diverging from state *i*, while the elements of j^{th} column represent signals associated with paths reemerging at state *j*. This organized arrangement offers a clear depiction of the signal flow and connectivity between different states within the TCM scheme. By visualizing the relationships and interactions between states, this representation aids in the analysis and optimization of the system's performance. It enables a comprehensive understanding of the signal dynamics and assists in fine-tuning the TCM scheme for improved efficiency and reliability.

By utilizing set partitioning techniques, the 64-QAM signal set is divided into two distinct subsets: $A_0 = \{s_0, s_2, s_4, s_6, s_8, s_{10}, \ldots\ldots\ s_{50}, s_{52}, s_{54}, s_{56}, s_{58}, s_{60}, s_{62}\}$ and $A_1 = \{s_1, s_3, s_5, s_7, s_9, s_{11}, s_{13}, \ldots\ldots\ s_{51}, s_{53}, s_{55}, s_{57}, s_{59}, s_{61}, s_{63}\}$. These subsets are defined based on their minimum intra-set distance, which is denoted as δ_1. The partitioning of the signal set into these subsets facilitates efficient organization and analysis of the signals within the TCM scheme. This enables the identification and utilization of specific subsets, which can be beneficial for optimizing the performance and efficiency of the TCM scheme. Signal constellation diagram has been shown in *figure 4*.

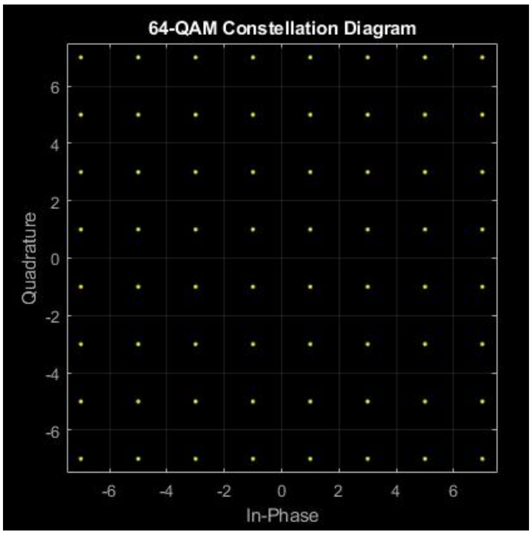

Fig. 4. 64-QAM signal constellation

In this context, the assignment of signal points to elements of matrix is guided by two rules that have been proposed:

The first rule dictates that each signal can appear once in either any row or any column.

The second rule takes into account the limited number of paths emerging from each state in a 64-state, rate 5/6 code. It specifies that a signal can be connected to a transition path between two states only if the Least Significant Bit (LSB) of the initial state label matches the same bit, y ∈ {0, 1}, as the Most Significant Bit (MSB) of the destination state label. For each value of y, all associated signals must be exclusively chosen from either set A_0 or set A_1.

4. CODE CONSTRUCTION

This section is dedicated to the design of a TCM code specifically tailored for a rate 5/6, 64-state, 64-QAM scheme, adhering to rules described in preceding section. Following second rule, initial stage involves eliminating the transitions that do not conform to the prescribed conditions. Subsequently, subset A_0 is assigned to signal paths where the Least Significant Bit (LSB) is 0, while subset A_1 is associated with signal paths where the LSB is 1. As a result, even-numbered rows in the transition matrix will utilize subset A_0, while odd-numbered rows will make use of subset A_1. During this process, any signal point from subset A_0 is selected as initial element for first row, and likewise, any other signal point from subset A_1 is chosen as first valid element for second row of transition matrix. Now, designate s_0 from subset A_0 and s_1 from subset A_1 as the respective first elements. In next step, signals belonging to subset A_0 and A_1 will be allocated to 1st, 2nd, 3rd, and 4throws in accordance with the second rule.

Moving forward, we can choose either s_2 or s_6 as first element of fifth row, and similarly, s_3 or s_7 can be selected as first valid element of sixth row. Opting for s_6 and s_7, the remaining signals will be allocated to the remaining rows, adhering to the second rule. With this, the code design is successfully finalized.

5. PERFORMANCE ANALYSIS

In the performance analysis, we consider a memoryless channel with statistically independent fading amplitudes. The probability of an error event plays a crucial role in evaluating the system's performance. A lower probability of error event indicates a lower number of errors, while a higher probability of error event implies a higher number of errors [14-15]. Therefore, understanding error event's probability is crucial for assessing system's performance accurately. In this section, we will derive the error event probability and explore upper bound of pairwise error probability [6]. We make several assumptions, including coherent detection, ideal Channel State Information, and independent fading from symbol to symbol. Under these assumptions, we can express upper limit of pairwise error probability for decoding the symbol sequence when the transmitted symbol is given a Rician Channel as follows:

$$P_2\left(S_l, \hat{S}_l\right) \leq \prod_{i=1}^{l} \frac{(1+K)}{1+K+\frac{1}{4N_0}\left|(S_i-\hat{S}_i)\right|^2} e^{\left(-\frac{K\frac{1}{4N_0}\left|(S_i-\hat{S}_i)\right|^2}{1+K+\frac{1}{4N_0}\left|(S_i-\hat{S}_i)\right|^2}\right)} \quad (4)$$

In scenarios where SNR is high, aforementioned equation is simplified to:

$$P_2(S_l, \hat{S}_l) \leq \prod_{i\in\eta} \frac{(1+K)e^{-K}}{\frac{1}{4N_0}\left|(S_i-\hat{S}_i)\right|^2} \quad (5)$$

The symbol η represents the values of *i* where the transmitted symbol and the received symbol are not equal. Let the number of such values be denoted by l_η. Then, *equation (5)* can be expressed as follows:

$$P_2(S_l,\hat{S}_l) \le \frac{((1+K)e^{-K})^{l_\eta}}{(\frac{1}{4N_0})^{l_\eta} d_P^2 l_\eta} \qquad (6)$$

Here, $d_P^2 l_\eta$ indicates squared product distance of signals when the transmitted symbol and the received symbol are not equal, along error event η path, and defined as:

$$d_P^2(l_\eta) = \prod_{i\in\eta} \left|(S_i - \hat{S}_i)\right|^2 \qquad (7)$$

An error event refers to a situation where the path of the received data deviates from the intended path as designed. This concept is depicted in *figure 5*, where the intended path corresponds to the sequence from s_1 to s_2 and continuing up to s_l. However, the actual path followed by the received symbols deviates and is represented by the sequence $\hat{s}_1$, $\hat{s}_2$, up to $\hat{s}_l$.

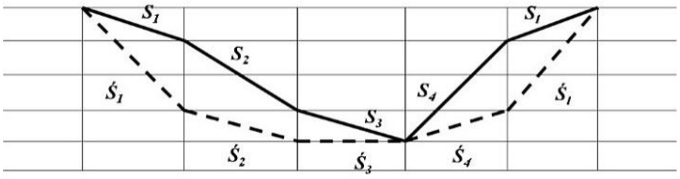

Fig. 5 Error event considering length as l

If we consider all transmitted sequences and sum up the probabilities of all error events over l, l=1…∞, we can calculate an upper bound, which can be expressed as follows

$$P_e \le \sum_{l=1}^{\infty}\sum_{S_l}\sum_{\hat{S}_l\ne S_l} P(S_l)P_2(S_l,\hat{S}_l) \qquad (8)$$

In the above equation, $P(S_l)$ signifies A Priori Probability of transmitting symbol S_l. $P_2(S_l,\hat{S}_l)$ which can be substituted in the equation at high SNRs using *equation (6)*, and consequently, the upper bound with regards to a Rician fading channel can be expressed as:

$$P_e \le \sum_{l_\eta}\sum_{d_P^2 l_\eta} \alpha(l_\eta, d_P^2(l_\eta)) \frac{((1+K)e^{-K})^{l_\eta}}{(\frac{1}{4N_0})^{l_\eta} d_P^2(l_\eta)} \qquad (9)$$

In *equation (9)*, the value of $\alpha(l_\eta, d_P^2(l_\eta))$ represents the average count of code sequences characterized by an effective length lη and a squared product distance denoted as $d_P^2 l_\eta$. In scenarios with high SNR, the error event is predominantly influenced by minimum effective length, denoted as l_η, and squared product distance $d_P^2 l_\eta$. In order to simplify the expression, we introduce L to represent minimum effective length and $d_P^2 l_\eta$ to represent corresponding squared product distance. This minimum effective length is regarded as the code's effective length, enabling us to approximate the error event probability as follows.

$$P_e \approx \alpha(L, d_P^2(L)) \frac{((1+K)e^{-K})^{L}}{(\frac{1}{4N_0})^{L} d_P^2(L)} \qquad (10)$$

In respect of Rayleigh fading channel, where K is equal to zero *equation (10)* can be further simplified as

$$P_e \approx \frac{\alpha(L, d_P^2(L))}{(\frac{1}{4N_0})^{L} d_P^2(L)} \qquad (11)$$

And in respect of AWGN channel, by considering K = ∞, we can rewrite P_e as below [6]

$$P_e \approx \frac{1}{2} N(d_{free}) erfc\left(\sqrt{\frac{d_{free}^2}{4N_0}}\right) \qquad (12)$$

where the value of d_{free} represents the code's free Euclidean distance.

This study primarily focuses on analyzing the performance of a TCM Scheme [7] in presence of Rician Fading Channel. The analysis specifically considers *equation (10)* for various values of Rician parameter K, recognizing that the cases where K is zero or infinity represent special scenarios that warrant additional examination. The TCM scheme employs convolutional encoders [16] and in this study we have utilized rate 5/6 convolutional encoders as part of its encoding process. To evaluate the performance of the TCM scheme, a comparison has been made with the uncoded 32 PSK scheme. The decoding process utilizes the Viterbi Decoding algorithm to recover the transmitted data. *Figure 8* illustrates the relationship between the Bit Error Rate (BER) and SNR for Rate 5/6, 64-State, 64-QAM TCM code designed according to the proposed rules. The figure also includes the BER versus SNR curve for the uncoded 32-PSK scheme, allowing for a direct comparison between the two.

6. RESULTS

The results obtained from the study have been shown in *figure 6*, which present compelling evidence supporting the efficacy of the proposed coding scheme, Trellis Coded Modulation (TCM), when compared to the conventional uncoded 32-PSK scheme. The study reveals that TCM has led to significant improvements, with the achieved gain surpassing 10 decibels (dB). This substantial gain is indicative of the coding scheme's effectiveness in enhancing overall communication performance. Specifically, the gain of more than 10 dB highlights the considerable error correction capability embedded in the TCM coding scheme. This capability is crucial for rectifying errors that may arise during the transmission of data. The study emphasizes that the enhanced communication performance resulting from TCM's error correction capability plays a pivotal role in mitigating the adverse effects associated with fading channels and other transmission impairments. In essence, the findings underscore TCM as a promising solution for improving the reliability and robustness of communication systems in the face of challenging transmission conditions.

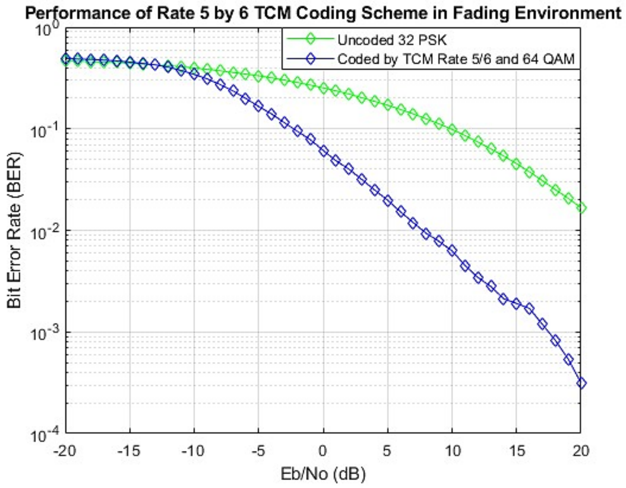

Fig. 6 Bit Error Rate Vs SNR

7. DISCUSSIONS

The study aimed to compare the performance of two communication schemes i.e. Trellis Coded Modulation (TCM) and the conventional uncoded 32-PSK scheme. PSK is a modulation technique where the phase of the carrier signal is varied to represent different symbols. The study confirmed that the proposed TCM scheme outperformed the conventional uncoded 32-PSK scheme and demonstrated better results in terms of certain metrics, such as reliability and efficiency, compared to the traditional 32-PSK scheme. The study quantified the performance improvement by measuring a gain of over 10 decibels (dB) for the TCM scheme. This gain is a numerical representation of the improvement in signal quality or communication performance. A gain of 10 dB is considered impressive and serves as a clear indicator of the substantial improvement achieved by the TCM scheme.

The measured gain of over 10 dB serves as a clear indicator of Trellis Coded Modulation's considerable potential to enhance communication performance. This implies that TCM has the capability to significantly improve the reliability and efficiency of data transmission. The substantial gain observed in the study underscores the efficacy of Trellis Coded Modulation in enhancing the reliability and efficiency of data transmission. This means that TCM can contribute to making communication systems more robust and dependable. The results of the study suggest that TCM can play a crucial role in scenarios where robust and dependable communication is required. This could include applications in telecommunications, networking, or any other field where effective data transmission is a necessity.

By surpassing the 10 dB threshold, Trellis Coded Modulation not only outshines its uncoded counterpart but also demonstrates its capacity to significantly improve data transmission. This promises more dependable and efficient communication in a variety of practical applications, indicating the potential real-world impact of adopting TCM in communication systems.

8. CONCLUSION

In the context of fading channels, characterized by fluctuating signal strength due to various factors, and situations where bandwidth is limited, the Trellis Coded Modulation (TCM) scheme emerges as a robust solution. Fading channels can lead to the corruption of data, posing challenges to reliable communication. However, TCM addresses this by efficiently utilizing the available bandwidth, making it particularly effective in mitigating the adverse effects of signal fluctuations. The error-correcting capability intrinsic to the TCM coding scheme holds significant implications across various applications. In scenarios where real-time or time-sensitive data transmission is crucial, such as in industrial automation or remote healthcare, the ability of TCM to provide error-free data becomes paramount. The enhanced reliability of data transmission facilitated by TCM not only ensures the integrity of information but also contributes to an overall improvement in the performance of systems operating in dynamic and challenging communication environments.

The findings of the study conclusively showcase the superior performance of the proposed Trellis Coded Modulation (TCM) scheme when compared to the conventional uncoded 32-PSK scheme. The measured gain, surpassing an impressive 10 decibels (dB), serves as a clear indicator of TCM's considerable potential to elevate communication performance. This substantial gain underscores the efficacy of TCM in enhancing the reliability and efficiency of data transmission. The results imply that TCM can play a pivotal role in real-world scenarios, where robust and dependable communication is paramount [17]. By achieving the gain of approximately 10 dB, TCM demonstrates its capacity to significantly improve data transmission, assuring more dependable and efficient communication in real world applications.

REFERENCES

[1] Ezio Biglieri, Dariush Divsalar, Peter J. Mclane and Marvin K. Simon, Introduction to Trellis-Coded Modulation with Applications, Maxwell Macmillan International Editions, 1991.

[2] J. Sharma and V. Lalitha, "Learning to Decode Trellis Coded Modulation," 2021 National Conference on Communications (NCC), Kanpur, India, 2021, pp. 1-6, DOI: 10.1109/NCC52529.2021.9530101.

[3] Patra, Trilochan & Mitra, Swarup. (2023). Application of a Trellis Coded Modulation to Ameliorate the 5G Communication for Tropical Regions. Indian Journal of Science and Technology. 16. 37-46. 10.17485/IJST/v16i1.2079.

[4] Dariush Divsalar and Marvin K. Simon, "The Design of Trellis Coded MQAM for Fading Channels: Performance Criteria," IEEE Trans. on Communications, Vol. 36, No. 9, pp. 1004-1012, Sept. 1988.

[5] Jamali Hamidreza S. and Tho Le Ngoc, Coded Modulation Techniques for Fading Channels, Boston: Kluwer Academic Publishers, 1994.

[6] J.B. Anderson and Arne Svensson, Coded Modulation System, Kluwer Academic / Plenum Publisher, 2003.

[7] Vanaja Shivakumar, “Performance Evaluation Parameters Analysis for Trellis Coded Modulation Systems”, International Journal of Recent Technology and Engineering (IJRTE) ISSN: 2277-3878, Volume-8 Issue-3, September 2019 pp 7062 – 7065

[8] Astharini, D., Asvial, M. & Gunawan, D. Performance of signal detection with trellis code for downlink non-orthogonal multiple access visible light communication. Photon Netw Commun 43, 185–192 (2022). https://doi.org/10.1007/s11107-021-00957-5

[9] John G. Proakis and Dimitris G. Manolakis, Digital Signal Processing: Principles, Algorithms and Applications, Second Edition, New Delhi: Prentice Hall of India, 1995.

[10] Christian B. Schlegel and Lance C. Pe´ rez, Trellis and Turbo Coding, John Wiley & Sons Inc., Publication, 2004
[11] Periyalwar,S. and Fleisher, S.M., “A modified design of trellis-coded MQAM for the fading channel”, IEEE Trans. Commun., Vol.41, No.6, June1993 pp.874-882
[12] Alamouti, S.M. and Kallel, S., “Adaptive trellis-coded multiple-phase-shift keying for Rayleigh fading channels” IEEE Trans. on Commun., Vol.42, pp.2305-2314, Jun. 1994, pp.2305-2314.
[13] R.K. Goswami, K. Srinivasa Rao and Swathi Nambari (2023), Implementation of Turbo Trellis Coding Modulation Scheme for Fading Channel. IJEER 11(3), 669-674. DOI: 10.37391/ijeer.110305.
[14] L. Hanzo, S. X. Ng, T. Keller, and W. Webb, Quadrature amplitude modulation: From basics to adaptive trellis-coded, turbo-equalized and space-time coded OFDM, CDMA and MC-CDMA systems, pp. 746–748. Wiley-IEEE Press, 2nd ed., December 15, 2004.
[15] Rajkumar Goswami, Sasi Bhusana Rao, Rajan Babu, Ravindra Babu, “8 State Rate 2/3 TCM Code Design for Fading Channel” IEEE conference On Control, Communications and Automation, Vol-II, pp. 323 -326, Dec 2008.
[16] Dasari Ramanna and V. Ganesan (2022), Low-Power VLSI Implementation of Novel Hybrid Adaptive Variable-Rate and Recursive Systematic Convolutional Encoder for Resource Constrained Wireless Communication Systems. IJEER 10(3), 523-528. DOI: 10.37391/IJEER.100320.
[17] G S Arun Kumar, Rajesh Singh, Anita Gehlot, Shaik Vaseem Akram (2022), LoRa enabled Real-time Monitoring of Workers in Building Construction Site. IJEER 10(1), 41-50. DOI: 10.37391/IJEER.100106.