PERFORMANCE EVALUATION OF DFE EQUALIZER ACROSS THREE REGIONS AND IONOSPHERIC CHANNEL CONDITIONS AS PER ITU STANDARDS

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Diajukan Sebagai Salah Satu Syarat Untuk Memperoleh Gelar Sarjana Teknik Pada Program Studi Teknik Elektro Fakultas Sains dan Teknologi

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ANALISIS PERFORMA EQUALIZER DFE UNTUK TIGA WILAYAH DAN TIGA KONDISI KANAL IONOSFER MENURUT ITU

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Performance Evaluation of DFE Equalizer Across Three Regions and Ionospheric Channel Conditions as per ITU Standards

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Abstract*— The advancement of technology has broadened the utilization of frequencies, significantly enhancing communication range. Among these frequencies, high frequency (HF) is frequently employed, particularly in conjunction with the ionospheric layer. However, practical applications often encounter challenges, notably the delay spread phenomenon caused by multipath propagation, which distorts signals at the receiver. This distortion contributes to a cascade of issues, including elevated Bit Error Rate (BER) values. To mitigate this problem, it is essential to implement methods that effectively reduce the high BER resulting from delays caused by multipath objects. One promising approach involves the application of equalization techniques, specifically the Decision Feedback Equalizer (DFE). This research aims to analyze the performance of a DFE equalizer for three regions and three ionospheric channel conditions based on ITU standards. Additionally, it examines the performance of the DFE equalizer under these conditions using simulations conducted in the MATLAB application. The findings show that the decision feedback equalizer significantly improves the performance of high-frequency (HF) radio communication systems in the Waterson model ionospheric channel. Moreover, the DFE equalizer effectively reduces Inter-Symbol Interference (ISI) and lowers the Bit Error Rate (BER), bringing the BER down to 10-3, compared to the higher BER of 10-1 in systems without the equalizer. This method also successfully mitigates interference caused by ionospheric channel fluctuations.

Keywords: High Frequency (HF); Ionosfer, Decision Feedback Equalizer (DFE);

I. Introduction

The advancement of high-frequency (HF) radio communication systems is progressing through the increased utilization of high frequencies that exploit the ionospheric layer to achieve extended communication ranges [1][2]. The ionosphere's capacity to reflect radio waves within the HF spectrum (3-30 MHz) [3], enables the transmission of signals over long distances [4][5]. This communication system presents a cost-effective infrastructure, offering a robust and versatile technology that can be deployed in various locations [1][5].

One of the digital modulations used in HF radio communication is Binary Phase Shift Keying (BPSK) modulation. BPSK modulation is a modulation technique used to encode digital information into radio signals. BPSK modulation is based on the principle of changing the phase of the carrier signal according to the binary data sent [6][7]. In performing digital transmission using BPSK modulation, the ionospheric channel is used as a place for transmission, one of which is the Watterson channel model (HF). The Watterson channel model is the most commonly used model to simulate ionospheric effects on HF radio communication transmission [8]. The Watterson Channel Model is an empirical model used to describe ionospheric channel characteristics in high frequency (HF) communications [9]. This model considers various important factors such as elevation angle, operating frequency, time, transmission distance, and interference in the ionosphere [10][11]. By utilising the ionospheric layer as a communication channel, it cannot be separated from the changing nature and characteristics of the ionospheric layer, this causes the ionosphere to be known as a multi-pass channel that changes over time. The challenge is that this ionospheric channel is a unique channel so a way is needed to overcome various channel variations. One of the main obstacles in achieving a good communication goal is Inter Symbol Interference (ISI) which is passed on the ionospheric channel with the Watterson channel model [4].

When a signal is transmitted from the source, as it reaches the destination, the delay spread generated by multipath objects will generate Intpr Symbol Interference (ISI) and this will result in a distorted signal at the receiver end. if Inter symbol Interference (ISI) is not handled properly, then this can cause a high Bit Error Rate (BER) in the recovery of the transmitted sequence at the receiver [12][13]. Therefore, to reduce Inter symbol Interference (ISI) and fluctuations and distortion that occur in the watterson channel, one of the methods used is the Equalizer technique, especially in the type of equalizer Decision Feedback Equalizer (DFE) [14][15]. The DFE technique is proposed as a solution to minimize the impact of ISI. Although DFE has been proven effective in various communication systems, its application in ionospheric channels with the Watterson model is still limited. This study will evaluate the performance of DFE in handling distortion and fluctuation in three ionospheric channel conditions based on ITU standards.

Some research related to the application of Equalizer Techniques to reduce ISI include research [10] which compares the performance of wireless communication systems using several equalizers namely LMS, RLS and MLSE on Multipath Rayleigh Fading channels. Multipath Fading is a signal level fluctuation at the receiver that occurs because there is more than one propagation channel. As a result, there is an error between the received signal and the transmitted signal [16][17]. The MLSE equalizer using BPSK modulation provides good performance results in reducing BER in static channels, but is less optimal in channels with dynamic or complex interference.

Furthermore, in research [14] which conducted a comparison between Linear and Non-Linear Equalizers in the Additive White Gaussian Noise (AWGN) Channel. AWGN channel is a channel where the information signal is given interference in the form of linear addition of white noise with constant spectrum density and gaussian distribution of noise samples [17][18]. The results of this study show that the linear equaliser is most suitable for a relatively flat channel spectrum.

The study [15] compares various equalization techniques, including LMS, RLS, and CMA, applied to OFDM systems with different digital modulation schemes. The research is conducted using both AWGN and Multipath Rayleigh Fading channels. Simulation results indicate that the CMA equalizer achieves the lowest BER compared to the other equalization methods.

Among the related studies mentioned, The use of DFE equalizers in ionospheric channels, especially those using the Watterson channel model, is still very limited, so the challenges of multipath and high channel fluctuations in this study are the main focus to demonstrate the effectiveness of DFE equalizers. Building on this context, the present research focuses on analyzing the performance of the DFE equalizer for three regions and three ionospheric channel conditions as defined by ITU. The performance evaluation is based on the Bit Error Rate (BER) against the Energy per Bit to Noise Ratio (Eb/N0) [19]. Considering the unique environmental factors in the three low-latitude regions, this study aims to simulate and assess the performance of the DFE equalizer for these regions and ionospheric conditions using MATLAB simulations [20]. Additionally, this research seeks to offer valuable insights for developing communication systems that can efficiently address channel fluctuations, while contributing to the advancement of more reliable and adaptive communication technologies in dynamic environments.

II. METHODS

A. Simulation Model Design

In the conducted simulation, several parameters were utilized, specifically:

1. BPSK modulation
2. Watterson Channel Model (HF)
3. HF Channel Conditions
4. DFE Equaliser
5. Eb/No
6. Bit Error Rate (BER)

The simulation design employs BPSK modulation with the Watterson (HF) channel model as the transmission medium. The DFE equalizer is positioned on the receiver side to mitigate the effects of Inter-Symbol Interference (ISI) in the channel. Overall, the block diagram for this simulation is illustrated as follows:

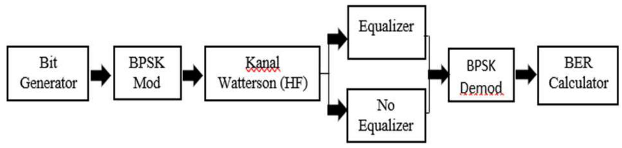

Fig. 1. Simulation Block

The design of the simulation model mentioned above is intended to assess the performance of the DFE equalizer across three regions and three ionospheric channel conditions. In this setup, a total of 2000 bit values are simulated using BPSK modulation, which is transmitted through the Watterson channel. The signal is then processed by the DFE equalizer, and the equalized signal is input into the BPSK demodulator. Finally, the Bit Error Rate (BER) is calculated.

To assess the effectiveness of using the Decision Feedback Equalizer (DFE), this study simulates two HF communication system conditions, namely without equalizer and with DFE equalizer. In the configuration without equalizer, the signal is sent through the Watterson channel model without any additional processing at the receiver to handle multipath interference, so the BER is expected to be higher due to uncompensated Inter-Symbol Interference (ISI). On the other hand, the simulation with the DFE equalizer incorporates this equalizer at the receiver side to reduce ISI and multipath distortion, so it is expected to lower the BER value significantly. The results of this comparison will show the effectiveness of DFE in overcoming interference in ionospheric channels.

B. Watterson Canal Model

The Watterson channel model serves to characterize the properties of ionospheric channels in high-frequency (HF) communications. This channel model is utilized to assess the performance of the DFE equalizer across three regions and three ionospheric channel conditions as specified by ITU, focusing on the relationship between Bit Error Rate (BER) and Eb/No. The transmission channel conditions for the ionospheric channel are categorized into three regions and three ionospheric conditions [21], namely :

TABLE I. Low Latitude Ionospheric Conditions

Channel Condition	Maximum Doppler Shift (Hz)	Maximum Delay Time (ms)
Quiet	0.5	0.5
Medium	1.5	2
Disturbed	10	6

TABLE II. Medium Latitude Ionospheric Conditions

Channel Condition	Maximum Doppler Shift (Hz)	Maximum Delay Time (ms)
Quiet	0.1	0.5
Medium	0.5	1
Disturbed	1	2

TABLE III. Disturbed Latitude Ionospheric Conditions

Channel Condition	Maximum Doppler Shift (Hz)	Maximum Delay Time (ms)
Quiet	0.5	1
Medium	10	3
Disturbed	30	7

III. Result and Discussions

A. Analysis of Low Latitude Region Simulation Results

This study examines the performance results of the HF channel both with and without an equalizer, which corresponds to the Watterson channel. As depicted in Figure 2 under quiet conditions, the red curve (representing the channel without an equalizer) demonstrates that the Bit Error Rate (BER) remains high at approximately 10^{-1} (0.11207) even when Eb/No increases to 40 dB, signifying poor signal quality due to distortion in the Watterson channel. In contrast, the blue curve (representing the channel with an equalizer) shows that the BER drops to around 10^{-3} (0.00114754) at an Eb/No of 40 dB, indicating that the implementation of an equalizer is effective in enhancing system performance by mitigating intersymbol interference (ISI) in the Watterson channel.

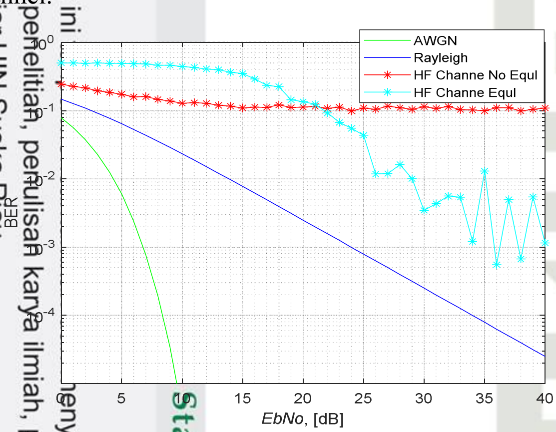

Fig. 2. iturHFLQ

In this medium, the red curve indicates a Bit Error Rate (BER) that remains high at approximately 10^{-1} (0.14744), even when Eb/No reaches 40 dB. This suggests that the Watterson channel experiences significant distortion without the equalizer. Conversely, the blue curve reveals a notable reduction in BER to around 10^{-2} (0.02984) at an Eb/No of 40 dB, despite some fluctuations. This indicates that the equalizer is capable of enhancing signal quality amidst interference in the Watterson channel, although not perfectly.

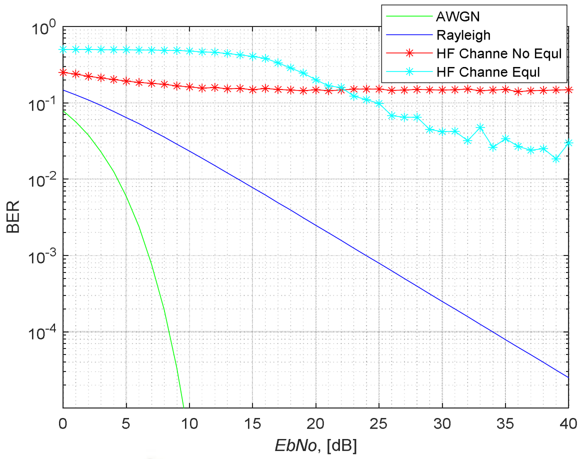

Fig. 3. iturHFLM

Figure 4 presents the results under disturbed conditions, where the red curve shows a Bit Error Rate (BER) of approximately 10^{-1} (0.14312) despite an increase in Eb/No to 40 dB, indicating no noticeable improvement in performance. In the case of the blue curve, the BER remains around 10^{-1} (0.4996) at an Eb/No of 40 dB. This suggests that in disturbed conditions within the Watterson channel, the equalizer may not be fully effective in mitigating intersymbol interference (ISI), likely due to the complex distortions present in the channel.

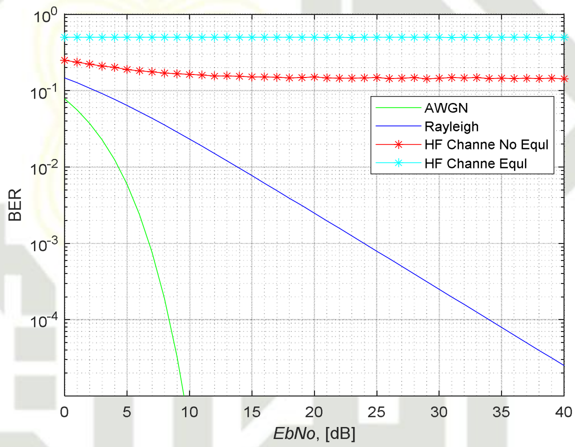

Fig. 4. IturHFLD

B. Analysis of Simulation Results of the Mid-Latitude Region

This study examines the performance outcomes of the HF channel both with and without an equalizer, which corresponds to the Watterson channel. In Figure 5, under quiet conditions, the red curve indicates that without an equalizer, the Bit Error Rate (BER) remains high at approximately 10^{-1} (0.101886) even as the Eb/No increases to 40 dB, signifying poor signal quality due to distortion in the Watterson channel. In contrast, the blue curve (with equalizer) shows a BER of approximately 10^{-3} (0.00348142) at an Eb/No of 37 dB, demonstrating that the implementation of an equalizer effectively enhances system performance by reducing intersymbol interference (ISI) in the Watterson channel.

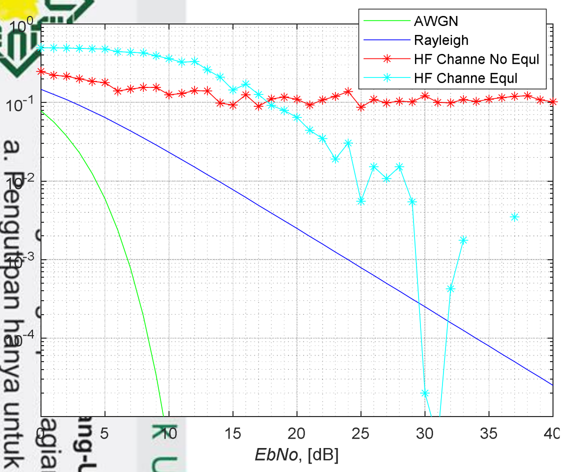

Fig. 5. iturHFMQ

Figure 6 illustrates the simulation results under medium conditions, where the red curve indicates a Bit Error Rate (BER) that remains high at approximately 10^{-1} (0.144621), even when Eb/No reaches 40 dB. This suggests that the Watterson channel experiences significant distortion without the equalizer. Conversely, the blue curve shows a notable reduction in BER to about 10^{-3} (0.00192673) at an Eb/No of 40 dB, demonstrating that the equalizer can enhance signal quality amidst interference in the Watterson channel, albeit not perfectly.

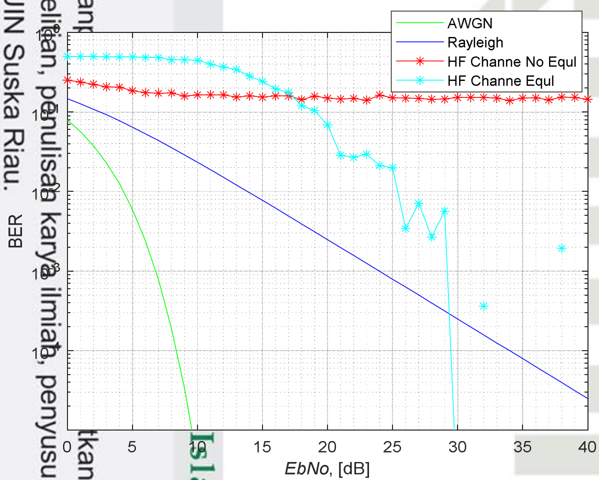

Fig. 6. iturHFMM

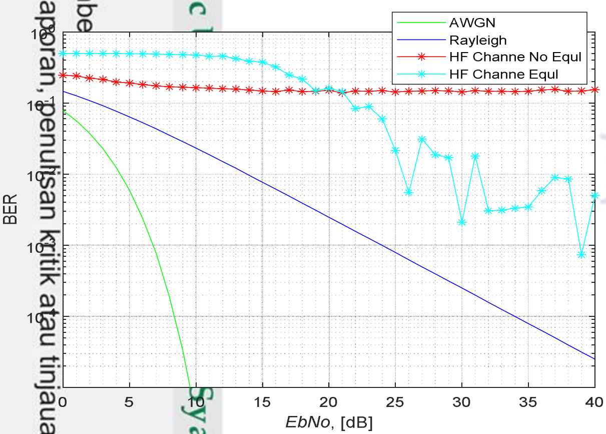

Fig. 7. iturHFMD

Figure 7 shows the simulation results of the medium condition, where the red curve shows a BER that remains high, around 10^{-1} (0.154787), even when Eb/No reaches 40 dB. This indicates that without the equaliser, the watterson channel suffers from poor distortion. However, the blue curve shows a significant BER reduction of about 10^{-3} (0.00503126) at Eb/No of 40 dB, showing that the equaliser is able to improve the signal quality in the face of ISI interference on the watterson channel.

C. *Analysis of High Latitude Region Simulation Results*

In this study, the focus is on the performance results of the HF channel without equaliser and HF channel with equaliser, which represents the Watterson channel. In Figure 8 under quiet conditions, the red curve shows that without an equaliser, the BER remains high at around 10^{-1} (0.143205) even though the Eb/No increases to 40 dB, indicating poor signal quality due to Watterson channel distortion. Meanwhile, the blue curve (with equaliser) shows a BER of up to about 10^{-3} (0.00247312) at Eb/No of 40 dB, indicating that the use of an equaliser is effective in improving system performance by reducing inter symbol interference (ISI) in the Watterson channel.

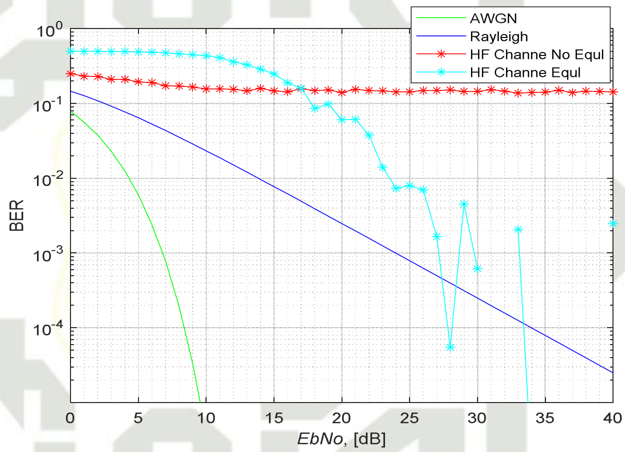

Fig. 8. iturHFHQ

Figure 9 shows the results of the disturbed condition, where the red curve BER is around 10^{-1} (0.14657) even though Eb/No increases to 40 dB, indicating no visible performance improvement. For the blue curve, the BER remains around 10^{-1} (0.49643) with Eb/No of 40 dB. It can be concluded that under disturbed conditions in the watterson channel, the equaliser may not be fully effective in dealing with ISI, this is also due to the complex distortions that occur in the channel.

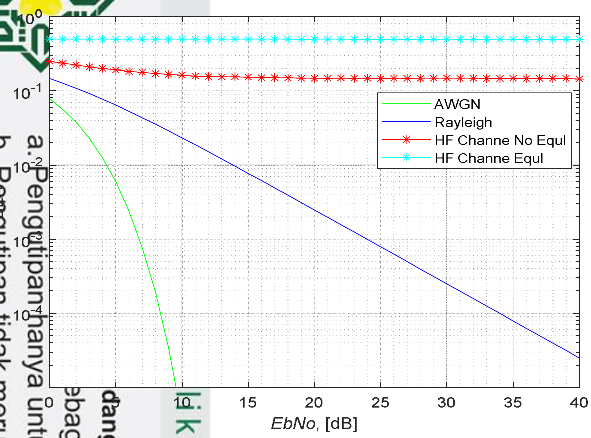

Fig. 9. iturHFHM

Figure 10 shows the results of the disturbed condition, where the red curve BER is around 10^{-1} (0.14745) even though the Eb/No increases to 40 dB, indicating no visible performance improvement. For the blue curve, the BER remains around 10^{-1} (0.49898) with Eb/No of 40 dB. It can be concluded that under disturbed conditions in the watterson channel, the equaliser may not be fully effective in dealing with ISI, this is also due to the complex distortions that occur in the channel.

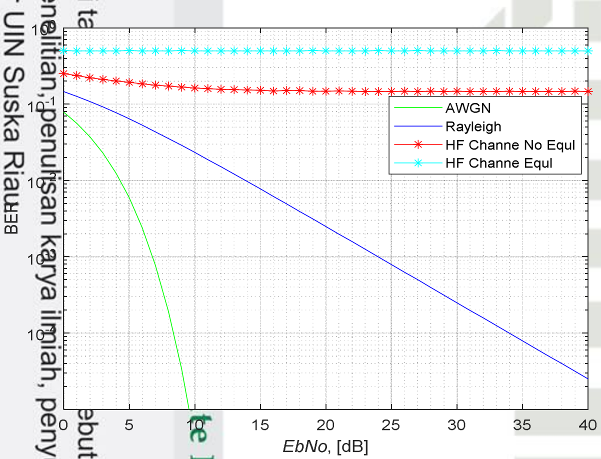

Fig. 10. iturHFHD

Overall, under disturbed conditions, the high doppler shift causes the frequency to change rapidly, making it difficult for the DFE equalizer to adjust properly. The large and random delay time also makes the DFE feedback less accurate in reducing interference. In addition, the many reflections of complex signals are difficult for DFE to correct, especially in changing channels. As a result, the performance of DFE degrades under these conditions, so the BER will remain high.

The BER graph in this study fluctuates in various ionospheric channel conditions due to variations in channel characteristics in each calm, moderate, and disturbed condition. In calm conditions, a stable channel allows DFE to work effectively to reduce BER. In contrast, in quiet and disturbed conditions, increased signal fluctuations and delays cause more complex multipath interference, which makes the BER increase and is difficult to reduce by DFE. This condition causes the graph to increase slightly even without significant improvement despite the increase in Eb/N0. This shows that the effectiveness of DFE depends on the stability of the ionospheric channel.

This study reveals that the performance of the Decision Feedback Equalizer (DFE) varies according to the region and ionospheric channel conditions tested. Based on simulations, low latitude regions in calm conditions show the lowest BER values, which is around 10^{-3} with Eb/N0 of 40 dB, when the DFE equalizer is applied. This indicates that DFE is effective in reducing Inter Symbol Interference (ISI) in more stable channels, such as in high latitude regions with little multipath interference. In contrast, under disturbed conditions in all regions, the use of the equalizer does not result in significant BER improvement, indicating that DFE has difficulty stabilizing the signal on channels with high fluctuations and complex multipath interference. Thus, the high latitude region under calm conditions can be considered as the best scenario for the application of DFE in reducing BER in ionospheric channels.

IV. Conclusions

Based on the research conducted, several conclusions can be drawn that the use of a decision feedback equaliser type equaliser is able to improve the performance of high frequency (HF) radio communication systems in the Waterson model ionospheric channel and effectively able to reduce Inter Symbol Interference (ISI) and at the same time reduce Bit Error Rate (BER) failure, where this equalizer is able to reduce the BER value to 10-1, smaller when compared to the condition without an equalizer which has a high BER value of 10-1. So it can be concluded that this DFE type equaliser is able to improve signal quality in the Watterson model ionospheric channel and make it better in the context of HF communication.

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Semarang, November 21, 2024

Dear **Luthfi Alfajri Zanil, Sutoyo Sutoyo, Varuliantor Dear, Teddy Purnamirza and Fitri Amillia**

We are pleased to inform you that your paper :

Paper ID : 121

Title : "Performance Evaluation of DFE Equalizer Across Three Regions and Ionospheric Channel Conditions as per ITU Standards"

submitted to the Second International Conference on Technology, Engineering, and Computing Applications (ICTECA 2024) has been ACCEPTED for an oral presentation. We cordially invite you to attend the ICTECA 2024 conference in Semarang, Indonesia.

It is mandatory to prepare the camera-ready paper as per the instructions listed on https://icteca.usm.ac.id/camera-ready-preparation/ . The three most important ones are:

1. Revise your paper(s) according to the reviewers' comments. The detail reviews are at the bottom of this email.
2. The accepted similarity level is maximum 20%, maximum similarity level for each reference is 4%, which you may check using Turnitin, iThenticate, or Crosscheck.
3. The camera ready needs to be submitted in docx and pdf that has successfully gone through pdfXpress (https://icteca.usm.ac.id/ieee-pdf-express-guideline/).

You will need to also complete e-copyright of your paper with IEEE prior to the conference day. After completing the registration, you are going to be contacted through email by IEEE regarding this e-copyright completion form. Please check the ICTECA website for the guideline on completing the registration process for the conference: https://icteca.usm.ac.id/registration/ . The due date for final registration is 11th November 2024, and at least one of the authors need to register the conference for the paper to be included in the conference proceedings.

The conference will be held in Semarang, Indonesia on 5th December 2024. All related conference materials can be found at https://icteca.usm.ac.id. Please let us know if you have any questions regarding the registration by emailing us to icteca@usm.ac.id or WhatsApp no. +6285226978290 (Mr. Khoirudin).

We sincerely look forward to welcoming you in ICTECA 2024.

With a warmest regard,

Program Chair of ICTECA 2024

ICTECA

Dr. Ari Endang Jayanti, M.T