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INVESTIGATING THE IMPACT OF ADAPTIVE DECISION-FEEDBACK EQUALIZER IN WIRELESS COMMUNICATION NETWORKS

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ABSTRACT

This study investigates the performance and operation of the adaptive Decision-Feedback Equalizer (DFE) in wireless communication networks. The DFE is a nonlinear equalizer that combines a forward filter and a feedback filter to mitigate Inter-Symbol Interference (ISI). The study examines the components of the DFE, including the forward filter; tap weights, training mode, decision device, and error calculation, using Matlab simulation. The results show that the DFE effectively reduces ISI in frequency-selective channels without enhancing noise. The study also evaluates the impact of different step sizes and tap delays on the DFE's performance, highlighting the trade-off between convergence speed and accuracy. The findings contribute to the understanding of the DFE's role in improving signal quality and data transmission efficiency in wireless communication systems. Further research and optimization of the DFE parameters and system-level configurations are recommended to enhance its performance in practical applications.

Keywords: **wireless network, throughput, DFE, ISI, feed-forward filter, feedback filter**

1. INTRODUCTION

In recent years, wireless communication networks have become an integral part of our daily lives, supporting a wide range of applications and services. However, these networks face several challenges that can significantly impact their performance, such as signal interference, multipath fading, and noise. These challenges can degrade the quality of transmitted signals, leading to errors, reduced throughput, and overall network inefficiency.

To address these challenges and improve the performance of wireless communication networks, the integration of adaptive Decision-Feedback Equalizer (DFE) techniques has gained considerable attention in the research community (Tariq et al., 2009). The adaptive DFE is a signal processing technique that aims to mitigate the effects of interference and channel distortions by leveraging feedback from detected symbols. By intelligently estimating and correcting the received signal, the adaptive DFE can enhance the overall signal quality and improve the network's throughput (Hong, 2022). However, despite the growing interest in adaptive DFE techniques, there is still a need to comprehensively investigate their impact on wireless communication networks. The existing literature such as Batra and Zeidler (2010) has provided valuable insights, but there are gap such as lack of studies that evaluate the effectiveness of adaptive DFE in real-world network scenarios, limited investigations on the performance of adaptive DFE under varying channel conditions, and a need for comprehensive performance analysis in terms of throughput improvement.

Therefore, this paper aims to bridge these gaps and contribute to the existing body of knowledge by investigating the impact of adaptive decision-feedback equalizer in wireless communication networks. The study will conduct a thorough evaluation of the adaptive DFE technique, considering different channel conditions and network scenarios. By analyzing the performance metrics, such as throughput and error rates, the study aims to provide valuable insights into the effectiveness of adaptive DFE and its potential for enhancing the overall performance of wireless communication networks. The findings of this study will not only contribute to the academic research in the field but also have practical implications for network designers, engineers, and service providers. The results can guide the development of more efficient and reliable wireless communication systems, leading to improved network performance, enhanced user experience, and expanded capabilities for various applications, such as streaming, IoT, and mobile communications.

2. LITERAURE REVIEW

Over the year, many studies have been presented to ensure quality of service (QoS) in wireless network. Bidikar et al. (2020) presented a study for mitigating Global Positioning Satellite (GPS) signal multipath errors. Their approach involved utilizing a linear combination of GPS measurement data and carrier frequency to develop an algorithm that exploited the random nature of multipath errors. However, it should be noted that the study did not consider the dynamic position of nodes, which could limit the applicability of the findings in real-world scenarios. Teresa et al. (2010) conducted a comparative analysis of various multipath error mitigation techniques for GNSS receivers. The techniques studied included narrow correlator, delay lock loop, and double delay discriminators. It is important to highlight that the study did not consider the dynamic position of nodes in their multipath model, which could potentially affect the generalizability of the findings. Saeed et al. (2013) focused on interference and multipath mitigation in global navigation satellite systems. They employed a two-stage beamformer to estimate and mitigate interference during radio communication. Their results demonstrated the effectiveness of beamforming in reducing interference signals in both narrow and wideband communication scenarios.

Miguel et al. (2021) developed advanced techniques for multipath estimation and interference mitigation in high precision RTK positioning. Their approach involved the use of an automatic gain control system and digital filters to remove near-band interference. The study reported a significant reduction of 60% in the interfering signal, highlighting the effectiveness of their approach in improving RTK positioning accuracy. Muzi et al. (2017) proposed an assessment method for evaluating the performance of multipath mitigation algorithms in GNSS receivers. Their algorithm considered errors caused by environmental reflections after signal processing. By selecting the best site to minimize multipath error, their approach aimed to enhance the overall performance of GNSS receivers. Sokunbi et al. (2020) investigated the use of a Rake receiver method for reducing multipath fading in wireless communication. Their approach involved employing correlators to individually spread out signal echoes, effectively mitigating multipath destructive interference. The study demonstrated high accuracy in terms of bit error rate, indicating the potential of the Rake receiver method for combating multipath fading.

In Elbatji et al. (2017) a testbed for the evaluation of QoS in 3G wireless network was develop. The use of packet path diversity networks and internet protocols for delivering web traffic fills the research gap in ensuring quality of service in broadband wireless, particularly in voice-over networks. Ekiz et al. (2015) provide an overview of handoff techniques in cellular networks and address the need for interoperability through a unified communication interface. In

Hossein (2013) a signal processing model with a path diversity technique for wireless local networks was presented. By emphasizing the importance of wave transmission mechanisms, they aim to optimize the efficiency of WLAN and enhance the performance of wireless local networks, addressing the research gap in this domain. Zia et al. (2015) contribute to mobility management by utilizing intra and inter mobility techniques to minimize signal traffic in UMTS. Their research addresses the research gap in improving mobility management and reducing signal traffic in wireless networks. Rosselti (2011) focus on eliminating disruptions and unavailable connections in wireless local networks. By utilizing the infinite state algorithm, the study contributes to the existing research on secure wireless communication. Matsunage (2012) explore the feasibility of an adaptive MIMO system with secure authentication in WLAN roaming. Their work addresses the need for security in wireless message transmission and contributes to the existing research on securing wireless networks. VanNee et al. (2019) investigate combinatorial optimization algorithms and their complexity in wireless communication, specifically in reducing congestion and sharing radio frequency. Their research contributes to addressing the research gap in congestion reduction and optimization in wireless networks. Chhaya et al. (2016) examine the BER performance of BPSK receivers over fading channels. By implementing the boundary resource control scheme, they address the research gap in minimizing the impact of fading channels in WLAN devices. Alex (2014) addresses the fundamentals of cellular network planning and optimization, focusing on radio resource control and management techniques. They highlight the research gap in performance optimization of local area networks. While these studies focused on proposing innovative approaches to improve efficiency, quality of service, security, mobility management, and resource optimization there is a research gap in exploring more advanced and adaptive resource allocation techniques specifically tailored for maximizing throughput in wireless communication networks.

3. METHODOLOGY

This paper begins with a comprehensive review of existing literature to identify gaps in the studies related to throughput performance in wireless networks. Based on the identified gaps, the proposed methodology focuses on the integration of an adaptive decision feedback equalizer (DFE) to optimize throughput. The integration of the DFE is achieved through channel equalization techniques. Specifically, the pilot symbol approach described in Wu et al. (2022) is employed, which utilizes a weighted average and superimposition strategy to capture the frequency response and time variation characteristics of the network channel. This approach effectively reduces interference induced by white Gaussian noise present in the channel. Additionally, the feed-forward equalizer is employed to process the received signal, cancel interference, and compensate for channel frequency. The DFE approach utilizes the detected symbols to estimate the received signal, effectively reducing inter-symbol interference. To further improve throughput performance, residual errors are corrected using a forward error correction strategy and Automatic Repeat Request (ARQ) mechanisms are implemented to request retransmission of specific packets. The evaluation of throughput performance is conducted under various channel conditions, and the obtained results are thoroughly discussed and analyzed

4. ADAPTIVE DECISION-FEEDBACK EQUALIZERS

An adaptive decision-feedback equalizer (DFE) is a nonlinear equalizer that combines a forward filter and a feedback filter to mitigate inter-symbol interference (ISI) in wireless communication networks. The operation of an adaptive DFE begins with the processing of the input signal x, which is distorted due to channel effects. The signal is then passed through a forward filter, as illustrated in Figure 1. The forward filter consists of tap delays (T) with associated tap weights which is the past signal (u_L). Each tap represents a past symbol x_L, and its weight (w_L) determines its contribution to the equalized output (y) in equation 1. The purpose of the forward filter is to reduce ISI by shaping the signal based on past symbols. The outputs from each tap in the forward filter are then summed up to generate the equalized signal output. The equalized output is compared with a reference signal (d) using a decision maker and error (e) model in equation 2 to generate the signal deviation error output (y_d) in equation 3. The decision maker applies decision criteria to determine the estimated symbols based on the equalized output. The error computes the discrepancy between the equalized output and the reference signal, representing the error in the equalization process. The output of the feed forward filter is feed to the feedback filter in figure 2 which used least mean square (LMS) error algorithm (Majeed et al., 2022; Rusu et al., 2022) as in equation 4 to adjust the weights to adapt the condition of the channel and improve the equalization performance at various step sizes.

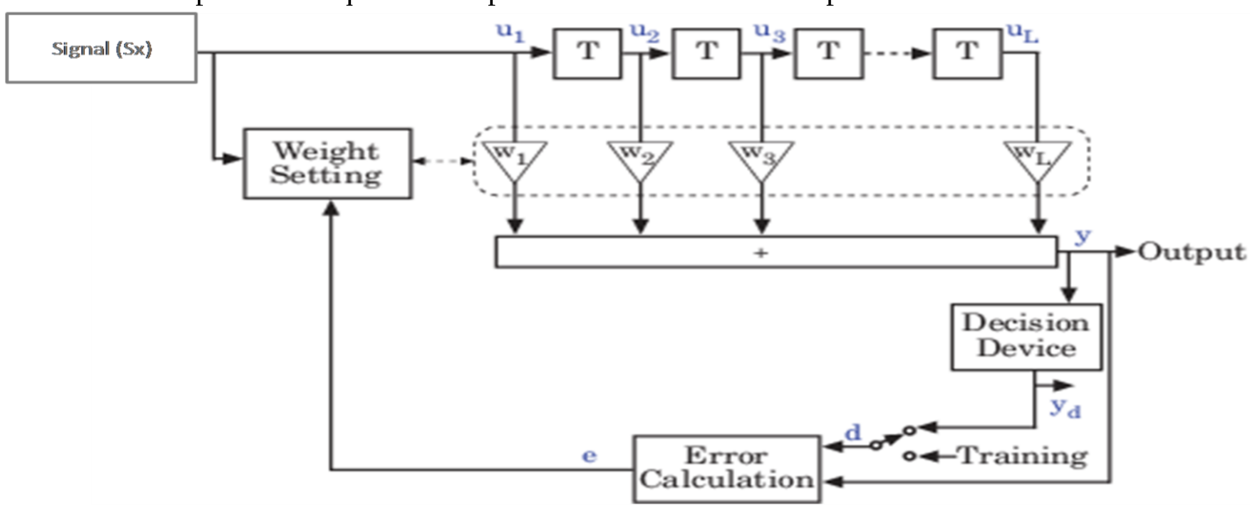

Figure 1: Feed forward filter

By utilizing both the forward and feedback filters, the adaptive DFE can effectively reduce ISI even in frequency-selective channels where linear equalizers may struggle. The nonlinear nature of the DFE allows it to adapt to changing channel conditions and improve equalization performance without significantly amplifying noise.

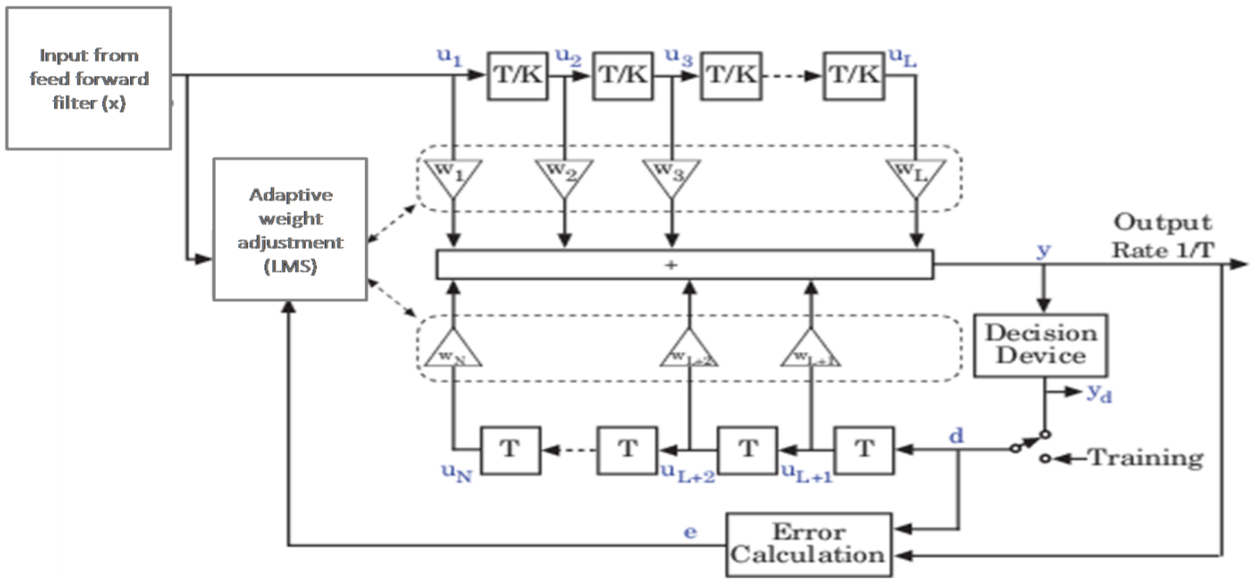

Figure 2: Feedback filter

The forward filter output y is given by:

$$y = \sum(u_L * x) \quad (1)$$

While the error is presented as;

$$e = d - y_d \quad (2)$$

While the estimated output is presented as;

$$y_d = y + \sum(w_L * x) \quad (3)$$

By combining the forward filter output y with the feedback filter output$\sum(w_L * x)$, the DFE estimate the transmitted symbol y_d. The error calculated by comparing this estimated symbol with the desired reference signal d. while the equation of the LMS was presented as;

$$w_{n+1} = w_n + 2\mu e_n x_n \quad (4)$$

Where u is the step size, e is the error, w is the weights and x is the input signal.

4.1 Implementation of the Model

Having developed the DFE technique, it was implemented inside the receiver of a wifi network and then evaluated considering throughput percentage during downlink. The transmitter was used to generate the data input to the network channel which was simulated using the Additive White Gaussian Noise (AWGN). The DFE algorithm was used for the receiver equalization through the utilization of the feed forward and feedback filter developed n the figure 1 and figure 2. During the equalization process, the weights were updated with the LMS algorithm until the error is minimized during the training. Once the training phase was complete the decision making used the equalizer to estimate the output of the transmitted signal. The figure 3 presents the receiver with the DFE algorithm, while the figure 4 presented the Simulink model of the wireless network.

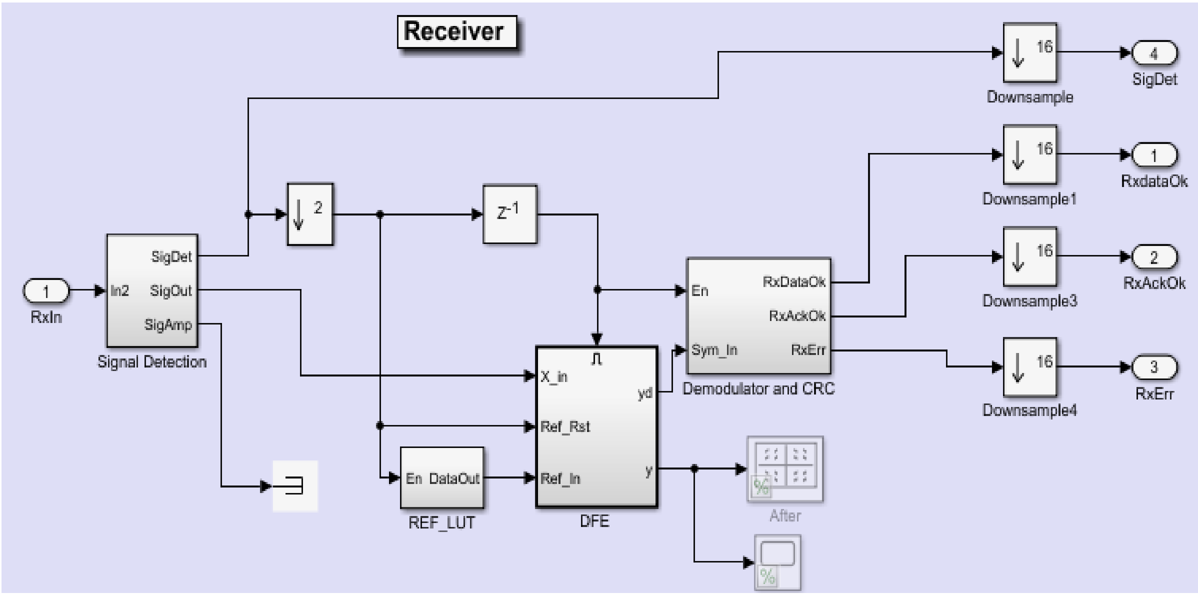

Figure 3: Simulink of receiver with DFE

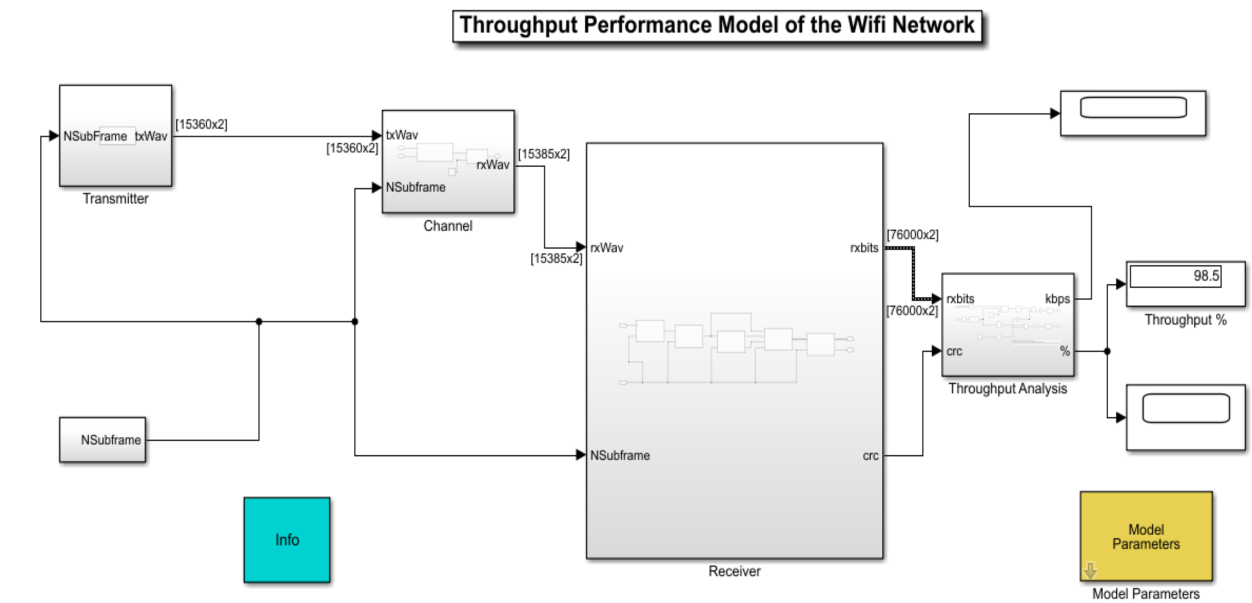

Figure 4: Simulink model of the wireless network with DFE

The performance evaluation considered the estimated mean error of the feed forward filter and also the feedback filter at a step size of 3.3 and tap delay of 0.029, considering several iterations. Also the filter performance was evaluated at various step size o the input signal at 0.07; 0.025 and 0.0007 respectively and then the throughput was evaluated to determine the quality of service.

5. RESULTS AND DISCUSSIONS

The result presents the performance of the feed forward filter and feedback filter when applied by the receiver for the channel equalization the wireless network. This was achieved with the LSM algorithm which adjusts the errors as shown in the figure 5 until the error is minimal and then the signal output equalized.

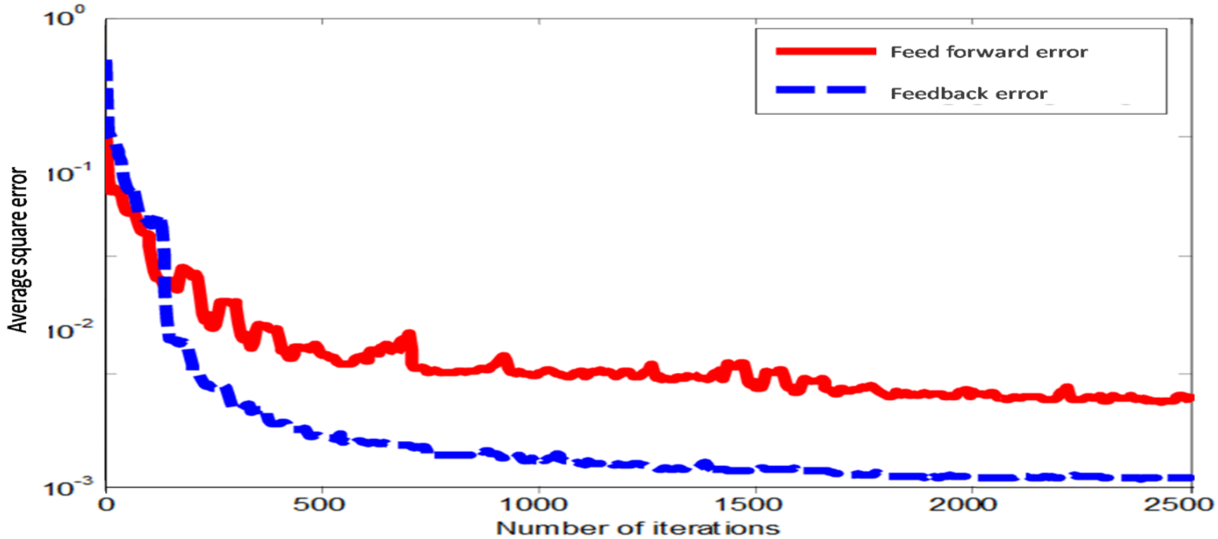

Figure 5: Average error of the DFE

Figure 5 illustrates the average error achieved on the channel by the Decision-Feedback Equalizer (DFE) when evaluated with a step size of 0.029. In this evaluation, the tap weights of the DFE were adjusted using the Least Mean Squares (LMS) algorithm, as indicated by equation 4. The error calculation involved comparing the desired signal with the output signal obtained from the equalizer, following equation 3. The reported minimum error of 0.004535 refers to the achieved error after applying the LMS algorithm to adjust the tap weights and minimize the error, thus implying its ability to address the problem of inter-symbol interference and achieve lower error rates during the equalization process. This minimized error value was then fed to the feedback filter shown in Figure 2. The feedback filter also employed the LMS algorithm to train the error and adaptively adjust the tap weights. Through this iterative training process, the error was further reduced to an average level of 0.00034243. For validation, the DFE was evaluated considering other step size of 0.07, 0.025, and 0.0075 respectively as in figure 6.

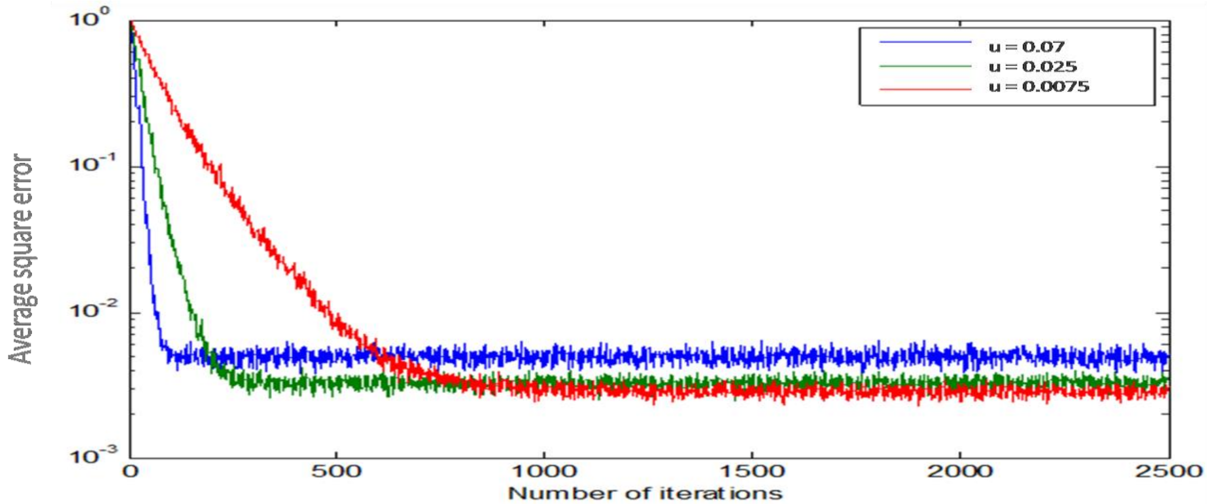

Figure 6: Average error of the LMS at varying

The figure 6 showcases the effect of different step sizes on the DFE's ability to mitigate inter-symbol interference and achieve lower error rates in the equalization process. The average error reported at step size of 0.07 is 0.0007014, when at step size of 0.025, the error was further reduced to 0.0042817 and when evaluated at step size of 0.0075, the error was 0.001831.Overall, these results emphasize the effectiveness of the DFE, utilizing the LMS algorithm for tap weight adaptation and minimizing errors in the presence of channel distortions and inter-symbol interference. These results highlight the effectiveness of the DFE in adapting its tap weights as shown in figure 7 and reducing errors in the presence of channel distortions and inter-symbol interference. The LMS algorithm plays a crucial role in updating the tap weights based on the error signals, ultimately improving the equalization performance of the DFE.

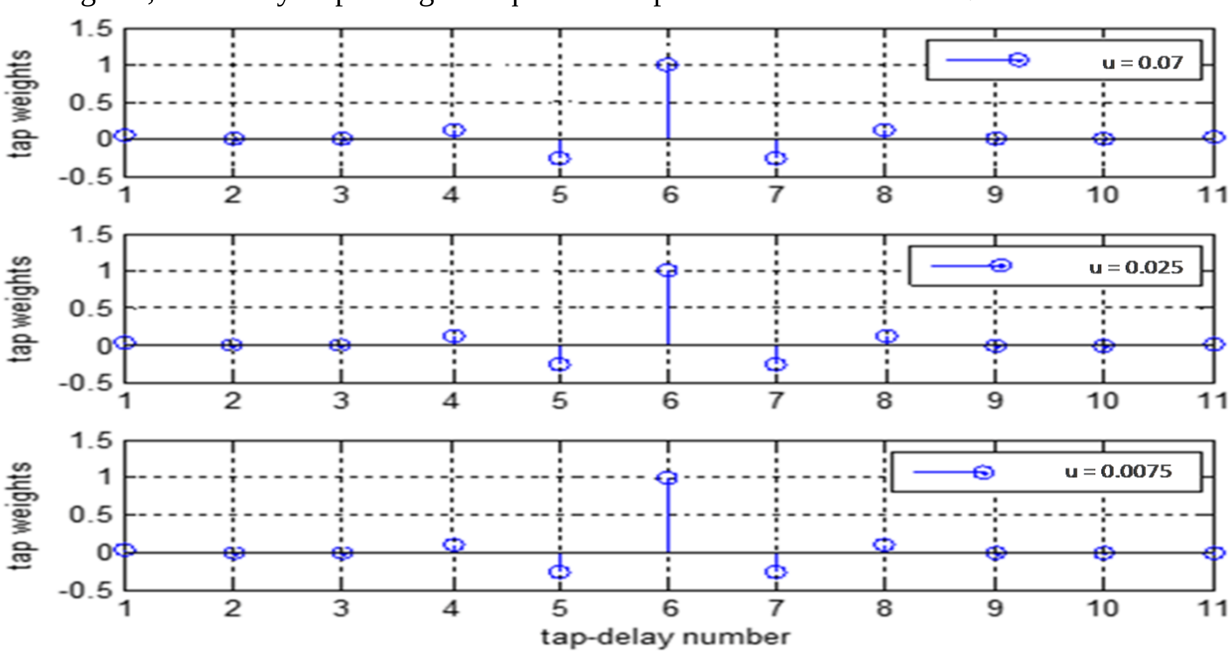

Figure 7: Result o the tap weight adjustment

In the figure 7, the adjustment in the DFE was used to update and minimize the error signal to optimize the equalization performance. From the result it was observed that from the various step sizes and tap delay which ranges from 1-11, the tap weights were symmetrical at 6. The step size determines the magnitude of the tap weight adjustment during each iteration. Larger step sizes result to faster convergence while smaller step sizes provide more gradual adjustments, which can enhance accuracy but may require more iteration for convergence. The tap delay represents the number of past symbols considered by the DFE. A tap delay of 1 means only the immediate past symbol is taken into account, while a tap delay of 11 considers a more extensive history. Increasing the tap delay allows the DFE to capture a broader range of inter-symbol interference and channel effects, potentially improving equalization performance. The overall results demonstrate a trend: as the step size decreases, the DFE's performance improves. This indicates that a smaller step size allows for more precise adjustments of the tap weights, resulting in enhanced equalization and reduced error rates. However, it is crucial to strike a balance between convergence speed and accuracy when selecting the appropriate step size, as it involves a trade-off. Achieving optimal equalization performance in practical applications necessitates careful consideration and balancing of these factors. To evaluate the average throughput of the network with the DFE, the figure 8 was presented.

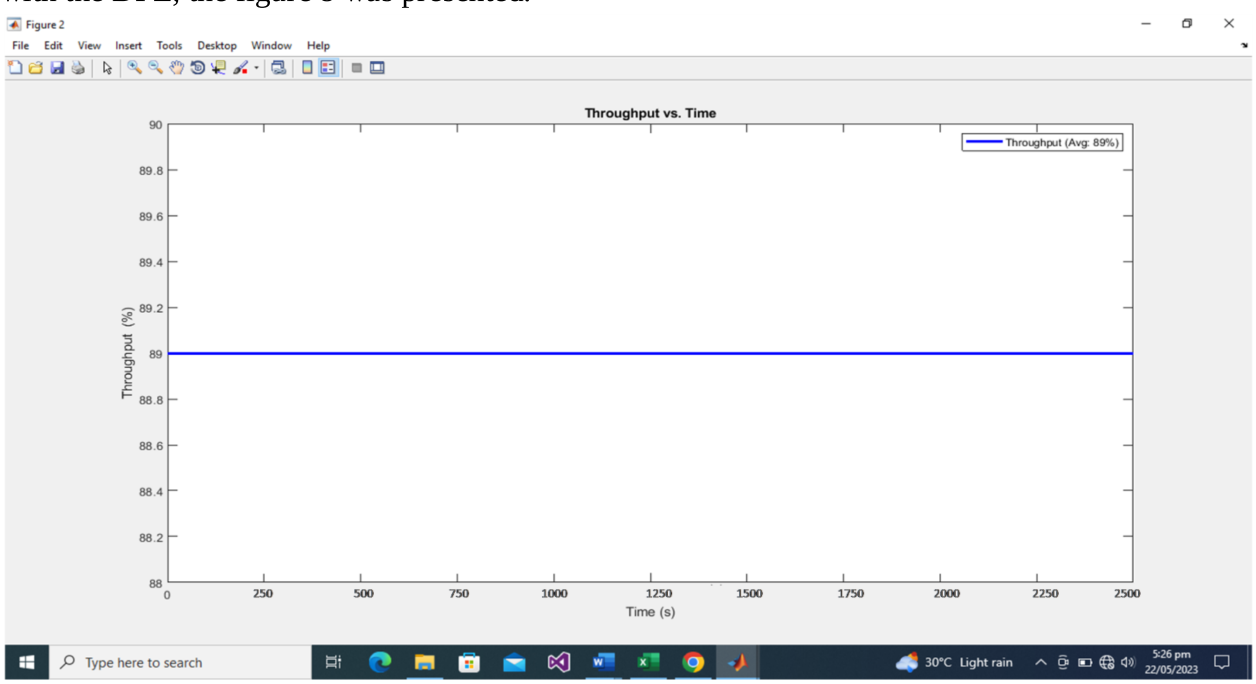

Figure 8: Average Network throughput with DFE

From the figure 8, the average throughput recorded for the wireless network is 89%. This indicates a relatively high level of successful data transmission and indicates that the system is effectively handling the challenges posed by the channel conditions, interferences, and other impairments. The high average throughput recorded suggests that the communication system, with adaptive DFE, effectively mitigates the effects of inter-symbol interference and channel distortions by minimizing errors and enhancing the quality of the received signals through equalization.

6. CONCLUSION

This paper utilized adaptive decision-feedback equalizer (DFE) in mitigating inter-symbol interference (ISI) in wireless communication networks and also channels equalization. By analyzing the various components and functionalities of the DFE, the study provided insight on the role of DFE in improving the quality of received signals and achieving higher data throughput. Through the evaluation of different step sizes and tap delays, it was demonstrated that DFE's performance improves as the step size decreases. This indicates that smaller step sizes allow for more precise adjustments of tap weights, leading to better equalization and lower error rates. However, the selection of an appropriate step size involves a trade-off between convergence speed and accuracy.

Furthermore, the study highlighted the importance of tap weight adjustment using algorithms such as the Least Mean Squares (LMS) algorithm. This adaptive adjustment of tap weights enables the DFE to effectively adapt to varying channel conditions and reduce inter-symbol interference without enhancing noise. The results also emphasized the significance of system-level factors, such as error correction mechanisms in achieving higher average throughputs. It is important to note that the study provides a foundation for further research and optimization of the DFE and its integration within wireless communication networks. Continued exploration and refinement of the DFE's parameters, algorithms, and system-level configurations will lead to enhanced equalization performance and improved data transmission efficiency. Further research and optimization of the DFE parameters and system-level configurations are recommended to enhance its performance in practical applications.

7. REFERENCE

Alex T. R, "Fundamentals of Cellular Network Planning &Optimization", 2014 John Wiley & Sons, Ltd. ISBN: 0-470-86267-X,PP 21-29.

Batra, Arun & Zeidler, J.R.. (2010). Beex, "Mitigation of narrowband interference using adaptive equalizers.

Bidikar, B., Chapa, B. P. , Kumar, M. V. , & Rao, G. S. (2020). GPS Signal Multipath Error Mitigation Technique. In V. Demyanov, & J. Becedas (Eds.), Satellites Missions and Technologies for Geosciences. IntechOpen. https://doi.org/10.5772/intechopen.92295

Chhaya E. Oh, S. H. and Li, K. H. (2016) "BER Performance of BPSK Receivers over Two-Wave with Diffuse Power Fading Channels", IEEE Transaction on wireless communications, vol. 4, No. 4 Phoenix, A.Z., IEEE

Majeed D., Hamsa & Saman, Goran. (2022). Adaptive Filter based on Absolute Average Error Adaptive Algorithm for Modeling System. UHD Journal of Science and Technology. 6. 60-69. 10.21928/uhdjst.v6n1y2022.pp60-69.

Ekiz.N, Salih.T, Küçüköner. S, and Fidanboylu. K, "An Overview of Handoff Techniques in Cellular Networks", Proceedings of World Academy of Science, Engineering and Technology, Volume 6, June 2015, ISSN 1307- 6884.

Elbatji. A, Elbatji. Y, Rachidi. T, and Bouzekri. H (2017) "A test bed for the evaluation of QoS provisioning in WCDMA based 3G wireless Networks", in Proceedings of the IASTED International Conference on Communication Systems and Networks.

Hossein .H.(2013)). Channel assignment in cellular radio. Selected Areas in Communications, IEEE Journal on, **5**(5): p. 871-878.

Li, Mingqi & Tan, Jianguo & Zhang, Wenjun. (2004). Channel estimation method based on frequency-domain pilots and time-domain processing for OFDM systems. Consumer Electronics, IEEE Transactions on. 50. 1049 - 1057. 10.1109/TCE.2004.1362498.

Matsunage. P (2012).Feasibility of adaptive MIMO System using channel reciprocity in FDD mode. In Communications,. APCC

Miguel González-Calvo, Luo, Xiaoguang, Aponte, José, Richter, Bernhard, "Advanced Multipath Estimation and Interference Mitigation for High-precision RTK Positioning," *Proceedings of the 34th International Technical Meeting of the Satellite Division of The Institute of Navigation (ION GNSS+ 2021)*, St. Louis, Missouri, September 2021, pp. 652-678.https://doi.org/10.33012/2021.17907

Muzi Y., Du L., Baiyu L., Huaming C., Gang O. (2017)" Assessement method of multipath mitigation performance of GNNSS antenna with receiver algorithm" [J] IJAP; volume 2017; ID: 1957572

Rosselti . J.G., Digital communications.2011, McGraw-Hill series in electrical and computer engineering. McGraw-Hill, Boston

Rusu, A.-G.; Paleologu, C.; Benesty, J.; Ciochin ˇa, S. A Variable Step Size Normalized Least-MeanSquare Algorithm Based on Data Reuse. Algorithms 2022, 15, 111. https://doi.org/10.3390/ a15040111

Saeed Daneshmand,Ali Broumandan,John Nielsen,Gérard Lachapelle (2013) "Interference and multipath mitigation utilising a two-stage beamformer for global navigation satellite systems applications; https://doi.org/10.1049/iet-rsn.2012.0027; **Sonar & Navigation; Volume 7, Issue 1** p. 55-66

Sokunbi O.O, Egbo K.O, Adeyemo K. (2020)" AKE RECEIVER METHOD OF MULTIPATH FADING REDUCTION" Inbook: Department of Electrical and Electronics Engineering Ladoke Akintola University of Technology, Ogbomoso; seminar.

Tariq Jamil Saifullah Khanzada, Ali Ramadan Ali, Abdul Qadeer Khan Rajput, (2009)"A Design and Chronological Survey of Decision Feedback Equalizer for Single Carrier Transmission Compared with OFDM" Wireless Networks, Information Processing and Systems, 2009, Volume 20; ISBN : 978-3-540-89852-8

Teresa G., Fernando D. (2020) "Advanced multipath mitigation tehcnqiues for GNNSS receivers; Navigation journal of the Institute of Navigation, vol 39; No 3; Fall 2020; pp. 344-357

VanNee E. Papadimitriou, C. H., & Steiglitz, K. (2019).Combinatorial optimization: Algorithms and complexity. Upper Saddle, NJ: Prentice-Hall.

Wu Q, Zhou X, Wang C, Qin Z. Channel estimation based on superimposed pilot and weighted averaging. Sci Rep. 2022 Jun 18;12(1):10293. doi: 10.1038/s41598-022-14482-6. PMID: 35717479; PMCID: PMC9206651.

Hong X., "Experimental Demonstration of 55-m / 2-Gbps Underwater Wireless Optical Communication Using SiPM Diversity Reception and Nonlinear Decision-Feedback Equalizer," in IEEE Access, vol. 10, pp. 47814-47823, 2022, doi: 10.1109/ACCESS.2022.3170889.

Zia R. Outes. J. Nielsen.L., Pedersen. K. and Mogensen .P, (2015) "Multi-cell admission control for UMTS, "Proc. IEEE veh. Technol. Conf., Rhodes, Greece, May.