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ELEC-E7250-Laboratory Course in Communications Engineering

Preliminary exercises: Theory Path Loss

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(1) Try to find frequency bands where following technologies operate in Finland [1]:
a. GSM downlink and uplink frequencies and the frequency bands different operators are using.
Uplink and Downlink Frequencies:
GSM 900 (Primary and Extended): Uplink frequencies range from 890 MHz to 915 MHz, and downlink frequencies range from 935 MHz to 960 MHz.
GSM 1800: Uplink frequencies range from 1710 MHz to 1785 MHz, and downlink frequencies range from 1805 MHz to 1880 MHz.
Operators: Various operators use these bands, and the allocation might vary regionally.

b. W-CDMA and/or HSPA downlink and uplink frequencies and the frequency bands different operators are using.
Uplink and Downlink Frequencies: Information specific to Finland isn't readily available, but W-CDMA and HSPA commonly use bands within the UMTS (Universal Mobile Telecommunications System) frequencies, which typically include the 2100 MHz band for 3G services.
Operators: Similar to GSM, different operators have their specific allocations within these bands.

c. LTE downlink and uplink frequencies and the frequency bands different operators are using.
Uplink and Downlink Frequencies: In Finland, LTE bands include, but may not be limited to, 800 MHz (Band 20), 1800 MHz (Band 3), 2100 MHz (Band 1), and 2600 MHz (Band 7). The specific uplink and downlink frequencies within these bands can be found in the detailed spectrum allocations.
Operators: Major operators like Telia, Elisa, and Alands Telecom operate in these bands, with varying frequency ranges allocated to each operator.

d. FM-radio
FM radio in Europe, including Finland, generally operates within the 87.5 to 108.0 MHz frequency range.

e. WLAN
WLAN, including Wi-Fi, typically operates in the 2.4 GHz (2400 to 2483.5 MHz) and 5 GHz (5150 to 5850 MHz) bands.

f. Bluetooth
Bluetooth technology commonly operates in the 2.4 GHz ISM (Industrial, Scientific, and Medical) band, similar to WLAN.

(2) How much 1 W (Watt) is on dBm scale. How much -40dBm is in Watts? Show the equations.

To convert Watts to dBm, we have the formula is:

$$dBm = 10\lg(P/1mW)$$

P is the power in watts (W). P = 1W, since 1 W = 1000 mW, we need to convert the power from watts to milliwatts before applying the formula.

$$dBm = 10\lg(1000mW/1mW)$$

After calculating, we could get that 1 Watt is equivalent to 30 dBm.

To convert dBm to Watts, we have the formula is:

$$P = 10^{\frac{dBm}{10}} \text{ mW}$$

For -40 dBm, we have the:

$$P = 10^{\frac{-40}{10}} \text{ mW}$$

After calculating, we could get that -40dBm is equivalent to 0.0001 mW, we need transfer the result to Watt, that's 0.0000001 Watt.

(3) What are the bandwidths of the described technologies and what is the shape of their spectrum. Explain briefly the shape and bandwidth of the spectrum. In addition to the bandwidth measurement on the laboratory exercise, the signal powers are measured. What kind of power levels (in dBm scale) you expect to find in the exercise?
GSM:
Bandwidth: Typically, each GSM channel has a bandwidth of about 200 kHz. GSM uses a combination of Frequency Division Multiple Access (FDMA) and Time Division Multiple Access (TDMA).
Spectrum Shape: The spectrum of a GSM signal is shaped by GMSK (Gaussian Minimum Shift Keying) modulation, resulting in a bell-shaped or Gaussian-like spectrum. This shape helps in minimizing the bandwidth while still allowing efficient use of the frequency spectrum.

W-CDMA/HSPA:
Bandwidth: W-CDMA typically operates with a bandwidth of 5 MHz per channel.
Spectrum Shape: W-CDMA uses Direct-Sequence Spread Spectrum (DSSS) technology, where the data signal is multiplied with a pseudo-random noise (PN) sequence, spreading the signal over a wider bandwidth. This results in a flatter, more uniform spectral distribution compared to narrowband signals.

LTE:
Bandwidth: LTE supports flexible bandwidths, ranging from 1.4 MHz up to 20 MHz.
Spectrum Shape: LTE utilizes Orthogonal Frequency-Division Multiplexing (OFDM), which divides the wideband LTE signal into multiple narrowband sub-carriers. The spectrum of each sub-carrier is typically shaped like a sinc function (sinc-shaped), leading to an overall rectangular-like spectrum for the entire LTE signal.

FM Radio:
Bandwidth: The typical bandwidth of an FM radio signal is about 200 kHz.
Spectrum Shape: FM radio signals have a V-shaped spectrum, with the highest power at the center frequency and gradually decreasing power levels as you move away from the center. This is due to frequency modulation, where the information is conveyed through variations in the frequency of the carrier wave.

WLAN (Wi-Fi):
Bandwidth: Wi-Fi bandwidth varies depending on the standard, with common values being 20 MHz, 40 MHz, 80 MHz, and 160 MHz.
Spectrum Shape: Wi-Fi also uses OFDM, similar to LTE. The spectrum shape is typically rectangular with distinct peaks representing individual sub-carriers.

Bluetooth:
Bandwidth: Bluetooth generally operates within a bandwidth of about 1 MHz.
Spectrum Shape: Bluetooth employs Frequency-Hopping Spread Spectrum (FHSS), where the signal rapidly hops between different frequencies within its allocated band.

This results in a spectrum that is spread across the entire allocated bandwidth, appearing as multiple peaks across the spectrum.

Regarding the expected power levels in the laboratory exercise, measurements are usually taken at different points in the communication link, and the power levels can vary based on factors like transmission power, antenna gains, path loss, and environmental conditions. Common power levels you might encounter in a lab setting for these technologies are:

Transmitted Power: Usually in the range of 0 dBm to 30 dBm, depending on the technology and regulatory limits.

Received Power: Typically lower due to path loss, possibly in the range of -30 dBm to -60 dBm.

(4) At the laboratory exercise you will measure the path loss of 2.4 GHz and 5.8 GHz signal when a cart is moving on the hallway according to the figure below. Use ITU indoor propagation model to compute path loss along the 10 meter distance in the hallway. Ignore loss from wall penetration.

To compute the path loss using the ITU indoor propagation model along the 10-meter distance in the hallway, we will use the following ITU model formula:

$$L = N \times \lg(d) + 20 \times \lg(f) + P_f(n) - 28$$

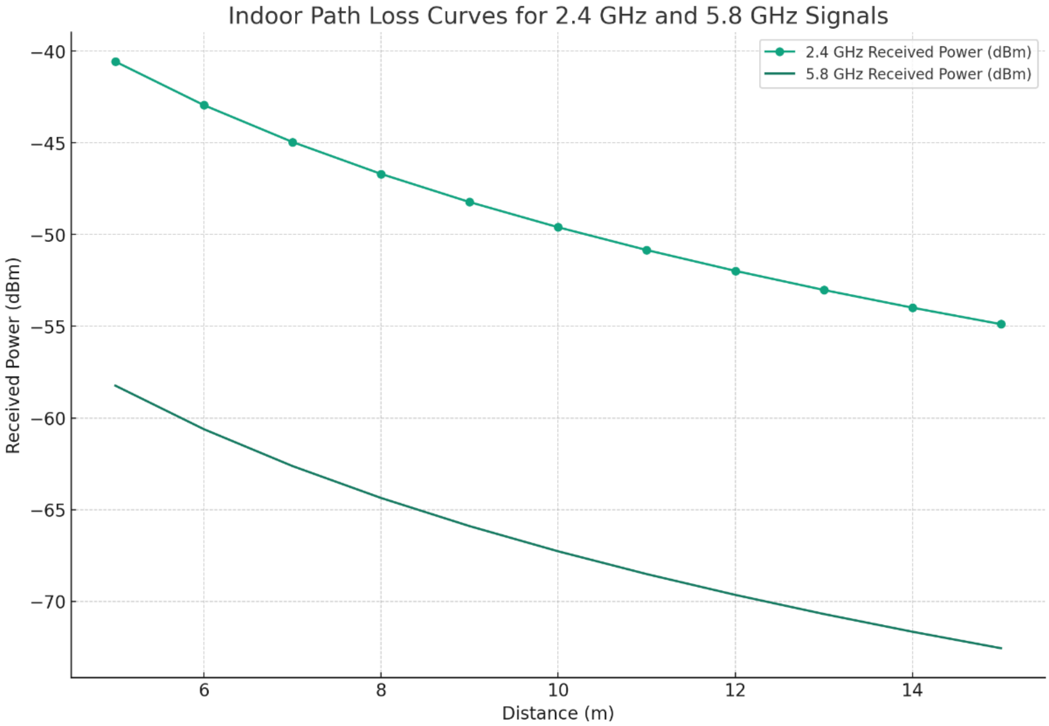
L is the path loss in dB.
N is the distance power coefficient.(typical indoor distance power coefficient is 30)
d is the distance between transmitter and receiver in meters
f is the frequency of the signal in MHz (2.4 GHz and 5.8 GHz for this exercise, after transferring that should be 2400 MHz and 5800 MHz).
Pf(n) is the floor loss penetration factor, which is 0 since we are ignoring wall penetration losses.

About the distance, we could get that at the start of the movement, the distance is $\sqrt{5^2 + 4.3^2} \approx 6.6$ meters, as the movement of the hallway, the distance change, the minimum distance is 5 meters, and the maximum distance is $\sqrt{5^2 + 5.7^2} \approx 7.6$ meters.
I will calculate the three places of both 2.4GHz and 5.8GHz.

2.4GHz:
5 meters: 60.57dB
6.6 meters: 64.19dB
7.6 meters: 66.03dB

5.8GHz:
5 meters: 68.24dB
6.6 meters: 71.85dB
7.6 meters: 73.69dB

(5) Plot the indoor path loss curves with link budget calculation for both frequencies. For the 2.4 GHz gains + losses are 10 dB including antenna gains, cable and connector losses etc. For the 5.8 GHz the gains + losses is approximately 0 dB. The transmission power is 10 dBm.



(6) What kind of path loss curve you expect to see in the laboratory exercise when the scenario is in real life?
In a real-life laboratory exercise, the path loss curve for wireless signal transmission might exhibit several features that deviate from idealized theoretical models due to practical factors:
Non-linearity:
The path loss may not increase linearly with distance because real-world obstacles and materials in the lab will attenuate signals to varying degrees.

Multipath Effects:
Signals can bounce off walls, ceilings, floors, and objects, leading to multipath propagation. This can cause constructive and destructive interference, resulting in a path loss curve with rapid fluctuations or fading.

Shadowing:
As the transmitter moves, or as people and objects move within the lab, they can block the line-of-sight (LOS) path between the transmitter and receiver, causing sudden dips in signal strength, known as shadowing.

Absorption:
Different materials in the lab (e.g., metal shelves, electronic equipment) can absorb signal energy to varying extents, which can cause localized increases in path loss.

Frequency Dependency:
Higher frequency signals (like 5.8 GHz) generally suffer more attenuation than lower frequency signals (like 2.4 GHz), especially when penetrating through materials or traversing longer distances.

Interference:
Electronic devices in the lab can introduce electromagnetic interference (EMI), which can superimpose additional signal variations on the path loss curve.

Considering these factors, the expected real-life path loss curve in a laboratory environment might show:
Irregularities: Sudden peaks and troughs due to the multipath effects and shadowing.
Smoothing: Over short distances, the curve may be smoother due to the averaging effect of the multipath signals.

Greater Overall Path Loss: Compared to free space or an open environment, the path loss might be higher due to obstructions and absorption.

Plateaus: There might be sections where the path loss does not change significantly with distance, particularly if the environment has uniform characteristics over those sections.

In essence, the real-life path loss curve would likely be irregular and exhibit a level of complexity that reflects the dynamic and heterogeneous nature of the laboratory environment.

(7) Explain receive diversity concept and why it improves the link performance on fast fading channel?

Receive diversity is a wireless communication technique used to improve the reliability and quality of a radio link, especially in environments prone to fading. Fading is a common issue in wireless communication where the received signal power fluctuates over time due to various factors, including multipath propagation, where the signal takes multiple paths to reach the receiver. Fast fading, in particular, refers to rapid changes in the amplitude and phase of the received signal caused by small-scale changes in the environment, such as movement of people or objects within the signal path.

Receive diversity typically involves using multiple antennas at the receiver (the number of antennas can vary, but there are often two or more). Each antenna receives the signal independently, and because they are spatially separated, the probability that all antennas will experience a deep fade simultaneously is reduced. The signals from these antennas are then combined using various techniques such as:

Selection Combining (SC): The receiver chooses the antenna with the strongest signal at any given time.

Maximum Ratio Combining (MRC): The signals from all antennas are added together, with each signal being weighted by its signal-to-noise ratio (SNR).

Equal Gain Combining (EGC): The signals from all antennas are co-phased and then added together with equal weights.

Switched Combining: The receiver switches between antennas and uses the one that meets a specific signal quality threshold.

The main benefits of receive diversity in a fast fading channel are:

Improved Signal Quality: By having multiple versions of the signal, the receiver can use the best or a combination of the best signals, leading to an overall improvement in signal quality.

Reduction of Fading Impact: Different antennas will experience fades differently at any given time. Even if one antenna experiences a deep fade, the others may not, thus mitigating the overall impact of fading.

Increased Signal-to-Noise Ratio (SNR): Combining signals from multiple antennas can lead to an increase in the effective SNR, which is critical for maintaining high data rate transmissions and reducing bit error rates.

Enhanced Channel Capacity: Diversity can effectively turn a fading channel into a more reliable communication link, which can improve the channel capacity according to Shannon's law.

Robustness to Interference: Diversity can provide a measure of protection against co-channel interference, as the interference might not affect all antennas equally.

In summary, receive diversity exploits the independence of fading and noise processes at different antennas to improve the reliability and performance of wireless communication links, particularly in fast fading environments.