E4.03
AS5
SO10
ISE4.3

IMPERIAL COLLEGE LONDON

DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING
EXAMINATIONS 2009

MSc and EEE/ISE PART IV: MEng and ACGI

MOBILE RADIO COMMUNICATION

Corrected Copy

Monday, 18 May 10:00 am

Time allowed: 3:00 hours

There are FOUR questions on this paper.

Answer THREE questions.

All questions carry equal marks. The maximum mark for each subquestion is shown in brackets.

Any special instructions for invigilators and information for candidates are on page 1.

Examiners responsible First Marker(s) : M.K. Gurcan
Second Marker(s) : K.K. Leung

Instructions to Candidates
Useful equations

The correction factors for the Okumura model are given as follows

$$G\left(h_t\right) = 20\log_{10}\left(\frac{h_t}{200}\right)$$

and

$$G\left(h_r\right) = \begin{cases} 10\log_{10}\left(\frac{h_r}{3}\right) & h_r \leq 3m \\ \\ 20\log_{10}\left(\frac{h_r}{3}\right) & 10m > h_r > 3m. \end{cases}$$

Taylor series expansion:

$$\left(1+\frac{a^2}{2}\right)^2 = 1 + a^2 \qquad \text{for } a << 1.$$

1. Answer the following sub-questions.

   (a) Consider a transmitter which radiates a sinusoidal carrier frequency of 1850 MHz and a vehicle moving at 60 mph. Compute the received signal's carrier frequency if the mobile is moving

      i. directly towards the transmitter; [1]

      ii. directly away from the transmitter; [1]

      iii. in a direction which is perpendicular to the direction of arrival of the transmitted signal. [1]

   (b) If a transmitter produces 50W of power, answer the following sub-questions.

      i. Express the transmitted signal's power in units of dBm. [1]

      ii. If 50 W is applied to a unity gain antenna with a 900 MHz carrier frequency, find the received signal power in dBm at a free space distance of 100 m from the antenna. [1]

      iii. What is the received signal power at 10 km? Assume unity gain for the receiver antenna. [2]

   (c) The Okumura curves for the median attenuation $(A(f,d))$, relative to free space, over a quasi-smooth terrain are shown in Figure 1. The Okumura curves for the correction factor G_{AREA} for different types of terrain are shown in Figure 2.

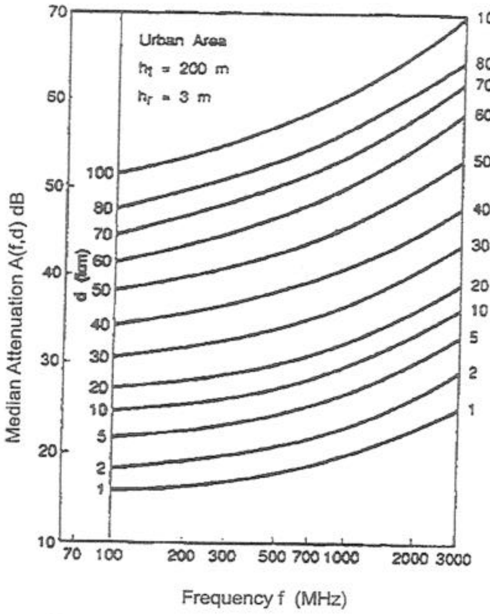

Figure 1 Median Attenuation.

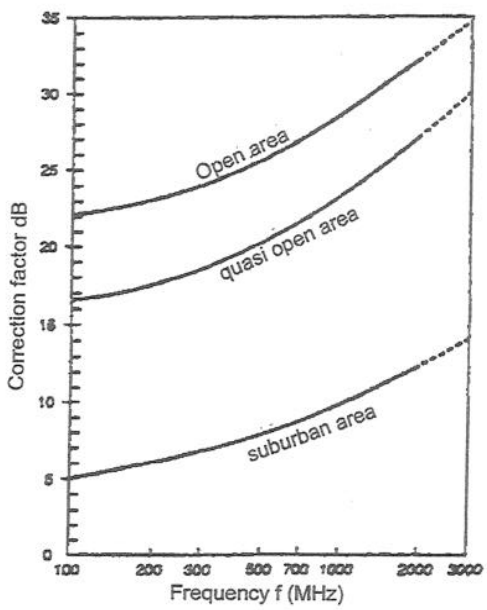

Figure 2. Correction factor G_{AREA}

The Okumura model gives the median path loss as follows

$$P_L(d) = L(f,d) + A(f,d) - G(h_t) - G(h_r) - G_{AREA}$$

where $L(f,d)$ is the free space path loss, the median attenuation ($A(f,d)$) is obtained from Figure 1, the correction factor G_{AREA} is obtained from Figure 2, the term $G(h_r)$ is the mobile antenna height gain factor and also $G(h_t)$ is the base-station antenna height gain factor.

i. Find the median path loss using Okumura's model for $d = 50$ km, $h_t =$ 100 m, $h_r = 10$ m in a suburban environment. [4]

ii. If the base station transmitter radiates 1 kW at a carrier frequency f=900 MHz, find the power at the receiver. [4]

(d) Given an indoor path loss model of the form:

$$\overline{PL}(d)_{dB} = 40 + 20\log d + \sum FAF \quad \text{for } d \geq 1 \text{ m.}$$

where d is measured in meters, find the mean received power if the transmitted signal goes through three floors of a building and also if the floor attenuation factor FAF is 15 dB per floor. Assume that the transmitter power is 20 dBm and unity gain antennas are used at both transmitter and receiver, and that the straight-line path between the transmitter and receiver is $d = 15$ metres through the floors. [3]

(e) An illustration of two-ray ground reflection is shown in Figure 3. Prove that in the two-ray ground reflection model the path length difference is $\Delta = d'' - d' \approx \dfrac{2h_t h_r}{d}$. Show when this holds as a good approximation. Hint use the geometry of Figure 3. [4] [3]

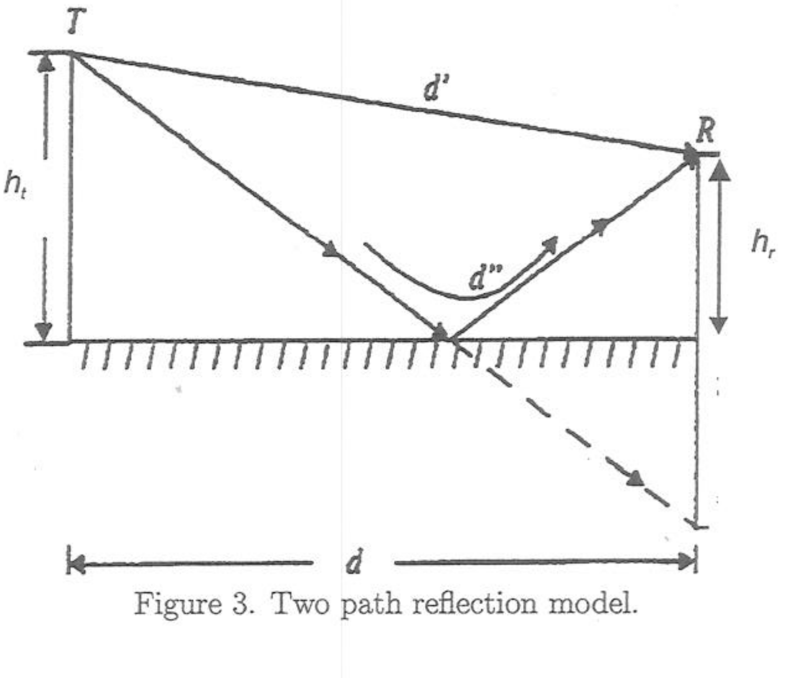

Figure 3. Two path reflection model.

2. Answer the following sub-questions.

(a) Assume a Rayleigh fading channel and answer the following questions.

i. Calculate the positive-going level crossing rate for the normalized envelope value $\rho = 1$ when the maximum Doppler frequency $f_m = 20$ Hz. [1]
What is the maximum velocity of the mobile for this Doppler frequency if the carrier frequency is 900 MHz? [1]

ii. Find the average fade duration for the threshold level $\rho = 0.1$ when the Doppler frequency is 200 Hz. [2]

(b) Assume that a mobile travelling at a velocity of 10 m/s receives two multipath components at a carrier frequency of 1000 MHz. The first component is assumed to arrive at τ=0 with an initial phase of zero degrees and a power of –70 dBm (which is equal to 100 pW). The second component is 3 dB weaker than the first component and is assumed to arrive at τ=1 μs with the initial phase of zero degrees. The mobile moves directly towards the direction of arrival of the first component and directly away from the direction of arrival of the second component. Answer the following questions.

i. For a narrow band system, consider the observation interval $0 \leq t < 0.5$ μ s and compute the instantaneous power at the times 0μs, 0.1μs, 0.2 μs, 0.3 μs, 0.4 μs, 0.5 μs; [4]

ii. Calculate the average power received over the observation interval for the narrowband signal; [2]

iii. Compare the average narrowband and wideband received powers over the interval. [4]

(c) Answer the following questions.

i. Compute the root-mean-square (RMS) delay spread for the power delay profile given in Figure 4. [3]

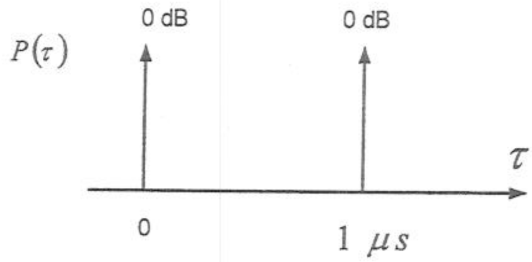

Figure 4 Power delay profile.

ii. If Binary Phase Shift Keying (BPSK) modulation is used, what is the maximum bit rate that can be sent through the channel without requiring an equalizer? [3]

(d) Assume that in a small scale propagation measurement system, the time between samples is equal to $\frac{T_c}{2}$, where T_c is the coherence time. Answer the following questions.

i. Determine the sampling interval required to make the measurements when it is assumed that consecutive samples are highly correlated in time. [2]

ii. How many samples will be required over 10 m travel distance if the carrier frequency is f_c=1900 MHz and v = 50 m/s? [1]

iii. How long would it take to make these measurements assuming they could be made in real time from a moving vehicle? [1]

iv. What is the Doppler spread B_D for the channel? [1]

3. Answer the following sub-questions.

(a) Answer the following sub-questions.

i. Explain what is meant by "Shannon's ergodic capacity upper bound" when transmitting adaptive modulated coded (AMC) signals over a time varying radio transmission channel where the channel gain is known at the receiver and both the transmitter and receiver know the distribution of the channel gain. [4]

ii. Consider a time varying radio transmission channel, explain how the capacity equation [3]

$$C = \sum_{i=1}^{N} B \log_2 \left(\frac{\gamma_i}{\gamma_0} \right) p(\gamma_i)$$

and the optimal power adaptation method are used to find the cut-off value γ_0 which satisfies the relationship

$$\sum_{\gamma_i \geq \gamma_0} \left(\frac{1}{\gamma_0} - \frac{1}{\gamma_i} \right) p(\gamma_i) = 1$$

in order to maximize the transmission channel capacity. In the above equations C is the channel capacity, γ_i is the SNR for $i = 1, \cdots, N$ and N is the total number of discrete SNR values, $p(\gamma_i)$ is the distribution for the SNR values, B is the transmission bandwidth.

iii. Explain how the main conclusion of the optimization concept described in 3.a.ii is used to improve the capacity achieved by the channel inversion method by introducing the truncated channel inversion method given by [4]

$$C = B \log_2 \left(1 + \frac{1}{E_{\gamma_0}\left[\frac{1}{\gamma}\right]} \right) p(\gamma \geq \gamma_0)$$

where $E_{\gamma_0}\left[\frac{1}{\gamma}\right]$ is

$$E_{\gamma_0}\left[\frac{1}{\gamma}\right] \triangleq \int_{\gamma_0}^{\infty} \frac{1}{\gamma} p(\gamma)\, d\gamma.$$

(b) Answer the following sub-questions.

i. Explain how the radio resources: the transmission energy, the number of bits per symbol per channel are allocated when using the high speed downlink packet access (HSDPA) transmission system with K parallel [3] channels and the processing gain of N. Assume that the channel gain h, the noise variance σ^2 and the gap value Γ are both known at the transmitter and receiver. Also assume that the HSDPA system uses $4QAM$ and $16QAM$ (Quadrature Amplitude modulation) modulations as well as the Turbo encoder rates $\frac{1}{2}$, $\frac{2}{3}$ and $\frac{3}{4}$ such that the transmission system transmits the data at the possible rates b_p of $\frac{1}{2}$, 1, $\frac{3}{2}$, 2 and 3 bits per symbol.

ii. When considering the HSDPA system described in 3.b.i answer the following sub-questions.

A. Explain why there exists a residual energy upper bounded by an amount equal to the number of parallel channels multiplied by the incremental energy, where the incremental energy is the minimum energy increase required to transmit the data at a rate of b_{p+1} instead of b_p bits per symbol. [3]

B. Explain how the residual energy is reduced to a value below the incremental energy by using the two group bit rate allocation method which uses the data rates at b_p and b_{p+1} bits per second over channels in two groups. [3]

iii. Consider an HSDPA system which uses a total $K = 15$ parallel channels and also a total transmission energy $E_T = 3.0$. The noise variance and the channel gains are $\sigma^2 = 10^{-6}$ and $h = 10^{-4}$ respectively. The gap value is $\Gamma_{dB} = 1.6$ dB and the possible transmission date rates are b_p of $\frac{1}{2}$, 1, $\frac{3}{2}$, 2 and 3 bits per symbol. Answer the following sub-questions.

A. Calculate the energy required to transmit different bit rates per symbol over each channel. [1]

B. Determine the incremental energy for each different bit rate. [1]

C. Find the total number of bits that can be carried over $K = 15$ channels without exceeding the total available energy when using the single group equal rate allocation algorithm. [1]

D. Find the residual energy for the HSDPA single group power allocation scheme. [1]

E. Calculate the total number of bits that can be carried by the two group allocation algorithm and also the corresponding residual energy. [1]

4. Answer the following sub-questions.

(a) Consider the Core Network (CN) for the third generation wideband UTRAN/FDD radio system.

i. Describe the functions/procedures of the following functional entities of the Global Systems Mobile (GSM) part of the system

A. the Mobile Switching Centre (MSC) ; [2]

B. the Visitors Location Register (VLR); [2]

C. the Home Location Register (HLR). [2]

ii. Describe which other functional entities are required for the packet switching transmissions over the GPRS part of the UTRAN system. [1] Explain what type of information these functional entities keep. [2]

(b) For the UTRAN radio system, answer the following questions.

i. Explain the RANAP and Node B protocol functions. [3]

ii. Describe the radio resource control (RRC) protocol functions. [2]

iii. Outline the mapping for the transport and physical channels. [4]

(c) When considering the inter-sytem handover from the HSDPA system to the GPRS system the UTRAN protocols and procedures are used for location management and hard handover processes. Answer the following questions.

i. Explain how the location management procedure works for the UTRAN system; [2]

ii. Explain how the inter-system handover procedure operates for the hard handover from the UTRAN system to the GSM/GPRS system handover using the protocol stack diagram shown in Figure 5. Hint just refer to the main message exchanges. [5]

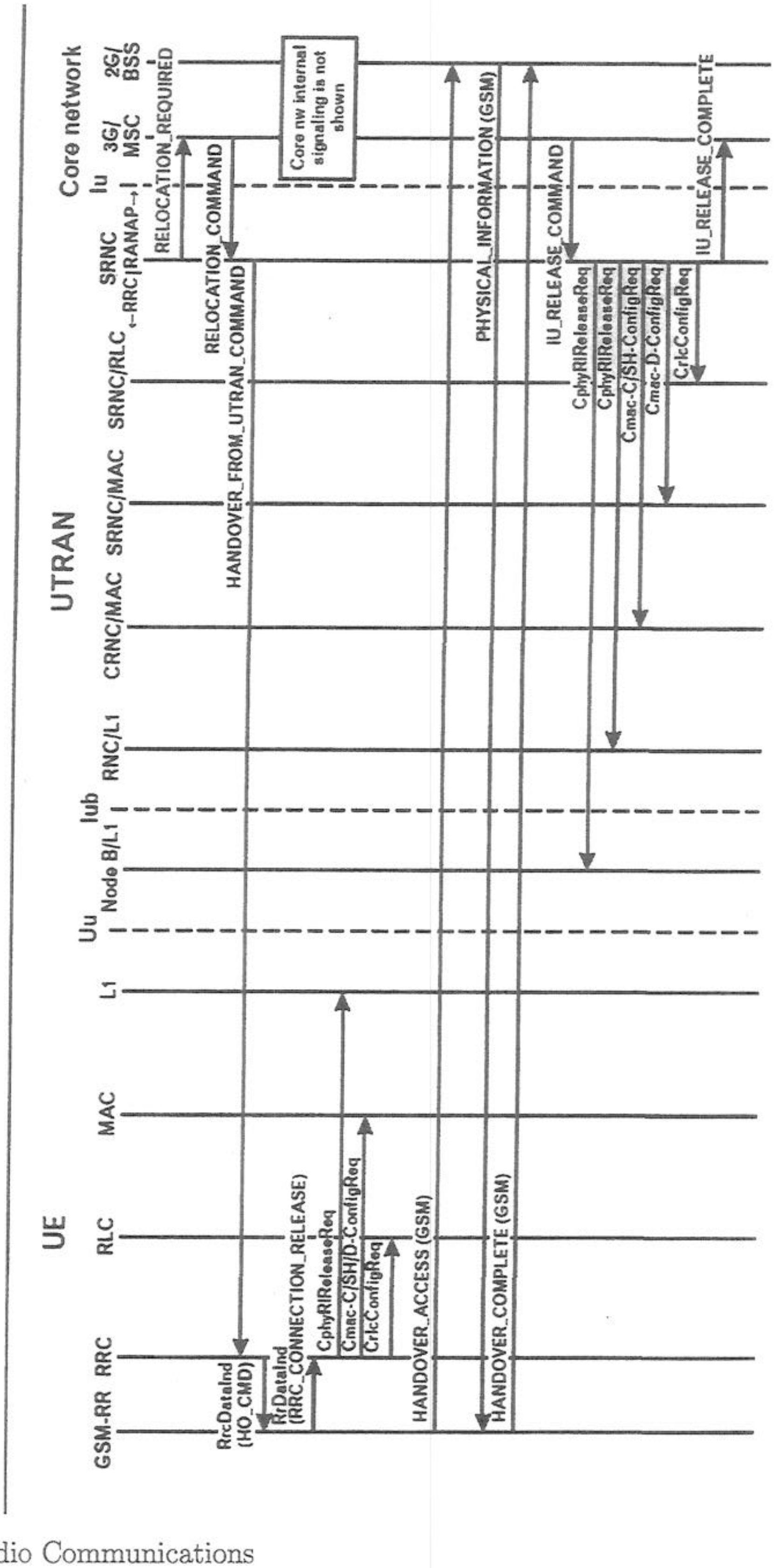

Figure 5 handover from UTRAN to GSM

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1.a Carrier frequency $f_c = 1850$ MHz,

The wavelength $\lambda = \frac{c}{f_c} = \frac{3\times10^8}{1850\times10^6} = 0.162$ m

Vehicle speed $v = 60$ mph $= 26.82$ m/s

i The vehicle is moving directly towards the transmitter Doppler shift in this case is positive and the received frequency is

$$f = f_c + f_d = 1850\times10^6 + \frac{26.82}{0.162} = 1850.00016 \text{ MHz}.$$

ii The vehicle is moving directly away from the transmitter. The Doppler shift in this case is negative and the received frequency is given by

$$f = f_c - f_d = 1850\times10^6 - \frac{26.82}{0.162} = 1849.999834 \text{ MHz}.$$

iii The vehicle is moving perpendicular to the angle of the transmitted signal. In this case $\theta = 90^\circ$. $\cos\theta = 0$ and hence there is no Doppler shift.

1.b i) The transmitter power $P_t = 50$W, carrier frequency $f_c = 900$ MHz. Using $P_t(\text{dBm}) = 10\log_{10}(P_t(\text{mW}))$

$$= 10\log_{10}(50\times10^3) = 47\text{dBm}$$

ii Received power

$$P_r = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2} = \frac{50\times1\times(1/3)^2}{(4\pi)^2(100)^2} = 3.5\times10^{-6}\text{W} = 3.5\times10^{-3}\text{mW}$$

iii The received power at 10 km can be expressed in terms of dBm

1.b.iii $$P_r(d)\,\text{dBm} = 10\log_{10}\frac{P_r(d_0)}{0.001\text{W}} + 20\log_{10}\left(\frac{d_0}{d}\right) \quad d \geq d_0 \geq d_f$$

$$= P_r(100) + 20\log\frac{100}{10000} = -24.5\text{dBm} - 40\text{dB}$$

$$= -64.5 \text{ dBm}.$$

1.c The free path loss L_f can be calculated using

$$L_F = 10\log_{10}\left[\frac{\lambda^2}{(4\pi)^2 d^2}\right] = 10\log_{10}\left[\frac{\left(\frac{3\times10^8}{90\times10^6}\right)^2}{(4\pi)^2\times(50\times10^3)^2}\right]$$

$= 125.5$ dB

From the Okumura curves $A(f,d) = A(900\times10^6, 50\text{km}) = 43\text{dB}$ and $G_{AREA} = 9\text{dB}$.

Also using $G(h_t) = 20\log_{10}\left(\frac{h_t}{200}\right) = 20\log_{10}\left(\frac{100}{200}\right) = -6\text{dB}$

$G(h_r) = 20\log_{10}\left(\frac{h_r}{3}\right) = 20\log_{10}\left(\frac{10}{3}\right) = 10.46\text{dB}$

using $L_{50}(\text{dB}) = L_F + A(f,d) - G(h_t) - G(h_r) - G_{AREA}$

$$= 125.5\text{dB} + 43 - (-6) - 10.46 - 9 = 155.04\text{dB}$$

Therefore the median received power is

$$P_r(d) = P_t(\text{dB}) - L_{50}(\text{dB}) + G(\text{dB}) = 60\text{dBm} - 155.04\text{dB}$$

$$= -95.04 \text{ dBm}.$$

1.d $$\overline{PL}(d)\,\text{dB} = 40 + 20\log_{10}15 + 15\times3 = 40 + 23.52 + 45 = 108.52$$

$$P_r = -88.52 \text{ dBm}.$$

1-e $\Delta = d'' - d' = \sqrt{(h_t+h_r)^2 + d^2} - \sqrt{(h_t-h_r)^2 + d^2}$

$= d\left(\sqrt{1+\frac{(h_t+h_r)^2}{d^2}} - \sqrt{1+\frac{(h_t-h_r)^2}{d^2}}\right)$

using Taylor series expansion

$1+\frac{(h_t+h_r)^2}{d^2} = \left(1+\frac{(h_t+h_r)^2}{2d^2}\right)^2$ and

$1+\left(\frac{h_t-h_r}{d^2}\right)^2 = \left(1+\frac{(h_t-h_r)^2}{2d^2}\right)^2$

$\Delta = d'' - d' = \frac{d}{2d^2}\left((h_t+h_r)^2 - (h_t-h_r)^2\right) = \frac{2h_t h_r}{d}$

ii This approximation holds when $h_t + h_r << d$

2.a.i) Number of level crossing rate is

$N_R = \sqrt{2\pi}\, f_m\, \rho \exp(-\rho^2) = \sqrt{2\pi} \times 20 \times 1 \times \exp(-1)$

$= 18.44$ crossings per second.

$f_{d,max} = \frac{V}{\lambda}$, $f_d = 20\ Hz$, $V = f_d \lambda = 20 \times \frac{1}{3} = 6.66\ m/s$

$= 24\ km/h$

2.a.ii $\bar{\tau} = \frac{\exp(\rho^2) - 1}{\rho f_m \sqrt{2\pi}} = \frac{\exp(0.1^2) - 1}{0.1 \times 200 \times \sqrt{2\pi}} = 200\ \mu s.$

2.b.i) Given $V = 10\ m/s$, the time of arrival of 0.1 s corresponds to spatial intervals of 1 m. The carrier frequency is 1000 MHz, the wavelength of the signal is

$\lambda = \frac{c}{f} = \frac{3 \times 10^8}{1000 \times 10^6} = 0.3\ m.$

The narrowband instantaneous power can be computed using

$|r(t)|^2 = \left|\sum_{i=0}^{N-1} a_i \exp(j\theta_i(t,\tau))\right|^2.$

Note that $-70\ dBm = 100\ pw$. At time $t = 0$, the phases of the multipath components are 0°, hence the instantaneous power is equal to

$|r(t)|^2 = \left|\sqrt{100\,pw} \times \exp(0) + \sqrt{50\,pw} \times \exp(0)\right|^2 = 291\ pw$

Now as the mobile moves, the phases of the two multipath components change in opposite directions.

At $t = 0.1$ s, the phase of the first component is

$\theta_i = \frac{2\pi d}{\lambda} = \frac{2\pi v t}{\lambda} = \frac{2\pi \times 10\ (m/s) \times 0.1 s}{0.3 m} = 20.94$ rad

Since the mobile moves towards the direction of arrival of the first component and away-from the direction of arrival of the second component θ_1 is positive and θ_2 is negative. Therefore, at $t=0.1s$, $\theta_1 = 120°$ and $\theta_2 = -120°$ and the instantenous power is equal to

$$|r(t)|^2 = \left|\sum_{i=0}^{N-1} a_i \exp(j\,\theta_i(t,\tau))\right|^2$$

$$= \left|\sqrt{100pw} \times \exp(j \times \tfrac{120}{360} \times 2\pi) + \sqrt{50pw}\, \exp\left(-j\,\tfrac{120}{360} \times 2\pi\right)\right|^2 = 78.2\ pw$$

Similarly, at $t=0.2s$, $\theta_2 = 240°$ and $\theta_2 = -240°$ and the instantenous power is equal to

$$|r(t)|^2 = \left|\sqrt{100pw} \times \exp\left(j\,\tfrac{240}{360} \times 2\pi\right) + \sqrt{50pw}\, \exp\left(-j\,\tfrac{240}{360} \times 2\pi\right)\right|^2 = 81.5\ pw$$

Similarly at $t=0.3s$, $\theta_1 = 360° = 0°$, $\theta_2 = -360° = 0°$ and the instantenous power is equal to

$$|r(t)|^2 = \left|\sqrt{100pw}\, \exp(j0) + \sqrt{50pw}\, \exp(-j0)\right|^2 = 291\ pw.$$

It follows that at $t=0.4s$ $|r(t)|^2 = 78.2\ pw$ and at $t=0.5$, $|r(t)|^2 = 81.5\ pw$.

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ii The average narrowband received power is equal to

$$\frac{2\times 291 + 2\times 78.2 + 2\times 81.5}{6} = 150.233\ pw$$

The wideband power is given by

$$E(P_{WB}) = \sum_{i=0}^{N-1} \overline{a_i} = 100pw + 50pw = 150\ pw$$

As can be seen, the narrowband and wideband received power are virtually identical.

2.c As $T_s = \frac{T_c}{2}$ and we use the smallest value of T_c

$$T_c = \frac{9}{16\pi f_m} = \frac{9\times\lambda}{16\pi V} = \frac{9\times 3\times 10^8}{16\pi V f_c} = \frac{27\times 10^8}{16\times 3.14\times 50\times 1900\times 10^6}$$

$T_c = 565\ \mu s.$

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Taking time samples at less than half T_c at $282.5\mu s$ corresponds to a spatial interval of

$$\Delta x = \frac{V T_c}{2} = \frac{50\times 565}{2} = 0.014125\,m = 1.41\,cm.$$

—///—

ii Therefore, the number of samples required over a 10m travel distance is

$$N_x = \frac{10}{\Delta x} = \frac{10}{0.014125} = 708 \text{ samples}$$

—///—

iii Time taken to make this measurement is equal to

$$\frac{10\,m}{50\,m/s} = 0.2s.$$

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iv The Doppler spread is

$$B_D = f_m = \frac{V f_c}{c} = \frac{50\times 1900\times 10^6}{3\times 10^8} = 316.66\ Hz$$

2.c $\bar{\tau} = \frac{1\times 0 + 1\times 1}{1+1} = \frac{1}{2} = 0.5\mu s$

$$\overline{\tau^2} = \frac{1\times 0^2 + 1\times 1^2}{1+1} = \frac{1}{2} = 0.5\mu s$$

$$\sigma_\tau = \sqrt{\overline{\tau^2} - (\bar{\tau})^2} = \sqrt{0.5-(0.5)^2} = \sqrt{0.25} = 0.5\mu s$$

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ii $\frac{\sigma_T}{T_s} \leq 0.1, \quad T_s \geq \frac{\sigma_T}{0.1} = \frac{0.5}{0.1}\mu s \Rightarrow T_s \geq 5\mu s$

$$R_s = \frac{1}{T_s} = 0.2\times 10^6 \text{ sps} = 200 \text{ ksps}, \quad R_b = 200 \text{ kbps}$$

3.a.i Shannon's ergodic capacity

$$C = \int_0^\infty B \log_2 (1+\gamma)\, p(\gamma) d\gamma$$

Jensen's inequality

$$E\left(B\log_2(1+\gamma)\right) = \int B \log_2 (1+\gamma)\, p(\gamma) d\gamma$$

$$\leq B \log_2\left(1 + E(\gamma)\right) = B\log_2(1+\bar{\gamma})$$

The capacity corresponding to the average SNR is the upper bound for the average capacity corresponding to time varying channel SNR.

//

3a.ii When receiving the signal with varying SNRs, γ_i, $i=1,\ldots,N$ if the distribution $p(\gamma_i)$, $i=1,\ldots,N$ is known we find the γ_0 value which satisfies the relationship

$$\sum_{\gamma_i \geq \gamma_0} \left(\frac{1}{\gamma_0} - \frac{1}{\gamma_i}\right) p(\gamma_i) = 1$$

when finding the solution we identify that for certain values of the relationship $\gamma_i > \gamma_0$ does not exist. These SNR values are not used to trasmit any signal hence transmission power for these is set to zero. New value for γ_0 is calculated to ensure that the remaining SNR values are greater than the threshold γ_0. The resultant γ_0 used to calculate the power allocations for different SNR values γ_i. This optimisation method shows that low SNR values need not be used by the transmission system.

3.a.iii) As the conclusion of 3.a.ii is that there is no need to use the channels with low SNRs, when we are are using the channel inversion method for power allocation we can ignore the low SNR channels. In this case we identify for which cut-off value γ_0 for the channel SNR.

We identify the value γ_0 which maximizes the capacity

$$C = B\log_2\left(1+\frac{1}{E_{\gamma_0}\left[\frac{1}{\gamma}\right]}\right)P(\gamma>\gamma_0)$$

in the equation both $E_{\gamma_0}\left[\frac{1}{\gamma}\right]$ and $p(\gamma>\gamma_0)$ decrease as γ_0 value is increased. But for a specific value of γ_0, the capacity is maximized. We usually identify this specific value to ensure that the truncated channel inversion method results in the average capacity which is close to the capacity corresponding to the average SNR.

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3.b) The system uses the channel energies

$$E(b_p) = \frac{2\sigma^2\Gamma}{h}\left(2^{b_p}-1\right)$$

for transmitting b_p bits over each channel. Number of channels K and the number of bits b_p per channel are used to test the inequality for a given total energy E_T

$$K\,E(b_p) \leq E_T < K\,E(b_{p+1})$$

The number K and the bit rate b_p satisfying the inequality are used to determine the data rate Kb_p over K channels.

3.b.ii A When transmitting over K channels at the bit rate b_p bits channel. We require the incremental energy equation

$$e_I(b_p) = \frac{\sigma^2\Gamma 2^{b_p}}{h}\left(2^{\beta_p}-1\right)$$

to transmit the data at b_{p+1} instead of transmitting b_p where we have an increase β_p bits over the given bit rate b_p. The term β_p is the bit granularity and the residual energy for K parallel channels is upper bounded by an amount

$$e_r(Kb_p) \leq K e_I(b_p)$$

From this equation we see that the number of channels influence the amount unused energy.

When having K parallel channels and having a residual energy $e_R(b_p)$, it might not be sufficient to put β_p bits per channel into all K parallel channels but it may be sufficient to put β_p bits to a given number of m channels.

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3b.ii.B A total of m channels can be used to transmit at the data rate b_{p+1} bits, and a total of $(K-m)$ channels can be used to transmit at the rate b_p bits per symbol. The number of channels, m, carrying the high data rate can be calculated from the inequality

$$m\,e(b_p) \leq E_T - K\,E(b_p) < (m+1)\,e(b_p)$$

3.b.iii A

$$E_b = \frac{2\Gamma\sigma^2}{h}\left(2^{b_p}-1\right)$$

$$b_p = [0.5,\ 1,\ 1.5,\ 2,\ 3]^T$$

Corresponding energies

$$E(b_p) = [0.012,\ 0.0289,\ 0.0529,\ 0.0867,\ 0.2024]^T$$

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B Incremental energies

$$e_I(b_p) = \frac{2\sigma^2 h\, 2^{b_p}}{h}\left(2^{\beta_p}-1\right)$$

$$\overline{e_I} = [0.0169,\ 0.0239,\ 0.0339,\ 0.1156]^T$$

—///—

3.b.iii C

$$15 \times 0.0867 \leq 3.0 < 15 \times 0.2024$$

$$1.3 \leq 3.0 < 3.036$$

hence we can carry 2 bits per symbol per channel.

A total of

$15 \times 2 = 30$ bits can be carried over a symbol period.

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D Residual energy is

$$3.0 - 1.3 = 1.6995$$

—///—

E Incremental energy test

$$14 \times 0.1156 \leq 1.6995 < 15 \times 0.1156$$

Residual energy

$1.6995 - 14 \times 0.1156 = 0.0811$. Hence the residual energy is reduced to 0.0811.

4.a.i A

MSC functions

- Paging
- Coordination of call set-up
- Dynamic allocation of resources
- Location registration
- IWF functions
- Handover management
- Billing of subscribers.
- Encryption management
- Frequency allocation management.

—///—

B

VLR procedures

- Authentication procedures
- Cipher key management and retriveal.
- Allocation of new TMSI numbers.
- Tracking of mobile states in its area.
- Paging procedure support.

—///—

4.a.i C

The HLR functions

- Tracks MSC number
- Tracks VLR number
- Keeps track of user data.
  - + IMSI number
  - + MSISDN number
  - + MS category information
  - + roaming restrictions
  - + Network access mode

—///—

4.a.ii Serving GPRS Support Node (SGSN) and Gatway GPRS Support Node (GGSN).

4.a.ii) SGSN information

Subscription information

IMSI
Temporary identity
PDP addresses.

Location Information

- The cell or the routing area where the MS is registered.
- VLR number.
- GGSN address of each GGSN for which an active PDP context exists.

—//—

Gateway GPRS Support Node

Subsription information

IMSI
PDP addresses

Location information

The SGSN address of the SGSN where the MS is registered.

The GGSN receives this information from the HLR and from the SGSN.

—//—

4.b) RANAP functions

- Iub transport resources management.
- Control of Node B logical operations
- System information management
- Traffic management of common channels.
- Macro diversity combining
- Allocation of DL channelization codes.
- Uplink overloop power control.
- Downlink power control.
- Admission control.
- Reporting management.

Examinations : Mobile Radio Communications Session *Confidential*
MODEL ANSWER and MARKING SCHEME
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Question labels in left margin Marks allocations in right margin

4.b.i) Node B functions

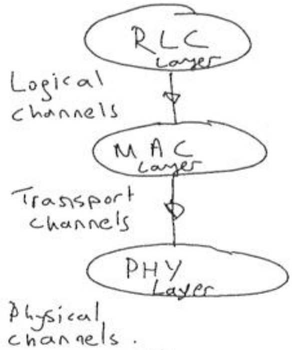
- Mapping of Node B logical resources onto hardware resources.
- Transmission of system information messages according to the RNC scheduling parameters.
- Macro diversity combining/splitting of data streams internal to Node B.
- Uplink inner loop power control.
- Reporting uplink interference measurement

—//—

4.b.ii) The RRC functions

- Initial cell selection and cell reselection.
- Broadcast of Information.
- Reception of paging messages.
- Establishment, maintenance and release of the RRC connections.
- Establishment, reconfiguration and release of radio bearers.
- Handover which includes the preparation and execution of Handovers and intersystem handovers.
- Measurement control
- Outer loop power control
- Security mode control
- Routing of higher layer PDUs
- Control requested QoS
- Support for DRAC, fast allocation of radio resources on the uplink DCH.
- Contention resolution in the TDD mode.
- Timing advance in the TDD mode.
- Management of CBS services.

4bii)



1/1

Logical Channels

Broadcast channels

- Downlink common channel
- Broadcast system and cell specific information

Paging Control channel

- Downlink channel.

Dedicated control channel

- Bidirectional point to point
- Transfers dedicated control information.

1/1

Shared Control Channel.

- Bidirectional
- Transfers control information for uplink & downlink.

4biii)

Transport channels

- Broadcast channel
- Paging channel
- Random access channel
- Common packet channel.
- Downlink shared channel.
- High speed downlink shared channel.
- Uplink shared channel.

///

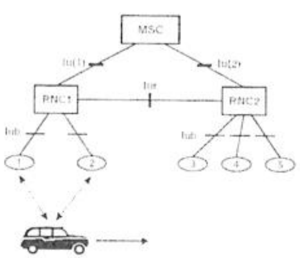
Physical channels

- synchronisation channel.
- Common pilot channel.
- Primary common control physical channel.
- Secondary common control physical channel.
- Paging indicator channel.
- Acquisition indicator channel.
- CPCH Access preamble Acquisition Indicator channel.
- CPCH Status indicator channel.
- High Speed Physical downlink shared channel.
- Shared control channel.

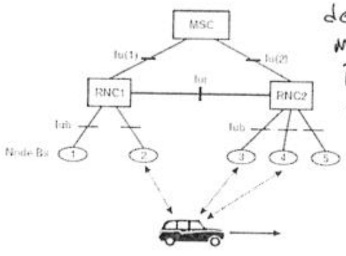
///

4c Handover descriptions.

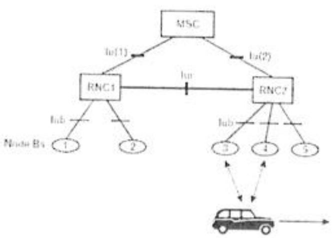
There may be two or more Node Bs are providing comparable transmission qualities. The RNC makes the decision in response from the UE and communicates with Node Bs to organise the transfer of use of resources from ~~one Node B to another~~ Node B.



If the UE requests the allocation of resources from another Node B connected to an RNC which is not controlling the current Node B communicating with the UE, the handover decision is then made by the MSC which controls the two RNCs. The calls are still routed to the current or the controlling RNC which is known as the serving RNC. The serving RNC relays the messages to the drift RNC where the packets are routed via appropriate node Bs to the UE.



Upon completion of link establishment between the Node B attached to the drift RNC and the UE, the link between the Node B attached to the serving RNC is released.



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4.C.ii)

Handover Procedure

- The on the GSM network requests a hadover,
- BSC initiates a handover request and sends it to the controlling MSC. The message used for this is the the handover request.
- The MSC, upon receiving the handover request message, ~~initiates relocation request message~~ and sends it to the SRNC.

4.C.ii continued

- The SRNC requests physical channels from the Node B.
- The Node B allocates the physical channels and informs the SRNC which channels will be available for the mobile.
- The SRNC sends this information in the "Relocation request acknowledgement" message to the MSC.
- MSC takes the channel information and puts into a handover-to-UTRAN" message which is encapsulated into a "handover command" message and transmits it to the base station controller who initiated the handover in the first place.
- The BSC transmits the handover-to-UTRAN message via the BTS to the mobile unit.
- The mobile identifies the channel information from the "handover-to-UTRAN" message and starts using the air interface over the UMTS system.
- When the Node B identifies successful packet transmission from the mobile, the node informs both the SRNC and MSC the the link has been set up.
- The MSC starts sending the information via the SRNC and Node B to the mobile unit and cancels the connections to the GSM system.