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A MULTI USER DETECTION RECEIVER BASED ON DECISION FEEDBACK EQUALIZATION AND SUCCESSIVE INTERFERENCE CANCELLATION

Mr. Kuldeep Singh Chauhan
ME Scholar, Dept. of Electronics
IET, DAVV, INDORE (M.P.)

Mrs. Pratibha Singh
Asst. Professor, Dept. of Electronics
IET, DAVV, INDORE (M.P.)

Abstract— **Orthogonal Frequency Division Multiplexing (OFDM) has emerged as one of the key enablers of high data rate in contemporary communication systems. OFDM finds its applications in almost all high data rate applications such as 3G and 4G networks, LTE, LTE+, DVB, IEEE 802.11(WLANs), Wi-Fi, WiMax just to name a few.[1][4] One of the greatest challenges that that OFDM or for the matter of fact any wireless communication system faces is the frequency selective nature of wireless channels. Thus, due to frequency selective fading, OFDM systems suffer from BER degradation. Various equalization techniques have been investigated for alleviating this problem. One of the techniques that have been extremely promising is the Decision Feedback Equalization Technique (DFE). In practical situations, the BER degradation problem becomes even more serious for multi user detection in multicarrier systems like OFDM and MC-CDMA. In this paper we propose a Multi User Detection (MUD) receiver that is capable of equalizing receiver signal power and detect all user signals despite differences in received signal strengths and under varying BER conditions.**

Keywords— Orthogonal Frequency Division Multiplexing (OFDM), Decision Feedback Equalization (DFE), Multi User Detection (MUD)

I. INTRODUCTION

Orthogonal Frequency Division Multiplexing (OFDM) is a form of multi carrier communication in which a channel of Bandwidth **'B'** is divided into narrow sub channels of bandwidth '**B/N**'. Thus OFDM splices the channel of high data rate into parallel sub channels of lower data rate. The advantage of such an approach is manifold. Compared to Frequency Division Multiplexing (FDM), the spectral utilization is much better since allocating non overlapping bands and leaving guard bands does not remain a mandatory requirement. The only requirement remains maintaining the mutual orthogonality among sub carriers. Since OFDM is used predominantly for wireless systems, therefore designing such systems pose challenges like large attenuation, noise, multipath, interference, time variance and channel frequency selectivity. The major consequence of using OFDM in wireless systems is the random nature of wireless channels. At the frequency range of a few hundreds of MHz to a few GHz, different users perceive a different variant of the same channel due to effects like Doppler Shift and non-existence of ultra wideband (UWB) channels. Therefore a frequency selective wireless channel acting in conjugation with time varying effects has the potential to severely degrade the BER performance of the OFDM system which may lead to considerable errors and render non reliability to the wireless system.

The solution to the above mentioned problem is the design of equalizers which can equalize non flat channels and which should not be computationally to complex to be practically implemented on hardware. Another aspect that needs serious attention is the detection of multiple users in the presence varying BER conditions due to frequency selective channels. It is practical to consider that in a multi user situation, receivers having better BER conditions would over ride receivers with poor BER conditions which would in turn mean failure of the OFDM technology in Wireless Cellular Networks. To address this problem, an efficient multi user detection mechanism needs to be developed which would satisfactorily detect multiple users with varying BER conditions while being able to equalize the receiver power from different users. Such a system with decision feedback equalization along with a multi user reception scheme has been proposed in the subsequent sections.

II. OFDM THEORY:[1][2][4]

The graph below depicts the mutual orthogonality among the sub carriers in OFDM systems. It can be seen that when one sub carrier reaches its maximum, the other sub carriers are at their zero crossing.

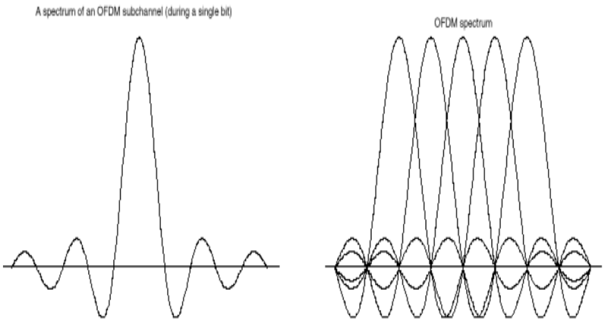

Fig1. Spectrum of OFDM[4]

OFDM System Description:
The figure below shows the basic block diagram of a general OFDM system.

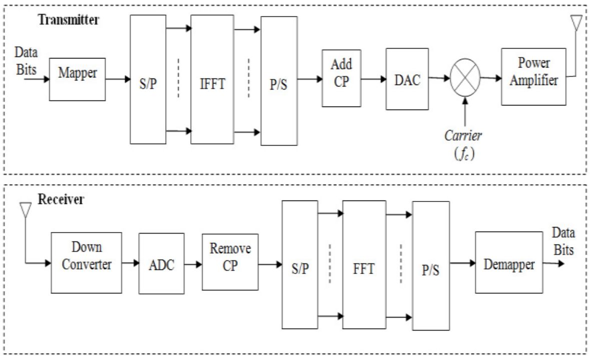

Fig.2 Block Diagram of OFDM[4]

The block diagram of OFDM can be understood as: N sub carriers are generated by the IDFT or the IFFT block which are modulated by a parallel binary message bit stream. Subsequently the parallel data stream is converted from parallel to serial and transmitted through the channel. Exactly the reverse process is carried out at the receiver end. Let N be the number of sub carriers to be modulated by the binary data source and *N* of these constellation points be stored for an interval of *Ts= N/R*, referred to as the OFDM symbol interval. A serial-to-parallel converter is used to achieve this. Now, each one of the *N* constellation points is used to modulate one of the subcarriers, then, all modulated subcarriers are transmitted simultaneously over the symbol interval *Ts.* The OFDM signal *x*(*n*) can be expressed as:

$$\mathbf{x[n]} = \frac{1}{N}\sum_{k=0}^{N-1} X[k]e^{\frac{j2\pi n}{N}} \quad 0 \le n < N \quad \mathbf{(1)}$$

III. NEED FOR EQUALIZATION:[33]

The major challenge for OFDM systems is the frequency selective nature of Wireless Channels. This results in varying sub carrier gains. The graph below depicts the scenario.

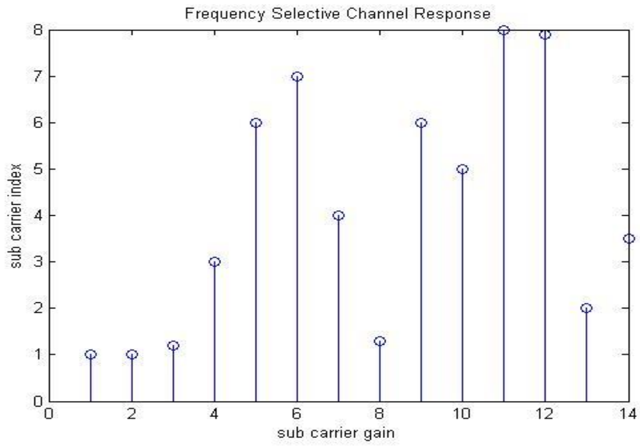

Fig.3 Variable Channel Gain

Due to varying sub carrier gains, the signal strength at the receiver varies. The result is a time varying Signal to Noise Ratio (SNR) and consequently a degraded BER performance. Such a scenario becomes a hindrance for reliable communication.
The Probability of Error (**P_e**) or Bit Error Rate (**BER)** is given by:

$$P_e=Q[sqrt(S/N)] \quad \mathbf{(2)}$$

Thus due to varying values of S/N, the BER weans where the signal strength falls. This causes increase in the errors. Since the frequency selectivity of the channel cannot be changed, therefore the concept of equalizers in introduced which when used in conjugation with the channel makes the channel response flat. This can be mathematically expressed as:

Generally an equalizer is designed such that it negates the effect of the imperfect nature of the channel's frequency response. This may be mathematically stated as:

$$H(z).E(z)=k \quad \mathbf{(3)}$$

So, after multiplication with the equalizers impulse response, the overall effect on the transmitted signal becomes analogous to '**Flat Channel'.**
Where H(z) represents the channels frequency response and
E(z) represents the equalizer's frequency response.

IV. DECISION FEEDBACK EQUALIZATION

The block diagram of the conventional Decision Feedback Equalizer is shown in figure 4. The concept of Decision Feedback Equalizer can be understood with the help of the above diagram. In the block diagram show, the DFE mechanism is implemented using a multi tap filter whose tap weights are decided according to the error or actuating signal based on the comparison between the output and the input.

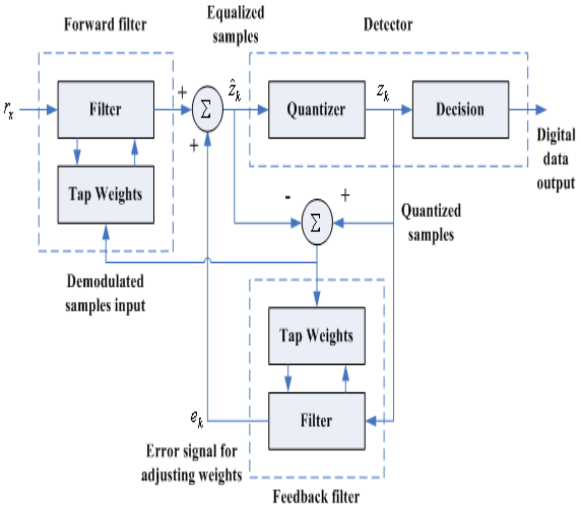

Fig.4 Decision Feedback (DFE) Equalization[32][33]

The DFE algorithm senses the channel and according to the training data obtained adjusts the tap weights. The major challenge of this approach is sensing the channel continuously and updating the tap weights.

V. MULTI USER DETECTION (MUD)[22][26][32]

The MUD approach is an efficient technique of equalizing the received signal power and is capable of detecting different user signals under varying signal strengths or BER conditions. The MUD approach requires the following information:

a) Individual signal strength of each user:

$$S_i = g_i\sqrt{P_i} \qquad (4)$$

Where S represents i^{th} signal power,
'g' represents gain of the i^{th} path
P represents the power of the i^{th} signal

b) The cross correlation of the spreading function applied on the data stream:

$$\text{Spreading Function} = R_i,j(k)$$

(c) The noise statistics for the k^{th} sample i.e. $n_i(k)$

Thus the different signals corresponding to different users can be mathematically written as:

$$r_k = R_k.D.S_k + n_k \qquad (5)$$

Where D represents the signal strength matrix corresponding to different signal strengths given by:

$$S_i = g_i\sqrt{P_i} \qquad (6)$$

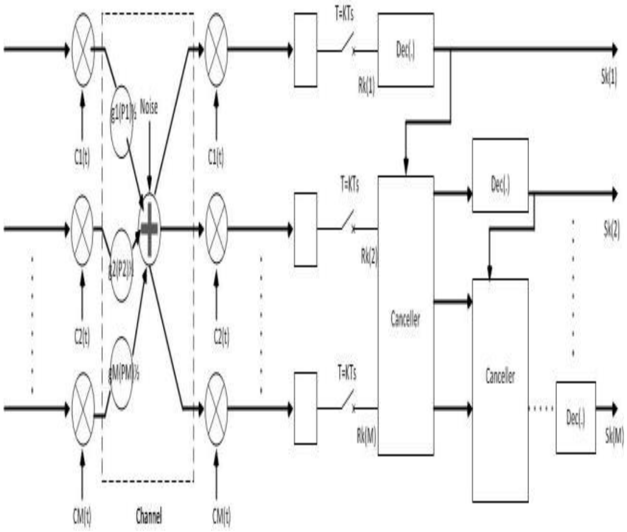

Fig.5 Multi User Detection (MUD) Receiver using Decision Feedback Mechanism[26][31][32]

The above diagram helps us to understand the concept behind the decision feedback mechanism applied to the MUD receiver. The main motive behind the design of such a receiver is to detect the strongest received signal under different signal strengths and subsequently cancel its interference effects from the other received signals.

VI. PROPOSED ALGORITHM

1. Let the various signal strengths be:
$S_1.G_1$, $S_2.G_2$, $S_3.G_3$................. $S_n.G_n$
It can be observed that the signal power of transmitter is multiplied with the corresponding channel gain where the channel gain for different users varies due to frequency selectivity of the channel.
Considering that we have the information about the signal strengths given by equation.7

$$P_1 g_1^2 > P_2 g_2^2 > \dots\dots\dots\dots\dots \quad (7)$$

We decide the strongest among all the received user signals.
2. Detect the **k^{th} strongest** signal among all the signals using the following equation:

$$S_k = dec(P_i G_i)^M \qquad (8)$$

3. Cancel the first strongest user interference at the receiver end according to the equation:

$$y_{e+1}^{(1)} = y_e^{(1)} \_ g_e\sqrt{} \qquad (9)$$

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Here we subtract the interference from the strongest interfering signal from each signal received at the receiver using the Decision Feedback actuating Signal $\mathbf{e(k)S_k^{(e)}}$

4. let **k=1,** and repeat the above process for all the received signals up to **k=M**

5. Plot the BER performance for the proposed MUD DFE algorithm and MUD reception without DFE mechanism.

VII. EXPERIMENTS & RESULTS

The results for the different cases of user detection for varying BER conditions have been plotted. The results clearly exhibit the improvement of the BER performance of the OFDM system for multi user scenarios.

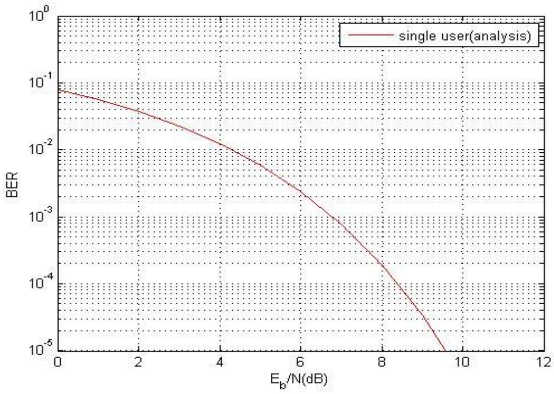

Fig.6 Single User Analysis

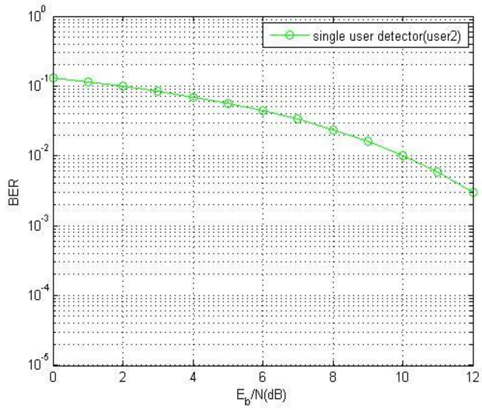

Fig.7 Single User detection (user2)

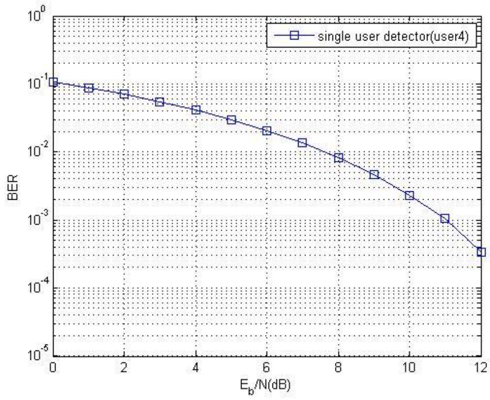

Fig.8 Single User Detection (User 4)

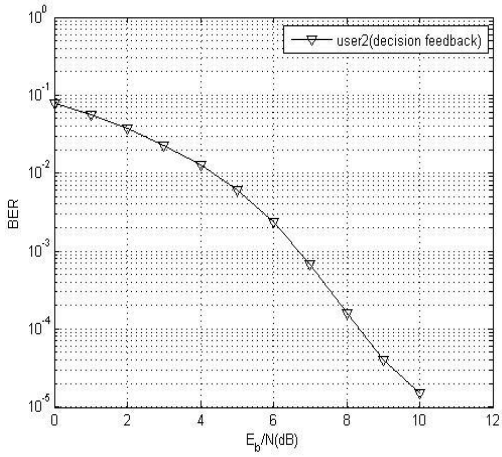

Fig. 9 Detection of user 2, with decision feedback

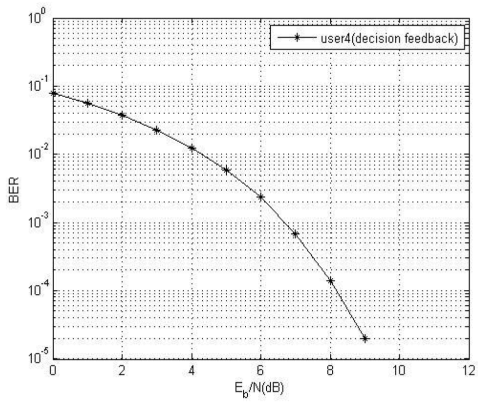

Fig 10 Detection of user 2, with decision feedback

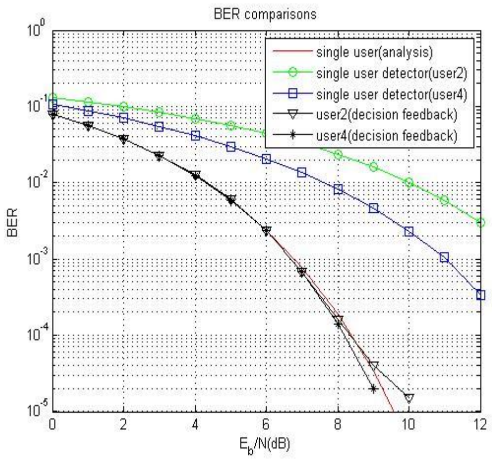

Fig.11 Comparison of different techniques under MUD conditions

User Analysis	BER	SNR required
Single user 2 with conventional Detection	10^{-2}	10dB
Single user 2 with Proposed Algorithm	10^{-2}	4dB
Single user 4 with conventional Detection	10^{-2}	7dB
Single user 4 with Proposed Algorithm	10^{-2}	4dB
Signal Detection with only one User	10^{-2}	4dB

Table.1 Comparison of proposed technique with conventional technique

Experimental Analysis of Results:
The simulation shown above has been run for 100000 samples. The spreading function has been implemented using a random matrix of size 31x4. The noise added in the channel has been considered to be Gaussian. It can be clearly seen from the graphs that different received signals corresponding to different users have different BER conditions. **Table.1** renders insight into the working of the proposed technique. It can be seen that the BER falls much more steeply for users 2 and 4 in case of the proposed DFE MUD receiver compared to singular detection of the same signals. Therefore the proposed technique would need much less SNR boiling down to lower Signal Power to achieve same BER performance compared to conventional techniques. Conversely, the same SNR would result in much improved BER performance for the proposed technique compared to the conventional technique. Also it can be seen that the proposed technique achieves results almost similar to a single user scenario.

VIII. CONCLUSION

In this paper, we analyzed the challenges faced by practical multi user OFDM systems under frequency selective channel conditions. It was shown that frequency selective nature of wireless channels resulted in different sub carrier gains and hence variable BER conditions for different users. It could be inferred that due to different varying conditions, some of the users suffer more in practical situations compared to other users. To mitigate this problem, a MUD receiver using the decision feedback mechanism was proposed which is based on successive interference cancellation after the strongest receiver signal is detected. From the results, it can be concluded that such an approach achieves better BER performance compared to the conventional approach thereby facilitating the accurate reception of different user signals under varying BER conditions. It can be observed from the results that the proposed technique attains results approximately similar to single user scenario thus pointing towards the fact that strong interference can be almost nullified.

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