ELEC-E7120 - Wireless Systems (Fall 2023)

Weekly Exercise Session #3

Unit III. Wireless Link

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Solutions for Homework 2

Unit II. Wireless channel

Homework 2

2.1. Link Budget in 5G FR1 Bands

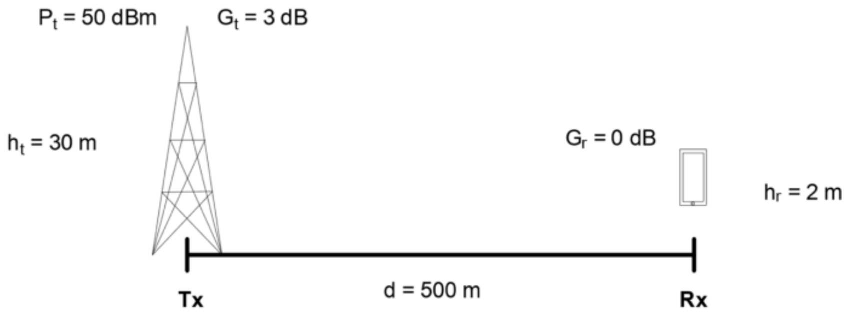
We have been given with scenario:

a. Calculate the propagation loss (in dB) using the free space path loss model 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 working in the 5G frequency band of 3.5 GHz when the distance (*d*) is 500 meters.

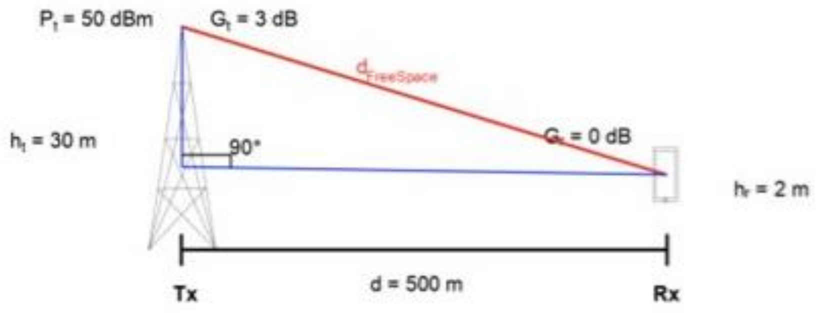
c. Assuming that the receiver sensitivity of the receiver is –80 dBm, what are the respective coverage ranges of a radio system that use both frequency bands (No shadowing and no Fast-Fading margins)?

d. Compare results in (c) and suggests considerations of a mobile operator when deploying base stations in both frequency bands in their existing cell sites.



Problem 2.1

Calculate the propagation loss (in dB) using the free space path loss model working in the 5G frequency band 700 MHz and 3.5 GHz when the distance (*d*) is 500 meters.



$$d_{FreeSpace} = \sqrt{(h_t - h_r)^2 + d^2} = 0.500783\ km$$

Friis equation

$$\frac{P_R}{P_T} = G_T G_R \left(\frac{\lambda}{4\pi r}\right)^2$$

Linear $$PL = \frac{P_T}{P_R} = \frac{1}{G_T G_R}\left(\frac{4\pi r}{\lambda}\right)^2$$

Logarithimic $$PL_{dB} = 10\log_{10}\left(\frac{1}{G_T G_R}\left(\frac{4\pi d f}{c}\right)^2\right)$$

$$= 20\log_{10} d + 20\log_{10} f + 20\log_{10}\frac{4\pi}{c} - (10\log_{10} G_T + 10\log_{10} G_R)$$

$$= 20\log_{10} d_{km} + 20\log_{10} f_{MHz} + 32.44 - (G_{T,dB} + G_{R,dB})$$

a. For $f = 700$ MHz,

$$PL = 32.44 + 20log_{10}d(km) + 20log_{10}f(MHz) - (G_t + G_r) = 80.335\ dB$$

b. For $f = 3.5$ GHz,

$$PL = 32.44 + 20\log_{10}d(km) + 20\log_{10}f(MHz) - (G_t + G_r) = 94.3144\ dB$$

Problem 2.1

Assuming that the receiver threshold is –80dBm, what are the respective radii of coverage area for usage of the 2 above frequencies (700MHz and 3.5GHz).

$$The\ sensitivity\ of\ receiver\ is - 80\ dBm$$
$$so\ P_r = -80\ dBm$$
$$PL = P_t/P_r$$
$$In\ dB\ equation\ is\ written\ as$$
$$PL = P_t - P_r$$
$$P_r = P_t - PL$$
$$\therefore\ PL = 20log_{10}(4\pi/c) + 20log_{10}(f) + 20log_{10}(d) - G_t - G_r$$
$$P_r = P_t - 20log_{10}(4\pi/c) - 20log_{10}(f) - 20log_{10}(d) + G_t + G_r$$
$$Put\ the\ given\ values$$
$$When\ f = 700\ MHz$$
$$\boxed{d = 152.37\ km}$$
$$When\ f = 3.5\ GHz$$
$$\boxed{d = 30.47\ km}$$

Problem 2.1

Compare both results and suggest considerations of a mobile operator when deploying transceivers in both frequency bands in their existing cell sites.

- Note that obtained results are too optimistic. Reason for this: 1) Path loss model was free-space, with path loss exponent 2 (LoS). In practice, path loss exponent closer to 4 (NLoS) is expected, especially in (dense) urban areas. 2) Antenna transmit power was large (macro base station) and only effect of path loss attenuation was considered (no penetration loss, shadow fading margin, fast fading margin, body absorption, etc.) 3) Co-channel interference coming from adjacent cells is assumed negligible.
- Higher frequency bands are more susceptible signal attenuation/Path loss (as result shows in part a and b) So operators need to consider antenna placement to minimize these issues.
- The lower frequency band (700 MHz) provides a significantly larger coverage area compared to the higher frequency band (3.5 GHz) so mobile operators may need to carefully plan and adjust the placement of base stations to ensure consistent coverage and avoid coverage gaps.
- Utilize 700 MHz to fill in coverage gaps in less populated regions, providing reliable connectivity to remote areas while deploy transceivers using the 3.5 GHz frequency band in urban and high-density areas where the coverage area is smaller, but data demand is high.

Homework 2

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2.2. 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 (ht) is 15 meters, the height of the mobile station antenna (hr) is 2 meters, and the frequency of the radio carrier is 900 MHz. Consider that isotropic antennas are deployed in both transmitter and receiver (i.e., antenna gain is 0 dBi in both cases).

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.

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 2.2

a) Two-Ray model

The formula is defined as:

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

So, in order to compute the ***path loss attenuation (linear scale)***:

$$PL = \frac{P_T}{P_R} = \frac{1}{4}\left(\frac{4\pi d}{\lambda}\right)^2 sin^{-2}\left(\frac{2\pi \cdot h_b \cdot h_m}{\lambda \cdot d}\right)$$

Path loss

$$\boxed{\boldsymbol{PL} = \frac{P_T}{P_R}}$$

Isotropic antennas

$$\boxed{\boldsymbol{G_T} = 0\ dBi,\quad \boldsymbol{G_R} = 0\ dBi}$$

Wavelength

$$\boxed{\lambda = \frac{c}{f}}$$

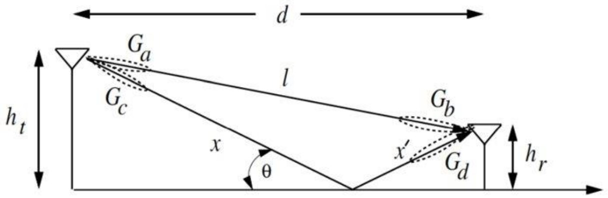


Figure 1: Two-ray model

b) Free Space model

According to the formula:

$$P_R = P_T G_T G_R \left(\frac{\lambda}{4\pi d}\right)^2$$

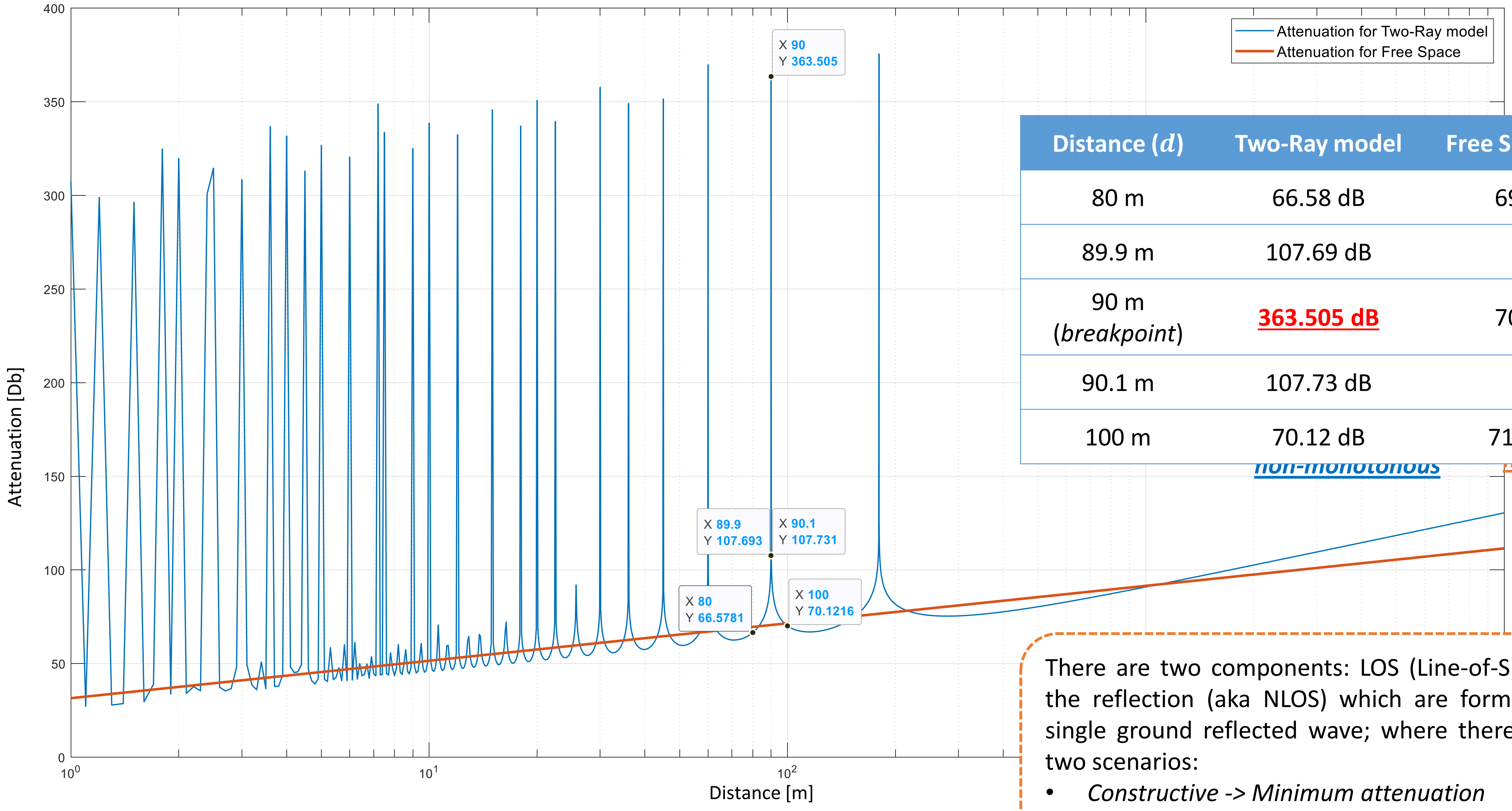
To obtain the ***path loss attenuation (linear scale)***:

$$PL = \frac{P_T}{P_R} = \frac{1}{G_T G_R}\left(\frac{4\pi d}{\lambda}\right)^2$$

Results:

Distance (d)	Two-Ray model	Free Space model
80 m	66.58 dB	69.58 dB
89.9 m	107.69 dB	-
90 m	363.505 dB	70.61 dB
90.1 m	107.73 dB	-
100 m	70.12 dB	71.526 dB
	non-monotonous	*monotonous*

Problem 2.2



Distance (d)	Two-Ray model	Free Space model
80 m	66.58 dB	69.58 dB
89.9 m	107.69 dB	-
90 m (*breakpoint*)	**363.505 dB**	70.61 dB
90.1 m	107.73 dB	-
100 m	70.12 dB	71.526 dB

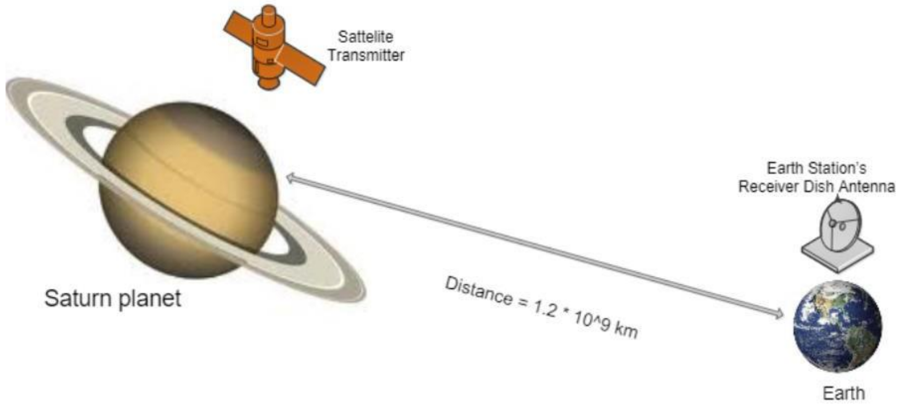
There are two components: LOS (Line-of-Sigh) and the reflection (aka NLOS) which are formed by a single ground reflected wave; where there can be two scenarios:

- *Constructive -> Minimum attenuation*
- *Destructive -> **High attenuation***

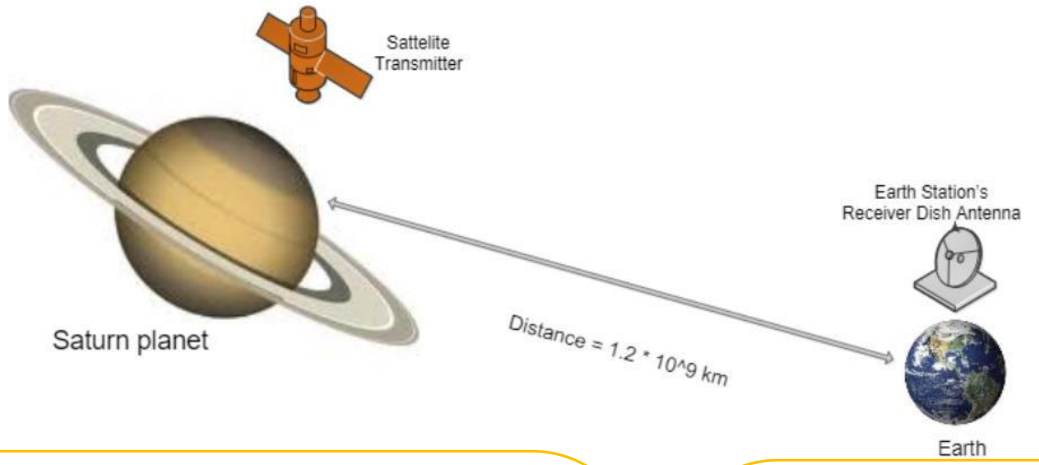
Homework 2

2.3. Free space propagation

a) A NASA space probe transmitter is communicating with the Earth station; when the planet Saturn is 1.2×10^9 km. the satellite transmitter power is 57 dBm using a carrier frequency of 28 GHz. The minimum received signal level must be -105 dBm at receiving dish antenna. What is the antenna gain of the satellite transmitter, assuming that the receiver's antenna gain is 13 dB larger than the transmitter antenna?



Problem 2.3 a)



- Consider the transmission range, assume it is free space propagation:

$$\frac{P_R}{P_T} = G_T G_R \left(\frac{\lambda}{4\pi r}\right)^2 \qquad \lambda = \frac{c}{f} = \frac{3\times 10^8}{28\times 10^9} m$$

- Receiver's antenna gain is 13dB larger than Transmitter's antenna gain

$$G_R = 10^{1.3} G_T$$

- Other requirements:

$$P_R = -105dBm \qquad P_T = 57dBm$$

$$G_T = \frac{P_R}{G_R P_T (\frac{\lambda}{4\pi r})^2} = \frac{P_R}{10^{1.3} G_T P_T (\frac{\lambda}{4\pi r})^2}$$

- When $r = 1.2 \times 10^{12} m$

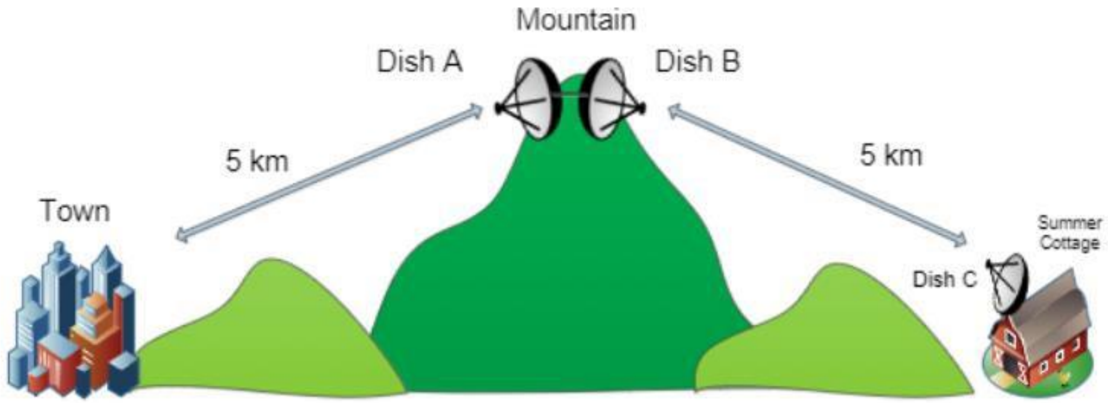
$$G_t = 64dBi$$

Homework 2

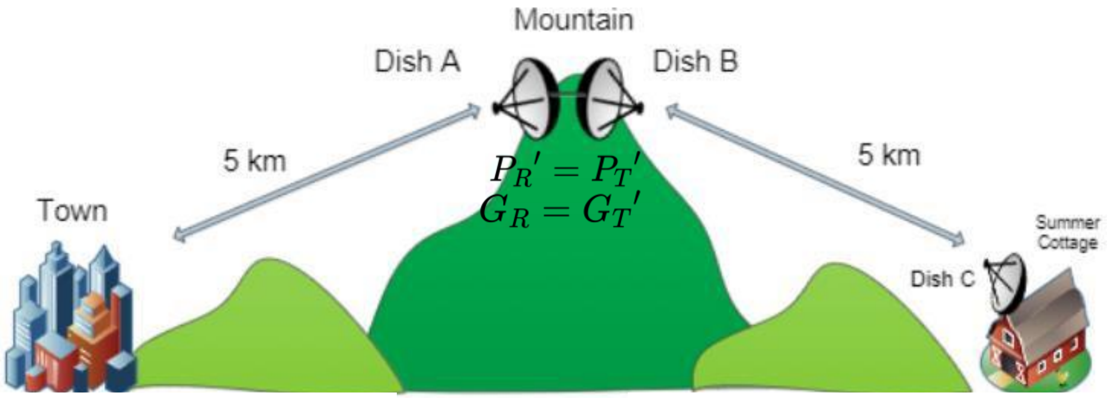
2.3. Free space propagation

B)In order to provide the Internet service, 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 below figure. This town has several unprotected Wi-Fi servers providing internet service. In order to propagate the signals from 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 30dBm with an antenna gain of 5 dBi. To enable optimal wireless internet at the summer cottage, the minimum received signal level must be -95 dBm. Cables are assumed to be matched and lossless. What is the minimum gain for all three microwave dish antennas in dBi in order to provide proper internet service in the summer cottage?



Problem 2.3 b)



$P_T = 30dBm = 10^3 mW = 1W$

$P_R = -95dBm = 10^{-9.5} mW = 10^{-12.5} W$

$G_T = 5dBi = 10^{0.5}$

G_R

- Consider the transmission range, assume it is free space propagation:

$$\frac{P_R}{P_T} = G_T G_R \left(\frac{\lambda}{4\pi r}\right)^2 \quad \lambda = \frac{c}{f} = \frac{3 \times 10^8}{2.45 \times 10^9} m$$

$$r = 5 \times 10^3 m$$

- From Town to Dish A:

$$\frac{P_R'}{P_T} = G_T G_R \left(\frac{\lambda}{4\pi r}\right)^2 \qquad (1)$$

- From Dish B to Dish C:

$$\frac{P_R}{P_T'} = G_T' G_R \left(\frac{\lambda}{4\pi r}\right)^2 \qquad (2)$$

- Since $P_R' = P_T'$, $G_R = G_T'$, after calculating (1)*(2):

$$\frac{P_R}{P_T} = G_T G_R^3 \left(\frac{\lambda}{4\pi r}\right)^4$$

- When $G_R \approx 1906.78 \approx 32.8dBi$ it can meet the minimum requirement.