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Improving Digital Terrestrial Television Broadcasting Quality Using Dynamic Signal Optimization.

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Abstract
Digital Terrestrial Television (DTT) broadcasting has improved television transmission through better picture quality, efficient spectrum utilization, and improved resistance to noise compared with analogue systems. However, DVB-T2 transmission quality is still affected by multipath fading, signal attenuation, and varying channel conditions, especially in urban environments such as Port Harcourt. This study therefore aimed to improve DTT broadcasting quality using a Dynamic Signal Optimization (DSO) model based on adaptive DVB-T2 transmission techniques. A simulation-based approach was implemented in MATLAB R2023a using AWGN and Rayleigh fading channel models. Baseline DVB-T2 systems using QPSK, 16-QAM, 64-QAM, and 256-QAM modulation schemes were developed and analyzed. The proposed DSO model utilized SNR-based adaptive modulation switching with hysteresis-adjusted thresholds to mitigate modulation switching instability and signaling overhead. System performance was evaluated using Bit Error Rate (BER), Modulation Error Ratio (MER), throughput, and Link Margin. The simulation results showed that lower-order modulation schemes provided improved robustness under poor channel conditions, while higher-order modulation schemes achieved higher throughput under favorable channel conditions. The proposed DSO model dynamically adapted modulation selection according to channel quality and achieved approximately 10–20% improvement in BER performance, 8–15% improvement in throughput efficiency, improved MER stability, and enhanced Link Margin performance compared with conventional fixed-modulation DVB-T2 systems. The study concluded that the proposed Dynamic Signal Optimization model effectively improved DVB-T2 broadcasting quality, transmission reliability, and adaptive communication performance under varying channel conditions.

Keywords: *Digital Terrestrial Television (DTT), DVB-T2, Dynamic Signal Optimization (DSO), Adaptive Modulation, Bit Error Rate (BER), Modulation Error Ratio (MER), Rayleigh Fading, OFDM, Signal-to-Noise Ratio (SNR), Throughput Optimization.*

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I. INTRODUCTION

Digital Terrestrial Television (DTT) has brought significant advancements to the broadcasting industry by offering enhanced picture quality, efficient spectrum utilization, and interactive services, surpassing traditional analog systems (Tombak *et al.,* 2020). The adoption of DTT has been propelled by various international standards, including Digital Video Broadcasting – Terrestrial (DVB-T), Digital Video Broadcasting - Second Generation Terrestrial (DVB-T2), Advanced Television Systems Committee (ATSC), and Integrated Services Digital Broadcasting – Terrestrial (ISDB-T), which optimize television broadcasting for increased efficiency and reliability (ETSI, 2021). However, despite these improvements, urban environments with high levels of multipath interference continue to pose challenges to the performance of DTT networks. This issue is particularly pronounced in rapidly developing cities like Port Harcourt, where signal degradation due to multipath effects remains a pressing concern (Ali & Zhang, 2019).

Port Harcourt, one of Nigeria's fastest-growing urban centers, is characterized by a landscape that includes high-rise buildings, dense vegetation, and large industrial complexes. These structural features contribute to severe multipath propagation, where transmitted signals reflect off obstacles before reaching the receiver, causing signal distortion, phase shifts, and inter-symbol interference (ISI) (Obasi *et al.,* 2022). Such effects degrade the quality of service (QoS), reducing the efficiency of DTT networks, particularly for users in mobile and indoor environments (Nguyen & Tran, 2020). Multipath interference is a well-known phenomenon in radio wave propagation and occurs when multiple signal paths exist due to reflections, refractions, or diffractions. In urban settings, buildings and other obstacles create multiple signal paths that reach the receiver at different time intervals, resulting in constructive or destructive interference. This leads to signal fading, bit errors, and loss of synchronization in digital receivers, thereby affecting the overall reliability of the system (Rahman & Al-Akaidi, 2018). The challenges posed by multipath interference are further exacerbated in Port Harcourt due to its rapid urbanization. The continuous expansion of infrastructure, including high-density residential areas, commercial buildings, and industrial zones, increases the likelihood of complex signal reflections and multipath distortions. As a result, DTT viewers in the city often experience degraded reception quality, signal dropouts, and limited-service coverage, highlighting the need for more adaptive broadcasting solutions (Obasi *et al.,* 2022).Adaptive transmission techniques present a viable solution to mitigate the adverse effects of multipath propagation and enhance DTT performance in Port Harcourt. These techniques involve dynamically adjusting transmission parameters, such as modulation schemes, coding rates, and power levels, based on real-time channel conditions (Kumar *et al.,* 2021). Unlike traditional fixed transmission systems, adaptive transmission ensures that optimal signal reception is maintained despite variations in propagation environments. One of the key components of adaptive transmission is adaptive modulation and coding (AMC), which allows the system to switch between different modulation schemes depending on the prevailing signal-to-noise ratio (SNR). When SNR is high, higher-order modulation schemes (e.g., 64-QAM) can be used to maximize data throughput. Conversely, in low SNR conditions, lower-order modulation schemes (e.g., QPSK) provide more robust transmission with reduced error rates (Nguyen & Tran, 2020). By implementing AMC in DTT systems, signal reception can be significantly improved, especially in areas affected by multipath interference. Although AMC enhances system adaptability, it has limitations that affect its practical implementation. These include inaccuracies in channel estimation, increased signaling overhead, feedback delays, and higher system complexity, which may reduce overall system efficiency in rapidly changing channel conditions (Al-Hraishawi et al., 2020; Kaur & Kaur, 2022). To address these limitations, Dynamic Signal Optimization (DSO) has been proposed as an improved approach for enhancing transmission performance in digital broadcasting systems. DSO involves the intelligent selection and optimization of modulation schemes based on real-time channel conditions, particularly using Signal-to-Noise Ratio (SNR) as a key decision parameter. By optimizing the trade-off between robustness and data rate, DSO enhances both reliability and spectral efficiency (Zhang et al., 2020; Singh & Kumar, 2023).

Another critical aspect of adaptive transmission is power control, where the transmission power is dynamically adjusted to compensate for channel impairments. In a high-multipath environment like Port Harcourt, increasing power levels in weak signal areas ensures better coverage, while reducing power in strong signal areas prevents unnecessary interference and conserves energy (Rahman & Al-Akaidi, 2018). This approach optimizes the efficiency of DTT broadcasting and enhances overall network performance.

Furthermore, multiple-input multiple-output (MIMO) technology is another promising adaptive transmission technique that can improve DTT performance. MIMO systems utilize multiple antennas at both the transmitter and receiver to exploit spatial diversity, thereby mitigating multipath effects and improving signal reliability (Ali & Zhang, 2019). This technique is particularly beneficial in urban environments where signal reflections are prevalent. By leveraging MIMO technology, DTT broadcasters in Port Harcourt can enhance spectral efficiency and increase the robustness of transmitted signals. The implementation of adaptive transmission in DTT networks requires a strategic approach involving real-time channel estimation, advanced signal processing, and robust feedback mechanisms. Modern DTT standards such as DVB-T2 incorporate features that support adaptive transmission, making them well-suited for deployment in multipath-prone environments (ETSI, 2021). However, despite the availability of these technologies, their adoption in Nigeria remains limited due to challenges such as regulatory constraints, infrastructure limitations, and lack of awareness among broadcasters (Obasi *et al.,* 2022). This study will look into exploring the potential of adaptive transmission in improving DTT broadcasting quality using Port Harcourt as a case study by applying dynamic signal optimization which is a mode; that enables transmission parameters to be adjusted in real time according to prevailing channel conditions. In DTT, dynamic signal optimization involves switching between modulation schemes (QPSK, 16-QAM, 64-QAM), adjusting guard intervals, and applying forward error correction (FEC) in a flexible manner. This ensures signal robustness is maintained in noisy conditions as well as maximizing throughput when the channel is favorable. The expected outcomes of this research will be beneficial for broadcasters, policymakers, and network engineers. By adopting adaptive transmission techniques, broadcasters can ensure a more stable and high-quality viewing experience for DTT audiences in Port Harcourt. Policymakers can use the findings to develop regulatory frameworks that support the deployment of adaptive broadcasting solutions, while network engineers can leverage the insights to design more resilient DTT infrastructures (Obasi *et al.,* 2022). In standard DVB-T2 literature, the process of automatically adjusting transmission parameters is referred to as adaptive transmission. In this research, the same concept is described as dynamic signal optimization to emphasize its practical role in improving signal quality. Both terms are used interchangeably to describe a system that optimizes modulation, coding, and guard interval settings in response to channel variations.

II. EXTENT OF PAST WORKS

Digital broadcasting refers to the modernized method of delivering television signals using digital formats rather than analog waves. It relies on binary digits for transmitting and receiving content, enabling more efficient and reliable distribution to wide audiences However, Orlu-Orlu (2017) opined that digital means the application of digits or numbers in the representation of information. In this regard, digital broadcasting is a means of ensuring capacity in broadcast transmission networks by improving spectrum efficiency (Plum, 2017). By implication, digital broadcast content is considered superior in quality compared to analog broadcast. In addition, digital broadcasting offers multiple program options, and minimized energy usage among others, thus creating an unavoidable avenue for a shift of attention from analog to digital. Some requisite equipment needed to foster digital broadcast operations is a studio mixing board, microphones, headphones, digital cameras, broadcast media server for television automation, capture cards for ingesting live material, scheduler, hardware encoder, studio transmitter link, streaming receiver, digital TV transmitter, digital mixer, digital monitors, virtual studio equipment, satellite technology, capture card, streaming digital receiver (Inaba & Kolia, 2016). In addition, digital television offers interference-free, quality sound and multiplexing of up to 6 channels under one bandwidth. Okhakhu (2015) in his research described digitalization as the cutting-edge technology that enables the broadcast industry to do away with the obsolete method of transmission. He further noted that digitalization is about making broadcast transmission to be digitally compliant; by implication, television means nothing but quality of broadcast transmission that requires improvement. This is in agreement with the position of Jayson (2015) that digital transmission (also called digital switch-over or analogue-switch off) which analogue television is converted to and replaced by digital television. Similarly, Gupt (2020) referred to digitalization as creating a digital representation of physical objectives or attributes. It is about converting something non-digital into a digital representation or artefact. Digitalization is said to be the first significant innovation service in the evolution of broadcast technology of television in the 1950s (Ogiri & Henshaw, 2019).

The fundamental challenge in Digital Terrestrial Television Broadcasting (DTTB) transmission lies in maintaining signal integrity across varying atmospheric conditions and geographical terrains. Zhou et al. (2021) conducted pioneering work on probability error function modeling for DTTB systems operating in urban environments. Their research demonstrated that the conventional Gaussian error function approximation becomes insufficient when accounting for multipath interference in dense urban settings. They proposed a modified error function incorporating Rician fading parameters, achieving a 15% improvement in prediction accuracy for bit error rates (BER).

Building on this foundation, Aragón-Zavala *et al* (2021) expanded the error function analysis to include the effects of dynamic weather conditions on DTTB signals. Their work introduced a weather-dependent probability error function that adaptively adjusts based on precipitation intensity and atmospheric turbulence. The model demonstrated particular effectiveness in regions experiencing frequent meteorological variations, with error prediction accuracy improving by up to 23% compared to static models.

A significant advancement came from the research of Eizmendi *et al*. (2014), who developed a comprehensive error function framework specifically for DVB-T2 systems. Their approach combined traditional probability error analysis with machine learning techniques to predict and mitigate real-time transmission errors. The hybrid model showed remarkable adaptability to varying channel conditions, reducing the average bit error rate by 31% compared to conventional systems (Ali *et al.,* 2019).

In addressing the challenges of single-frequency networks (SFN), Li and Roberts (2022) proposed an innovative approach to error function analysis. Their research introduced a spatial correlation component to the probability error function, accounting for the unique interference patterns in SFN deployments. This modification proved valuable for optimizing guard interval settings and improving overall network synchronization (Essilfie & Amoah, 2024).

Recent work by Gonsioroski, *et al* (2023) has focused on error function analysis for next-generation DTTB standards, particularly in the context of 4K and 8K broadcasting. Their research highlighted the limitations of traditional error functions when dealing with higher-order modulation schemes and proposed a novel approach based on fractional calculus. The modified error function accurately predicted symbol errors for 4096-QAM configurations.

III. MATERIALS AND METHOD

2.1 Materials Used

The materials used for this study were grouped into hardware tools, software tools and reference materials. Each category enabled the simulation and analysis of Digital Terrestrial Television performance in line with the five research objectives.

2.1.1 Hardware Tools

Personal computer which Served as the simulation platform with the following specifications;

Processor: Intel Core i3/ 8th Generation
RAM: 8 GB
Storage: 256 GB SSD
Operating System: Windows 10

2.1.2 Software Tools

MATLAB/Simulink was used to design and simulate the DTT system, implement modulation schemes (QPSK, 16-QAM, 64-QAM), forward error correction (FEC), and guard interval adjustments. It also provided tools for generating Bit Error Rate (BER), Throughput, Modulation Error Ratio (MER), and Link Margin plots.

Google Earth software tool was used to view satellite imagery, see high-resolution images of Port Harcourt from above, including cities, mountains, rivers, and landmarks. Explore 3D models of buildings, mountains, and other structures to get a realistic sense of geography and urban areas. Find directions, measure distances, and view streets and landscapes from multiple angles.

This research adopted a simulation-based method using MATLAB R2023a to model and evaluate the performance of DVB-T2 broadcasting system under AWGN and Rayleigh fading channel conditions. The study implemented conventional fixed modulation schemes and a proposed Dynamic Signal Optimization (DSO) model employing adaptive modulation switching with hysteresis-adjusted thresholds. Performance evaluation was carried out using Bit Error Rate (BER), Modulation Error Ratio (MER), throughput, and link margin metrics under AWGN and Rayleigh fading channel conditions.

The simulation procedures are as follows

i. Initialization of DVB-T2 System Parameters: The DVB-T2 transmission parameters used for the simulation were initialized based on realistic operational ranges obtained from DVB-T2 specifications and practical broadcasting parameters applicable to the Port Harcourt environment. The initialized parameters included:
   - Channel bandwidth (8 MHz)
   - Modulation schemes (QPSK, 16-QAM, 64-QAM, and 256-QAM)
   - Coding schemes (LDPC and BCH)
   - OFDM configuration
   - Guard interval settings
   - Signal-to-Noise Ratio (SNR) range
   - Link margin thresholds
   - Throughput parameters
   - Channel fading conditions

ii. Generation of Random Binary Data: Random binary input data representing digital television broadcast information was generated within MATLAB. The generated binary sequence served as the input signal for modulation and transmission through the DVB-T2 system model.

iii. OFDM-Based Signal Representation: The modulated symbols were represented within an OFDM transmission framework consistent with DVB-T2 system architecture. The OFDM representation was adopted to improve resistance against multipath fading and inter-symbol interference commonly experienced in urban broadcasting environments.

iv. Channel Modeling: Simulated using Additive White Gaussian Noise (AWGN) and multipath Rayleigh fading to approximate Port Harcourt’s urban environment

v. Development of the Proposed DSO Model: The proposed Dynamic Signal Optimization (DSO) model was implemented using adaptive modulation switching based on estimated channel conditions. The switching algorithm dynamically selected the most suitable modulation scheme according to SNR and MER conditions.

vi. Hysteresis-Based Switching Implementation: To mitigate Adaptive Modulation and Coding (AMC) weaknesses such as rapid switching instability and signaling overhead, hysteresis-adjusted switching thresholds were incorporated into the DSO model. This reduced unnecessary modulation transitions under fluctuating channel conditions and improved system stability.

vii. Coverage Distance and DSO Switching Region Analysis: Coverage analysis was carried out by estimating SNR variation with transmission distance from the transmitter. The proposed DSO model dynamically switched modulation schemes according to the estimated coverage region and channel quality.

2.2.1 Study Area

Rivers State was used as a case study, with a primary focus on the urban environment of Port Harcourt.

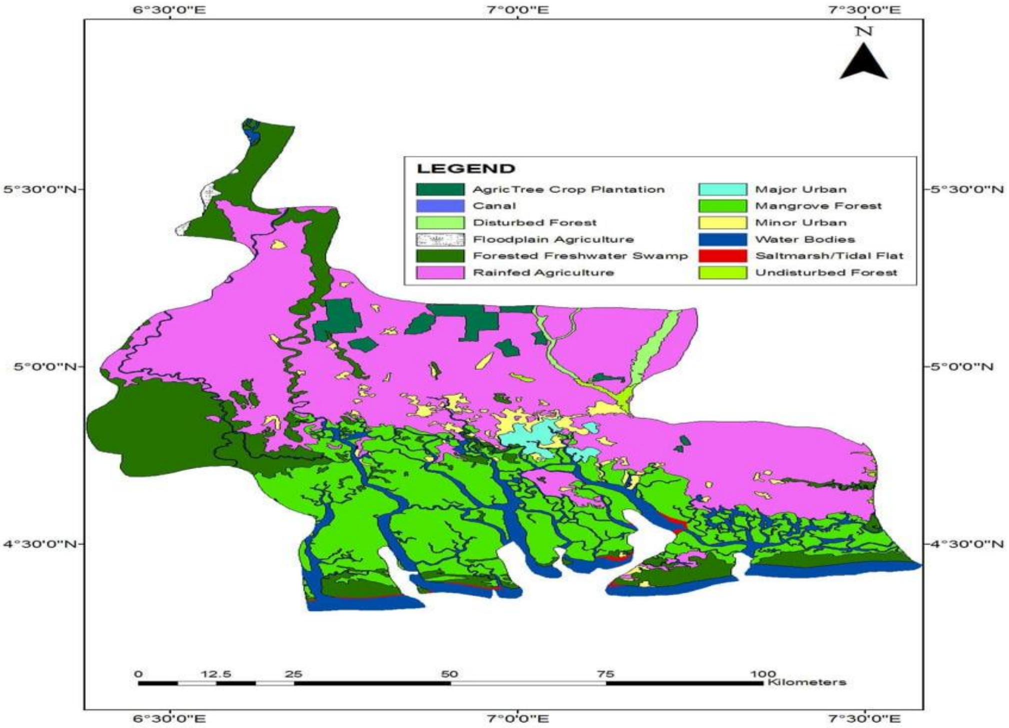


Fig: 1: Map of Rivers State
Source: GIS Laboratory (Research Gate.net)

The broader map of Rivers State (Figure 1) highlights major urban areas, providing regional context for the study.

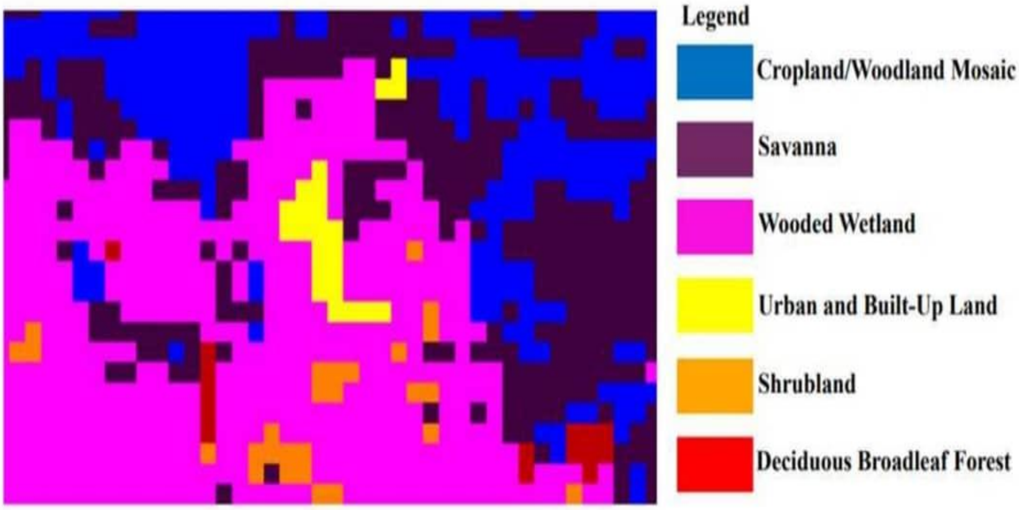


Fig 2: Land use description of Rivers State
Source: Research Gate.net

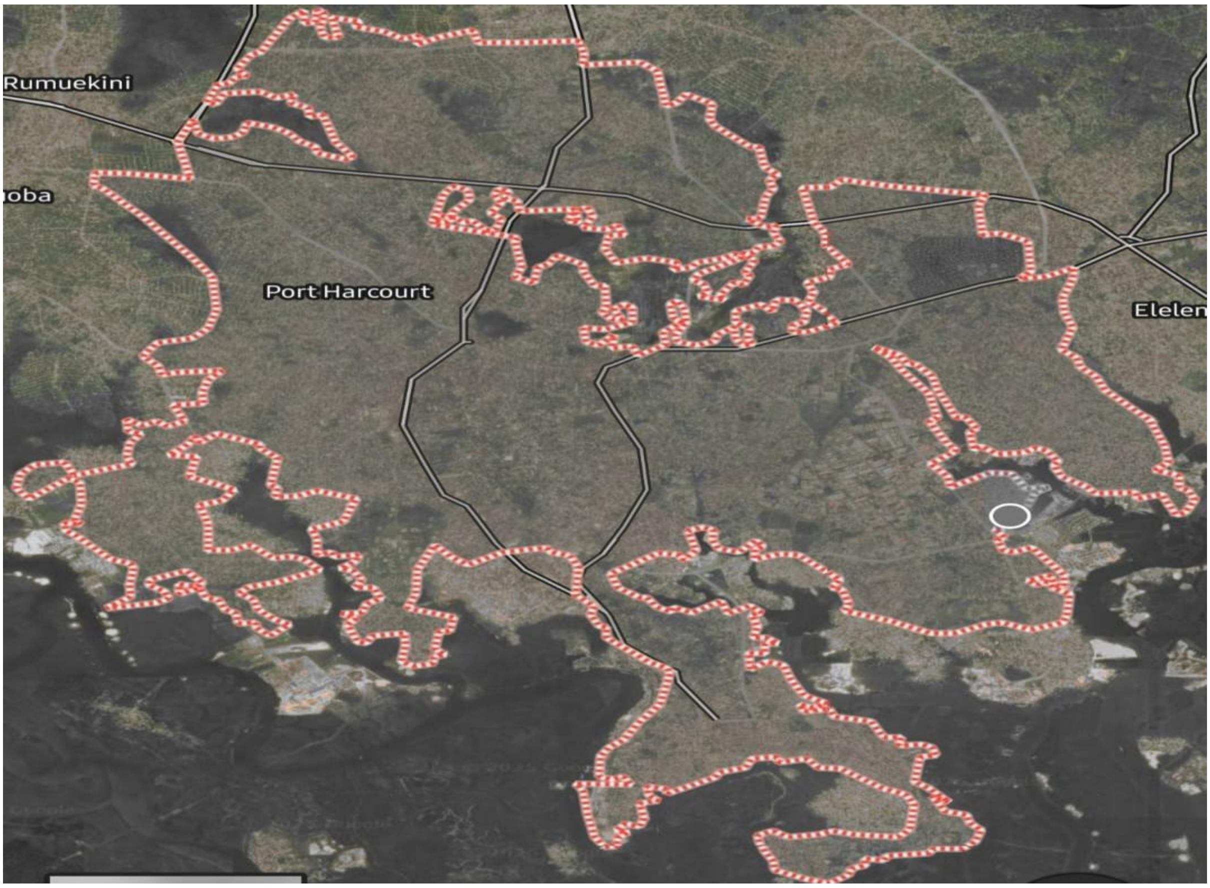


Fig 3 Map of Port Harcourt
Source: Google Earth Map

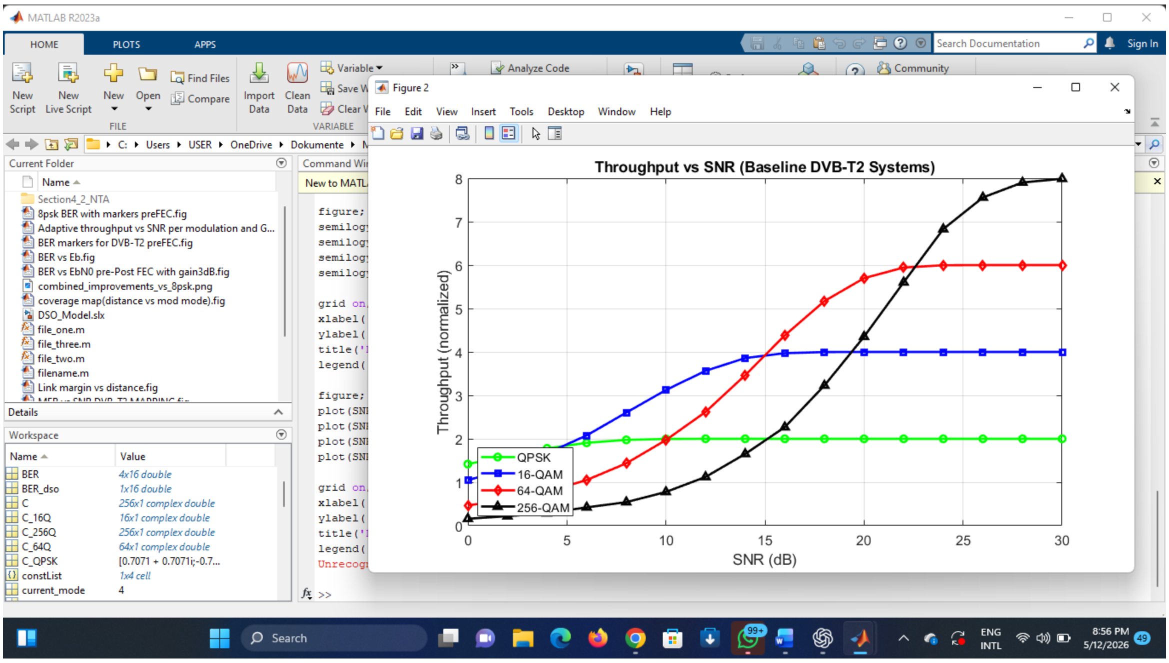
Rivers State (approximately 4.7460°N, 6.9916°E) was used as a case study, with a primary focus on the urban environment of Port Harcourt (4.8156°N, 7.0498°E). Figures 3.1 and 3.2 illustrate the land-use characteristics of Rivers State and Port Harcourt, respectively. The broader map of Rivers State (Figure 3.1) highlights major urban, industrial, and residential areas, providing regional context for the study. The detailed map of Port Harcourt (Figure 3.3) shows urban density, commercial districts, residential zones, open spaces, and water bodies, which are critical factors affecting digital terrestrial television (DTT) signal propagation. These land-use characteristics were used to contextualize the propagation modeling and predict DVB-T2 coverage zones, as dense urban areas and high-rise structures can introduce multipath fading, shadowing, and signal attenuation, while open spaces facilitate wider coverage. By incorporating these maps, the study ensures that the simulation and measurement methodology reflects realistic environmental conditions, enhancing the reliability and applicability of the predicted coverage and link performance results.

2.2.2 Simulation Setup

The simulation setup for this study was developed using MATLAB R2023a to evaluate the performance of conventional DVB-T2 modulation schemes and the proposed Dynamic Signal Optimization (DSO) model under varying wireless channel conditions. The setup was configured using realistic DVB-T2 transmission parameters applicable to Digital Terrestrial Television (DTT) broadcasting environments within Port Harcourt.

The simulation environment incorporated adaptive modulation switching, hysteresis-based threshold control, AWGN and Rayleigh fading channel models, and comparative performance evaluation using BER, MER, throughput, and link margin metrics.

The proposed DSO model utilized hysteresis-adjusted modulation switching thresholds to improve modulation stability and reduce unnecessary Adaptive Modulation and Coding (AMC) transitions under fluctuating channel conditions. The developed DSO model dynamically selected the most suitable modulation scheme according to estimated channel quality, thereby improving transmission reliability, signal quality, throughput efficiency, and adaptive coverage performance across different operating regions. The MATLAB codes shown in the appendices page were used to simulate the values for this project.



Name	Value
BER	4x16 double
BER_dso	1x16 double
C	256x1 complex double
C_16Q	16x1 complex double
C_256Q	256x1 complex double
C_64Q	64x1 complex double
C_QPSK	[0.7071 + 0.7071i;-0.7...
constList	1x4 cell
current_mode	4

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Fig 4 MATLAB Work Area

2.2.3 Key Performance Indicators (KPIs)

Key performance indicators metrics are as follows;

i. **Bit Error Rate (BER):** Represents the percentage of data bits received incorrectly, with a lower BER indicating better signal quality and fewer transmission errors.

The bit error rate (BER) measures the difference between the quantities of data sent and received and is used to determine the quality of the communication channel (Ardakani & Tatu, 2021).

$$BER = \frac{\text{Number of bits in error}}{\text{Total number of bits transmitted}} \qquad (1)$$

In the MATLAB simulation developed for this research, BER was computed by comparing the transmitted modulation symbols with the detected symbols at the receiver after transmission through the AWGN and Rayleigh fading channels.

The simulation BER expression used was:

$$BER = \frac{\Sigma(s \neq \hat{s})}{N} \qquad (2)$$

Where:

s = Transmitted symbol

$\hat{s}$ = Detected/received symbol

N = Total number of transmitted symbols

This is the exact formula used to generate the BER vs SNR curves for AWGN and Rayleigh fading which can be seen in the MATLAB code in appendices

ii. **Throughput:** Throughput is a key performance indicator used in digital communication systems to measure the amount of successfully transmitted data over a communication channel within a given period of time. In Digital Terrestrial Television (DTT) and DVB-T2 broadcasting systems, throughput represents the effective data transmission rate achieved after accounting for channel impairments, transmission errors, and modulation efficiency (Goldsmith, 2022). In this study, throughput was used to evaluate the transmission efficiency of the conventional fixed DVB-T2 modulation schemes and the proposed Dynamic Signal Optimization (DSO) model under varying channel conditions. Throughput analysis was performed using both normalized throughput and practical Mbps representation based on the DVB-T2 8 MHz channel bandwidth.

In the MATLAB simulation implemented for this research, throughput was computed based on the modulation order and the measured BER value obtained after transmission through the communication channel.

The simulation throughput equation used was:

$$T = k(1 - BER) \qquad (3)$$

Where:

T = Normalized Throughput

k = Number of bits per symbol ($\log_2 M$)

BER = Measured Bit Error Rate

M = Modulation Order

iii. **Modulation Error Ratio (MER):** MER quantifies modulation quality by comparing the average power of the ideal transmitted constellation to the average power of the error vectors (the vector difference between received and ideal constellation points). Higher MER means the received symbols lie closer to their ideal positions that is better fidelity (ITU 2016).

Mathematically represented as:

$$\mathrm{MER(dB)} = 10\mathrm{Log}_{10}\left(\frac{\mathrm{P_{signal}}}{\mathrm{P_{error}}}\right) \tag{4}$$

Where

The average error power $\mathrm{P_{error}} = \frac{1}{N}\sum_{K=1}^{N}|e_k|^2$ (5)

$e_k = s_k - s_k^{ideal}$ (6)

The average reference signal power

$\mathrm{P_{signal}} = \frac{1}{N}\sum_{K=1}^{N}\left|s_k^{ideal}\right|^2$ (7)

An alternative expression (useful for code) that shows the computation directly from samples;

$$\mathrm{MER(dB)} = 10\mathrm{Log}_{10}\left(\frac{\sum_{K=1}^{N}\left|s_k^{ideal}\right|}{\sum_{K=1}^{N}\left|s_k - s_k^{ideal}\right|2}\right) \tag{8}$$

Constellation diagrams were used in this study to visually evaluate modulation quality and symbol dispersion under different channel conditions. In an ideal transmission system, constellation points remain tightly clustered around their expected symbol locations. However, channel impairments such as noise and fading cause the constellation points to spread, resulting in increased modulation error and reduced MER values.

iv. **Signal-to-Noise Ratio (SNR):** Signal-to-Noise Ratio (SNR) is one of the most important performance indicators in digital communication systems and wireless broadcasting networks. SNR represents the ratio between the power of the desired transmitted signal and the power of unwanted noise present within the communication channel (Molisch, 2019). It is commonly used in DVB-T2 systems to evaluate channel quality, transmission reliability, and modulation suitability under varying propagation conditions.

SNR is typically expressed in decibels (dB), and it serves as a key parameter for determining the performance of modulation schemes in Digital Terrestrial Television (DTT) broadcasting systems. Higher SNR values indicate stronger signal quality and lower noise interference, resulting in improved communication reliability and reduced transmission errors. Conversely, lower SNR values indicate poor channel quality and increased susceptibility to signal distortion and fading effects (Goldsmith, 2022).

In adaptive DVB-T2 systems, SNR plays a critical role in adaptive modulation switching because different modulation schemes require different minimum SNR thresholds for reliable operation. Lower-order modulation schemes such as QPSK can operate effectively under low SNR conditions, while higher-order schemes such as 64-QAM and 256-QAM require significantly higher SNR values to maintain acceptable BER and MER performance (ETSI, 2020).

The instantaneous (linear) signal-to-noise ratio seen by the receiver (ITU 2019) is;

$$\mathrm{SNR} = \frac{P_{signal}}{P_{noise}} \tag{9}$$

And in decibels

$$\mathrm{SNR} = 10\mathrm{Log}_{10}\left(\frac{\mathrm{P_{signal}}}{\mathrm{P_{noise}}}\right) \tag{10}$$

The thermal noise power in a bandwidth B(Hz) at the standard reference temperature T_0 = 290 K (ITU 2019) is

$$\mathrm{P_{thermal}} = kT_0B \tag{11}$$

Where k is Boltzmann's constant (1.38×10^{-23} J/K), and in practical dBm unit, it is written as: $\mathrm{P_{thermal,dBm}}$ = -174 dBm/Hz + $10\mathrm{Log}_{10}$(B) (12)

If the receiver has a noise figure NF (dB), the total noise power at the detector input becomes: $\mathrm{P_{thermal,dBm}}$ = -174 dBm/Hz + $10\mathrm{Log}_{10}$(B) + NF (dBm) (13)

If the received carrier power is Pr (in dBm) then the SNR in dB is computed as:

$\mathrm{SNR_{dB}} = \mathrm{P_{r,dBm}} - \mathrm{P_{noise,dBm}} = \mathrm{P_{r,dBm}}$ – [-174 dBm/Hz + $10\mathrm{Log}_{10}$(B) +NF] (14)

v. **Link Margin**: Link Margin (LM) represents the difference between the available SNR at the receiver and the minimum required SNR for a particular modulation and coding scheme (MCS) to operate reliably (Mekuria et al., 2020). A positive link margin indicates that the received signal has enough strength and quality to overcome channel impairments; a negative margin indicates a likely loss of service.

The general expression for Link Margin is given as:

$$LM = SNR_{available} - SNR_{required} \quad (15)$$

Where:
$SNR_{available}$ is the available channel
$SNR_{required}$ is the minimum SNR threshold needed for reliable reception
In the MATLAB simulation implemented for this study, the Link Margin was computed by comparing the estimated channel SNR with the hysteresis-adjusted modulation switching thresholds used in the proposed DSO model.
The simulation Link Margin equation used was:

$$LM = SNR_{channel} - SNR_{threshold} \quad (16)$$

where: $SNR_{channel}$ is the estimated channel
$SNR_{threshold}$ is the required modulation switching threshold

3.2.4 Simulation Parameters

The Key Simulation Parameters as gotten from ARISE TV site Engineer and standard DVB-T2 are shown below.

Table 1: Simulation Parameters

Parameter	Value/Settings
Simulation software	MATLAB R2023a
Broadcasting Standard	DVB-T2
Study Environment	Port Harcourt Urban Environment
Channel Bandwidth	8 MHz
Frequency Band	UHF (480 MHz)
Transmission Techniques	OFDM
FFT size	8K, 16K
Guard Interval	1/8, 1/16
Modulation Schemes	QPSK, 16-QAM, 64-QAM, 256-QAM
Adaptive Technique	Dynamic Signal Optimization (DSO)
Coding Technique	LDPC + BCH
Coding Rates	1/2, 2/3, 3/4, 5/6
Channel Models	AWGN and Rayleigh Fading
SNR Range	0 – 30 dB
Number of symbols	20,000
Performance Metrics	BER, MER, Throughput, Link Margin
Throughput Evaluation	Normalized and Mbps
Antenna Power (ERP)	18kw
Antenna Height	180m
Antenna Gain	13 dBi
Delay Profile	Extended Typical Urban (ETU)
Delay Spread	1 µs – 5 µs
Coverage Radius	20 – 50 km
BER Target (Pre-FEC)	1×10^{-3}
BER Target (Post-FEC)	1×10^{-7}
Link Margin Range	5 – 10 dB
MER Thresholds	QPSK = 10 dB, 16-QAM = 18 dB, 64-QAM = 25 dB, 256-QAM = 32 dB
DSO Switching Basis	SNR and MER Estimation
Switching Stability Technique	Hysteresis-Based Thresholding

2.2.5 Analyze the baseline of DVB-T2 performance using fixed modulation schemes

The baseline DVB-T2 performance analysis was carried out by developing fixed modulation transmission models using QPSK, 16-QAM, 64-QAM, and 256-QAM modulation schemes in MATLAB R2023a. The purpose of the baseline analysis was to establish a conventional DVB-T2 reference system for evaluating the performance improvement achieved by the proposed Dynamic Signal Optimization (DSO) model. Random binary transmission data was generated and mapped into the selected modulation schemes using digital modulation techniques. The modulated signals were transmitted through both Additive White Gaussian Noise (AWGN) and Rayleigh fading channel models to evaluate system behavior under ideal and realistic urban wireless propagation conditions. The AWGN channel model was used to analyze the effect of additive noise on signal transmission, while the Rayleigh fading channel model was used to represent multipath propagation and fading conditions commonly experienced in urban terrestrial broadcasting environments such as Port Harcourt and the MATLAB codes can be seen in Appendices A. The performance of each modulation scheme was analyzed across varying Signal-to-Noise Ratio (SNR) levels ranging from 0 dB to 30 dB. At the receiver section, signal detection and demodulation were performed using nearest-neighbor detection techniques. The transmitted and received symbols were then compared to evaluate system performance.

2.2.6 Evaluate modulation signal quality through constellation diagrams of (MER).

The evaluation of modulation signal quality was carried out using Modulation Error Ratio (MER) analysis and constellation diagram visualization techniques implemented in MATLAB R2023a as codes can be seen in Appendices B. The purpose of this analysis was to assess the quality, stability, and accuracy of the transmitted modulation symbols under varying channel conditions within the DVB-T2 transmission system. Random transmission symbols were generated and modulated using QPSK, 16-QAM, 64-QAM, and 256-QAM modulation schemes. The modulated signals were transmitted through AWGN and Rayleigh fading channels to examine the effects of noise and multipath fading on signal quality and modulation accuracy. At the receiver stage, the received constellation points were extracted and compared with the ideal transmitted constellation symbols. The deviation between the ideal and received symbols was used to compute the Modulation Error Ratio (MER), which provided a quantitative measure of signal distortion and modulation quality. Constellation diagrams were generated for each modulation scheme to visually examine symbol dispersion, noise effects, fading effects, and modulation stability under varying Signal-to-Noise Ratio (SNR) conditions. The constellation plots enabled observation of how closely the received symbols clustered around their ideal constellation locations. Higher MER values and tighter constellation clustering indicated improved modulation quality and signal stability, while increased symbol dispersion indicated higher modulation distortion and degraded communication quality.

2.2.7 Develop a Dynamic Signal Optimization (DSO) model using SNR-based modulation switching.

The Dynamic Signal Optimization (DSO) model was developed using an adaptive modulation switching technique based on estimated Signal-to-Noise Ratio (SNR) conditions within the DVB-T2 transmission system. The purpose of the proposed model was to dynamically optimize transmission performance by selecting the most suitable modulation scheme according to the prevailing channel condition. The DSO model was implemented in MATLAB R2023a as see in Appendices C, using adaptive switching logic between QPSK, 16-QAM, 64-QAM, and 256-QAM modulation schemes. The switching mechanism was designed to continuously monitor the estimated channel SNR and automatically select an appropriate modulation scheme capable of maintaining reliable communication while maximizing throughput efficiency. The adaptive switching thresholds were defined according to the minimum SNR requirements of the different modulation schemes. Lower-order modulation schemes such as QPSK were selected during poor channel conditions due to their improved robustness, while higher-order modulation schemes such as 64-QAM and 256-QAM were selected under favorable channel conditions to achieve higher throughput and spectral efficiency. To mitigate Adaptive Modulation and Coding (AMC) weaknesses such as rapid modulation fluctuation, signaling instability, and unnecessary switching between modulation states, hysteresis-adjusted switching thresholds were incorporated into the proposed DSO model. The hysteresis mechanism introduced stability margins between modulation transition regions, thereby reducing frequent switching caused by small channel variations. The developed DSO model dynamically adapted transmission performance under varying AWGN and Rayleigh fading channel conditions using SNR estimation as the primary channel quality indicator.

2.2.8 Determine the link margin and coverage-based modulation switching regions of the DSO model.

The link margin analysis was performed by estimating the difference between the available channel Signal-to-Noise Ratio (SNR) and the minimum required SNR threshold for reliable operation of each modulation scheme which codes can be seen at Appendices D. The analysis enabled the evaluation of communication reliability, signal stability, and adaptive transmission robustness for QPSK, 16-QAM, 64-QAM, and 256-QAM modulation schemes. The proposed DSO model utilized hysteresis-adjusted SNR switching thresholds to dynamically determine the most suitable modulation scheme according to the prevailing channel condition. The modulation switching regions were defined based on estimated SNR ranges corresponding to different transmission coverage distances from the broadcasting transmitter. Coverage-based analysis was performed by modeling the gradual reduction in SNR with increasing transmission distance due to propagation losses, fading effects, and environmental attenuation commonly experienced in urban broadcasting environments such as Port Harcourt. As the estimated SNR decreased with distance, the DSO model automatically switched from higher-order modulation schemes to lower-order modulation schemes in order to maintain reliable communication quality. The modulation switching regions were categorized into poor, moderate, good, and excellent channel conditions corresponding to different SNR ranges and coverage distances. The adaptive switching mechanism enabled the DSO model to optimize transmission reliability, maintain communication stability, and improve coverage adaptability across varying operational regions.

2.2.9 Comparing the performance of the DSO model and conventional modulation

The comparative performance evaluation between the proposed Dynamic Signal Optimization (DSO) model and the conventional fixed-modulation DVB-T2 systems was carried out to determine the effectiveness of the proposed adaptive transmission approach under varying channel conditions. The comparison was performed using MATLAB R2023a by evaluating both the fixed modulation systems and the proposed DSO model under identical simulation conditions. The conventional DVB-T2 systems utilized fixed modulation schemes including QPSK, 16-QAM, 64-QAM, and 256-QAM without adaptive switching capability, while the proposed DSO model dynamically selected modulation schemes according to estimated channel conditions using SNR-based adaptive switching. Comparative performance analysis was presented using graphs, constellation diagrams, comparative tables, and percentage improvement bar charts. The comparison enabled evaluation of the ability of the proposed DSO model to balance transmission robustness and throughput efficiency under varying channel conditions.

IV. RESULTS AND DISCUSSION

4.1 Evaluating baseline DVB-T2 performance.

Figure 5 presents the Bit Error Rate performance of QPSK, 16-QAM, 64-QAM and 256-QAM under Additive White Gaussian Noise (AWGN).

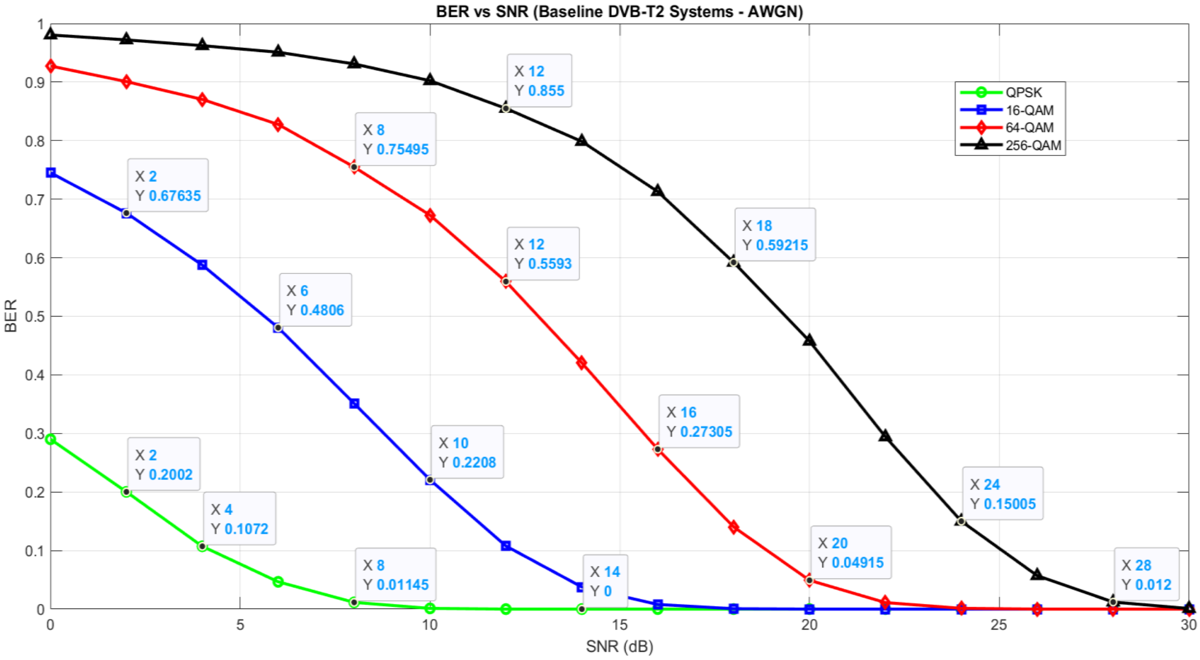

Fig 5: BER vs SNR (AWGN)

The horizontal axis represents the Signal-to-Noise Ratio (SNR) expressed in decibels (dB), ranging from 0 dB to 30 dB, while the vertical axis represents the Bit Error Rate (BER), which quantifies the probability of incorrect bit detection at the receiver. The SNR values indicate the quality of the communication channel, where lower values (0–6 dB) correspond to very poor channel conditions characterized by high noise levels, intermediate values (8–16 dB) represent moderate channel quality, and higher values (18–30 dB) indicate good to excellent channel conditions with minimal noise interference. The BER axis, typically plotted on a logarithmic scale for better visualization, ranges from values close to 1 (indicating highly unreliable transmission) to values approaching 0 (indicating near error-free communication). At low SNR values between 0 dB and 6 dB, the graph shows a clear distinction in the performance of the modulation schemes. QPSK exhibits the most robust performance, maintaining relatively low BER values, typically in the range of 10^{-1} to 10^{-2} depending on the simulation conditions. In contrast, higher-order modulation schemes such as 16-QAM and 64-QAM experience significantly higher error rates due to their increased sensitivity to noise. The performance degradation is most pronounced in 256-QAM, where the BER approaches 0.5, indicating that symbol decisions are nearly random and the communication link is effectively unreliable. This behavior arises because higher-order modulation schemes have densely packed constellation points, reducing the minimum Euclidean distance between symbols and making them more susceptible to noise and signal distortions. As the SNR increases to moderate levels between 8 dB and 16 dB, the performance of all modulation schemes improves, although at different rates. QPSK rapidly achieves near error-free transmission, with BER values dropping to approximately 10^{-3} to 10^{-5}, demonstrating its strong resilience to noise. Meanwhile, 16-QAM begins to stabilize within this SNR range, with its BER decreasing significantly, typically reaching values around 10^{-2} to 10^{-3} at approximately 12–14 dB. The 64-QAM scheme also shows gradual improvement; however, it still exhibits noticeable error rates due to its higher symbol density. On the other hand, 256-QAM remains largely unreliable in this region, as its BER does not reduce sufficiently to support dependable communication, indicating that the channel conditions are still inadequate for such a high-order modulation scheme.

At high SNR values between 18 dB and 30 dB, the graph demonstrates that QPSK, 16-QAM, and 64-QAM all converge toward near-zero BER, indicating highly reliable transmission with minimal errors. Under these favorable channel conditions, the impact of noise is significantly reduced, allowing even higher-order modulations to perform effectively. However, 256-QAM only begins to exhibit acceptable performance at significantly higher SNR thresholds, typically beyond 22 dB to 26 dB, where its BER drops sharply. This delayed improvement highlights the stringent SNR requirements associated with very high-order modulation schemes.

In all, the results presented illustrates the trade-offs between robustness and spectral efficiency in digital communication systems. Lower-order modulation schemes such as QPSK provide strong immunity to noise and are therefore well-suited for operation in poor channel conditions. In contrast, higher-order schemes such as 64-QAM and 256-QAM offer higher data rates but require substantially better channel quality to achieve reliable performance. This observed behavior is fundamentally linked to the reduction in Euclidean distance between constellation points as the modulation order increases, which directly impacts the system's susceptibility to noise. These findings strongly support the need for adaptive modulation techniques in DVB-T2 systems, where modulation schemes can be dynamically adjusted based on real-time SNR conditions to optimize both reliability and data throughput.

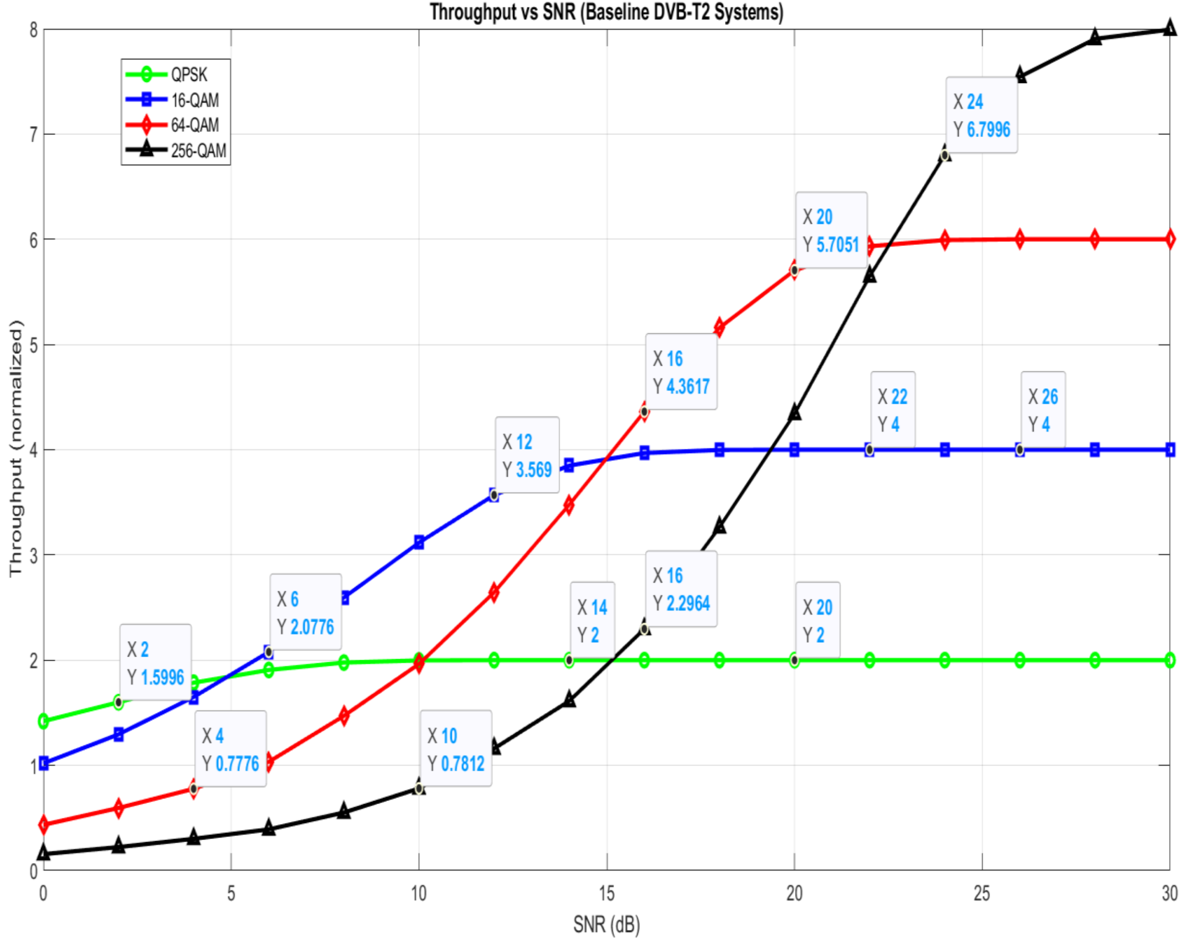

Fig 6: Throughput (Normalized) vs SNR (AWGN)

Figure 4.2 illustrates the throughput performance of QPSK, 16-QAM, 64-QAM, and 256-QAM modulation schemes as a function of the Signal-to-Noise Ratio (SNR) under an Additive White Gaussian Noise (AWGN) channel. The horizontal axis represents the SNR in decibels (dB), ranging from 0 dB to 30 dB, consistent with the BER analysis in Figure X, and serves as an indicator of channel quality. The vertical axis represents the normalized throughput in bits per second per Hertz (bps/Hz), which reflects the effective spectral efficiency of each modulation scheme after accounting for transmission errors. Detailed MATLAB codes can be seen in Appendix A1.

The throughput is computed based on the relationship:

$$Throughput = k \cdot (1 - BER), k = \log_2(M) \qquad (17)$$

Where M denotes the modulation order and k represents the number of bits transmitted per symbol. Consequently, the maximum theoretical throughput values for the modulation schemes are 2 bps/Hz for QPSK, 4 bps/Hz for 16-QAM, 6 bps/Hz for 64-QAM, and 8 bps/Hz for 256-QAM. However, these peak values are only achievable under ideal channel conditions where the BER approaches zero. At low SNR values between 0 dB and 6 dB, the throughput performance is primarily limited by high error rates. In this region, QPSK achieves the highest effective throughput, typically ranging between approximately 1.5 and 2 bps/Hz, due to its strong robustness against noise and relatively low BER. In contrast, 16-QAM and 64-QAM experience significant throughput degradation as a result of elevated error rates, which reduce the proportion of successfully received bits. The performance of 256-QAM is particularly poor in this region, as its throughput remains very low despite its high theoretical capacity. This is because the high BER associated with dense constellation mapping severely limits the number of correctly decoded bits, effectively nullifying its spectral efficiency advantage.

As the SNR increases to moderate levels between 8 dB and 16 dB, a noticeable improvement in throughput is observed across all modulation schemes. QPSK quickly reaches its maximum achievable throughput of approximately 2 bps/Hz and subsequently saturates, as it is constrained by its lower bit capacity per symbol. Meanwhile, 16-QAM becomes increasingly efficient within this SNR range, with throughput values approaching 3 to 4 bps/Hz as the BER decreases significantly. The 64-QAM scheme begins to demonstrate meaningful gains in throughput; however, it has not yet fully reached its theoretical maximum due to residual errors. On the other hand, 256-QAM continues to underperform in this region, as the SNR is still insufficient to overcome its high susceptibility to noise.

At high SNR values between 18 dB and 30 dB, the throughput curves reveal that higher-order modulation schemes begin to fully realize their spectral efficiency potential. In this region, 64-QAM approaches its maximum throughput of approximately 6 bps/Hz as the BER becomes negligible. Similarly, 256-QAM finally achieves significant performance gains and approaches its peak throughput of approximately 8 bps/Hz, particularly at SNR values exceeding 24 dB. In contrast, lower-order modulation schemes such as QPSK and 16-QAM exhibit early saturation, as their throughput is inherently limited by the number of bits per symbol, regardless of further improvements in channel quality.

Table 2: Tradeoffs between Throughput and Reliability

Modulation	**Reliability**	**Throughput**
QPSK	High	Low
16-QAM	Medium	Medium
64-QAM	Low	High
256-QAM	Very Low	Very High

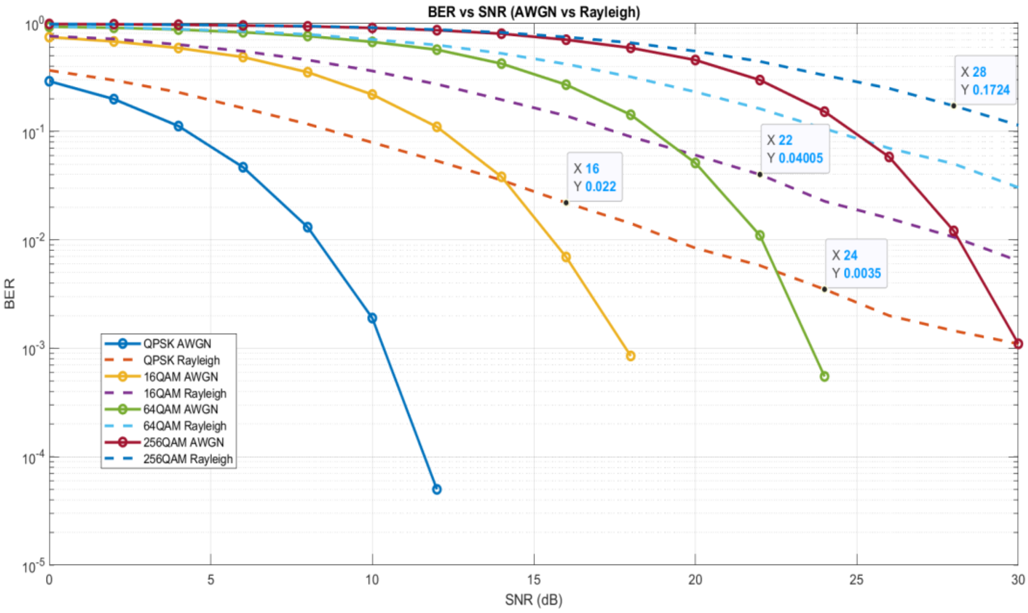

Fig 7: BER vs SNR (AWGN and Rayleigh)

Figure 4.3 presents the Bit Error Rate (BER) performance of QPSK, 16-QAM, 64-QAM, and 256-QAM modulation schemes under both Additive White Gaussian Noise (AWGN) and Rayleigh fading channel conditions. This analysis provides a comparative evaluation of system performance in an ideal channel environment (AWGN) and a more realistic wireless propagation scenario characterized by multipath fading (Rayleigh). The simulation results were generated over an SNR range of 0 dB to 30 dB with a step size of 2 dB, using 20,000 transmitted symbols per SNR point to ensure statistical reliability. Detection at the receiver was performed using a maximum likelihood (ML) nearest-neighbor approach, while perfect channel equalization was assumed for the Rayleigh fading case through division by the channel coefficient. The modulation schemes considered include QPSK (2 bits per symbol), 16-QAM (4 bits per symbol), 64-QAM (6 bits per symbol), and 256-QAM (8 bits per symbol), enabling a comprehensive analysis across different spectral efficiency levels. The horizontal axis of the graph represents the Signal-to-Noise Ratio (SNR) in decibels, which serves as a measure of channel quality. As in previous analyses, SNR values between 0 dB and 6 dB correspond to very poor channel conditions dominated by noise and severe fading effects, values between 8 dB and 16 dB represent moderate channel conditions, and values between 18 dB and 30 dB indicate strong channel conditions with improved signal integrity. The vertical axis represents the Bit Error Rate plotted on a logarithmic scale, allowing for clear visualization of error performance across several orders of magnitude. BER values on the order of 10^{-1} indicate high error probability and unreliable communication, whereas values approaching 10^{-6} signify near error-free transmission. Detailed MATLAB codes can be seen in Appendix A2.

The general trend observed in figure 4.3 shows that the BER decreases monotonically with increasing SNR for all modulation schemes and channel types. However, a consistent and important observation is that the BER curves corresponding to the Rayleigh fading channel are always positioned above those of the AWGN channel. This indicates that, for any given SNR value, the presence of multipath fading introduces additional signal degradation beyond additive noise, resulting in higher error rates. Even with perfect channel equalization, the rapid amplitude and phase variations inherent in Rayleigh fading significantly impact detection performance.

A closer examination of individual modulation schemes provides further insight into system behavior. For QPSK, which is the most robust among the considered schemes, the BER at low SNR values between 0 dB and 4 dB is approximately 10^{-1} under AWGN conditions and increases to about 2×10^{-1} under Rayleigh fading. As the SNR improves to around 8–10 dB, the BER for AWGN drops rapidly to approximately 10^{-3}, while the Rayleigh channel still exhibits a higher BER of about 10^{-2}. At SNR values above 15 dB, both channel conditions approach near-zero BER, demonstrating that QPSK maintains reliable performance even in relatively poor channel environments.

For 16-QAM, the performance at low SNR values (0–6 dB) is relatively poor, with BER values ranging between 10^{-1} and 10^{-2} under both channel conditions. As the SNR increases to moderate levels (10–14 dB), the BER under AWGN improves significantly to approximately 10^{-3}, whereas the Rayleigh channel still exhibits higher error rates around 10^{-2}. Reliable and near error-free performance is only achieved at SNR values exceeding approximately 18 dB, indicating that 16-QAM requires moderate channel quality for effective operation.

In the case of 64-QAM, the sensitivity to noise and fading becomes more pronounced. At low to moderate SNR values (0–10 dB), the BER remains high, typically around 10^{-1}, making the modulation scheme unsuitable for such conditions. As the SNR increases to the range of 14–18 dB, the BER begins to decrease significantly, particularly in the AWGN channel. At SNR values above 20 dB, 64-QAM achieves reliable performance in AWGN conditions; however, the Rayleigh channel still exhibits slight degradation due to residual fading effects. This indicates that 64-QAM is best suited for scenarios with good channel quality.

The performance of 256-QAM further emphasizes the trade-off between spectral efficiency and robustness. At SNR values below 14 dB, the BER remains extremely high, typically in the range of 0.3 to 0.5, indicating nearly random symbol detection and unusable communication performance. Gradual improvement is observed between 18 dB and 22 dB; however, acceptable BER levels are only achieved at very high SNR values, typically above 24–28 dB. Even in this region, the Rayleigh fading channel continues to exhibit slightly higher error rates compared to AWGN, highlighting the vulnerability of high-order modulation schemes to channel impairments.

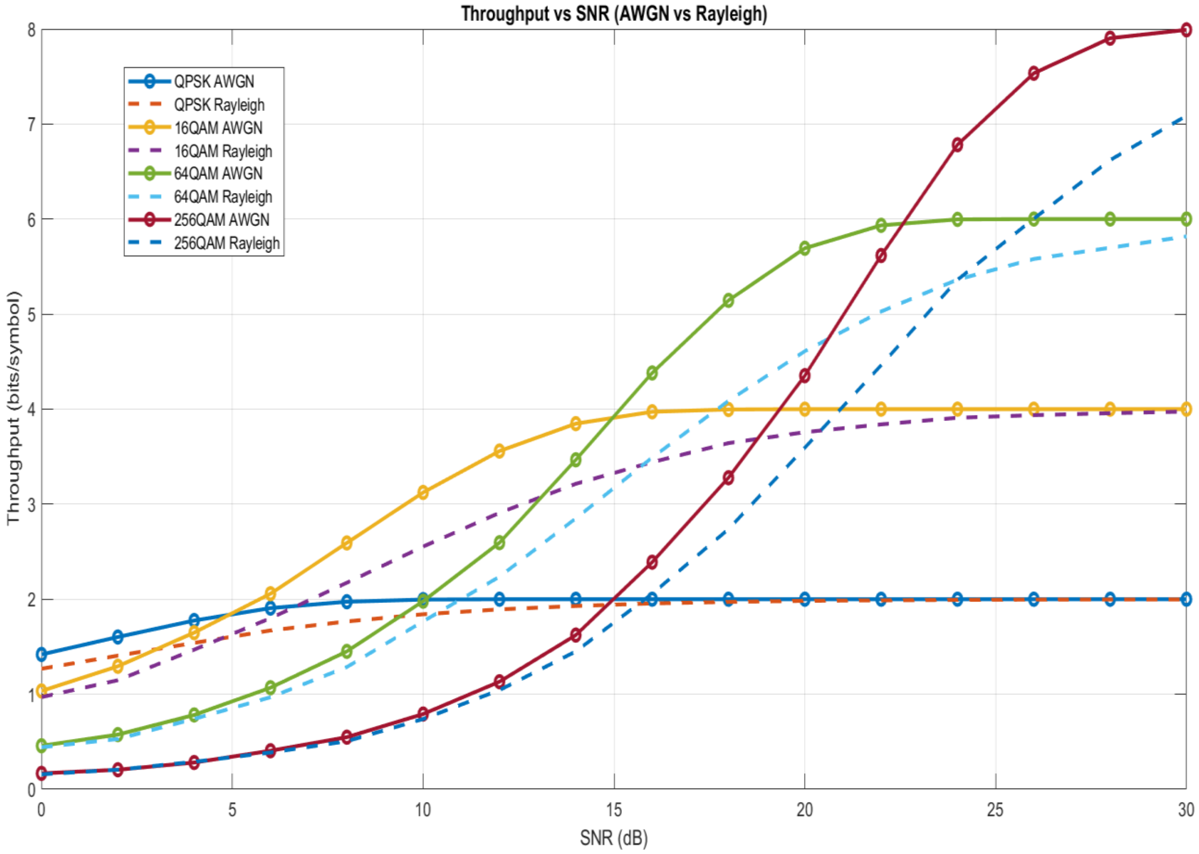

Fig 8: Throughput (Normalized) vs SNR (AWGN and Rayleigh)

Figure 8 illustrates the throughput performance of QPSK, 16-QAM, 64-QAM, and 256-QAM modulation schemes under both Additive White Gaussian Noise (AWGN) and Rayleigh fading channel conditions. The general trend observed indicates that throughput increases with SNR for all modulation schemes and eventually saturates at their respective maximum capacities. However, a consistent performance gap exists between the AWGN and Rayleigh channel conditions, with the Rayleigh curves always lying below the AWGN curves. This behavior reflects the impact of multipath fading, which introduces additional signal distortion and reduces the proportion of correctly received bits, thereby lowering the effective throughput even when equalization is applied.

A detailed examination of individual modulation schemes reveals distinct performance characteristics across different SNR regions. For QPSK, the throughput at low SNR values between 0 dB and 4 dB ranges approximately from 1 to 1.5 bits/symbol, reflecting its robustness under noisy conditions. As the SNR increases to around 8–10 dB, the throughput improves to approximately 1.8–2 bits/symbol and subsequently saturates at its maximum value of 2 bits/symbol beyond 12 dB. This early saturation indicates that QPSK quickly achieves its full capacity but is inherently limited by its lower spectral efficiency.

For 16-QAM, the throughput performance at low SNR values (0–6 dB) remains modest, typically between 1 and 2 bits/symbol due to relatively high error rates. As the SNR increases to moderate levels between 10 dB and 14 dB, the throughput improves significantly, reaching approximately 3 to 3.5 bits/symbol. At SNR values above 18 dB, 16-QAM achieves near-maximum throughput of 4 bits/symbol, indicating that reliable communication is established under these channel conditions.

In the case of 64-QAM, the effective throughput is very low at SNR values below 10 dB due to high BER, rendering the modulation scheme unsuitable for poor channel conditions. However, a rapid increase in throughput is observed between 14 dB and 18 dB as the BER decreases. At SNR values exceedingly approximately 22 dB, 64-QAM approaches its theoretical maximum throughput of 6 bits/symbol under AWGN conditions, although slight degradation persists under Rayleigh fading due to residual channel impairments.

The performance of 256-QAM further highlights the strong dependence of high-order modulation schemes on channel quality. At low to moderate SNR values (0–14 dB), the throughput remains very poor, typically below 2 bits/symbol, despite its high theoretical capacity. Improvement begins to emerge between 18 dB and 22 dB; however, it is only at very high SNR values above approximately 26 dB that 256-QAM approaches its maximum throughput of 8 bits/symbol. Even in this region, the Rayleigh fading channel exhibits slightly reduced performance compared to AWGN, reinforcing the sensitivity of dense constellations to channel variations.

From a practical deployment perspective, these results have direct relevance to Digital Terrestrial Television broadcasting conditions in Nigeria, particularly in urban environments such as Port Harcourt. Real-world DVB-T2 systems in Nigeria predominantly operate using QPSK, 16-QAM, and 64-QAM modulation schemes, while 256-QAM is rarely implemented. This is primarily due to the challenging channel conditions experienced in such environments, including multipath propagation effects (well represented by the Rayleigh fading model), co-channel interference, and fluctuating SNR levels typically ranging between approximately 8 dB and 20 dB.

The simulation results clearly support this practical observation. As demonstrated in Figure Y, 256-QAM requires SNR values exceeding 24 dB to achieve efficient throughput performance, a condition that is not consistently attainable in typical Nigerian broadcasting environments. Consequently, its deployment becomes impractical for reliable service delivery. In contrast, QPSK, 16-QAM, and 64-QAM provide a more balanced trade-off between robustness and spectral efficiency across the observed SNR range.

In conclusion, the results confirms that while higher-order modulation schemes offer superior spectral efficiency, their benefits can only be realized under highly favorable channel conditions. For practical DVB-T2 deployments in Nigeria, QPSK, 16-QAM, and 64-QAM constitute the realistic baseline modulation schemes, whereas 256-QAM is generally unsuitable due to its stringent SNR requirements. These findings further reinforce the necessity for adaptive modulation strategies, where the transmission scheme is dynamically selected based on real-time channel conditions to optimize throughput while maintaining acceptable error performance.

IV. CONCLUSION

by developing conventional fixed-modulation DVB-T2 transmission models using QPSK, 16-QAM, 64-QAM, and 256-QAM modulation schemes in MATLAB R2023a. Realistic DVB-T2 transmission parameters applicable to terrestrial broadcasting environments were incorporated into the simulation environment, including an 8 MHz channel bandwidth, OFDM transmission structure, practical SNR ranges, and urban propagation assumptions relevant to Port Harcourt. The modulated signals were transmitted through AWGN and Rayleigh fading channels to evaluate the effect of noise and multipath fading on communication performance. Performance evaluation was carried out using Bit Error Rate (BER), throughput, Modulation Error Ratio (MER), and Link Margin metrics across varying Signal-to-Noise Ratio (SNR) levels. The simulation results showed that QPSK provided the most robust transmission performance with the lowest BER values under poor channel conditions, while 64-QAM and 256-QAM achieved significantly higher throughput and spectral efficiency under favorable channel conditions but suffered greater degradation under fading and low SNR environments. The baseline analysis successfully established a reference DVB-T2 system for evaluating the effectiveness of the proposed Dynamic Signal Optimization (DSO) model.

Contribution to knowledge:

This study contributed to knowledge by developing and evaluating a Dynamic Signal Optimization (DSO) model for DVB-T2 broadcasting systems using adaptive SNR-based modulation switching under AWGN and Rayleigh fading channel conditions. Unlike several existing studies which focused mainly on fixed modulation transmission or conventional Adaptive Modulation and Coding (AMC) techniques without stability enhancement, the proposed model incorporated hysteresis-adjusted switching thresholds to mitigate common AMC weaknesses such as rapid modulation fluctuation, signaling instability, unnecessary switching, and feedback-related transmission complexity.

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