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The radio wave propagation and mechanisms between a transmitter and receiver

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ABSTRACT

There are two principal modes of wave propagation and wavelength is the main consideration which determines the mode of propagation of earth-based transmissions. Ground wave; they are radio waves that travel near the surface of the Earth and are modified by the nature of the terrain over which they travel (surface and space waves). Sky wave; these are radio waves that are reflected back to earth from the ionosphere. In the troposphere, as the ground and surface wave propagates, there are some mechanisms like reflection, refraction, diffraction, scattering, free space loss, etc which affect the signal propagation. These mechanisms are influenced by terrain contours, environment (urban or rural, vegetation and foliage), frequency, the distance between the transmitter and the receiver, and the height and location of antennas.

Keywords: radio wave, propagation, atmosphere and scattering

The Atmosphere

The earths atmosphere is divided into three regions; The Troposphere; this is the portion of the earths atmosphere that extends from the surface of the earth to a height of about 3.7 miles (6km) at the North Pole or the South Pole and 11.2 miles (18km) at the equator. The usable frequency range at the troposphere is from about 100 megahertz to 10 gigahertz which is used for radio communication. The mechanisms that affect a radio wave in this region would be discussed in details. The Stratosphere; this is located between the troposphere and the ionosphere. It is considered to have almost constant temperature and little water vapor. The Ionosphere; It extends upward from about 31.1 miles (50km) to a height of about 250 miles (402km). This layer contains four cloud-like layers of electrically charged ions, which enable radio waves to be propagated to great distances around the earth. This is an essential region for long distance point-to-point communications (satellite). Refraction and absorption are the main mechanisms here. However, this medium is important at frequencies of up to and above 10,000mega hertz.

Modes of Wave Propagation

There are two principal modes of wave propagation and wavelength is the main consideration which determines the mode of propagation of earth-based transmissions; Ground wave; also known as guided wave, they are radio waves that travel near the surface of the Earth and are modified by the nature of the terrain over which they travel (surface and space waves).

Sky wave; these are radio waves that are reflected back to earth from the ionosphere. Usually the high frequency band is used for sky wave propagation, also called ionospheric wave. It is radiated in an upward direction and returned to Earth at some distant location because of refraction from the ionosphere. However, this propagation method is not used for mobile communications.

Ground wave; The ground wave consists of the space wave and the surface wave. The surface wave travels along the surface of the earth. It can follow the contours of the earth because of the process of diffraction.Space Wave; The space wave follows two paths, one through the air directly, the other reflected from the ground to the receiving antenna.

Propagation Mechanisms

In the troposphere, as the ground and surface wave propagates, there are some mechanisms like reflection, refraction, diffraction, scattering, free space loss, etc which affect the signal propagation. These mechanisms are influenced by terrain contours, environment (urban or rural, vegetation and foliage), frequency, the distance between the transmitter and the receiver, and the height and location of antennas. Some of these mechanisms are explained below.

Scattering

Scattering is the process by which small particles suspended in a medium of a different refractive index diffuse a portion of the incident radiation in all directions. With scattering, there is no energy transformation, but a change in the spatial distribution of the energy. Scattering, along with absorption, causes attenuation problems with signal propagation. In a typical mobile-radio application, propagation between them is largely through scattering, either by reflection or diffraction from buildings and terrain or objects within buildings, because of obstruction of the line-of-sight (LOS) path. Scattering depends on the roughness of the surface. Surface roughness is stated in terms of the Rayleigh criteria, defined in terms of critical height (hc) of surface protuberances for given incident angle of reflection.

Absorption

Absorption is the process by which incident radiant energy is retained by a substance. The absorbing medium absorbs a portion of the total energy. The other energy will be reflected, refracted, or scattered. The energy absorbed can also be transmitted back into other parts of the atmosphere. Absorption is mainly caused by three different atmospheric gases; water vapor, carbon dioxide and then ozone. However, absorption effects due to atmospheric effects are neglected in propagation models for mobile communication applications at radio frequencies, but are important when higher frequencies (e.g., 60 GHz) are used.

Reflection

Reflection is the process by which a surface of discontinuity turns back a portion of the incident radiation into the medium through which the radiation approached. To have true reflection, a real discontinuity in the index of reflection is required. This discontinuity must be significant compared to the wavelength of the radiation, or the energy could be returned by way of refraction rather than reflection.The energy reflects off of a surface at the same angle at which it initially struck the surface.

Refraction

Refraction is the atmospheric bending of the radio path away from a straight line. Radio waves get bent downwards and are able to propagate beyond the geometric horizon, which extends range.

$$\text{Refraction} = \frac{\sin(\theta i)}{\sin(\theta r)} = n^1$$

The bending of radio waves occurs when it enters a medium where its speed is different. The amount of bending depends on the indices of refraction of the two media and is described very well by Snells law. The index of refraction is defined as the speed of light in a vacuum divided by the speed of light in the medium.

Diffraction

Diffraction is the bending of wavefronts around obstacles. Diffraction occurs with all propagating waves, including sound waves and electromagnetic waves. Diffraction effects are generally only noticeable for waves where the wavelength is similar to the size of the diffracting object. Christian Huygens (1629-1695) came up with a theory that light was a wave. His rule is Each point on a wavefront acts as a source of secondary wavelets. The combination of these secondary wavelets produces the new wavefront in the direction of propagation.

Clutter and Vegetation

Clutter means things spoiling the view that are not part of theterrain.Vegetation mainly refers to trees and large bushes that also get in the way of the radio path. Clutter causes loss as it is usually made of lossy materials. There is no such thing as a typical tree but figure 2 shows examples of the loss in dB/m experienced while moving into woodland. It can be seen that the effect is more severe in higher frequencies.

Multipath Propagation

The propagation between the base station and mobile unit is through scattering, either by reflection or diffraction from buildings and terrain or objects within buildings, because of obstruction of the line-of-sight (LOS) path. Radio waves therefore arrive at the mobile receiver from different directions with different amplitudes, phases, and time delays, resulting in a phenomenon known as multipath propagation.The radio channel is then obtained as the sum of the contributions from all of the paths. If the impulse is δ(t), the output will be the channel impulse response, which can be written as;

$$h(t) = \sum_{n=1} A_n \delta(t - \gamma_n) \exp(-j\Phi_n))$$

The channel impulse response can thus be characterized by N time delayed impulses, each represented by an attenuated and phase shifted version of the original transmitted impulse. Here A_n, γ_n, and Φ_n are the attenuation, delay in time of arrival, and phase, corresponding to path n, respectively. Although multipath interference seriously degrades the performance of communication systems, if multipath medium is characterized well with sound knowledge of the propagation mechanisms and their influence on the system, the best design for the system can be selected to achieve good propagation performance, hence, achieve a better quality of service.

The Cell Structure

Cell: A cell is a relatively small geographical area of coverage determined by factors such as frequency band, power level, and line of sight (LOS). This sort of architecture serves to increase the effective subscriber capacity of radio systems by breaking the area of coverage into cells, or smaller areas of coverage so that each frequency band could be reused in nonadjacent cells. The size of a cell becomes smaller and smaller from macrocell to microcell and then to Picocell to suit coverage and capacity.

Macrocell is used for outdoor location, cell radius of 0.5km to 30km, with typical base station antenna installation height of above medium roof-top level. All surrounding buildings are below antenna height(s) or some surrounding buildings are above antenna height (for small macro cell). High base stations are installed to cover longer distances called macrocell. The transmit power of the macrocell base stations is high in order to maximize the covered distance, with a disadvantage of taking into account only the outdoor coverage.

Microcell is used for outdoor location, cell radius of up to 1km, with typical base station antenna installation height of below medium roof top level. To increase the capacity, operators started to install smaller outdoor base stations called microcells. These are deployed in specific areas in which extra capacity is known to be needed, for example near a train station or in a city centre or special occasions like sporting events. Adding microcells allows subdivision of the cells leading to an optimization of the use of the spectrum and ensuring a better capacity.

Picocell is used for indoor/outdoor location, cell radius of up to 500m, with typical base station antenna installation height of below roof-top level. A picocell is a small base station very similar to an access point and usually small (typically A4 paper size, and a few centimeters thick), and integrates an antenna that radiates a low power signal. It is a simplified base station, with low power and lower capacity than microcell or macrocell base stations. Picocells are cheaper, have low installation cost and effectively increase indoor coverage and capacity.

Femtocell is a simplified picocell directly installed by a customer in their home that combines in the same device all the functionalities of a picocell and a BSC. Femtocells cover a smaller area and have fewer users than picocells, they are cheap and are limited to power (between 10 and 20dBm) and capacity (between four and six users). In Urban areas, macrocell, microcell and picocell are all deployed consideringcoverage and capacity with respect to number of subscribers and cost of infrastructure.Hence, in an urban environment, the operators would have to install more base stations with lower power and ensure improved signal coverage by improving outdoor signal quality.

CONCLUSION

Radio propagation models have been developed to calculate losses and hence make predictions in mobile communication network planning. The challenges posed to radio propagation models are;The distances between a base station and a mobile station range from some metres to several kilometers. Man-made structures and natural features have sizes ranging from smaller to much larger than a wavelength and affect the propagation of radio waves. The description of the environment is usually not at our disposal in very much detail

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