TLT-6106 Basic Course on Wireless Communications, Exam 15.12.2009, 9:00-12:00
Please give the answers in English. *Students' own calculators or faculty's calculators are allowed.* Attached 2-page formulas allowed. Exam's compiler: Simona Lohan, TG116.

1. **(6p)** A commercial mobile receiver for data transmission is specified with a sensitivity of -90 dBm (dBm=power in dB per mW). Assuming a 0.9 mW transmit power, a transmission frequency of 1.8 GHz, transmitter (or base station) antenna height of 10 m, and receiver antenna height of 0.1 m, what would be the radius of service area under the following path loss models?

$$a) L_{dB} \approx 32.44 + 20\log_{10} d_{km} + 20\log_{10} f_{MHz}$$
$$b) L_{dB} = 46.3 + 33.9\log_{10}(f_{MHz}) - 13.82\log_{10}(h_{T,m}) + (47 - 6.55\log_{10}(h_{T,m}))\log_{10}(d_{km})$$
$$c) L_{dB} \approx 120 + 40\log_{10} d_{km} - 20\log_{10} h_{T,m} h_{R,m}$$

$h_{T,m}$ is the transmit antenna height in meters and $h_{R,m}$ is the receive antenna height in meters.

To which path loss model each of the formulas above corresponds?

At equal cell radius, for which of the 3 models above do you get the minimum path loss and why?

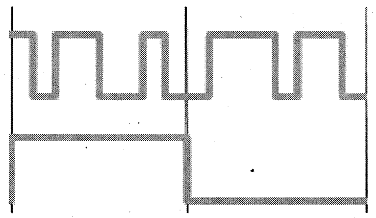
How is the path loss varying with the distance (in linear scale) for these models?

2. a) **(2p)** Describe at least 2 of the following 4 concepts: i) Soft handover, ii) Softer handover, iii) Inter-system handover, iv) Vertical handover.

b) **(2p)** Assume that the transmitted power of an isotropic radiator is 1 kW and the operating frequency is f = 1.5 GHz. What is the power density at the receiver 100 km away? What is the transmission loss, assuming a free space loss model and an isotropic antenna?

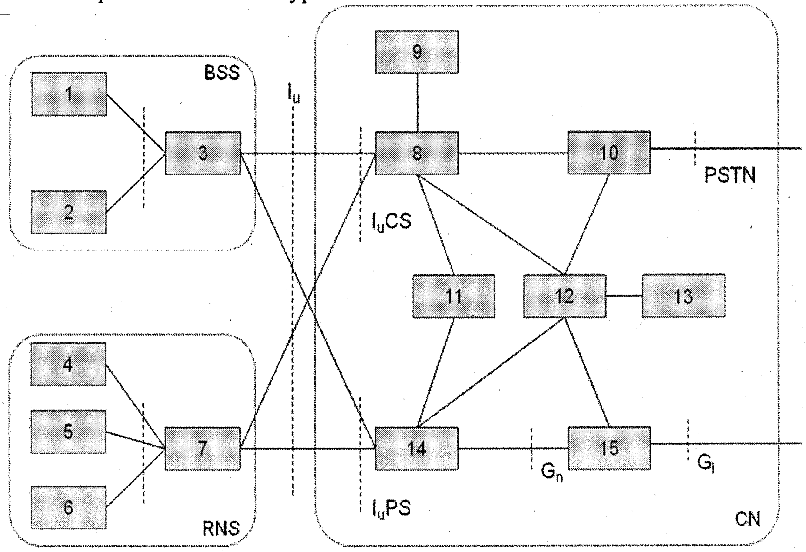
c) **(2p)** Describe the hidden node and the exposed node problems in the context of MAC protocol.

3. a) **(2p)** The following figure shows (in the upper part) a spreading sequence of spreading factor SF=8 and different codes from one data symbol to another. The lower part shows 2 data symbols. Plot the spread sequence (i.e., the output after spreading the 2 data symbols with the given spreading code). What is the processing gain (in dB) of this spreading sequence?

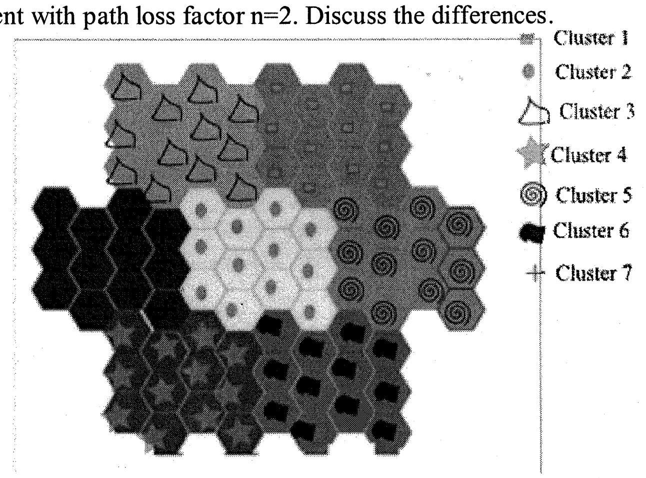


b) **(4p)** Describe briefly the following concepts related to wireless communications: a) Space Division Multiple Access (SDMA); b) Time Division Multiple Access (TDMA); c) Frequency Division Multiple Access (FDMA); d) Orthogonal Frequency Division Multiplexing (OFDM)

4. **(6p)** The following block diagram shows the simplified GSM+UMTS network architecture. Explain the name and functionality of each of the blocks from 1 till 15. Hint: some blocks have the same functionality/name. Based on this block diagram, compare GSM system architecture with UMTS system architecture, by emphasizing the similarities and differences. Gives some examples of data rates typical for GSM and for UMTS based connections.



5. a) **(3p)** What is the cluster size (N) in the figure below? If the cell range is R=300 m, what is the value of the re-use distance? What is the value of the Signal to Interference ratio (SIR) in decibels for this cluster size, in an environment with the path loss factor n=4? What about SIR in an environment with path loss factor n=2. Discuss the differences.



b) **(3p)** Make a judgment on the evolution and challenges on the future wireless communications (write down your ideas what on what will be next and what are the challenges we have to cope with). Think about the physical layer and Medium Access Control (MAC) layer requirements and how to achieve them.

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Appendix to the Exam 30.1.2009 (part 1 of 2)

List of formulas:

$$P_R = \frac{P_T}{4\pi R^2} A_e \qquad G = \eta\left(\frac{\pi D f}{c}\right)^2 \qquad P_N = -228.6 + 10\log_{10} T + 10\log_{10} B + NF_{dB}$$

$$L_{dB} = 32.4 + 20\log_{10} d_{km} + 20\log_{10} f_{MHz} \qquad L = 4\sin^2\left(\frac{2\pi h_T h_R}{\lambda d}\right)\left(\frac{\lambda}{4\pi d}\right)^2 \qquad P_R(d) = P_R(d_0)\left(\frac{d_0}{d}\right)^n$$

$$L = A + B\log_{10}(f_{MHz}) - 13.82\log_{10}(h_b) + (C - 6.55\log_{10}(h_b))\log_{10}(d_{km}) - K$$

$$L = L_{ref} + 20\log_{10} d + \sum_{f=1}^{F} FAF(f) + \sum_{w=1}^{W} WAF(w)$$

$$P_R(d) = P_R(d_0) - 10n\log_{10}(d/d_0) + \Psi_{dB}$$

$$p_{out} = p(P_R(d) < P_{\min}) = 1 - Q\left(\frac{P_{\min} - P_R(d_0) + 10n\log_{10}(d/d_0)}{\sigma_{\Psi_{dB}}}\right) \qquad Q(x) = \frac{1}{\sqrt{2\pi}}\int_x^{\infty} e^{-t^2/2}dt$$

$$f_{Z_r}(z_r) = \frac{1}{\sqrt{2\pi}\sigma} e^{-z_r^2/2\sigma^2} \qquad f_R(r \mid \sigma) = \frac{r}{\sigma^2} e^{-r^2/2\sigma^2} \qquad f_R(r \mid v, \sigma) = \frac{r}{\sigma^2} e^{-\frac{(r^2+v^2)}{2\sigma^2}} I_0\left(\frac{rv}{\sigma^2}\right)$$

$$f_R(r \mid k, \sigma) = \frac{2}{\Gamma(k)}\left(\frac{k}{2\sigma^2}\right)^k r^{2k-1} e^{-\frac{kr^2}{2\sigma^2}} \qquad \Gamma(k) = \int_0^{\infty} y^{k-1} e^{-y} dy$$

$$\mu_\tau = \frac{1}{P_{av}}\sum_{\tau=0}^{\infty} \tau\, P(\tau) \qquad \sigma_\tau = \sqrt{\frac{1}{P_{av}}\sum_{\tau=0}^{\infty}(\tau - \mu_\tau)^2\, P(\tau)}$$

$$\boxed{S_E(f) = \frac{1.5}{\pi f_m \sqrt{1 - \left(\frac{f - f_c}{f_m}\right)^2}}}$$

$$s_k(t) = \sum_{n=0}^{N-1} c_k(n) \underbrace{p(t - nT_c)} \qquad T = \lambda_p T_p e^{-2\lambda_p T_p} = Le^{-2L} \qquad T = \lambda_p T_p e^{-\lambda_p T_p} = Le^{-L}$$

$$\boxed{C = MkN = MS} \qquad N = i^2 + ij + j^2 \qquad SIR = \frac{d_0^{-n}}{\sum_{j=1}^{J} d_j^{-n}}$$

$$\boxed{SIR = \frac{R^{-n}}{\sum_{j=1}^{J} D_j^{-n}} = \frac{\left(\frac{D}{R}\right)^n}{J} = \frac{Q^n}{J} = \frac{\left(\sqrt{3N}\right)^n}{6}}$$

$E_u = H(1/\mu)$, $E = UE_u$

$$\Pr[delay > 0] = \frac{\frac{E^M}{M!}\frac{M}{M-E}}{\frac{E^M}{M!}\frac{M}{M-E} + \sum_{i=0}^{M-1}\frac{E^i}{i!}} \qquad \Pr[blocking] = \frac{E^M / M!}{\sum_{i=0}^{M} E^i / i!}$$

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Appendix to the Exam 30.1.2009 (part 2 of 2)

$$Q = \frac{D}{R} = \sqrt{3N}$$

$$IM = 10\log_{10}\left(\frac{1}{1-\eta}\right) = 10\log_{10}\left(\frac{N+I}{N}\right)$$

$$\eta_{UL} = \sum_{k=1}^{K} \frac{1}{1+\frac{W}{\rho_k R_k}} \nu_k (1+i_{UL})$$

$$\eta_{DL} = \sum_{i=1}^{I}\left[\frac{\rho_i R_i \nu_i}{W}((1-\alpha_i)+i_i)\right]$$

$$P_{rx,j} = G_{ij} P_{tx,i}$$

$$PG = 10\log_{10}\left(\frac{R_c}{R_b}\right)$$

$$\Gamma_i = \frac{G_{ji} P_j}{\sum_{k \neq j} G_{ki}\theta_{ki} P_k + N_i}$$

$$P_i(t) = \frac{R_i(t)}{\lambda_i(t)}$$

$$P_i(t) = \frac{R_i(t)}{\lambda_i(t)} \cdot \left[\frac{\max_j \{\overline{R_i(t)}\}}{\overline{R_i(t)}}\right]$$

ρi = c(tR - tT) = r + cΔt;

$$s_{SinBOC}(t) \triangleq sign\left(sin\left(\frac{N_{BOC}\pi t}{T_c}\right)\right)$$

Erlang B capacity with 1%, 2%, 3% and 5% blocking

CHs	1%	2%	3%	5%
1	0.01	0.02	0.03	0.05
2	0.15	0.22	0.28	0.38
3	0.46	0.60	0.72	0.90
4	0.87	1.09	1.26	1.52
5	1.36	1.66	1.88	2.22
6	1.91	2.28	2.54	2.96
7	2.50	2.94	3.25	3.75
8	3.13	3.63	3.99	4.54
9	3.78	4.34	4.75	5.37
10	4.46	5.08	5.53	6.22
11	5.16	5.84	6.33	7.08
12	5.88	6.61	7.14	7.95
13	6.61	7.40	7.97	8.83
14	7.35	8.20	8.80	9.73
15	8.11	9.01	9.65	10.60
16	8.88	9.83	10.50	11.50
17	9.65	10.70	11.40	12.50
18	10.40	11.50	12.20	13.40
19	11.20	12.30	13.10	14.30
20	12.00	13.20	14.00	15.20

CHs	1%	2%	3%	5%
21	12.80	14.00	14.90	16.20
22	13.70	14.90	15.80	17.10
23	14.50	15.80	16.70	18.10
24	15.30	16.60	17.60	19.00
25	16.10	17.50	18.50	20.00
26	17.00	18.40	19.40	20.90
27	17.80	19.30	20.30	21.90
28	18.60	20.20	21.20	22.90
29	19.50	21.00	22.10	23.80
30	20.30	21.90	23.10	24.80
31	21.20	22.80	24.00	25.80
32	22.00	23.70	24.90	26.70
33	22.90	24.60	25.80	27.70
34	23.80	25.50	26.80	28.70
35	24.60	26.40	27.70	29.70
36	25.50	27.30	28.60	30.70
37	26.40	28.30	29.60	31.60
38	27.30	29.20	30.50	32.60
39	28.10	30.10	31.50	33.60
40	29.00	31.00	32.40	34.60