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Homework 1.

Wireless and Mobile Networks - LRT4112

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Robotics and Telecommunications Engineering.

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Abstract

A complete analysis of wireless communication system fundamentals together with practical applications takes place within this laboratory report. The report uses structured problems to explain fundamental wireless communication topics that cover 1G to 5G cellular network wireless access methods and isotropic antenna characteristics along with multipath fading and diffraction and scattering phenomena. The report provides detailed explanations about antenna design principles while showing how to calculate half-wave dipole frequencies and wavelengths while discussing submarine communication difficulties at low frequencies. The report performs power analysis and path loss modeling in addition to studying antenna gain through mathematical descriptions and MATLAB simulated graphics for free space and urban areas. The work integrates theoretical knowledge with practical problem-solving which enhances core wireless communication concepts along with providing design insights about modern communication system development.

Introduction

Cellular networks have experienced substantial advancements in wireless communication technology throughout the past four decades by implementing new network generation developments. This laboratory document delivers comprehensive explanations about these systems by using thoughtfully created problems. The study starts with an analysis of 1G to 5G wireless access methods to demonstrate the technological development pathway of today's communication systems.

Wavelength and multipath fading and scattering and antenna diffraction form the core concepts in the following section of the report. This section explains how these phenomena influence signal propagation as signals travel through complex real-world environments. Such concepts play a vital role for revealing electromagnetic wave interactions within environments while explaining their influence on communication systems performance.

The report follows basic antenna design concepts by teaching methods for finding half-wave dipole wavelength and frequency selection. A power calculation section of the report presents an explanation of power conversions between transmit dBm and dBW units alongside free space and urban path loss model applications for received power analysis.

The report incorporates MATLAB simulations which generate and display path loss calculations in open, suburban and urban locations through simulations using the Hata and Okumura-Hata models. Long-distance wireless communication requires simulation tools for naive insights regarding signal propagation factors together with essential design parameters for achieving reliable connection.

Methodology

- 1. Research and Theoretical Foundation
  - Wireless Access Techniques (Problem 1):

    The researcher performed a literature review to document all wireless access methods across 1G, 2G, 3G, 4G, and 5G cellular networks.

    A review summarized important advancements of generations along with their method of access which included FDMA for 1G and OFDMA for 4G.
  - Fundamental Concepts (Problem 2):

    The research examined fundamental principles of isotropic antennas as well as multipath fading and diffraction and scattering phenomena based on academic literature and textbooks.

    A precise definition of the concepts accompanied by an explanation of their contributions to wireless communication networks.
- 2. Mathematical Analysis and Calculations

- Antenna Design and Wavelength Calculations: Used the fundamental relationship between wavelength (lambda), frequency (f), and the speed of light (c = 3 × elevated to 8 m/s) to calculate the optimal wavelength and frequency for a half-wave dipole of length 10m.
- Applied the formula

$$\lambda = \frac{c}{f} \tag{1}$$

  to determine the antenna length for a 30Hz submarine communication system and a 300Hz voice transmission system.
- Calculated the required carrier frequency for a half-wave antenna of 1m length.

- 3. Computational Simulations
  - Implemented the Hata model for path loss calculations in suburban environments using the formula:

$$L_{dB} = 69.55 + 26.16log_{10}(fc) - 13.82log_{10}(h_t) - a(h_r) + (44.9 - 6.55log_{10}(h_y))log_{10}(d) \tag{2}$$

    where fc is the carrier frequency ht is the transmitter antenna height, hr is the receiver antenna height, and a(hr) is the correction factor for the receiver antenna height.
  - Extended the analysis to open and urban areas by adjusting the model parameters

- 4. Validation and Analysis
  - Cross-verified all mathematical calculations and MATLAB results with theoretical expectations and known benchmarks.
  - Analyzed the results to draw meaningful conclusions about the behavior of antennas, signal propagation, and the impact of environmental factors on wireless communication systems.

- 5. Documentation and Reporting
  - Compiled the findings into a structured report, ensuring clarity and coherence.
  - Included detailed explanations, mathematical derivations, and graphical representations to support the results.
  - Concluded with a discussion of the practical implications of the findings and their relevance to real-world wireless communication systems.

Results and Discussions

Activity 1

Draw and explain the architecture of MTSOs connected to a cellular network, internet and PSTN

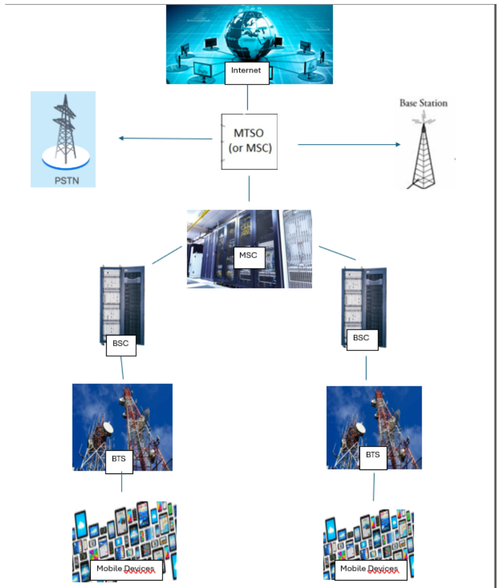

Figure 1: Architecture of MTSOs in a Cellular Network

- Base Transceiver Station (BTS):
  Mobile devices establish radio frequencies links with the BTS for communication purposes. The BTS performs both radio frequency transmit and receive operations.

- Base Station Controller (BSC):
  Manages multiple BTSs.The system manages radio frequency assignments as well as base station power rates and mobile station transfer operations.

- Mobile Switching Center (MSC):
  The MTSO possesses its MSC unit to accomplish setup calls together with handovers in addition to routing functions. Interfaces with the PSTN for traditional telephony connections. A mobile device accesses the internet through the packet-switched core network.

- Mobile Telephone Switching Office (MTSO):
  The central switching center for a group of MSCs. The system links mobile subscribers with PSTN and Internet through its routing functionality.

- PSTN (Public Switched Telephone Network):
  The traditional landline network. Mobile users gain access to connect with landline-based telephone systems.

- Packet-Switched Core (Internet Gateway):
  Mobile devices obtain internet connectivity through a network based on packet switching protocols. The network provisions various data service capabilities including page browsing and VoIP and messaging software functions.

- Internet Backbone:
  A worldwide infrastructure which enables portable device users to reach different web services and digital platforms through the Internet.

What is ISI? During digital communication transmission symbols in the channel will blend together which results in degraded signal reception quality. The main source of ISI is the phenomenon known as multipath propagation which allows signals to arrive at the receiver through different paths at separate times. The delayed signals merge with following symbols. The received signal experiences quality degradation through this effect which causes higher bit errors and decreased system performance. Both equalization techniques alongside system designs that reduce multipath interference provide compensation for channel distortions.

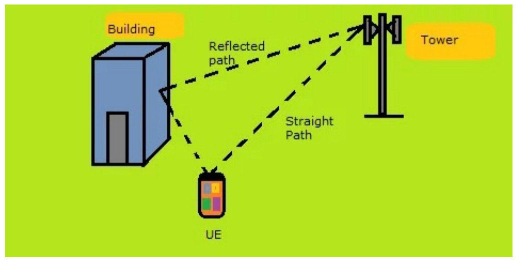

Figure 2: Inter Symbol Interference

Example: In a large conference room where the speaker has activated a microphone. The sound waves reflect from walls and ceiling and every person present in the room. Your ears receive reflected sound waves from the microphone that reach late than the direct sound emitted by the microphone. The delay of reflected sounds will create interference with the microphone's direct signal when the speaker talks fast interfering with speech comprehension.

What is Shadowing? The signal power variations known as shadowing develop when large obstacles such as buildings along with terrain elements interrupt the straight path connecting the transmitter to the receiver. The signal experiences substantial attenuation in distinct areas because Obstacles both absorb the signal energy and reflect and scatter signal waves. Opacity Regions occur when transmission signals fail to reach particular areas and are considered as "shadowed" coverage areas. To ensure coverage the transmission power needs to be increased and diversity techniques with multiple antennas can be implemented along with repeater deployment.

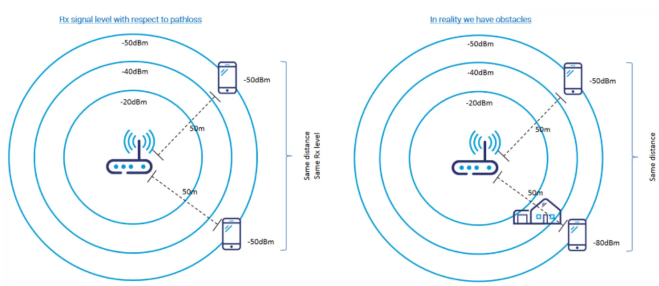

Figure 3: Shadowing with obstacles

Example: Your cellular connection becomes weak when you stand behind a very high structure because the building interferes with the straight communication link to the cell tower. Since this is an instance of shadowing the received power signal weakens when encountering significant obstacles. The solution requires either higher cell tower placement or repeater installations within city areas.

What is small-scale fading? Small-scale fading describes rapid fluctuations in the received signal strength over short distances or short time intervals. The transmission path in multipath propagation results in signals arriving with different delays and phases. Signal paths combine either in a constructive manner or a destructive manner which results in quick signal intensity changes. Deep signal fades become noticeable when signal strength drops significantly during this condition thus creating brief communication breakdowns.

- Flat fading: All frequency components of the signal are affected similarly.
- Frequency-selective fading: Different frequency components experience different fading levels.

Channel coding techniques together with equalization systems and diversity methods such as space or time or frequency diversity strengthen the signal transmitted through radio paths.

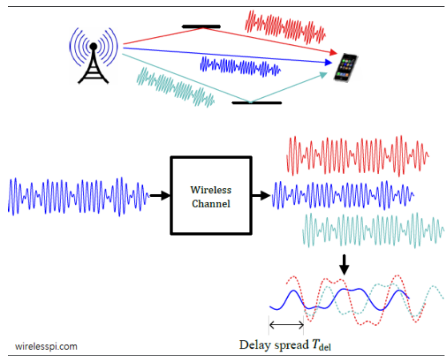

Figure 4: Small-Scale Fading in wireless channel

Example: When you loss the quality of a call while driving under a bridge. The signal takes multiple paths due to reflections from the bridge and nearby objects. Signal pathways from either conjoin constructively or destructively which produce either strong or weak signals that affect call quality rapidly. Under the absence of direct Line-of-Sight (LOS) connections Rayleigh fading occurs in such urban settings.

An isotropic antenna represents an imaginary antenna which sends equal power to all directions. Radiation from this device occurs with complete uniformity in every direction because it acts as the perfect radio wave point source. The equipment functions as a light bulb that distributes energy without distinction in every direction it faces. Real antennas cannot match the standards of complete isotropy yet serve as benchmarks to evaluate actual antenna behavior. The measurement of antenna gain frequently takes place regarding an isotropic antenna (dBi).

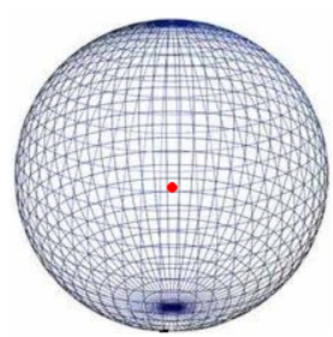

Figure 5: 3D- Antenna Pattern of an Isotropic Antenna

Example: We can take a balloon as an example. The point at the center of the balloon is like an isotropic radiator, and the expanding balloon surface represents the uniform radiation in all directions.

What is multipath propagation? The propagation of radio signals into multiple routes between transmitters and receivers creates multipath propagation. The signal experiences reflection while scattering and diffraction when passing through buildings and other obstacles such as trees or hills or the ground surface. Multipath transmission provides both favorable uses alongside detrimental consequences. Signal reception can benefit from this phenomenon when properly managed although such optimization becomes possible because of deteriorating signal quality through ISI and fading.

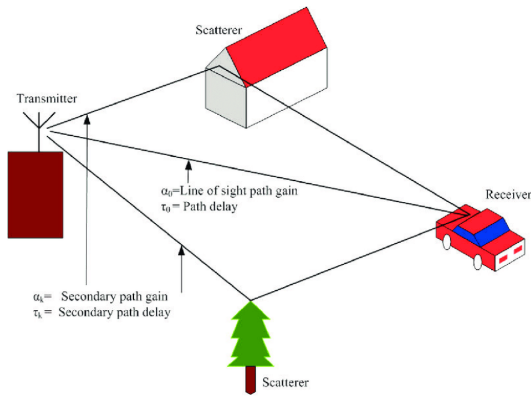

Figure 6: Mutipath propagation example

Example: Listening to a radio while inside an urban environment serves as an example. Radio waves coming to your receiver arrive through direct transmission from the transmitter or indirect transmission after reflecting off buildings. When a signal reaches its destination there may be several duplicate signals arriving from different paths which we call multipath.

What is the difference between reflection and scattering? Radio waves meeting smooth large surfaces (comparable in size to the signal frequency) result in reflection of the waves. A radio wave reflects predictably from such surfaces in a manner similar to how mirrors reflect light. The same angle which the wave approaches the surface becomes the angle in which the wave reflects.
A radio wave that encounters a rough or non-smooth surface or a size-comparable object with respect to signal wavelength will experience scattering. The signal breaks in many irregular directions when it encounters the surface. Light scatters in diverse directions when it comes in contact with airborne particles and fog elements.

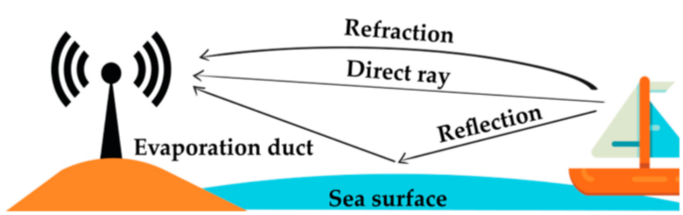

Figure 7: Radio propagation near the sea surface

Example: A radio wave that reflects from the flat exterior of a major building demonstrates reflection as a phenomenon. A radio wave hitting leaves or the uneven tops of rocks constitutes an example of scattering. Movement of the signal occurs throughout various spatial directions.

An antenna requires polarization that specifies how its electric field will oscillate when it transmits or receives radio waves. Here are the main types:

- Horizontal Polarization: Radio waves maintain their electric field oscillations along a horizontal plane that runs parallel with the ground surface. The electric field aligns in a straight line which resembles a clothesline linked between two anchors.

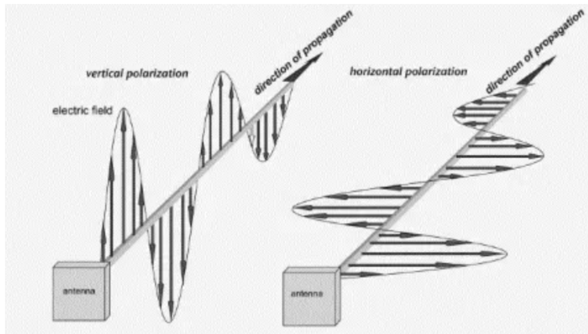

Figure 8: Horizontal polarization

- Vertical Polarization: During vertical polarization the electric field moves along a direction that runs perpendicular to the ground surface. The direction of electric field resembles the way a flagpole stands.

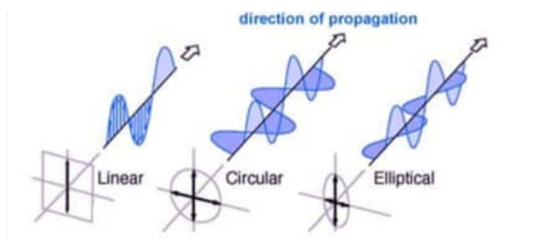

Figure 9: Vertical polarization

- Circular Polarization: The electric field rotates in a circular path as the wave propagates. Antennae operate either where the field rotates right-handed (RHCP) or left-handed (LHCP) based on their rotational direction.

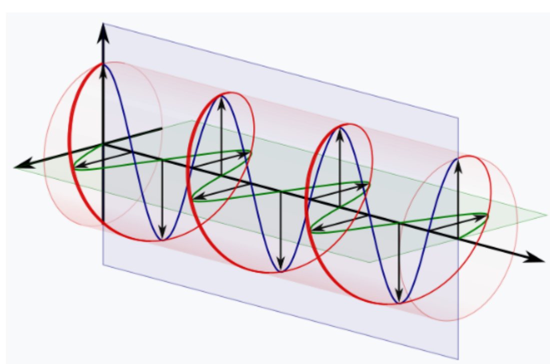

Figure 10: Circular polarization

Polarization Mismatch The antennas achieve their highest transmission efficiency when they possess identical polarization modes. The misalignment of polarization between antennas results in polarization mismatch which reduces the received signal strength.

Loss due to Mismatch

The mismatch degree determines the level of signal loss.

Perfect Match: No loss.
The extent of loss during partial mismatch depends on the degree to which polarizations differ from each other.

Complete Mismatch: Significant loss. A vertically polarized antenna which attempts to receive a horizontally polarized signal experiences significant loss going to infinity if conditions are perfect.

Cost propagation closely resembles the process of assembling puzzle pieces into place. The shapes match exactly when they have the same polarization characteristics and this leads to a strong signal transmission. A weak signal results from a mismatch in polarizations between receiving and transmitting antennas.

Activity 2

Find the round-trip delay of data sent between a satellite and the earth for LEO, MEO, and GEO satellites assuming the speed of light is 3 × 10 8 m/s. If the maximum acceptable delay for a voice system is 30 ms, which of these satellite systems would be acceptable for two- way voice communication?

Answer

To determine the round trip delay for LEO, MEO and Geo satellites, we need to consider the typical altitudes for the satellites and the speed of light.

The typical altitude for LEO is 2000 km.
The typical altitude for MEO is 2,000-40,000 km.
The typical altitude for GEO is 35,000 km.

For the LEO satellite we consider an altitude of 2,000 km so we have a delay of:

$$\frac{2(2,000)}{3*10^3} = \frac{4,000*10^3}{3*10^3} = 13.3 \tag{3}$$

For the MEO we consider an altitude of 20,000 km so we have a delay of:

$$\frac{2(20,000)}{3*10^3} = \frac{4,000*10^3}{3*10^3} = 133.3 \tag{4}$$

For the GEO we consider an altitude of 35000 km so we have a delay of:

$$\frac{2(35,000)}{3*10^3} = \frac{70,000*10^3}{3*10^3} = 233.33 \tag{5}$$

Given these altitudes, we conclude that the LEO satellite in this scenario satisfies the requirement of a round-trip delay under 30 ms for two-way voice communication. In contrast, MEO and GEO satellites exhibit delays that exceed the acceptable threshold for such applications.

Activity 3

Find the optimum wavelength and frequency for a half-wave dipole of length 10 m.
For a half-wave dipole, the lenght of the dipole (in this case L) is half the wavelenght:

$$L = \frac{\lambda}{2} \tag{6}$$

We now that L= 10 m so we can solve for lambda:

$$\lambda = 2 * L = 2 * 10m = 20m \tag{7}$$

We solve for f (frequency):

$$f = \frac{c}{\lambda} \tag{8}$$

We substitute the values and we obtain:

$$f = \frac{3 * 10^8 m/s}{20m} = 15 * 10^6 Hz = 15Mhz \tag{9}$$

The optimum wavelength is equal to 20 m. The optimum frequency is equal to 15 MHz.

Activity 4

It turns out that the depth in the ocean to which airborne electromagnetic signals can be detected grows with the wavelength. Therefore, the military got the idea of using very long wavelengths corresponding to about 30 Hz to communicate with submarines throughout the world. It is desirable to have an antenna that is about one-half wavelength long. How long would that be?

Using the formula of the frequency:

$$c = \lambda * f \tag{10}$$

We solve for lambda to calculate the wavelength:

$$\lambda = \frac{3 * 10^8 m/s}{30Hz} = 10^7 m = 10,000km \tag{11}$$

To calculate the Length:

$$L = \frac{\lambda}{2} \tag{12}$$

We make the necessary substitutions:

$$L = \frac{10,000km}{2} = 5,000km \tag{13}$$

Antenna length should be 5000 km.

Activity 5

5. The audio power of the human voice is concentrated at about 300 Hz. Antennas of the appropriate size for this frequency are impracticably large, so that to send voice by radio voice signal must be used to modulate a higher (carrier) frequency for which the natural antenna size is smaller.
a. What is the length of an antenna one-half wavelength long for sending radio at 300 Hz?
b. An alternative is to use a modulation scheme for transmitting the voice signal by modulating a carrier frequency, so that the bandwidth of the signal is narrow band centered on the carrier frequency. Suppose we would like a half-wave antenna to have a length of 1 m. What carrier frequency would we use?

For solving a) we use the formula of the frequency and solve for lambda.

$$f = \frac{c}{\lambda} \tag{14}$$

And solve for lambda.

$$\lambda = \frac{c}{f} \tag{15}$$

Substituting values, we obtain the following: the following:

$$\lambda = \frac{3 * 10^8 m/s}{300Hz} = 1 * 10^6 m = 1000km \tag{16}$$

To calculate the length of a half-wave antenna we use the following operation:

$$\frac{\lambda}{2} = \frac{1,000km}{2} = 500km \tag{17}$$

Solving b)
Here, the antenna length is given as 1 meter for a half-wave antenna. So, the full wavelength would be twice that 2 meters.

So in this case, lambda is equal to:

$$\lambda = 2 \tag{18}$$

We use the formula of the frequency:

$$f = \frac{c}{\lambda} \tag{19}$$

We substitute and solve the following.

$$f = \frac{3 * 10^8 m/s}{2} = 1.5 * 10^8 Hz = 150MHz \tag{20}$$

The carrier frequency we will use is 150MHz.

Activity 6

6. Suppose a transmitter produces 50 W of power.
a. Express the transmit power in units of dBm and dBW.
b. If the transmitter's power is applied to a unity gain antenna with a 900 MHz carrier frequency, what is the received power in dBm at a free space distance of 100 m?
c. Repeat (b) for 10 km.
d. Repeat (c) but assume a receiver antenna gain of 2.

a) To express the transmit power in dBm we need to convert watts to miliwatts so 50W=50,000mW and then we solve using the following procedure:

$$10log_{10}(50,000) = 47dBm \tag{21}$$

If we want to convert W to dBW we only solve using the following procedure:

$$10log_{10}(50) = 17dBW \tag{22}$$

b)
Pt=50W
F=900 MHz
D=100m

First, we need to calculate the wavelength:

$$\lambda = \frac{c}{f} \tag{23}$$

We substitute:

$$\lambda = \frac{3 * 10^8 m/s}{900MHz} = .333m \tag{24}$$

Then we apply the Friss equation.

$$\frac{P_r}{P_t} = (\frac{\lambda}{4\pi d})^2 G_t G_r \tag{25}$$

We solve for Pr:

$$P_r = (\frac{\lambda}{4\pi d})^2 G_t G_r \tag{26}$$

We substitute:

$$P_r = (\frac{.333m}{4\pi * 100m})^2 \approx 7.0210^{-8} \tag{27}$$

We convert to dBm:

$$P_t = 50W = 47dBm \tag{28}$$

Path Loss

$$10log_{10}(7.02 * 10^{-8}) \approx -71.54dB \tag{29}$$

Received Power

$$P_r = 47dBm - 71.54dB = -24.5dBm \tag{30}$$

c)

$$PathLoss(dB) = 20log_{10}P_W(\frac{4\pi * 10,000}{0.333}) \tag{31}$$

Calculate the argument of the algorithm

$$\frac{4\pi * 10,000}{0.333} \approx \frac{125,664}{0.333} \approx 377,375 \tag{32}$$

Calculate the logarithm

$$log_{10}(377,375) \approx 5.577 \tag{33}$$

Calculate the path loss:

$$PathLoss(dB) = 20 * 5.577 \approx 111.54dB \tag{34}$$

Calculate Received Power:

$$P_{r,d\,Bm} = 47dBm - 111.54dB = -64.54dBm \tag{35}$$

The received power at a distance of 10 km is approximately -64.54 dBm.
d)

The receiver antenna gain will add to the received power. The gain in dB is:

$$G_{r,d\,B} = 10log_{10}(G_r) = 10log_{10}(2) \approx 3dB \tag{36}$$

Add the receiver antenna gain:

$$P_{r,d\,Bm} = -64.54dBm + 3dB = -61.54dBm \tag{37}$$

The received power at a distance of 10 km with a receiver antenna gain of 2 is approximately -61.54 dBm

Activity 7

7. Instead of assuming a free space environment in Problem 6, assume an urban area cellular radio scenario. Use a path loss exponent of n = 3.1 and a transmitter power of 50 W.
a. What is the range of path loss exponents for this environment?
b. If the transmitter's power is applied to a unity gain antenna with a 900 MHz carrier frequency, what is the received power in dBm at a free space distance of 100 m?
c. Repeat (b) for 10 km.
d. Repeat (c) but assume a receiver antenna gain of 2.

Common Data:

- Transmit power: $P_t = 50\,\mathrm{W} = 47\,\mathrm{dBm}$.
- Carrier frequency: $f = 900\,\mathrm{MHz} \implies \lambda = \frac{3\times10^8}{900\times10^6} = 0.333\,\mathrm{m}$.
- Reference distance: $d_0 = 1\,\mathrm{m}$.
- Path loss at d_0 (free space model):

$$\mathrm{PL}(d_0) = 20\log_{10}\left(\frac{4\pi d_0}{\lambda}\right) \approx 31.52\,\mathrm{dB}.$$

a. Range of Path Loss Exponents for Urban Environments:

In urban areas, the path loss exponent (n) varies due to obstacles such as buildings and vegetation.

$$\boxed{2.7 \leq n \leq 3.5}$$

b. Received Power at $d = 100\,\mathrm{m}$:

Path Loss ($n = 3.1$):

$$\mathrm{PL}(100\,\mathrm{m}) = \mathrm{PL}(d_0) + 10\cdot n\cdot\log_{10}\left(\frac{d}{d_0}\right) = 31.52 + 10\cdot 3.1\cdot\log_{10}(100) = 93.52\,\mathrm{dB}.$$

Received Power (P_r):

$$P_r = P_t - \mathrm{PL} = 47\,\mathrm{dBm} - 93.52\,\mathrm{dB} = \boxed{-46.5\,\mathrm{dBm}}.$$

c. Received Power at $d = 10\,\mathrm{km}$:

Path Loss ($n = 3.1$):

$$\mathrm{PL}(10\,\mathrm{km}) = 31.52 + 10\cdot 3.1\cdot\log_{10}(10,000) = 31.52 + 124 = 155.52\,\mathrm{dB}.$$

Received Power (P_r):

$$P_r = 47\,\mathrm{dBm} - 155.52\,\mathrm{dB} = \boxed{-108.5\,\mathrm{dBm}}.$$

d. Received Power at $10\,\mathrm{km}$ with Receiver Antenna Gain ($G_r = 2$):

Antenna Gain in dB:

$$G_r = 10\log_{10}(2) \approx 3\,\mathrm{dBi}.$$

Received Power (P_r):

$$P_r = -108.5\,\mathrm{dBm} + 3\,\mathrm{dB} = \boxed{-105.5\,\mathrm{dBm}}.$$

Part	Result
a	$2.7 \leq n \leq 3.5$
b	$-46.5\,\text{dBm}$
c	$-108.5\,\text{dBm}$
d	$-105.5\,\text{dBm}$

Note: The calculations assume $G_t = G_r = 0\,\text{dBi}$ (isotropic antennas) unless otherwise specified.

Activity 8

A microwave transmitter has an output of 0.1 W at 2 GHz. Assume that this transmitter is used in a microwave communications system where the transmitting and receiving antennas are parabolas, each 1.2 m in diameter.

- a. What is the gain of each antenna in decibels?

```
% Clear workspace and command window
clc; clear; close all;

% Given data
D = 1.2;                    % Diameter of the parabolic antenna (m)
f = 2e9;                    % Frequency (Hz) - 2 GHz
c = 3e8;                    % Speed of light (m/s)

% Compute Wavelength (lambda)
lambda = c / f;  % Wavelength (m)

% Compute Antenna Area (A)
A = (pi * D^2) / 4;  % Area of the parabolic antenna (m^2)

% Compute Antenna Gain (G)
G = (7 * A) / (lambda^2); % Gain (linear scale)

% Convert Gain to Decibels (dB)
G_dB = 10 * log10(G); % Gain in dB

% Display results
fprintf('Antenna Gain Calculation\n');
fprintf('-----------------------------------\n');
fprintf('Wavelength (lambda): %.4f m\n', lambda);
fprintf('Antenna Area (A): %.4f m^2\n', A);
fprintf('Antenna Gain (linear scale): %.4f\n', G);
fprintf('Antenna Gain (dB): %.2f dB\n', G_dB);
```

Figure 11: Matlab code for problem 8

Antenna Gain Calculation

Wavelength (lambda): 0.1500 m

Antenna Area (A): 1.1310 m^2

Antenna Gain (linear scale): 351.8584

Antenna Gain (dB): 25.46 dB

- b. Taking into account antenna gain, what is the effective radiated power of the transmitted signal?

  Pt= PG = (0.1)(351.858) = 35.1858 W

- c. If the receiving antenna is located 24 km from the transmitting antenna over a free space path, find the available signal power out of the receiving antenna in dBm units.

  LdB=20log(4pi)+20(f)20log(Gr)10log(Gt) LdB =21.98+87.6+186.02169.5425.4625.46 = 75.14dB dBm = 10 log(100) = 20

  So the available received signal power is : 20 dBm - 75.14 dBm = -55.14 dBm

Activity 9

Use the Okumura–Hata model to compute the path loss in dB for a suburban environment, with fc = 900 MHz, ht = 45 m, hr = 3 m, and d = 5 km. Furthermore, write a Matlab Program/Matlab Simulink to compute the propagation path loss in dB for open, suburban and urban areas as function of the transmitter antenna high (ht).

```
% Parameters
fc = 900; % Carrier frequency in MHz
ht = 45; % Transmitter antenna height in meters
hr = 3; % Receiver antenna height in meters
d = 5; % Distance in km
area = 'suburban'; % Area type ('urban', 'suburban', or 'open')

% Correction factor for receiver antenna height
a_hr = (1.1 * log10(fc) - 0.7) * hr - (1.56 * log10(fc) - 0.8);

% Urban area path loss
L_urban = 69.55 + 26.16 * log10(fc) - 13.82 * log10(ht) - a_hr + (44.9 - 6.55 * log10(ht)) * log10(d);

% Adjust for area type
if strcmp(area, 'urban')
    path_loss = L_urban;
elseif strcmp(area, 'suburban')
    path_loss = L_urban - 2 * (log10(fc / 28))^2 - 5.4;
elseif strcmp(area, 'open')
    path_loss = L_urban - 4.78 * (log10(fc))^2 + 18.33 * log10(fc) - 40.94;
else
    error('Invalid area type. Use "urban", "suburban", or "open".');
end

% Display the result
disp(['Path Loss for ', area, ' area: ', num2str(path_loss), ' dB']);
```

Figure 12: Matlab code for problem 9

As we can see in Fig 12, we use different formulas to calculate the propagation in each area, urban, suburban and open. In this case the result that we find after select the area ”suburban” was 134.0175dB. We can say that the receiving antenna and the distance is constant, so we are declaring in the next figure from 20 to 200 with steps of 10, so we will be able to check the propagation along the 3 environments as well as a label with the height of the antenna.

```
ht_values = 20:10:200; % Transmitter antenna height range (30m to 300m, in steps of 10m)

% Initialize arrays to store path loss values
L_urban = zeros(size(ht_values));
L_suburban = zeros(size(ht_values));
L_open = zeros(size(ht_values));

% Loop through each ht value and compute path loss
for i = 1:length(ht_values)
    ht = ht_values(i);

    % Correction factor for receiver antenna height
    a_hr = (1.1 * log10(fc) - 0.7) * hr - (1.56 * log10(fc) - 0.8);

    % Urban area path loss
    L_urban(i) = 69.55 + 26.16 * log10(fc) - 13.82 * log10(ht) - a_hr + (44.9 - 6.55 * log10(ht)) * log10(d);

    % Suburban area path loss
    L_suburban(i) = L_urban(i) - 2 * (log10(fc / 28))^2 - 5.4;

    % Open area path loss
    L_open(i) = L_urban(i) - 4.78 * (log10(fc))^2 + 18.33 * log10(fc) - 40.94;
end

% Plot the results
figure;
plot(ht_values, L_urban, 'b', 'LineWidth', 2);
hold on;
plot(ht_values, L_suburban, 'r', 'LineWidth', 2);
plot(ht_values, L_open, 'g', 'LineWidth', 2);
hold off;

% Add labels and legend
xlabel('Transmitter Antenna Height (h_t) [m]');
ylabel('Path Loss [dB]');
title('Path Loss vs. Transmitter Antenna Height (h_t)');
legend('Urban', 'Suburban', 'Open');
grid on;
```

Figure 13: Matlab code for problem 9 for propagation

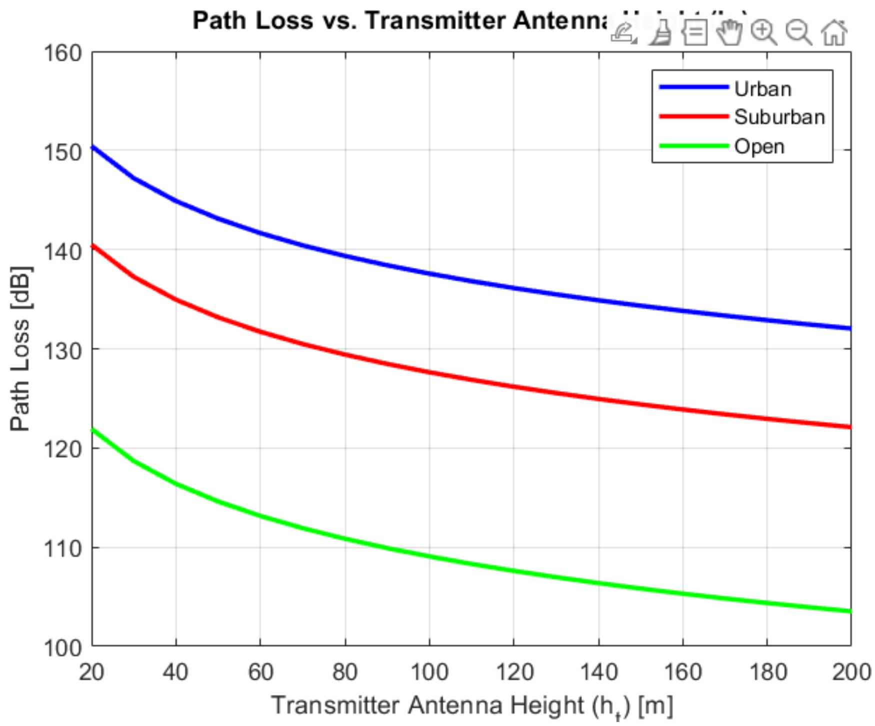

Figure 14: Propagation path for the 3 environments

So as we can see, higher the antenna we will have lower propagation.

Activity 10

Determine the height of an antenna for a TV station that must be able to reach customers up to 80 km away. Use the Okumura–Hata model for a rural environment with fc = 76 MHz and hr = 1.5 m. Transmit power is 150 kW and received power must be greater than $10^{-13}W$.

```
% Parameters
fc = 76; % Carrier frequency in MHz
hr = 1.5; % Receiver antenna height in meters
d = 80; % Distance in km
Pt = 150e3; % Transmit power in watts (150 kW)
Pr_min = 1e-13; % Minimum received power in watts (10^-13 W)

% Step 1: Convert Transmit and Received Power to dBm
Pt_dBm = 10 * log10(Pt * 1e3); % Transmit power in dBm
Pr_min_dBm = 10 * log10(Pr_min * 1e3); % Received power in dBm

fprintf('Step 1: Convert Transmit and Received Power to dBm\n');
fprintf('Transmit power (Pt) in dBm: %.2f dBm\n', Pt_dBm);
fprintf('Received power (Pr_min) in dBm: %.2f dBm\n\n', Pr_min_dBm);

% Step 2: Path Loss Formula for Rural (Open) Area
% Required path loss
L_open = Pt_dBm - Pr_min_dBm; % Path loss in dB

fprintf('Step 2: Path Loss Formula for Rural (Open) Area\n');
fprintf('Required path loss (L_open): %.2f dB\n\n', L_open);

% Step 3: Solve for ht
% Correction factor for receiver antenna height
a_hr = (1.1 * log10(fc) - 0.7) * hr - (1.56 * log10(fc) - 0.8);

fprintf('Step 3: Solve for ht\n');
fprintf('Correction factor (a_hr): %.4f\n', a_hr);

% Urban path loss formula
syms ht
L_urban = 69.55 + 26.16 * log10(fc) - 13.82 * log10(ht) - a_hr + (44.9 - 6.55 * log10(ht)) * log10(d);

% Open area path loss formula
L_open_eqn = L_urban - 4.78 * (log10(fc))^2 + 18.33 * log10(fc) - 40.94 == L_open;

% Solve the equation for ht
ht_solution = double(vpasolve(L_open_eqn, ht));
```

Figure 15: Matlab code for problem 10

```
% Step 4: Compute a(hr)
fprintf('Step 4: Compute a(hr)\n');
fprintf('a(hr) = (1.1*log10(fc) - 0.7)*hr - (1.56*log10(fc) - 0.8)\n');
fprintf('a(hr) = %.4f\n\n', a_hr);

% Step 5: Compute L_urban
L_urban_numeric = 69.55 + 26.16 * log10(fc) - 13.82 * log10(ht_solution) - a_hr + (44.9 - 6.55 * log10(ht_solution)) * log10(d);

fprintf('Step 5: Compute L_urban\n');
fprintf('L_urban = 69.55 + 26.16*log10(fc) - 13.82*log10(ht) - a_hr + (44.9 - 6.55*log10(ht))*log10(d)\n');
fprintf('L_urban = %.2f dB\n\n', L_urban_numeric);

% Step 6: Compute L_open
L_open_numeric = L_urban_numeric - 4.78 * (log10(fc))^2 + 18.33 * log10(fc) - 40.94;

fprintf('Step 6: Compute L_open\n');
fprintf('L_open = L_urban - 4.78*(log10(fc))^2 + 18.33*log10(fc) - 40.94\n');
fprintf('L_open = %.2f dB\n\n', L_open_numeric);

% Step 7: Solve for ht
fprintf('Step 7: Solve for ht\n');
fprintf('Solving L_open = %.2f dB for ht...\n', L_open);
fprintf('Required transmitter antenna height (ht): %.2f meters\n', ht_solution);
```

Figure 16: Matlab code for problem 10 part 2

Step 1: Convert Transmit and Received Power to dBm
Transmit power (Pt) in dBm: 81.76 dBm
Received power (Pr$_m in)indBm : -100.00dBm$
$Step2 : PathLossFormulaforRural(Open)Area$

$Requiredpathloss(L_open) : 181.76dB$
$Step3 : Solveforht$
$Correctionfactor(a_hr) : -0.0807$
$Step4 : Computea(hr)$
$a(hr) = (1.1 * log10(fc) - 0.7) * hr - (1.56 * log10(fc) - 0.8)$
$a(hr) = -0.0807$
$Step5 : ComputeL_urban$
$L_urban = 69.55 + 26.16 * log10(fc) - 13.82 * log10(ht) - a_hr + (44.9 - 6.55 * log10(ht)) * log10(d)$
$L_urban = 205.13dB$
$Step6 : ComputeL_open$
$L_open = L_urban - 4.78 * (log10(fc))^2 + 18.33 * log10(fc) - 40.94$
$L_open = 181.76dB$
$Step7 : Solveforht$
$SolvingL_open = 181.76dBforht.$
$Requiredtransmitterantennaheight(ht) : 0.93meters$

Conclusions

The laboratory investigation has delivered an extensive analysis of essential wireless communication system principles along with practical implementations. The investigation involved various structured problems that allowed us to study basic concepts between cellular network generations 1G through 5G along with fundamental characteristics of isotropic antennas together with multipath fading and diffraction and scattering. We studied key principles of antenna design such as how to determine appropriate half-wave dipole wavelength and frequency values in addition to identifying challenges in working with low-frequency signals.

Power calculations together with path loss modeling and antenna gain analysis took place in two different settings through the use of mathematical formulations and MATLAB simulation tools to generate visual outputs. The combination between theoretical information with physical problem-solving strengthened base knowledge about wireless communication systems while delivering understanding about future system optimization methods.

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