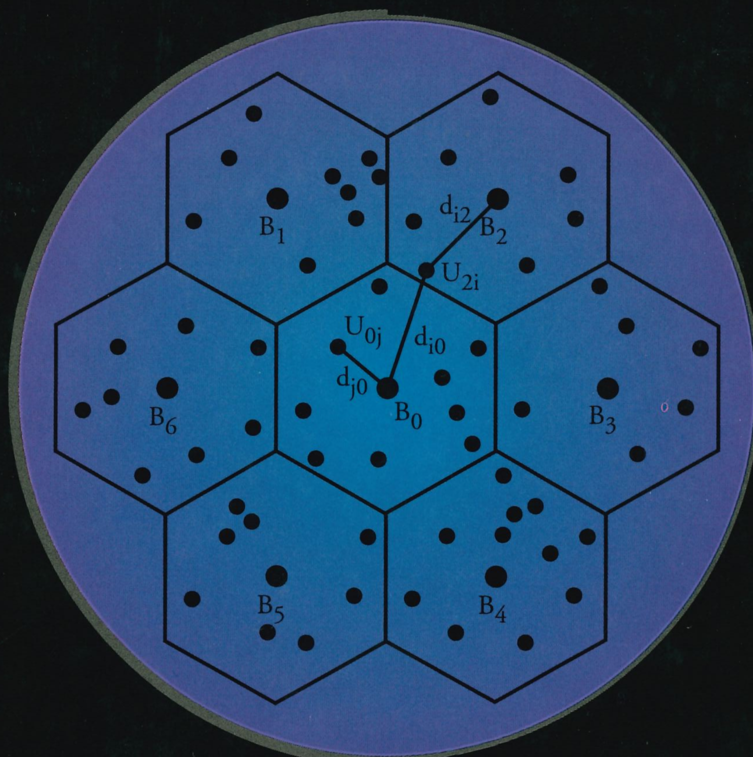
WIRELESS communications

Principles & Practice



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6.10 Diversity Techniques

Diversity is a powerful communication receiver technique that provides wireless link improvement at relatively low cost. Unlike equalization, diversity requires no training overhead since a training sequence is not required by the transmitter. Furthermore, there are a wide range of diversity implementations, many which are very practical and provide significant link improvement with little added cost.

Diversity exploits the random nature of radio propagation by finding independent (or at least highly uncorrelated) signal paths for communication. In virtually all applications, diversity decisions are made by the receiver, and are unknown to the transmitter.

The diversity concept can be explained simply. If one radio path undergoes a deep fade, another independent path may have a strong signal. By having more than one path to select from, both the instantaneous and average SNRs at the receiver may be improved, often by as much as 20 dB to 30 dB.

As shown in Chapters 3 and 4, there are two types of fading – small-scale and large-scale fading. Small-scale fades are characterized by deep and rapid amplitude fluctuations which occur as the mobile moves over distances of just a few wavelengths. These fades are caused by multiple reflections from the surroundings in the vicinity of the mobile. Small-scale fading typically results in a Rayleigh fading distribution of signal strength over small distances. In order to prevent deep fades from occurring, *microscopic diversity techniques* can exploit the rapidly changing signal. For example, the small-scale fading shown in Figure 3.1 reveals that if two antennas are 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-scale fading effects (this is called *antenna diversity* or *space diversity*).

Large-scale fading is caused by shadowing due to variations in both the terrain profile and the nature of the surroundings. In deeply shadowed conditions, the received signal strength at a mobile can drop well below that of free space. In Chapter 3, large-scale fading was shown to be log-normally distributed with a standard deviation of about 10 dB in urban environments. By selecting a base station which is not shadowed when others are, the mobile can improve substantially the average signal-to-noise ratio on the forward link. This is called *macroscopic diversity*, since the mobile is taking advantage of large separations between the serving base stations.

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.

virtually any diversity application, although often at much greater cost and complexity than other diversity techniques.

6.10.3 Practical Space Diversity Considerations

Space diversity, also known as antenna diversity, is one of the most popular forms of diversity used in wireless systems. Conventional cellular radio systems consist of an elevated base station antenna and a mobile antenna close to the ground. The existence of a direct path between the transmitter and the receiver is not guaranteed and the possibility of a number of scatterers in the vicinity of the mobile suggests a Rayleigh fading signal. From this model [Jak70], Jakes deduced that the signals received from spatially separated antennas on the mobile would have essentially uncorrelated envelopes for antenna separations of one half wavelength or more.

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. However, since the important scatterers are generally on the ground in the vicinity of the mobile, the base station antennas must be spaced considerably far apart to achieve decorrelation. Separations on the order of several tens of wavelengths are required at the base station. Space diversity can thus be used at either the mobile or base station, or both. Figure 6.12 shows a general block diagram of a space diversity scheme [Cox83a].

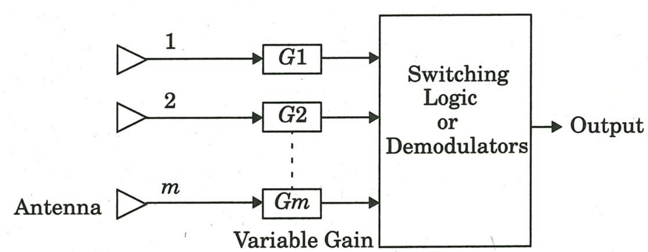

Figure 6.12
Generalized block diagram for space diversity.

Space diversity reception methods can be classified into four categories [Jak71]:

1. Selection diversity
2. Feedback diversity
3. Maximal ratio combining
4. Equal gain diversity

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6.10.3.1 Selection Diversity

Selection diversity is the simplest diversity technique analyzed in section 6.10.1. A block diagram of this method is similar to that shown in Figure 6.12, where m demodulators are used to provide m diversity branches whose gains are adjusted to provide the same average SNR for each branch. As derived in section 6.10.1, the receiver branch having the highest instantaneous SNR is connected to the demodulator. The antenna signals themselves could be sampled and the best one sent to a single demodulator. In practice, the branch with the largest $(S+N)/N$ is used, since it is difficult to measure SNR. A practical selection diversity system cannot function on a truly instantaneous basis, but must be designed so that the internal time constants of the selection circuitry are shorter than the reciprocal of the signal fading rate.

6.10.3.2 Feedback or Scanning Diversity

Scanning diversity is very similar to selection diversity except that instead of always using the best of M signals, the M signals are scanned in a fixed sequence until one is found to be above a predetermined threshold. This signal is then received until it falls below threshold and the scanning process is again initiated. The resulting fading statistics are somewhat inferior to those obtained by the other methods but the advantage with this method is that it is very simple to implement — only one receiver is required. A block diagram of this method is shown in Figure 6.13.

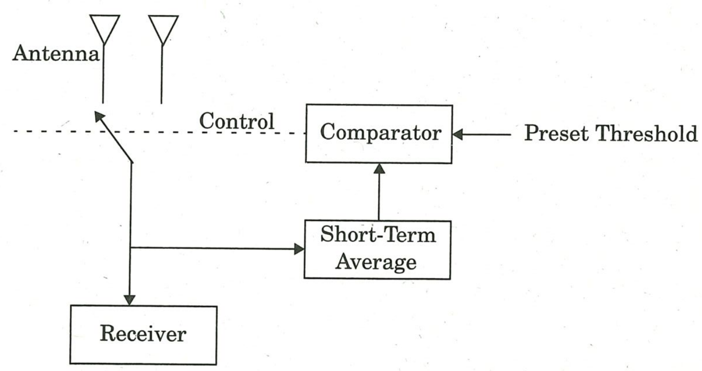

Figure 6.13
Basic form of scanning diversity.

6.10.3.3 Maximal Ratio Combining

In this method first proposed by Kahn [Kah54], the signals from all of the M branches are weighted according to their individual signal voltage to noise power ratios and then summed. Figure 6.14 shows a block diagram of the technique. Here, the individual signals must be co-phased before being summed

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