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ECE 1150: Computer Networks

Channel Impairments

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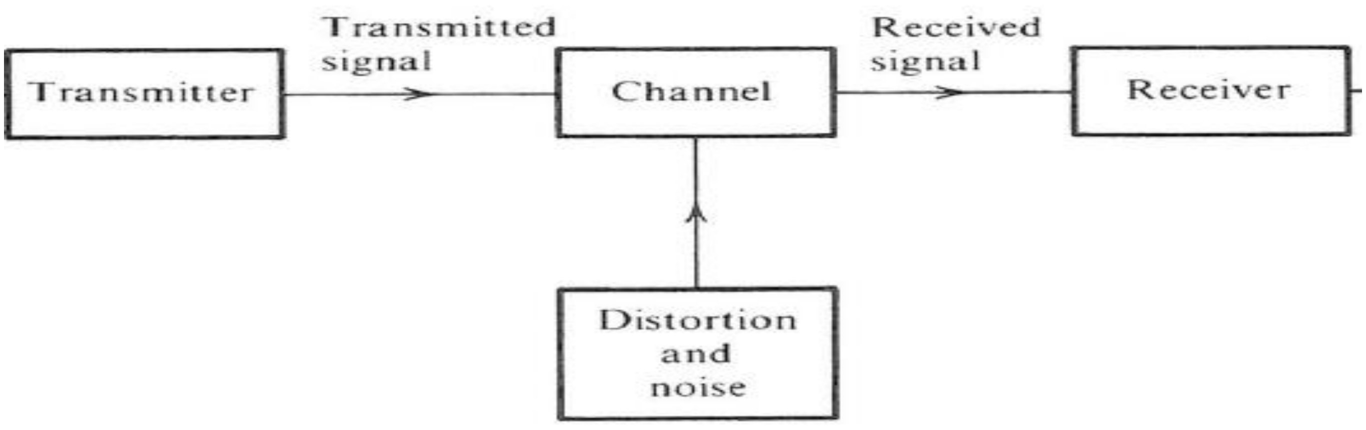
Communications Impairments

- Many impairments affecting a signal as it travels over the medium
  - Delay (covered)
  - Attenuation
  - Noise
  - Others factors interference, dissipation, ..



dB Scale

- It is a **logarithmic** scale – "decibel"(dB)
  - Used extensively in Telecom
  - Represent large values and small values with short number
- P_1 is power in watts at transmitter A, P_2 is power level in watts at receiver B,
  - The ratio P_1/P_2 can be represented in dB by calculating:

$$\textbf{Ratio in dB} = 10 \log_{10}(P_1/P_2)$$

dB is a relative measure

- It is a **“relative measure”** – dimensionless arguments to the log
  - Measures ratios (unit dB)
  - Measures power (unit dBW or dBm)

Example dB Calculations

- $\mathbf{P_1=P_2}$
  - $10\log_{10}(P_1/P_2) = 10\ \mathbf{\log_{10}(1)}=10 \times 0=\mathbf{0\ dB}$
- $P_1=10\ P2$
  - $10\log_{10}(P_1/P_2) = 10\log_{10}(10\ P_2/P_2)$
    $=10\log_{10}(10) = 10 \times 1= 10dB$
- $P_1=0.1\ P2$
  - $10\log_{10}(P_1/P_2) = 10\log_{10}(0.1\ P_2/P_2)$
    $=10\log_{10}(0.1) = 10 \times - 1= -10dB$
- $P_1=2P2$
  - $10\log_{10}(P_1/P_2) = 10\log_{10}(2\ P_2/P_2)$
    $=10\log_{10}(2) = 10 \times 0.3= 3dB$
- $P_1=0.5\ P2$
  - $10\log_{10}(P_1/P_2) = 10\ \log10\ (0.5\ P_2/P_2)$
    $=10\log_{10}(0.5) = 10 \times (- 0.3)= -3dB$

Example dB Calculations

- If P1 =1 microwatt, P2 = 10 watt
  - $10 \log_{10}(P_1/P_2) = 10 \log_{10}(10^{-6}/10) = 10 \times -7 =$ **- 70 dB**
- If P_1 = 100 Kilowatt, P_2 =10 watt
  - $10 \log_{10}(P_1/P_2) = 10 \log_{10}(100 \times 10^{3}/10) = 10 \times 4 =$ **40 dB**

Review of Logarithms

- Simplifies math: Multiplication becomes addition, exponentiation becomes multiplication
- General Properties
  - $\log(a*b) = \log(a) + \log(b)$
  - $\log(a/b) = \log(a) - \log(b)$
  - $\log_n(n) = 1$
  - $\mathrm{Log}_n(x)=\log_{10}(x)/\log_{10}(n)$

dB Calculations

- If x is positive, then $\log_n(x)$ is exponent of the base (n) that gives x

$$\log_n(x) = y \Rightarrow \text{ then } x = n^y$$

- **Get magnitude value from the dB value:**

$$10 \log_{10} (P_1/P_2) = 15\text{dB}$$

$$\log_{10}(P_1/P_2) = 15/10 = 1.5$$

$$P_1/P_2 = 10^{1.5} = 31.625$$

dBm and dBW are used in device specifications

WIRELESS FEATURES	
Frequency	2.4-2.4835GHz
Signal Rate	11n: Up to 450Mbps(dynamic) 11g: Up to 54Mbps(dynamic) 11b: Up to 11Mbps(dynamic)
EIRP	<20dBm(EIRP)
Reception Sensitivity	270M: -68dBm@10% PER 130M: -68dBm@10% PER 108M: -68dBm@10% PER 54M: -68dBm@10% PER 11M: -85dBm@8% PER 6M: -88dBm@10% PER 1M: -90dBm@8% PER

Effective Isotropically Radiated Power (EIRP) and sensitivity measured in dBm – what is dBm?

Magnitude Values in dB

- If we have a transmitter sending a signal with transmit power *X* Watts, how can we represent this in dB?
  - Use some known quantities as a reference,
    - Then get: **10 x $\log_{10}$ (X value /reference)**
  - Typically, we use 1 mW or 1 W as the **reference**
  - If the reference is **1 mW**, then unit is **dBm**
  - If the reference is **1 W**, then unit is **dBW**

dBm and dBW

- Example: If the transmit power is 100 mW, then we can represent it in dBm or dBW as follows:

100mw=20dBm = -10dBW

dBm and dBW

- Example: If the transmit power is 100 mW, then we can represent it in dBm or dBW as follows:
  - In dBm (<u>reference 1mW</u>)
    $10 \log(100 \text{ mW}/\underline{\mathit{1mW}}) = 10 \log(100) = 20 \text{ dBm}$
  - In dBW (<u>reference 1W</u>)
    $10 \log(100 \text{ mW}/\underline{1\text{W}}) = 10 \log(0.1) = -10 \text{ dBW}$

Tophat

Power in dB scale

P=10milliwatts, then in dBm it is equal to

A	1dBm
B	10dBm
C	-10dBm
D	None of the above

Power Loss

- In“Tele”communications
  - Destinations are far away ⇒ Loss of signal power as it travels from transmitter to receiver
- **Why power received is less than the power transmitted?**
  - energy gets scattered in many directions
  - energy is absorbed (can be converted to heat)

Attenuation

- **In magnitude**: received power (Rx power) is Transmitted power (Tx power) **divided** by attenuation

  Rx power (in watts)= Tx power (in watts) / attenuation

  - **Similarly:**
    attenuation (magnitude value)= Tx power (in watts) / Rx power (in watts)

- **With dB units, we subtract**

  Rx power (in dBm or dBW) = Tx power (in dBm or dBW) – |total attenuation (in dB)|

Attenuation Example

- Let the signal power at the input of an optical link (fiber optic cable) be $P_t = 0.1$ Watt
- Let the signal power at the output of the optical link be $P_r = 0.05$ Watt
  - Note the power is reduced by half

- What is the attenuation of the link in dB?

$$10 \log_{10} (P_t/P_r) = 10 \log_{10}(0.1/0.05) \approx 3\text{dB}$$

- If the power in a signal gets **reduced by half every 1 km**, we say
  - The **attenuation is 3 dB per km**

Attenuation

1:00 Show Correct Answer

On a copper wire link, signals lose half their power every 1km. If a signal is transmitted over 11 km link. What is the total attenuation at the end of the link

Attenuation - Question

- On a copper wire link, signals lose half their power every 1km. If the transmit power is 0.02Watt, compute the received power (in dBm) at the end of an 11 km link .

Attenuation - Solution

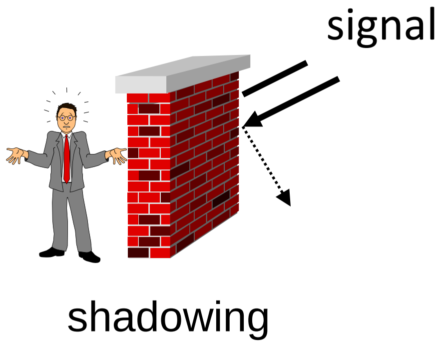
- On a copper wire link, signals lose half their power every 1km. If the transmit power is 20mW, compute the received power at the end of an 11 km line.
- P_t = 20mW
  - P_t (dB)= 10 $\log_{10}$ (P_t /1mW)=10 $\log_{10}$ (20) = 13 dBm
- **Total attenuation = total distance in km x attenuation per km**
  - A(dB) =11x 10 log(2) = 11 x (3)dB= 33 dB
- Received power =P_t (dBm) – |A (dB)|=13 – 33 = -20 dBm
  - In mWatts: 10 $\log_{10}$ (P_r/1) = - 20 => P_r= 0.01mW

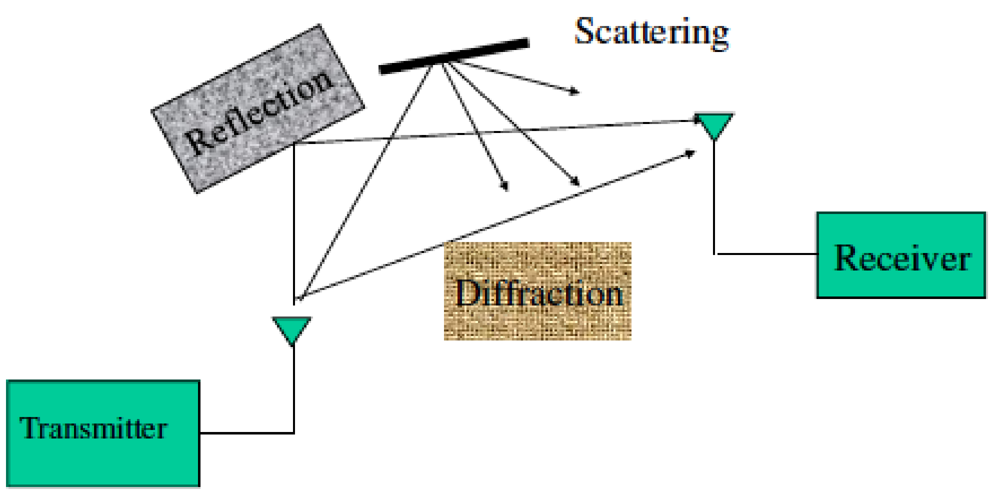
Top hat: Q_Attenuation2 - Question

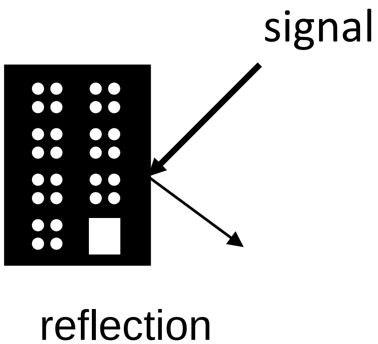
- Consider a optical fiber link of 10 km. The attenuation is 2 dB per Km. If the transmit power is 1mW, What is the received power at the end of the fiber in dBm.

Wireless Channels

- Large scale fading: due to path loss and shadowing
- Multipath fading







Source: Fundamentals of Wireless Communications

Wireless Links Path Loss

- Attenuation and dissipation
- **Path loss** models how the signal power is reduced as it **propagates along** a wireless medium
- **Path loss is function of the distance and frequency**
  - Logarithmic loss with distance

Wireless Links Path Loss

- Free space loss, ideal isotropic antenna

$$\frac{P_t}{P_r} = \frac{(4\pi d)^2}{\lambda^2} = \frac{(4\pi f d)^2}{c^2}$$

- P_t = signal power at transmitting antenna
- P_r = signal power at receiving antenna
- λ = carrier wavelength
- d = propagation distance between antennas
- c = speed of light (3×10^8 m/s)
- where d and λ are in the same units (e.g., meters)

Isotropic antenna radiates power uniformly in all directions

Beard and Stallings, Chapter 5, Wireless Comm Networks and Systems

Attenuation is called path loss

- In dB scale

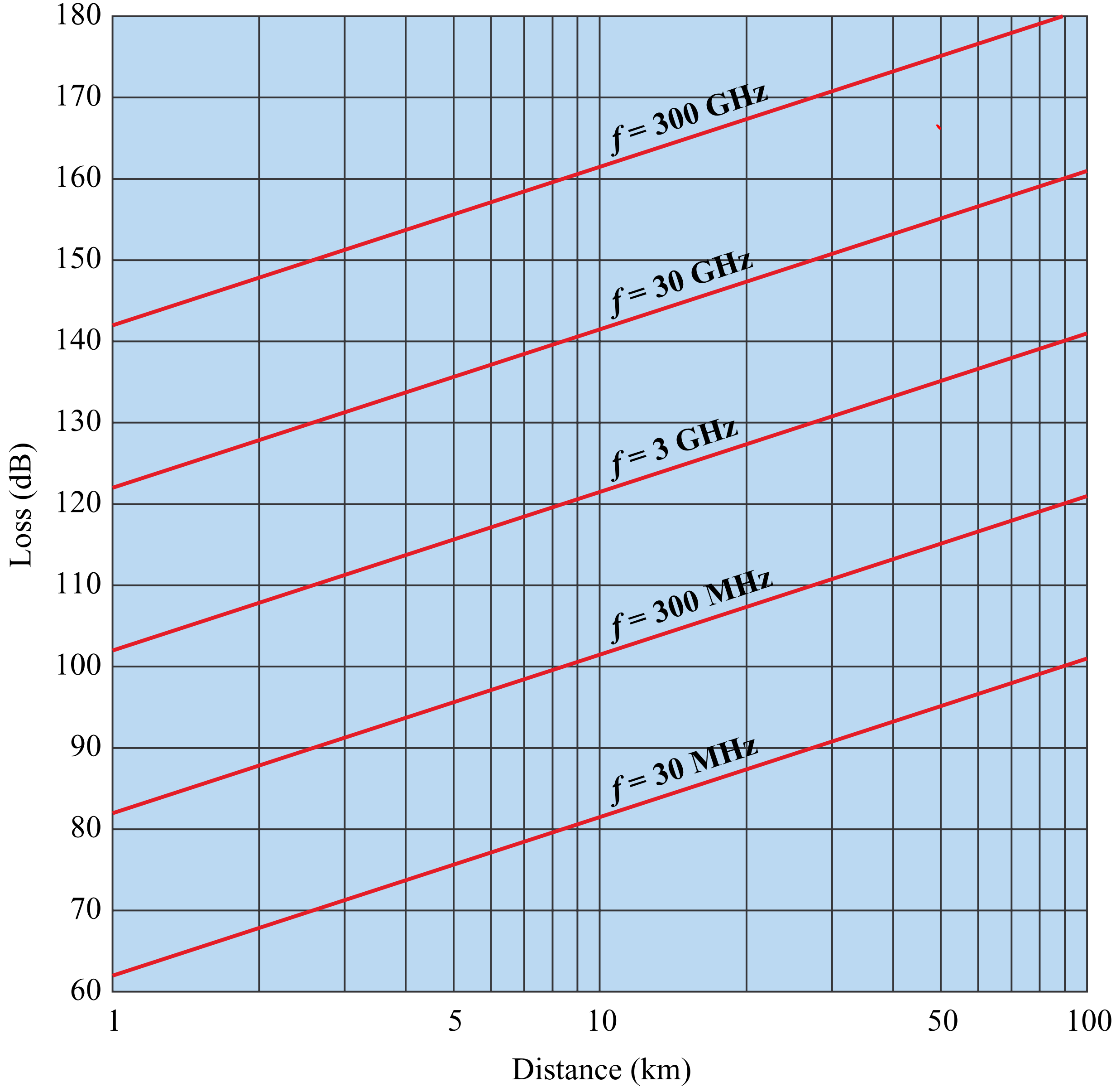
$$L_{dB} = 10\log\frac{P_t}{P_r} = 20\log\left(\frac{4pd}{l}\right)$$

$$= -20\log(\lambda) + 20\log(d) + 21.98\,\text{dB}$$

$$= 20\log\left(\frac{4\pi fd}{c}\right) = 20\log(f) + 20\log(d) - 147.56\,\text{dB}$$

Path loss exponent depends on the frequency and distance

Beard and Stallings, Chapter 5, Wireless Comm Networks and Systems



Wireless Links Path Loss: Path Exponent

- Path loss exponent varies depending on the environment
  - Path loss (dB)= 20 log (f) + 10 n log (d) + Constant

f: Frequency of the signal

d: the distance between transmitter and receiver

n: path loss exponent (n=2 in free space, higher in indoor environment)

Constant = -147.56 dB

Received power (dBm) = transmitted power (dBm) – path loss (dB)

- Derived from empirical measurements

Table 5.1 Path Loss Exponents for Different Environments [RAPP02]

Environment	**Path Loss Exponent, *n***
Free space	2
Urban area cellular radio	2.7 to 3.5
Shadowed cellular radio	3 to 5
In building line-of-sight	1.6 to 1.8
Obstructed in building	4 to 6
Obstructed in factories	2 to 3

Beard and Stallings, Chapter 5, Wireless Comm Networks and Systems

Wireless Links Path Loss: Path Exponent

- **Antennas may have antenna gains**
  - Antenna gain at transmitter At
  - Antenna gain at receiver Ar

In this case:

Received power (dBm) = transmitted power (dBm) – path loss (dB) + 10$\log_{10}$(Ar At)

Notes and Takeaways

- Medium (the channel) introduces losses to the signal

- The received power is attenuated

  Rx power (dBm) = Tx power (dBm) – total losses + Total gains

- Receiver needs to detect the attenuated signal in the presence of noise
  - Noise will be covered next