Department of Electrical Engineering, IIT Madras

EE5141 : Fundamentals of Wireless and Cellular Communications

Not for Submission **Tutorial #1** **March 18, 2016**

1. The following questions from Chapter 2 of T.S.Rappaport's book (E-version!): pp:64 onwards

(i) 2.1
(ii) 2.3 (Impact of sectoring on SIR)
(iii) 2.4
(iv) 2.5 and 2.7 (Trunking efficiency related)
(v) 2.8
(vi) 2.10(on cell splitting)
(vii) 2.14 and 2.15 (Rx sensitivity)
(viii)2.18 (*optional*)
(ix) 2.20 (*optional*)

2. From D.Tse & P.Viswanath Chapter-2: (i) 2.2 (ii) 2.3 (iii) 2.4 (iv) 2.5 (v) 2.10 (vi) 2.14 (vii) 2.15* (viii) 2.16, and (ix) 2.17* (questions with "*" are a bit tougher, and are optional)

3. A communication link between a fixed base-station and a mobile-station uses a bandwidth of 20MHz at a carrier frequency of f_c=1.5GHz.The mobile which is moving at 50kmph, experiences a delay-spread of 4μsec. Find the following:
(a) What is the Doppler spread f_D in Hz? What is the coherence time?
(b) What is the normalized Doppler spread f_DT (where T is the symbol duration)?
(c) What is the coherence band-width?
(d) At that mobile speed will be f_DT=0.001 ?

4. Recall that in the derivation of the power spectral density S(f) for the Clarke's model, the fraction of the power p(α) reaching the receiver in angle α is assumed to be uniform. Suppose instead we have a directional antenna with $p(\alpha) = \beta(1 + Cos(\alpha)), \alpha\epsilon[0,2\pi]$, with β appropriately chosen. What will be the modified expression for S(f) then?

5. From D.Tse & P.Viswanath Chapter-5: (i) 5.1 (ii) 5.2 (iii) 5.3 (iv) 5.6 (v) 5.10 (vi) 5.11 (vii) 5.13*

6. A transmitter with carrier frequency f=600MHz is 1500m away from a large wall, where both are on a level field. A receiver, which is currently 500m away from the wall, is moving with a constant velocity 54kmph *towards* the transmitter.
(a) Draw a rough sketch of the above situation. What are the Doppler components of the direct and reflected wave (in Hz)? Assume speed of light is air is c=3x10^8 m/sec.
(b) What is the coherence time?
(c) What is the coherence band-width currently?
(d) After how much time will the coherence band-width reduce by half (assuming uniform, linear motion)?

7. Consider the two multi-path models $h_m = \sum_{i=0}^{L-1} a_i \; \delta(m - \tau_i)$ as given below, defined by their power delay profiles (PDPs).

Channel Model #**1**

Path Gain σ_i^2(in dB)	0	-3	-8	-15
Path Delay τ_i (in μsecs)	0	0.5	1.7	2.2

Channel Model #**2**

Path Gain σ_i^2(in dB)	-2	0	-1	-6	-9	-14
Path Delay τ_i (in μsecs)	0	1.8	3.5	5.7	8.1	12.3

Hint: To normalize average channel gain to unity, in each of these models, rescale the (linear value of) the path variance $\sigma_i^2$to ensure that over the L paths, $\sum_{i=0}^{L-1} \sigma_i^2 = 1$. For each of the above models, determine:
(a) Mean delay spread
(b) Mean square delay spread
(c) Root mean square (RMS) delay spread
(d) Maximum excess delay (X dB) for: (i) X = 6dB; (ii) X = 10dB
(e) Coherence bandwidth

8. We now develop sample-spaced channel models, which are defined at the sampling rate f_S (assumed to be equal to the pass-band signal bandwidth). Here, each path is “rounded” to the nearest tap location (where the taps are at sampling intervals). For each of the below sampling rates, re-compute the sample-spaced PDP for the 2 examples in Pbm.7. For each case, also compute (a) thro (e) given in Pbm.7 and comment about your result.
(a) f_S = 1MHz
(b) f_S = 5MHz

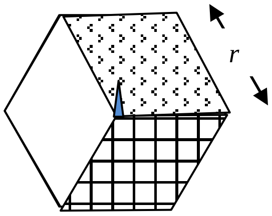
9. If 20% blocking can be tolerated, how many Erlangs of traffic load can be offered to 2 servers? Use the Erlang-B formula discussed in class to arrive at your answer.

10. It is decided to use omni-antennas at the base-station in a TDMA based cellular system with reuse 1/4 deployment. The side of each hexagonal cell is r = 1km, and the path loss exponent, n = 3.
(a)Make a neat sketch of the reuse-pattern, using A,B,C&D to mark the 4 frequency bands (colours).
(b) Using only the 1st tier interferers, find the exact expression for the worst case Signal to Interference (SIR) ratio on the **downlink**. Clearly mark the location of the different mobile equipment which cause this worst-case SIR.
(c) What is the numerical value of this SIR for the given r and n?
(d) Now, if the 2nd tier of interferers are also considered, what are the co-channel interference terms (as a function of r and n) contributed by only the 2nd tier interferers?
(e) What is the new numerical value of SIR for the given r and n?

11. Repeat the above problem for reuse 1/3, but with all other factors the same.

12. Repeat Pbm. **10** part(b), but now for finding the worst case SIR on the **uplink**. Also repeat parts (c) thro (e).

13. It is decided to use 120^O sectored-antennas at the cell-site, and deploy 3 base-station equipment (one per sector) in a TDMA based cellular system. Each sector uses 1/3 of the total bandwidth available with the operator.The side of each hexagonal cell is r = 2km, and the path loss exponent, n = 2.Assume that the sectored antennas have a transmit gain of unity within the 120^O beam-width, and zero outside it. The same reuse pattern as shown below is repeated in each cell.



(a) Make a neat sketch of the reuse-pattern, using A,B,&C to mark the 3 frequency bands (colours) in each sector. How many “first-tier” **downlink** interferers are there?
(b) If the *weakest* interferer considered on thedownlinkis within 12dB of the *strongest* interferer, how many interfering signals should you consider while computing the (approximate) worst-case SIR? Mark these interferers on the hexagonal grid that you made for part (a).
(c) What is the value of this worst-case SIR for the given r ?

14. The following questions from Chapter 3 of T.S.Rappaport’s book (E-version), pp:133 onwards
(i) 3.1 **-- Expression for Brewster angle (*optional*)
(ii) 3.3 to 3.8 – 2-ray model (*optional*)
(iii) 3.9 to 3.11 – Knife edge diffraction model (*optional*)
(iv) 3.13 – Comparision of different path-loss models
(v) 3.17 and 3.18 – Log normal fading
(vi) 3.20 – City-wide network planning
(vii) 3.21 – Finding cell radius

15. Assume that the thermal noise power spectral density at the receiver (in the dBm scale) can be taken as -174dBm. The path-loss exponent is n=2, and the 1m loss at the Tx end can be taken to be 42dB. Both the Tx and Rx use ideal omni antennas with gain of 0dBi. It is also given that the Rx noise figure is 7dB, and the required post-processing SINR = 5dB for the considered modulation.
The Frequency-Division-Duplexed (FDD) communication link uses a one-way bandwidth of 5MHz, and the (peak) uplink transmit power is P_T =10dBm. Three different multiple access schemes using the same modulation are considered for the **uplink**, namely: (a) FDMA with 100KHz channelization per user, (b) TDMA with 1MHz channelization for 10 user slots, and (c) DS-CDMA with 5MHz channelization and a spreading factor W=512.
(a) If the TDMA and FDMA use reuse-1/4 deployment, compare the number of simultaneous (fixed-rate) users, N, that can be supported on the uplink per base-station. Compare this number with the pole-capacity N_P of the DS-CDMA system.
(b) Compute the maximum link distance possible for the TDMA and the FDMA links.
(c) Assuming only 1 user is connected to the base-station, repeat this for DS-CDMA.
(d) Repeat part (c) when N=N_P-1 users are connected on the uplink to the DS-CDMA base-station.

(e) For the *same link distance* as you determined in part (d), how much transmit power will TDMA and FDMA transmitters require? Provide both these answers in dBm scale.

16. Now consider a 10MHz DS-CDMA system with W=1024. Assuming perfect uplink power-control, the aim is to compute the uplink power P required from each user at the base-station. Assume that on the linear scale the SINR required is 5, and the receiver noise variance is σ^2, answer the below:
(a) For N=1, what is the P required (as a function of σ^2) ?
(b) What is the pole capacity N_P of this system?
(c) For $0<N<N_P$, what is the expression for the set-point of P?
(d) Repeat (a) & (c) for the narrow-band W=128 example, with the same SINR=5 required for each uplink. Compare your results and discuss.

17. Assume that the thermal noise power spectral density at the DS-CDMA base-station receiver can be taken as -174dBm. The path-loss exponent is n=3, and the 1m loss at the Tx end of the mobile station can be taken to be 35dB. Both the Tx and Rx use ideal omni antennas with gain of 0dBi. It is also given that the Rx noise figure is 5dB, and the required post-processing SINR = 9dB for the considered modulation. The Frequency-Division-Duplexed (FDD) communication link uses a one-way bandwidth of 2MHz, and the (peak) uplink transmit power is P_T =15dBm. The system uses a spreading factor of$W$=256 to send a 9.6kbps bit-stream over the given bandwidth.
(a) Find the value (in dBm scale) of the thermal noise (power) variance σ_n^2 at the receiver.
(b) Let the pole capacity of this DS-CDMA system be N_P. Recall that the number of users $N< N_P$ that can be practically supported on the **uplink** is a function of the allowed noise rise, L. The required power control setting P_R at the base-station receiver for a given N is therefore a function of L. Find the expression of P_R in terms of L, N_P, and σ_n^2.
(c) For an allowed noise rise of 6dB(i.e., L=4), find the *maximum link distance* in meters that this DS-CDMA base-station can support on the uplink.

18. In a DS-CDMA downlink, Orthogonal Variable Spreading Factor (OVSF) codes are being used to provide different rates to 15 users currently connected to the base-station. Recall that in the OVSF tree, R_0 represents the rate at level 0 (which the root of the tree, and for this rate there is no spreading done). Next, R_1 represents the rate of each of the 2 code-streams at level 1, formed by using the spreading codes {11} and {10}. Clearly, $R_1 = R_0/2$, and in general, $R_J = R_0/2^J$, for level J. Given that among the 15 users, 1 user is at rate R_2, 1 user at rate R_3, 6 users at R_4, and 7 users at R_5, answer the following:
(a) What is the sum rate supported over the 15 users? Express your answer as a function of R_0.
(b) Sketch the OVSF code tree up to level 5, and indicate how the 15 users are allotted resources (codes) from this tree, by circling (or ticking) the appropriate code.

19. Let us again consider an OVSF based rate (and code) assignment scheme as in Pbm.18. Assume that at current time-instant $t=t_0$, a new user arrives who wants to be assigned rate R_1. Already, from $t < t_0$, there are 2 existing users who have been assigned distinct OVSF codes from level 3 (i.e., codes corresponding to rate R_3). Assume that the probability that a user gets assigned to a code at level J is given by $1/2^J$ if he is the first user at that level, and is $1/(2^J -1)$ if he is the second user at that level, and in general, will be $1/(2^J -j+1)$, if he is the j^{th} user entering level J, where $j=1,2,3\ldots, 2^J$.
(a) Given such a random assignment of codes, what is the probability that the new user *cannot* be served (rate R_1) at level 1?
(b) Assume now that the 3rd user was indeed probabilistically accommodated with rate R_1. Now, what is the probability under this random assignment of codes that a 4th user entering at some later time $t=t_1$ where $t_1 > t_0$, can successfully be assigned rate R_2 (from level 2)?

KG/IITM/March 2016