University of Pittsburgh

ECE 1150: Computer Networks

Channel Impairments

Mai Abdelhakim, PhD

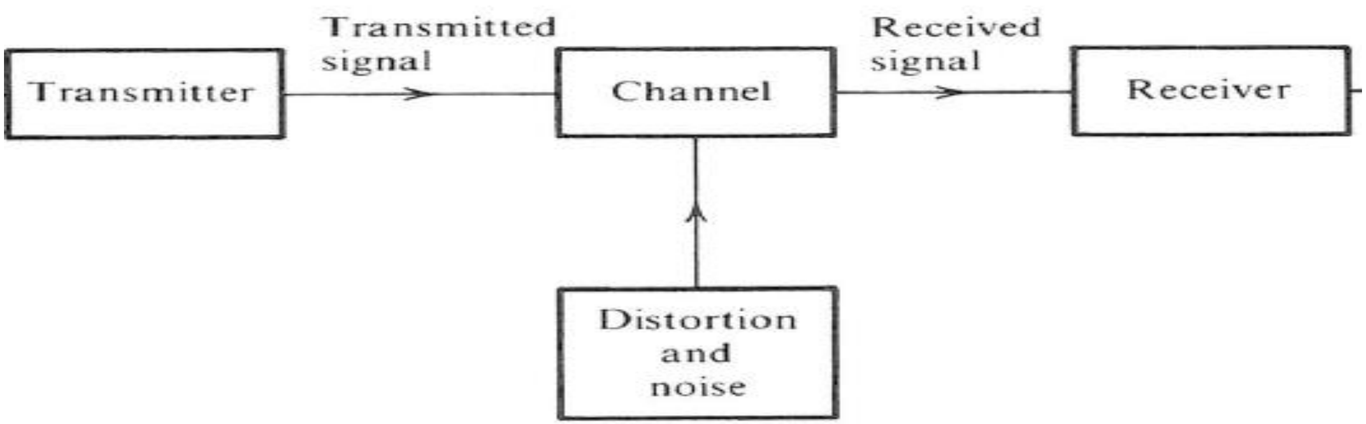
ECE Department

Swanson School of Engineering

University of Pittsburgh

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

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

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:**

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

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

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

Magnitude Values in dB

- If we have a transmitter sending a signal with transmit power *X* watt, 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 mW/<u>*1mW*</u>) = 10 log(100) = 20 dBm
  - In dBW (<u>reference 1W</u>)
    10 log(100 mW/<u>1W</u>) = 10 log(0.1) = −10 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

A	33dB
B	11dB
C	3dB
D	None of the above

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

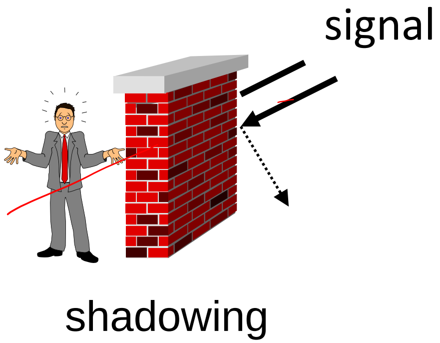
- On a copper wire link, signals lose half their power every 1km. If the transmit power is 20mW, compute the received power at the end of an 11 km line.
- P_t = 20mW
  - P_t (dB)= 10 $\log_{10}$ (P_t /1mW)=10 $\log_{10}$ (20) = 13 dBm
- **Total attenuation = total distance in km x attenuation per km**
  - 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

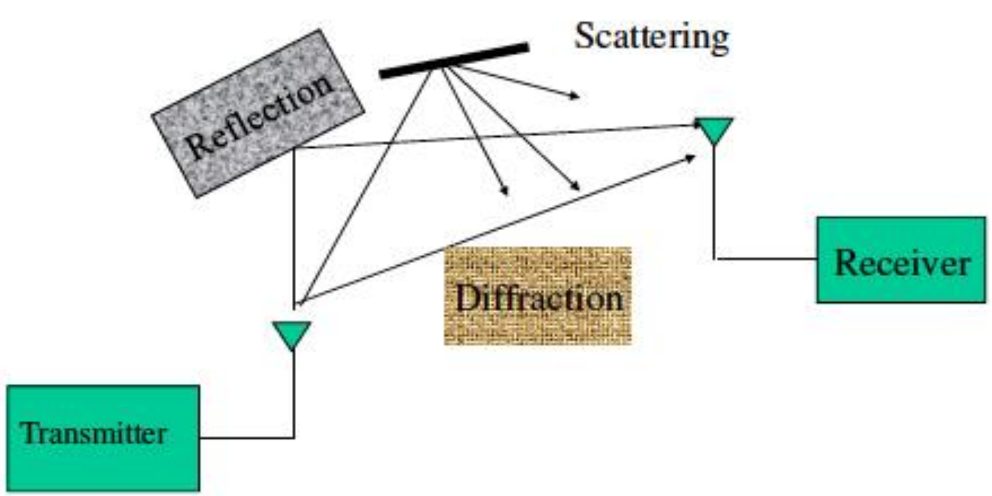
Q_Attenuation2 - Question

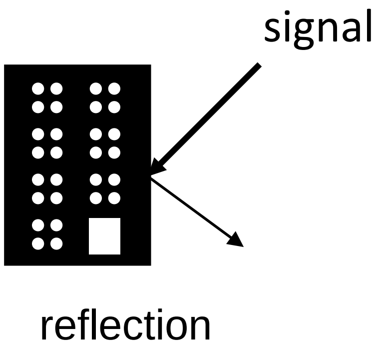
- Consider a optical fiber link of 10 km. The attenuation is 2 dB per Km. If the transmit power is 1mW (0dBm), What is the received power at the end of the fiber in dBm.

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

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

Isotropic antenna radiates power uniformly in all directions

- 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)

Attenuation is called path loss

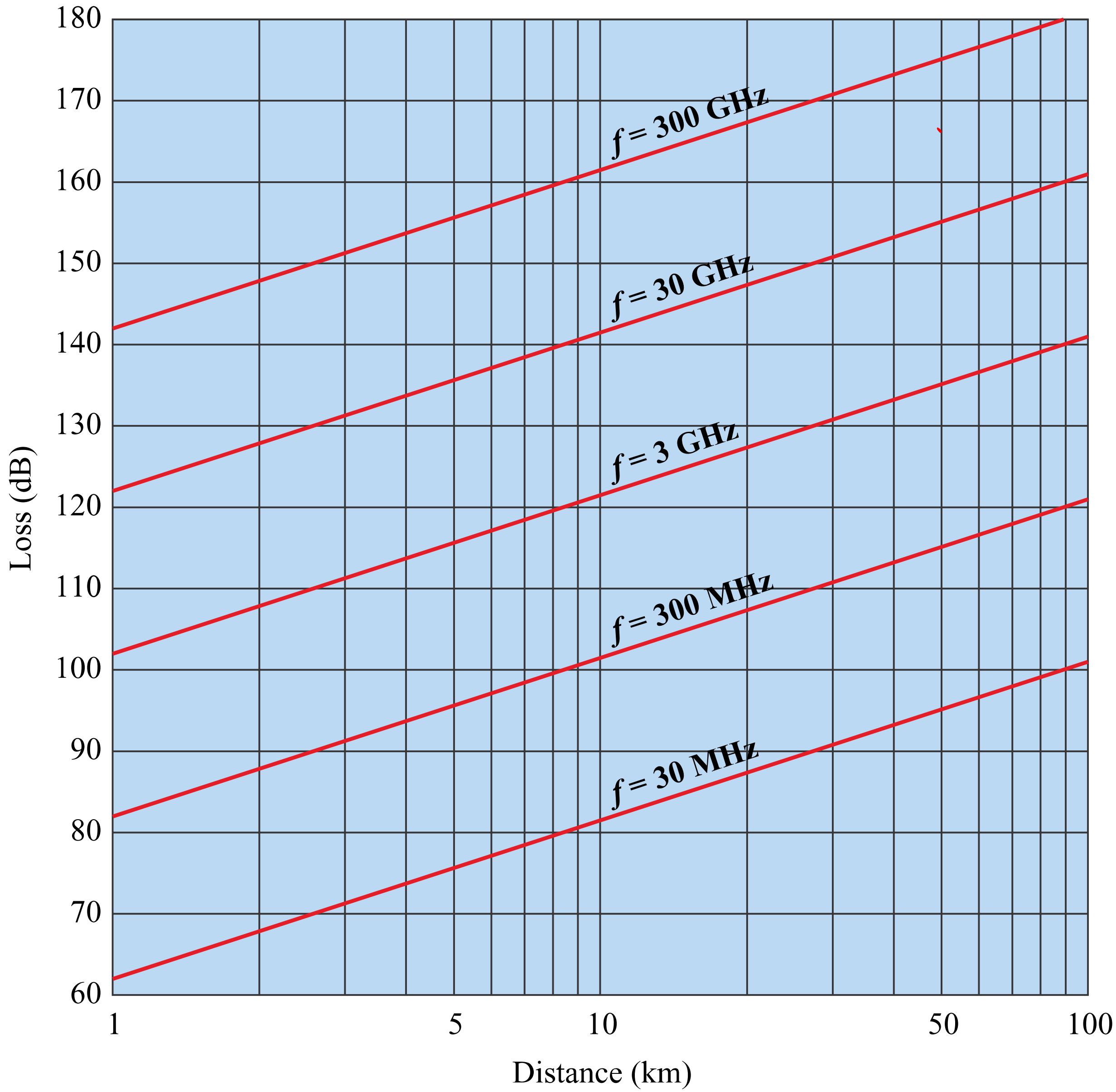
- In dB scale

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

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

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

Path loss exponent depends on the frequency and distance


180
170
160
150
140
130
120
110
100
90
80
70
60
Loss (dB)
1
5
10
50
100
Distance (km)
f = 300 GHz
f = 30 GHz
f = 3 GHz
f = 300 MHz
f = 30 MHz

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