16.36 Communication Systems Engineering
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Lecture 12: Link Budget Analysis and Design

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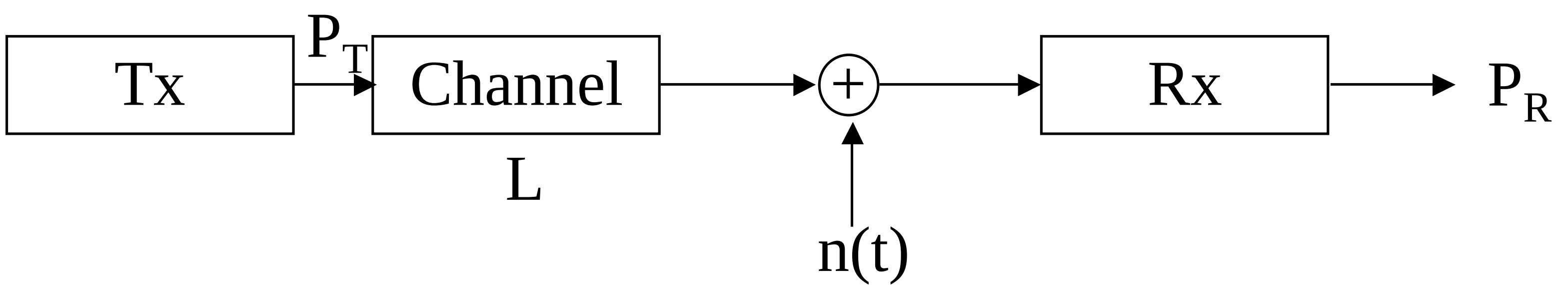
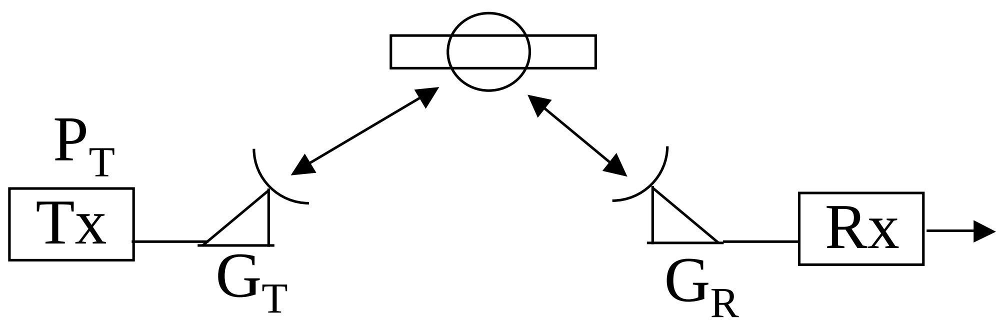
Signal attenuation



- **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**



$$L = (4\pi d/\lambda)^2$$

$$P_R = P_T\, G_T G_R / L$$

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

λ = signal wavelength

Antenna Gains

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

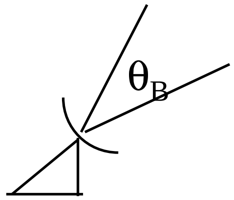
A_R is the effective area of the antenna

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

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

=> $G_R = \eta(\pi D/\lambda)^2$
=> $PR = P_T G_T D^2 \eta/(4d)^2$

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) s proportional to $(\theta_B)^{-2}$
  - Hence a doubling of the diameter D increases gain by a factor of 4

Example (GEO Satellite)

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

$f_c = 4$ Ghz => $\lambda = 0.075$m

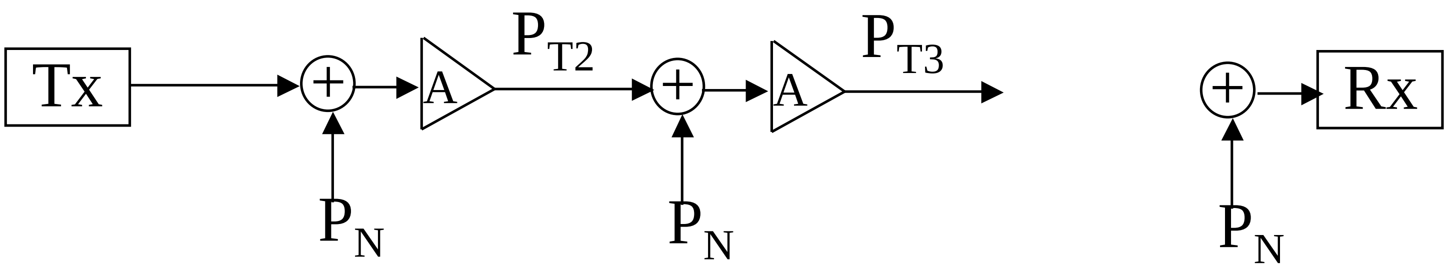
$P_T = 100$w, $G_T = 18$ dB

Receiver antenna is parabolic with D = 3 meters

A) What is PR?

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

Repeaters



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

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

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

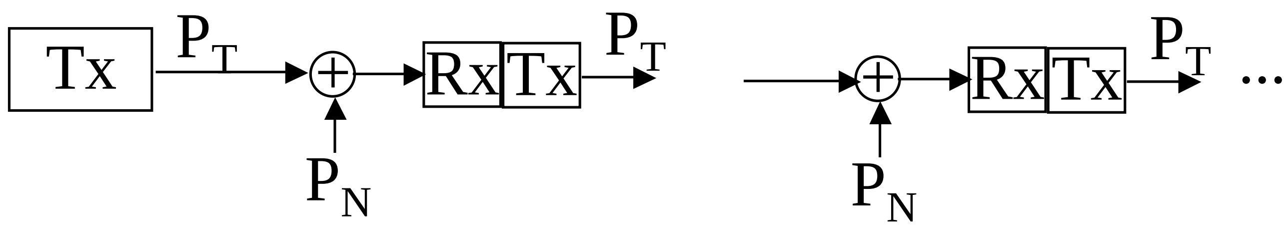
Let $A = L \Rightarrow P_{RK} = P_T/L,\ P_{NK} = KP_N$

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

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(no error) = 1 - $(1-P_b)^K$ ~ KP_b**
- **Now compare repeater to regenerator (e.g. PAM)**

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

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

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

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

Satellite example

- Uplink received $(E_b/N_0)_u$ = downlink received $(E_b/N_0)_d$ = 10dB
- 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 dB - 3dB = 7dB
  - => Pb = 5×10^{-4} from table 7.55 or 7.58
- Regenerator: P_b(up) = P_b(down) = 3×10^{-6}
  - (from table with $(E_b/N_0)_d$ = 10dB)
  - Hence P_b (up/down) ~ 2 P_b(up) ~ $6\times3\times10^{-6}$
- Two orders of magnitude difference between repeaters and regeneration
  - Greater difference with more segments