1.

(a) A wireless channel can be modelled using a simplified path loss model, or a model incorporating the effect of shadowing, or a more complex fading model, depending on the types of the channels assumed.

(i) The path loss model that includes shadowing can be expressed as,

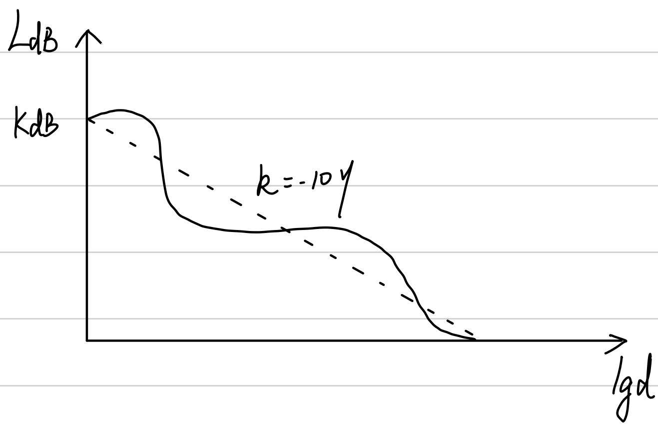
$$P_r = P_t K(d)^{-\gamma}\psi$$

where P_r and P_t are the received and transmitted signal power respectively, d is the distance between the transmitter and the receiver, K is a constant, γ is the path loss exponent, and ψ is a random variable due to shadowing. Convert this model into the dB form and use it to sketch a graph of path loss (in dB) versus distance (in dB) and indicate how K_{dB} and γ fit in the graph.

Answer 1i) $10\lg P_r = 10\lg P_t + 10\lg K - 10\gamma\lg d + 10\lg\psi$

$$10\lg\left(\frac{P_r}{P_t}\right) = K_{dB} - 10\gamma\lg d + \psi_{dB}$$

$$L_{dB} = K_{dB} - 10\gamma\lg d + \psi_{dB}$$



(ii) For the model described in part (a)(i) above, if the mean value of $P_{r,dB}$ is 10 dB higher than the minimum received signal power needed for non-outage, determine the maximum value of the variance of ψ_{dB} that will result in an outage probability lower than 1%.

Answer 1ii) $x = P_{model} - P_{min} = 10\text{ dB}$

$$P_{out} = Q\left(\frac{x}{\sigma_\psi}\right) < 1\%$$

$$\frac{x}{\sigma_\psi} > 2.33$$

$$\sigma_\psi < \frac{10}{2.33} \approx 4.29$$

$$\sigma_\psi^2 = 18.4$$

(iii) A signal, $s(t)$, with a symbol duration of 1 ms, is transmitted through a fading channel. The channel has a time invariant channel impulse response and a rms delay spread of 0.01ms. What is the fading type of this channel? Explain your answer.

Answer: (iii) $\sigma_D = 0.01$ ms $T_s = 1$ms

$T_s = 100\,\sigma_D$

The symbol duration is much greater than the delay spread, so this is Flat Fading.

(iv) Consider the Rayleigh fading channel. At an outage probability of ε, the outage capacity per Hz of the channel can be expressed as

$$C_\varepsilon = log_2\left[1 + \bar{\gamma}_R ln\left(\frac{1}{1-\varepsilon}\right)\right]$$

where $\bar{\gamma}_R$ is the average signal to noise ratio for the fading channel. Determine the fade margin at an outage probability of 0.1%.

(12 Marks)

Answer (iv) for the AWGN channel the channel capacity is

$$C = B\log_2(1+\gamma_0)$$

Channel capacity per Hz $\log_2(1+\gamma_0)$

To acheive the same capacity performance in fading channel.

$$\log_2(1+\gamma_0) = \log_2\left(1+\bar{\gamma}_R \frac{1}{\ln(1+\varepsilon)}\right)$$

$$\gamma_0 = \bar{\gamma}_R \ln\left(\frac{1}{1-\varepsilon}\right)$$

$$\frac{\bar{\gamma}_R}{\gamma_0} = \frac{1}{\ln\left(\frac{1}{1-\varepsilon}\right)}$$

When $\varepsilon = 0.1\%$

Fading margin $\bar{\gamma}_{R\,dB} - \gamma_{0\,dB} = 10\ln\left(\frac{1}{\ln\left(\frac{1}{1-\varepsilon}\right)}\right) \approx 69.07$ dB

(b) Diversity techniques can be used to lower the outage probability of a wireless system operating in a fading channel.

(i) A Differential Phase Shift Keying (DPSK) system uses a 2-branch Selection Diversity (SD) scheme to mitigate fading. The signal to noise ratio (*SNR*) of the received signal for each branch is assumed to be a discrete random variable with the following distribution:

$$\begin{cases} 10 \text{ dB with a probability of } 0.2 \\ 12 \text{ dB with a probability of } 0.8 \end{cases}$$

Determine the average *SNR* in dB of the received signals and the average symbol error probability of the SD scheme. Note: Symbol error probability of DPSK is $\frac{1}{2}e^{-SNR}$.

Answer: b(i) $\bar{\gamma} = 10 \times 0.2 + 12 \times 0.8 = 11.6$ dB

$$\gamma_{\Sigma} = \begin{cases} 10 \text{ dB} & 0.04 \\ 12 \text{ dB} & 0.96 \end{cases}$$

$$\bar{P}_s = \frac{1}{2} e^{-10^{1}} \times 0.04 + \frac{1}{2} e^{-10^{1.2}} \times 0.96 \approx 9.71 \times 10^{-7}$$

(ii) Briefly describe the basic principle of the spatial multiplexing scheme and the mathematical relationship between the number of transmit antennas and the number of receive antennas for the scheme. For a MIMO system with 3 transmit antennas and 5 receive antennas, find the maximum possible multiplexing gain.

Answer (ii) N data symbols are transmitted over N transmit antennas, enhance the transmission data rate by N times.

Multiplexing Gain $\leq \min(N_t, N_r)$

max Multiplexing Gain $= \min(3,5) = 3$

(iii) A Space-Time Block Coding system uses 2 transmit antennas and 2 time slots to transmit 2 complex symbols, s_1 and s_2. The code can be represented by the matrix

$$\mathbf{X} = \begin{pmatrix} s_1 & -s_2^* \\ s_2 & s_1^* \end{pmatrix}$$

where s_1 and s_1 are the two transmitted symbols, and s_1^* and s_2^* are the complex conjugates of s_1 and s_1 respectively. Show that this is or is not an orthogonal space time block code.

Answer iii) $X = \begin{pmatrix} S_1 & -S_2^* \\ S_2 & S_1^* \end{pmatrix}$ $X^H = \begin{pmatrix} S_1^* & S_2^* \\ -S_2 & S_1 \end{pmatrix}$

$$X X^H = \begin{pmatrix} S_1^2 + S_2^2 & S_1 S_2^* - S_2^* S_1 \\ S_2 S_1^* - S_1^* S_2 & S_2^2 + S_1^2 \end{pmatrix} = (S_1^2 + S_2^2) \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}$$

$$X X^H = \|S\|^2 I$$

∴ This is an orthogonal space time block code.

(iv) Does the Alamouti code have diversity gain? Explain your answer.

Answer: (iv) The Alamouti code transmits symbols in 2 independent fading path
Use the linear combination to combine the symbols, exploit the orthogonality of the code.
So the Alamouti code have diversity gain.

2.

(a) The discrete time representation of the received signal, $\{r[i], i = 1,2, \ldots\}$, at the output of an Additive White Gaussian Noise (AWGN) Inter-Symbol-Interference (ISI) channel can be expressed as,

$$r[i] = \sum_{n=1}^{3} h[n]m[i-n+1] + w[i]$$

where $m[k]$ is the k^{th} transmitted symbol which is assumed to be equally likely to be -1 or 1, $h[n]$ is the n^{th} component of the sampled channel impulse response, and $w[i]$ is the i^{th} sample of the AWGN with zero mean and a variance of 0.3.

(i) Explain how the discrete time representation above shows that ISI is present.

Answer: (i) the presentation shows that different time stamp $W[i]$ is added together to get the out put $r[i]$

$h[1]\, m[i] + h[2]\, m[i-1] + h[3]\, m[i-2]$

(ii) If the Z-transform of the channel is, $H(Z) = 1 + 0.6Z^{-2}$, determine all non-zero values of $h[n]$.

Answer: (ii) $h[n] = \delta[n] + 0.6\,\delta[n-2]$

(iii) The received signal is processed by a linear filter which has a Z-transform of

$$C(Z) = 1 - 0.6Z^{-2}.$$

The output of the filter is used as the decision variable for detecting $m[i]$. Derive the decision rule.

Answer: (iii) $c[n] = \delta[n] - 0.6\,\delta[n-2]$

$w'[i] = w[i] - 0.6\, w[i-2] \sim N(0, 0.408)$

$H(z) = 1 + 0.6z^{-2} \qquad C(z) = 1 - 0.6z^{-2}$

$H(z) \cdot C(z) = 1 + 0.6z^{-2} - 0.6z^{-2} - 0.36z^{-4} = 1 - 0.36z^{-4}$

$r'[i] = m[i] - 0.36\, m[i-4] + w'[i]$

$\because m[i] = \pm 1 \quad p(1) = p(-1) = \frac{1}{2} \qquad w'[i] \sim N(0, 0.408)$

$\therefore$ Decision Rule

$r'[i] > 0 \qquad m[i] = 1$

$r'[i] \le 0 \qquad m[i] = -1$

(iv) Using the decision rule, determine the average probability of bit error of this system.

Answer: (iv) $P_e = P[r'[i] < 0 \mid m[i] = 1] = P[1 - 0.36\, m[i-4] + w'[i] < 0]$

$= P[w'[i] < 0.36\, m[i-4] - 1]$

$= \frac{1}{2} Q\left(\frac{1-0.36}{\sqrt{0.408}}\right) + \frac{1}{2} Q\left(\frac{1+0.36}{\sqrt{0.408}}\right)$

(b) A wireless system operates with a bandwidth of 1 MHz and implements an OFDM scheme with N sub-carriers. The fading channel has a coherence bandwidth of 500 kHz and a sampled channel impulse response of $\{1, -0.6,\ 0.2\}$.

(i) Determine the value of N if the bandwidth of each OFDM sub-carrier is to be half of the coherence bandwidth.

Answer: (b) (i) $B_W = 1\times10^6\ Hz$ $B_C = 500\ kHz$ $B_S = \frac{1}{2}B_C = 250\ kHz$

$N = \frac{B_W}{B_S} = \frac{1\times10^6\ Hz}{250\times10^3\ Hz} \approx 4$

(ii) Determine the channel gain coefficient values for the N sub-channels.

Answer: (ii) $h[n] = \{\overset{0}{1}, \overset{1}{-0.6}, \overset{2}{0.2}, \overset{3}{0}\}$

$H[k] = \sum_{n=0}^{3} h[n]\, e^{-j\frac{2\pi kn}{N}} = \sum_{n=0}^{3} h[n]\, e^{-j\frac{\pi}{2}kn}$

$H[0] = \overset{0}{1} \overset{1}{-0.6} \overset{2}{+0.2} = 0.6$

$H[1] = 1 + (-0.6)(-j) + 0.2(-1) = 0.8 + 0.6j$

$H[2] = 1 + (-0.6)(-1) + 0.2\cdot(1) = 1.8$

$H[3] = 1 + (-0.6)j + 0.2(-1) = 0.8 - 0.6j$

(iii) Using the simplified formula, $T = \frac{1}{B}$, where T is the signal symbol duration and B is the signal bandwidth, determine the total OFDM block duration if a Guard interval of 1 microsecond is added.

Answer: (iii) $T_s = \frac{1}{B_S} = 4\ \mu s$

$T_G = 1\ \mu s$

$T = T_G + T_S = 1\mu s + 4\mu s = 5\mu s$

(iv) For the question in 2(b) part (iii) above, determine the power loss due to the addition of the guard interval.

Answer: Power Loss: $L = \frac{T_G}{T} = \frac{1}{5} = 20\%$

2023 - 2024

3. (a) A heavily populated small island has a user density of 720 users per km^2 for the service area. The operator A decides to select a cellular system that has a cluster size $N_c = 7$ and a total of 399 duplex traffic channels. The system uses a fixed channel assignment, blocked calls cleared scheme and omni-directional antennas at the base station (BS). During the busy hour, on the average, a user generates 0.9 call with a holding time of 90 seconds. The expected Grade of Service (GOS) is given by 1% blocking probability. The service area will be covered by hexagonal cells with radius R. Note: The area of each hexagonal cell is $A_{ce} = \frac{3\sqrt{3}}{2} R^2$. State and justify any necessary assumptions.

(i) Determine the number of channels per cluster and the offered traffic supported by the GOS.

Answer (i) There are 399 channels per cluster.

There are $399/7 = 57$ channels per cell

GoS: $P_b = 1\%$

According to the blocked call clear scheme, we should look up the Erlang B Table

Offered traffic should be $A = 44.2$ Erlang

The offered traffic in a cell is 44.2 Erlang supported by the GoS.

The offered traffic in a cluster is 309.4 Erlang supported by the GoS.

(ii) Determine the number of users m and the offered traffic generated by users in each cell.

Answer: (ii) $m = 720 \times A_{ce} = 720 \times \frac{3\sqrt{3}}{2} R^2 = 1080\sqrt{3} R^2$

$\mu = 0.9$ call/h holding time: $h = 90s = \frac{1}{40} h$

$A_u = \mu \times h = 0.0225$ Erlang

$A = m \cdot A_u = 1080\sqrt{3} R^2 \times 0.0225 \approx 42.09 R^2$ Erlang.

The number of users in a cell is $m = 1080\sqrt{3} R^2$

The offered traffic generated by users in a cell is $42.09 R^2$ Erlang.

(iii) Determine the cell radius R, when the offered traffic generated by users is equal to the offered traffic supported for the given GOS for each cell.

Answer (iii) Let $A_{GoS} = A_{user}$

$42.09 R^2 = 44.2$

$\therefore R \approx 1.02$ km

2023-2024

3 (a) (iv) Determine the trunking gain T_g of the system.

Answer: (iv) Supported user number $n = \frac{A_{GoS}}{A_u} = \frac{44.2}{0.0225} = 1964$ in a cell

$T_g = \frac{n}{n_{ch}} = \frac{1964}{57} \approx 34.46$

The system trunking gain is 34.46

(v) Suppose the operator A decides to improve the hexagonal cellular design further where one uses the 120-degree sector being deployed in each cell for the BS. For this new design, calculate the new value of *R* and T_g. State your observation and comment on the changes to the results from the operator's perspective.

Answer: (v) The number of channels in each sector $57/3 = 19$

GoS: $P_b = 1\%$

Offered traffic supported by GoS is 11.2 Erlang in a sector according to Erlang B Table.

$A_{GoS} = 11.2 \times 3 = 33.6$ Erlang

Let $A_{GoS} = A_{user}$

$42.09 R^2 = 33.6$

$\therefore R \approx 0.89$ km

The user number in a cell is $\frac{A_{GoS}}{A_u} \approx 1493$

Trunking gain $T_g = \frac{1493}{57} \approx 26.19$

After the sectoring, trunking gain and radius of a cell all decreases.

But with the effect of directional antennas, the SIR in the system will also decrease, which means we can use smaller reuse distance to increase the system capacity.

3. (b) Multiple access schemes are important features in mobile cellular systems as they allow many users to share the limited spectrum simultaneously. There are three basic multiple access schemes used in the 1G-3G mobile cellular systems. Briefly describe each of the multiple access schemes and give an example of an existing mobile cellular system for each scheme.

Answer: FDMA: Frequency Division Multiple Access

Description: Divide the frequency band into small bands, each small band serves as a Sub channel, which allows a user's signal to access and transmit. Example: AMPS

TDMA: Time Division Multiple Access

Description: Divide the time domain into different slots, each slot allocates to a user. Narrow band TDMA = FDMA + TDMA

Example: GSM

CDMA: Code Division Multiple Access Description: Use different orthogonal code to transmit different users' signals.

Example: CDMA2000.

2023 - 2024

4. (a) For Internet of Things (IoT), the simplified IoT architecture consists of two parallel stacks, i.e., the Management and Compute Stack and Core IoT Functional Stack. Briefly describe the major components in each of the two stacks.

(7 Marks)

Answer : 4 (a) Management and compute Stack

Cloud
Fog
Edge

Core IoT Functional Stack

Application & Analytic Layer	Application and Analytics Layer
Communication & Network Layer	Communications Network Layer
IoT devices Layer	Things Layer

For management and compute stack :

The edge and fog computing layers simply act as a first line of defence for filtering, analysing, and otherwise managing data endpoints. It saves cloud from be queried by each node for every event.

After the processing of edge and fog layer, the less time-sensitive data will be sent to cloud layer for historical analysis. big data analysis and long-term storage.

For Core Functional Stack :

Things Layer : Classify the sensors and actuators in the network. Determine which technology should be used to allow devices to communicate.

Communications Network Layer : Connect the devices for communication.

Access Network Sublayer : Decide the access technology depends on connection topology, network volume, communication range.

Gateways and Backhaul Sublayer : The gateway is in charge of the inter-medium communication. The smart objects are static or mobile within a limited area while the gateway is often static.

Network and transport Sublayer : Network protocols for routing and forwarding packets, which should be standard-based and scalable to accomodate large number of devices.

Transport Protocols is responsible for the end-to-end transmissions. In the network, existing protocols like TCP or UDP can be used.

IoT Network Management Sublayer : Application Protocols need to take care of data transmission between the smart objects and other systems. Multiple protocols have been leveraged or designed to solve IoT data communication problems.

Applications and Analytics Layer : Collect and interpret data from IoT system, control and improve the efficiency of the whole system.

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4.(b) Discuss the necessity to introduce Fog Computing into the simplified IoT architecture.

Answer (b) There are huge amount of data generated in an IoT system.

The data processing and analysis work is very heavy and cannot be totally handled by the Cloud, due to several reasons:

1) The available bandwidth of cloud server is not big enough for all of the IoT system data.

2) The latency requirement of some time-sensitive data is very high, cloud service cannot meet the requirement.

3) The communication link between cloud and IoT system sometimes is not reliable enough.

4) The devices themselves do not have enough compute ability to analysis all the data generated.

So Fog Computing is necessary to distribute the data management throughout the IoT system as close to the edge of the IP network as possible.

(c) Derive and establish the following relationship between Signal-to-Interference Ratio SIR_{dB} and cluster size N_c.

$$SIR_{dB} = 1.76 + 20\log_{10}(N_c)$$

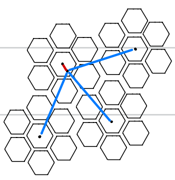
Answer (c) $SIR_{dB} = 10\lg\frac{1}{6} + 10n\lg Q = 10\lg\frac{1}{6} + 10n\lg\sqrt{3N_c} = -10\lg 6 + 5n\lg 3 + 5n\lg N_c$

When $n = 4$

$SIR_{dB} \approx 1.76 + 20\lg N_c$

(i) Consider the Simplified SIR analysis where $SIR = \frac{1}{6}Q^n$ and Q is the co-channel reuse factor and there are six co-channel interferers in the first tier. You may assume a path loss exponent of $n = 4$ in your initial evaluation. Determine the SIR_{dB} for N_c=7 and comment on your results.

Answer: (c)(i) $SIR = \frac{S}{\sum_i I_i}$



Suppose the signal power is proportional to minus exponential of n of the distance

Then $SIR = \frac{R^{-n}}{6 \cdot D^{-n}}$, where R is the radius of cell, D is the reuse distance.

Simplify: $SIR = \frac{1}{6}\left(\frac{D}{R}\right)^n$

For $N_c = 7$, $D = (i^2+j^2+ij)^{\frac{1}{2}}\sqrt{3}R = \sqrt{21}\,R$

$SIR_{dB} = 10\lg\frac{1}{6} + 10n\lg Q \approx -7.78 + 10\times 4\lg(\sqrt{21}) = -7.78 + 54.10 \approx 18.66\ dB$

The result is pretty good performance.

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4. c. (ii) If the required minimum SNR_{dB} is to be least 20 dB, derive the corresponding value of the path loss exponent n for this case.

Answer: (ii) For this case,

$$SIR_{dB} = -7.78 + 10n \lg Q$$

When $N_c = 7$, $Q = \sqrt{21}$

$$SIR_{dB} = -7.78 + 6.61n$$

Let $SIR_{dB} > 20\,dB$

$n > 4.20$ The least value for exponent n is 4.20.

(iii) Using the new value of n from part (ii), determine Co-Channel interference SIR for the worst case omnidirectional as shown below.

$$SIR = \frac{1}{2(Q-1)^{-n} + 2Q^{-n} + 2(Q+1)^{-n}}$$

Answer: (iii) Given that $Q = \sqrt{21}$ $n = 4.20$

$$SIR \approx 79.76$$

The Co channel Interference SIR in the worse case is 79.76

(iv) Using the new value of n from part (ii), determine the SIR when using co-channel interference *SIR* with 120° sectoring. State and comment on your results when compared to part (iii).

Answer: (iv) $n = 4.20$

With the 120° directional antenna, the co-channel interference is:

$$SIR = \frac{1}{Q^{-n} + (Q+0.7)^{-n}} \approx 385.66 \approx 25.86\,dB$$

The sectoring operation increase the SIR, contain co-channel interference a lot.