4.4 DIVERSITY

Fundamentals of Diversity Techniques

Diversity exploits the random nature of radio propagation by finding independent signal paths for communication, so as to boost the instantaneous SNR at the receiver.

Diversity is a powerful communication receiver technique that provides wireless link improvement at relatively low cost. Requires no training

A diversity scheme is a method that is used to develop information from several signals transmitted over independent fading paths.

Small Scale fading causes deep and rapid amplitude fluctuations as mobile moves over a very small distances.

If we space 2 antennas at 0.5 m, one may receive a null while the other receives a strong signal. By selecting the best signal at all times, a receiver can mitigate or reduce small-scale fading. This concept is called Antenna Diversity.

In virtually all applications, diversity decisions are made by the receiver, and are unknown to the transmitter.

Two types of diversity

Microscopic diversity - small scale fading

Macroscopic diversity - large scale fading

Microscopic diversity

Small-scale fades: deep and rapid amplitude fluctuations over distances of just a few wavelengths. Caused by multiple reflections from the surroundings in the vicinity of the mobile. Results in a Rayleigh fading distribution of signal strength over small distances.

Microscopic diversity techniques can exploit the rapidly changing signal.

For example, use two antennas at the receiver (separated by a fraction of a meter), one may receive a null while the other receives a strong signal.

By selecting the best signal at all times, a receiver can mitigate small-scalefading effects called antenna diversity or space diversity.

Example: Rake receiver

Macroscopic diversity

Macroscopic diversity is also useful at the base station receiver.

By using base station antennas that are sufficiently separated in space, the base station is able to improve the reverse link by selecting the antenna with the strongest signal from the mobile.

Used to combat slow fading (shadowing)

Samples: Base-station handoff in cellular networks.

Derivation of Selection Diversity improvement

Consider M independent Rayleigh fading channels available at a receiver as in figure 4.4.1. Each channel is called a diversity branch.

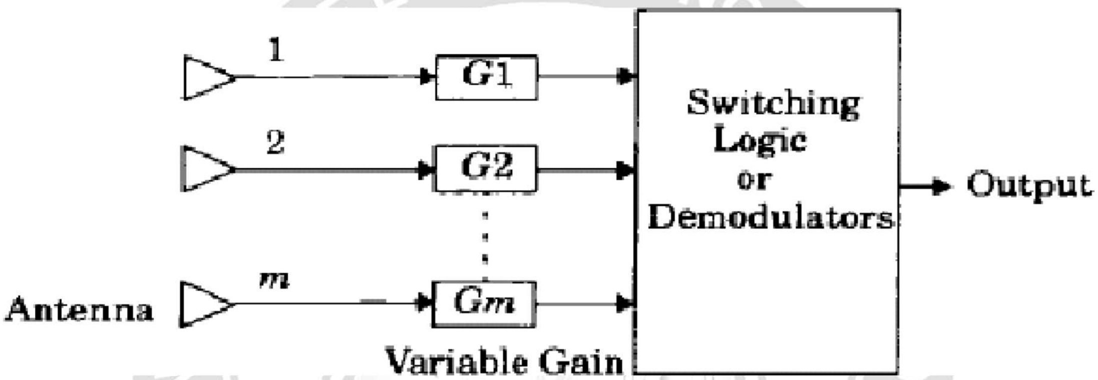

Fig4.4.1: Space diversity

[Source : "Wireless communications" by Theodore S. Rappaport,Page-330]

Assume that each branch has the same average SNR given by

$$SNR = \Gamma = \frac{E_b}{N_0}\overline{\alpha^2}$$

$$\overline{\alpha^2} = 1\,.$$

$$p(\gamma_i) = \frac{1}{\Gamma}e^{\frac{-\gamma_i}{\Gamma}} \qquad \gamma_i \geq 0$$

Assume, If each branch has an instantaneous SNR= γ_i ,

Where Γ́ is the mean SNR of each branch.

The probability that a single branch has SNR less than some threshold is

$$Pr[\gamma_i \le \gamma] = \int_0^{\gamma} p(\gamma_i)\,d\gamma_i = \int_0^{\gamma} \frac{1}{\Gamma} e^{\frac{-\gamma_i}{\Gamma}}\,d\gamma_i$$

Practical Space Diversity Considerations

Space diversity (also known as antenna diversity), is one of the most popular forms of diversity used in wireless systems.

The signals received from spatially separated antennas on the mobile would have essentially uncorrelated envelopes for antenna separations of one half wavelength or more.

Space diversity can be used at either the mobile or base station, or both.

Since the important scatterers are generally on the ground in the vicinity of the mobile, when base station diversity is used, the antennas must be spaced considerably far apart to achieve decorrelation (several tens of wavelengths).

Space diversity reception methods:

Selection diversity.

It is the simplest diversity technique.

Selection diversity offers an average improvement in the link margin without requiring additional transmitter power or sophisticated receiver circuitry.

Selection diversity is easy to implement because all that is needed is a side monitoring station and an antenna switch at the receiver.

It is not an optimal diversity technique because it does not use all of the possible branches simultaneously.

Feedback or Scanning diversity

Scanning all the signals in a fixed sequence until the one with SNR more than a predetermined threshold is identified. Also called switch and stay combining.

Basic form of Scanning diversity(Fig:4.4.2).

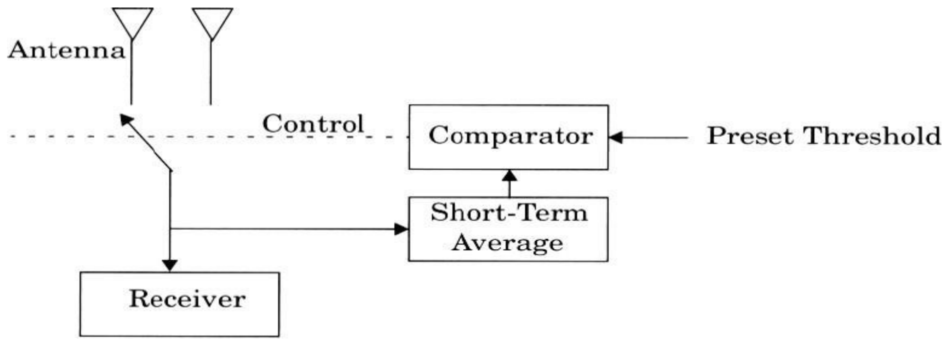

Fig4.4.2: Basic form of Scanning diversity

[Source : "Wireless communications" by Theodore S. Rappaport,Page-331]

Maximal Ratio Combining

In this method proposed by Kahn, the signals from all of the M branches are weighted according to their individual signal voltage to noise power ratios and then summed.

Combining all the signals in a co-phased and weighted manner so as to have the highest achievable SNR at the receiver at all times.

Consider M branches which are maximal ratio combined in a co phased and weighted manner in order to achieve high SNR.(Fig: 4.4.3)

Here the individual signals must be co-phased before being summed.

Maximal ratio combining produces an output SNR equal to the sum of the individual SNRs.

Thus, it has the advantage of producing an output with an acceptable SNR even when none of the individual signals are themselves acceptable.

This technique gives the best statistical reduction of fading of any known linear diversity combiner. Modern DSP techniques and digital receivers are now making this optimal form of diversity practical.

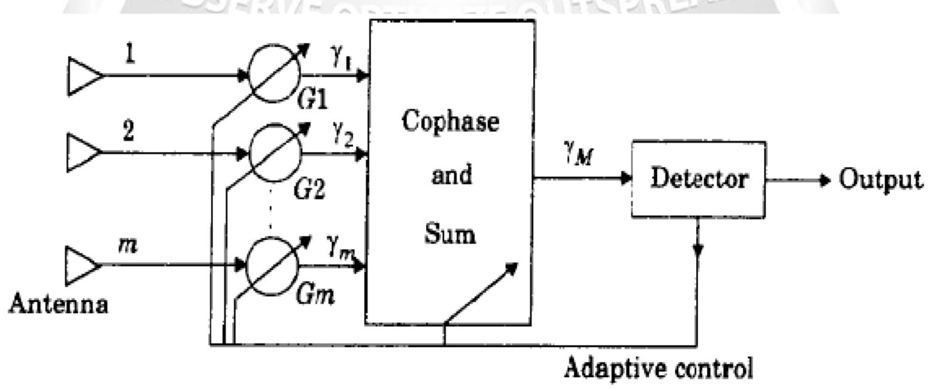

Fig4.4.3: Maximal ratio combiner

[Source : "Wireless communications" by Theodore S. Rappaport,Page-332]

Equal Gain Combining

Combining all the signals in a co-phased manner with unity weights for all signal levels. The possibility of producing an acceptable signal from a number of unacceptable inputs is still retained, and the performance is only marginally inferior to maximal ratio combining and superior to selection diversity.

Polarization Diversity

At the base station, space diversity is considerably less practical.

Polarization diversity only provides two diversity branches, but allows the antenna elements to be co-located.Measured horizontal and vertical polarization paths between a mobile and a base station are reported to be uncorrelated.

De correlation for the signals in each polarization is caused by multiple reflections between mobile and base station antennas.

The reflection coefficient for each polarization is different, which results in different amplitudes and phases for each, or at least some, of the reflections.

After sufficient random reflections, the polarization state of the signal will be independent of the transmitted polarization.

In practice, there is some dependence of the received polarization on the transmitted polarization.

Transmits information on more than one carrier frequency.

Frequencies separated by more than the coherence bandwidth of the channel will not experience the same fades.

Frequency diversity is employed in microwave LOS links.

Frequency diversity transmits information on more than one carrier frequency.

Due to tropospheric propagation and resulting refraction, deep fading sometimes occurs. In practice, 1:N protection switching is provided by a radio licensee, wherein one frequency is nominally idle but is available on a stand-by basis to provide frequency diversity switching for any one of the N other carriers (frequencies) being used on the same link, each carrying independent traffic.

When diversity is needed, the appropriate traffic is simply switched to the backup frequency.

Disadvantage: not only requires spare bandwidth but also requires that there be as many receivers as there are channels used for the frequency diversity.

For critical traffic, the expense may be justified.

New OFDM modulation and access techniques exploit frequency diversity by providing simultaneous modulation signals with error control coding across a large bandwidth.

If a particular frequency undergoes a fade, the composite signal will still be demodulated.

Time Diversity

Time diversity repeatedly transmits information at time spacings that exceed the coherence time of the channel

Multiple repetitions of the signal will be received with independent fading conditions.

One modern implementation of time diversity involves the use of the RAKE receiver for spread spectrum CDMA, where the multipath channel provides redundancy in the transmitted message.