Laboratório 1 Comunicações Moveis

1. Using Google find out the typical sensitivity of receivers for GMS, WLAN and Bluetooth receivers. Indicate these values both in dBm and W. Indicate also the web links from where the information was retreived.

R: The sensitivity of receivers is the minimum power required for the receiver to identify and process the signal.

For the technologies requeste we found values of:

- Bluetooth — -70 dBm to -100 dBm — 10^{-10} W to 10^{-13} W
- Wifi — -40 dBm to -80 dBm — 10^{-7} W to 10^{-11} W
- GSM — up to -120 dBm — 10^{-15} W

Source: www.everythingrf.com/community/what-is-receiver-sensitivity

2. The IEEE 802.11g technology enables the transmission of data using multiple bitrates. Some manufactures provide the receiver sensitivity required for each bitrate for their receivers. Using Google again, try to find an example of it. Please provide the link and indicate the sensitivity values both in dBm and W.

R: SOURCE: WWW.ATEL-ELECTRONICS.EU/GRUPA.PHP?GRUPA=BEZ01

WIRELESS CLIENT DEVICE AIRCLIENT NEXUS PRO TOTAL (SMART BRIDGES SB3412)

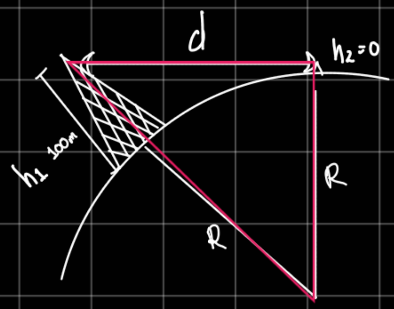
- RECEIVER SENSITIVITY

dBm	W	FREQ (GHz)	BITRATE
-97		2,4	@ 1 Mbps
-73		2,4	@ 54 Mbps
-91		5.x	@ 6 Mbps
-69		5.x	@ 54 Mbps

3. ASSUME TWO ANTENAS, ONE ANTENNA IS 100M HIGH AND THE OTHER IS AT GROUND LEVEL.

a) CALCULATE THE MAXIMUM LINE-OF-SIGHT (LOS) DISTANCE BETWEEN THESE ANTENNAS.

R:



PELA FORMULA $d = 3570 \cdot (\sqrt{Kh_1} + \sqrt{Kh_2})$, COM $K = 4/3$

$d = 3570 \cdot (\sqrt{4/3 \cdot 100} + \sqrt{\cancel{K \cdot 0}}) = 41.223$ Km

b) ASSUME ONE THAT ONE ANTENNA IS 10M HIGH. HOW HIGH MUST BE THE SECOND ANTENNA TO OBTAIN THE SAME LOS DISTANCE?

$d_1 = 41\,223$ m, $d_2 = 3570 \cdot (\sqrt{K \cdot 10} + \sqrt{K \cdot h_2})$, $d_1 = d_2$

$$\Leftrightarrow 41223 = 3570 \cdot \left(\sqrt{\frac{4}{3} \cdot 10} + \sqrt{\frac{4}{3} \cdot h_2} \right)$$

$$\Leftrightarrow \left(\frac{41223}{3570} - \sqrt{\frac{4}{3} \cdot 10} \right)^2 \times \frac{3}{4} = h_2$$

$$\Leftrightarrow h_2 = 46.755 \text{ m}$$

4. CONSIDER A SQUARE CITY OF 100 Km^2. SUPPOSE YOU DESIGN A CELULAR SYSTEM FOR THIS CITY WITH SQUARE CELLS, WHERE EVERY CELL (REGARDLESS OF CELL SIZE) HAS 100 CHANNELS AND CAN SUPPORT 100 ACTIVE USERS (IN PRACTICE THE NUMBER OF USERS THAT CAN BE SUPPORTED PER CELL IS MOSTLY INDEPENDENT OF CELL SIZE AS LONG AS THE PROPAGATION MODEL AND POWER SCALE APPROPRIATELY). WHAT IS THE TOTAL NUMBER OF ACTIVE USERS THAT YOUR SYSTEM CAN SUPPORT FOR A CELL SIZE OF 1 Km^2? WHAT CELL SIZE WOULD YOU USE IF YOU REQUIRE THAT YOUR SYSTEM SUPPORT 250 000 ACTIVE USERS?

R: $\frac{A_T}{A_{CELL}} = \frac{100 \cancel{K}m^2}{1 \cancel{K}m^2} = 100$ CELLS $\quad N_{USER} = N_{CHANNELS} \times N_{CELLS}$

$$N = 100 \times 100 = 10 \cdot 10^3 = 10 \text{K USERS}$$

REVERSING THE PROCESS FOR 250 000 USERS WE GET

$250000 = 100 \times N_{CELLS} \rightarrow N_{CELLS} = 2500 \quad A_{CELL} = \frac{A_T}{N_{CELL}} = \frac{1 \text{Km}^2}{2500}$

$A_{CELL} = 400 \text{ m}^2$

5. CONSIDER AN INDOOR WIRELESS LAN WITH $f_c = 900\,MHz$, CELLS OF RADIUS 100 M, AND OMNIDIRECTIONAL ANTENNAS. UNDER THE FREE SPACE PATH-LOSS MODEL (FRISS MODEL), WHAT TRANSMIT POWER IS REQUIRED AT THE ACESS POINT SUCH THAT ALL TERMINALS WITHIN THE CELL RECEIVE A MINIMUM POWER OF 10 nW? CONSIDER $G_1 = 1$

R: $f_c = 900\,MHz$ $\quad r_{CELL} = 100\,m$ $\quad P_R = 10\,nW$ $\quad G_1 = 1$

↳ $d_{MAX} = r_{CELL}$ $\qquad$ ↓ T & R

BY THE FRISS MODEL:

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

WHERE

$P_R \rightarrow$ POWER RECEIVED

$P_T \rightarrow$ POWER TRANSMITED

$G_T \rightarrow$ GAIN TRANSMITER ANT

$G_R \rightarrow$ GAIN RECEIVER ANT

$\lambda \rightarrow$ WAVE LENGH

$d \rightarrow$ DISTANCE BETWEEN ANT.

ASSUMING UNITARY GAINS FOR BOTH ANTENNAE, AND REWORKING THE EXPRESSION

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

$$\lambda = \frac{c}{f} \rightarrow 3\times10^8 \Leftrightarrow \lambda = \frac{3\times\cancel{10}^8}{9\times\cancel{10}^8} = 0,3(3)\,m$$

$$P_T = \frac{10\,nW}{\left(\frac{1/3}{4\pi \cdot 100}\right)} = 142,122\,mW$$

6. SUPPOSE A PEDESTRIAN IS MOVING IN A URBAN ENVIRONMENT THAT HAS A WIRELESS CHANNEL WITH A COHERENCE TIME $T_C = 70$ ms AND A COHERENCE BANDWIDTH $B_C = 150$ KHz. ASSUME WE WOULD LIKE TO CONSIDER THE CHANNEL AS SLOW FADING ($T_{SYMBOL} < 0{,}1 * T_C$) AND NO-FREQUENCY SELECTIVE ($B < 0{,}1 * B_C$)

a) INDICATE THE BAUD RATE INTERVAL, IN SYMBOL/S OR BAUD, AT WHICH THE INFORMATION COULD BE TRANSMITTED THROUGH THIS CHANNEL. ASSUME THAT $T_{SYMBOL} = 1/B$

R: $\frac{1}{B} < 0{,}1 * T_C \iff \frac{1}{7m} < B \iff B = 142{,}9$ Hz

$B < 150\,\text{KHz} \cdot 0{,}1 \iff B = 15\,\text{KHz}$ $\quad 142{,}9\text{ Hz} < B < 15\,\text{KHz}$

b) CALCULATE THE VELOCITY THE PEDESTRIAN IS MOVING, IN KM/H, ASSUME $f_c = 1$ GHz AND $\theta = 0°$

R: $f_D = \frac{1}{2\pi \cdot T_c} = 0{,}00227$

$f_D = \frac{V}{\lambda} \iff V = f_D \cdot \lambda = 0{,}681\,m/s = 2{,}4\,Km/h$

7. CONSIDER THE SET OF EMPIRICAL MEASUREMENTS OF P_R/P_T GIVEN IN THE TABLE BELOW FOR AN INDOOR SYSTEM AT 900 MHz

d (m)	$M_{dB} = P_{R\,dB} - P_{T\,dB}$
10 m	- 70 dB
20 m	- 75 dB
50 m	- 90 dB
100 m	- 110 dB
300 m	- 125 dB

a) FIND THE PATH LOSS EXPONENT γ THAT MINIMIZES THE MEAN SQUARE ERROR (MSE) BETWEEN THE SIMPLIFIED MODEL $P_{R_{dB}} = P_{T_{dB}} + K_{dB} - 10 \cdot \gamma \cdot \log(d/d_0)$ AND THE EMPIRICAL dB POWER MEASUREMENTS, ASSUMING $d_0 = 1$ m.

THE MSE IS GIVEN BY THE EQUATION REPRESENTED BELOW; TRY TO FIND γ WHICH MINIMIZES $F(\gamma)$.

$$F(\gamma) = \sum_{i=1}^{5} \left[M_{measured}(d_i) - M_{model}(d_i) \right]^2$$

R: $\lambda = \frac{c}{f} = \frac{3\times10^8}{9\times10^8} = \frac{1}{3} = 0{,}33$ m $\quad K_{dB} = 10 \log\left[\frac{1/3}{4\pi \cdot 1}\right]^2$

$$\Leftrightarrow K_{dB} = 10 \log\left[\frac{1}{12\pi}\right]^2 \Leftrightarrow K_{dB} = -31{,}52 \text{ dB}$$

$$F(\gamma) = (-70 + 31{,}5 + 10\log(10))^2 + (-75 + 31{,}5 + 10\log(20))^2$$
$$+ (-90 + 31{,}5 + 10\log(50))^2 + (-110 + 31{,}5 + 10\log(100))^2$$
$$+ (-125 + 31{,}5 + 10\log(500))^2$$

$$\Leftrightarrow F(\gamma) = 21701 - 16661\,\gamma + 1571\,\gamma^2$$

$$F'(\gamma) = 0 \rightarrow \gamma = 3{,}71$$

b) FIND THE POWER RECEIVED AT 150 M FOR THE SIMPLIFIED PATH LOSS MODEL WITH THIS PATH LOSS EXPONENT AND A TRANSMIT POWER OF 1 mW (0 dBm)

R: $d = 150\ m \quad P_T = 1\ mW = 0\ dBm$

$$P_{R_{dBm}} = P_{T_{dBm}} + K_{dB} - 10\,\gamma \log\left[\frac{d}{d_0}\right]$$

$$= 0 - 31{,}5 - 10 \cdot 3{,}71 \log\left[\frac{150}{1}\right]$$

$$P_{R_{dBm}} = -112\ dBm$$

8. ASSUME IN THE PREVIOUS EXAMPLE THAT THE EXPONENT FOR THE SIMPLIFIED PATH LOSS MODEL THAT BEST FITS THE MEASUREMENTS OF THE TABLE WAS $\gamma = 3{,}7$. ASSUMING THE SIMPLIFIED PATH LOSS MODEL WITH THIS EXPONENT AND $K = -31{,}5$ dB, FIND $\sigma^2_{\psi\,dB}$, THE VARIANCE OF LOG-NORMAL SHADOWING ABOUT THE MEAN PATH LOSS BASED ON THESE EMPIRICAL MEASURMENTS. PLEASE REMENBER THAT:

$$VAR(x) = E[(x-\mu)^2]$$

R:

$$\frac{F(\gamma)}{5} = E[(x-\mu)^2] \iff VAR(x) = \frac{F(\gamma)}{5}$$

$$\sigma^2_{\psi} = \frac{1}{5} \cdot \left[\sum_{N=1}^{5} \left[M_{MEASURED} - M_{MODEL}\right]^2\right]$$

$$= 13{,}6\ dB$$

9. CONSIDER A CHANNEL WITH RAYLEIGH FADING AND RECEIVING AN AVERAGE POWER OF $P_R = 20$ dBm

a) FIND THE PROBABILITY THAT THE RECEIVED POWER IS BELOW 10 dBm. AS DISCUSSED, THE POWER RECEIVED ALONG THE TIME IN THIS SITUATION IS EXPONENCIALLY DISTRIBUTED HAVING A P.D.F GIVEN BY:

$$P_{z^2}(x) = \frac{1}{P_r} e^{-x/P_r}$$

WHERE P_R REPRESENTS THE AVERAGE POWER OF THE SIGNAL RECEIVED, I.E. THE POWER RECEIVED BASED ON PATH LOSS AND SHADOWING ALONE

R: $P_{R_{dBm}} < 10\,dBm \rightarrow P_R < 0{,}01\,W \qquad 20dBm = 0{,}1\ W$

$$P(P_R < 0{,}01) = \int_0^{0{,}01} \frac{1}{0{,}1} e^{-x/0{,}1}\,dx = 0{,}95 = 95\%$$

b) FIND THE PROBABILITY THAT THE RECEIVED POWER IS BELOW 20 dBm (THE AVERAGE POWER) COMPARE THIS PROBABILITY WITH THE PROBABILITY OBTAINED USING A GAUSSIAN DISTRIBUTION

$$P(P_R < 0{,}1) = \int_0^{0{,}1} \frac{1}{0{,}1} e^{-x/0{,}1}\,dx = 0{,}63 = 63\%$$

10. CONSIDER 4 TRANSMITTER, --- T_1 --- T_2 --- T_3 --- T_4. SEPARATED BY DISTANCES OF 2 KM. THE TRANSMITTERS ARE TRANSMITTING CONTINUOUSLY INFORMATION AT POWERS P_T = 20 dBm. T_1 AND T_3 OPERATE IN CHANNEL 1; T_2 AND T_4 OPERATE IN CHANNEL 2. CHANNEL 1 IS CHARACTERIZED BY A CARRIER OF 5 GHz AND BANDWIDTH B = 40 MHz. CONSIDER 2 RECEIVERS R_1 AND R_2, LOCATED RESPECTIVELY AT LEFT AND RIGHT SIDES OF T_3 AT DISTANCES OF 1 KM FROM T_3.

------ T_1 ------ T_2 --- R_1 --- T_3 --- R_2 --- T_4 ------

RECEIVERS R_1 AND R_2 RECEIVE INFORMATION FROM T_3, HAVE THERMAL NOISE $(N = N_0 \cdot B)$, AS WELL AS INTERFERENCE POWER (I) GENERATED BY T_1. USING THE SHANNON LAW, $C/B = \log_2(1 + P_r(N+I))$, AND ASSUMING THE FRIIS PROPAGATION MODEL, ESTIMATE THE MAXIMUM SPECTRAL EFFICIENCY (BIT/S/Hz), OBTAINABLE AT R_1 AND R_2.

R: $P_t = 20\,\text{dBm} = 0{,}1$ CHANNEL 1: 5 GHz; B = 40 MHz $\lambda = 3/50$

$N = N_0 \cdot B \qquad E/N = 1{,}38 \cdot 10^{-23} \cdot 300 \cdot 40 \cdot 10^{6} = 1{,}6564 \cdot 10^{-13}$

$$P_R = \left(\frac{\lambda}{4\pi d}\right)^2 \cdot P_T = \left(\frac{0{,}06}{4\pi \cdot 1000}\right)^2 \cdot 0{,}1 = 2{,}28 \cdot 10^{-12}$$

$$I = \left(\frac{\lambda}{4\pi d}\right)^2 P_T \Rightarrow d_1 \neq d_2$$

$$I_{R1} = \left(\frac{0{,}06}{4\pi \cdot 3000}\right)^2 \cdot 0{,}1 = 2{,}53 \cdot 10^{-13}$$

$$I_{R2} = \left(\frac{0{,}06}{4\pi \cdot 5000}\right)^2 \cdot 0{,}1 = 9{,}12 \cdot 10^{-14}$$

$$R_1: \frac{C}{B} = \log_2\left(1 + \frac{2{,}28 \cdot 10^{-12}}{1{,}6564 \cdot 10^{-13} + 2{,}53 \cdot 10^{-13}}\right) = 2{,}7 \text{ bit/s/Hz}$$

$$R_2: \frac{C}{B} = \log_2\left(1 + \frac{2{,}28 \cdot 10^{-12}}{1{,}6564 \cdot 10^{-13} + 9{,}12 \cdot 10^{-24}}\right) = 3{,}3 \text{ bit/s/Hz}$$

11. SUPPOSE A SIGNAL ENCODING TECHNIQUE REQUIRES $E_b/N_0 = 8{,}4$ dB FOR A BIT ERROR RATIO (BER), BER $= 10^{-4}$. IF THE EFFECTIVE NOISE TEMPERATURE IS 290K (ROOM TEMPERATURE) AND THE BITRATE IS 100 Kbit/s WHAT RECEIVED SIGNAL POWER IS REQUIRED TO OVERCOME THE THERMAL NOISE?

R: $\frac{E_b}{N_0} = SNR \frac{B}{R} \rightarrow SNR = \frac{P_r}{N_0 B}$ $\quad SNR_{dB} = P_{R_{dBm}} - P_{N_{dBm}}$

$$SNR = \frac{E_b \cdot R}{N_0 \cdot B} \qquad R = B \cdot \log_2 M \rightarrow B = \frac{100K}{\log_2 2} = 100K$$

$$P_{N_{dBm}} = 10 \log(K_B T B \cdot 10^3) = -174 + 10 \log(100K)$$
$$= -124 \text{ dBm}$$

$$N_0 = 1{,}38 \cdot 10^{-23} \cdot 290$$

$$SNR_{dB} = P_{R_{dB}} - P_{N_{dB}} = -124 + 8{,}4 = -115{,}6 \text{ dBm}$$

12. USING THE SHANNON LAW, $C = B * \log_2(1 + \frac{S}{N})$, C IN BIT/S, B IN HZ, AND S AND N IN W, FIND THE MINIMUM E_B/N_0 REQUIRED TO ACHEIVE A SPECTRAL EFFICIENCY OF 6 BIT/S/HZ.

R: $C = B \cdot \log_2\left(1 + \frac{S}{N}\right) \Leftrightarrow \frac{C}{B} = \log_2\left(1 + \frac{S}{N}\right)$

$\Leftrightarrow 6 = \log_2\left(1 + \frac{S}{N}\right) \Leftrightarrow 2^6 = 1 + \frac{S}{N} \Leftrightarrow \frac{S}{N} = 63$

$\frac{S}{N} = \frac{E_B}{N_0 B T_B} = \frac{E_B \cdot R_B}{N_0 \cdot B} = \frac{E_B}{N_0} \cdot \frac{C}{B} \Leftrightarrow 63/6 = \frac{E_B}{N_0}$

$\frac{E_B}{N_0} = 10{,}5 \text{ dB}$ ASSUMINDO A CAPACIDADE É TODA USADA.

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