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The Performance of Different Channel Equalizer Techniques in Wireless Communications using SISO and MIMO

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Abstract: Channel equalizers are used to reduce the Inter-Symbols Interference (ISI) arising from the delay spread or band-limitation of the channel by modifying the pulse shape, so that, it does not interfere with the nearby pulses. Major equalization techniques are linear equalization, Viterbi Maximum-Likelihood Sequence Estimation (MLSE) and Decision-Feedback Equalization (DFE). These receivers for frequency-selective channels can be easily extended to multiple antenna cases. Classical channel equalization methods such as the linear equalizer and the DFE are based on training sequences. There are some blind algorithms which avoid the use of training sequences. So that, led us to Maximum Likelihood Sequence Estimation (MLSE) is the best form of sequence exposure but is extremely complex and having the smallest probability of detecting the incorrect sequence.

Key words: Decision-Feedback Equalization (DFE), Maximum Likelihood Sequence Estimation (MLSE), Binary Phase-Shift Keying (BPSK), Single-Carrier Frequency Domain Equalizer (SC-FDE), Single-Input Single-Output (SISO), Multiple-Input Multiple-Output (MIMO)

INTRODUCTION

Digital transmission systems have a remarkable characteristic for voice, data and video communications is their higher reliability in noise environment comparing with analog. Unluckily, most of the time the transmission of digital information attached with a phenomenon known as Inter-Symbol Interference (ISI) (Haykins, 1996). This means that the pulses that transmitted are smeared out, for this reason pulses that match to various symbols are not separable. The transmission media that is the main causes for ISI knowing as (cellular communications multipath propagation) and (cable lines).

This ISI has been familiar as the major barrier to high speed data transference over radio channel. Thus, it is very critical to reduces ISI, so, we can have an error free communication (Petersen and Falconer, 1994).

Solving this issue a technique called equalization is used at the front end of the receiver an inverse filter has been installed, his research is to inverse the transfer function of the channel and make it equal to the transfer function of the equalizer.

Equalizer is intended to research in environment that SNR (Signal-to-Noise Ratio) must be high and BER (Bit Error Rate) must be low and. Received signal inversed by equalizer with the combination of channel and equalizer gives a linear phase and flat frequency response (Haykins, 1996; Petersen and Falconer, 1994).

Using of multiple antennas at the receiver and transmitter in wireless systems, popular as MIMO (Multiple-Input Multiple-Output) technology has quickly acquired in popularity over the past few years due to a combination of signal processing techniques that have been sophisticated to boost the performance of wireless communication systems by installing multiple antennas at the receiver, transmitter or both of them for better performance. Communications performance improve using MIMO techniques by either combating or take advantage of multipath scattering in the communications channel between a receiver and transmitter. MIMO techniques generate what is name spatial diversity and those techniques that use multipath to do that by execute spatial multiplexing (Hampton, 2014).

The normal method for make spatial diversity to combat fading without extending the bandwidth of the transferred signal is employing multiple antennas at the receiver. Spatial diversity can be accomplished by using multiple antennas at the transmitter part. Multiple transmitting antennas can also be used to create multiple spatial channels and thus supply the ability to boost the data average (Hampton, 2014; Cavalcanti and Soren, 2009).

Communication in wireless channels is damage most of the time by multi-path fading. Multi-path is the incoming of the transferred signal at a meant receiver through varying angles and/or varying time delays and/or

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varying frequency (i.e., Doppler) shifts due to the spreading of electromagnetic waves in the space. So, the received signal power oscillates in space (due to angle diffuse) and/or frequency (due to delay diffuse) and/or time (due to Doppler diffuse) through the random super status of the hitting multi-path components. This random turn in signal level, known as fading, can hardly affect the goodness and accuracy of wireless communication.

Open-and closed-loop MIMO: MIMO techniques normally require that either the transmitter or the receiver have knowledge of the characteristics of the communications channel. As such MIMO techniques are often classified as either open or closed-loop, depending on whether the transmitter or the receiver uses knowledge of the communications channel. MIMO techniques that require the transmitter to have knowledge of the channel are called closed-loop because they require the receiver to estimate the channel and to send that information back to the transmitter, so, requiring a closed loop.

Open loop techniques in MIMO that require the receiver to have knowledge of the channel, these terms are used throughout the MIMO literature and in the wireless standards (Tuchler *et al*., 2002).

MATERIALS AND METHODS

In this study, the behavior of channel equalizer will analyzed in MATLAB environment. The performance of different channel equalizer will give in typical communication system. After that the performance of channel equalizer will analyzed with MIMO system.

Comparison of BER performance of different equalizers: In this study, we will simulate different equalizers type with MATLAB and we see bit error rate of these equalizers with channel null in pass-band. In our scenario we will generate signal with no pulse shaping then processes it through the channel (5-tap symmetric channel impulse response), we called it a Binary Phase Shift Keying (BPSK) at receiver side the equalizer will perform with different techniques as following:

- Linear equalizer with 30 weights
- DFE equalizer with RLS in feed-ward filter and LMS in feedback filter. And 15 weights for feed-forward and also for the feedback filter
- The MLSE equalizer is first mention with ideal channel information (ideal MLSE), then with a simple but incomplete channel estimation technique (imperfect MLSE)
- For comparison, ideal BPSK BER performance is shown without equalizer at receiver and assuming the noise is AWGN (Giordano and Levesque, 2015)

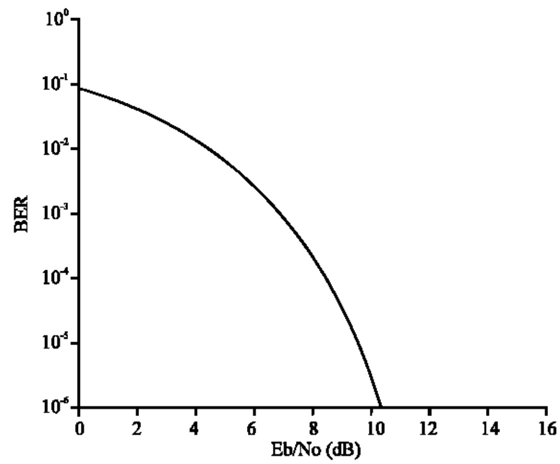

Fig. 1: BER performance for un-equalized BPSK; equalizer BER comparison

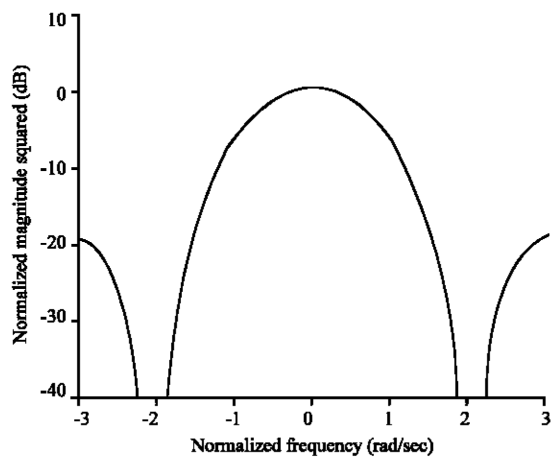

Fig. 2: Un-equalized BER performance; unequalized channel frequency response

Figure 1 shows un-equalized BER performance. When the signal is transmitted from source, then at the receiver side we haven't used the equalizer, i.e., the output which we get at the receiver end is un-equalized output. In Fig. 1 as the SNR increases the BER decreases.

Figure 2 shows the un-equalized signal power spectrum. In Fig. 3-7, there are very deep nulls which means that the channel is to severe and the signal can be strongly distorted by ISI. But in this, the main lobe has very high amplitude and side lobes have very small amplitudes which means that 99.9% information is contained by main lobe.

As MLSE is superior to all other structures. DFEs, though worse than MLSE estimators are better than linear equalizers. The quantitative difference between the structures depends on the channel impulse response.

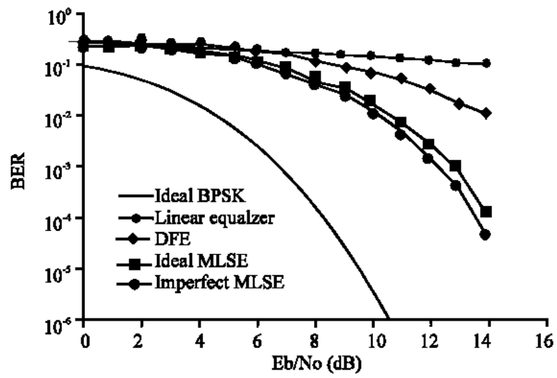

Fig. 3: BER performance of different equalizers

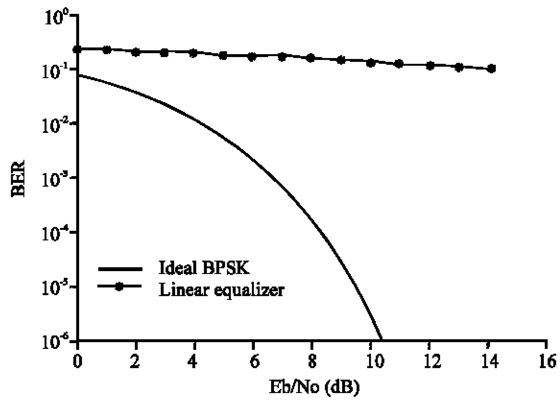

Fig. 4: BER ideal BPSK and linear equalizer

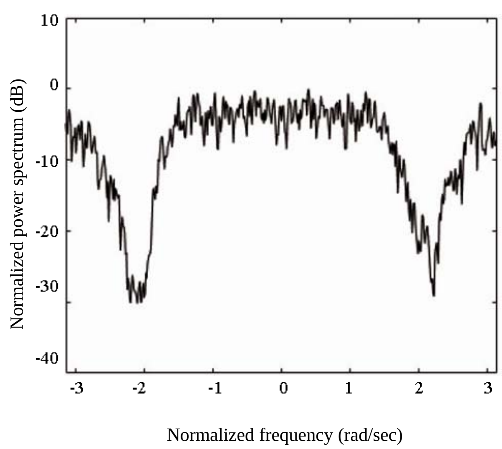

Fig. 5: Linear equalizer signal power spectrum

As when the Eb/N_0 raise, the signal spectrum (for linear equalizer) hold spectral nulls, consequently for that a linear equalizer should have additional taps to sufficient equalize a channel with a deep null. (Ergen, 2009) These nulls in channel case the noise power is greatly enhanced. In general, linear equalizer case more noise enhancements then non-linear equalizes.

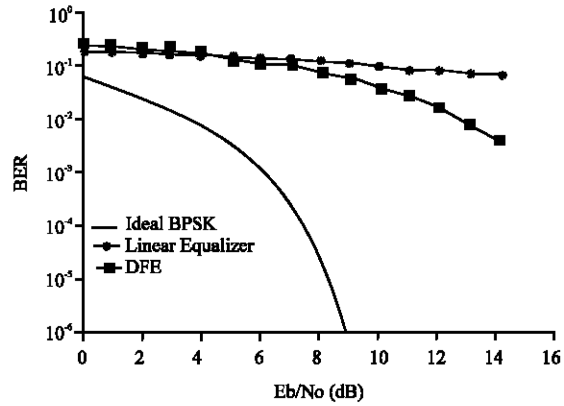

Fig. 6: BER of ideal BPSK and linear and DFE linear; Equalizer BER comparison

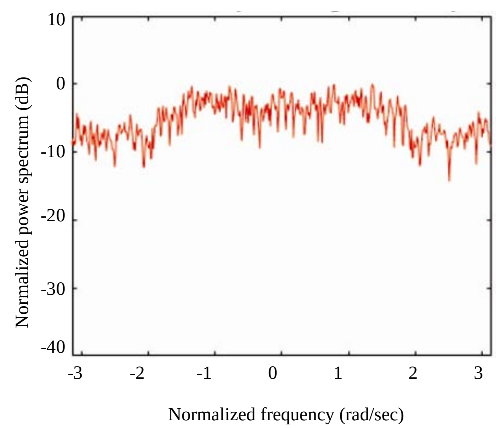

Fig. 7: DFE signal power spectrum; Decision feedback equalized signal power spectrum

Here, we find that the amplitude of side lobes are increases but the deepness of nulls decreases. Note: about the normalized frequency the Nyquist frequency is the unit frequency, known as semi the sampling frequency fs. Nyquist frequency used to normalize the cutoff frequency parameter. To transform normalized frequency to angular frequency about the unit circle, multiplying by π. To transform normalized frequency back to hertz, multiply by semi the sample frequency (MathWorks, 1996).

The frequency response represented as H (e j ω) the frequency variable ω is understood as the normalized frequency $\omega T = \omega/fs$. Also normalized frequency represented by θ (radians) (Shenoi, 2005).

For DFE equalizer as in Fig. 6, that the DFE is a lot preferable to qualify the channel null than the linear equalizer and as the SNR raise, the BER of the DFE reduce more quickly as contrast to the linear equalizer.

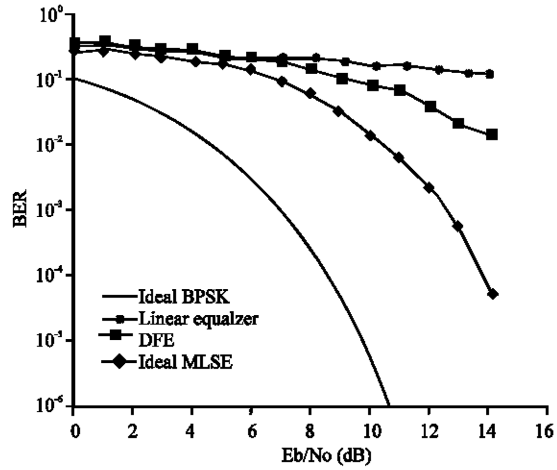

Fig. 8: BER performance for ideal BPSK, linear equalizer, DFE and MLSE; Equalizer BER comparison

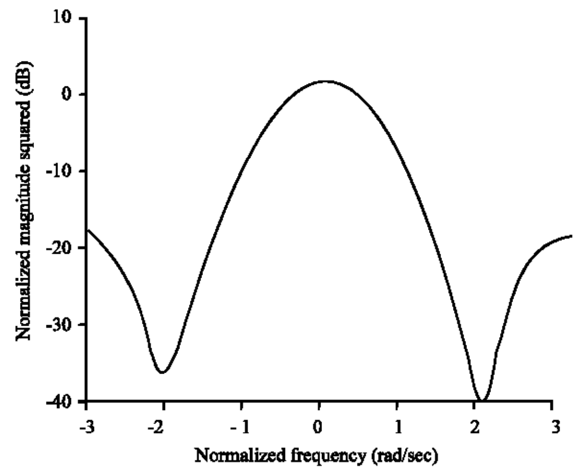

Fig. 10: Imperfect MLSE channel frequency response; Estimated channel frequency response

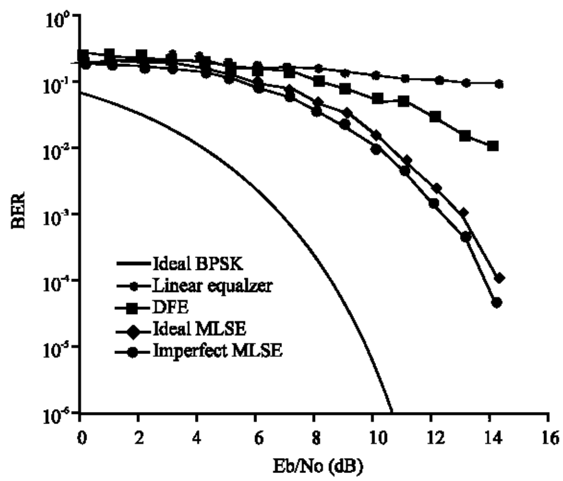

Fig. 9: MLSE equalizer with an imperfect channel estimate; Equalizer BER comparison

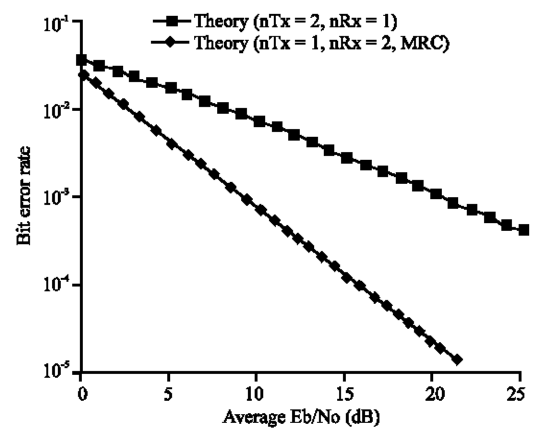

Fig. 11: BPSK with ZF (2×2 MIMO); BER for BPSK modulation with 2×2 MIMO and ZF equalizer (Rayieigh channel)

And the nulls are less deep and the magnitude of side lobes is also small as shown in the spectral plot (Fig. 7) (Karthikeya *et al.*, 2010).

For ideal MLSE equalizer with perfect channel knowledge (complete knowledge of channel earning related with all signals). On the analysis basis of BER vs. SNR performance we found that the BER achievement of perfect MLSE is greater than that of others as shown in Fig. 8.

Figure 9 Shows comparison among BPSK, linear, DFE, ideal MLSE and imperfect MLSE equalizer. Here, the BER performance of the imperfect MLSE is fairly closely to that of ideal MLSE. For ideal MLSE we assume that the channel is known and for imperfect MLSE the channel is time varying.

Figure 10 shows imperfect MLSE channel frequency response. Here, the nulls are deep but the magnitude of the main lobe is very high.

Channel equalizer with MIMO system: In this study, by using MATLAB we will analysis the performance of equalization with MIMO. In simulation environment we perform BPSK in Rayleigh channel with 2×2 MIMO system first with ZF, ZF-SIC, MMSE-SIC, ML.

As in Fig. 11, the performance of ZF (2×2) the matching as a system (1×1) BPSK in Rayleigh channel and the MRC is optimal detector. The variety order done by the ZF technique is NR+NT-1 and when NR = NT the diversity order which is equal to SISO (1×1). Now perform ZF with SIC (Successive Interference Cancellation with optimal control).

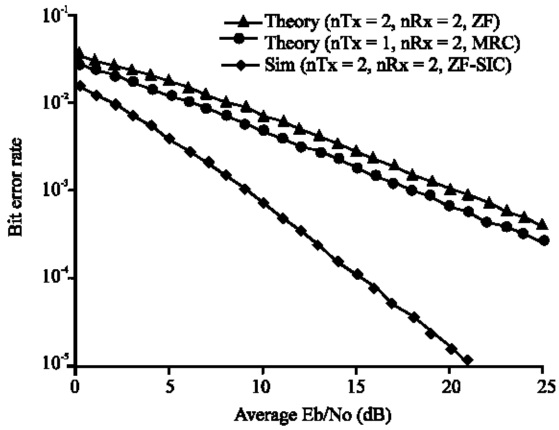

Fig. 12: BPSK with ZF-SIC (2×2 MIMO); BER for BPSK modulation with 2×2 MIMO and ZF-SIC equalizer (Rayieigh channel)

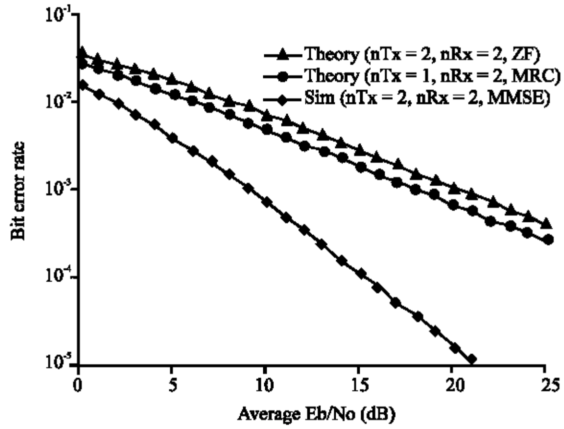

Fig. 14: BPSK with 2×2 MIMO with MMSE; BER for BPSK modulation with 2×2 MIMO and MMS equalizer (Rayieigh channel)

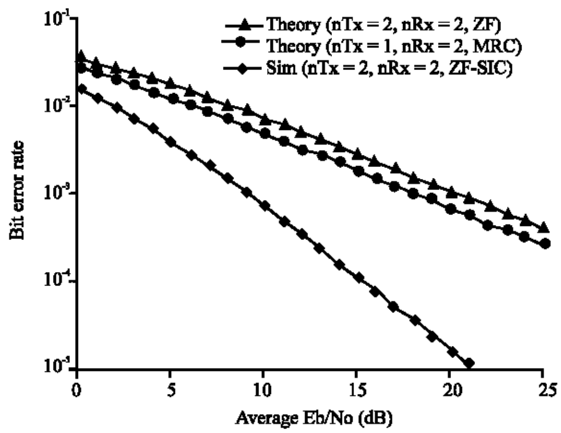

Fig. 13: BPSK with 2×2 MIMO with ZF-OSIC; BER for BPSK modulation with 2×2 MIMO and ZF-SIC serted equalizer (Rayieigh channel)

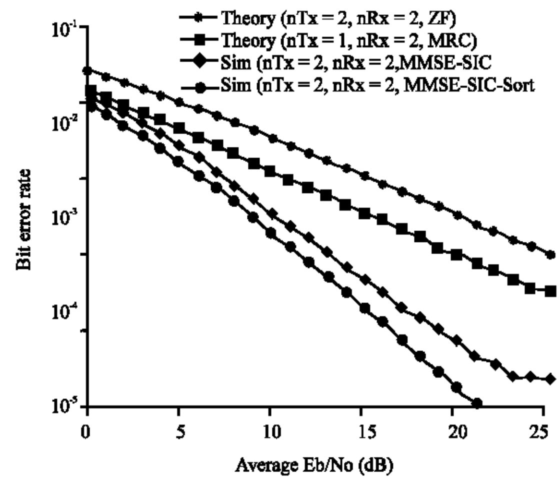

Fig. 15: BPSK with 2×2 MIMO with MMSE-SIC-OSIC; BPSK modulation with 2×2 MIMO and MMSE-SIC equalizer

As the performance of ZF with SIC has improvement about 2 dB for BER 10-2. When, we use SIC with optimal order the performance of equalizer improve about 4 dB as shown in Fig. 12. Because of decoding the information from the primary spatial dimension has a minimum error probability then the symbol transmitted from the latter dimension, so an improvement is brought in Fig. 13.

Now, we analysis the MMSE with same simulation parameters, Fig. 14 shows the MMSE with 2×2 MIMO system.

As we see that, MMSE equalizer has better performance compare with ZF around 3 dB at 10^{-3} BER point. Figure 14 illuminated the MMSE with SIC with and without optimal order.

Figure 15, the MMSE-SIC add improvement about 5 dB compare with MMSE. And the performance of MMSE-SIC with optimal order is now closely to MRC technique. By doing sequential interference cancellation with optimal planning guarantee that the accuracy of the first decoded symbol with reduce probability of fault than the other symbols. Next, performing the ML with MIMO as in Fig. 16, again we used the same simulation parameters.

As shown in Fig. 17 that, ML has performance close to MRC system. The ML equalizer is the best, since, it reduces the probability of a series mistake. moreover, this equalizer demand information of the channel feature and statistical distribution of noise mess up the signal to calculate the metrics for decision-making. And if, we

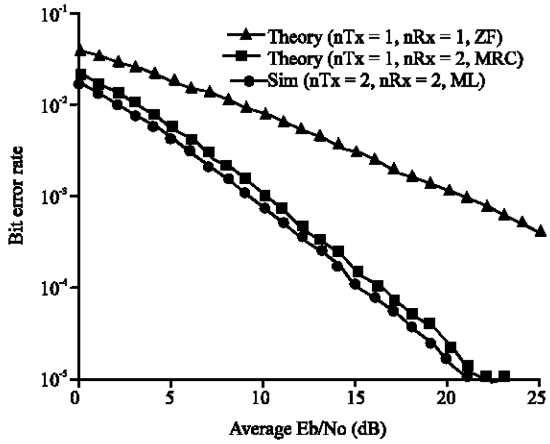

Fig. 16: BPSK with 2×2 MIMO with ML; BER for BPSK modulation with 2×2 MIMO and ML equalizer (Rayleigh channel)

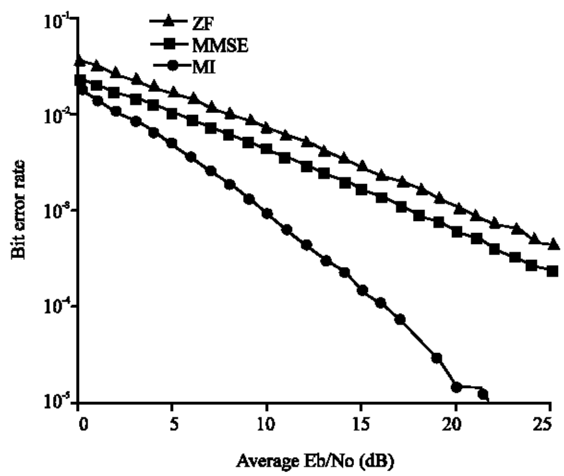

Fig. 17: BER of different 2×2 MIMO equalizer; the BER performance of different 2×2 MIMO equalizer

employ a higher demand such as 64QAM, then the calculation of the maximum likelihood equalizer could become too complex 64QAM with 2 spatial streams and we require to discover the least of 642 = 4096 collection.

Finally, as in Fig. 17 different performance of equalizer with 2×2 MIMO and as expect the ML equalizer provide better result comparing with other equalizers.

RESULTS AND DISCUSSION

As we seen that the Inter-Symbol Interference (ISI) introduced by frequency selective fading, the impact of blend of symbols which can minimize signal clarity. The receiver output becomes incorrect at the decision device. If inter-symbol interference happens within a system, so, we can control ISI by shaping the transmitting plus. But for the multipath environment an equalizer need at receiver in order to reduces ISI case by the channel.

The channel equalizer operates in time domain also can work in frequency domain. As shown the equalizer in time domain required matrix operation in order to inverse the channel effect. But time domain equalization has much higher signal processing complexity comparing with the frequency domain equalizer. We fix this by using the FFT and IFFT, the equalizer in frequency domain will became simple (one tap) and the matrix operation not required.

As we seen the channel equalizer play important role in multiple antenna system (MIMO) in detecting symbols received from multiple transmitters. The presented research in this study shows the performance of channel equalizer in wireless communications which can show as follow. Different channel equalizer in typical communications system with one transmitter and one receiver. Equalization technique with MIMO systems.

Different channel equalizer in typical communications system. The conclusions obtained from the results of using linear equalizer, DFE, MLSE in Single Input Single Output (SISO).

We can summary the simulation results as follow: Linear equalizers suffer from noise enhancement and it is best suited for comparatively flat channel spectrum. Decision-Feedback Equalizers (DFEs) employ decisions on data to take off parts of the ISI to let the linear equalizer section to be less" strong" and that way suffer less from noise growing. since, an incorrect decision may add ISI in state take it off. Wrong decisions may cause error-propagation in DFEs, Maximum-Likelihood Sequence Estimation (MLSE) is the best in the sense of having the minimum chance of detecting the incorrect sequence. The signal power spectrum of DFE is the best comparing with the linear equalizer. At the low BERs, both the MLSE and the DFE algorithm suffer from error bursts. Equalization technique with MIMO systems the conclusions obtained from the results of using ZF, MMSE, SIC, MLSE equalizer with 2×2 MIMO.

We can summary the simulation results as follow: the performance of ZF equalizer is matching to (1×1) SISO system because the diversity order =1 (diversity order of SISO =1). Also zero-forcing suffer from noise enhancement as the channel matrix is big that is the lower singular value is very little.

MMSE equalizer has better performance compare with ZF from BER point of view. And the impact of noise enhancement in MMSE filtration is minimal crucial than that in ZF filtering. Zero forcing with successive interference cancellation get better the execution of equalizer. This process gets better the estimator execution on the next component contrast to the past one.

Zero forcing with successive interference cancellation with best organizing guarantee that the accuracy of the symbol which is decoded first is guaranteed to have a minimum mistake probability than the other symbol. The MMSE-SIC add improvement about 5 dB compare with MMSE. And the performance of MMSE-SIC with optimal order is now closely to MRC technique.

Finally, the ML has performance close to MRC system and this equalizer demand information of the channel feature and statistical allocation of noise corrupting the signal to count the metrics for decision-making. But the complexity will be too big.

CONCLUSION

This research introduces a comparative studies of channel equalizer techniques in wireless communications. Firstly, with different techniques will introduce in time domain in typical communications system with one antenna at transmitter and one antenna at receiver (SISO) (Single-Input Single-Output) and introduce to channel equalizer behavior in frequency domain secondly the same different techniques will introduce extension to MIMO communication will analyzed. All simulation results carrying up in MATLAB 2015a environments.

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