Department of Electrical Engineering

EE3007: RF and Optical Communications

Mar. 2022 **Tutorial #2** KG / IITM

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1. TDMA MAC Channel: A cellular TDMA base-station is required to serve users who are up to 9km away on the uplink. The RF bandwidth used by this system is W=2MHz, sync pulses are used to produce the 8-PSK encoded waveforms. The frame duration is 6msec with 5 slots per frame of 1.2msec duration each.

(a) Find the symbol duration, and the number of symbols per slot.

(b) What is the number of guard symbols required on the uplink MAC channel to compensate for the worst-case time of flight difference?

(c) What is the effective (useful) bit-rate per user, if 10% of the slot duration is given for pilot symbols and other control overheads? What is the useful spectral efficiency in bits/sec/Hz ?

(d) Now, the RF bandwidth is increased to 20MHz and 50 slots are planned in every 6msec frame duration (with all other parameters as before). What is the new value of useful spectral efficiency?

(e) Recall also that the received power P_R in dBm at a distance d meters from the transmitter can be determined from the below formula in the log-scale:

$$P_R(d) = P_T - L - 10log_{10}(d^{\alpha})$$

where P_T is the transmit power in the dBm scale (note that 1mwatt = 0dBm), n is the path loss exponent, and L (in dB) accounts for all other fixed losses. Also recall that the receiver sensitivity or minimum detectable signal strength (MDS) required at the receiver is given by

$$MDS\ (dBm)\ = -174dBm + 10log_{10}(W) + NF(dB) + SNR(dB)$$

where NF is the receiver noise figure, and SNR is the signal to noise ratio required to achieve the target bit error rate for the given modulation.

(e1) Given P_T = 1watt, L=47dB, n =2, NF=6dB, and required SNR=8dB, find the link distance d for W=2MHz.

(e2) Repeat the above, but for W=20MHz.

(e3) If it is required to serve users up to 9km link distance on the uplink for W=20MHz, that should be the new P_T ? Compare with (e2) and comment.

2. From "**Wireless Comm. (E-version)**", by T.S. Rappaport Chapter 2, problem **2.14** (review of Sensitivity). This E-book is available on my URL currently.

3. Problem **2.15** from this E-book.

4. A signal of bandwidth 2 MHz is radiated through a 16dBi antenna with a power of 10milliWatts. The carrier frequency is 1 GHz, and the receive antenna has a gain of 4dBi.

a) For a required SNR at the detector input of 6dB, and given the receiver noise figure of 5dB, find the receiver sensitivity in dBm. (Assume that the thermal noise power density at the ambient temperature of 300^0K is -174dBm/Hz.)

b) Assuming a path-loss exponent n=3 and a shadow loss that is uniformly distributed between -8dB and +8dB, find the range of SNRs (maximum and minimum values will be fine) that one would see at a distance d=300m from the transmitter. Express your answer in dB scale.

c) Repeat part (b) if (i) n=3, d=3000m, and (ii) n=4, d=3000m.

5. Over <u>wire-line</u> channels, a signal of bandwidth 10KHz is to be transmitted over a distance of 200km. The channel (wire used) that has an attenuation of 2dB/km. Assume that the thermal noise PSD is -174dBm/Hz.

a) Determine the transmit power P_T required to achieve an SNR_0=20dB at the output of the receiver amplifier that has a noise figure F=6dB. Express the desired P_T in dBm as well as in Watts. Is this reasonable?

b) Repeat the calculation when a repeater is inserted every 10km with a gain (G or A) of 20dB (to compensate the loss) and a noise figure F=6dB, as shown in the Figure below. Express the desired P_T in dBm as well as in Watts. How does it compare to (a)? Comment.

Hint: Use the fact when L_i=L and F_i =F for each i, then $SNR_0 = \frac{1}{Fo}\left(\frac{P_T}{kT\Delta f}\right)$ where Fo is the overall Noise Figure of the cascade (as derived in class). In the figure below, take L_i as $1/L_i$ following the notation used in the class.

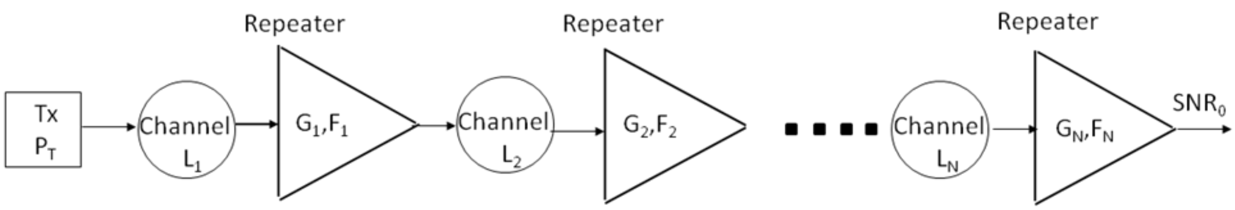

Figure2

6. A 10 MHz signal is to be wirelessly transmitted over a distance of 50km, where the channel has a path loss exponent of n=3. Repeaters are to be used to make this possible where both the Tx and Rx antennas have a gain of 26dBi each , the loss 1meter away from the antenna is L_{1m}=35dB. Assume that the thermal noise PSD is -174dBm/Hz. The power amplifier in each repeater has a gain A=30dB, and noise figure F=6dB.

a) Find the number of hops, N, that we need in this case. *Hint:* The repeater needs to compensate (only) the "effective" loss per hop so that in the linear scale A/L=1. Use this to find the hop length, and hence number of repeaters N.

b) Determine the transmit power P_T required to achieve an SNR_0=15dB at the output of the N^{th} amplifier output. Express the P_T in dBm as well as in Watts.

7. A 20 MHz signal is to be wirelessly transmitted over a distance of 24km, where the channel has a path loss exponent of n=2. Repeaters are to be used to make this possible where both the Tx and Rx antennas have a gain of 23dBi each , the loss 1meter away from the antenna is L_{1m}=36dB. Assume that the thermal noise PSD is -174dBm/Hz. Two choices of the Rx/Tx chain (used in each repeater) are possible:

(i) Choice-1: Gain A=30dB, and noise figure F=4dB

(ii) Choice-2: Gain A=40dB, and noise figure F=9dB

Assuming a system with N hops, the required SNR at the output of the N^{th} receiver chain is SNR_0=18dB. The regulatory specification does not allow the transmit power P_T to exceed -30dBm (1microwatt) in any of repeaters. Which of the above two choices will then be preferred? Specify the number of hops and the P_T that will be used in each case.

8. The received signal in a given application needs to be amplified by 86dB. Instead of a single-stage amplifier, it is decided to use 3 amplifier stages in cascade. The 3 available amplifiers have gain A and noise figure F as follows: A_1=30dB & F_1=6dB; A_2=20dB & F_2=3dB; and A_3=36dB & F_3=15dB. Determine the order in which these 3 amplifiers must be cascaded so as to give the least overall noise figure. What is this (lowest) overall F in dB scale?

9. In this problem, we are interested in calculating the bit error rate (BER) of a N-hop link using regenerative repeaters (decode-and-forward relays). For N=12, consider the following cases:

(i) Probability of bit error in each hop is $p=10^{-5}$. What is the overall BER?

(ii) If 8 links have $p=10^{-6}$and the remaining links have $p=10^{-4}$, what is the overall BER?