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A Review of Equalizers for Frequency Selective Fading over OFDM channels

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ABSTRACT

In this paper, the diverse types of equalizers for frequency selective fading over Orthogonal Frequency Division Multiplexing (OFDM) technique implied in a wireless environment are discussed. These equalizers when combined with optimal coefficients criteria can be assured for combating fading. Adaptive Zero Forcing (AZF) equalizer, Minimum Mean Square Error (MMSE) equalizer, Maximum Likelihood (ML) equalizers.

Keywords: Equalizers, Frequency Selective, Intersymbol Interference (ISI), Orthogonal Frequency Division Multiplexing (OFDM), Coherence Bandwidth

I. INTRODUCTION

Wireless communication systems ostensibly provide multimedia accommodations with different quality of accommodation, offering high throughput and reliability under constrained bandwidth resources. In wireless communication, the signals propagate through free space. No matter what channel we talk about, signals always experience several form of deformation during communication. A signal is typically characterized by its frequency response which represents the range of frequencies required to constitute the signal. For signals to pass factually through a channel, the frequency response of the channel must be wider and more or less constant over the signal bandwidth. The main impairments constraining the capacity and maximum data rate offered to the cessation users of wireless communication system are multipath fading, delay spread, and multiple access interference (MAI). Multiple access (MA) techniques sanction different users to apportion the same channel efficaciously as possible. Direct sequence code division multiple access (DS-CDMA) is one of the MA techniques for its amended performance in terms of system capacity and coverage compared to time division multiple access and frequency-division multiple access [1]. OFDM is better than FDMA, TDMA transmission from both perspectives in many cases, especially at a low power and low signal-to-noise ratio regime [2] in smaller environments because the bandwidth required to resolve all multi paths in time is inversely proportional to the cubic root of the volume of the environment, such as interiors of cars or inside computer consoles, frequency-selective fading will be a more severe issue [3].

II. RELATED WORK

Bin Sheng, (2015) projected a non-data-aided (NDA) method to estimate the noise variance for orthogonal frequency division multiplexing (OFDM) system in frequency-selective channels. The proposed method is developed based on the signal correlation introduced by the use of the cyclic prefix (CP) and uses the difference between two discrete Fourier transform (DFT) outputs in the CP interval to estimate the noise variance as in [4].

Si-Yue Sun et.al, (2016) presented a Joint Pre-Equalization and Adaptive Combining for CC-CDMA Systems Over Asynchronous Frequency-Selective Fading Channels, where Pre-equalization is used at a transmitter to either enhance diversity gain or compensate channel selectivity leveraged by a controlling parameter ζ, whereas a recursive least square (RLS) adaptive combining algorithm is employed at a receiver to determine the optimal combining coefficients, aiming at minimizing detection errors under different channel conditions. It makes use of extra diversity gains across element codes in a CC-CDMA system with the help of pre-equalization and adaptive combining. It gives us the ways to leverage a tradeoff between diversity gains and MAI elimination in a CC-CDMA system under varying channel conditions in [5].

Ning Liang et al (2016) investigated the recently developed mixed-analog-to-digital converter (ADC) architecture for frequency-selective channels. Multi-carrier techniques, such as orthogonal frequency division multiplexing, are deployed to handle inter-symbol interference. A frequency-domain equalizer is designed for mitigating the inter-carrier interference introduced by the nonlinearity of one-bit quantization. The analytical framework is naturally applicable to the multi-user scenario, for both static and time-varying channels. Extensive numerical studies reveal that the mixed-ADC architecture with a small proportion of high-resolution ADCs does achieve a dominant portion of the achievable rate of ideal conventional architecture, and that it remarkably improves the performance as compared with one-bit massive multiple-input multiple-output in [6]

D. Judson and A. Albert Raj (2016) analyzed the performance of MC CC-CDMA system with different amalgamating schemes for downlink transmissions under frequency-selective Nakagami-m fading channels. Performance measures in terms of BER versus SNR were plotted for different amalgamating schemes exhibiting the preponderation of complementary codes in frequency-selective channels under various channel conditions. It was shown that in the presence of MAI, only MMSE-PIC with MRC can be more tolerant to interference with much higher gain than MRC-predicated PIC in [7].

Irma Zakia, (2016) explored the impact of slightly frequency selective rician fading channel on the performance of least squares received beam forming. This channel type is encountered in the communications from high-altitude platform (HAP) to high-speed train (HST) in urban area and at Ka-band operating frequency. The system performance in terms of mean-square error (MSE) and bit error rate (BER) for different scenarios of Direction of Arrival (DOA) were evaluated by Monte Carlo simulation. The existence of specular component in the HAP to HST communication link in Ka-band impacts the receiver performance. The Recursive Least Square (RLS) received the beam forming algorithm considering the specular component as unwanted signal. Hence, the receiver performed beam forming by rejecting the spatially specular component in [8].

Tian-Ming Ma (2017) studied a novel Phase Rotated Conjugate Cancellation (PRCC) scheme with the method of separating the odd and even sequences of the transmission signals into two independent paths to further mitigate the ICI over frequency-selective fading channels that achieved an improvement of the BER performance as well as higher data transmission efficiency in [9].

III. FREQUENCY SELECTIVE FADING

A Wireless Communication Channel experiences frequency selective fading emerges when signal bandwidth is larger than the coherence bandwidth. In other words for flat fading the whole of received signal bandwidth experiences almost same channel. Frequency selective arises in a real-life situation wherein the channel is not narrowband. Instinctively, subdividing the wideband channel into N narrowband ones and then summing the capacities of these N frequency flat channels can achieve this. The bandwidth of each of these subchannels will be B/N Hz where B is the overall channel bandwidth. This is provided the coherent bandwidth of the channel permits this (i.e., it is more than or equal to B/N Hz), as otherwise the subchannels will not be frequency flat. If Coherence bandwidth B_C is above 0.9 the frequency correlation occurs.

When the coherence bandwidth is comparable with or less than the signal bandwidth, the channel experiences frequency selective otherwise it experiences frequency flat or non-selective. Flat channel passes all spectral components with approximately equal gain and linear phase. It is not possible to provide an exact relationship between coherence bandwidth and RMS delay spread, as it is a function of specific channel impulse response and applied signals. Coherence time is the measure of time duration over which the channel impulse response is essentially time invariant. If the symbol period of the baseband signal which is approximately the reciprocal of the baseband signal bandwidth is greater than the coherence time of the channel, then the channel will change during the transmission of the signal. Hence there will be distortion at the receiver. The coherence time T_C is defined as 1 over f_m where f_m is the maximum Doppler shift. Doppler shift depends on the velocity of the mobile. The wave length of the frequency that are used and also the relative angle at which the signal impinges on the mobile as in [10].The signal that is transmitted is x (t) and received is y (t). s (t) is much smaller in terms of the width of the symbol t(s). For simplicity, there are lots of peaks and troughs as being present in most of the profile measurements. Clearly the frequency selective fading has introduced distortions and hence the name frequency selective fading is given. This selectively fades some of the frequency components.

IV. ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING (OFDM)

The Orthogonal Frequency Division Multiplexing (OFDM) system has been widely used for modern digital communications in the multipath fading channel. With the cyclic prefix (CP) in the OFDM signal, the receiver can remove the intersymbol interference and enable the one-tap equalization. For every time slot, receiver estimates the channel response (CR) of every subchannel for equalization and data detection. OFDM systems use pilot-assisted schemes that are transmitted among data symbols to help the receiver estimate the CR. OFDM is a multicarrier transmission technique, which divides the available spectrum into many carriers, each one being modulated by a low-rate data stream. By placing the channels closely together OFDM uses the spectrum much more efficiently which is achieved by making all the carriers orthogonal to one another, preventing interference between closely spaced carriers. OFDM overcomes bandwidth problem by splitting the available bandwidth into many narrow band channels. The carriers for each channel are made orthogonal to one another, presenting them to be spaced very close together with no overhead. The orthogonality of the carriers means that each carrier has an integer number of cycles over a symbol period. Due to this, the spectrum of each carrier has a null at the center frequency of each of the other carriers in the system. Each carrier in an OFDM system signal has a very narrow bandwidth thus resulting in low symbol rate. This results in the signal having a high tolerance to multipath delay spread, as the delay spread must be very long to cause significant Inter Symbol Interference (ISI) [11-12].

OFDM can be generated by maintaining the orthogonality between the carriers. Because of this, OFDM is generated by first choosing the spectrum required, based on the input data and modulation scheme used. Each carrier to be produced is assigned some data to transmit based on the modulation scheme, amplitude and phase of the carrier is then calculated. The required spectrum is then converted to its time domain signal using an IFFT. The IFFT performs the transformation very efficiently and provides a simple way of ensuring the orthogonality of the carrier signals. The FFT transforms a cyclic time domain signal into its equivalent frequency spectrum. This is done by finding the equivalent waveform generated by a sum of orthogonal sinusoidal components. The amplitude and phase of the sinusoidal components represent the frequency spectrum of the time domain signal. The IFFT performs the reverse process, transforming a spectrum into a time domain signal. The orthogonal carriers required for the OFDM signal can be easily generated by setting the amplitude and phase of each bin, then performing the IFFT. The amplitude and phase of set of orthogonal sinusoids is the bin of IFFT.

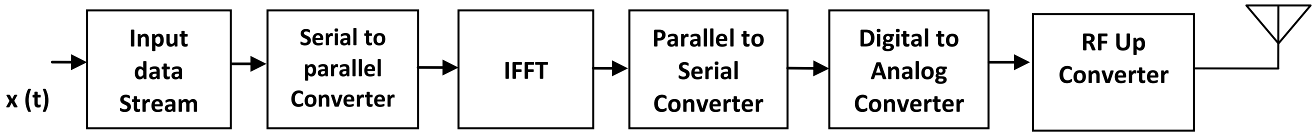

Figure1 Block diagram of OFDM Transmitter

Figure 1 shows the block diagram of OFDM transmitter. The input x(t) is a binary serial data stream. This is encoded using any suitable modulation technique. The binary input will be converted into a multilevel signal reducing the symbol rate to symbols/sec, where R is the bit rate of the data stream in bits/sec. If we convert this serial data to parallel, the data rate gets further reduced by N, where N is the number of parallel channels. Hence, these parallel channels are essentially low data rate channels and since they are narrowband, they experience flat fading into a multilevel signal reducing the symbol rate to symbols/sec, where R is the bit rate of the data stream in bits/sec. If we convert this serial data to parallel, the data rate gets further reduced by N, where N is the number of parallel channels. Hence, these parallel channels are essentially low data rate channels and since they are narrowband, they experience flat fading. This is the greatest advantage of the OFDM technique. This parallel data stream is then subjected to an IFFT and then summed.

$$x(t) = \sum_{n=1}^{N}(a_n + jb_n)(cosw_n t + jsinw_n t) \quad (1)$$

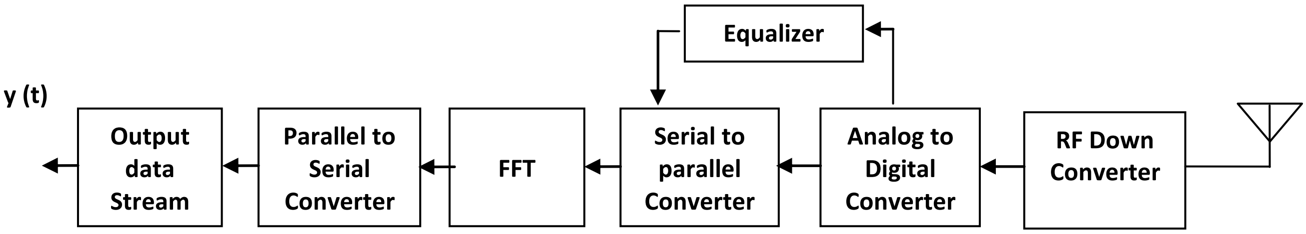

Figure 2 Block diagram of OFDM Receiver

$$Y(t)=x(t)*h(t)*\sin c(t)* e^{jt} + n(t) \quad (2)$$

Figure 2 shows the block diagram of OFDM Receiver. A guard interval is additionally referred to as cyclic prefix. A cyclic prefix may be a copy of the last a part of the OFDM symbol, that is prepended' to the transmitted symbol. This makes the transmitted symbol periodic, that plays a decisive role in characteristic frames properly, thus on avoid ISI and intercarrier interference (ICI).

This provides multipath immunity similarly as image time synchronization tolerance. As long because the multipath delay echoes keep inside the guard amount length, there's strictly no limitation concerning the amplitude of the echoes: they will even exceed the amplitude of the shorter path. The signal energy from all the ways simply add at the input to the receiver and since the FFT is energy conservative, the total offered power feeds the decoder. If the delay unfold is longer than the guard interval, then international intelligence agency is caused. The signal is then up converted to RF by using Digital to Analog in order to provide the analog baseband signal, , then transmitted. A major disadvantage of OFDM is that the envelope is not constant. Due to the summation of sine waves, there is a large peak to average ratio (PAR). This poses problems regarding the linear bandwidth of the RF amplifiers.

In order to combat frequency selective fading, equalization techniques are pioneered within the receiver to enhance the performance of the OFDM channels. The different types of equalizers that can be classified according to the optimization criterion are Adaptive Zero-Forcing (AZF), when a zero-forcing solution is sought or Minimum Mean-Square Error (MMSE) when the equalizer optimizes the mean-square error (MSE) of the symbol estimate, or Maximum Likelihood (ML) when the maximum likelihood sequence estimation criterion is utilized.

Adaptive Zero-Forcing Equalizer

Adaptive Zero Forcing Equalizer is a form of linear equalization algorithm utilized in communication systems which applies the inverse of the frequency response of the channel. The Adaptive Zero-Forcing Equalizer applies the inverse of the channel frequency response to the received signal, to renovate the signal after the channel [13]. The term Zero Forcing corresponds to bringing down the intersymbol interference (ISI) to zero in a noise free case. This will be useful when ISI is significant compared to noise.

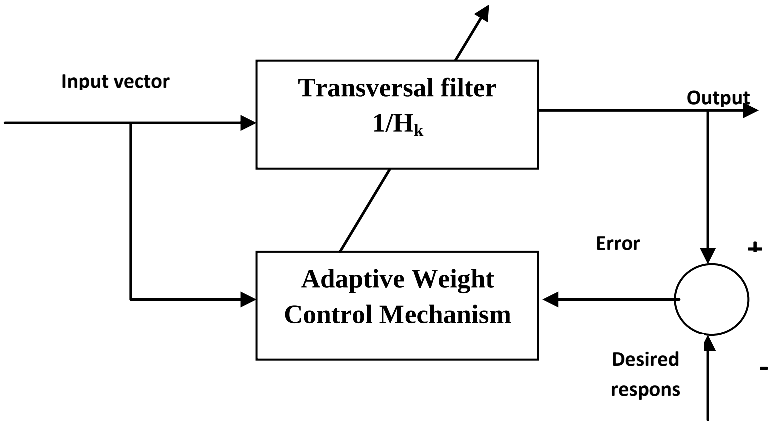

Figure 3 Adaptive Zero Forcing Equalizer

Figure 3 illustrates the Adaptive Zero Forcing equalizer technique. For a channel C(f) with frequency response F(f) the zero forcing equalizer is constructed by

$$C(f)=\frac{1}{F(f)} \tag{3}$$

The co-efficient of zero forcing equalizer is $\frac{1}{H_k}$ (4)

where H_k is the k-FFT point of the channel. Thus the combination of channel and equalizer gives a flat frequency response and linear phase.

In reality, zero-forcing equalization does not work in some applications, for the following reasons

- Even though the channel impulse response has finite length, the impulse response of the equalizer needs to be infinitely long.
- At some frequencies the received signal may be weak. To compensate, the magnitude of the zero-forcing filter ("gain") grows very large. As a consequence, any noise added after the channel gets boosted by a large factor and destroys the overall signal-to-noise ratio. Furthermore, the channel may have zeroes in its frequency response that cannot be inverted at all.

MMSE Equalizer

The equalizer coefficients are optimized in order to minimize the Inter Symbol Interference (ISI) and additive noise effects by means of the minimum mean squared error (MMSE). The Signal to Noise Ratio (SNR) has prominent values the MMSE equalizer works as Zero Forcing does, but as the SNR has lower values, the MMSE equalizer takes into account the noise and signal variance, makes to not amplify the noise as Zero Forcing does. Even as the SNR has high values, the MMSE equalizer works as the Zero Forcing does, but for the rest of values that SNR can take, the MMSE equalizer works better in terms of distortion. This equalizer does not amplify the received signal just multiplying for the inverse of the channel it takes into account the SNR in order to not amplify so much the noise term. At high SNR, MMSE equalizer will reduce to ZF equalizer [14]

The co-efficient of MMSE equalizer is $\frac{H_K}{|H_k|^2+\sigma^2{}_w/\sigma^2{}_x}$ (5)

where $\sigma^2{}_w/\sigma^2{}_x$ is deep null appearing in the frequency response of the channel.

Maximum Likelihood Equalizer

Maximum Likelihood Equalizer is the optimum in terms of minimizing the overall error probability than AZF and MMSE. By using small numbers of transmit antennas and low-order constellations, the complexity of ML detection is not overwhelming [15-16]

$$X_{ML} = \text{argmin}\ [Y\ .XH]^2{}_F \qquad (6)$$

Where X_{ML} is estimated ML symbol and $[.]_F$ represents Frobenius norm.

Maximum Likelihood detection calculates the Euclidean distance between product of all possible transmitted signals vectors and the received signal vector within the given channel realization H and finds the one with minimum distance is calculated. ML decoding determines the estimated transmitted signal vector X.

V. CONCLUSION

In this paper, various equalization techniques for OFDM system that suffer from frequency selective fading have been presented. Maximum Likelihood detection equalizer has more advantages than the MMSE and AZF equalizers that are obliqued on wireless environments. This paper study gives a thought of choosing an equalizer for designing an efficient system that can combat frequency selective fading.

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