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Improving Wireless Communication Reliability through Equalization Techniques: A Performance Comparison

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Abstract:

With the growing demand for high-speed data rates in wireless communication, ensuring system reliability is crucial. However, no communication system can achieve 100% reliability due to various channel impairments that distort transmitted signals at the receiver. To improve the quality of communication between the sender and receiver, effective techniques are required to mitigate the impact of channel distortions and minimize errors. Among these techniques, diversity and equalization methods are commonly employed to counteract channel effects and enhance signal quality at the receiver. This paper explores different equalization techniques used to reduce channel impairments. A comparative analysis of linear and non-linear equalizers based on Bit Error Rate (BER) is conducted using MATLAB simulations, providing valuable insights into their performance and effectiveness in improving wireless communication.

Keywords: Delay dispersion, Inter-symbol interference, equalizer, Doppler shift, Error propagation, White Gaussian noise, Bit error rate, burst error, Signal-to-noise ratio, FIR filter.

I. Introduction.

In wireless communication and mobile communication, the main aim is to transmit information at the highest possible data rate [1, 2]. But in wireless multipath system, it is often considered that fading is a random process which shows attenuation, delay and phase shift in the received signal. So, the key target is to reduce the effect of fading created by the wireless multipath channels. The multipath components (MPCs) that exist between the transmitter and the receiver, have different runtimes, which results in delay dispersion [3]. This delay dispersion leads to Intersymbol Interference (ISI) which can interrupt the transmitted digital signal [4]. For ISI, some advancement at the receiver side has to be done. Equalizers are such receiver structure that is used to reduce or eliminate ISI [5,6].

A. Fading

Rapid fluctuation in the strength of the receiver signal for a short period of time and/or travel distance is referring to as fading.

Fading occur due to multipath propagation of the transmitted signals which results in constructive or destructive interference and phase shifting of signals at the receiver side [7,8]. The causes of fading are mainly refraction, reflection, scattering and Doppler shift. Fig.1 shows types of fading.

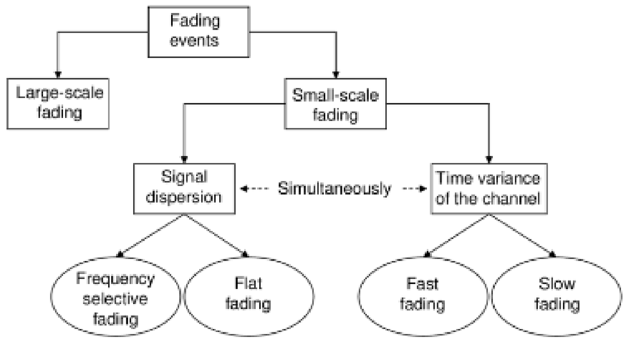

Fig 1. Types of fading

B. Multipath propagation

In wireless telecommunication, multipath is the propagation phenomenon in which radio signals reached the receiving antenna by two or more paths. Causes of multipath include ionospheric reflection, refraction, atmospheric ducting and reflection from terrestrial objects and water bodies which results in delay dispersion and hence leads to Intersymbol interference (ISI) [9].

C. Intersymbol interference (ISI)

In this, one symbol interferes with the subsequent symbols which results in the distorted signal and hence makes the system more unreliable. Its presence introduces error in the decision device at the receiver side. For credible communication, some advancement should be done at the receiver end in order to mitigate the effect of ISI [10].

To alleviate ISI, equalization techniques are used at the receiver side.

II. Equaizer

It is a device that endeavors to reverse the effect and distortion incurred by the channel on the transmitted signal. Its main aim is to combat ISI created by the time dispersive or time varying channels in order to recover the transmitted symbols. This technique is known as equalization. In order to mitigate ISI introduced by the channel, for an equalizer it is necessary to estimate the channel frequency and impulse response [11-15]. For this, an equalizer sends a training sequence (pseudorandom binary signal/fixed-length known bit sequence) over the channel for tracking the channel response and then updates its filter coefficients for minimizing the error. The length of the training sequence depends on the structure of the equalizer and the algorithm used for updating its tab and also on the channel response [16].

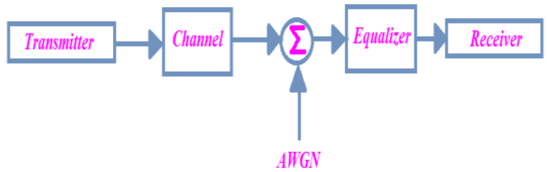

Fig 2. System Model

Fig.2 shows the system model. Here the transmitter sends information to the receiver through a dispersive and varying channel which results in corrupted output by the additive white Gaussian noise (AWGN). To eliminate the effect of channel from signal and to recover the distorted signal, an equalizer is used at receiver side and hence at the output of receiver we get the original information [1].

III. Equalizer Types

There are two types of equalizers:

- Linear equalizer- substandard, but simple, no feedback path to adapt the equalizer.
- Non-linear equalizer- complex, but effective for severe noisy channels, feedback path to change the equalizer's subsequent output.

A. Linear equalizer

The most common, simple and easy to implement equalizer is the linear equalizer. It is highly effective for the channels having ISI not severe. It can be implemented as an FIR filter and hence also called linear transversal filter [2]. In such type of equalizer, the present and past values of the received signal are linearly weighted by the adjustable coefficient of the filter and then summed to get the output [10, 17]. Fig.3 shows structure of a linear transversal equalizer.

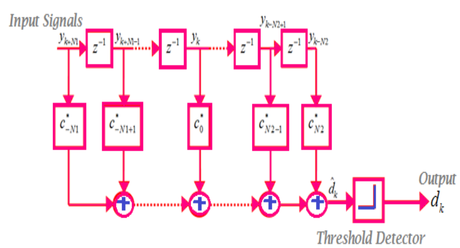

Fig 3. Structure of a linear transversal equalizer

Following expression shows the minimum mean squared error which a linear equalizer can achieve-

$$E[|e(n)|^2] = \frac{T}{2\pi} \int_{-\pi/T}^{\pi/T} \frac{N_0}{|F(e^{j\omega T})|^2 + N_0} d\omega \qquad (1)$$

B. Non-linear equalizer

Linear equalizers do not perform nicely on channels having deep spectral nulls in the pass band. It gives best result only in case of static environment, but in dynamic environmental condition, it fails to provide pretty good results and hence to improve the performance and reliability of the system, non-linear equalizer are taken into account for such dynamic environmental condition [13].

Non-linear equalizers are mainly used in application where the channel distortion is too severe and not possible for linear equalizer to mitigate the effect of channel impairments [11]. They are classified as-

1) Decision feedback equalizer: Decision feedback equalizer (DFE) is a simple non-linear equalizer, generally useful for the channels having severe amplitude distortion. DFE consist of feed forward filter, feedback filter and decision device [7]. Here, feed forward section is a linear equalizer and its output is given to the decision device. The input of feedback section is the output made by the decision device. The basic idea behind DFE is that once an information symbol has been detected and decided by the decision device, the ISI induces on the future symbols can be estimated and subtracted out before detection of later symbol [18-20].

In DFE, error propagation is the one possible source of problem. If the decision device takes the wrong judgment even for a single bit, then the computed ISI is also erroneous, so the subsequent symbols reaching to the decision device are even more afflicted by ISI as compared to unequalized symbols. For a small BER, error propagation is not taking into account and this small error rates can be achieved via coding. Fig.4 shows block diagram of decision feedback equalizer (DFE).

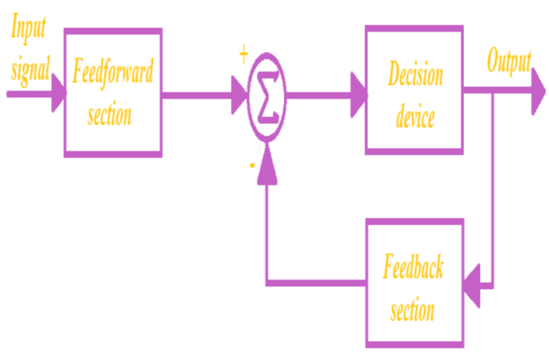

Fig 4. Block diagram of decision feedback equalizer

The minimum mean squared error of decision feedback equalizer can be achieved as:

$$E[|e(n)|^2] = \exp\left\{ \frac{T}{2\pi} \int_{-\pi/T}^{\pi/T} \ln\left[\frac{N_0}{|F(e^{j\omega T})|^2 + N_0} \right] d\omega \right\} \qquad (2)$$

The minimum mean squared error of decision feedback equalizer is smaller than the minimum mean squared error of linear equalizer.

2) Maximum Likelihood Sequence Estimation: Maximum likelihood sequence estimation (MLSE) is a mathematical algorithm which extracts useful data from the noisy data stream. It provides optimum performance and best estimation of the transmitted symbols with the least possible number of errors [19]. Hence, the equalizer based on MLSE also called as optimum equalizer. MLSE test all the possible data sequence and selects that sequence of data as output which has the maximum probability. An MLSE usually required a large computational analysis, especially when the channel has large delay spread. As an equalizer, MLSE was first proposed by Forney in which he set up an ultimate MLSE estimator structure and equipped it with the Viterbi algorithm. The number of states of the Viterbi decoder is expressed as M^L, where M is the number of symbols in constellation, and L is the speed length channel [4, 8]. Fig.5 shows the block diagram of MLSE receiver based on DFE.

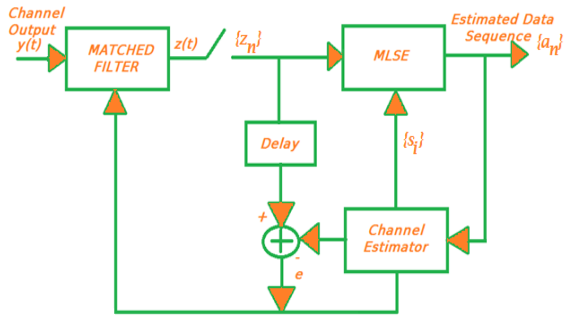

Fig 5. Block diagram of MLSE.

Signal To Noise Ratio

Receiver signal to noise ratio (SNR) is a measure of the received signal power P_r by the noise power within the transmitted signal $s(t)$ bandwidth.

$$SNR = \frac{P_{signal}}{P_{noise}} = \frac{P_r}{\mathrm{N}_0 B} \qquad (3)$$

where, $\mathrm{N}_0 B$ is the total noise power within the bandwidth $2B$.

Mathematically, SNR is also expressed as

$$\mathrm{SNR} = 10\log_{10}(\mathrm{E_b}/\mathrm{N_0})\,\mathrm{dB} \qquad (4)$$

where, $(\mathrm{E_b}/\mathrm{N_0})$ is the normalized SNR and also known as SNR per bit.

We always needed a high signal to noise ratio for regaining the original signal. If it is low, it means the noise created by the channel is high and the signal is too much distorted and it is not possible or very difficult for us to recover the original signal.

V. Bit Error Rate

When the bits stream transmitted from source to destination then the number of bits altered over the communication channel is referred to as number of bits error. Hence, BER is the rate of the corrupted number of bits of the bits stream while travelling through the channel. It is a unitless measure of performance, usually expressed as a percentage. BER is defined as

$$\mathrm{BER} = \frac{\text{No. of Errors}}{\text{Total no. of transferred bits}} \qquad (5)$$

or

$$\mathrm{BER} = \frac{1}{2}\mathrm{erfc}(\sqrt{\mathrm{E_b}/\mathrm{N_0}} \qquad (6)$$

VI. Burst Error

When two or more bits of data unit are altered from 1 to 0 or 0 to 1 referred as bust error. In burst error, it is not essential that errors happen only in successive bits, it can also occur in inconsecutive way. This type of error mainly occurs in a serial transmission. The length of the burst error is measured from first altered bit to the last altered bit. Fig.6 shows burst error.

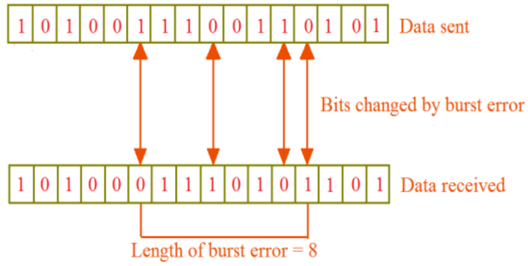

Fig 6. Burst Error

VII. Simulations And Results

Following BER performance, burst error performance and channel frequency response of linear equalizer and non-linear equalizers (DFE, MLSE) are obtained by using the MATLAB simulation.

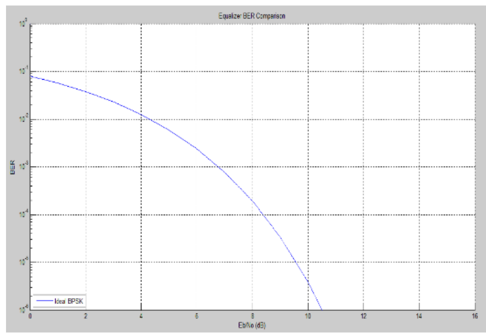

Fig 7. Unequalized BER performance

Fig.7 shows unequalized BER performance. It is so called unequalized performance because in this, no equalizer is used at the receiver side, which means we get an unequalized signal at the receiver output. It shows that as the SNR increases, the BER decreases rapidly but at some points, the strength of the signal tends to zero and hence it becomes impossible to restore the original signal.

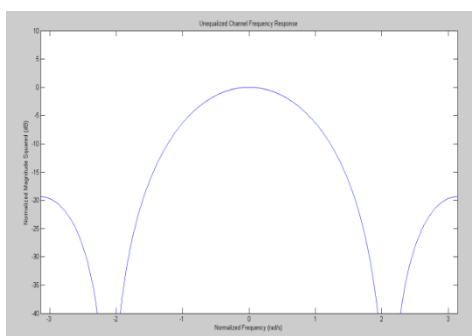

Fig 8. Unequalized Channel Frequency Response

Fig.8 shows the power spectrum or frequency response of unequalized signal. Frequency response shows that how the output gain and phase changes at different frequencies. Here in the figure, at some frequencies, wave is out of phase to cause deep nulls which means that the condition of the channel is too severe and due to ISI, signal can be easily distorted. The main lobe has very high magnitude which means that it contain maximum number of information, while side lobes have very small gain.

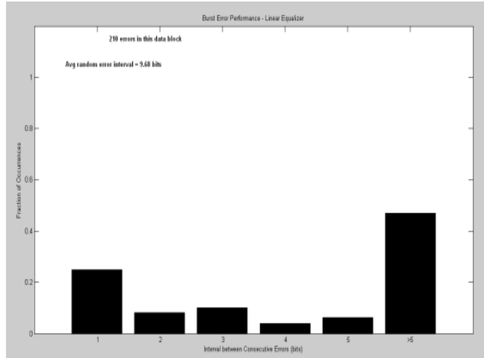

Fig 9. Burst Error Performance - Linear Equalizer

Fig.9 shows burst error performance of linear equalizer. In this, the errors occur with short inter-error interval which results in high rate of error.

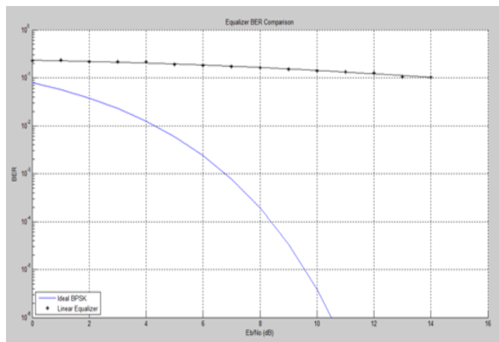

Fig 10. Comparison between Ideal BPSK and linear equalizer

Fig.10 shows comparison between ideal BPSK and linear equalizer. Here, SNR of the linear equalizer increased but BER decreased too slowly which means that if the channel is varying rapidly with time, then their will the high possibility of error.

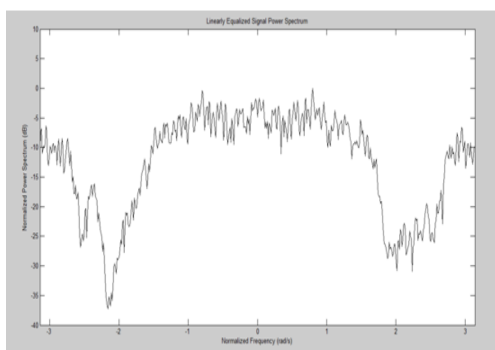

Fig 11. Linear Equalizer Signal Power Spectrum

Fig.11 shows signal power spectrum of linear equalizer. Here, as the normalized SNR increased, the deep nulls of the power spectrum of linearly equalized signal is also successively increased which highlights the certainty that a linear equalizer need more taps to adequately equalize the channel with deeper nulls. But these nulls are not as deep as in unequalized channel frequency response. This plot also shows that the magnitude of the side lobes is also increased which can be results in grating lobes and can creates interference with the main lobe.

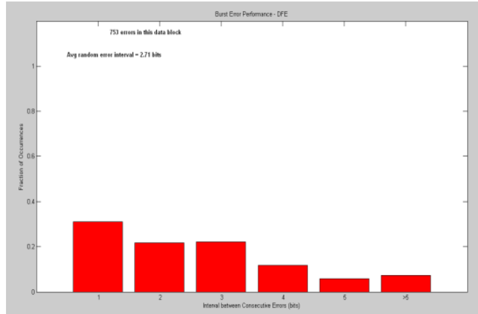

Fig 12. Burst Error Performance – DFE

Fig.12 shows burst error performance of DFE. Due to error propagation, DFE errors are relatively bursty which means that wrong bits are feeding back to the decision device. This plot shows that as the BER decreases, with an inter-error interval of five bits or less, a significant number of errors occur. If all the time, a DFE equalizer runs in training mode, then the error would be fairly less bursty.

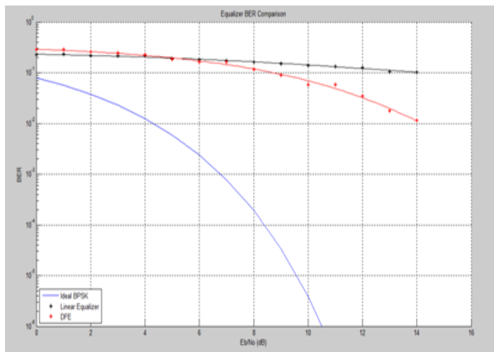

Fig 13. Comparison among BPSK, Linear and DFE equalizer

Fig.13 shows comparison between BPSK, linear and DFE equalizer. This plot shows that the BER of the DFE, with respect to SNR, decreases more rapidly as compared to the linear equalizer. These BER points of the plot at a given E_b / N_0 value are used to update every data block in order to move up and down lies on the number of errors gathered in that block.

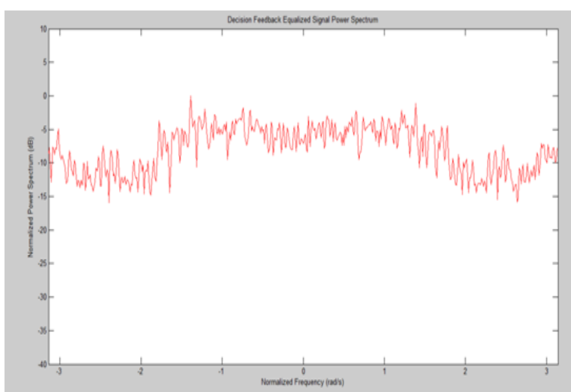

Fig 14. DFE Signal Power Spectrum

Fig.14 shows signal power spectrum of DFE. Here, the nulls of the wave are less deep as compared to linear equalizer but the gain of side lobes is still high.

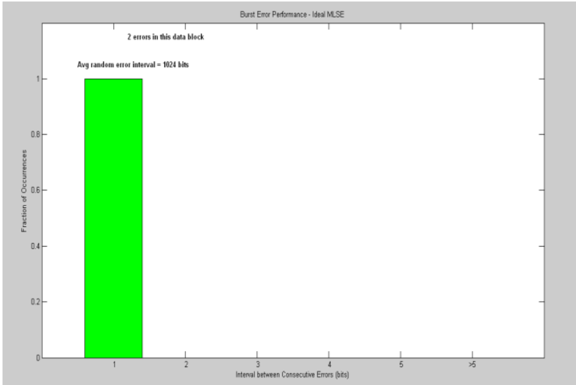

Fig 15. Burst Error Performance – Ideal MLSE

Fig.15 shows burst error performance of ideal MLSE. In this, the error occurs in enormously burty manner. But as the BER decreases, the percentage of error also decreases.

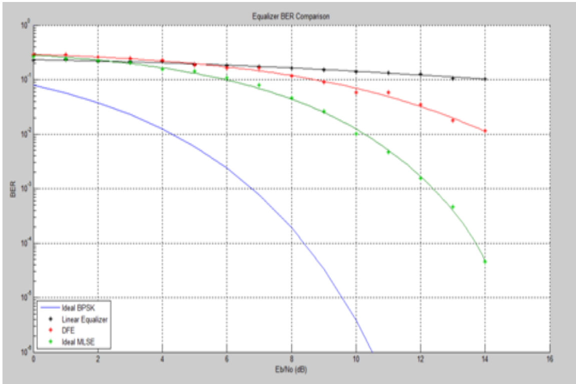

Fig 16. Comparison among BPSK, Linear, DFE and Ideal MLSE equalizer.

Fig.16 shows comparison between BPSK, linear, DFE and ideal MLSE equalizer which showed who's doing well. Here, the BER of ideal MLSE decreases expeditiously with respect to SNR than that of other equalizers.

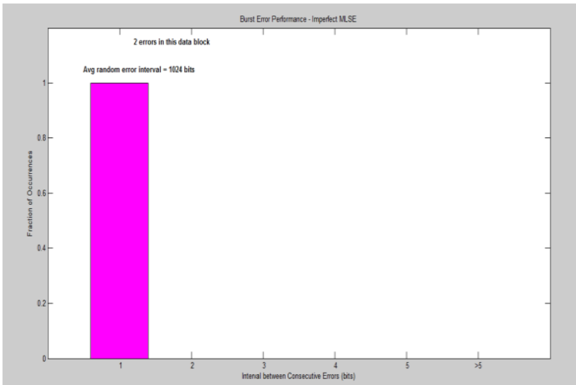

Fig 17. Burst Error Performance – Imperfect MLSE

Fig.17 shows burst error performance of imperfect MLSE. In this, the burst error performance is fairly closely to that of ideal MLSE.

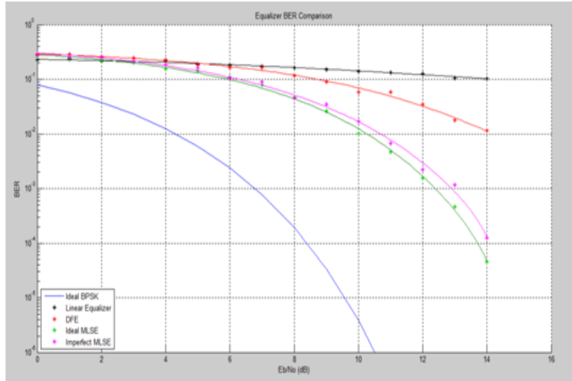

Fig 18. Comparison among BPSK, Linear, DFE,Ideal MLSE and Imperfect MLSE equalizer.

Fig.18 shows comparison between BPSK, linear, DFE, ideal MLSE and imperfect MLSE equalizer. This final graph itself explains that whose performance is best. Here, the BER vs normalized SNR performance of the imperfect MLSE is much closer to the ideal MLSE. For imperfect MLSE, we assume that the channel varies with time and for ideal MLSE we supposed that that the channel conditions are known.

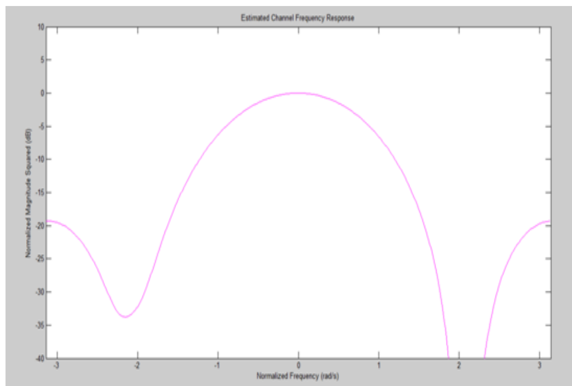

Fig 19. Imperfect MLSE Channel Frequency Response

Fig.19 shows Imperfect MLSE Channel Frequency Response. Here, the estimated channel spectrum plot is somewhat similar to actual channel spectrum plot with less deep nulls.

VIII. Conclusion

To conclude, this paper provides the entire knowledge of the equalizers, their techniques and BER performances. Many services required transmission of data at high bit rate, but these leads to Intersymbol interference (ISI) which deteriorate the transmitted signal and we get distorted signal at the receiver side. The ultimate goal is to mitigate the effect of channel impairments and to combat ISI in order to recover the original transmitted signal. To achieve such an objective, equalizers are used at the receiver side. This paper summarized that which equalization technique should be adapted on which state of channel.

Linear equalizer is generally suitable for static channel. But when channel varies with time and for linear equalizer, it is not feasible to combat ISI, then non linear equalizers are taken into account. For severe and noisy channel, DFE performs well, but due to error propagation, instead of getting better signal, it gets worse. In such condition, MLSE equalizer is used. Due to least chance of detecting the wrong sequence, MLSE is also called optimal equalizer. On the basis of simulation using the MATLAB, the conclusion comes out that the BER performance of MLSE equalizer is better than that of others. But at low BERs, MLSE algorithm suffers from burst error. This burst error problem can be overcome by using burst error-correcting codes at the receiver side.

References

1. Seema Paliwal, Dilpreet Kaur Grover and Jyoti Krayla, “Comparision of Linear and Non-Linear Equalizer using the MATLAB”, Communication on Applied Electronics (CAE) – ISSN : 2394-4714, Foundation of Computer Science FCS, New York, USA, Volume 4-No.1, January 2016 – www.caeaccess.org.

2. Chen, L., & Wang, Z. (2021). Diversity and equalization techniques in wireless systems: A comparative study on performance under various channel conditions. International Journal of Wireless Communications, 19(2), 98-110. https://doi.org/10.1016/j.ijwc.2021.08.003

3. Sharma, M., & Gupta, P. (2020). Bit error rate analysis of linear and non-linear equalizers for high-speed wireless communication. IEEE Access, 8, 47890-47902. https://doi.org/10.1109/ACCESS.2020.2986274

4. Seema Paliwal, Jyoti Krayla and Dilpreet Kaur Grover, “BER Analysis of Equalizers with BPSK Signaling”, CiiT bringing the world locally, Programmable Device Circuits and Systems, Vol 7, No. 10 (2015).

5. Vikash Kumar Tiwary, Subham Agarwal and Samarendra Nath Sur, “Performance Analysis of Non-linear Equalizer in MIMO System for Vehicular Channel”, I.J. Image, Graphics and Signal Processing, 2013,11,68-75.

6. R. Yadav, P. Moghe, M. Patidar, V. Jain, M. Tembhurney and P. K. Patidar, "Performance Analysis of Side Lobe Reduction for Smart Antenna Systems Using Genetic Algorithms (GA)," 2023 14th International Conference on Computing Communication and Networking Technologies (ICCCNT), Delhi, India, 2023, pp. 1-5, https://doi.org/10.1109/ICCCNT56998.2023.10306796

7. M. Patidar, G. Bhardwaj, A. Jain, B. Pant, D. Kumar Ray and S. Sharma, "An Empirical Study and Simulation Analysis of the MAC Layer Model Using the AWGN Channel on WiMAX Technology," 2022 2nd International Conference on Technological Advancements in Computational Sciences (ICTACS), Tashkent, Uzbekistan, 2022, pp. 658-662, https://doi.org/10.1109/ICTACS56270.2022.9988033

8. Shreyaskumar Patel. "Optimizing Wiring Harness Minimization through Integration of Internet of Vehicles (IOV) and Internet of Things (IoT) with ESP-32 Module: A Schematic Circuit Approach", International Journal of Science & Engineering Development Research (www.ijrti.org), ISSN:2455-2631, Vol.8, Issue 9, page no.95 - 103, September-2023, Available :http://www.ijrti.org/papers/IJRTI2309015.pdf

9. Zhang, Y., & Li, H. (2023). A performance analysis of linear and non-linear equalization techniques in wireless communication systems. IEEE Transactions on Wireless Communications, 22(4), 712-725. https://doi.org/10.1109/TWC.2023.3124567

10. Patel, S., & Singh, R. (2022). Channel impairment compensation using adaptive equalizers for 5G communication systems. Journal of Communication and Networks, 24(3), 125-137. https://doi.org/10.1109/JCN.2022.3104571

11. Vipin Parihar, Sumeet Sambyal, Amit Sharma and Deepak Rawat, “Simulation of BER and SNR of Linear and Non-Linear Equalizer”, i\ International Journal of Advanced and Innovatie Research (2278-7844) / # 377 / Volume 3 Issue 3.

12. Nisha Wadhwa, Savita Rangi and Dheeraj Rathee, “Intersymbol Interference Resuction and Bit Error Rate Reduction in Wireless Channels Using Zero Forcing Equalizer”, IOSR Journal of

Electronics and Communication Engineering (IOSR-JECE), e-ISSN: 2278-8735, Volume 9, Issue 3, Ver. III (May – Jun. 2014), PP 82-85.

13. J. G. Proakis, ‖Digital Communications‖, New York: McGraw-Hill, 2000.
14. Amit Agarwal, S.N. Sur, Arun Kumar Singh, Hemanth Gurung, Abhishek Kumar Gupta and R. Bera "Performance Analysis of Linear and Non-linear Equalizer in Rician Channel", SciVese ScienceDirect Procedia Technology 4 (2012) 687-69.
15. T. S. Rappaport, Wireless Communication, Chapter 5 and 16, second edition Upper Saddle River, NJ: Prentice Hall, 1996.
16. Darshna Kundu and M.K. Jain, "The Comparative Study of Adaptive Channel Equalizer Based on Fixed and Variables Step-Size LMS Algorithm & its Variants for Non Stationary Wireless Channel", International Journal of Engineering Trends and Technology (IJETT) – Volume4 Issue6 – June 2013, ISSN: 2231-5381..
17. Ilia Kempi, "Adaptive Channel Equalization", Multicore Processor Implimentation, Helsinki Metropolia University of Applied Sciences, Bachelor of Engineering, Degree Programme in Electronics, Bachelor's Thesis, 15.05.2015.
18. A. T. Erdogan, B. Hassibi, and T. Kailath, "H1 Equalization of Communication Channels", submitted to IEEE Tr. Signal Pr., 1997. E. A. Lee, D. G. Messerschmitt, Digital communications, 2nd Edn., Kluwer Academic Publishers, 1994.
19. Shreyaskumar Patel. (2021). Enhancing Image Quality in Wireless Transmission through Compression and De-noising Filters. In International Journal of Trend in Scientific Research and Development (Vol. 5, Number 3, pp. 1318–1323). IJTSRD. https://doi.org/10.5281/zenodo.11195294
20. Shreyaskumar Patel. (2022). Performance Analysis of Acoustic Echo Cancellation using Adaptive Filter Algorithms with Rician Fading Channel. In International Journal of Trend in Scientific Research and Development (Vol. 6, Number 2, pp. 1541–1547). IJTSRD. https://doi.org/10.5281/zenodo.11195267