MULTISCIA
JOURNALS PUBLISHERS

FRONTIERS IN ELECTRONICS AND COMMUNICATION ENGINEERING

ISSN: (3065- 4106)

editor.fece@gmail.com
https://multisciajournals.com/journals/index.php/fece

Frontiers in Electronics and Communication Engineering
Volume 1 Issue 2 2025

Efficient Methods for Reducing Fading in Wireless Communication Systems

Marcos André Gonçalves
Department of ECE

Article Info

Received: 22-03-2025 ***Revised:20-04-2025*** ***Accepted:03-05-2025*** ***Published:15-05-2025***

AbstractFading is a significant signal transmission problem in wireless communication channels. Multipath propagation is the cause. In other words, signals from several pathways may interact with one another in a positive or negative way. Reducing this impact is therefore crucial for efficient signal transmission to the receiver. This essay looks at fading and its different forms. There is also discussion of several methods used to lessen the impact of fading, such as equalization, rake receiver, and diversity.

Keywords: Multipath Propagation, Diversity, Equalization, Fading, Rake receiver

Introduction

Multi-path propagation is the phenomenon in wireless telecommunication where radio signals travel along two or more routes before reaching the receiving antenna. Atmospheric scattering, ionospheric reflection, reflection from aquatic bodies, and reflection from land-based objects like buildings and mountains are the causes of multi-path. [1] Every terrestrial radio link experiences multi-path radio signal propagation. Not only do radio transmissions follow the direct line of sight (LOS) path, but even when a directional antenna is employed, the sent signal travels over a variety of angles rather than just in the direction of the receiver. As a result, the signal is dispersed from the transmitter and eventually reaches other objects, including buildings, hills, and reflecting surfaces like water and the ground. Refer to Figure 1.

The signals may travel through different routes than the direct LOS path to the receiving antenna after reflecting off of a range of surfaces. The total signal received is the sum of all the signals that appear at the antenna when radio signals travel through a number of routes to reach the receiver. These signals can occasionally add to the main signal to strengthen it because they are in phase with it. They will occasionally be out of phase or interfere with the primary signal, which will lower the signal's overall power.

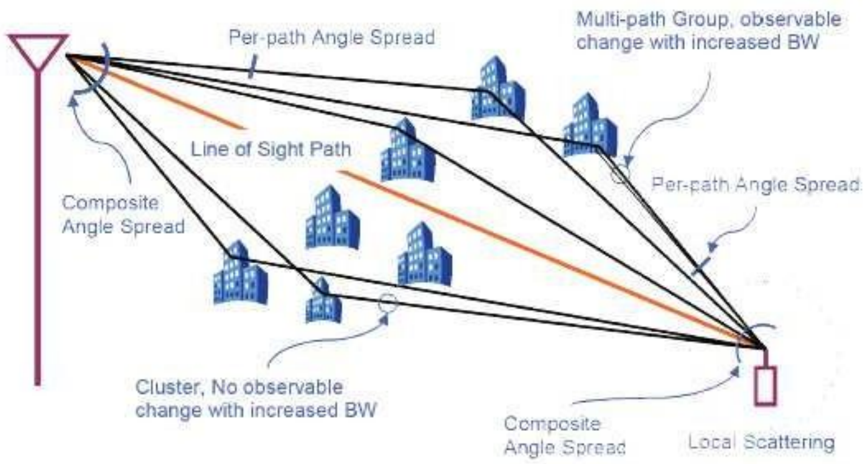


Figure 1: Multipath Propergation

The relative travel lengths will fluctuate from time to time. Any movement of the transmitter, receiver, or any of the things that create a reflective surface could cause this. As a result, the signal's phases will change as it reaches the receiver, which will alter the signal's power.A moving antenna's instantaneous received power becomes a random variable that depends on the intenna's location when it receives a lot of reflected and scattered signals due to the signal cancellation effect. [2]

The radio transmission environment in urban regions is characterized by multi-path propagation since modern wireless communication systems are usually utilized in metropolitan settings where several tall buildings, vegetation, and street signs are situated between the transmitter and receiver. [3]

I. Background Information

II. Due to dispersion by various objects, there are several propagation paths between the transmitter and receiver in a typical wireless communication environment. As a result, attenuation, distortions, delays, and phase shifts might differ between copies of the signal that use various routes. At the receiver, interference can be both constructive and detrimental. Signal power can be greatly reduced when destructive interference takes place. We refer to this phenomenon as fading.

2.1 Types Of Fading

Frequency Selective fading The sent signal, which has a varied relative delay and amplitude, travels via several propagation pathways before reaching the receiver. This phenomenon, known as multipath propagation, results in frequency-selective fading, which is the attenuation of distinct regions of the transmitted signal spectrum. The channel spectral response is not flat in this case. Reflections cause some frequencies to be canceled at the receiver, resulting in dips or fades in the response.

Frequency Non-Selective fading: The channel is categorized as frequency non-selective (also known as flat fading) if all of the signal's frequency components would roughly experience the same level of fading.

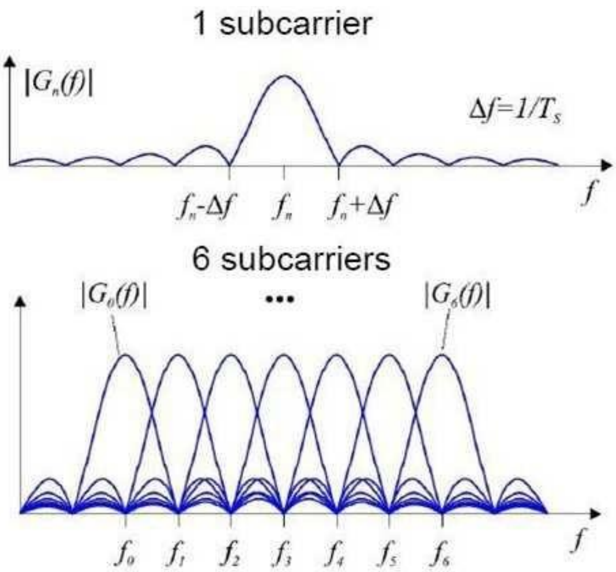


Figure 2: Frequency selective fading

Slow fading:
A long-term fading effect that modifies the received signal's mean value is called slow fading. Moving away from the transmitter and seeing the anticipated decrease in signal strength are typically linked to slow fading. Events like shadowing, in which the main signal route between the transmitter and the receiver is obscured by a big object like a hill or huge structure, can result in slow fading.

Fast fading: The short-term aspect of multipath propagation is called fast fading. It has an influence.
by the signal's transmission bandwidth and the mobile terminal's speed. When a channel is fast fading, its rate of change exceeds the signal symbol period, causing the channel to change during a single period.

III. Methodology

IV. The material obtained from research papers, reports, and journals, as well as qualitative information sourced from libraries relevant to this research paper, forms the basis of this paper's methodology. This section discusses techniques that can lessen the issue of fading in wireless communication channels, as shown in figure 2. These techniques include channel coding for deep fading, rake receiver for multipath fading, equalization for flat and frequency selection fading, and diversity for fast and slow fading.

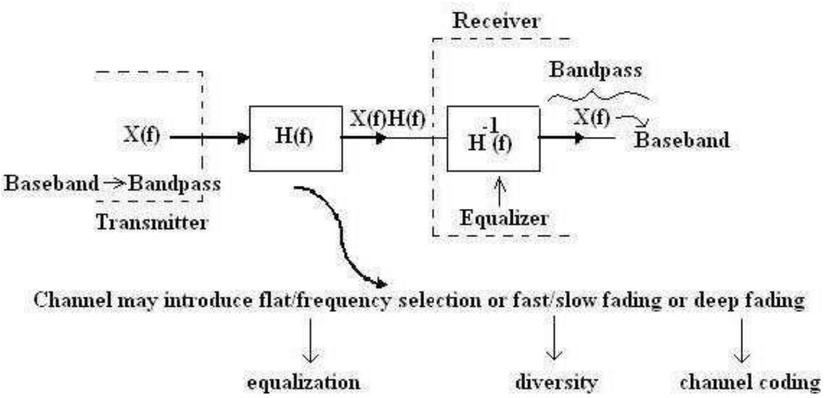


Figure 3:

V. Diversity Technique

VI. A technique for creating information from many signals sent via separate fading pathways is called diversity. By locating independent signal pathways for transmission, it takes use of the unpredictable nature of radio propagation. The idea is straightforward: if one path has a deep fade, a significant signal may be present on another independent line. Both the immediate and average SNRs at the receiver may be enhanced since there are multiple paths to choose from. Diversity decisions are typically decided by the recipient.

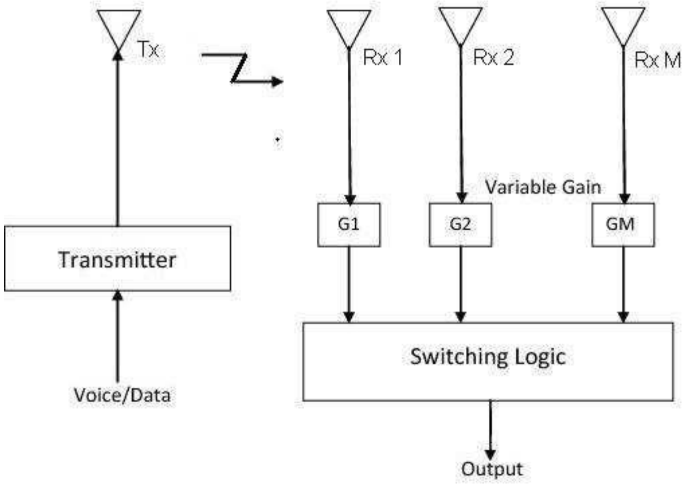


Figure 4: Receiver selection diversity

4.1 Types Of Diversity

(4.1.1) Space Diversity

5 The most popular diversification plan is this one. Multiple receiving antennas positioned at various spatial positions produce distinct (potentially independent) received signals in space diversity. [4] making use of two

6 Six antennas (TX and RX) spaced apart the phase delay makes multi-path signals arriving at the antennas differ fading as illustrated in figure (5) below. Due to the higher transmission frequencies that allow for the application of this type of diversity mechanics in smaller terminals, space diversity is currently the focus of attention. Additionally, it is used to counteract both time-selective and frequency-selective fading. A transmitted signal's signal to noise ratio (SNR) rises with space diversity.

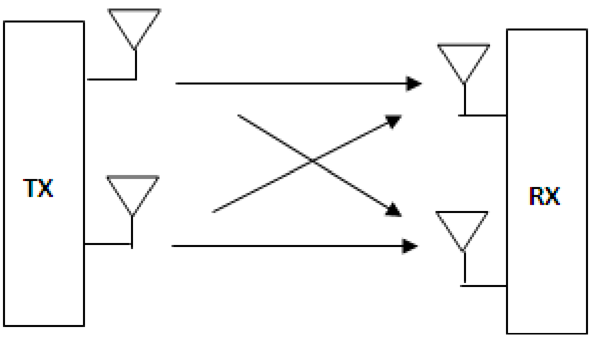


Figure 5: Space Diversity

(4.1.2) Frequency Diversity

As seen in Figure (6) below, frequency diversity involves simultaneously transmitting and receiving the same information signal on two or more separate fading carrier frequencies. This method's justification is that frequencies that are farther apart than the channel's coherence bandwidth will be uncorrelated and won't have the same fades. The product of each fading probability will be the likelihood of synchronous fading. Frequency selective fading is lessened by using frequency diversity.

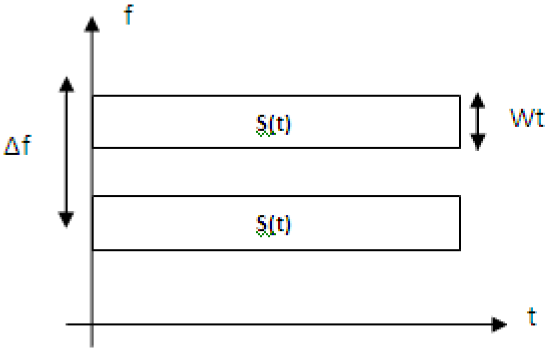


Figure 6: Frequency Diversity

(4.1.3) Angle Diversity

The signals that reach the antennas come from various angles. These signals are suitable for angle or angular variety since they exhibit independent fading changes. Two omnidirectional antennas that function as parasitic elements to one another by altering their patterns to control the reception of signals at various angles can be used to produce angle diversity at a mobile terminal. Two orthogonal antennas are used on a single base at various angles, as seen in figure (7).

Figure 7: Angle Diversity

(4.1.4) Time Diversity

The same information is represented by signals that are broadcast over the same channel at different periods in time diversity. Information is periodically sent using time diversity at intervals longer than the channel's coherence time. Diversity will be provided by receiving many repetitions of the signal under different fading conditions. Before the message is sent, bit-interleaving is used to spread it over time and include a redundant forward error correcting code. Error bursts are thereby prevented, making error rectification easier.

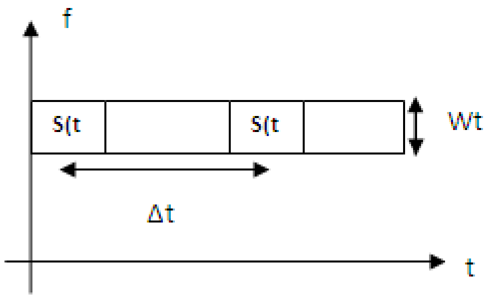


Figure 8: Time Diversity

(4.1.5) Polarization Diversity

To attain diversity gain, polarization diversity depends on the de-correlation of the two receive ports. Cross-polarization of the two receiver ports is required. The polarization of Antenna spacing is not necessary for diversity at a base station. Pairs of antennas having orthogonal polarizations (horizontal/vertical, 45° slant, left-hand/right-hand, etc.) are combined in polarization diversity. Depending on the channel, reflected signals may experience polarization variations. This method can protect a system against polarization mismatches that might otherwise result in signal fade by pairing two complimentary polarizations. Because polarization diversity is less vulnerable to the nearly random orientations of transmitting antennas, it has proven useful at radio and mobile communication base stations.

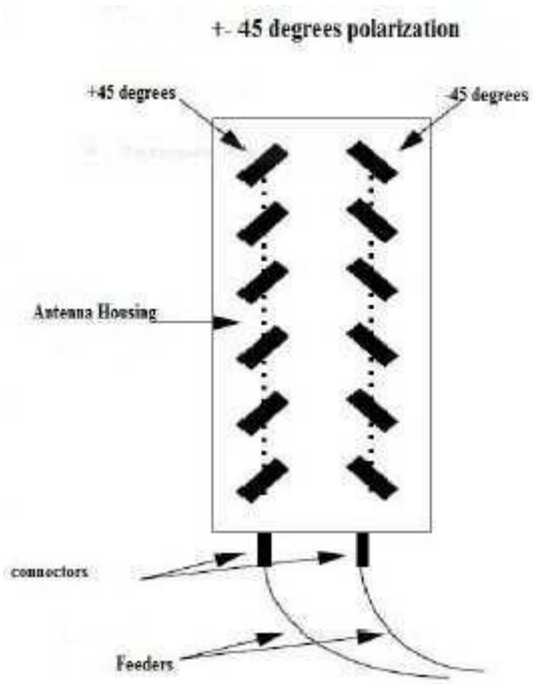


Figure 9: Polarization Diversity

6.1 Diversity Processing Techniques

7 In order to merge the uncorrelated faded signals that were obtained from the diversity branches, diversity processing techniques are crucial. Diversity processing should be done in a way that enhances the communication system's performance, such as the power of the received signal at the receiving end or the signal to noise ratio (SNR). [5] Below is a discussion of the following diversity processing methods.

(4.2.1) Switching

The signal from a single antenna is supplied into a switching receiver for as long as the signal quality is higher than a predetermined threshold. Another antenna is turned in if and when the signal deteriorates. The simplest and least power-intensive of the antenna diversity processing methods is switching, however there may be fading and desynchronization intervals while one antenna's quality deteriorates and a new antenna link is created.

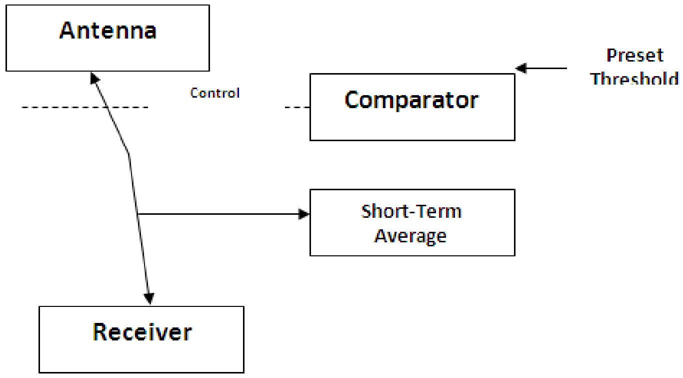


Figure 10: Switching Diversity

(4.2.2) Selecting

Only one antenna's signal is ever shown to the receiver at a time due to selection processing. However, the best signal-to-noise ratio (SNR) among the received signals determines which antenna is used. This results in a greater power need since it necessitates a pre-measurement and the establishment of connections between all antennas (at least during the SNR measurement). [6] The actual selection procedure may occur in between information packets that are received. This guarantees the maximum maintenance of a single antenna connection. If required, switching can then occur on a packet-by-packet basis.

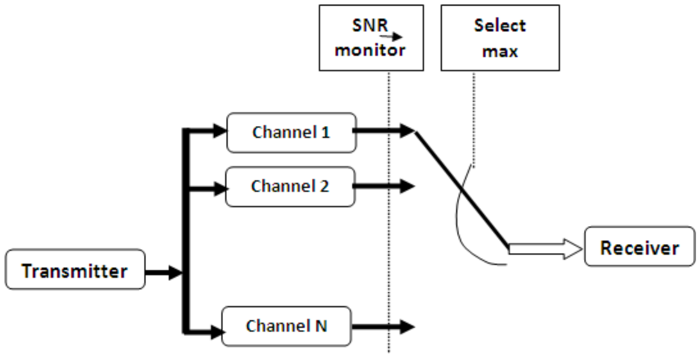


Figure 11: Selection Diversity

(4.2.3) Combining

All antennas keep their established connections during the merging process. After that, the receiver receives the merged signals. The signals can be merged directly (equal gain combining) or weighted and added coherently (maximal-ratio combining), as shown below, depending on how complex the system is.

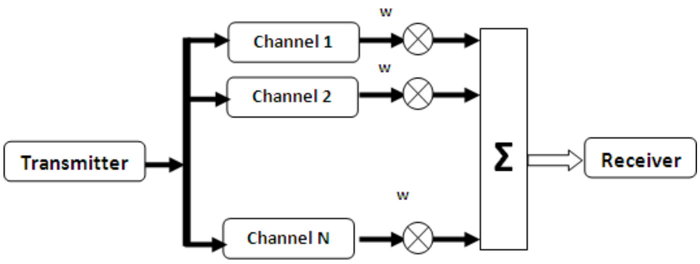


Figure 12: Equal Gain Combining

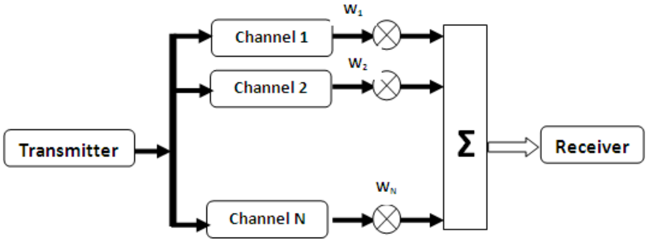


Figure 13: Maximal Ratio Combining

(4.2.4) **Dynamic Control**

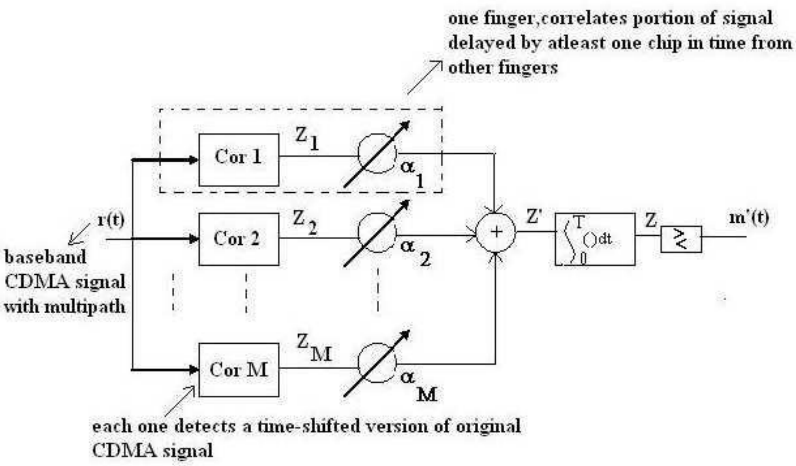
When the need arises, dynamically controlled receivers can select from the aforementioned processing strategies. They maximize the power vs. performance trade-off despite being far more complicated. A shift in the link's perceived quality indicates a change in modes and/or antenna connections. When there is little fading, the receiver can use the signal from a single antenna without using any diversity. [7]

7.1 Rake Receiver

Multipath components—time-delayed replicas of the original signal transmission—can be combined by rake receivers, which are particularly useful in CDMA cellular systems. The goal of this combining is to increase the receiver's signal to noise ratio (SNR).

By offering a distinct correlation receiver for every multipath signal, the rake receiver aims to gather the time-shifted versions of the original signal. This is possible because, after their relative propagation delay surpasses a chip period, multipath components are essentially uncorrelated from one another. A rake receiver's design can be thought of as a sequence of time-delayed correlator taps that are fed by a single antenna. [8]

The outputs of each correlator tap can be recombined in phase if they are timed to coincide with the arrival of a certain broadcast signal. It is necessary to determine the gain or loss that an RF signal with a specific travel time experiences after it has been locked onto by the correlator tap. This gain normalizing operation is carried out by the tap weighting. A better version of the



broadcast signal can be created by combining the outputs of each rake finger after they have been modified.

Figure 14 : A Rake Receiver

A time-shifted version of the original CDMA transmission is detected by each correlator, and each rake finger correlates to a segment of the signal that is at least one chip behind the other fingers in time. Assume that a CDMA receiver employs M correlators in order to catch M of the strongest multipath components. For bit judgment, a linear combination of the correlator output is provided by a weighting network. The strongest multipath, m1, is synchronized with Correlator 1. Despite having a poor correlation with m1, the multipath component m2 arrived t1 later than m1.

Figure 14 illustrates how the M decision statistics are weighted to create an overall decision statistic. The letters Z1, Z2, …, and ZM stand for the outputs of the M correlators. Their relative weights are determined by α1, α2,…, and αM. Each correlator output's power or SNR (signal-to-noise ratio) serves as the basis for the weighting coefficients. If the power or SNR is small out of a certain c'
correlator, it will be given a little weighting factor, α. If maximal-ratio combining is applied, Z' can be expressed using equation 1.

$$Z' = \sum_{m=1}^{M} \alpha_m Z_m \qquad \cdots \ldots\ldots\ldots\ldots\ldots (1)$$

Equation 2 illustrates how the weighting coefficients, αm, are normalized to the correlator's

$$\alpha_m = \frac{Z_m^2}{\sum_{m=1}^{M} Z_m^2}$$

output signal power so that the coefficients add up to unity.

… ………………… (2)

VII. Equalization

VIII. In temporal dispersive channels, equalization corrects for deep fading and Inter Symbol Interference (ISI) caused by multipath. A receiver's equalization adjusts for the typical range of anticipated delay and channel amplitude characteristics. To put it another way, an equalizer is a filter at the mobile receiver whose impulse response is the opposite of the impulse response of the channel.

IX. Equalizers are therefore used in frequency-selective fading channels. An equalization is essentially the channel's inverse filter. The equalizer attenuates the frequency components with large amplitudes and amplifies those with small amplitudes if the channel is frequency selective. A flat composite-received frequency response and linear phase are intended outcomes of the equalizer filter and channel combination. [9]

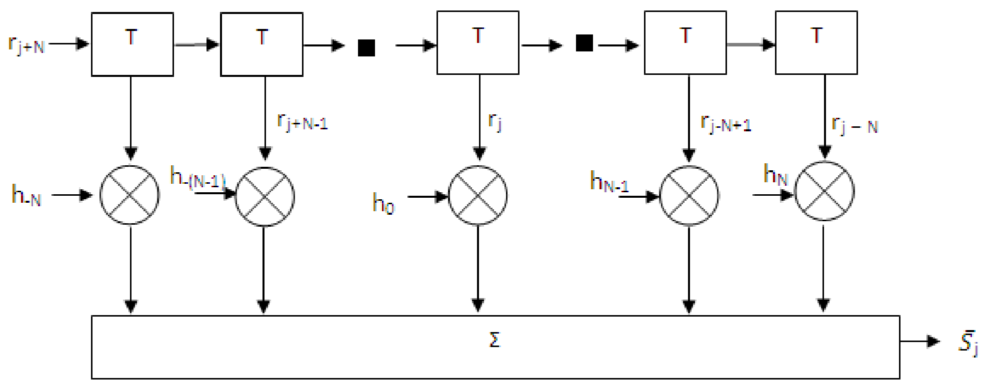


Figure 15: Transversal Filter equalizer (Schwartz, P49)

The received samples r are weighted by the filter taps h after being passed through the filter in a sequential manner as shown in the above image. This can be expressed numerically as:

$S = \sum h_{n=-N}$ … … … … … . (3)

The frequency response of the channel must be determined in order to choose the filter coefficients (taps) that will reduce intersymbol interference the most. This can be accomplished by measuring the response after delivering known pulse sequences over the channel. [10].

X. The filter coefficients can then be determined using minimization algorithms to ensure that the sent and received pulses match. Equalization must be completed quickly in comparison to the pace at which the channel parameters change since the channel response varies over time, primarily due to receiver motion.

XI. Channel coding adds redundant data bits to the sent message so that, in the event of an immediate channel fade, the data can still be recovered at the receiver without requiring retransmission.

XII. The transmitted message is converted into a different, more-bit coding sequence by a channel coder. After that, the coded message is modulated for wireless channel transmission. The receiver uses channel coding to identify or fix problems that the channel introduces. Error detection codes are codes that are used to identify errors. Under deep fading conditions, error correction codes are able to identify and fix faults.

XIII. Conclusion

XIV. The fundamentals of fading in wireless communication systems have been covered in this work. It was also highlighted how diversity, rake receiver, equalization, and channel coding can effectively reduce the impact of fading. The study's findings also make it clear that using these strategies will improve wireless communication systems' ability to reduce interference from fading and interference from inters symbols.

Citations [1]. J. Beasley and G. Miller, Modern Electronic Communication Textbook, Eighth Edition, pp. 736–739, 2008.
[2]. Hata's Equation Simulation for Signal Fading Mitigation, J.J. Popoola. 2009's Pacific Journal of Science and Technology https://www.akamaiuniversity.us/PJST.htm.
[3]. W-CDMA and CDMA 2000 for 3G Mobile Networks: A Textbook by M. Karim and M. Sarraf, Mc Graw-Hill, 2002.
In the International Journal of Advanced Research in Computer Science and Software Engineering, Volume 2, Issue 6, ISSN: 2277 128X, 2012, S. Nitika and S. Deepak discuss Diversity: A Fading Reduction Technique. You can get the research paper online at www.ijarcsse.com.
[5]. Diversity Techniques for Wireless Communication, by W. Pravin and S.L. Badjate, International Journal of Advance Research in Engineering & Technology (IJARET), volume 4, issue 2, March–April 2013, pp. 144–160.
[6] Digital Communications over Fading Channels: A Unified Approach to Performance Analysis, by M. Simon and M. Alouini, New York: John Wiley, 2000.
[7]. Antenna diversity: http://en.wikipedia.org/wiki/
[8] T. Heikkilä, Radio Communications Postgraduate Course, S-72.333, (2004).
[9] T. S. Rappaport, Wireless Communications (Prentice-Hall, Upper Saddle River, NJ, 1996).
[10]. Schwartz, Lecture 1 on Mobile Communication, pp. 49