

Signal Propagation in the 900 MHz to 5 GHz Wireless Bands

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This tutorial article reviews the major propagation characteristics at the lower microwave frequencies, and their effects on wireless voice and data communication systems operating in that range

The effects of signal propagation are part of the transmission path for all radio signals. However, with the proliferation of digital modulation formats (some very complex), propagation effects play a much larger role. In fact,

dealing with such issues as fading and multipath are primary considerations in baseband signal processing. This brief tutorial identifies the issues in signal propagation that affect today's wireless communications systems.

Basic Path Loss Characteristics

All radio signals have their field intensity reduced with increasing distance, as the wave front spreads out like the surface of an inflating balloon. Microwave system designers will be familiar with the free-space loss equation:

$$\alpha = 36.6 + 20 \log f + 20 \log d$$

where α is the attenuation in dB, f is the frequency in MHz and d is the distance in miles. To obtain a result in dB, the above equation uses log notation, and is another form of the following:

$$P_{TX}/P_{RX} = 4.56 \times 10^3 f^2 d^2$$

where P_{TX} and P_{RX} are the transmitted and received power respectively. The latter equation shows that the loss is a function of both f^2 and d^2 . The dependence on frequency is, essentially, a conversion factor to express distance in wavelengths. The main characteristic

to note is that attenuation increases as the square of the distance. However, in the near-field—which is often considered to be zero distance to 10 times the largest dimension of the antenna—the attenuation increases approxi-

Propagation factors

Free-space path loss—Solely distance-related; loss vs. distance is $1/d^3$ in the near-field, $1/d^2$ in the far-field.

Absorption—Atmospheric absorption a relatively small factor; water vapor effects increase with frequency; vegetation and structures (walls, windows, etc.) have significant effects.

Natural and man-made noise—Natural noise is very small; man-made noise varies with location and type of environment (e.g. residential vs. commercial).

Reflection, refraction and multipath—Effects increase with frequency due to shorter wavelengths; time-delay effects require compensation in signal processing.

Specific areas of interest for wireless

The mobile environment—Motion results in changing patterns of fades and time delays.

The indoor environment—System design must accommodate variability in building materials, furnishings and building layout.

Statistical analysis—A proven tool for dealing with complex propagation issues.

Table 1. A summary of key propagation characteristics and related issues in wireless communications.

mately as the cube of the distance. With this information, we can make our first-order estimates of signal loss due to distance at the various frequencies of operation.

The next propagation characteristic to consider is absorption. Although atmospheric absorption is small up to 5 GHz (increasing at higher frequencies), other absorption types are part of the wireless environment. These mechanisms include the attenuation due to lossy dielectrics in structures, such as walls, windows, doors, cubicle partitions etc. The effects of each type of material can be evaluated individually, but measurement is the usual method of evaluating this type environment. More about this later.

Noise is the next characteristic to note. At microwave frequencies, natural noise sources are trivial. Atmospheric noise is predominant at lower frequencies; solar and galactic noise is low-level and further attenuated by the atmosphere. This is not the case for man-made noise sources.

Noise is usually considered to be random and wideband. Many electrically-operated devices have the potential to create wideband noise that reaches to the GHz range. Any “spark” or fast rise time voltage transition generates unwanted signals over a wide frequency range. Although usually small, the proximity of these devices to our wireless equipment can result in detectable, or even interfering, noise levels (remember the $1/d^2$ and $1/d^3$ relationships). Finally, all the discrete-frequency low-level signals from clock oscillators, leakage and other low-level artifacts of normally-operating high frequency circuitry can add up to a measurable total power, with noise-like wideband characteristics.

Direct Paths and Multipath

The final major part of signal propagation at 900 MHz to 5 GHz is the behavior of the radio waves as they travel from the transmitter to

receiver. Signals are reflected from the ground, buildings and other objects. At distinct edges (e.g. corners of buildings) the signals will be diffracted, and variations in the atmosphere cause refraction. In other words, the transmitted signal is scattered, bent and bounced before it reaches the receiver.

The Mobile Environment

At the receive antenna, the direct signal and these modified signals are summed, which can result in either reinforcement or cancellation. If our radios and the environment are stable (e.g. point-to-point microwave over short distance), all we need to do to avoid signal problems is move the antenna to a spot where the signal is strong. But if we are moving, the reinforcements and cancellations will be constantly varying—the single most important matter in mobile wireless communications.

The Indoor Environment

Although a self-contained indoor wireless system like a WLAN has very little motion to deal with, the environment is much more cluttered than that between a cellular base station and a mobile handset. Walls, floors, ceilings, cubicles, office furniture and people are present. As noted earlier, this environment is too complex to model as a collection of discrete objects, in the same way that the constantly-varying mobile environment cannot be modeled.

Measurements and Statistics

Why do we need to understand propagation so thoroughly? Because of the high performance of our wireless systems. An analog voice-only radio can tolerate a lot of variation—we may know what the other party means even if there is a fade, or we can ask for it to be repeated. If the system operates 99 percent of the time, one percent isn’t missed.

But in a digital system, 1 percent is a lot of data. Detecting missing

data, requesting a repeat and re-sending the data take up even more time. Also, because they are numerically-based, digital systems do not tolerate errors. 1 percent outage may result in 20 or percent or greater reduction in throughput. To achieve higher reliability, we need to know what conditions our digital system must tolerate. Since we can’t model the exact propagation path, we must have an alternative method for performance prediction. Thus, statistical methods have been developed.

Based on mathematical models and measured data, these methods are now the basis of evaluating the reliability of communications in both mobile and indoor environments. While work continues, the most significant work was done in the 1980s, providing many graduate students with topics for their theses!

The mobile environment generally uses a combination of Rayleigh fading model and Additive White Gaussian Noise (AWGN). The Rayleigh model determines the reliability of the path by providing a relationship between the average signal-to-noise ratio and the number of expected errors. AWGN is used to set specific signal-to-noise ratios. Both computer simulation and simulated-path test equipment use these models to evaluate the quality of particular system, circuit and signal processing schemes.

The indoor environment remains more complex. Measurements remain an important technique, with several vendors offering test sources and receivers for relatively fast on-site evaluation of a proposed system.

There are valid models for the prediction of indoor system performance, some of them proprietary. In general, these use a floor plan and basic structural data to estimate indoor wireless performance. These models are usually backed up with measurements, which usually can be coupled to the software models to refine the prediction.