Bilkent University
Computer Engineering Department

CS 515
Mobile and Wireless Networking
Midterm Solution
Date: 29 November, 2002
Duration: 120 minutes

Name of the Student	
ID of the Student	

GRADE

1 – (30)	
2 – (10)	
3 – (5)	
4 – (11)	
5 – (9)	
6 – (10)	
7 – (10)	
8 – (10)	
9 – (5)	

Please try to write as clean as possible!

Good Luck!

Problem 1 (30 points)

Put a tick under T (True) or F (False) for each of the statements below. A correct answer will get **+2** points, a wrong answer will get **-1** points (.i.e two wrong answers will cancel a correct answer). Hence, there is a chance of getting a negative total grade if you mark without knowing the answers.

	Statement	T	F
a	Both TDMA and FDMA systems require digital modulation.		x
b	Cellular phones usually use higher data-rate speech coding than cordless phones because they are more complex.		x
c	GPRS and EDGE are examples of 2.5G networks and EDGE supports more data-rates than GPRS.	x	
d	Rayleigh fading is more likely to occur for low symbol-rate (narrowband) message signals compared to the high symbol-rate (wideband) message signals.	x	
e	Low-tier systems has usually lower user/system capacity in a region than high-tier systems.		x
f	RMS delay spread value is usually smaller in micro-cell environments compared to macro-cells.	x	
g	Fast fading occurs when the coherence time of the RF channel is smaller than the symbol period of the message.	x	
h	If a receiver station is stationary, then no small-scale fading occurs.		x
i	A periodic sinusoidal signal has larger spectral bandwidth than a periodic square wave signal.		x
j	Frequency selective fading does not cause inter-symbol interference.		x
k	Ricean fading occurs when there is one LOS component in a multipath channel.	x	
l	Amplitude modulation performs better in multipath environment than frequency modulation.		x
m	QPSK is more bandwidth efficient then BPSK.	x	
h	Adding error control codes on digital messages reduces the power efficiency of a modulation technique, because messages gets larger and we need to consume more energy.		x
o	CDPD is overlaid on AMPS US cellular telephone system.	x	

Problem 2 (10 point)

a) (4) If a mobile radio link operates with 30 dB SNR and uses 200 kHz RF channel for transmission, find the theoretic data-rate limit that can be transported over this channel

$30dB = 1000$

$$C = 200,000 \times \log_2(1 + \frac{S}{N}) = 200,000 x \log_2(1 + 1000) = 1,993,445 bps.$$

b) (3x2) A multi-path radio environment has an RMS delay spread (σ) value of 2μs.
   1. Find the 50% coherence bandwidth for the channel

$$\frac{1}{5\sigma} = 100 Kbps.$$

2. Can a GSM cellular system operate in this environment without needing an equalizer? (yes or no)

No, GSM requires 200Kbps RF channel bandwidth.

3. A signal that is to be transmitted over this channel has symbol-rate of 721 Kbps. Does signal experiences <u>flat fading</u> or <u>frequency selective fading</u> when transmitted over this multi-path channel.

Since the symbol rate is larger than the channel coherence bandwidth, the signal undergoes frequency-selective fading.

Problem 3 (5 points)

You are driving on a straight and endless Central-Anatolian highway with your car. Ahead of you, at the horizon, a policeman stands and points his radar to you and measures your speed. The radar he is using is working on Doppler shift principle at 900Mhz. It detects a frequency shift of 450 Hz in the reflected signal from your car compared to the transmitted signal. What is the speed of your car measured by the radar? Express you answer in <u>km/hour</u>.

$$f_d = \frac{v}{\lambda} \Rightarrow v = f_d \lambda = 450 x \frac{3x10^8}{900x10^6} = 450x0.33 = 148.5 m/s = 534.6 km/hour.$$

Problem 4 (11 points)

A macro-cell base station transmits at a power of 100 W at 1800 MHz. . A mobile receiver, that is traveling in a direction that makes 30 degrees angle with the direction of the received signals from the base station, measures the received   signal   strength as -53.9 dBm and reports this to the base station over a reverse channel. After 20 seconds later, the mobile again measures the received signal strength, this time as -51.97 dBm and reports it to the base station. Assume the 30 degrees angle nearly remains constant during the 20 seconds travel. Assume antenna gain of 1 for both receiver and transmitter antennas and assume free space propagation model (n = 2) between base station and mobile.

    a) (7)   What is the speed of the mobile expressed in <u>km/hour</u>?
    b) (4)   What is the Doppler shift experienced by the mobile?

    a)
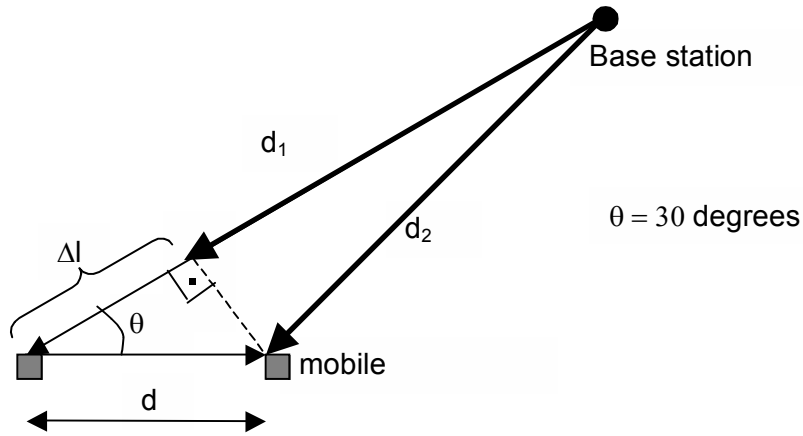
$$-53.8 dBm = 4.17x10^{-9}W = P_1$$

$$-51.97 = 6.35x10^{-9}W = P_2$$

$$P_1 = \frac{P_t x (0.166)^2}{(4\pi)^2 (d_1)^2} \Rightarrow d_1 = \sqrt{\frac{P_t x (0.166)^2}{(4\pi)^2 P_1}} = 2047m$$

$$P_2 = \frac{P_t x (0.166)^2}{(4\pi)^2 (d_2)^2} \Rightarrow d_2 = \sqrt{\frac{P_t x (0.166)^2}{(4\pi)^2 P_2}} = 1658m$$

$$\Delta l = d_1 - d_2 = 389m$$

$$d = \Delta l x \cos 30 = 449m$$

$$v = \frac{d}{\Delta t} = \frac{449}{20} = 22.45 m/s = 80.82 km/hour$$

  b) $f_d = \frac{v}{\lambda}\cos\theta = 117 Hz$

Problem 5 (9 points)

An FM modulator has a frequency deviation constant of 50Hz/V. The modulating signal is a sinusoid of amplitude 4V and frequency 1 kHz. The carrier signal has a carrier frequency of 100kHz and a constant amplitude of 40V.

a) (3) What is the peak frequency deviation?

$$\Delta f = 4Vx50Hz/V = 200Hz$$

b) (3) What is the modulation index?

$$\beta_f = \frac{k_f A_m}{f_m} = \frac{50x4}{1000} = 0.2$$

c) (3) Using Carson's rule, find the upper and lower bounds for the 98% required channel bandwidth (B$_T$) that can be used to transmit this signal.

$$B_T = 2(\beta_f+1)f_m = 2(0.2+1)1000 = 2400Hz$$
$$B_T = 2\Delta f = 2x200 = 400Hz$$
$$400Hz \le B_T \le 2400Hz$$

Problem 6 (10 points)

In a street micro-cell environment, a base station transmits at a power level of 1W at 900 MHz. The reference distance d_0 is 100m. For a mobile receiver that is moving along the street, the path loss exponent (n) is 2 between 100m and to a break-point distance. After that break-point distance, the path loss exponent (n) is 4. The mobile receiver measures the received power as -69.57 dBm at a distance of 1000 meters from the base station. What is the break-point distance at which the path loss exponent changes from 2 to 4 (Assume free space propagation model between transmitter and reference distance; assume antenna gains are 1).

P_t P_0 P_1 P_2

d_0=100m d_1 d_2=1000m

$$P_0 = \frac{1Wx(0.33)^2}{(4\pi)^2 100^2} = 6.9x10^{-8}$$
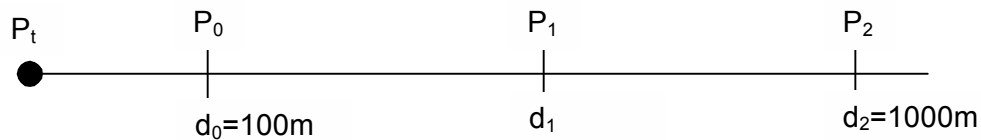
$$P_2 = -69.37 dBm = 1.1x10^{-10}$$

$$= \frac{P_0}{P_1} = \left(\frac{d_1}{d_0}\right)^2, \frac{P_1}{P_2} = \left(\frac{d_2}{d_1}\right)^4$$

$$\frac{P_0}{P_2} = \frac{P_0}{P_1} x \frac{P_1}{P_2} = \left(\frac{d_1}{d_0}\right)^2 x \left(\frac{d_2}{d_1}\right)^4 = \frac{d_2^4}{d_0^2 d_1^2}$$

$$d_1^2 = \frac{d_2^4}{d_0^2} x \frac{P_2}{P_0} = \frac{10^{12}}{10^4} x \frac{1.1x10^{-10}}{6.9x10^{-8}} = 399m.$$

Problem 7 (10 points)

	IS-95	GSM	IS-136	PDC
Uplink Frequencies (MHz)	824-849 MHz	890-915 MHz	824-849 MHz	810-826 MHz
Downlink Frequencies	869-894 MHz	935-960 MHz	869-894 MHz	940-956 MHz
Duplexing	FDD	FDD	FDD	FDD
Multiple Access	CDMA	TDMA with FDMA	TDMA with FDMA	TDMA with FDMA
Modulation	BPSK	GMSK	$\pi/4$ DQPSK	$\pi/4$ DQPSK
Channel Bandwidth	1.25 MHz	200 KHz	30 KHz	25 KHz
Channel Data Rate	1.228 Mbps	270.833 Kbps	48.6 Kbps	42 Kbps
Voice circuits per channel	64	8	3	3
Speech Coding	CELP at 13Kbps	RPE-LTP at 13 Kbps	VSELP at 7.95 Kbps	VSELP at 6.7 Kbps
Frequency Reuse Factor	1	1/3	1/4	1/4

Using the table above, compute the parameters asked in a) and b) for the following systems (Assuming that a user uses exactly one voice channel –or- circuit):
- IS-95 (USA CDMA based digital cellular system),
- GSM (European digital cellular system),
- IS-136 (USA TDMA based digital cellular system)
- PDC (Japanese digital cellular system).

a) (4) The <u>modulation bandwidth efficiency</u> of each system.

$$modulation\ bandwidth\ efficiency = \frac{Data\text{-}rate\,(R)(bps)}{Channel\,RF\,Bandwidth\,(B)(Hz)}$$

$$\eta_B(IS-95) = \frac{1.228 Mbps}{1.25 MHz} = 0.9824 bps/Hz$$

$$\eta_B(GSM) = \frac{270.833 Kbps}{200 KHz} = 1.354165 bps/Hz$$

$$\eta_B(IS-136) = \frac{48.6 Kbps}{30 KHz} = 1.62 bps/Hz$$

$$\eta_B(PDC) = \frac{42 Kbps}{25 KHz} = 1.68 bps/Hz$$

b) (6) <u>System capacity</u> of each system normalized to GSM system capacity. (Assume the range of a cell is same for all systems). (By normalized I mean: you will take the system capacity of GSM as 1 and express the system capacity of other systems with respect to this).

With the given information, the followings are the parameters that affect the system capacity:
1. Number of RF channels that can be supported in the allocated spectrum (This depends on the RF channel bandwidth of a system and the allocated spectrum width for the system)
2. The number users that can be supported in an RF channel
3. The frequency reuse factor.
All of these factors are **directly** proportional with the system capacity.

A. Let GSM system capacity be **1**.
   GSM has 25MHz simplex spectrum width.
   GSM can support 125 RF channels in this spectrum width (200KHz per RF channel required)
   GSM can support 8 users in an RF channel using TDMA
   GSM frequency re-use factor is 1/3

B. IS-95
   IS-95 has 25MHz simplex spectrum width
   IS-95 can support 20 RF channels in this spectrum
   IS-95 can support 64 users in an RF channel using CDMA.
   IS-95 frequency re-use factor is 1.

   Hence, IS-95/GSM = (20/125)x(64/8)x(1/(1/3))= **3.84**
C. IS-136
   IS-136 has 25MHz simplex spectrum width
   IS-136 can support 833 RF channels in this spectrum
   IS-136 can support 2 users in an RF channel using TDMA.
   IS-136 requency re-use factor is 1/4.

   Hence, IS-136/GSM = (833/125)x(3/8)x((1/4)/(1/3))= **1.87**
D. PDC
   PDC has 16MHz simplex spectrum width
   PDC can support 640 RF channels in this spectrum
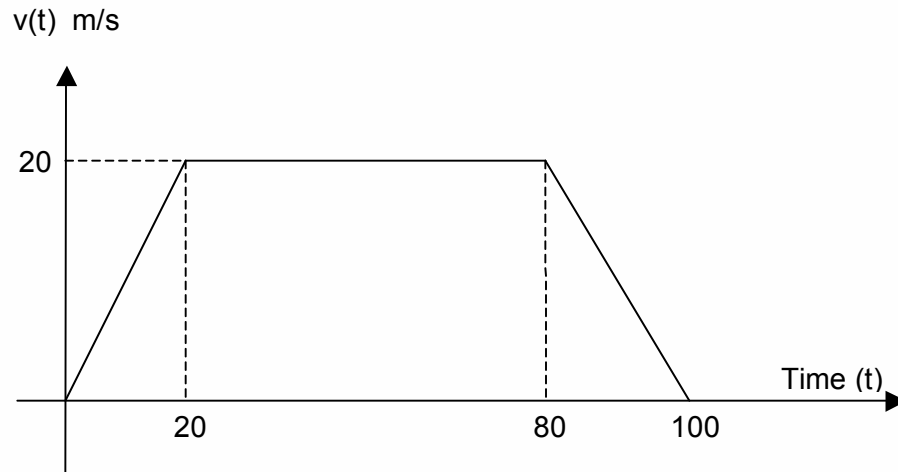   PDC can support 3 users in an RF channel using CDMA.
   PDC frequency re-use factor is 1/4.

   Hence, PDC/GSM = (640/125)x(3/8)x((1/4)/(1/3))= **1.44**

Problem 8 (10 points)

v(t) m/s

A car is traveling along a street with velocity v(t) as shown in the figure. The received signal experiences multi-path Rayleigh fading on a 900 MHz CW (continues wave) modulated carrier. Assume ρ=0.1 and ignore large-scale fading affects.

a) (5) What is the average level crossing rate over the 100s interval?
b) (5) What is the average fade duration over the 100s interval?

a)

$$N_R = \sqrt{2\pi}\, f_m\, \rho e^{-\rho^2}$$

$$f_m = \frac{v(t)}{\lambda}$$

$$N_R(t) = \sqrt{2\pi}\, \frac{v(t)}{\lambda}\, \rho e^{-\rho^2}$$

$$avg(N_R) = \frac{\displaystyle\int_0^T N_R(t)\,dt}{T} = \frac{1}{100}\int_0^{100}\sqrt{2\pi}\,\frac{v(t)}{\lambda}\,\rho e^{-\rho^2}\,dt = \frac{\sqrt{2\pi}}{\lambda}\,\rho e^{-\rho^2}\,\frac{\displaystyle\int_0^{100} v(t)\,dt}{100}$$

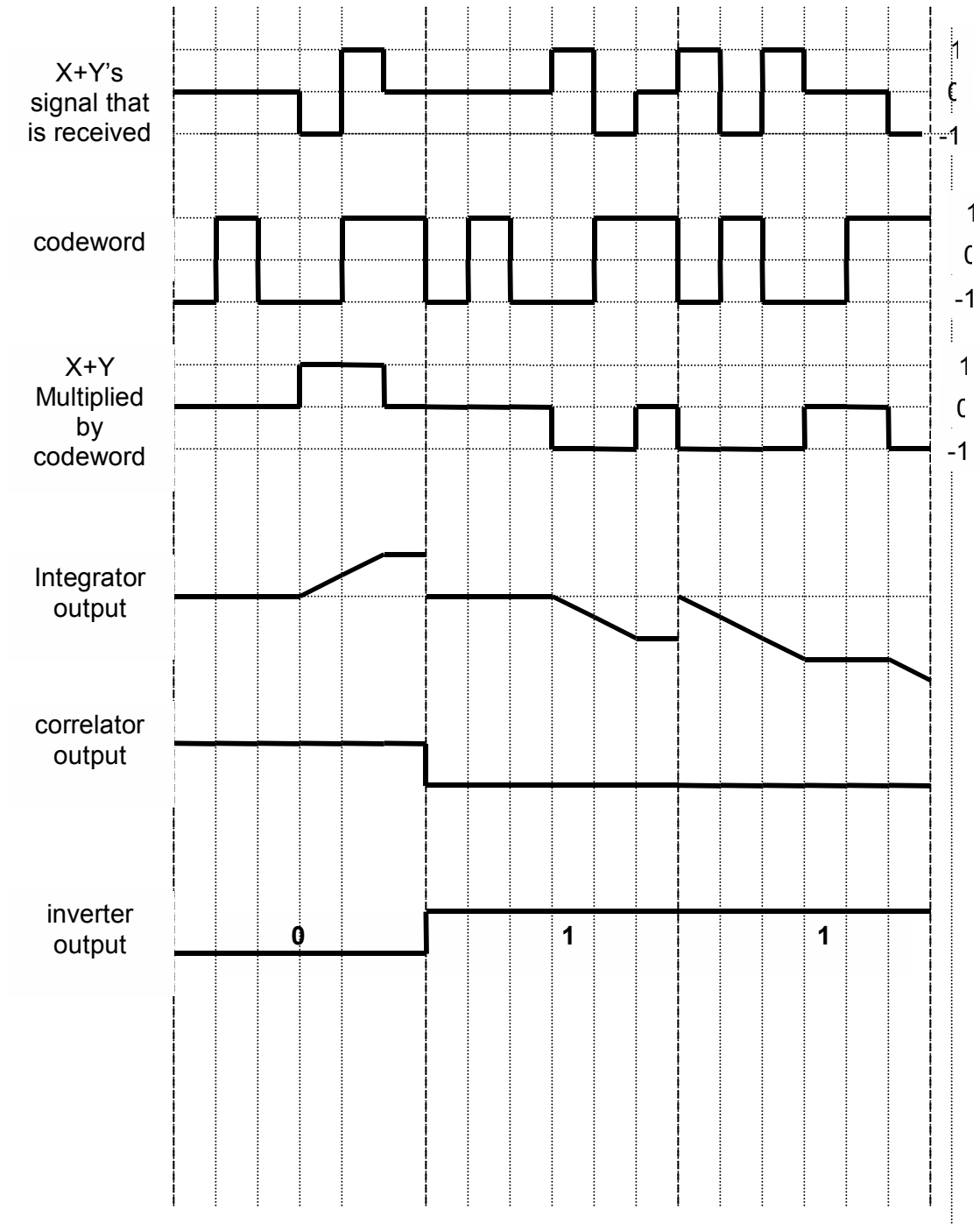$$= \frac{\sqrt{2\pi}}{\lambda}\,\rho e^{-\rho^2}\,\frac{\displaystyle\int_0^{100} v(t)\,dt}{100} = 0.75x16 = 12 = avg(N_R)$$

b)

$$\bar{\tau} = \frac{1}{N_R}\Pr(r \le R) = \frac{1}{N_R}(1 - e^{-\rho^2})$$

$$\bar{\tau} = \frac{1}{20}(1 - e^{-0.1^2}) = 5x10^{-4}\,s = 0.5ms$$

9

Problem 9 (5 points)

Two mobiles, X and Y, are transmitting concurrently using code division multiple access (CDMA) technique. A receiver hearing both of these transmissions, receives the combined signal X+Y and uses CDMA technique to despread it and obtain the original message signal (data bits) of mobile X. The receiver has the <u>codeword</u> of X as **010011.** Obtain the data bits (message signal) that is transmitted from X.

X+Y's signal that is received

codeword

X+Y Multiplied by codeword

Integrator output

correlator output

inverter output

0   1   1

Write down your answer for this question here: **0 1 1**