1. (a) The error symbol probability of a DPSK system can be expressed as $\frac{1}{2}e^{-SNR}$. The system employs a receiver combining technique.

(i) Maximal Ratio Combining (MRC) and Equal Gain Combining (EGC) are two possible receiver combining techniques. Briefly describe the difference between the basic designs of the MRC and the EGC techniques.

Answer 1 (a) (i) Maximal Ratio Combining : the technique multiply the conjugate of the channel gain to each of the diversity signal. Make the signal to noise rate of the combining signal to the max.

Equal Gain Combining: Multiply the $e^{-j\phi_i}$ phase correction factor to each diversity signal and add them together. The computational complexity is much lower than MRC but performance is similar.

$$MRC = \sum_i A_i e^{-j\phi_i} r_i(t)$$

$$EGC = \sum_i e^{-j\phi_i} r_i(t)$$

(ii) Suppose MRC is now used as the receiver combining technique. The possible signal-to-noise ratio (*SNR*) values at the MRC output are as given in Table 1 below. Determine the average symbol error probability of this receiver.

Table 1

SNR	**Probability**
12 W	1/9
14 W	4/9
16 W	4/9

Answer (ii)

$$\overline{P_s} = \frac{1}{2}e^{-12} \times \frac{1}{9} + \frac{1}{2}e^{-14} \times \frac{4}{9} + \frac{1}{2}e^{-16} \times \frac{4}{9} \approx 5.51 \times 10^{-7}$$

(iii) The *SNR* of the Alamouti code can be expressed as,

$$\gamma_A = \left(\frac{T}{K \times N}\right)\gamma_{MRC}$$

where γ_{MRC} is the *SNR* of MRC, and *T*, *K*, and *N* are the number of channels, symbols, and transmit antennas of the Alamouti code, respectively. Using this formula, compare the *SNR* between MRC and the Alamouti code.

Answer: (iii) For the Alamouti code, $T=2$ $K=2$ $N=2$

$$\gamma_A = \frac{2}{2 \times 2} \cdot \gamma_{MRC}$$

$$\gamma_A = \frac{1}{2}\gamma_{MRC}$$

The SNR of Alamouti code is a half of the MRC

(b) For flat fading channels, the received signal component vector, $\mathbf{y}$, of a Multiple-Input-Multiple-Output (MIMO) system can be represented by,

$$\mathbf{y} = \mathbf{H}\mathbf{x}$$

where $\mathbf{x}$ is the transmitted signal vector and $\mathbf{H}$ is the channel matrix.

(i) Consider a 2 × 2 MIMO system. Denoting the transmitted signals as x_1, x_2, the received signal components as y_1, y_2, and the channels linking x_i to y_j as $h_{i,j}$, express the equation above as two simultaneous equations.

Answer (i)
$$\begin{pmatrix} y_1 \\ y_2 \end{pmatrix} = \begin{pmatrix} h_{11} & h_{21} \\ h_{12} & h_{22} \end{pmatrix} \begin{pmatrix} x_1 \\ x_2 \end{pmatrix}$$

$$y_1 = h_{11}x_1 + h_{21}x_2$$
$$y_2 = h_{12}x_1 + h_{22}x_2$$

(ii) By performing singular-value-decomposition (SVD), the channel matrix $\mathbf{H}$ can be represented by,

$$\mathbf{H} = \mathbf{U}\boldsymbol{\Sigma}\mathbf{G}^H$$

where $\mathbf{U}$ and $\mathbf{G}$ are unitary matrices and $\boldsymbol{\Sigma}$ is a matrix with singular values. If the received signal component is now $\mathbf{HGx}$, suggest how this signal can be processed to make the receiver output signal component equal to $\boldsymbol{\Sigma}\mathbf{x}$.

Answer: (ii) $r = HGx = U\Sigma G^H G x = U\Sigma x \quad (GG^H = I)$

In order to get Σx, we need to multiply H^T to $r \rightarrow H^T r$

$\because H^T H = I \quad \therefore H^T r = H^T H \Sigma x = \Sigma x$

(iii) If the channel is now a frequency selective fading channel with a memory of 4 past symbols, what would the equation, $\mathbf{y} = \mathbf{Hx}$, become? Explain your answer.

Answer (iii) The channel gain of a frequency selective channel can be seen as a FIR Filter Matrix

$$y(n) = \sum_{l=0}^{3} H_l x(n-l)$$

3. (a) A mobile radio system receives the same transmitted signal from two additive white Gaussian noise (AWGN) channels. The signal powers of the two received signals are given as,

$$P_{r,1} = P_a + N_1$$

$$P_{r,2} = P_a + N_2$$

where P_a is the average power of the transmitted signal, and N_1 and N_2 are the two noise powers with zero mean and variance σ^2 each. Outage is considered to have occurred when both $P_{r,1}$ and $P_{r,2}$ fall below P_m, where P_m is the minimum acceptable received signal power.

(i) If N_1 and N_2 are statistically independent, express the outage probability in terms of $P_{r,1}, P_{r,2},$ and P_m.

Answer (i) $P_{out} = P\{P_{r,1} < P_m,\ P_{r,2} < P_m\} = P\{N_1 < P_m - P_a,\ N_2 < P_m - P_a\}$

$\because$ N_1 and N_2 are independent. $\therefore$ $P_{r,1}$ and $P_{r,2}$ are independent

$\therefore P_{out} = P\{P_{r,1} < P_m\} P\{P_{r,2} < P_m\}$

(ii) Derive the Q-function expression of the outage probability of this system.

Answer: (ii) $N_1 \sim N(0, \sigma^2)$ $N_2 \sim N(0, \sigma^2)$

$P_{out} = P\{P_a + N_1 < P_m\} \cdot P\{P_a + N_2 < P_m\}$

$= P\{N_1 < P_m - P_a\} \cdot P\{N_2 < P_m - P_a\}$

$= \left(1 - Q\left(\frac{P_m - P_a}{\sigma}\right)\right)\left(1 - Q\left(\frac{P_m - P_a}{\sigma}\right)\right)$

$= \left[1 - Q\left(\frac{P_m - P_a}{\sigma}\right)\right]^2 = Q^2\left(\frac{P_a - P_m}{\sigma}\right)$

(iii) If $P_a = 1.5$, $P_m = 1$, and $\sigma^2 = 0.25$, determine the value of the outage probability using the Q-function Table provided.

Answer: (iii) $P_{out} = Q^2\left(\frac{P_a - P_m}{\sigma}\right) = Q\left(\frac{0.5}{\sqrt{0.25}}\right) = Q(1) \approx 1.587 \times 10^{-1} = 15.87\%$

2021 - 2022

3. (b) An analog FDMA cellular system is configured with a cluster size of 7 with the allocated system bandwidth of 12.5 MHz. Two guard spacings of 10 kHz at the edge of the allocated bandwidth is used to protect it from the presence of interference. The number of channels allocated for control signalling for the Base Station (BS) and the Mobile Station (MS) is 21. Assume that each of the cell area is 6 km^2. Determine the following:

(i) the number of available channels per cluster

Answer 3 (b) (i) $B_w = 12.5$ MHz $B_g = 10$ kHz $\times 2 = 20$ kHz

The total number of channels per cluster is $\frac{B_w}{B_s} = \frac{12.5 \times 10^6}{20 \times 10^3} = 625$

(ii) the number of channels available for user data transmission

Answer: (ii) The number of signaling control channels is 21

The number of data transmission channels is $625 - 21 = 604$

(iii) the number of channels available for user data transmission per cell if the cluster size or frequency reuse factor is 7

Answer: (iii) The number of data transmission channels per cell is $604/7 \approx 86$

(iv) the overall system spectral efficiency in channels/MHz/km^2.

Answer: (iv) The modulation system spectral efficiency is $\eta_m = \frac{625-21}{12.5 \times 6 \times 7} \approx 1.15$ channels/MHz/km^2

The multiple access spectral efficiency is $\eta_a = \frac{20 \text{ kHz} \times (625-21)}{12.5 \text{ MHz}} = 0.9664$

The overall spectrum efficiency is $\eta = \eta_m \cdot \eta_a = 1.11$ channels/MHz/km^2

2021 - 2022

4\. (a) A cellular service provide deploys 210 cells in an area of 2100 km^2, where it has 30% market penetration rate. The system uses a cluster size of 7 and a total of 420 simplex channels. The system uses a fixed channel assignment, blocked calls cleared scheme and omni-directional antennas at the base station. The population density of the service area is 73 per km^2 and the average traffic load needed by each user is 0.1 Er.

(i) Determine the number of trunk channels per cell.

Answer 4 (a) (i) There are total 420 simplex channels per cluster which mean 210 duplex channels per cluster

The number of trunk channels in a cell is $210/7 = 30$

(ii) Determine the traffic load per cell that needs to be offered by the system.

Answer: (ii) The size of a single cell is $\frac{2100\ km^2}{210} = 10\ km^2$

The population per cell is $73 \times 10 = 730$

The subscribers per cell are $730 \times 30\% = 219$

The traffic load per cell is $219 \times 0.1 = 21.9$ Erlang

(iii) Determine the amount of traffic blocked (Erlangs) for the service area.

Answer: (iii) The traffic load of the service area is $21.9 \times 210 = 4599$ Erlangs

$N_{ch} = 30$ offered traffic load 21.9 Erlangs

According to Erlang B table, the $P_B = 2\%$ So the blocked traffic is $4599 \times 2\% \approx 91.98$ Erlangs

(iv) Suppose the service provider decides to use the block call delayed scheme instead of the block call cleared scheme. Explain one advantage and one disadvantage of this change from the user's perspective. Justify your answer.

Answer: (iv) Numbers of channels per cell is 30

Offered traffic per cell is 21.9 Erlangs

When applying the blocked call clear scheme, according to the Erlang B table, the $P_B = 2\%$

When applying the blocked call delay scheme, according to the Erlang C table, the $P_D = 7\%$

The advantage of this change is that there will barely no call be blocked after waiting for a certain amount of time.

The disadvantage of this change is that the probability of successfully making a phone call without any delay or block is dropping from 98% to 93%.

2021 - 2022

4 (b) Considering a typical cellular system with the service area partitioned into clusters with each cell having a BS serving the MS. There are four other basic components in a typical cellular network system besides the "MS" and the "BS". Explain the functions of these four components and sketch the block diagram to show how all these components function as a cellular network system.

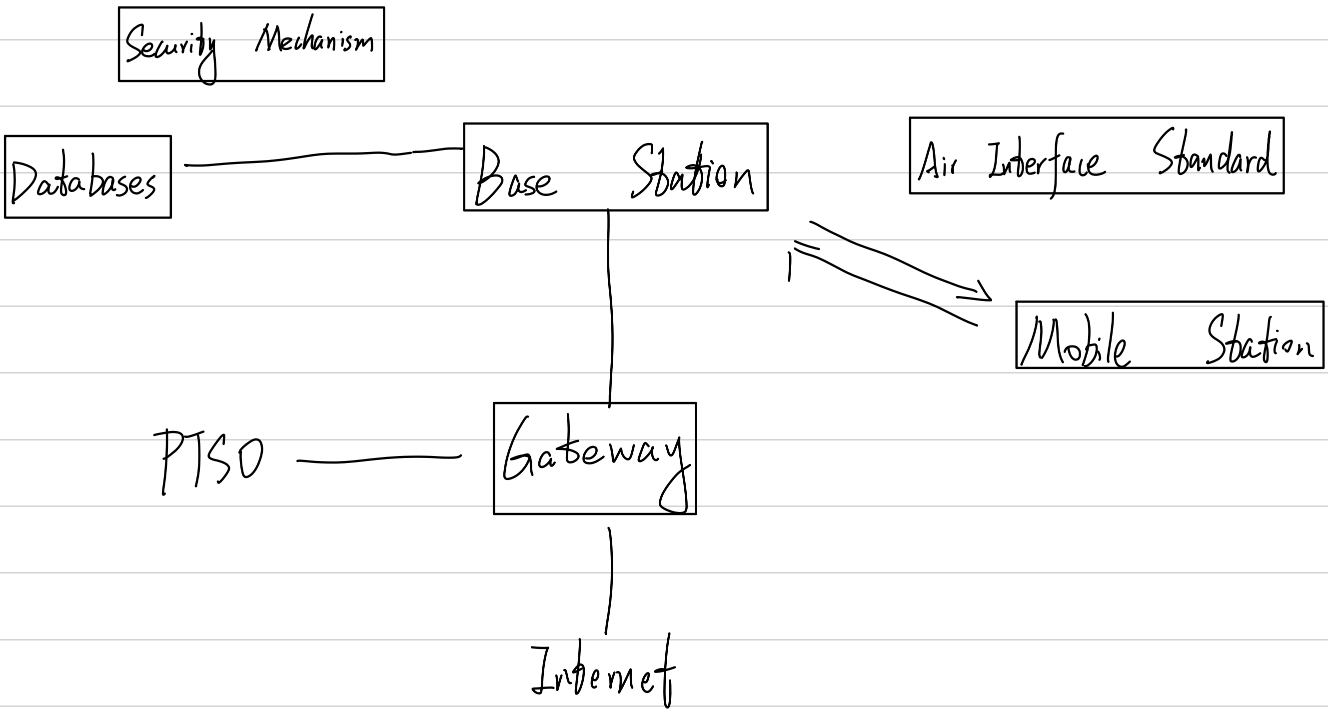
Answer (b) 1. Gateway 2. Databases 3. Air interface standard 4. Security mechanism

1. Gateway: to connect the Radio access network with the wireline network, as well as connect the cellular system with the PTSO

2. Databases: store the necessary access data and user information.

3. Air Interface Standard: Define the protocols and rules how the Mobile station and base station communicate in the wireless channels.

4. Security mechanism: protect the integrity and privacy of the users' data as well as the security of the system.



2021 - 2022

5. (a) One of the upgrades of the air interface for the Long-Term Evolution (**LTE**) 4th generation wireless systems is the provision of Evolved Universal Terrestrial Radio Access (E-UTRA). Describe the four key features of E-UTRA designed for the LTE wireless networks.

Answer: 5 (a) Scalable bandwidth: LTE supports scalable bandwidth from 1.4 MHz to 20 MHz for a physical channel.

High data rate: The peak data rate in the downlink can reach up to 300 Mbps when 4 by 4 MIMO is used.

The uplink peak data rate can be as high as 86 Mbps.

High mobility: LTE is designed to optimize for low mobile speed up to 15 km/h

It supports up to 350 or even 500 km/h

Scalable Coverage: The radio coverage ranges from femtocells to 100 km cells.

(b) For terrestrial cellular systems there are two types of handovers. Describe the basic mechanisms of these two handovers and identify the type of cellular systems that deploys this mechanism.

Answer (b) There are two types of handover: Hard Handover and Soft Handover.

Hard Handover: Break the the connection from previous base station before establish a new connection to a new base station. It is used in GSM and early 3G systems.

Soft Handover: Establish the connection to a new base station before break the connection from the previous base station. This type of handover is common in CDMA - based systems such as UMTS and CDMA2000.

(c) In a satellite system with Medium Earth Orbit (MEO) or Low Earth Orbit (LEO) satellites, there could also be handovers in the system if the satellite acts as a base station. Briefly describe the different types of handovers that can happen for this type of satellite system.

Answer (c) Intra-Satellite Handover: The UE moves from one service area to another service area within a satellite coverage zone.

Inter - Satellite Handover: The UE moves from one satellite coverage zone to another.

Gateway Hand over: The satellite moves out of the range of ground station.

Intra-satellite handovers: caused by the movement of mobile users within the coverage zone of a satellite over different sectors.

Inter-satellite handovers: caused by the movements of mobile users between the coverage zones of 2 satellites or satellite moves away.

Gateway handovers: the satellite moves away from the current gateway.

Inter-system handovers: handovers between a satellite system and a wireless system. Due to the signal strength and QoS performance.