SIGNAL PROPAGATION

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Abstract

One of the participants that affects the loss of signal quality is propagation. In addition to it, we also have connection attenuation, latency, topology and network design. The quality of the digital signal transmitted from the transmitting to the receiving radio-relay device depends on the influence of environmental effects on the propagation of electromagnetic waves. Signal propagation is defined as path loss when the transmitter and receiver are directly facing each other, and in the event that there are no obstacles present in free space, there is still some signal attenuation. This is decisive for designing communication systems so that they can work despite the problems they may encounter. As the application of local wireless networks grows, so does the need for quality assessment of signal propagation in buildings. The Fresnel zone represents the air space between two transmitters through which radio waves propagate. It has an unlimited number of such zones, but the first three zones are important for signal quality and strength. Most often, only the first zone is counted because it occupies the largest volume and the quality and strength of the signal mostly depends on it. Within these environments, it is extremely important to take into account the types of obstacles and the type of room in which the signal is propagated. As part of this work, there is an overview of the most important propagation models and a review of them.

Keywords: *signal, propagation, environmental influences, electromagnetic waves.*

1. INTRODUCTION

When we say the word communication, the first thing we think of is talking, but it is a very complex way of communicating, transferring information, data and files over a certain distance. There are various types of communication, body language, drawings, symbols and many others. Nowadays, communication is reduced to a wired connection between users located at greater or lesser distances. This is achieved by using radio waves. Radio-connections are a large group of professional telecommunications that are represented in the system through various fields: radio-telegraphy, radio-telephony, radio-telemechanics, radio-location, internal television and the like.

Radio communication systems represent another large group of telecommunications. Radiocommunications includes the field of science and communication techniques in which the field of sending, transmitting and receiving messages by electromagnetic waves is investigated using electronic elements and circuits that are necessary for a defined process. Radio communications work in a wide range of frequencies and powers, and within them the study of radiation problems, i.e. antennas, as well as the propagation of electromagnetic waves is carried out. Either in analog or digital form, the electronic elements and circuits that form part of the entire mentioned "system" serve to generate signals, their processing, mixing and transposition of frequencies, as well as amplification and detection.

Low capacity systems work at frequencies below 3 GHz, and medium and high capacity systems use frequencies from 3 GHz to 15 GHz. Frequencies of values higher than 15 GHz are mostly used when it comes to transmission over short distances. Compared to other microwave transmissions, radio transmissions are less sensitive to natural disasters, accidental damage, links in mountainous terrain or along waterways. They have economic justification, installation and maintenance, which is why they are very simple, and putting them into operation is very fast. Microwave radio communications require the existence of line-of-sight-LOS. Due to normal atmospheric conditions, the radio horizon is located 30% below the optical horizon. Radio LOS takes into account the Fresnel zone (ellipsoid) and the corresponding propagation criteria.

2. RADIO COMMUNICATIONS

Radio communications follow the development of radio technology, and today radio energy is also used outside the field of communications in a limited space, however, this use does not fall within the scope of radio communications. It is an essential feature that describes radio communications that they operate in a wide range of frequencies and powers and use a variety of devices.

In the framework of radio communications, the problems of radiation (antennas) and the propagation of electromagnetic waves are studied. Radio communication devices are the technical basis of all radio communication services such as terrestrial directional links (radio relay links), mobile radio communication services (land, sea and air), satellite radio communication services, broadcasting, radio astronomy, radar, radio location, remote control, and similar devices are used and in the electromagnetic measurement of electrical and non-electrical quantities, and in the application of high frequencies in industry and medicine.

Electronic elements and circuits are used in radio communications for many functions, including: signal generation (oscillators), signal processing (modulation), frequency mixing and transposition, and amplification and detection. All this is done in analog or digital form. Optical communications are related to the border area of radio communications, and they operate in a frequency range above that in which radio communications operate.

1. FREQUENCY DIVISION

In order to achieve the transmission of information with the help of a radio connection, radio waves are used as a transmission medium, which are a type of electromagnetic waves marked by a wavelength or frequency, and their relationship is defined by the expression:

$$\lambda = \frac{c}{f}\ [m]$$

c – speed of propagation of radio waves (c = 300.000 $\left[\frac{km}{h}\right]$ - speed of light.

Given that the frequency range that is important for radio communications is on the order of a hundred MHz, then the previously mentioned expression can be modified into an expression of the form:

$$\lambda = \frac{300}{f[MHz]}\ [m]$$

The frequency of radio waves is less than f = 3000 GHz. This corresponds to a wavelength of the order of 1.0 mm. The lower limit of the radio spectrum is the frequency f = 10 kHz.

A division into nine frequency areas is proposed based on the frequency spectrum of occurrence and properties during the propagation of radio waves. The listed items are shown in the following table.

Table 1. Frequency division of the spectrum of radio waves

Frequency range symbol	Name	Frequency range	Wavelength
VLF	Very low frequency	3-30 kHz	100-10 km
LF	Low frequencies	30-300 kHz	10-1 km
MF	Medium frequencies	300-3000 kHz	1000-100m
HF	High frequencies	3-30 MHz	100-10 m
VHF	Very high frequency	30-3000 MHz	10-1 m
UHF	Ultra high frequency	300-3000 MHz	100-10 cm
SHF	Super high frequency	3-30 GHz	10-1 cm
EHF	Extremely high	30-300 GHz	10-1 mm
-	-	300-3000 GHz	1-0.1 mm[9]

2.2.FRESNEL'S ZONE

The Fresnel zone is defined as the air space located between two transmitters through which radio waves travel. The number of specified zones is unlimited, but the first three are important for the quality and strength of the signal, of which the calculation is usually made only for the first one because it occupies the largest volume and the quality and strength of the signal depend on it the most.

The first Fresnel zone is not completely flat. It is a rotational ellipsoid and in cross-section it looks like an ellipse where the

[9] Anon.: Radiokomunikacije, s.l., s.a. [Online]. Dostupno na (URL): https://www.fpz.unizg.hr/ztos/PRSUS/Radiokomunikacije.pdf (Datum pristupa: 25.05.2023.), str. 7.

edge points are on the semi-major axis of the transmitter.[10]

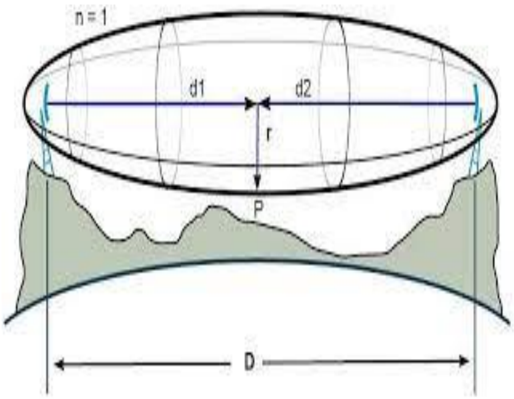

Figure 1. The first Fresnel zone

Source: Magić, S.: „Bežično umrežavanje računala u rijetko naseljenim područjima“, diplomski rad, Sveučilište u Zagrebu, Prirodoslovno-matematički fakultet, matematički odsjek, Zagreb, 2018.

The calculation of the Fresnel zone is carried out using the expression:

$$F_n = \sqrt{\frac{n\,\lambda\,d_1 d_2}{d_1 + d_2}}$$

Fn [m] - the nth Fesnel zone of the diameter of the minor axis of the ellipsoid,

d1- distance from an arbitrary point between two transmitters to the first transmitter,

d2 - distance from an arbitrary point between two transmitters to the second transmitter,

λ - wavelength,

n - natural number (n =1 for the first Fresel zone).

The area of Fresnel's zone means that area of constructive and destructive interference that arose as a result of the propagation of electromagnetic waves in free space, be it reflection or diffraction. It is based on the products of half the wavelength, which are defined as the difference in the propagation path of the radio wave and its direct path.

The Fresnel zone must be out of reach of all obstructions.[11]

The radius of the first Fresnel zone, shown in the following picture:

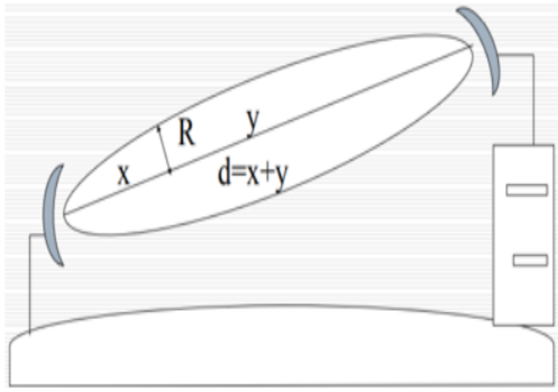

Figure 2. Radius of the first Fresnel zone

Source: Anon.: Mikrotalasni prenosni sistemi-predavanje, Elektrotehnički univerzitet u Banja Luci, Banja Luka, s.a., str. 19.

The direct path between the transmitter and the receiver requires clearance, that is, a criterion that provides sufficient antenna height even for the most unfavorable refraction conditions above the Earth's surface in the amount of at least 60% of the radius of the first Fresnel zone. In this way, adequate conditions of expansion in free space would be achieved. The Earth-radius factor k compensates for refraction in the atmosphere.

[10] Magić, S.: „Bežično umrežavanje računala u rijetko naseljenim područjima“, diplomski rad, Sveučilište u Zagrebu, Prirodoslovno-matematički fakultet, matematički odsjek, Zagreb, 2018.

[11] Anon.: Mikrotalasni prenosni sistemi-predavanje, Elektrotehnički univerzitet u Banja Luci, Banja Luka, s.a., str. 19.

3. DESIGN OF MICROWAVE LINK

Designing a link is a methodological procedure that consists of several calculations:

- Calculation of attenuation/losses,
- Calculation of fading/fading margin,
- Frequency planning and calculation of interference,
- Calculation of quality and availability

The entire process is iterative and goes through several stages of redesign before achieving the desired quality and availability of the system.

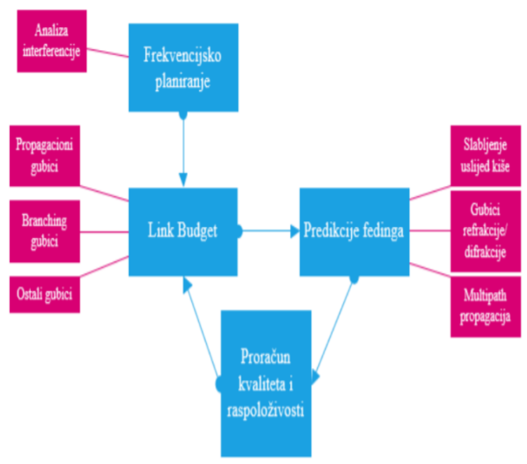

Figure 3. Designing a microwave link

Source : author

Losses/weakening calculations are based on three basic elements:

- Propagation losses (atmospheric influences and terrain structure) - losses in free space, i.e. losses where the transmitter (transmitter) and receiver have a clear LOS (no obstructions). The expression used for the said budget reads:

$$L_{fsl} = 92.45 + 20log(f) + 20 \log d \ \ [dB]$$

where d [km] is the LOS range between the antennas.

If the weakening was caused by the influence of vegetation, then the calculation of losses is done using the expression:

$$L = 0.2\, f^{0.3} R^{0.6} \ [dB]$$

In case the losses are due to some obstacles, they are also called diffraction losses, i.e. attenuation. One of the calculation methods is based on the "knife edge" approximation. Gas absorption in the case of propagation losses occurs primarily when water vapor and oxygen appear in the atmosphere, in the area of the radio-relay link. The absorption maximum occurs at approximately 23 GHz for water molecules and 50-70 GHz for oxygen molecules. Specific attenuation depends on frequency, temperature and absolute or relative humidity.

Attenuation due to rain occurs as a phenomenon in the frequency range used by commercial radio links, which increases exponentially with stronger rain intensity. The specific attenuation that occurs due to the occurrence of rain depends on several parameters, namely: the shape and size of the distribution of raindrops, polarization (horizontal leads to greater attenuation compared to vertical), rain intensity and frequency. Attenuation increases with frequency and becomes dominant in the range above 10 GHz. Rain attenuation is not considered when calculating the link budget and is used only for the fading budget.

- Branching losses (hardware structure that connects the output of the transmitter/receiver to the antenna)
- Other losses - unpredictable and occasional. Examples include: the appearance of fog, the movement of objects along the path, bad installation of equipment, an unsuitable antenna system, and the like.

3.1. MULTI-STAGE ENVIRONMENT

The carrier of information that is responsible for wireless communications is an electromagnetic wave, which spreads through the medium from the transmitter to the receiver. A typical way of propagation of an electromagnetic wave through a medium in terrestrial communications is through a direct beam, then by reflection, diffraction and scattering. All shapes are shown in Figure 4.[12]

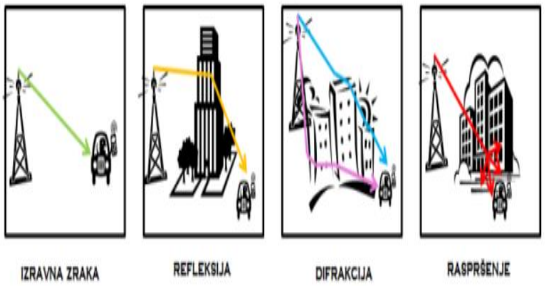

Figure 4. Propagation mechanisms in free space

Source: https://dokumen.tips/documents/2-propagacija-rf-signala-feding-i-predikcioni-modeli.html?page=26 date of access:(25.05.2023.)

Different ways of wave propagation create the so-called multipath environment. The signal spreads through the radio channel in different ways, and the receiver receives the sum of all signal components or rays that reached the receiver directly or through some interaction with objects in the radio environment.

3.2.REFLECTION

Reflection is a phenomenon that occurs when an electromagnetic wave bounces off objects whose dimensions are large and whose roughness is small in relation to the wavelength of the signal (eg ground, walls, buildings, etc.). When colliding with an object, the wave can be completely or only partially reflected, depending on the properties of the medium, polarization, angle of incidence and frequency. Reflection is present in all radio environments, but it is particularly significant in those where there is some prominent object (e.g. an extremely tall building, silo or factory chimney, etc.) or an area of larger dimensions (e.g. sea surface or meadow), where such the reflected beam contains a large proportion of the total signal power.

3.3. DIFFRACTION

Bending or diffraction occurs when a wave collides with an obstacle whose surface has sharp edges, and the wave created on the surface of the obstacle continues to propagate into space, even when there is no direct optical line of sight between the transmitter and receiver. The phenomenon of diffraction, not only for radio waves, is explained by Huygens' principle, which states that each point of the wave front is actually the source of a new wave. In radio communications, diffraction is most often described by the knife-edge model. Diffraction is the dominant mode of propagation in urban environments where there are a number of natural and man-made obstacles. Diffraction appears in urban areas in two typical forms, namely:

- diffraction around the side edges of buildings
- diffraction over the roofs of buildings (over-the-roof-top, ORT).

3.4. DISPERSION

In broadband considerations, all the distorted signal components with a long time delay, which often cannot be classified as either reflection or diffraction, and arise as reflections or dispersions of the beam from a rough and irregular surface (facades, decorative wall elements, pipes, cables, irregular buildings etc.), are called diffuse scattering.

3.5. FEEDING

Fading represents the variation of the signal strength of the receiving radio carrier due to atmospheric changes and reflections on the

[12] https://dokumen.tips/documents/2-propagacija-rf-signala-feding-i-predikcioni-modeli.html?page=26

propagation path. During the design of radio links, four types of fading are considered, and each of them depends on the length of the path and is estimated as the probability of exceeding the given or calculated fading margin:

- Multipath fading-dominant fading for value frequencies smaller than f = 10 GHz. Multipath occurs as a result of reflected waves, i.e. when, in addition to the direct wave emitted from the transmitter, waves appear in the receiver as a result of reflection. If two signals are in phase and arrive at the receiver, then the signal is amplified, which is called so-called raids:

$$UPFADE_{max} = 10\ log_d - 0.03d\ [dB]$$

where d is the length of the path.

If it is the case that the two waves arriving at the receiver are not in phase, then the overall signal is weakened. The location where the signal is canceled as a result of multipath is called the null or downfade.

There are differences between flat and frequency selective fading. It is about flat fading if the fading for radio-link bandwidth is less than f = 40MHz and the path length is less than d = 30km, where all frequencies in the channel are equally exposed to the influence of fading.

As mentioned, in addition to flat, there is also frequency selective fading (FSF). With this type of fading, amplitude distortions and group delay distortions occur along the channel bandwidth. There is an impact on the transmission medium and high-capacity radio links, i.e. <32[Mb/s] . The sensitivity of digital radio equipment to this type of fading is described using a "signature curve". It is used when calculating the Dispersive Fade Margin (DFM):

$$\text{DFM} = 17.6 - 10\log\left[\frac{2(\Delta f)e^{\frac{B}{3.8}}}{158.4}\right]dB$$

Δf- signature width of equipment,

B - notch depth equipment

Modern digital radio systems are robust and immune to fading, so the appearance of dispersive fading can occur due to a significant error in the design of the equipment (it happens with a bad choice of antennas and the like).

Fading due to rain - when rain occurs, the signal weakens, more precisely, electromagnetic waves are scattered and absorbed. This type of fading is especially pronounced on longer routes, more precisely longer than ten kilometers. The increase occurs when the frequency exceeds f = 10GHz. For frequencies of f = 15GHz, this type of fading becomes dominant. It is necessary that the length of the microwave link be reduced in areas of heavy rain. Weather data is generated, in most cases, in the form of a statistical description of the amount of precipitation in a certain period of time.

Fading due to refraction/diffraction (k-type fading) - when the coefficient k takes on smaller values, the curvature of the Earth's surface and terrain irregularities come to the fore. In this way, the disruption of the Fresnel zone is affected. Also, a better LOS is achieved, because the height of the antenna is lower. The probability of this type of fading is indirectly related to the attenuation due to obstruction for a given value of the Earth-radius factor, and since it is not constant, the probability of fading during refraction/diffraction is calculated based on the cumulative distribution of the Earth-radius factor.

The fading margin is obtained by comparing the expected strength of the received signal with the sensitivity or threshold of the receiver. The measure that shows how much margin there is in the communication link between the working point and the point where the link is higher cannot close. It is calculated in relation to the threshold level of the receiver for a certain given bit error probability (BER), and in case it is exceeded, then the radio link may become unavailable.

CONCLUSION

Radio technology and radio communications have been used for a long period of time for various purposes, and every day they are progressing more and more in the field of transmitting a larger amount of information for a shorter period of time wirelessly over greater distances. This work is designed to show the basics of radio communications, as well as the physical properties of each of the elements, with a special focus on the propagation of signals in free space and the phenomena that follow and affect their path. Some of the basic phenomena are: reflection, diffraction, scattering. The signal spreads through the radio channel in different ways, and the receiver receives the sum of all signal components or rays that reached the receiver directly or through some interaction with objects in the radio environment. As a result, and depending on whether the signal components are in phase with each other or not, the overall received signal can be amplified (if all multipath components are added together, i.e. constructive interference occurs), but also significantly reduced if the beams cancel each other out (destructive interference). This represents one of the biggest problems in designing communication systems.

As we could already see through the work, radio communications are a distinct group of telecommunications with a connection path from the place of transmission to the place of reception of some information in space. The considered system has found application in many frameworks, and we could see that in this paper, considering the budget of the communication link, it is confirmed that it is indeed a professional group of telecommunications.

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