Aalto University
School of Electrical Engineering

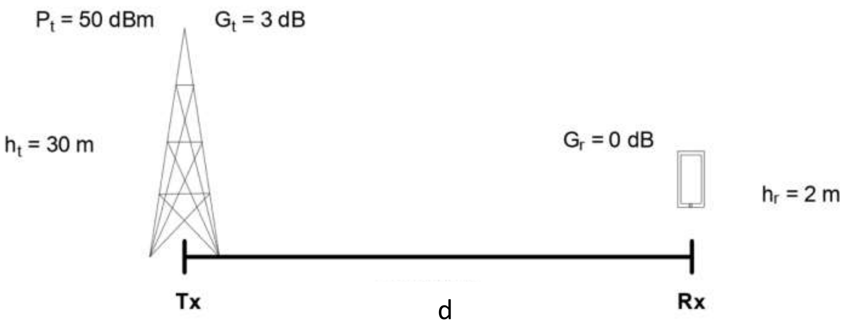
ELEC-E7120 Wireless Systems
Homework for Unit 2

Released on 15.9.2023
Due date 22.9.2023 (by 9:00 AM - Finnish Time)

Guidelines:
- Return the electronic version of your answers before the deadline using the corresponding homework link in MyCourses.
- Homework is individual.
- Some references to do the homework are
    - Slide-sets covered in “Lec3” and “Lec4” (@ MyCourses)

Problem 2.1 (1 point). *Link Budget in 5G FR1 (Low and mid bands)*

According to the scenario below:



a. Calculate the propagation loss (in dB) using the free space path loss model when working in the 5G frequency band 700 MHz when the distance (*d*) is 500 meters.
b. Calculate the propagation loss (in dB) using the free space path loss model when working in the 5G frequency band of 3.5 GHz when the distance (*d*) is 500 meters.
c. Assuming that the sensitivity of the receiver is –80 dBm, what are the respective coverage ranges of a radio system that use both frequency bands (i.e., 700 MHz and 3.5 GHz)? For this computation, only use the free space path loss (i.e., shadowing and fast fading margins are neglected)
d. Compare results in (c) and suggests considerations of a mobile operator when deploying base stations in both frequency bands in their existing 4G cell sites.

Problem 2.2 (1.5 points). *Path loss in a two-ray model with flat earth*

Assume a two-ray model, like the one shown in the figure below, where the height of the transmit antenna (h_t) is 15 meters, the height of the mobile station antenna (h_r) is 2 meters, and the frequency of the radio frequency carrier is 900 MHz. Consider that isotropic antennas are deployed in both transmitter and receiver (*i.e.*, antenna gain is 0 dBi).

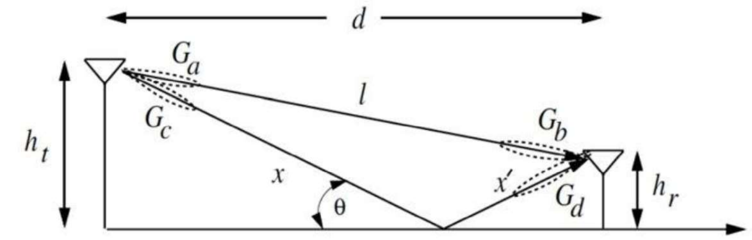


Figure 1: Two-ray model

a. Using the exact formula below of the path loss attenuation for the **two-ray model**, which is valid before and after the so-called breakpoint distance, compute the attenuation (dB) that the radio signal experience in reception when d = 80, 89.9, 90.1, and 100 meters. What happens when the receiver is precisely at a horizontal distance of 90 meters from the transmitter? Why? Please, justify you answer in a simple but clear way.

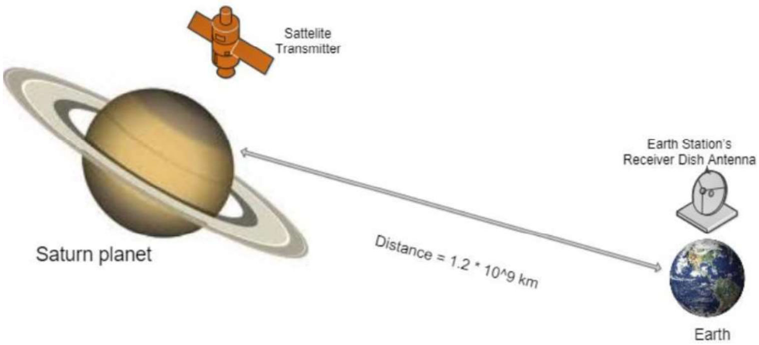
$$P_R = 4P_T \cdot \left(\frac{\lambda}{4\pi \cdot d}\right)^2 \sin^2\left(\frac{2\pi \cdot h_b h_m}{\lambda \cdot d}\right)$$

b. Let us now assume that reflected signal on the ground becomes negligible due to absorption, and that the **line-of-sight (free-space)** propagation between transmitter and receiver dominates. What is the attenuation (dB) that the received signal observes in this new situation at the same distances (i.e., d = 80, 90 and 100 meters)?

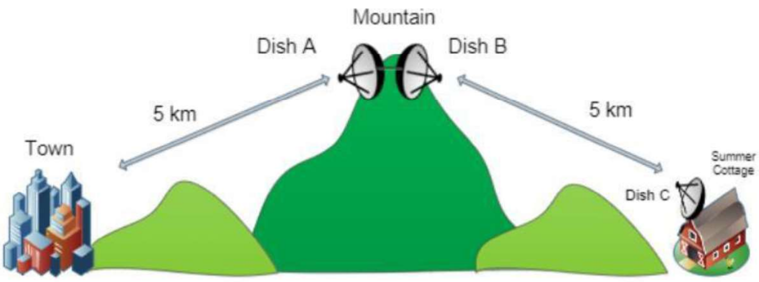
c. **Compare the results in both cases**. How does attenuation change with distance in both cases? Does it show a monotonous or non-monotonous behavior? Is it always stronger the received signal power in presence of a second ray reflected from ground (i.e., a two-ray model) in a) when compared to the single-ray case in b)? Why/why not? Justify your observations in a simple but clear way.

Problem 2.3 (1.5 points). *Free space propagation in space & terrestrial point-to-point links*

a) **Deep space missions.** ESA space probe transmitter is communicating with the Earth station. When the planet Saturn is 1.2×10^{9} km, the satellite transmit power is 57 dBm using a carrier frequency of 28 GHz. The minimum power of the received signal must be -105 dBm at the parabolic dish antenna on Earth for a proper detection of the transmitted information. What is the antenna gain of the satellite transmitter, assuming that the receiver's antenna gain is 13 dB larger than the one of the transmitter antenna?



b) **Passive repeater for hilly terrain.** To provide the Internet service in a rural location, there is an option to *"borrow"* Wi-Fi service (unprotected with no security key) from the town, which is located 10 km away from the summer cottage on the other side of the mountain as shown in the figure below. This town has several unprotected Wi-Fi servers providing internet service. To forward the Wi-Fi signals from the town to the summer cottage, three microwave dish antennas operating at 2.45 GHz are arranged in the following configuration: Dish A and Dish B located on the mountaintop work as a passive repeater that retransmits the signals towards the Dish C located on the rooftop of a summer cottage.



The transmission power of Wi-Fi servers in town is assumed to be 30 dBm with an antenna gain of 5 dBi. To enable optimal wireless internet at the summer cottage, the sensitivity of the receiver (i.e., the minimum received signal level for a proper operation) must be -95 dBm. Cables are assumed to be perfectly matched in impedance, introducing no power losses. What is the minimum gain for all three microwave dish antennas in dBi in order to provide proper Internet service in the summer cottage?