

Part 2: Radio Propagation

This course is not on physical property of radio transmission. As you will see later, little knowledge of radio transmission will be required when you study upper layer (MAC, Network, Transport, Application) protocols. You may, however, need to know and understand several commonly used radio propagation models. For this reason, we only focus on materials related to the purpose of this course.

1. Radio Spectrum

The radio spectrum is usually taken to comprise that part of the electromagnetic spectrum between frequencies of **3 kHz and 3000 GHz**. With present technology, it is not yet practical to use spectrum much above 100 GHz.

Different frequencies have different characteristics that make them suited for particular applications. Broadly speaking, lower frequencies travel further so are useful for applications such as broadcasting. Higher frequencies travel less far, which limits their usefulness in some respects but means they can be re-used more intensively, and have greater information carrying capacity.

Technical developments are continually raising the upper limit of the usable spectrum and developing ways of using lower frequencies more intensively. However, technology is being outpaced by rapidly growing demand for spectrum. The problem is greatest between **30 MHz and 30 GHz**. These are currently the most useful frequencies and so are most in demand.

Radio Spectrum is a valuable national resource and is usually managed by the government. However, the **Industrial, Scientific and Medical (ISM)** radio bands were originally reserved internationally for non-commercial use of RF electromagnetic fields for industrial, scientific and medical purposes. In recent years they have also been used for *license-free* error-tolerant communications applications such as wireless LANs and Bluetooth.

ISM bands: Usually the 900MHz band and the 2.45 GHz band are used. According to ITU (International Telecommunication Union), more bands are allocated to ISM applications. [Check: <http://www.itu.int/ITU-R/terrestrial/faq/4ISM.html> for details]

2. Frequency Reuse

Frequency reuse is the ability to use the same frequencies repeatedly across a cellular system. Since each cell is designed to use radio frequencies only within its boundaries, the same frequencies can be reused in other cells not far away with little potential for interference. The reuse of frequencies is what enables a cellular system to handle a huge number of calls with a limited number of channels.

The N cells which collectively use the complete set of available frequencies is called a cluster. N is called the cluster size and is typically equal to 3, 7, or 12, if a cell is modelled as a hexagon.

Due to the fact that the hexagonal geometry has exactly six equidistance neighbours and that the lines joining the centres of any cell and each of its neighbours are separated by multiples of 60 degrees, there are only certain cluster sizes and cell layouts which are possible. N can only have values which satisfy the following equation:

$$N = i^2 + ij + j^2$$

which i and j are non-negative integers. [Explain why]

In order to find the nearest co-channel neighbours of a particular cell, one must do the following: (1) move i cells along any chain of hexagons (2) turn 60 degrees counter-clockwise and move j cells.

[Examples]

3. Line-Of-Sight (LOS) Propagation Model

Unlike wired channels that are stationary and predictable, radio channels are extremely random and **do not offer easy analysis**. Modeling the radio channel has historically been one of the most difficult parts of mobile radio system design, and is typically done in a **statistical** fashion.

Propagation models have traditionally focused on predicting the average received signal strength at a given distance from the transmitter, as well as the variability of the signal strength in close spatial proximity to a particular location.

Propagation models that predict mean signal strength over large distances (several hundreds or thousands of meters) are called *large-scale propagation models*. On the other hand, propagation models that characterize the rapid fluctuations of the received signal strength over very short travel distance (a few wavelength) or short time durations (on the order of seconds) are called *small-scale or fading models*.

To facilitate the performance study of protocols at upper layers (MAC, networks, transport), we need some simple mathematical models to approximate the (mean) signal strength with the mind that the mathematical models are based on measurement and statistics and in no means the models are consistently accurate.

3.1 Free Space Path Loss

Due to its simplicity, Free Space Propagation model is one of the mostly-used large-scale models.

$$P_r(d) = P_t G_t G_r \lambda^2 / \{(4\pi)^2 d^2 L\}$$

Where P_t is the transmitted power, $P_r(d)$ is the received power, G_t is the transmitter antenna gain, G_r is the receiver antenna gain, d is the distance in meters, L is the system loss factor not related to propagation ($L \geq 1$, $L = 1$ indicates no loss in the system hardware) and λ is the wavelength in meters.

It is clear that the above equation does not hold for $d=0$. For this reason, large-scale propagation models use a close-in distance d_0 as a known received power **reference point**.

$$P_r(d) = P_r(d_0) * (d_0/d)^2$$

For further simplicity, free space propagation model can be modeled as:

$$P_r(d) = k/d^2$$

where k is a constant value.

Generalized free space propagation model:

$$P_r(d) = k/d^\mu$$

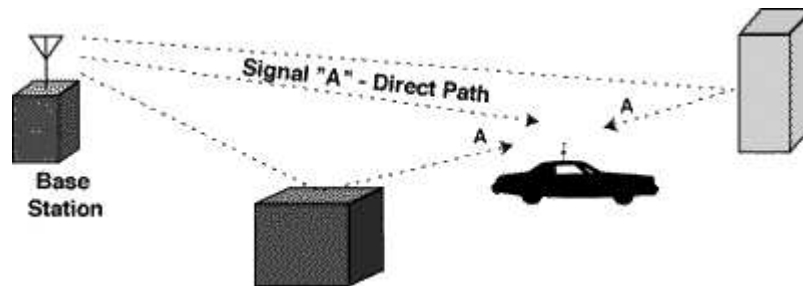
where k is a constant value and μ is a value between 2 and 4 depending on the transmission medium (for example medium with different humidity).

The concept of dB

[Example]

[The following materials are optional]

3.2 Multipath and fading



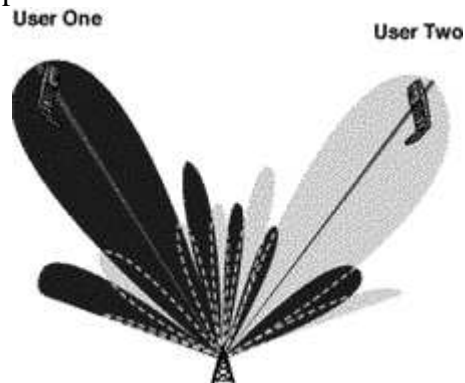
Radio wave is just like the wave generated by throwing a stone into a lake.

Fading—When the waves of multipath signals are out of phase, reduction in signal strength can occur. One such type of reduction is called a fade; the phenomenon is known as "Rayleigh fading" or "fast fading."

4. Smart Antenna

Smart antennas referred to an antenna array (system) combining with a digital signal-processing capability to transmit and receive in an adaptive and spatially sensitive manner. The key to this system is the ability to automatically change the directionality of its radiation patterns in response to its signal environment. This helps to combat impairments such as multi-path fading (also leading to delay spread) and co-channel interference, thereby improving the performance of wireless system. In wireless networks, smart antenna will be a promising technology in increasing the capacity of ad hoc networks and cellular based wireless networks. There exist many different types of smart antenna system. We will not touch the details of smart antenna, but we will study why new protocols are required in order to fully take advantage of this technology.

In truth, antennas are not smart—antenna systems are smart. Generally co-located with a base station, a smart antenna system combines an antenna array with a digital signal-processing capability to transmit and receive in an adaptive, spatially sensitive manner. In other words, such a system can automatically change the directionality of its radiation patterns in response to its signal environment. This can dramatically increase the performance characteristics (such as capacity) of a wireless system, by pointing the main lobes of the antenna-beam patterns in the direction of the users.



There are already commercial products of smart antenna. **But development of upper layer (MAC, network) protocols taking full advantage of such technique is still in its infancy.**