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Multi-User Detection in Wireless Networks using Successive Signal Detection and Decision Feedback Equalization

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***Abstract*—** Multi User Detection or MUD is a major challenge faced in the field of wireless and cellular communications. Wireless Networks are becoming increasingly everywhere in computer networks due to less cost and maintenance overhead. While some wireless networks may operate in regulated spectrum and the majority operate in the unregulated (ISM) band. It is highly challenging for a base or control station to successfully detect signals from multiple users in the same frequency range. This may occur due to comparatively small frequency re-use distance. This paper proposes a technique based on decision feedback equalization (DFE) and strongest signal cancellation for multi-user detection (MUD) in wireless networks. It has can be seen that by employing the proposed system, the Bit Error Rate (BER) for strong, average and weak users assemble. Thus it indicates the fact that all the signals are detected with equal accuracy.

***Keywords*—** Multi User Detection (MUD), User Equipment (UE), Inter Symbol Interference (ISI), Frequency Selective Channel, Bit Error Rate (BER).

I. INTRODUCTION

The effects of fading and frequency selective nature of wireless channels often results in high level crossing rate (LSR) for user equipment undergoing fading dips. While most of the MUD schemes may be derived from different principles, they usually rely on some prior estimate of the channel, obtained by either a blind or a training-sequence assisted channel estimation algorithm. However, channel estimation are usually affected by errors and most of existing MUD schemes are known to be sensitive to such errors.

Moreover, for effective interference suppression, many MUD schemes also require an estimate of the covariance matrix of the received signal, which is typically the sample covariance matrix. The sample covariance matrix converges slowly, resulting in a poor estimate of the true covariance matrix when the number of samples of the received signal is relatively low. In wireless telecommunications, multipath is the propagation phenomenon that results in radio signals reaching the receiving antenna by two or more paths.

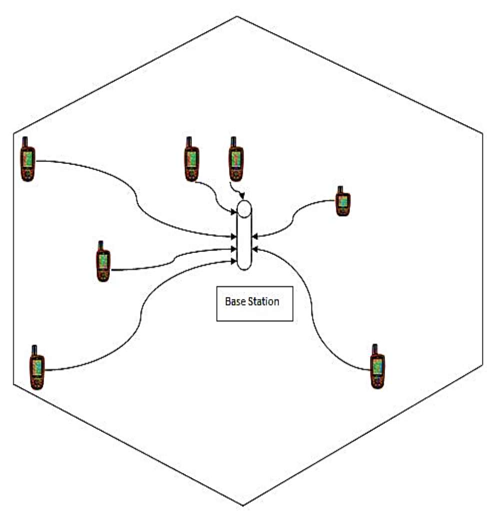

Figure 1. A Typical Multi-User Situation

Causes of multipath include atmospheric ducting, ionosphere reflection and refraction, and reflection from water bodies and terrestrial objects such as mountains and buildings. The effects of multipath include constructive and destructive interference, and phase shifting of the signal. In digital radio communications (such as GSM) multipath can cause errors and affect the quality of communications. Multipath signals are received in a terrestrial environment, i.e., where different forms of propagation are present and the signals arrive at the receiver from transmitter via a variety of paths. Therefore there would be multipath interference, causing multipath fading. Adding the effect of movement of the transmitter, receiver or the surrounding clutter to it, the overall received signal amplitude or phase changes over a small amount of time. Mainly this causes the fading.

The term fading, or, small-scale fading, means rapid fluctuations of the amplitudes, phases, or multipath delays of a radio signal over a short period or short travel distance. This might be so severe that large scale radio propagation loss effects might be ignored. The multiple paths carry multiple copies of the same signal. This causes information from the same source being received by the receiver at different times and thereby causing the phenomenon of Inter Symbol Interference (ISI) which is often responsible for high BER.

II. MULTIPATH FADING EFFECTS

Multipath Fading Effects:

In principle, the following are the main multipath effects:

1. Rapid changes in signal strength over a small travel distance or time interval.

2. Random frequency modulation due to varying Doppler shifts on different multipath signals.

3. Time dispersion or echoes caused by multipath propagation delays.

Factors Influencing Fading:

The following physical factors influence small-scale fading in the radio propagation channel:

a) Multipath propagation – Multipath is the propagation phenomenon that results in radio signals reaching the receiving antenna by two or more paths. The effects of multipath include constructive and destructive interference, and phase shifting of the signal.

b) Speed of the mobile – The relative motion between the base station and the mobile results in random frequency modulation due to different Doppler shifts on each of the multipath components.

c) Speed of surrounding objects – If objects in the radio channel are in motion, they induce a time varying Doppler shift on multipath components. If the surrounding objects move at a greater rate than the mobile, then this effect dominates fading.

d) Transmission Bandwidth of the signal – If the transmitted radio signal bandwidth is greater than the “bandwidth” of the multipath channel, the received signal will be distorted.

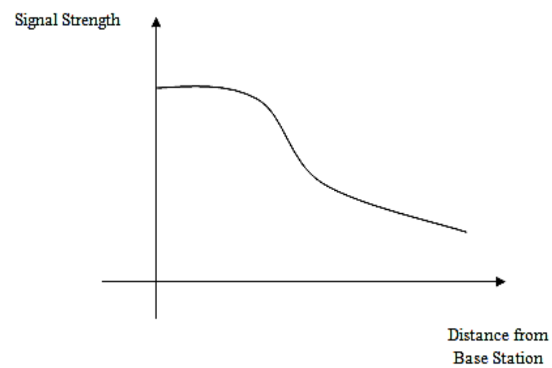

Figure 2. Signal Strength Variation in Multi-User Situations

After considering the multipath effects, it is convenient to understand the concept of successive signal detection and equalization.

III. NEED FOR EQUALIZATION

The need for equalization lies in the fact that practical wireless channels do not fulfill the condition of distortion less transmission. A mechanism that reverses or nullifies the derogatory effects of distortion introducing channel is called an equalizer. The rate of data transmissions over a communication system is limited due to the effects of linear and nonlinear distortion. Linear distortions occur in from of inter-symbol interference (ISI), co-channel interference (CCI) and adjacent channel interference (ACI) in the presence of additive white Gaussian noise. Nonlinear distortions are caused due to the subsystems like amplifiers, modulator and demodulator along with nature of the medium. Sometimes burst noise occurs in communication system. Different equalization techniques are used to mitigate these effects. Different applications and channel models suit a different equalization technique. The main challenge of wireless communications is the random and frequency selective nature of wireless channels which does not follow the conditions for distortion less transmission.

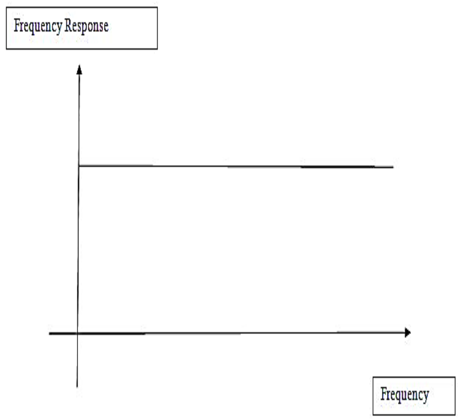

Figure 3. Frequency Response of a Flat (Ideal Channel)

For the transmission to be distortion less, the channel should have a flat frequency response as shown in the figure above. But practically, wireless channels are random and show non ideal characteristics.

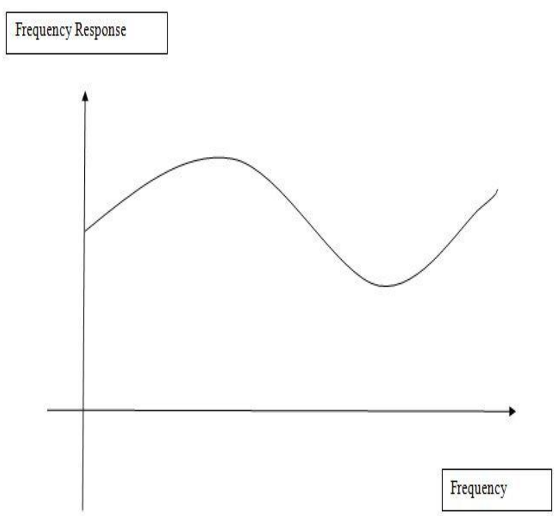

Figure 4. Frequency Response of a Frequency Selective (Non-Ideal Channel)

Such a channel introduces distortions in the received signal thereby degrading the BER performance of the system. If we know the frequency response of the channel H(z), then we can design the frequency response of the equalizer as E(z)= 1/H(z).

Since the wireless channels are realized as filters, hence equalizer structures also need to be realized as filters. One of the biggest challenges of realizing an equalizer is in designing an algorithm that would implement the equalizer transfer function. The design objective of the equalizer is to undo the effects of the channel and to remove the interference. Conceptually, the equalizer attempts to build a system that is a "delayed inverse" of the channel, removing the inter symbol interference while simultaneously rejecting additive interferers uncorrelated to the source. If the interference n (kTs) is unstructured (for instance white noise) then there is little that a linear equalizer can do to improve it. But when the interference is highly structured (such as narrow band interference from another user) then the linear filter can often notch out the offending frequencies and thereby reduce the effects of inter symbol interference.

The effect can be graphically understood as:

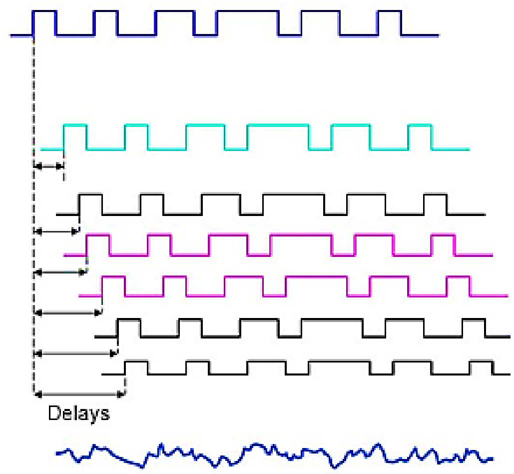

Figure 5. Multipath Interferences causing ISI

Since errors arising out of ISI cannot be removed by simply increasing the transmitter power, hence they are called irreversible errors. The only way out is reversing the effect of the channel by design of equalizer.

IV. THE MUD MODEL.

The multi-detection mechanism can be understood using the conceptual block diagram of a MUD system which is shown in the following figure.

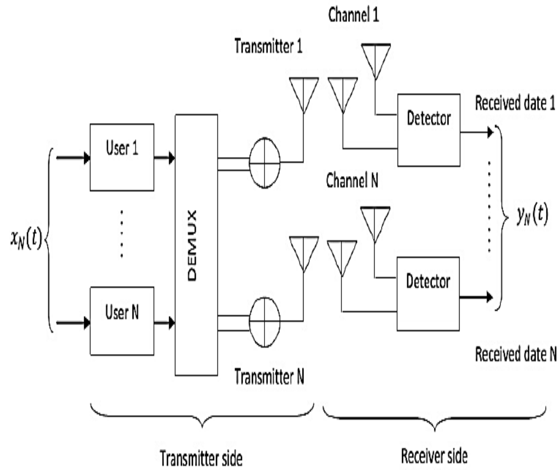

Figure 6. The MUD Transceiver

V. Proposed Algorithm

The successive DFE equalization approach is an efficient technique of equalizing the received signal power and is capable of detecting different multi-path components (MPCs) under varying signal strengths or BER conditions. The approach requires the following information:

a) Individual signal strength of each MPC be given by:

$$S_1 = g_1\sqrt{P_1} \quad (1)$$

Where S represents i^th MPC power,
'g' represents gain of the i^th path
P represents the power of the i^th MPC

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

Spreading Function = $R_1, j(k)$

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

Thus the different MPCs corresponding to paths can be mathematically written as:

$$r_k = R_k D S_k + n_k \quad (2)$$

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

$$S_1 = g_1\sqrt{P_1} \quad (3)$$

The proposed algorithm can be explained as: Let the various MPC 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 MPCs varies due to frequency selectivity of the channel.

Considering that we have the information about the signal strengths given by equation (4.6)

$$P_1 g_1^2 \rangle P_2 g_2^2 \rangle \ldots\ldots\ldots\ldots P_M g_{M^2} \quad (4)$$

We decide the strongest among the entire received user MPCs.

2. Detect the k^th strongest MPC among all the signals using the following equation:

$$S_K = dec\left(P_i G_i\right)^M \quad (5)$$

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

$$y_{e+1}^{(1)} = y_e^{(1)} g_e \sqrt{P_e} R_1 e(k) S_k^{(e)} \quad (6)$$

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

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

1. Plot the BER performance for the proposed system for the following cases:

a) When there is only one signal travelling from transmitter to receiver

b) When a multi-path model has many MPCs with different run lengths and hence different phase shifts

c) MPC governed BER without proposed system

d) MPC governed BER with proposed system.

The system is said to exhibit equalizing effects only if the MPC governed BER performance matches to a large extent the one without multi path communication and hence no multi path propagation.

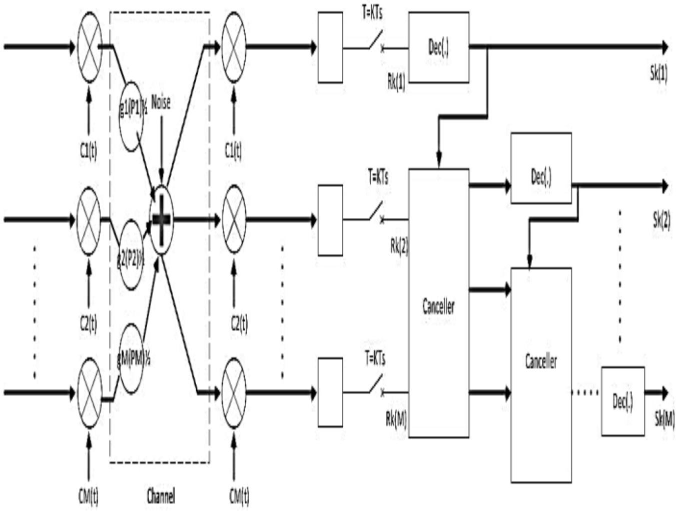

Figure 7. Proposed System Design with multipath propagation and MPCs corresponding to different path lengths.

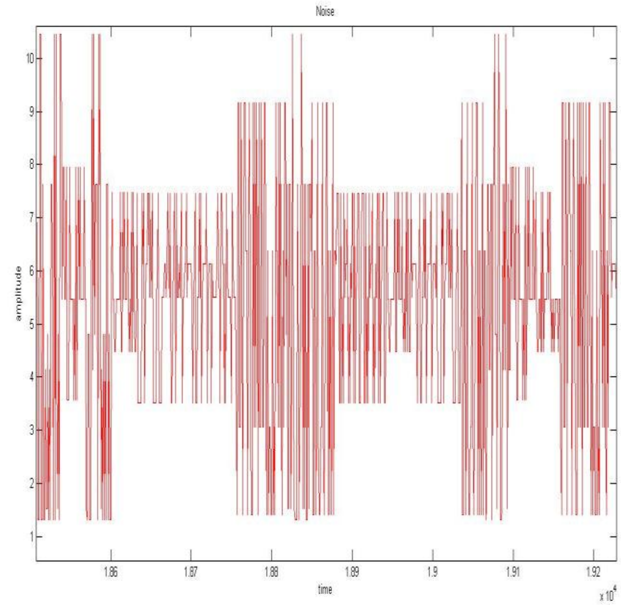

Figure 9. Noise Added in the Channel

VI. RESULTS

The simulations for the proposed system are being shown in the subsequent section:

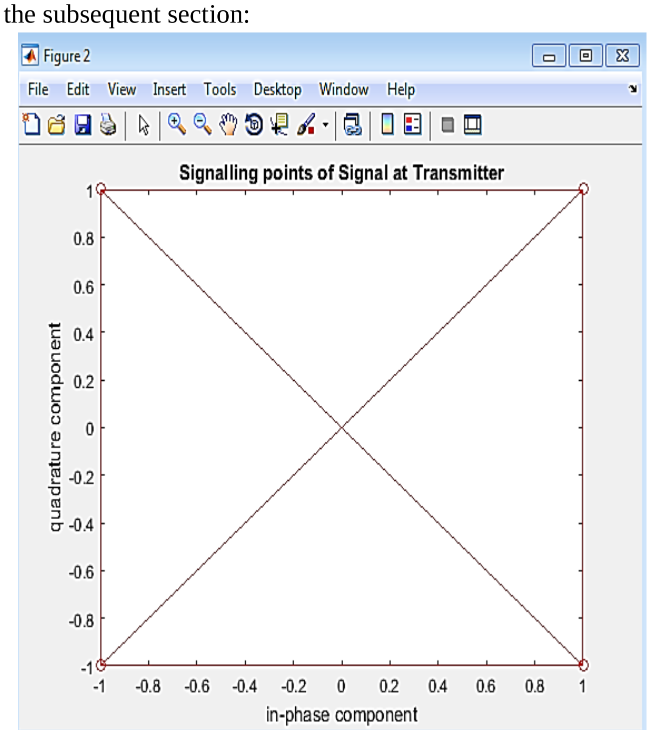

Figure 8. Signalling Points

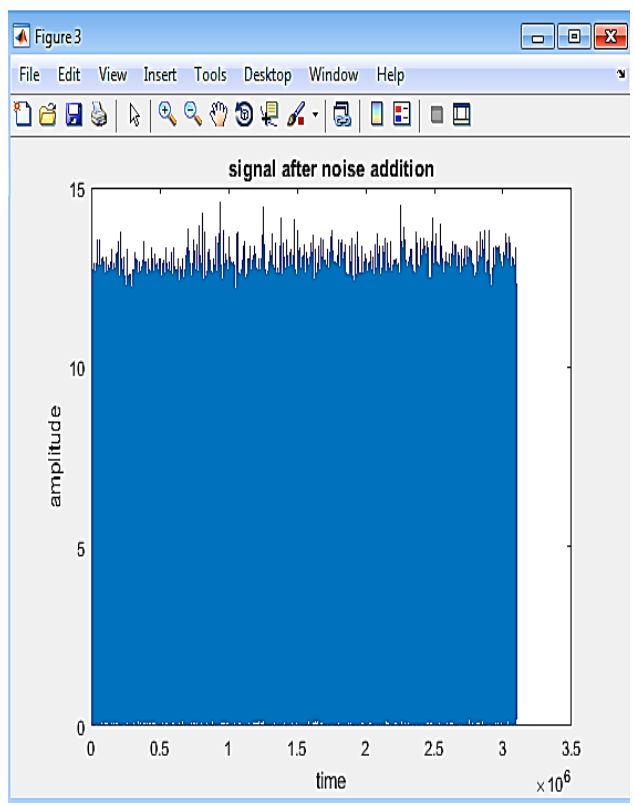

Figure 10. Signal after Noise Addition

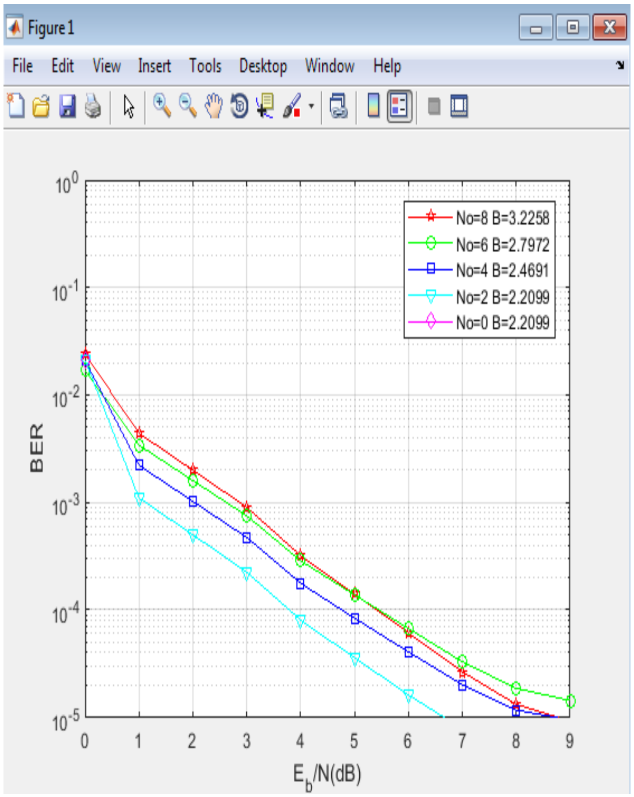

Figure 11. BER analysis of Proposed System with k=40

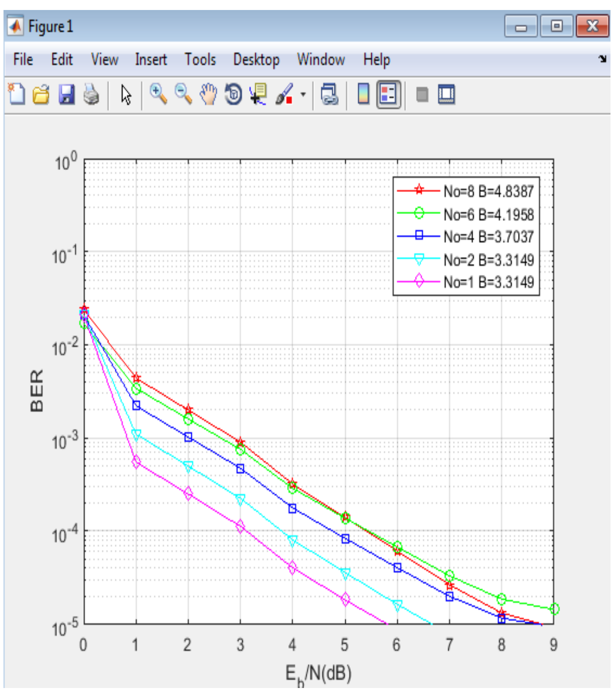

Figure 12. BER analysis of Proposed System with k=60

It can be seen from the above table that the proposed system clearly outperforms the conventional system as far as the BER fall is concerned or even the SNR needed is concerned as it reduces both.

VII. CONCLUSION

From the previous discussions, it can be said that there are two important challenges in the detection of multiple signals corresponding to multi-user detection in Wireless Networks. One important problem is the difficulty in reception of weak signals in the presence of string signals. The other is nullifying the effect of degradations done by the wireless channel. For the detection of multiple users with varying signal strengths, successive signal subtraction is the algorithm is used. The performance metrics used is bit error rate (BER) or Probability of Error (Pe). It can be seen that the proposed system attains BER performance almost equal to that of the Strongest Signal.

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