Department of Microtechnology and Nanoscience

Wireless and Photonic System Engineering SSY085

2010-08-16 14.00-18.00

Teacher in charge:
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Aids: Open book examination. Any printed material and calculator of choice is allowed. Communication devices (computers, mobile phones etc) are *not* allowed.

Examination checking: On Monday Sept. 6th, 12-13 in room A604 at MC2

Convince yourself that you have understood the problem before you get started. Constructive and valuable gambits will also give points. If information is lacking in the description of the task, you must yourself introduce technical plausible assumptions. Make sure you clearly state such assumptions.
Grades: 3: ≥24, 4: ≥36, 5: ≥48

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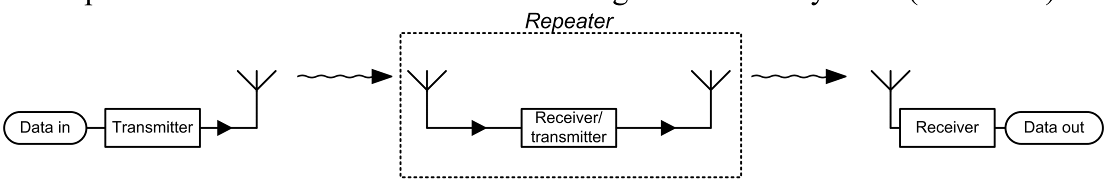
1. "Repeaters" can be used to extend the coverage of wireless systems (see below).



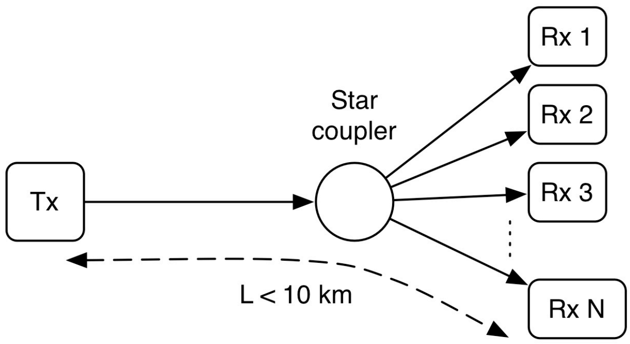
By using multiple repeaters, you should now design a fixed 100 km point-to-point wireless link for use in the protected Swedish mountain areas. All system components should be very discreet and must therefore have dimensions <30 cm, including the antennas. Each repeater unit must consume less than 5W to allow for solar cell operation. You may assume a one-way link and a maximum capacity of 60 Mbit/s.

To get full marks you must present RF block diagrams for the transmitter, the repeaters, and the receiver. The cost should be minimized, so design for minimum number of repeaters. The number of repeaters, component parameters, antenna sizes, frequencies, bandwidths, modulation formats etc. should be motivated considering signal and noise power levels, power consumption, propagation effects, BER etc. Use realistic assumptions where needed. You only need to consider a one-way link.

(30 points)

2. An optical broadcast network should supply a number (N) households with a 2Gb/s OOK-modulated digital TV signal at a wavelength of 1552.1 nm. The network is a star-configuration with N receivers using direct detection, and with no optical amplifiers. The receivers have a photodetector responsivity of 0.5 A/W, an input load impedance of 50 Ohms and can be assumed to operate at room temperature. The transmitter average optical output power is 4 dBm. There is a 1 dB coupling loss between the transmitter and the fiber, and the same between the fiber and photoreceiver. The fiber is SMF with a loss is 0.3 dB/km, and the excess loss in the star coupler is 2 dB. No end user is further than 10 km from the transmitter, as shown in the figure below.

a) Calculate the receiver sensitivity, assuming a required SNR of 20 dB.
b) How many end users can be supported? Assume for simplicity that the star coupler is ideal, i.e. that it distributes the power evenly among the N users.



Problem 2. A broadcast star network.

(10 points)

3. A wireless 10 GHz transmitter has an output power of 20 dBm. The receiver is placed at a distance of 10 km and has a noise figure of 3 dB. A digital signal is then transmitted using QAM64 modulation.

a) Calculate the maximum bitrate if the receiver bandwidth is 10 MHz.
b) Calculate the receiver sensitivity (minimum received power) required to get a bit error rate of 10^{-5}.
c) Calculate the minimum transmitter and receiver antenna diameters needed. Identical antennas are used.

(10 points)

4. You design an optically amplified receiver, and need to have an optical amplifier with 30 dB of gain. There is 6.5 dB of SNR margin to the targeted BER, which is BER < 10^{-9}. Unfortunately, all you have access to is two different EDFA:s,
- amplifier A, which has 15 dB of gain and a noise figure of 6 dB, and
- amplifier B, which has a gain of 20 dB and 10 dB of noise figure.

You plan to use them together with a 5 dB attenuator to reach the required 30 dB of gain. Is it possible to reach the BER target with these three components, and if so in which order should they be cascaded?

(10 points)

Solutions:

1.
This is a proposed solution outline – other solutions may be equally good or better. Further details are needed in the complete solution.

- Initial assumptions
  - The transmit power is dominating power consumption. Assuming <30% PA efficiency & consumption of other components → P_{tx} = 1 W.
  - Bitrate = 60 Mbit/s. Assume QAM64 modulation → IF bandwidth = 60 Mbit/s / 6 = 10 MHz
  - We choose an operating frequency of f = 15 GHz
    - Higher frequency → Higher antenna gain, but lower PA efficiency and higher cost.
- Antenna design
  - Dimensions < 30 cm → Antenna diameter = 30 cm → Antenna gain = ca 30 dBi. Identical antennas are used for TX and RX.
- Receiver design (same receiver for repeater and end receiver)
  - Receiver noise figure = ca 3 dB (including LNA NF of 2 dB, 1 dB filter losses for suppression of image frequency)
  - Important that the receiver and transmit frequency differ (ex: f_{RX} = 14.5 GHz & f_{TX} = 15.5 GHz) to avoid self oscillation. Two LOs are needed.
- Link budget calculations
  - Propagation model: Free space propagation is not realistic for such long distance and without high masts. We assume ground propagation model (Pozar eq. 4.58): $P_r = P_t \cdot G_r \cdot G_t \cdot h_1 \cdot h_2 / R^4$, where R is the link distance. We assume $h_1 = h_2 = 1$ m (discreet antenna mounts).
  - If N repeaters are used: R → R/(N+1) in the propagation model.
  - We use simple repeaters without demodulaton/modulation → noise is added in each stage and adds incoherently to the final stage noise power (cf. Optically amplified chains in photonic part). Output SNR is therefore degraded linearly by the number of repeaters, N.
  - Assuming BER $<10^{-5}$ with QAM64 and F = 3 dB → {see exam problem 2b} → $(S/N)_{in}$ = 723. With N repeater stages: Required $(S/N)_{in}$ = $723\cdot(N+1)$ at each stage. → $S_{in} = P_{r,min} = 723\cdot(N+1)\cdot k\cdot T_0\cdot B = 2.9\cdot10^{-11}\cdot(N+1)$
  - P_r is calculated by the propagation model and compared with P_{rmin} for different number of repeaters N. The minimum N for which $P_r > P_{rmin}$ → Minimum 14 repeaters needed.
- System design
  - N = 14 → $P_r = 5\cdot10^{-10}$ W = -63 dBm, combined with transmit power of 30 dBm → total repeater gain should be at least 93 dB, which will be divided between the RX (25 dB), IF gain (40 dB), TX (30 dB). The gain at each frequency should not exceed 40 dB to prevent oscillations.
  - An IF frequency of ca 100 MHz is used to allow easy channel filtering (10 MHz) and cheap amplifiers.

2.

a). In absence of optical amplifiers thermal noise and shot noise will determine the receiver sensitivity. The thermal noise power is (T=300 K, Δf =2 GHz)

$\sigma_T^2=4k_B T \Delta f/R_L=4k_BT/R_L= 0.66\bullet10^{-12}$ [A^2]

Lets neglect the shot noise and check that this assumption is valid later.

The required received optical signal power is thus obtained from the SNR relation as $(RP_{rec})^2=SNR\ \sigma_T^2$

from which we find the sensitivity to be $P_{rec}=16.2\bullet10^{-6}$ W= <u>-17.9 dBm</u>.

(using SNR=100, and responsivity R=0.5).

The shot noise corresponding to this power is $5.2\bullet10^{-15}$ [A^2], which is negligible compared to the thermal noise.

b). Make a power budget:

The transmitted power minus the sensitivity is 4-(-17.9)=21.9 dB, which then is the allowed losses. The known attenuation is 1+1+2+10*0.3=7 dB, leaving 21.9-7=14.9 dB= 30 times for the splitting loss.

Thus 30 end users can be supported with an ideal star splitter.

3.

a) Max. bitrate = (Spectral Efficiency for modulation)· Bandwidth = 6 · 10 MHz = <u>60 Mbit/s</u>

b) From (9.105) & Lecture 2: S/N = Eb/n0 · Rb/B, where Rb/B = spectral efficiency.
Table 9.5 gives Eb/n0 = 17.8 dB for QAM64 @ BER = 10^{-5} → S/N = 361.5
Noise figure definition: $F = (S/N)_{in} / (S/N)_{out} = 3$ dB → $(S/N)_{in} = 723$.
$S_{in,min} = N_{in}\cdot(S/N)_{in} = kT_0B\cdot(S/N)_{in} = \underline{29\cdot10^{-12}\text{ W}} = \underline{-75\text{ dBm}}$

c) We assume free space propagation → Friis Equation: $P_r = P_t\cdot G_r\cdot G_t\cdot\lambda^2/(4\pi R)^2$
where: R = 10^4 m, Pt = 0.1 W, Pr = $29\cdot10^{-12}$ (from b), $\lambda = c/f = 3\cdot10^{-3}$ m.
Identical transmit/receive antennas: Gr = Gt = G →
$G = \text{sqrt}[P_r\cdot(4\pi R)^2 / (P_t\cdot\lambda^2)] = 713 = 28$ dBi
We assume parabolic type of antennas, where physical area and effective antenna area are similar: $A_e = D\cdot\lambda^2/(4\pi) = \{\text{gain} \approx \text{directivity}\}=5\cdot10^{-4}\ m^2$.
Circular antenna area: $A = \pi d^2/4$ → Antenna diameter, <u>d = 2.5 cm.</u>
Minimum antenna diameter is ca 3 cm.

4.

Obviously, it is best to put the attenuator last, since this will not affect the SNR (signal and noise will be attenuated the same amount).

For the two amplifiers, the noise figure cascade rule (which is straightforward to derive) says that the total NF is (approximately) $F_{tot}=F_1+F_2/G_1$, where F is the noise figure, G the gain, and index 1 represents the first amplifier and index 2 the second amp. To have amp A first then gives F_{tot}= 6dB+10dB/15dB=$10^{0.6}+10^{-0.5}$=4.30=<u>6.3 dB</u>.

To have amp B first gives F_{tot}=10dB+6dB/20dB=$10^{1.0}+10^{-1.4}$=10.04=10.0 dB.

Thus amplifier A should be first, then amp B, and last the attenuator. Then it is possible to have a noise figure within the required range of 6.5 dB.