Diversity in Wireless Systems

In Chapter 3, we pointed out that a radio channel is subjected to fading, time dispersion, and other degradations. Diversity techniques are employed to overcome these impairments and improve signal quality [6,13,15,20]. The basic concept of diversity is that the receiver has more than one version of the transmitted signal available, and each version of transmitted signal is received through a distinct channel. When several versions of the signal, carrying the same information, are received over multiple channels that exhibit independent fading with comparable strengths, the chances that all the independently faded signal components experience the same fading simultaneously are greatly reduced. Suppose the probability of having a loss of communications due to fading on one channel is *p* and this probability is independent on all *M* channels. The probability of losing communications on all channels simultaneously is then p^M. Thus, a 10% chance of losing the signal for one channel is reduced to 0.1^3 _ 0.001 _ 0.1% with three independently fading channels [5,17]. Typically, the diversity receiver is used in the base station instead of the mobile station, because the cost of the diversity combiner can be high, especially if multiple receivers are necessary. Also, the power output of the mobile station is limited by the battery. Handset transmitters usually lower power than mobilemounted transmitters to preserve battery life and reduce radiation into the human body. The base station, however, can increase its power output or antenna height to improve the coverage to a mobile station.

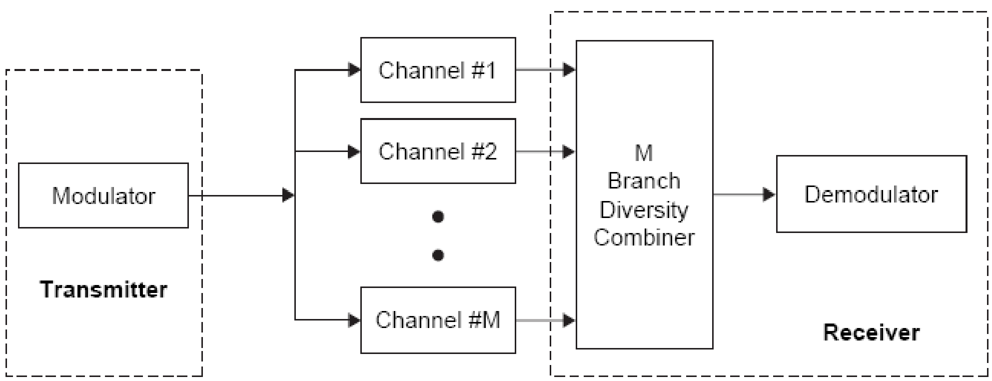

Figure 10.5 Diversity channel model.

Each of the channels, plus the corresponding receiver circuit, is called a *branch* and the outputs of the channels are processed and routed to the demodulator by a *diversity combiner* (see Figure 10.5). Two criteria are required to achieve a high degree of improvement from a diversity system. First, the fading in individual branches should have low cross correlation. Second, the mean power available from each branch should be almost equal. If the cross-correlation is too high, then fades in each branch will occur simultaneously. On the other hand, if the branches have low correlation but have very different mean powers, then the signal in a weaker branch may not be useful even though it has less fades than the other branches.

Types of Diversity

The following methods are used to obtain uncorrelated signals for combining:

1. **Space diversity:** Two antennas separated physically by a short distance *d* can provide two signals with low correlation between their fades. The separation *d* in general varies with antenna height *h* and with frequency. The higher the frequency, the closer the two antennas can be to each other. Typically, a separation of a few wavelengths is enough to obtain uncorrelated signals. Taking into account the shadowing effect (see Chapter 3), usually a separation of at least 10 carrier wavelengths is required between two adjacent antennas. This diversity does not require extra system capacity; however, the cost is the extra antennas needed.

2. Frequency diversity: Signals received on two frequencies, separated by coherence bandwidth (see Chapter 3) are uncorrelated. To use frequency diversity in an urban or suburban environment for cellular and personal communications services (PCS) frequencies, the frequency separation must be 300 kHz or more. This diversity improves link transmission quality at the cost of extra frequency bandwidths.

3. Time diversity: If the identical signals are transmitted in different time slots, the received signals will be uncorrelated, provided the time difference between time slots is more than the channel *coherence time* (see Chapter 3). This system will work for an environment where the fading occurs independent of the movement of the receiver. In a mobile radio environment, the mobile unit may be at a standstill at any location that has a weak local mean or is caught in a fade. Although fading still occurs even when the mobile is still, the time-delayed signals are correlated and time diversity will not reduce the fades. In addition to extra system capacity (in terms of transmission time) due to the redundant transmission, this diversity introduces a signifi cant signal processing delay, especially when the channel coherence time is large. In practice, time diversity is more frequently used through bit interleaving, forward-error-correction, and automatic retransmission request (ARQ).

4. Polarization diversity: The horizontal and vertical polarization components transmitted by two polarized antennas at the base station and received by two polarized antennas at the mobile station can provide two uncorrelated fading signals. Polarization diversity results in 3 dB power reduction at the transmitting site since the power must be split into two different polarized antennas.

5. Angle diversity: When the operating frequency is _10 GHz, the scattering of signals from transmitter to receiver generates received signals from different directions that are uncorrelated with each other. Thus, two or more directional antennas can be pointed in different directions at the receiving site and provide signals for a combiner. This scheme is more effective at the mobile station than at the base station since the scattering is from local buildings and vegetation and is more pronounced at street level than at the height of base station antennas. Angle diversity can be viewed as a special case of space diversity since it also requires multiple antennas.

6. Path diversity: In code division multiple access (CDMA) systems, the use of direct sequence spread spectrum modulation allows the desired signal to be transmitted over a frequency bandwidth much larger than the channel coherence bandwidth. The spread spectrum signal can resolve in multipath signal components provided the path delays are separated by at least one chip period. A Rake receiver can separate the received signal components from different propagation paths by using code correlation and can then combine them constructively. In CDMA, exploiting the path diversity reduces the transmitted power needed and increases the system capacity by reducing interference

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