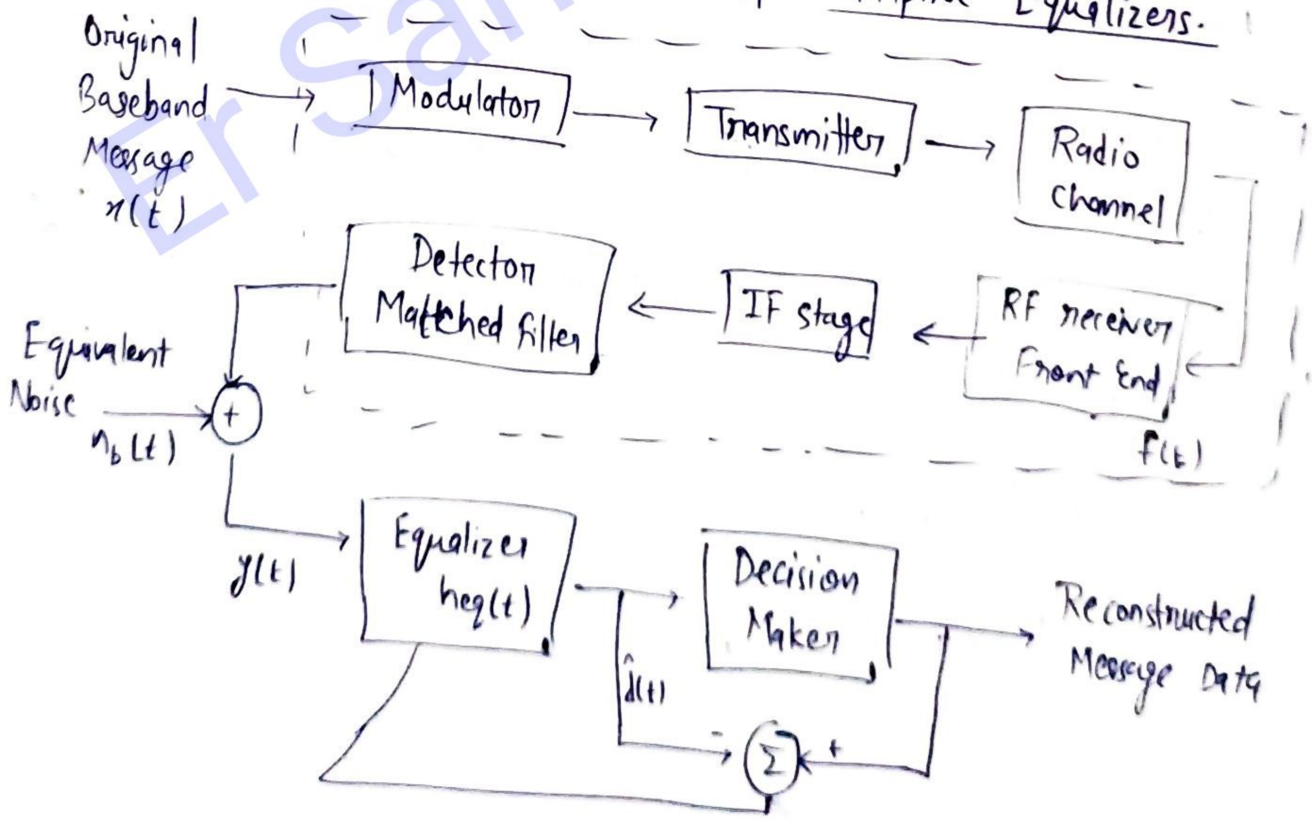
Multipath Mitigation Techniques

Equalizer:- Equalizers are RA structures that work both ways: they reduce or eliminate ISI, and at same time exploit the delay diversity inherent in the channel. The operational principle of an equalizer can be visualized either in time domain or the frequency domain.

→ Wireless channels can exhibit delay dispersion. Delay dispersion leads to Inter-Symbol Interference (ISI), Equalization is technique used to combat ISI.

→ In radio channels, a variety of adaptive equalizers can be used to cancel interference while providing diversity. Since the mobile fading channel is random & time varying, equalizers must track the time varying characteristics of mobile channel & thus we called adaptive Equalizers.



$$y(t) = x(t) \otimes f^*(t) + n_b(t)$$

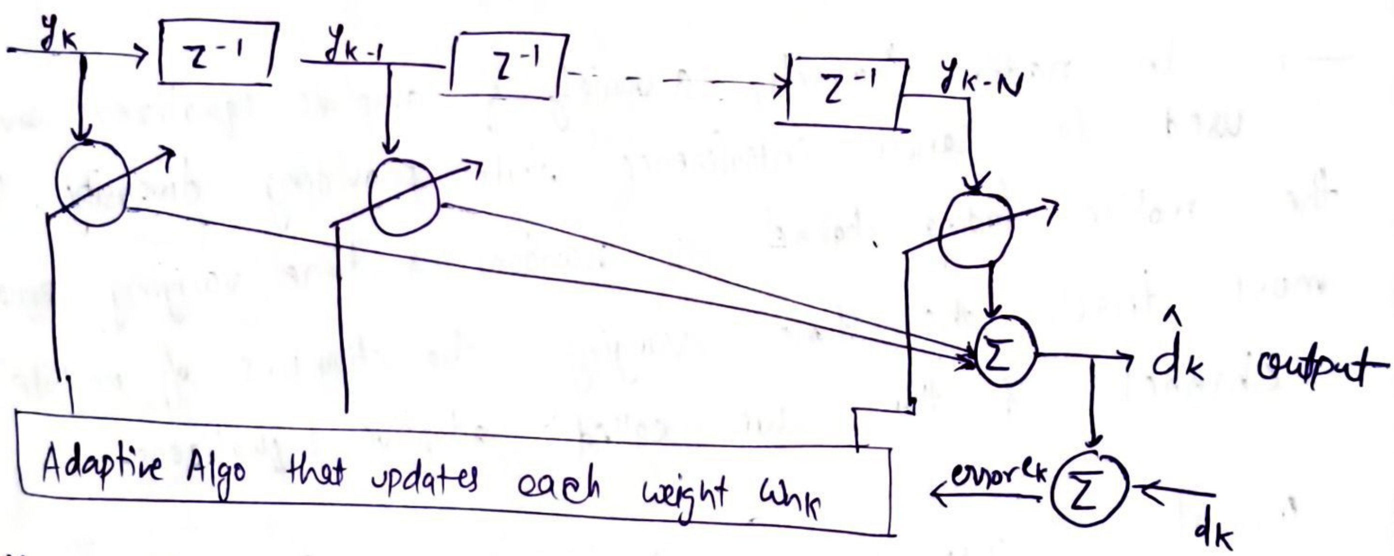
$$h_{eq}(t) = \sum c_n \, \delta(t - nT)$$

$$g(t) = f^*(t) \otimes h_{eq}(t) = \delta(t)$$

$$H_{eq}(f) F^*(-f) = 1$$

Adaptive Equalizer :-

An adaptive equalizer is a time-varying filter which must constantly be returned. The basic structure of an adaptive equalizer is shown in figure, where subscript k is used to denote a discrete time index.



New weights = Previous weights + (constant) × Previous Error × Current input vector

where

Previous error = Previous desired output − Previous actual output

Types of Equalizers

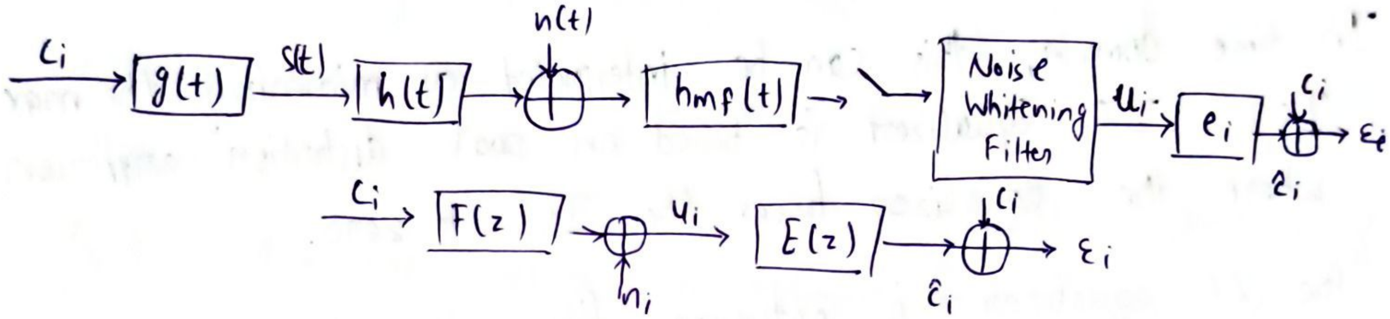
1. Linear Equalizer

2. Non Linear Equalizer

Linear Equalizer:- It is simple linear filter structures. Linear Equalizer try to invert the channel in sense that the product of transfer functions of channel & equalizer fulfills a certain criterion that can either be:

(i) flat transfer function of channel filter concatenation, or

(ii) minimizing the mean-squared error at the filter output



$$\varepsilon_i = c_i - \hat{c}_i$$

we aim to find a filter so that $\varepsilon_i = 0$ for $N_0 = 0$ which gives the ZF equalizer or that

$$E\{|\varepsilon_i|^2\} \to \min \quad \text{for } N_0 \text{ having a finite value}$$

which gives the Minimum Mean Square Error (MMSE) equalizer.

Non linear Equalizer:- A non-linear equalizers are used where the channel distortion is too severe for a linear equalizer to handle.

(i) Decision Feedback Equalization (DFE)
(ii) Maximum likelihood Symbol Detection
(iii) Maximum likelihood Sequence Estimation

3 are very effective non-linear methods offers improvements over linear equalization techniques.

Er Sahil ka Gyan

Zero-forcing Equalizer in Linear Equalizer ⇒

The ZF Equalizer can be interpreted in the frequency domain as enforcing a completely flat transfer function of combination of channel & equalizer by choosing the equalizer transfer function as

$$E(z) = \frac{1}{F(z)}$$

In time domain, this can be interpreted as minimizing the max. ISI. ZF Equalizer is based on peak distortion criterion, where the equalizer forces the ISI to zero.

The ZF equalizer is optimum for elimination of ISI.

At frequencies where the transfer function of channel attains small values, the equalizer has a strong amplification and thus also amplifies the noise.

$$\underline{\overline{H}}\left(e^{j\omega T_s}\right) = \frac{1}{T_s}\sum_{n=-\infty}^{\infty}\left|\hat{\underline{\overline{H}}}\left(\omega + \frac{2\pi n}{T_s}\right)\right|^2 \quad |\omega| \le \frac{\pi}{T_s}$$

The noise power at detector is

$$\sigma^2_{n\text{-}LE\text{-}ZF} = N_0 \frac{T_s}{2\pi}\int_{-\frac{\pi}{T_s}}^{\pi/T_s} \frac{1}{\underline{\overline{H}}\left(e^{j\omega T_s}\right)}\, d\omega$$

Minimum Mean Square Error Equalizer :-

The ultimate goal of an equalizer is minimization of the bit error probability & not ISI. Noise enhancement make ZF equalizer not suitable for this purpose. A better criterion is minimization of Mean Square Error (MSE) b/w transmit signal & output of the equalizer.

$$MSE = E\{|\varepsilon_i|^2\} = E\{\varepsilon_i \varepsilon_i^*\}$$

$$e_{opt} = R^{-1} p$$

Least Mean Square Algorithm :-

The LMS algorithm : also known as the stochastic gradient method, consists of the following steps :

1. Initialize the weights with values e_0.
2. With this value, compute an approximation for the gradient of MSE, We are using an estimate for R & p.

$$\hat{R}_n = u_n^* u_n^T$$

$$\hat{p}_n = u_n^* c_n$$

Where subscript n indexes the iterations. The gradient is estimated as $\hat{\nabla}_n = -2\hat{p}_n + 2\hat{R}_n e_n$

3. We next compute an updated estimate of the weight vector e by adjusting weights in the direction of negative gradient :

$$e_{n+1} = e_n - \mu \hat{\nabla}_n$$

4. If the stop criterion is fulfilled the algo. has converged. Otherwise, we return to step 2.

It can be shown that the LMS algorithm converges if

$$0 < \mu < \frac{2}{\lambda_{max}}$$

Here λ_{max} is the largest eignvalue of correlation matrix R.

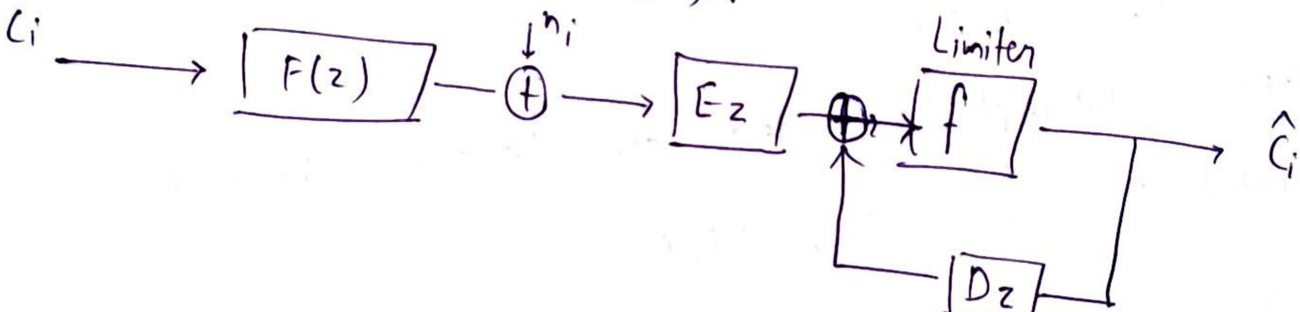
~~Non linear Methods offers~~

Non Linear Methods offers improvements over linear techniques

(1) Decision Feedback Equalizers :-

Once a bit is correctly detected, the effect this bit on subsequent bit is determined. The ISI caused by each bit is then subtracted from these later samples.

The DFE consists of a forward filter with transfer function E(z), which is a conventional linear equalizer as well as feedback filter with transfer function D(z).



MMSE DFE :-

The goal of MMSE DFE is again minimization of mean square error. We now aim to minimize the sum of noise & average precursor ISI.

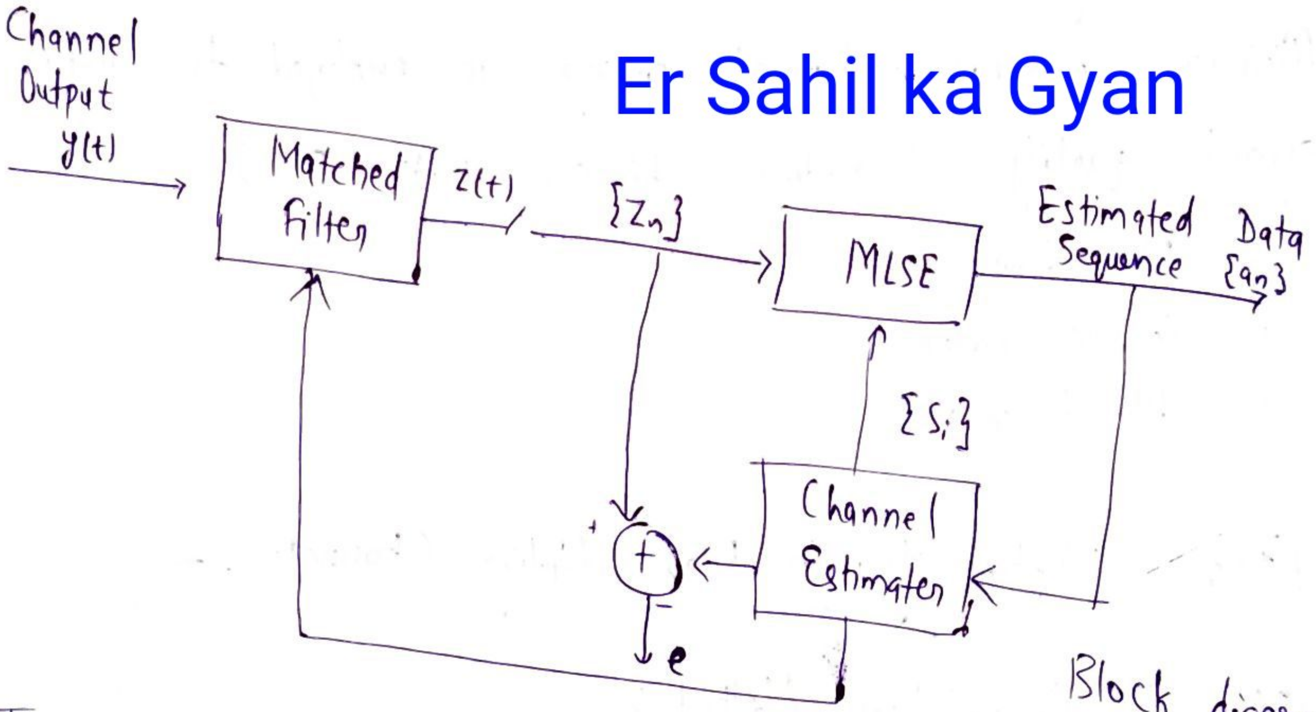
coefficient of feedback filter $\quad d_n = -\sum_{k,j,b}^{0} e_m f_{n-m}$

$$\sigma_n^2(DFE-MMSE) = N_0 \exp\left[\frac{T_s}{2\pi}\int_{-\pi/T_s}^{\pi/T_s} \ln\left[\frac{1}{\Xi(e^{j\omega T})+N_0}\right] d\omega\right]$$

(ii) Maximum Likelihood Sequence Estimation (MLSE) Equalizer

A DFE is not an optimum equalizer because it just outmatches the linear equalizer. MLSE gives optimum performance as it tests all the possible data sequences and choose that data as output which has the maximum probability. MLSE as an equalizer was first proposed by Forney.

→ The MLSE is optimal in the sense that it minimized the probability of a sequence error.



Block diagram of MLSE

The MLSE requires the knowledge of:

1. The channel characteristics in order to compute the metrics for making decisions.
2. The statistical distribution of noise corrupting the signal.

Diversity

Error Probability in Fading Channels :-

Speech Coding ⇒ Speech coding is the process for reducing the bit rate of digital speech representation for transmission, while maintaining a speech quality that is acceptable for application.

Speech coding is used to save bandwidth & improve bandwidth efficiency whereas channel coding is employed to improve signal quality & reduce bit-error-rate (BER).

⟶ Waveform coders
⟶ Source coders
⟶ Hybrid coders

ERROR Probability in Flat-fading Channels :-

Classical Computation Method ⇒

The error probability of diversity systems by averaging the conditional error probability over the distribution of the SNR.

$$\overline{SER} = \int_0^{\infty} pdf_\gamma(\gamma)\, SER(\gamma)\, d\gamma$$

$$SER(\gamma) = Q(\sqrt{2\gamma})$$

$$pdf_\gamma(\gamma) = \frac{1}{(N_t-1)!} \frac{\gamma^{N_t-1}}{\bar{\gamma}^{N_t}} \exp\left(-\frac{\gamma}{\bar{\gamma}}\right)$$

$$\overline{SER} = \left(\frac{1}{4\bar{\gamma}}\right)^{N_r}\left(\frac{2N_r - 1}{N_r}\right)$$

Computation via the Moment-Generating function

$$SER(\gamma) = \int_{\theta_1}^{\theta_2} f_1(\theta)\exp\left(-\gamma_{MRC}\, f_2(\theta)\right) d\theta$$

$$\overline{SER} = \frac{1}{\pi}\int_0^{\pi/2}\left[\frac{\sin^2\theta}{\sin^2\theta + \bar{\gamma}}\right]^{N_t} d\theta$$

Symbol Error Rate in Frequency - Selective fading Channels

$$\overline{SER} = \frac{(2N_r - 1)!!}{2(N_r!)}\left(\frac{1 - |\rho_{xy}|^2}{2(Im\{\rho_{xy}\})^2}\right)^{N_r}$$

Principle of Diversity

→ Diversity is a technique used to compensate for fading channel impairments & is usually implemented by using two or more receiving antennas.

→ Diversity is usually employed to reduce the depth & duration of fades experienced by a receiver in flat fading channel.

→ Diversity techniques can be employed at both base station & mobile receivers.

→ The principle of diversity is to ensure that the same information reaches the receiver (RX) on statistically independent channels.

Diversity is a powerful communication receiver technique that provides wireless link improvement at relatively low cost. Diversity exploits the random nature of radio propagation by finding independent signal paths for communication.

Diversity

- Micro diversity
- Macrodiversity

There are two types of fading:-

1. Small Scale fading
2. Large Scale fading

→ Small scale fades are characterised by deep & rapid amplitude fluctuations. In order to prevent deep-fades from occurring, microscopic diversity techniques are used.

→ Large scale fading is caused by shadowing due to variations in both terrain profile & the nature of surroundings. In order to prevent large-scale fades from occuring, macroscopic diversity techniques are used.

Macrodiversity :-

Macrodiversity is used to combat large scale fading due to shadowing.

Macrodiversity can be achieved by

1. Simulcast
2. On-frequency repeaters.

Simulcast :—

In simulcast, the same signal is transmitted simultaneously from different BSs. In cellular applications the two BSs should be synchronized, & transmit the signals intended for specific user in such way that two waves arrive at RX almost simultaneously.

On-frequency Repeaters:—

The simplest method for macrodiversity is the use of on-frequency repeaters that receive the signal & retransmit an amplified version of it.

Microscopic Diversity

Small-scale fades are characterised by deep & rapid amplitude fluctuations which occur as the mobile moves over small distances. In order to prevent deep fades from occurring, microscopic diversity techniques are used. Microscopic diversity is used to combat small-scale fading. The 5 most common methods are as follows:

The Space/ Spatial Diversity Techniques :-

In this techniques, several antenna elements separated in space.

The concept of antenna space diversity is also used in base station design. At each cell site, multiple base station receiving antennas are used to provide diversity reception.

Space diversity reception method can be classified into 4 categories:

→ Selection diversity
→ Feedback diversity
→ Maximal Ratio Combining
→ Equal Gain diversity

Er Sahil ka Gyan

~~The Poloziati~~

The Polarization, Time & Frequency Diversity Techniques

Polarization Diversity :-

It is assumed that the signal is transmitted from a mobile with vertical polarization. It is received at the base station by polarization diversity antenna with two branches.

Circular & linear polarization antennas have been used to characterise multipath inside buildings. When the path was obstruced, polarization diversity was found to to dramatically reduce the multipath delay spread without significantly decreasing the received power.

Frequency Diversity :-

It is implemented by transmitted information on more than one carrier frequency. The rationable behind this technique is that frequencies separated by more than the coherence bandwidth of channel will be uncorrelated & will thus not experience the same fades.

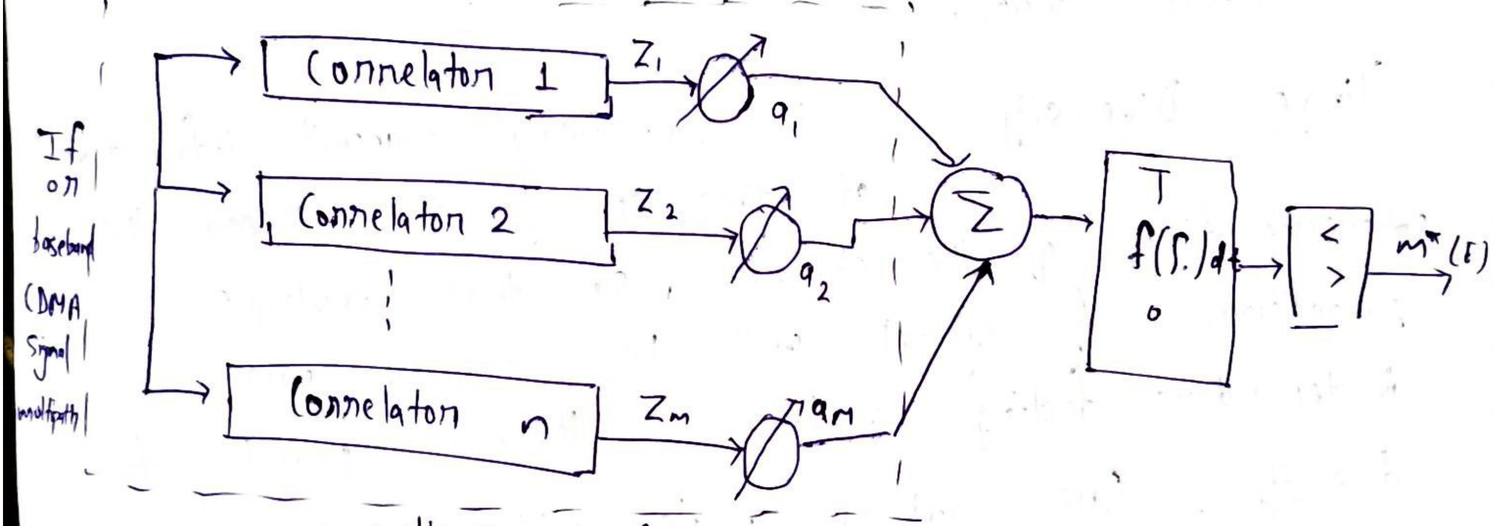
Time Diversity :- It repeatedly transmits information at time spacing that exceed the coherence time of the channel, so that multiple repetitions of signal will be received with independent fading conditions, thereby providing for diversity. One modern implementation of time diversity involves the use of RAKE receiver for spread spectrum CDMA, where the multipath channels provide a redundancy in transmitted message.

Angle Diversity :- A fading dip is created when MPCs interfere destructively. Two co-located antennas with different patterns see differently weighted MPCs, so that the MPCs interfere differently for the two antennas. This is the principle of angle diversity (also known as pattern diversity)

RAKE Receiver

It reduces the multipath interference by combining direct & reflected signals in the receiver.

The RAKE receiver is essentially a diversity receiver designed specifically for CDMA, where the diversity is provided by the fact that the multipath components are practically uncorrelated from one another when their relative propagation delays exceed a chip period.



multipath interference suppression

Er Sahil ka Gyan

A rake receiver utilizes multiple correlators to separately detect the M strongest multipath components. The output of each correlators are then weighted to provide a better estimate of transmitted signal than is provided by a single component.

$$a_M = \frac{Z_M^2}{\sum_{m=1}^{M} Z_M^2} \qquad Z' = \sum_{m=1}^{M} a_M Z_M$$

The weighting coefficients, α_M are normalized to output signal power of correlator in such a way the coefficients sum to unity.