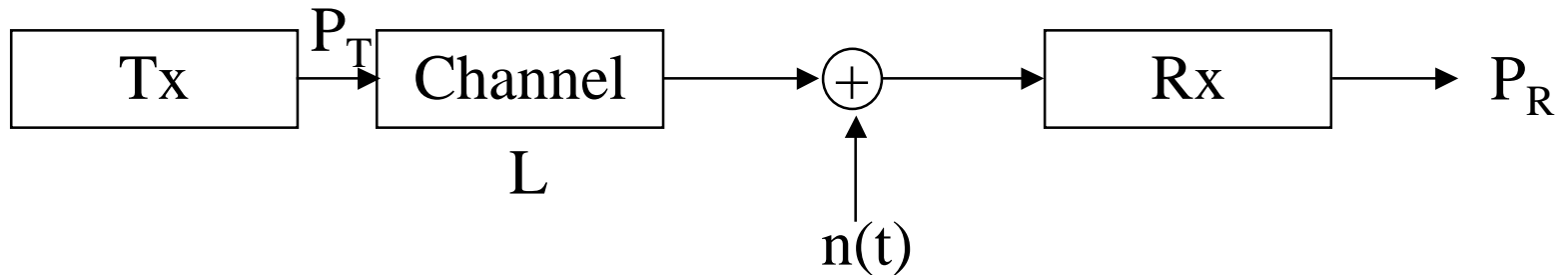
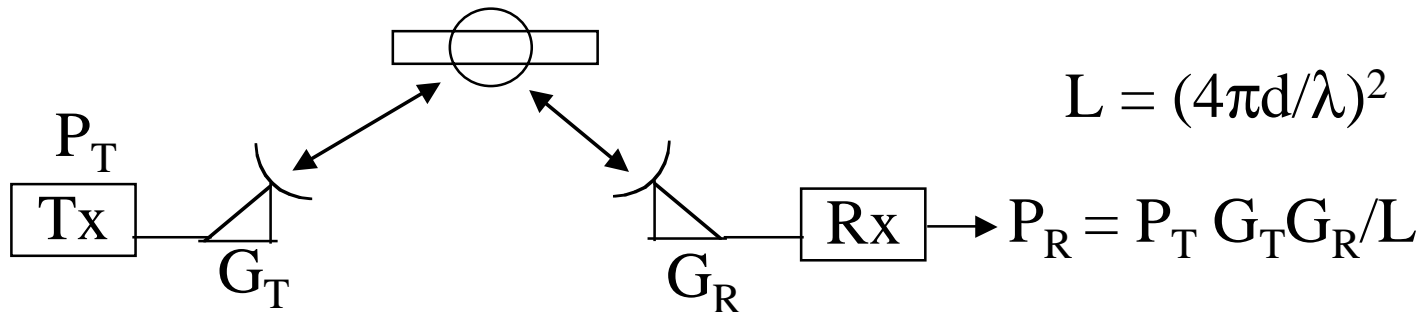

Lecture 10: Link Budget Analysis and Design

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Signal attenuation



- The signal suffers an attenuation loss L
 - Received power $P_R = P_T/L$
 - Received SNR = E_b/N_0 , $E_b = P_R/R_b$
- Antennas are used to compensate for attenuation loss
 - Capture as much of the signal as possible



L = free space loss, d = distance between Tx and Rx
 λ = signal wavelength

Antenna Gains

$$G_R = A_R 4\pi/\lambda^2$$

A_R is the effective area of the antenna

For Parabolic antenna $A_R = \pi\eta D^2/4$

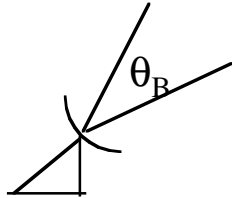
η = illumination efficiency factor, $0.5 < \eta < 0.6$

D = dish diameter

$$\Rightarrow G_R = \eta(\pi D/\lambda)^2$$

$$\Rightarrow PR = P_T G_T D^2 \eta / (4d)^2$$

Antenna Beamwidth



- **Beamwidth is a measure of the directivity of the antenna**
 - Smaller beamwidth concentrated power along a smaller area
- **Free space loss assumes that power is radiated in all directions**
- **An antenna with a smaller beamwidth concentrates the power hence yields a gain**
 - For parabolic antenna, $\theta_B \sim 70\lambda/D$
 - Gain (G_T) is proportional to $(\theta_B)^{-2}$
 - Hence a doubling of the diameter D increases gain by a factor of 4

Example (GEO Satellite)

$$d = 36,000 \text{ km} = 36,000,000 \text{ meters}$$

$$f_c = 4 \text{ GHz} \Rightarrow \lambda = 0.075 \text{ m}$$

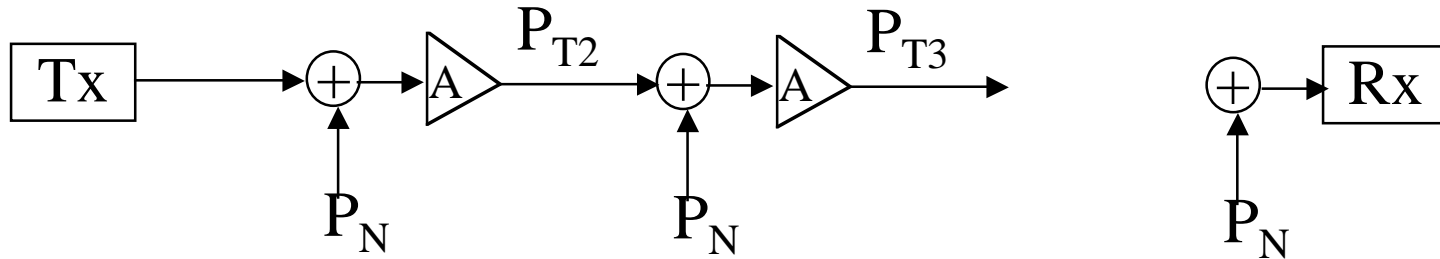
$$P_T = 100 \text{ W}, G_T = 18 \text{ dB}$$

Receiver antenna is parabolic with $D = 3$ meters

A) What is PR?

B) Suppose $(E_b/N_0)_{\text{req}} = 10 \text{ dB}$, what is the achievable data rate R_b ?

Repeaters



- A repeater simply amplifies the signal to make up for attenuation

$$P_{R1} = P_T/L, P_{T2} = P_{R1}A, P_{R2} = P_{T2}/L, \dots$$

$$P_{N1} = P_N, P_{N2} = P_{N1}A/L + P_N, \dots$$

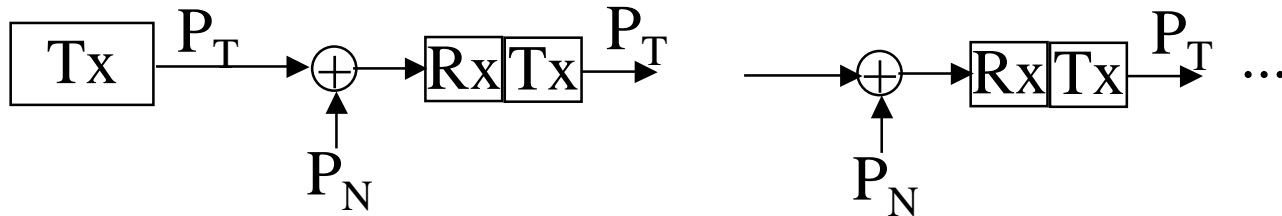
$$\text{Let } A = L \Rightarrow P_{RK} = P_T/L, P_{NK} = KP_N$$

$$P_{RK}/P_{NK} = P_T/LKP_N = 1/K (P_{R1}/P_{N1})$$

Received SNR is reduced by a factor of K

$$(E_b/N_0)_k = 1/K (E_b/N_0)$$

Regenerators



- **A regenerator demodulates, detects and retransmits the signal**
 - Each segment has the same P_R/P_N and the same received E_b/N_0
 - P_b = probability of error on a segment (independent between segments)
 - P_b (overall) = $1 - P(\text{no error}) = 1 - (1 - P_b)^K \sim KP_b$
- **Now compare repeater to regenerator (e.g. PAM)**

$$P_b = Q(\sqrt{2E_b / N_0})$$

$$\text{For repeater : } P_b(\text{overall}) = Q(\sqrt{2E_b / KN_0})$$

$$\text{For regenerator : } P_b(\text{overall}) = KQ(\sqrt{2E_b / N_0})$$

$$KQ(\sqrt{2E_b / N_0}) < Q(\sqrt{2E_b / KN_0})$$

Satellite example

- Uplink received $(E_b/N_0)_u = \text{downlink received } (E_b/N_0)_d = 10\text{dB}$
- PAM modulation $P_b = Q(\sqrt{2E_b / N_0})$
- Repeater: Received $(E_b/N_0)_{u/d} = 1/2 (E_b/N_0)_u = 10 \text{ dB} - 3\text{dB} = 7\text{dB}$
 - $\Rightarrow P_b = 5 \times 10^{-4}$ from table 7.55 or 7.58
- Regenerator: $P_b(\text{up}) = P_b(\text{down}) = 3 \times 10^{-6}$
 - (from table with $(E_b/N_0)_d = 10\text{dB}$)
 - Hence $P_b(\text{up/down}) \sim 2 P_b(\text{up}) \sim 6 \times 3 \times 10^{-6}$
- Two orders of magnitude difference between repeaters and regeneration
 - Greater difference with more segments