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PERFORMANCE EVALUATION OF DIGITAL TERRESTRIAL TELEVISION BROADCASTING USING THE MONTE CARLO SIMULATION METHOD IN AN AWGN CHANNEL

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ABSTRACT

Purpose: The study investigates the performance of digital terrestrial television broadcasting in Ghana.

Design/Methodology/Approach: The experimental methodology employed MATLAB R2018a as the primary simulation environment, operating on a Dell laptop with Windows 8, 16GB RAM, and an Intel Core i7 processor. The Monte Carlo simulation framework was implemented to analyse probabilistic outcomes in complex systems where deterministic approaches prove inadequate.

Findings: This work performs a MATLAB simulation of a digital network in an Asynchronous white Gaussian Noise (AWGN) channel using Monte Carlo Simulation. The performance of BER vs. SNR is analysed using several QAM modulation schemes. The effect of noise over the AWGN channel was observed using constellation diagrams.

Research Limitation: This study concentrated on digital terrestrial television in Ghana, QAM modulation techniques, and MATLAB as a modelling tool.

Practical Implication: BER and SNR are excellent measurements of a digital communication system's performance. Understanding the bit-error rate (BER) facilitates optimising other digital communication system parameters for improved performance.

Social Implication: A Bit Error Rate (BER) offers an impartial, measurable measure of the system closely linked to its operational performance. A higher bit error rate (BER) indicates poor system performance. There is an apparent variance in the BER in the AWGN channel between low and high modulation techniques.

Originality/ Value: This paper simulates the BER performance of a digital communication system. The benchmark compares the BER variation in an AWGN channel for various SNRs using various modulation techniques.

***Keywords**: Bit error rate. digital terrestrial television. signal. simulation. synchronous*

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INTRODUCTION

In 1900, Guglielmo Marconi sent his renowned Morse code from England to Canada, marking the beginning of wireless transmission technology. Until television came along and started using high-frequency radio waves to transmit TV signals, broadcasting was mainly employed for radio and wireless telegraphs (Patil & Patil, 2021; Hsu, 2010). Initially, data was encoded and sent as analogue signals, which use a continuous carrier signal whose phase, amplitude, or frequency fluctuates according to the analogue message (Safari & Pourrostam, 2024; Griffiths, 1980). Because of the significant signal attenuation that causes analogue broadcasting to operate poorly, digital broadcasting—which is superior to analogue communication—was required (Hsu, 2010). Since digital signals can transmit information at higher rates, with better quality assurance, greater interference resistance, and higher spectrum efficiency than analogue signals, they garnered increased attention in the 1990s compared to analogue communication. Digital broadcasting uses digital data to carry broadcast information over television channels but only transmits discrete messages (Falkowski-Gilski, 2018). In baseband transmission, data is represented as a series of pulses, but in passband transmission, data is presented using a limited selection of predefined waveforms.

Digital symbols comprise the transferred data (Basudewa et al., 2020). Because of the numerous advantages of digital broadcasting, there was a need to migrate from analogue to digital broadcasting. The "Recommendations" of the International Telecommunication Union (ITU), the Regional Radio Communications Conference of 2006 (RRC06), and the Geneva 2006 Agreement (GE06), to which Ghana was a member, mandated that Ghana switch from analogue to digital broadcasting by 2015 (Conference, 2006). The Ghanaian Ministry of Communication established a twenty-six-member National Digital Broadcasting Migration Technical Committee on January 13, 2010, to carry out digital migration in compliance with ITU recommendations and develop a digital migration policy that would enable a smooth transition to DTT (Mohammed, 2011). Ghana deployed the world's most sophisticated digital terrestrial television (DTT) system, Digital Video Broadcasting-Second Generation Terrestrial (DVB-T2). This system boosts transmission reliability and capacity and offers enhanced robustness and flexibility. Additionally, it enhances the SNR threshold in intricate multipath channels (European Telecommunications Standards Institute, 2015 ;En, 2011); European Telecommunications Standard Institute, 2012; Office, 2023).

LITERATURE REVIEW

The evolution of digital terrestrial television broadcasting (DTTB) has necessitated sophisticated analysis of probability error functions to ensure reliable signal transmission and reception. This literature review examines key research developments in error function analysis within DTTB systems, focusing on contributions from the past decade.

The fundamental challenge in 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 modelling 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 optimising guard interval settings and improving overall network synchronisation (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.

Integrating multiple-input multiple-output (MIMO) technology in DTTB systems has introduced new complexities in error function analysis. Shitomi (2024) developed a matrix-based probability error function for spatial diversity and channel correlation in MIMO-DTTB systems. Shitomi's work showed that conventional scalar error functions significantly underestimate system performance in MIMO configurations.

Current research trends indicate a growing focus on applying artificial intelligence to enhance error function analysis. Several studies have explored using deep learning algorithms to adapt error functions dynamically based on real-world transmission conditions. These approaches show promise in addressing the increasing complexity of modern DTTB systems, particularly as broadcasting standards evolve toward higher resolution and more sophisticated modulation schemes.

This review demonstrates the significant progress made in probability error function analysis for DTTB systems while highlighting areas requiring further research, particularly in emerging broadcasting technologies and standards.

Bit Error Rate (BER) Analysis

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).

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

BER can also be expressed by equations (2)

$$BER = \frac{1}{2}\int_0^\infty P_t erfc\ (\frac{SNR}{2\sqrt{2}}t)dt \qquad (2)$$

With P_t as PDF and standard deviation σ, and also taking into account the multiplication of noise. BER can further be written as in equation (3)

$$BER(K, SNR, \sigma) = \frac{1}{2}\int_0^\infty \frac{t}{\sigma^2} e^{\frac{-t^2}{2\sigma^2}} e^{-K} I_0\left(\frac{t}{\sigma}\sqrt{(2K)}\right) erfc\left(\frac{KSNR_{add}}{2\sqrt{2}(K+SNR_{add}}t\right) dt(3)$$

(Basudewa et al., 2020)

Probability Error Function Analysis

Probability relating two events, A and B, is given by

$$P(A\ or\ B) = P(A) + P(B) - P(A\ and\ B) \leq P(A) + P(B) \qquad (4)$$

The probability P_e given that $\tilde{a}_0$ was transmitted for two events (two bits) $\tilde{a_\iota}\ and\ \tilde{a}_0$, is given by

$$P(e|\tilde{a}_0) \le G_0 P(\tilde{a}_1|\tilde{a}_0) \qquad (5)$$

$$= \frac{G_0}{2}\, erfc\left(\frac{|\tilde{d}|^2}{8\sigma_\omega^2}\right) \qquad (6\,)$$

$P(e|\tilde{a}_0)$ Represents the probability of error given that the bit $\tilde{a}_0$ was transmitted. The average probability of symbol error P_e, is given by eqn (7)

$$P(e) \le \sum_{i=1}^{M} \frac{G_i}{2M} erfc\left(\frac{|\tilde{d}|^2}{8\sigma_\omega^2}\right) \qquad (7\,)$$

Assuming that all symbols occur with the probability $of\ \frac{1}{M}$. Where G_i is the number of nearest neighbors at a distance $|\tilde{d}|$ from $\tilde{a}_i$ The average transmitted power

$$P_{av} = \sum_{i=1}^{M} \frac{|\tilde{a}_0|^2}{M} \qquad (8)$$

For the same minimum distance, the average transmit power P_{av} is proportional to M and increases as M increases. The signal-to-noise ratio (SNR) is an additional criterion for high-quality digital transmission. The ratio of signal strength to noise is measured as the signal-to-noise ratio, or SNR, where noise is any unwanted noise source (e.g., phase noise, white Gaussian noise, non-linear or linear ISI) that results in the received symbol deviating from its optimal state position (Elechi & Bakare, 2022). Finding the average signal-to-noise ratio (SNR_{av}), having obtained P_{av}, in Eq. (8), therefore for the two-dimensional constellation, the average SNR is given by in Eq. (9)

$$SNR_{av} = \frac{P_{av}}{2\sigma_\omega^2} \qquad (9)$$

The factor of $\frac{1}{2}$ is because the average signal power P_{av} is defined over two- dimensions, real and imaginary, while noise power σ_ω^2 is over one dimension, imaginary or accurate, and noise variance $2\sigma_\omega^2$ over two dimensions. SNR can also be defined per unit as

$$SNR_{av,\ b} = \frac{P_{av}}{2K\sigma_\omega^2} \qquad (10)$$

Where $K = \ long_2(M)$ which is the number of bits per symbol. The average Power per unit can also be given as

$$P_{av,\ b} \triangleq \frac{P_{av}}{K} \qquad (11)$$

(Vasudevan, 2008, pp. 3–15)

Probability of error function P_e can be defined in terms of BER as in eqn.

$$P_e = \frac{1}{2}(1 - \text{erf})\sqrt{\frac{E_b}{N_o}} \qquad (12)$$

Where N_0 is the noise power spectral density (noise power in 1Hz bandwidth), erf is the error function, and **E$_b$** is the energy in one-bit (*Explaining Those BER Testing Mysteries | Lightwave*, n.d.)

The Additive White Gaussian Noise (AWGN) Model

Since the noise in this situation is primarily white, has a flat probability distribution function (PDF), and a Gaussian distribution, the AWGN model is primarily employed to analyse it. (Park et al., 2009; Dou & Abraham, 2006).

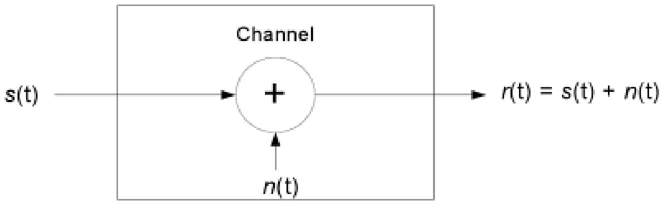

Figure 1: AWGN Channel model

Figure 1 displays the mathematical representation of the AWGN channel.
Noise contaminates the transmitted signal in the AWGN paradigm. The model AWGN can be written as

$$r(t) = s(t) + n(t) \qquad (15\,)$$

The channel and electronic parts, such as receiver amplifiers, are noise sources. This type of noise is categorised as thermal noise or statistically as Gaussian noise. Its PDF is articulated by

$$p(x) = \frac{1}{\delta\sqrt{(2\pi)}} e^{-(x-m_x)^2/2\delta^2} \qquad (16)$$

Where $m_x\, and\, \sigma^2$ is the Gaussian random variable variance. Using an AWGN communication channel, one can determine how BER and SNR relate. (Raju & Reddy, 2016).

METHODOLOGY

The experimental methodology employed MATLAB R2018a as the primary simulation environment, operating on a Dell laptop with Windows 8, 16GB RAM, and an Intel Core i7 processor. The Monte Carlo simulation framework was implemented to analyse probabilistic outcomes in complex systems where deterministic approaches prove inadequate.

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The simulation architecture was structured in three primary phases: initialisation, iteration, and analysis. During the initialisation phase, system parameters, including signal-to-noise ratio (SNR), range from -10dB to 30dB in 2dB steps, modulation schemes (QPSK, 16-QAM, 64-QAM), and channel conditions. The channel model incorporated both Additive White Gaussian Noise (AWGN) and Rayleigh fading characteristics to simulate real-world transmission environments.

For each simulation scenario, 10^6 symbols were generated to ensure statistical significance. The symbol generation process utilised MATLAB's built-in random number generators, specifically 'randi' for symbol mapping and 'randn' for noise generation. Channel impairments were modelled using the 'rayleighchan' function, configured with appropriate Doppler spread and path delays representative of urban broadcasting environments.

The iterative phase implemented a nested loop structure where the outer loop-controlled SNR values while the inner loop managed symbol transmission and reception. For each iteration, the following steps were executed:

Symbol generation and modulation mapping
Channel application (AWGN and Rayleigh fading)
Receiver processing and symbol detection
Error calculation and accumulation

Error probability was calculated using a custom function that compared transmitted and received symbols, maintaining separate counters for different error types. The simulation employed parallel processing through MATLAB's Parallel Computing Toolbox to optimise execution time, utilising all available CPU cores.

Statistical analysis of the results incorporated first-order (mean, variance) and second-order (correlation, spectral density) metrics. Confidence intervals were calculated using the batch means method with a 95% confidence level. To ensure simulation stability, convergence tests were performed by monitoring the running average of error rates, with simulation termination occurring when the variance fell below a predefined threshold of 10^-6.

Data visualisation was accomplished through MATLAB's plotting functions, generating semi-logarithmic plots of Bit Error Rate (BER) versus SNR. Error bars were included to represent confidence intervals, and results were exported in both graphical and numerical formats for subsequent analysis. Figure 2 is the block diagram of a DVBT.

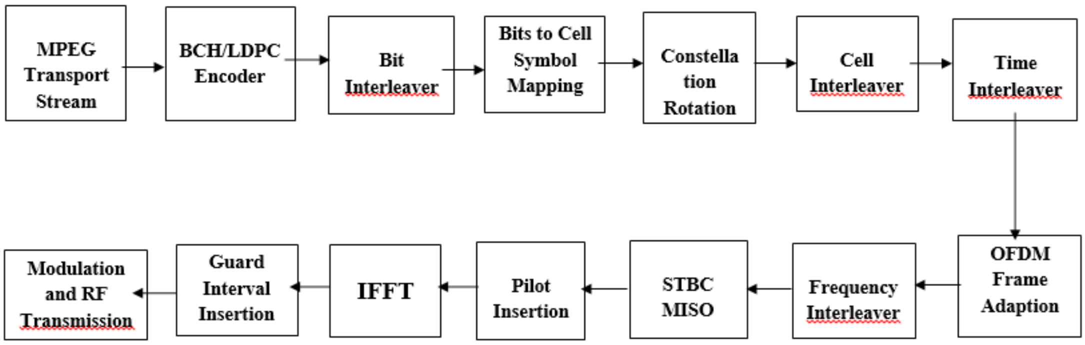

Figure 2: Block diagram of DVBT

SIMULATION RESULTS

First, software simulation assessed a communication's BER performance in its early phases. The pre-silicon evaluation was conducted using MATLAB and Simulink simulation tools (Mahjabeen et al., 2019) In software simulations, every element of a communication system is represented by a software model that displays its attributes. A software channel model is used to build a communication system when performing software-based BER testing. Conducting the simulations under various SNR settings makes it simple to assess how well the communication system performs in terms of BER. Software simulations are easy to set up, but their BER evaluation takes a while.

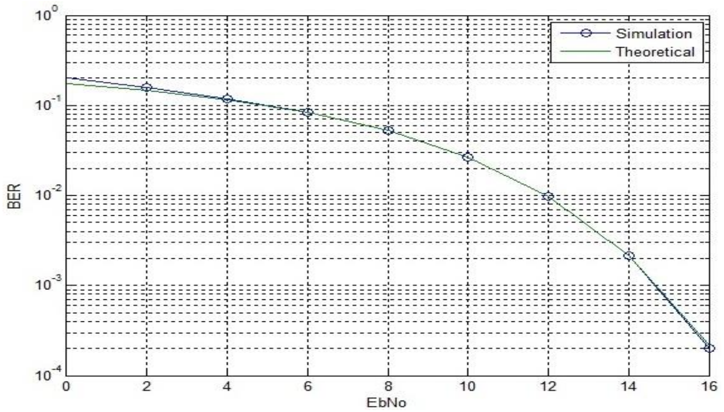

Figure 3: A simulation plot of BER vs SNR in AWGN channel and 64-QAM modulation scheme

From Figure 3, it is observed that the theoretical curve almost overlaps the simulation results. There is only a very marginal difference at very low SNR. The BER of 64 QAM at 15.8dB is approximately equal to the BER for Quadrature Phase Shift Keying (QPSK) at 8dB this makes 64 QAM useful only in scenarios where there is a very good SNR

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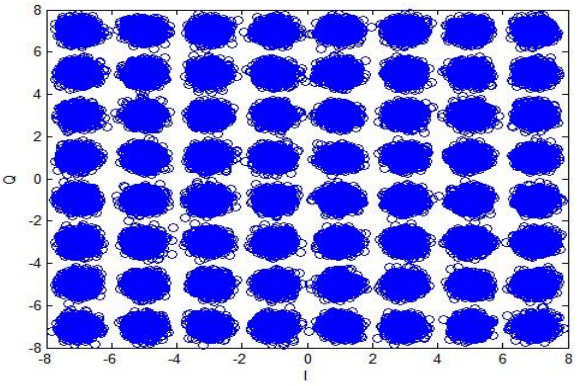

Figure 4: A Constellation diagram in 64QAM

A 64-QAM modulation system is depicted in Figure 4 as a diagram. It is simple to see where the transmission parameter signalling (TPS) carrier, which is a constellation point inside the constellation diagram, is located on the I axis, as well as the scattered and continuous pilots, which are located on the left and right outside the 64 QAM constellation diagram. (Pandya & Patel, 2017) They compared different modulation schemes, such as 64 QAM and 16 QAM, and their results show some agreement with our findings.

The dispersed pilots lead the constellation diagram, which is constantly modified to the same place and utilized for channel estimation and correction. The TPS serves this purpose as a quick information channel between the transmitter and receiver. Other than noise, no other factors influence the constellation diagram, as depicted in Figure 4.

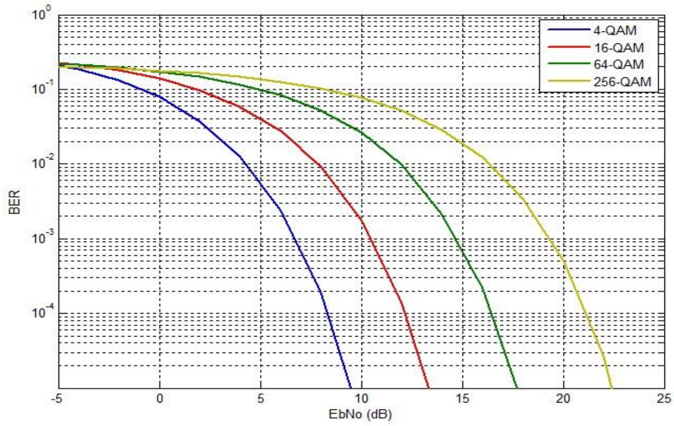

Figure 5: An AWGN channel, the SNR required for varying BER for different QAM modulations

Using Monte Carlo simulations, Figure 5 illustrates the usual SNR needed for the different QAM modulation techniques for an Additive White Gaussian Noise (AWGN) channel. The AWGN channel was shown to have a lower BER versus SNR. However,

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radio communication systems can achieve improved spectral efficiency and substantially quicker data rates at higher order modulation rates, albeit at a cost. Since higher-order modulation algorithms are far less impervious to noise and interference, dynamic adaptive modulation techniques are frequently used in radio communication systems. They analyse the channel's conditions and adjust the modulation technique to attain the maximum practical data rate. Throughput deteriorates when SNR drops because errors rise as data retransmission increases. A slower-order modulation strategy can improve radio channel reliability by reducing data errors and retransmissions. (Zreikat & Alabed, 2022). 64-QAM is the ideal modulation scheme used in DTT. Broad bandwidth modulation techniques allow Higher data rates within constrained radio bandwidths.

CONCLUSION

BER and SNR are excellent metrics that provide a clear picture of a digital communication system's performance. Knowledge of the BER also helps optimise other digital communication system parameters to achieve better performance. BER simulation can help accomplish end-to-end testing of the digital transmission system.

A BER test provides an objective, quantifiable indicator of the system that is directly related to its operational performance. A higher BER is a sign of subpar system operation. By introducing a regulated quantity of noise into the transmitted signal, the BER performance of a digital communication system was successfully simulated.

This noisy signal served as the receiver's input. After the receiver demodulated the signal using noise, we compared the broadcast and received bits and plotted the BER with En/No to calculate the errors. The benchmark compares the BER fluctuation for different SNRs using different modulation techniques.

In the AWGN channel, the BER is low at low modulation schemes and high at high modulation schemes. The modulation schemes can greatly impact signal quality, especially in an environment with high interference.

The study can help system designers and policymakers design an efficient and stable digital terrestrial transmission system over varying channel conditions. A well-designed system will produce high-quality pictures and videos and thus offer a good user experience.

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