Difficulties of Mobile Radio

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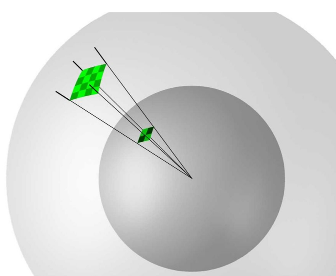
Transmission and reception of electromagnetic with enough control to transmit information is extremely difficult in uncontrolled environments. Here is a list of a few of the difficulties.

(Free Space) Path Loss

Distance

A wave emanating spherically from a point source with power P_t and received at source a distance d away from the point source has received intensity $I=P_t/(4\pi d^2)$. Thus, doubling the d distance from transmitter to receiver decreases intensity I by a factor of 4.

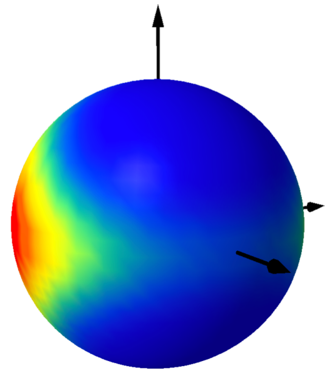


Wavelength

The received power is P_r = AI where A is the effective area of the receiver. Since size of an antenna scales with the wavelength λ it is designed to receive, $A \propto \lambda^2$. Thus, $P_r \propto \lambda^2/d^2$, and short wavelength electromagnetic waves have very weak received power.

In particular, if the receiving antenna was a sphere of radius λ, then its cross sectional area for absorbing the transmitted signal would be the area of the cross sectional circle, $\pi\lambda^2$. However, Antenna can not be 100% efficient in absorbing, reducing their effective area. Effective area of an antenna is called aperture. The aperture of an ideal spherical antenna of radius λ is $A_e=\lambda^2/(4\pi)$. Therefore,

$$P_r= \lambda^2 / 4\pi d^2.$$

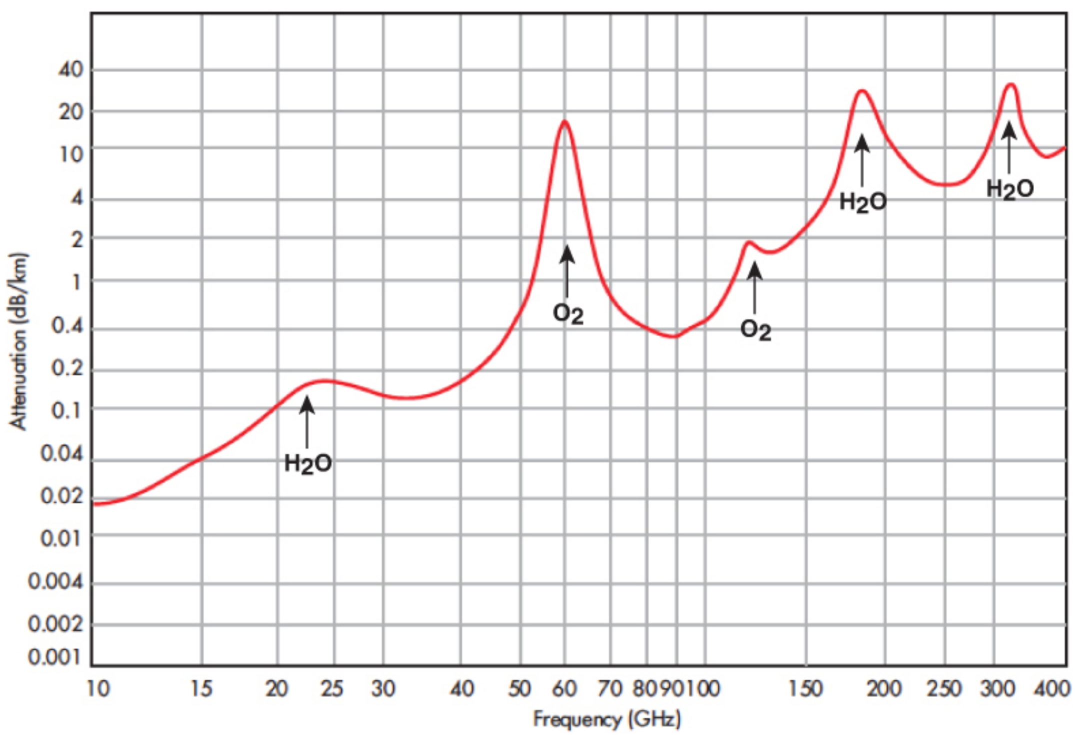


Intensity of an isotropically radiated wave (incoming from the right) received by a spherical antenna

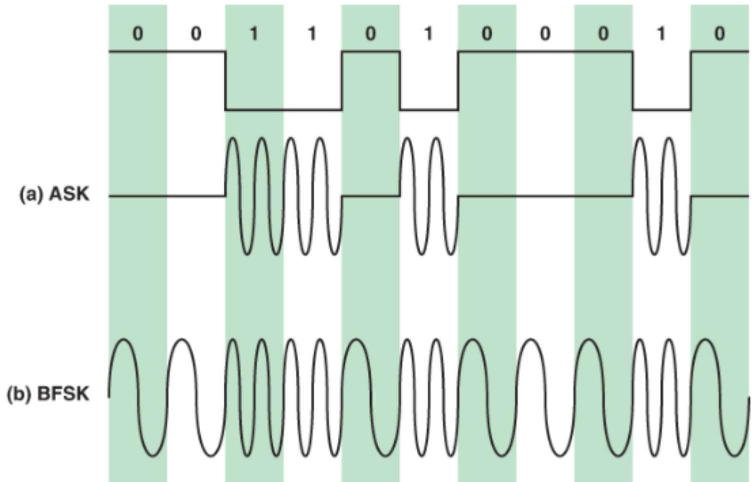
Recall that 5G new radio includes quite a bit of new spectrum (relative to 4G), especially in the short wavelength (cm scale) region. While this cm spectrum transmits data very rapidly, its path loss is very high. This is why future dense deployments of high frequency antennas are discussed.

Attenuation Distortion

Some materials (like water) absorb electromagnetic waves of particular frequencies. The diagram below shows dark green bands of frequencies that are absorbed by several atmospheric gasses.

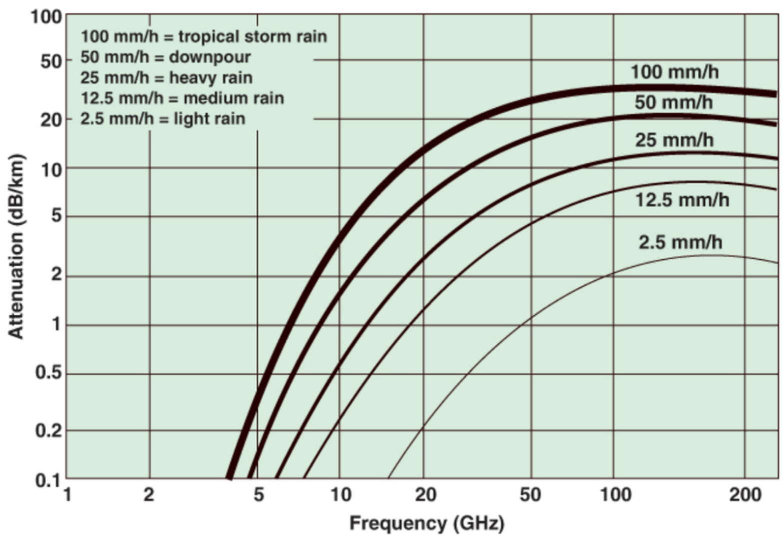


Information is often sent by changing the wavelength sent from one frequency to another. The diagram below shows amplitude shift keying (ASK) and binary frequency shift keying (BFSK). In BFSK different frequencies, the receiver expects that in each millisecond window the signal will be of one of two frequencies. Because of the dependence of atmospheric attenuation on frequency, one of the two frequencies might experience much more attenuation than the other. This is called attenuation distortion.



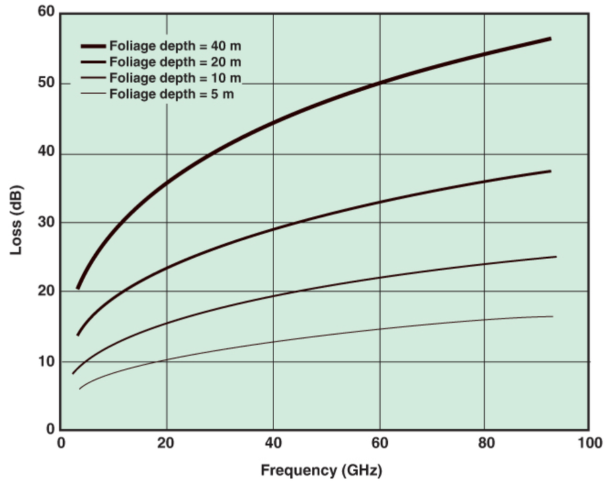
Rain Loss

Electromagnetic waves interact with rain droplets in a variety of ways that depend on wavelength. The greater the intensity of the rain, the greater the attenuation due to rain.



Foliage Loss

A tree is between a transmitter and a receiver causes attenuation. The depth of the foliage and the frequency affect the attenuation.



Blocking Loss

Solid objects in the human environment also case attenuation. There are a wide variety of materials, and for each material there is a unique attenuation dependence on wavelength and material thickness. The table below gives attenuation in decibels.

Material	Thickness (cm)	< 3 GHz	40 GHz	60 GHz
Drywall	2.5	5.4	—	6.0
Office whiteboard	1.9	0.5	—	9.6
Clear glass	0.3/0.4	6.4	2.5	3.6
Mesh glass	0.3	7.7	—	10.2
Particle board	1.6	—	.6	—
Wood	0.7	5.4	3.5	—
Plasterboard	1.5	—	2.9	—
Mortar	10	—	160	—
Brick wall	10	—	178	—
Concrete	10	17.7	175	—

Noise

Unwanted electromagnetic waves are called noise.

Thermal noise

All accelerating electric charge creates electromagnetic waves. The electrons and protons that make up atoms in matter are accelerating in the form of vibration whenever the temperature of the matter is above absolute zero. Thus, all matter emits electromagnetic waves that are one of the sources background noise for a receiving antenna.

Intermodulation Noise

Waves of frequencies f_1 and f_2 combine to form beats, which are waves of frequency f_1-f_2 and f_1+f_2. Thus, a wave a 2GHz and a wave a 3GHz form beats at 1GHz and 4GHz that are one of the sources of background noise for antennas intended to receive signals at 1GHz and 4GHz.

Crosstalk

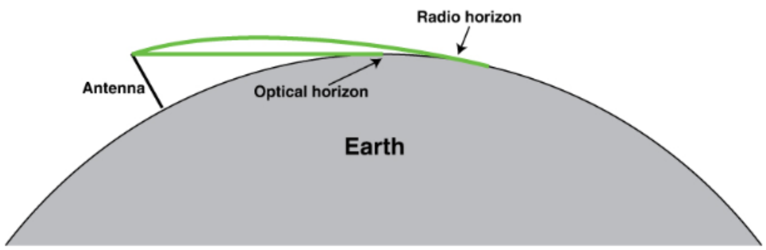
In free space electromagnetic waves add linearity and have no non-linear reactions. However, in transmission mediums like copper wires, electromagnetic waves move electric charges which in turn create electromagnetic waves. This coupling between waves was historically experienced in circuit switched telephone networks as hearing conversations on your neighbors on your telephone line; crosstalk. Forms of this kind of signal coupling (non-linearity) are still found in the electrical components of packet switched networks.

Impulse Noise

Lightning, solar flares, electromagnetic pulses and many other uncontrollable electromagnetic disturbances constitute the primary source of error in digital data transmission.

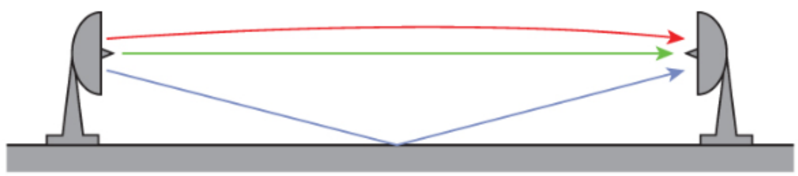
Refraction

Because air density exponentially decreases with altitude, and since the speed of electromagnetic waves is lower in higher density air, electromagnetic waves bend toward the surface of the earth.

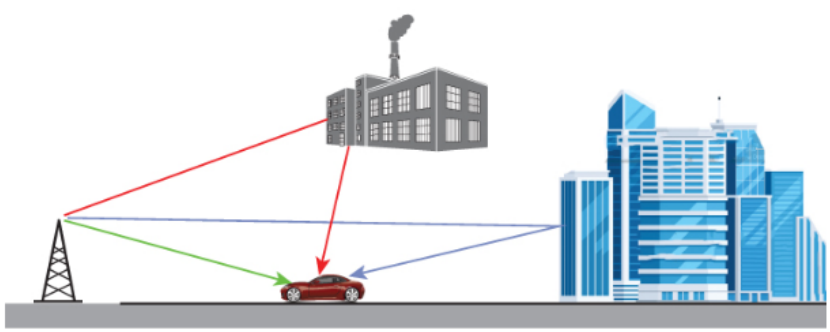


Reflection

Electromagnetic waves reflect off of surfaces including the ground,

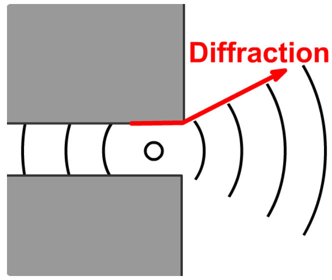


and including walls of buildings.



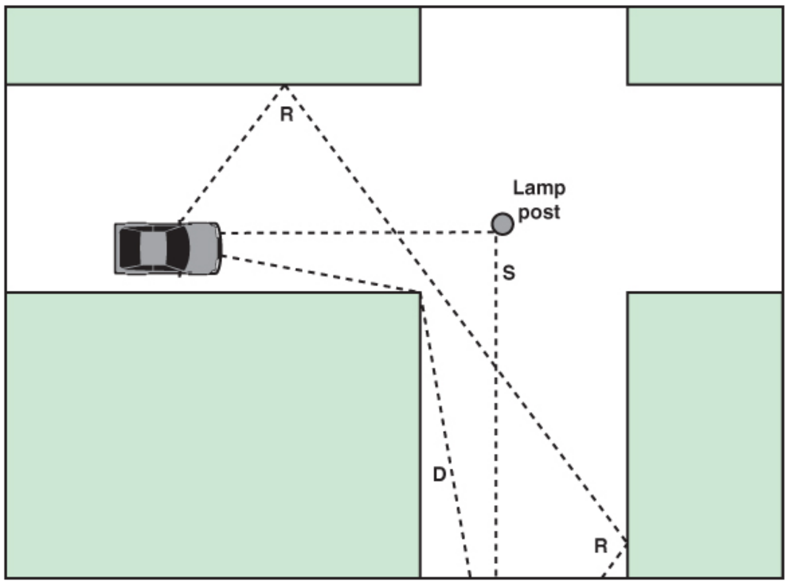
Diffraction

Waves that encounter corners form wavefronts that propagate around the corners.



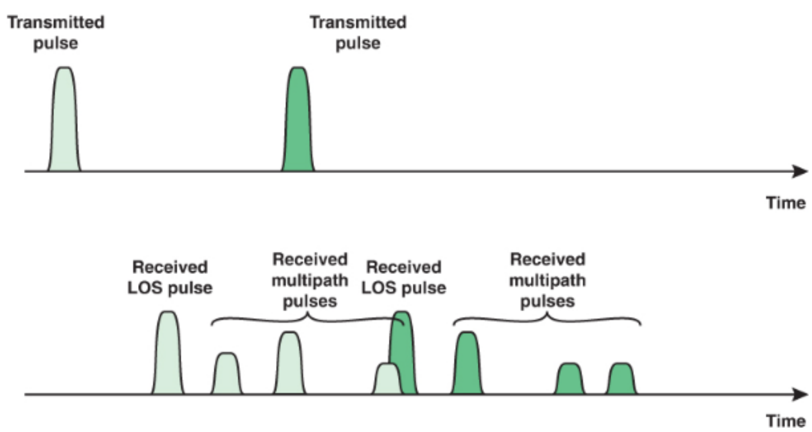
Scattering

When a electromagnetic wave of wavelength λ encounters an obstacle of width or height about λ the wave scatters. The diagram below depicts reflection, diffraction, and scattering of a electromagnetic signal emanating from a car.



Multipath Propagation and Multipath Fading

As presented above electromagnetic waves wan take multiple paths from a transmitting to a receiving antenna through various physical phenomena. The image below if two pulses are transmitted, then what is received may be much more complicated due to multi-path effects.

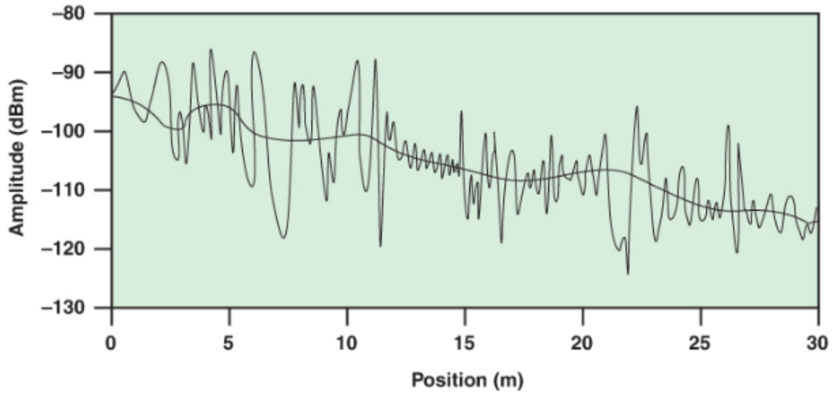


When waves are transmitted instead of pulses, the copies of the signal can interfere with each other constructively or destructively.

Definition: The fading of a signal sent from transmitter to receiver is the time variation in phase, polarization, or strength of a received signal.

One of the causes of fading is multipath propagation. This phenomena is called multipath fading. It is divided into two parts;

1. fast fading is multipath fading that comes from the transmitter or receiver changing moving distances on the scale of the wavelength. The resulting multipath signal changing from constructive to destructive interference rapidly, as in the diagram below.
2. slow fading is multipath fading that comes from antennas moving over distances longer than a wavelength so that new surfaces for reflection, new corners for refraction, etc, are encountered and contribute to interference. The resulting multipath signal has variation even when smoothed with, say a moving average, ash shown in the diagram below.



Quantifying Difficulties

To quantify the attenuation of signals, it is common to use free space path loss as a point of comparison. Recall that path loss is the ratio of power transmitted P_t to power received P_r and that free space path loss is characterized by the relationship between that ratio an the distance d between the transmitter and receiver $P_t/P_r \propto d^2$.

Definition: If the ratio of power transmitted P_t to power received P_r is proportional to the nth power of the distance between transmitter and receiver, then n is the path loss exponent.

That is if $P_t/P_r \propto d^n$ then n is the path length exponent.