800 to 900 MHz Radio Frequency Propagation Characteristics

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The following short paper has been prepared to provide a background in the radio propagation characteristics which affect Cellular and Specialized Mobile Radio Communications.

Radio Frequency, or RF signals, weaken as they travel through free space because of divergence or dispersal, much the way light travels away from a light bulb. The free space attenuation, or weakening, which RF signals experience as they travel is based on the square of the distance traveled. When the distance of an RF path is increased by a factor of ten, the signal is decreased by a factor of one hundred.

Traditionally, free space path loss has been defined by the following formula:

$$\textbf{Free Space Path Loss in dB} = 20 \log_{10} (\text{km}) + 20 \log_{10} (\text{MHz}) + 32.45 \text{ dB}$$

Example: 10 miles = 16 km = 115 dB @ 850 MHz

As you can see, the path loss of RF signals traveling through the medium of free space is simply a function of the distance traveled and frequency of the signal, between two isotropic antennae. This however pertains only to RF signals traveling through free space, a perfect vacuum, and not necessarily to RF signals traveling along the surface of the earth. In addition to free space path loss, or attenuation, there is absorption of RF signals here on earth by the medium through which the energy travels. Our atmosphere, including falling rain drops and snow flakes, affords negligible attenuation to RF signals in the 800 to 900 MHz frequency range. This is because the relative size of these electrically conductive particles are so small when compared with the size of one wavelength, or Lamba, at these frequencies. Typically, there is little absorption when the largest dimension of the medium is less than 1/10 Lambda. Other media such as leaves, building materials, and terrain obstructions do absorb RF signals at different rates depending on the characteristics of the medium and the frequency of the RF signals. In general, absorption is higher as frequency increases. Of course, some media such as uncoated glass window pane, and plastics offer very little absorption. Some electrically conductive media are particularly lossy when the largest dimension of the medium, aligned in the plane of the polarization of the electric field component of the electro-magnetic wavefront, is precisely 1/2 Lambda. In this instance the medium is actually resonant at the frequency of interest, and is resonated by the RF energy, such that RF current will flow and be measurable on the medium.

The size of one wavelength, or Lambda, at a frequency of interest is calculated as follows:

A. For One Wavelength In Meters:

$$\frac{300}{\text{(Frequency in MHz)}}$$

B. For One Wavelength In Feet:

$$\frac{984}{\text{(Frequency in MHz)}}$$

In many cases springtime foliage growth can be linked to a degradation in RF Propagation compared with seasons with reduced foliage growth, such as winter. Some generalized RF absorption rates for the 800 to 900 MHz frequency range, due purely to foliage absorption are as follows:

Percent Forested	**Attenuation (dB)**
less than 25 %	5
25 to 49 %	10
50 to 74 %	15
more than 75 %	20
Dense Swamp	25

Man-made structures such as buildings and other obstructions typically attenuate RF signals through absorption and scattering. Some generalized RF attenuation rates for the 800 to 900 MHz frequency range, due purely to land development clutter are as follows:

Land Development	**Attenuation (dB)**
Rural	0
Town	5
Suburban	10
City	15
Dense Urban	20

When one end of the radio link moves past large shadowing obstructions, the variation in the mean signal received has a lognormal distribution (a normal distribution of decibel measurements).

Often the desired path is into or out of a building, in which case building construction determines the ability of RF signals to penetrate the building in question. The size of the openings in the exterior of the building, and the size of the typical spaces within the building normally lend an advantage to higher frequencies. Some typical building penetration losses for the 800 to 900 MHz frequency range are as follows:

Type of Building	Penetration Loss (dB)
Large Commercial Bldg or Shopping Mall	15
Small to Medium Offices, Stores, or Factories	10
Residential and Light Commercial Bldgs	5
Typical Automobile	10

Having said this, some local terrains support reflection, refraction, and diffraction which can sometimes help to bend or bounce our signal to where it is needed. The snow and ice covered ground which some areas experience in winter would clearly afford some reflection of desired, as well as undesired, RF signals. Bodies of water can do this all year long. Man-made structures such as water towers can often reflect RF signals. In addition, in some areas in the late spring through early fall, there can be RF Propagation enhancements caused by changes in temperature and humidity affecting the lowest level of our atmosphere, the troposphere. Sometimes these changes will afford a refractive tropospheric layer which will encourage scattering of RF signals over much longer than usual paths. The aforementioned boons to RF Propagation are not always such a good thing, since they can result in extraordinary interference from the substantial frequency re-use characteristic of a cellular constructed network. Increased co-channel, or same channel, frequency re-use interference through an improved path to an undesired site will manifest itself as degraded Bit Error Rate, and more specifically degraded voice quality. Finally, desired signals traveling between two points usually travel along multiple paths causing differences in phase and amplitude upon their arrival. This is seen as the fading which causes variation in the amplitude of received signals, due to the combining in the receiver of both in-phase and out-of-phase energy. In the event that two RF signals traveling along different paths arrive at the receiver in-phase with one another, they will combine additively and the amplitude of the received signal will be greater than that which would have been received on only one path. While this beneficial condition is often the case, we are more concerned about when the RF signal traveling via the secondary path arrives at the receiver out-of-phase from the RF signal traveling along the primary path. If the phase difference between the two RF signals is 180 degrees there will instead be cancellation, such that if both signals are precisely 180 degrees out-of-phase and at precisely the same amplitude, neither signal will be received. Deeper fades will be experienced when the variation in amplitude between the primary and the secondary paths is reduced by selective enhancement of the secondary path, with respect to the primary path. All of this is made more complicated in environments supporting many RF signal paths, such as the dense urban environment.

When more than one half of the received RF signal is derived from RF signals traveling via reflections, the distribution of the amplitude of the composite received RF signal strength resembles a Rayleigh distribution. In the Rayleigh distribution the mean composite received RF signal is greater than the median, as contrasted to the Gaussian distribution where the mean and median are equal. Some typical fade margins and their probabilities are as follows:

Fade Margin (dB)	Percent Probability
-5	75
-10	90
-15	95
-20	99

In addition to reflections, RF signals are often refracted, or bent, as they travel from one medium to another. When two mediums which support the propagation of RF signals, such as air masses with different humidity and temperature characteristics, form a distinct boundary, this boundary can be refractive and cause bending of RF signals. Often enhanced propagation over longer than usual distances is the result of such a condition. RF signals traveling through the troposphere, the lowest level of the atmosphere, normally are refracted earthward because of the characteristic drop in humidity and temperature as altitude increases. This typically causes an RF signal horizon which is approximately 15 percent further out than the visual horizon, in normal conditions. However, temperature inversions and unusual weather patterns can sometimes support tropospheric ducting of RF signals, such that the RF signal horizon is extended to areas far beyond those expected in normal propagation conditions. This enhanced condition has been noted during extraordinary propagation of 800 to 900 MHz RF signals between points 500 to 1000 miles apart.

Natural obstructions such as hills and mountains can diffract RF signals around their peaks. Areas which would be thought of as entirely shadowed by such obstructions often surprise us by supporting meaningful RF signal levels. This is because the lower portion of the RF signal wavefront is slowed as it approaches the peak, while the upper portion of the RF signal wavefront surges forward, causing diffraction over the peak. In extreme cases where substantial RF signal is diffracted this is referred to as knife edge diffraction, however it is also common in less obvious cases as well. Soft absorptive hills can support diffraction such that RF signals propagated into their shadow are attenuated by at least 40 dB, while sharp rocky peaks can support diffraction such that RF signals propagated into their shadow are attenuated by less than 20 dB.

When analyzing the RF signal propagation over a given path, it is easiest to convert the transmitter antenna power (ERP) and receiver antenna sensitivity to dBm values (dB relative to one milliwatt), and deduct dBm which in your judgment represent the extent of attenuation due to the previously mentioned conditions. The resulting path loss "budget", of available dBm is used to "pay" for all of these "tolls" and provide reliable RF signal propagation over the path, at the system signal to noise requirement. While excess "budget" increases your prediction confidence level, it does come at a system cost.