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Why Reflection, Diffraction, and Scattering are Crucial for RF Communication?

The term *free space propagation* used commonly by engineers refers to line of sight (LOS) communication. Line of sight implies that the transmitter and receiver can see each other without any obstructions between them. Unfortunately, it is impossible to have only a line of sight for most communication systems like mobile phones where the tower antenna and the mobile antenna may not see each other.

In real-world systems reflection, diffraction, and scattering properties come into play. While LOS is desired, the above three non-line of sight (NLOS) propagation properties play a major role in carrying energy from transmitter to receiver.

Reflection

A radio frequency (RF) signal reflects when the transmitted signal falls on an object which has dimensions very large than the wavelength of the signal. Mobile devices operate in frequencies above 1GHz which implies a wavelength of ~30cm. Buildings, trees, vehicles, and large water bodies are reflectors for signals in the spectrum used for mobile phones which fall from 800MHz to 3GHz.

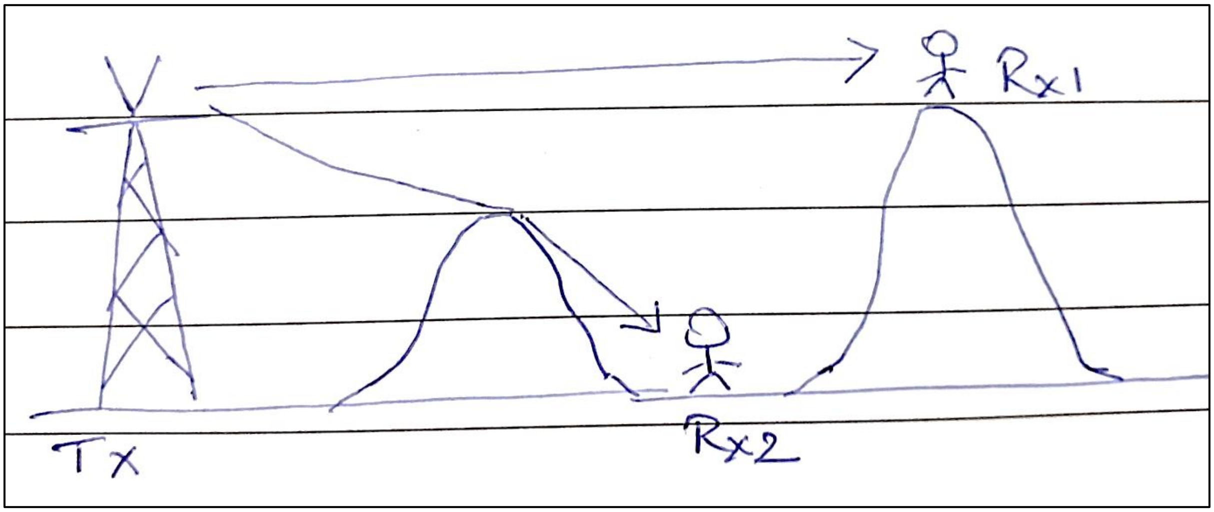
Reflection can be zero from materials that absorb electromagnetic (EM) waves like carbon-based graphene. Partial reflection occurs when the signal hits low-conductivity materials. Materials like glass and walls reflect some part of the signal, while the rest of it is transmitted through these objects. Signal reflection is maximum when the signal hits a very good conductor like aluminium.

The actual direction of signal reflection is dependent on the angle at which the signal falls on an object and the surface properties like whether the surface is rough or smooth.

Diffraction

RF signal on its way to the receiver from the transmitter has the property to bend around objects. This leads to change in the direction of signal propagation from the intended path. While this may seem like a disadvantage, diffraction is a key propagation property that ensures the signal navigates around the curvature of the earth. Figure-1 shows receiver 1 (Rx1) on a hill, gets a direct line of sight signal and receiver 2 (Rx2) is shadowed by a hill yet gets connected to the network due to a diffracted signal path.

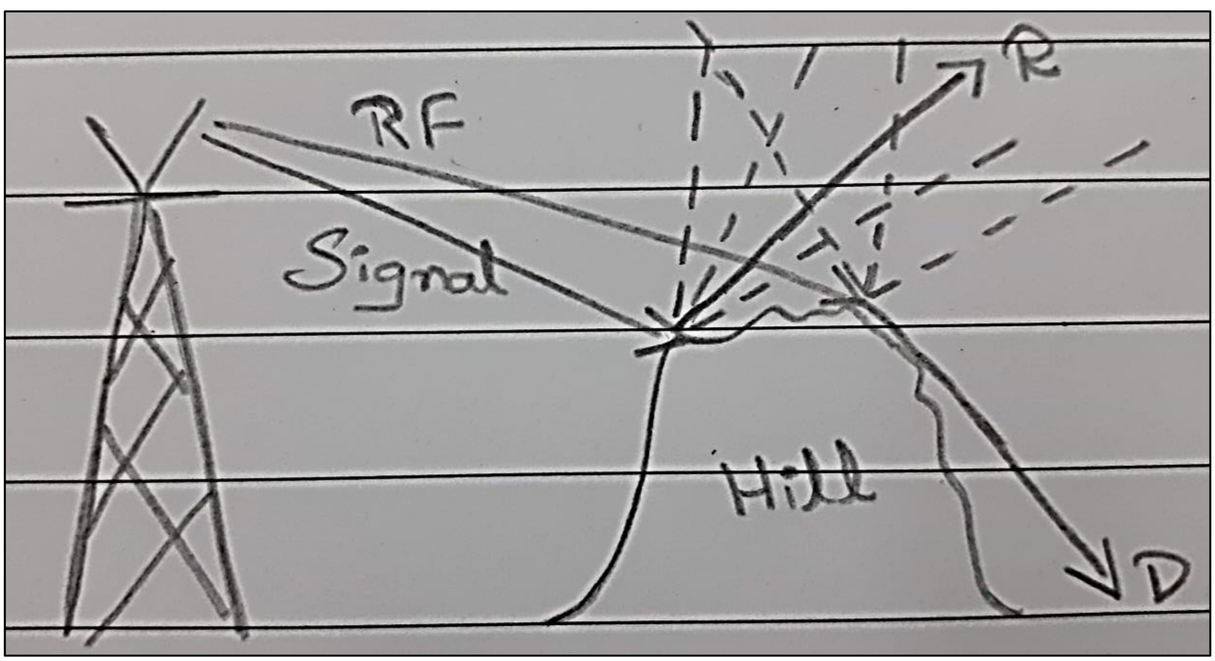
FIGURE-1: RF Signal Diffraction



Scattering

Scattering refers to a signal falling on a rough surface and then traveling in multiple directions in a 3D space. Complete reflection happens when the surface is smooth which is not the case in a practical environment. Signals impinging on the rough surface result in signal scattering. Figure-2 shows all 3 propagation properties. R and D represent signal reflection and diffraction of the original RF signal while the dotted lines show the scattered signal paths. Signal reflection and diffraction could also be a result of scattering. This makes arriving at the mathematical expression of scattering complex compared to reflection and diffraction properties as the energy is spread out in multiple directions.

FIGURE-2: RF Signal Reflection, Diffraction and Scattering



Total received power

The power from the transmitter arrives at the receiver through 2 major propagation paths – LOS and NLOS. To arrive at a general equation, transmit power is normalized and set to 1.

Theoretical received power $P_r = P_{LOS} + P_{ref} + P_{dif}$

Where P_{LOS}, P_{ref}, and P_{dif} are received powers through line-of-sight, reflected, and diffracted paths.

Practically there will be multiple reflections before the signal arrives at the destination. Some amount of power is absorbed by the environment represented by P_{abs}.

Transmitted power (P_t) components can be written as $P_t = P_{LOS} + P_{ref} + P_{dif} + P_{abs} = P_r + P_{abs}$

Actual field measurements show that $P_r > P_{LOS} + P_{ref} + P_{dif}$. This is because of the contribution to total received power from scattering (P_{sca}) which was not considered earlier.

Summary

In practical working systems, the signal undergoes a mix of multiple reflections, diffraction, and scattering properties to eventually carry the signal from transmitter to receiver.

Typically, such NLOS power components will be much smaller (almost 10 to 100 times) compared to LOS component. Nevertheless, in a wireless system signal power received through any path is significant. Receivers are designed to **combine** powers from various paths and improve the signal-to-noise ratio (SNR) defined as the ratio of the power of the desired signal over the noise power.