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Effective Fading Reduction Techniques in Wireless Communication System

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Abstract: *Fading is a major impairment when transmitting a signal in wireless communication channel. It is cause by multipath propagation. That is signals from different paths can constructively or destructively interfere with each other. Thus, it becomes very necessary to reduce this effect, to transmit the signal effectively to the receiver. This paper examines fading and it various types. Different techniques being employed to reduce the effect of fading using Diversity, rake receiver and equalization are also discussed.*
Keywords: *Diversity, Equalization, Fading, Multipath Propagation, Rake receiver*

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I. Introduction

In wireless telecommunication, multi-path is the propagation phenomena that results in radio signals reaching the receiving antenna by two or more paths. The Causes of multi-path include atmospheric scattering, ionospheric reflection, reflection from water bodies and terrestrial objects such as mountains and buildings. [1]
Multi-path radio signal propagation occurs on all terrestrial radio links. The radio signals not only travel by the direct line of sight (LOS) path, but as the transmitted signal does not leave the transmitting antenna in only the direction of receiver, but over a range of angles even when a directive antenna is used. Consequently, the transmitted signal spread out from transmitter and they will reach other objects: hills, buildings, reflection surfaces such as the ground , water, etc. See fig. 1.

The signals may reflect of a variety of surfaces and reach the receiving antenna via paths other than the direct LOS path. When the radio signals arrive at the receiver via variety of paths, the overall signal received is the sum of all the signals appearing at the antenna. Sometimes, these signals may be in phase with the main signal and will add to it to increase its strength. At other times, they will be out of phase or interfere with the main signal, therefore resulting in overall signal strength reduction.

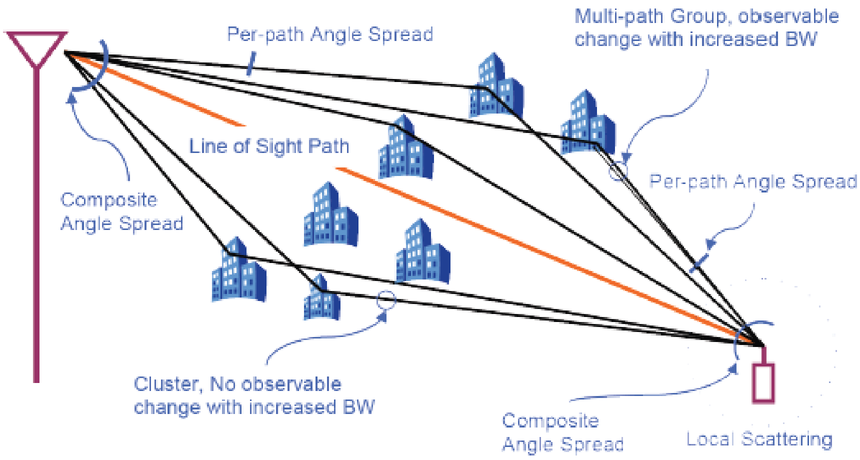

Figure 1: Multipath Propergation

At times, there will be changes in the relative path lengths. This could result from either transmitter or receiver moving, or any of the objects that provide a reflective surface moves. This will result in phases of the signal arriving at the receiver changing, and in turn this will result in the signal strength varying.

When a mobile receiving antenna receive a large number of reflected and scattered signals, because of the signal cancellation effect, the instantaneous received power seen by a moving antenna becomes a random variable, dependent on the location of the antenna.[2]

Since, modern wireless communication systems are typically used in urban setting, where many high buildings, foliage and street signs are located between the transmitter and receiver, the radio transmission environment in urban areas is characterized by multi-path propagation. [3]

II. Background Information

In a typical wireless communication environment, multiple propagation paths exist between transmitter and receiver due to scattering by different objects. Thus, copies of the signal following different paths can undergo different attenuation, distortions, delays and phase shifts. Constructive and destructive interference can occur at the receiver. When destructive interference occurs, the signal power can be significantly diminished. This phenomenon is called fading.

2.1 Types Of Fading

Frequency Selective fading: The transmitted signal reaching the receiver through multiple propagation paths, having a different relative delay and amplitude. This is called multipath propagation and causes different parts of the transmitted signal spectrum to be attenuated differently, which is known as frequency-selective fading. In this, the channel spectral response is not flat. It has dips or fades in the response due to reflections causing cancellation of certain frequencies at the receiver.

Frequency Non-Selective fading: If all the frequency components of the signal would roughly undergo the same degree of fading, the channel is then classified as frequency non-selective (also called flat fading).

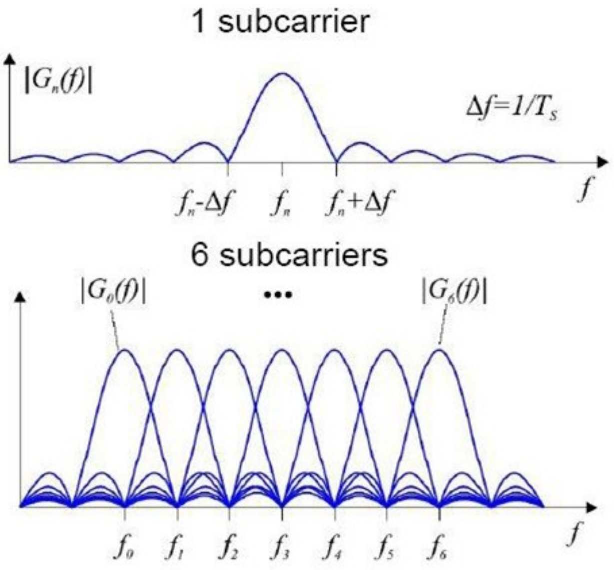

Figure 2: Frequency selective fading

Slow fading:

Slow fading is a long-term fading effect changing the mean value of the received signal. Slow fading is usually associated with moving away from the transmitter and experiencing the expected reduction in signal strength. Slow fading can be caused by events such as shadowing, where a large obstruction such as a hill or large building obscures the main signal path between the transmitter and the receiver.

Fast fading:

Fast fading is the short term component associated with multipath propagation. It is influenced by the speed of the mobile terminal and the transmission bandwidth of the signal. In a fast fading channel, the rate of change of the channel is higher than the signal symbol period and hence the channel changes over one period

III. Methodology

The methodology of this paper is based on the information gathered from research works, reports , journals as well as qualitative sourcing of information from the libraries which are related to this research paper. This section describe methods that can help reduce the problem of fading in wireless communication channels as illustrated by figure 2; they are Diversity for fast and slow fading , Equalization for flat and frequency selection fading , Rake receiver for multipath fading and Channel Coding for deep fading.

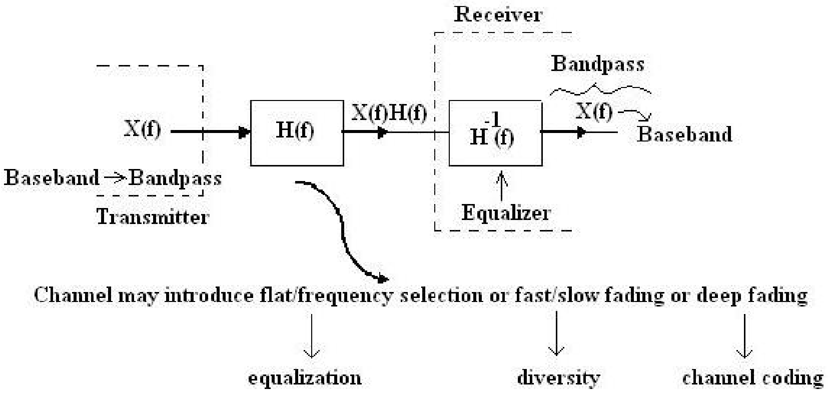

Figure 3:

IV. Diversity Technique

Diversity is a method used to develop information from several signals transmitted over independent fading paths. It exploits the random nature of radio propagation by finding independent signal paths for communication. It is a very simple concept where if one path undergoes a deep fade, another independent path may have a strong signal. As there is more than one path to select from, both the instantaneous and average SNRs at the receiver may be improved. Usually diversity decisions are made by receiver.

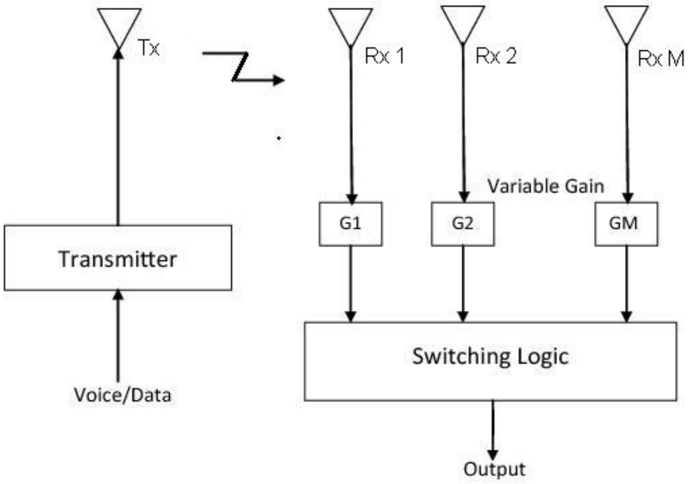

Figure 4: Receiver selection diversity

4.1 Types Of Diversity

(4.1.1) Space Diversity

This is the most common diversity scheme. In Space diversity, there are multiple receiving antennas placed at different spatial locations, resulting in different (possibly independent) received signals.[4] Using two antennas (TX AND RX) with a distance between them the phase delay makes multi-path signals arriving at the antennas differ fading as shown in figure (5) below. Space diversity is nowadays in focus because of the higher frequencies used for transmission making it possible to apply this kind of diversity mechanics in smaller terminals. It is also employed to combat both frequency selective fading and time selective fading. The space diversity increases the signal to noise ratio (SNR) of a transmitted signal.

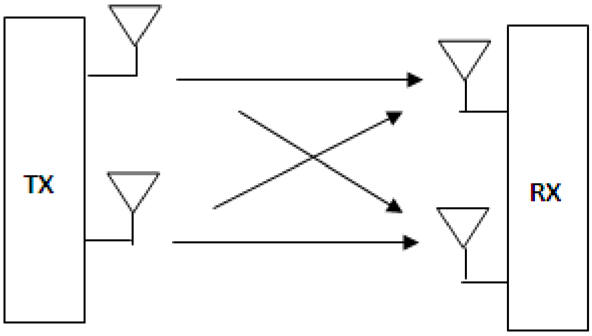

Figure 5: Space Diversity

(4.1.2) Frequency Diversity

In Frequency Diversity, the same information signal is transmitted and received simultaneously on two or more independent fading carrier frequencies as shown below in Figure(6). Rationale behind this technique is that frequencies separated by more than the coherence bandwidth of the channel will be uncorrelated and will thus not experience the same fades. The probability of simultaneous fading will be the product of the individual fading probabilities. The frequency diversity is use to reduce frequency selective fading.

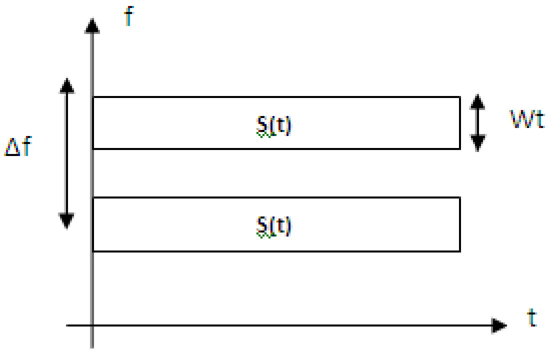

Figure 6: Frequency Diversity

(4.1.3) Angle Diversity

Signals arriving at the antennas are coming from different directions. Being independent in their fading variations these signals can be used for angle or angular diversity. At a mobile terminal angle diversity can be achieved using two Omni directional antennas acting as parasitic elements to each other changing their patterns to manage the reception of signals at different angles. As shown in figure (7), two orthogonal antennas are employed on a single base at different angles.

Figure 7: Angle Diversity

(4.1.4) Time Diversity

In time diversity, the signals representing the same information are sent over the same channel at different times. Time diversity repeatedly transmits information at time spacing that exceeds the coherence time of the channel. Multiple repetition of the signal will be received with independent fading conditions, thereby providing for diversity. A redundant forward error correction code is added and the message is spread in time by means of bit-interleaving before it is transmitted. Thus, error bursts are avoided, which simplifies the error correction.

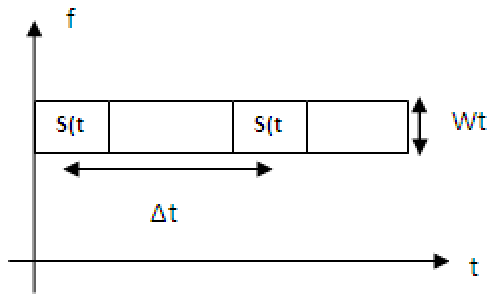

Figure 8: Time Diversity

(4.1.5) Polarization Diversity

Polarization Diversity relies on the de-correlation of the two receives ports to achieve diversity gain. The two receiver ports must remain cross-polarized. Polarization Diversity at a base station does not require antenna spacing. Polarization diversity combines pairs of antennas with orthogonal polarizations (i.e. horizontal/vertical, ± slant 45^o, Left-hand/Right-hand etc). Reflected signals can undergo polarization changes depending on the channel. Pairing two complementary polarizations, this scheme can immunize a system from polarization mismatches that would otherwise cause signal fade. Polarization diversity has prove valuable at radio and mobile communication base stations since it is less susceptible to the near random orientations of transmitting antennas.

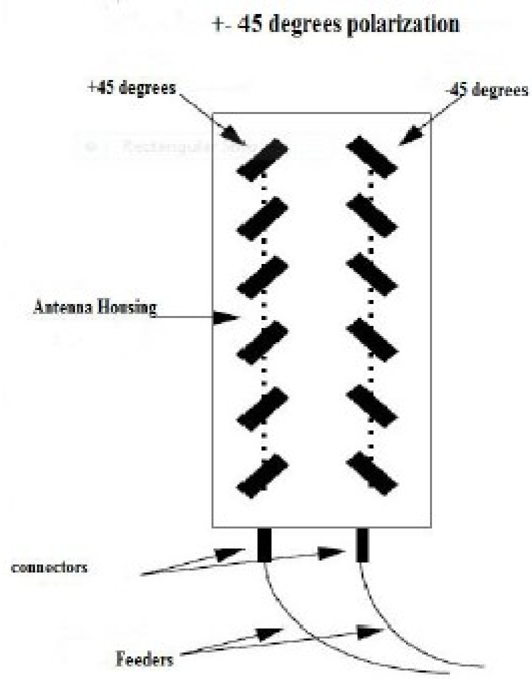

Figure 9: Polarization Diversity

4.2 Diversity Processing Techniques

Diversity processing techniques is of great importance, so as to able to combine the uncorrelated faded signals which were obtained from the diversity branches. The diversity processing should be in such a manner that improves the performance of the communication system like the signal to noise ratio (SNR) or the power of the received signal at the receiving end. [5] The following diversity processing techniques are discussed below

(4.2.1) Switching

In a switching receiver, the signal from only one antenna is fed to the receiver for as long as the quality of that signal remains above some prescribed threshold. If and when the signal degrades, another antenna is switched in. Switching is the easiest and least power consuming of the antenna diversity processing techniques but periods of fading and de synchronization may occur while the quality of one antenna degrades and another antenna link is established.

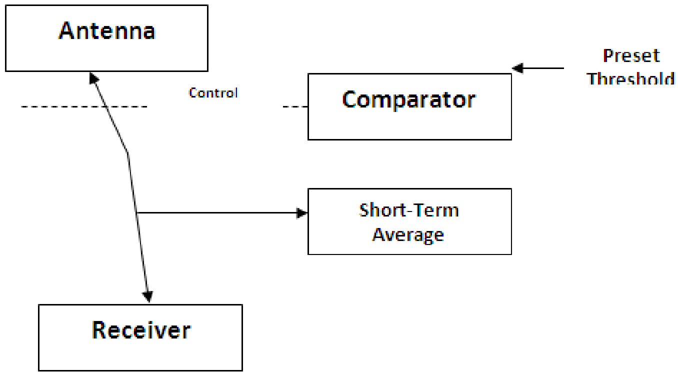

Figure 10: Switching Diversity

(4.2.2) Selecting

Selection processing presents only one antenna's signal to the receiver at any given time. The antenna chosen, however, is based on the best signal-to-noise ratio (SNR) among the received signals. This requires that a pre-measurement take place and that all antennas have established connections (at least during the SNR measurement) leading to a higher power requirement. [6]

The actual selection process can take place in between received packets of information. This ensures that a single antenna connection is maintained as much as possible. Switching can then take place on a packet-by-packet basis if necessary.

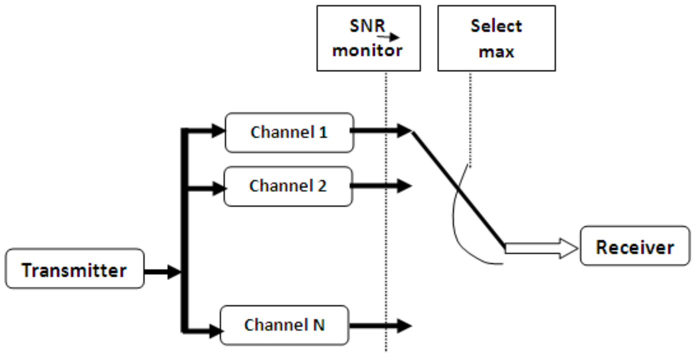

Figure 11: Selection Diversity

(4.2.3) Combining

In combining, all antennas maintain established connections at all times. The signals are then combined and presented to the receiver. Depending on the sophistication of the system, the signals can be added directly (equal gain combining) or weighted and added coherently (maximal-ratio combining) as illustrated below

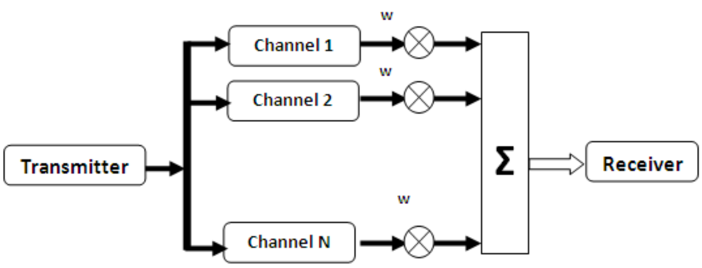

Figure 12: Equal Gain Combining

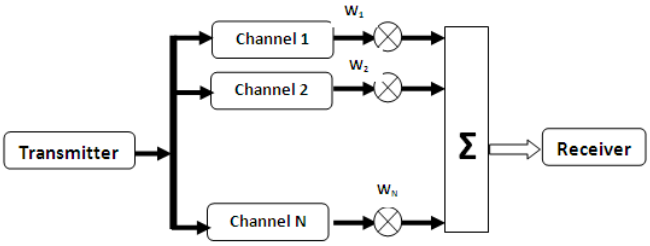

Figure 13: Maximal Ratio Combining

(4.2.4) **Dynamic Control**

Dynamically controlled receivers are capable of choosing from the above processing schemes for whenever the situation arises. While much more complex, they optimize the power vs. performance trade-off. Transitions between modes and/or antenna connections are signaled by a change in the perceived quality of the link. In situations of low fading, the receiver can employ no diversity and use the signal presented by a single antenna. [7]

4.3 Rake Receiver

Rake receiver, used specially in CDMA cellular systems, can combine multipath components, which are time-delayed versions of the original signal transmission. This combining is done in order to improve the signal to noise ratio (SNR) at the receiver.

Rake receiver attempts to collect the time shifted versions of the original signal by providing a separate correlation receiver for each of the multipath signals. This can be done due to multipath components are practically uncorrelated from another when their relative propagation delay exceeds a chip period. The design of a rake receiver can be visualized as a series of time delayed correlator taps fed from a common antenna. [8]

If each correlator tap is delayed to match the arrival of a particular transmitted signal, then the outputs of each tap can be recombined in phase. Once an RF signal with a particular travel time is locked onto by the correlator tap, an estimate of the gain or loss experienced by that signal must be made. The weighting of the taps perform this gain normalization function. Once adjusted, the outputs of each finger of the rake can be combined to form a better version of the transmitted signal.

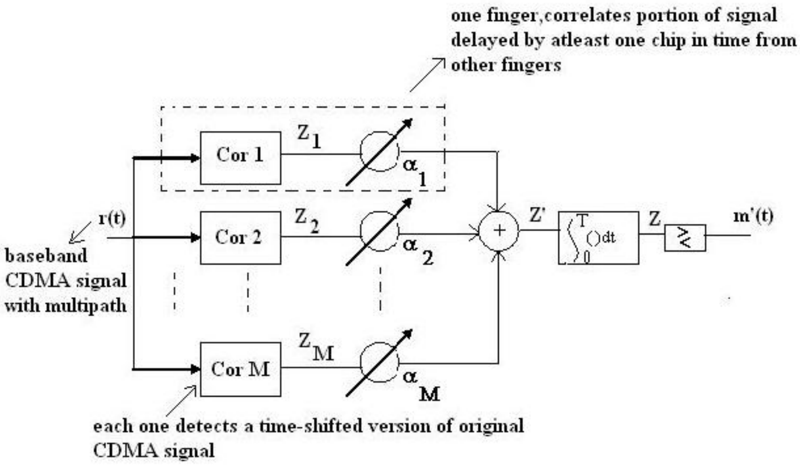

Figure 14 : A Rake Receiver

Each correlator detects a time-shifted version of the original CDMA transmission, and each finger of the rake correlates to a portion of the signal, which is delayed by at least one chip in time from the other fingers. Assume M correlators are used in a CDMA receiver to capture M strongest multipath components. A weighting network is used to provide a linear combination of the correlator output for bit decision. Correlator 1 is synchronized to the strongest multipath m1. Multipath component m2 arrived t1 later than m1 but has low correlation with m1.

The M decision statistics are weighted to form an overall decision statistic as shown in Figure 14. The outputs of the M correlators are denoted as Z_1, Z_2 … and Z_M. They are weighted by α_1, α_2… and α_M, respectively. The weighting coefficients are based on the power or the SNR (Signal-to- Noise Ratio) from each correlator output. If the power or SNR is small out of a particular c'

\orrelator, it will be assigned a small weighting factor, α If maximal-ratio combining is used, following equation 1 can be written for Z'.

$$Z' = \sum_{m=1}^{M} \alpha_m Z_m \qquad \text{.........................} \quad (1)$$

The weighting coefficients, α_m, are normalized to the output signal power of the correlator in such a way that the coefficients sum to unity, as shown in equation 2.

$$\alpha_m = \frac{Z_m^2}{\sum_{m=1}^{M} Z_m^2} \qquad \text{.........................} \quad (2)$$

V. Equalization

Equalization compensates for Inter Symbol Interference (ISI) and deep fading created by multipath within time dispersive channels. An equalizer within a receiver compensates for the average range of expected channel amplitude and delay characteristics. In other words, an equalizer is a filter at the mobile receiver, whose impulse response is inverse of the channel impulse response.

As such equalizers find their use in frequency selective fading channels. In effect, an equalizer is an inverse filter of the channel. If the channel is frequency selective, the equalizer enhances the frequency components with small amplitudes and attenuates those with large amplitudes. The goal is for the combination of channel and equalizer filter to provide a flat composite-received frequency response and linear phase. [9]

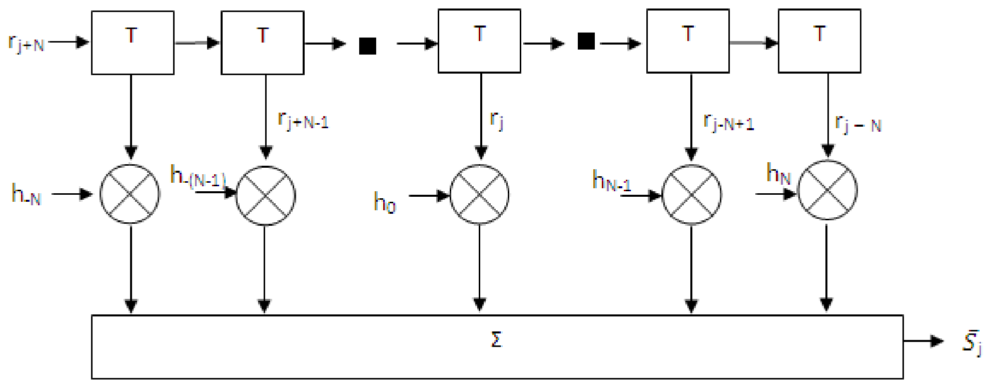

Figure 15: Transversal Filter equalizer (Schwartz, P49)

In the figure above, the received samples r are passed sequentially through the filter and are weighted by the filter taps h. This can be described mathematically as:

$$\bar{S}j = \sum_{n=-N}^{N} h \qquad \text{...............} (3)$$

To be able to select the filter coefficients (taps) h_n to provide the greatest reduction in intersymbol interference, the frequency response of the channel needs to be obtained. This can be done by sending known sequences of pulses across the channel and measuring the response.[10].

Minimization algorithms can then be applied to calculate the filter coefficients so that the received pulses match the transmitted pulses. As the channel response changes with time,mainly according to receiver motion, equalization needs to be performed rapidly compared with rate of change of the channel properties.

VI. Channel Coding

In channel coding, redundant data bits are added in the transmitted message so that if an instantaneous fade occurs in the channel, the data may still be recovered at the receiver without the request of retransmission.

A channel coder maps the transmitted message into another specific code sequence containing more bits. Coded message is then modulated for transmission in the wireless channel. Channel Coding is used by the receiver to detect or correct errors introduced by the channel. Codes that used to detect errors are error detection codes. Error correction codes can detect and correct errors under deep fading condition.

VII. Conclusion

This paper has examined basics of fading in wireless communication system. The effective ways of mitigating the effect of fading using diversity, rake receiver, equalization and channel coding were also discussed. Also from the result of this study, it is obvious that the implementation of these techniques will indeed enhance effective fading and inters symbol interference reduction in wireless communication systems.

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