1. Consider 4 modulation scheme：QPSK、offset QPSK、π/4-DQPSK、CPM

(a) Show the possible phase trajectory for each scheme?

(b) Compare these schemes in the viewpoint of the linearity and dynamic range requirements of a power amplifier.

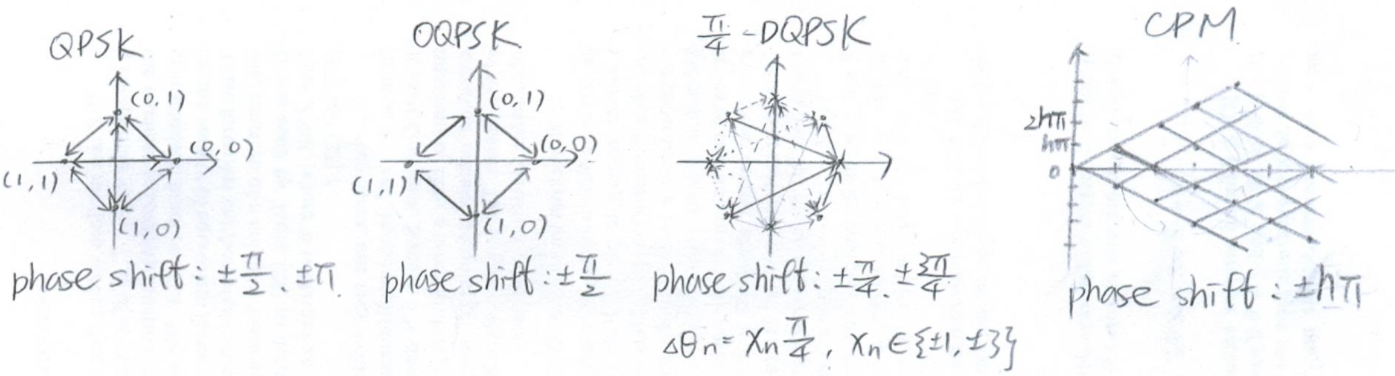
(c) Compare these schemes in the viewpoint of carrier phase synchronization for demodulation (coherent/non-coherent) in wireless propagation environments.

(d) Compare these schemes in the viewpoint of symbol-interval synchronization at a receiver.

(e) If high-order modulation schemes, such as 16-QAM and 64-QAM, are used for improving bandwidth efficiency, what additional information is required at a receiver for fading channels? Why?

Ans：

(a)



(b)

QPSK > $\frac{\pi}{4}$-DQPSK > OQPSK > CPM (對 nonlinearity 的敏感度較低)

(依據 phase trajectory 是否經過原點判斷，越近原點 ⇒ PAPR↑

⇒ 對非線性區的敏感度↑)

(c) 因為 QPSK 和 offset QPSK 是以各個不同的相位作為 symbol，所以需要參考相位才能做同步（coherent）。

而π/4-DQPSK和CPM是以相位差來決定symbol，所以不需要參考相位即可做同步(non-coherent)。

(d) QPSK、offset QPSK：每過一個週期相位**不一定**會發生變化(如 data 連續相同)，因此較難做 symbol-interval synchronization。

π/4-DQPSK、CPM：每過一個週期相位一定會發生變化，因此較容易做 symbol-interval synchronization。

(e) 需要知道 channel 的 gain 和 phase information。

因為通道會改變訊號的振幅與相位，需要有 gain 和 phase information 才能解調訊號。

2. The excess phase of minimum shift keying (MSK) can be expressed as $\phi(t) = \pi h \sum_{k=0}^{n-1} x_k + 2\pi h x_n \beta(t - nT)$,

where $\beta(t) = \begin{cases} 0, & t < 0 \\ t/2T, & 0 \le t \le T \\ 1/2, & t \ge T \end{cases}$ and $h = 1/2$.

(a) Show that MSK can be regarded as a type of frequency shift keying (FSK). [Hint: The carrier phase is $\phi_c(t) = 2\pi f_c t + \phi(t)$.] (5%)

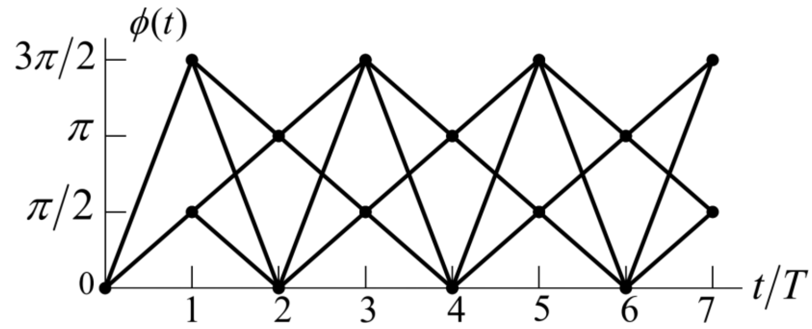
(b) Determine the two frequencies. (2%)

(c) Plot the excess phase diagram (i.e., $\phi(t)$) within $(0, 2\pi]$ of 7 consecutive symbol intervals. (3%)

(a) 背 $\phi(t) = \pi h \sum_{k=0}^{n-1} x_k + 2\pi h x_n \beta(t - nT)$，手算。

(b) 手算。

(c)



3.

(a) Explain and compare (in the performance, complexity, required information, …) the 3 diversity combining techniques: SC, MRC and coherent EGC.

(b) Assume that the bit error probability in the high SNR region can be expressed as $P_b \propto \beta \bar{\gamma}_c^{-L}$, where β and L are constants and $\bar{\gamma}_c$ is the average received bit energy-to-noise ratio for each diversity branch. Derive the diversity order and illustrate the meaning of diversity order in a figure of P_b versus $\bar{\gamma}_c$。

(c) For a fixed number of diversity branches, does the diversity order depend on the applied diversity combining techniques (SC, EGC and MRC)? Why?

Ans：

(a) 解釋：

SC：選擇 SNR 最高的 branch。

MRC：將 branch 乘上各自的權重（根據 channel fading gain），再做 combine。

coherent EGC：將各 branch 平等的做 combine（會做相位補償）。

比較：

performance：MRC > EGC > SC

complexity：MRC > EGC > SC

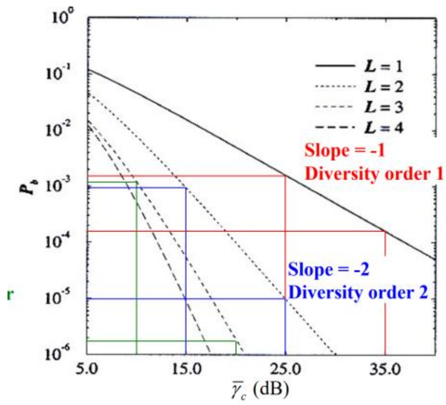
required information：SC 需要 SNR、MRC 需要 gain 跟 phase、EGC 需要 phase。

(b) $P_b \propto \beta \bar{\gamma}_c^{-L}$

$\Rightarrow 10 \log P_b \propto (10 \log \beta - L \cdot 10 \log \bar{\gamma}_c)$。

L 為 diversity order。

圖的斜率為 $-L$。



(c) No. 由上題算式可知，diversity order 跟 combining techniques 無關，只跟 diversity branches 的數量有關。而 combining techniques 只和 β、P_b 有關。

4.

Show that the performance of the 2×2 (兩個傳送天線兩個接收天線) space-time transmit diversity scheme <u>is equivalent to</u> the MRC scheme with the number of diversity branches $L = 4$. [Hint: The symbol pairs transmitted from antennas 1 and 2 in two contiguous baud periods are $(\tilde{s}_{(1)}, \tilde{s}_{(2)})$ and $(-\tilde{s}^*_{(2)}, \tilde{s}^*_{(1)})$. The corresponding channel gains are $g_{11}, g_{12}, g_{21}, g_{22}$.]

Ans：要手算。

先列出 received signals，再算出 $\tilde{v}_{(1)}$, $\tilde{v}_{(2)}$（背）、令 $g_{ab}g^*_{ab} = \alpha^2_{ab}$。~~可列出 MRC 的式子。~~得證 equal。

5.

To improve system performance, each cell can be divided into an inner cell and an outer cell by using reuse partitioning. Channels are assigned to the inner and outer cells according to 4-cell and 7-cell frequency reuse plans, respectively. The radius of the outer cell is assumed to be R_o.

(a) Find the maximum acceptable radius R_i of the inner cells.

(b) According to the result obtained in (a), if the traffic distribution is homogenous, find the percentages of the channel numbers assigned to the inner-cell set and the outer-cell set.

(c) Find the capacity improvement when compared with the original system using the 7-cell frequency reuse plan.

Ans：

(a) $D_o = \sqrt{3N}R_o = \sqrt{21}R_o$、$D_i = \sqrt{21}R_i \Longrightarrow R_i = \frac{D_i}{\sqrt{21}} = \frac{\sqrt{12}\cdot R_o}{\sqrt{21}} = \frac{2}{\sqrt{7}} R_o$。

可背 $R_i = \frac{\sqrt{3\cdot 4}}{\sqrt{3\cdot 7}} R_o$。

(b) $R_i = \frac{2}{\sqrt{7}} R_o \Longrightarrow A_i = \frac{4}{7} A_o \Longrightarrow$ channel numbers $N_i : N_o = \frac{4}{7} : \frac{3}{7} = 4:3$。

(c) total channel number $N_T = \frac{4}{7} N_c \cdot 4 + \frac{3}{7} N_c \cdot 4 = \frac{37}{7} N_c$

only 7-cell：$N_T = 7\, N_c{}'$

capacity improvement：$\frac{N_c - N_c{}'}{N_c{}'} = \frac{\frac{7}{37}N_T - \frac{1}{7}N_T}{\frac{1}{7}N_T} = \frac{12}{37}$

6.

(a) Explain why cell sectoring can improve the worst case carrier-to-interference ration (CIR) in comparison with the omni-directional cell planning.

(b) Determine the disadvantages of applying cell sectoring.

(c) Assume that multiple narrow beam antennas are used at base stations. Determine the channel assignment (usage) when trunkpool techniques (sector-trunkpool and omni-trunkpool) are applied.

(d) Determine the advantages/disadvantages of using trunkpool techniques.

Ans：

(a) omni-directional　　　　3-sector cell sectoring

⇒ 使用 cell sectoring 可以減少 co-channel interference，因此 CIR 會提高 #

(b) 1.每個 cell 需要更多天線 ⇒ 成本提高
    2.有更多 inter-sector handoff
    3.降低 trunking efficiency

(c) sector-trunkpool：若 MS 在同一個 sector 中移動時，不需做 handoff；若 MS 從一個 sector 移動到另一個 sector，則需要做 handoff。
    omni-trunkpool：MS 在同一個 cell 中移動時，不用做 handoff。MS 可以使用 cell 中的所有 channels。

(d) 優點：增加 trunking efficiency ⇒ blocking rate 降低
    缺點：強迫中止通話的機率提高

7. Consider 7-cell system with aa 4-cell frequency reuse plan. There are a total of 12 channels available, and the channel numbers used in the cells are shown in the figure.

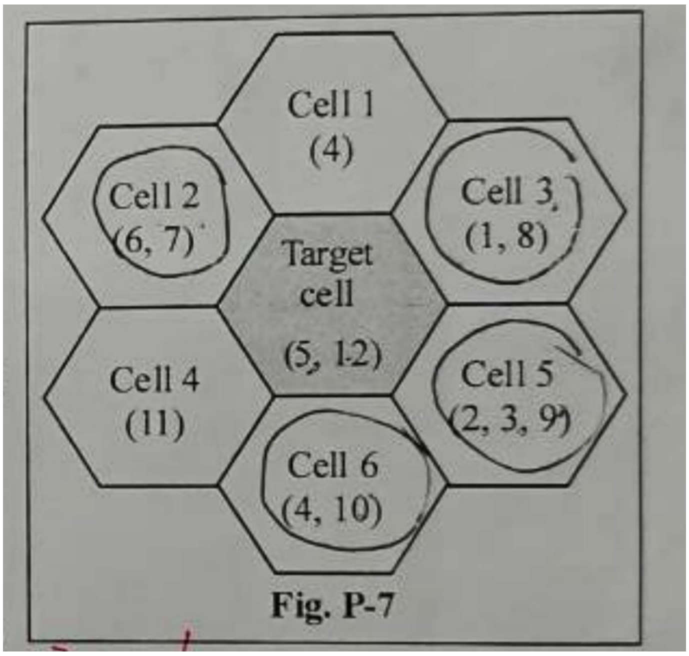


Fig. P-7

(a) Assume that system-wide channel information is available, and that channel rearrangements in all cells can be performed (i.e., the centralized DCA-maximum packing scheme). How many additional users can be accommodated in the target cell?
(b) According to the result obtained in (a), find a feasible channel assignment for all cells to accommodate the users.
(c) According to the result in (b), if a user in **Cell 3** terminates its call, how many additional users can be accommodated in the target cell? Why?
(d) According to the result in (b), if a user in **Cell 2** terminates its call, how many additional users can be accommodated in the target cell? Why?

Ans：手算。

8. Consider 2 roaming users, **A** and **B**, travelling outside the geographical coverage area of the home network, as shown in the figure.

(a) Determine the telephone traffic routing for a mobile originating call from user **A** to the wired telephone.
(b) Determine the telephone traffic routing for a mobile originating call from the wired telephone to user **A**.
(c) Determine the telephone traffic routing for a mobile originating call between the users **A** and **B**.

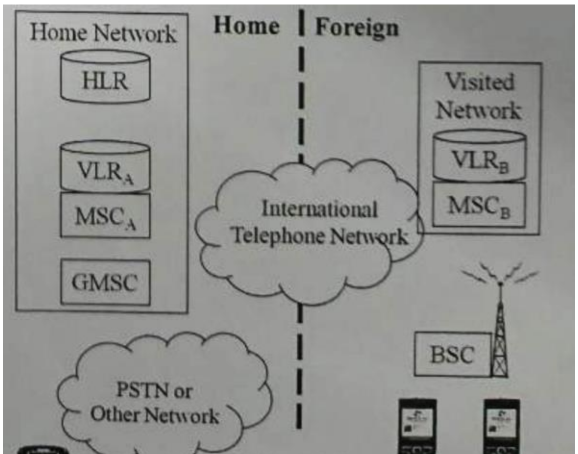


Fig. P-8

Ans：手畫。

9. Show that the average symbol energy-to-noise ratio with MRC is $\gamma_s^{MR} = \sum_{k=1}^{L} \gamma_k$, where γ_k is the average symbol energy-to-noise of the k-th branch and L is the number of diversity branches. [Hint: The channel-gain envelope of the composite signal is $\alpha_C = \sum_{k=1}^{L} {\alpha_k}^2$, and $\gamma_s^{MR} = {\alpha_C}^2 E_{av}/\sigma_{\tilde{n},tot}^2$.]
Ans：背 $\sigma_{\tilde{n},tot}^2 = N_0 \sum_{k=1}^{L} {\alpha_k}^2$，手算。

10. Explain in detail the following random access protocols:
(a) Pure ALOHA protocols.
(b) Slotted ALOHA protocols.
(c) p-persistent Carrier Sense Multiple Access (CSMA) protocol.
(d) Non-persistent CSMA protocol.
Ans：要記圖
(a) User 可隨時傳送，當 collision 發生時，user 要等一個 random backoff time 後再傳。
(b) User 若要傳送，一定要在每個 time slot 的開端傳送。當 collision 發生時，user 要等一個 random backoff time 後，在下一個 time slot 的開端傳送。
(c) 當 user 要傳送時，會先看有沒有其他人在傳。如果有，則等到通道空閒後，以 p 的機率傳送、$1-p$ 的機率再等一個 random backoff time。
(d) 當 user 要傳送時，會先看有沒有其他人在傳。如果有，會直接再等一個 random backoff time。

11. Considering a cell with only one co-channel cell, the average received signal power from base station at distance d can be expressed as $\mu_{\Omega(d)} = \mu_{\Omega(d_0)} - 10\beta \log(d/d_0)$, where $\mu_{\Omega(d_0)}$ is the average received power (in dBm) at a reference distance d_0, and β is the path loss exponent. The standard deviation of the received signal power caused by shadowing is assumed to be σ_Ω。

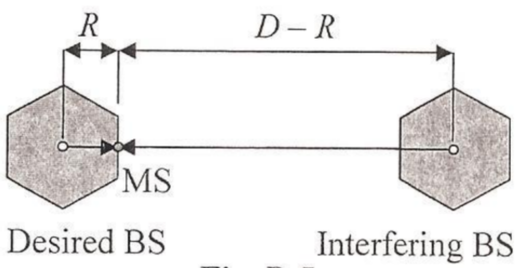


Fig. P-5

(a) Determine the worst case average received carrier-to-interference power ratio (CIR) (in dB) as a function of R, D and β.
(b) If the desired CIR threshold is Λ_{th} (in dB), determine the worst case CIR outage probability.
(c) If the CIR margin required for sustaining a specific CIR outage probability is M_Λ (in dB), determine the frequency reuse factor N. [Hint: $D/R = \sqrt{3N}$, and the CIR outage is $Q\left(\frac{\mu_{\Lambda(\mathrm{dB})}-\Lambda_{th(\mathrm{dB})}}{\sqrt{2}\sigma_\Omega}\right)$.]

Ans：手算。

12. Consider the handoff mechanisms for mobile cellular systems.
(a) Compare and explain the NCHO, MAHO and MCHO handoff mechanisms.
(b) Propose (with detailed explanation) two possible schemes that adopt handoff priority to reduce the probability of forced termination.

Ans：

(a) NCHO：Network Controlled Handoff

(1) Serving cell 會監測 MS 是否在 boundary。
(2) 鄰近的 cell 也會監測 MS，並將資料回傳給 Network。
(3) Network controller 會找出最佳的 serving cell 和 frequency channel。

MAHO：Mobile Assisted Handoff

(1) MS 會監測鄰近的 cell，然後回傳至 serving cell。
(2) Serving cell 會監測 MS 是否在 boundary。
(3) Network controller 會找出最佳的 serving cell 和 frequency channel。

MCHO：Mobile Controlled Handoff

(1) MS 主動監測鄰近的 cell，尋找比現在的 serving cell 品質更好的 cell。
(2) 如果有，MS 選擇一個新的 frequency channel 並 access 到 target cell。
(3) 新的 serving cell 接受 MS 並通知舊的 serving cell 可以終止和 MS 之間的 link。

比較：

NCHO 是由 BS 去監測，而 MAHO 跟 MCHO 是由 MS 去監測。NCHO 跟 MAHO 是由 network controller 做決定，MCHO 則是由 MS 自行做決定。

NCHO：當 reuse factor 較小時，可能發生錯誤。

MAHO：因為 MS 只有一個 transceiver，無法同時保持通話與監測。因此不適用於 FDMA。

MCHO：MS 的功能較強，因此 network 不需要太強。

(b) – Guard channel：保留一些 channel 專門給 handoff requests。

– Handoff queuing：如果沒有 channel 來 handoff，則 handoff request 會在 target cell 排隊，等到有 channel 可用。等的同時 MS 和 serving cell 會維持 link。

13. Considering a macrocellular system, the required forward link carrier-to-interference ratio is $\Lambda_{th} \geq 9$ dB and the path loss model is assumed to be $L(d) = L(d_0) - 40\log_{10}(d/d_0)$.
(a) Find the smallest allowable frequency reuse factor for the omni-cell configuration.
(b) Find the smallest allowable frequency reuse factor for the 3-sector-cell configuration.
(c) If an additional fading margin of 6 dB is required, find the smallest allowable frequency reuse factors for the omni-cell configuration and the 3-sector-cell configuration.

[Hint: Omni-cell $\Lambda = \frac{1/2}{\left(\frac{D}{R}-1\right)^{-\beta}+\left(\frac{D}{R}\right)^{-\beta}+\left(\frac{D}{R}+1\right)^{-\beta}}$, 3-sector-cell $\Lambda = \frac{1}{\left(\frac{D}{R}\right)^{-\beta}+\left(\frac{D}{R}+0.7\right)^{-\beta}}$; $D/R = \sqrt{3N}$, $\sqrt{12} \approx 3.5$、$\sqrt{21} \approx 4.6$.]

Ans：背 $10 \cdot \beta = 40$，手算。

Path loss model: $L(d) = L(d_0) - 40\log_{10}(d/d_0) \rightarrow \beta = 4$

(a) $\Lambda = \frac{1/2}{\left(\sqrt{3N}-1\right)^{-4}+\left(\sqrt{3N}\right)^{-4}+\left(\sqrt{3N}+1\right)^{-4}} = \begin{cases} 8.03\text{dB, for } N=3 \\ 11.59\text{dB, for } N=4 \\ 17.35\text{dB, for } N=7 \end{cases}$

$\because \Lambda_{th} \geq 10\text{dB} \rightarrow \therefore N = 4.$

(b) $\Lambda = \frac{1}{\left(\sqrt{3N}\right)^{-4}+\left(\sqrt{3N}+0.7\right)^{-4}} = 17.52\text{dB, for } N = 3$

$\because \Lambda_{th} \geq 10\text{dB} \rightarrow \therefore N = 3.$

(c) $\because \Lambda_{th} \geq 10\text{dB} + 6\text{dB} = 16\text{dB}$

$\rightarrow \therefore \begin{cases} N = 7, \text{for the omni-cell configuration} \\ N = 3, \text{for the 3-sector-cell configuration} \end{cases}$

15. As shown in the figure, a mobile station is traveling from BS_0 to BS_3.

(a) Illustrate the received signal strength (in dBm) coming from those four BSs versus the MS traveling distance from 0 to 500 m. Explain the reason in detail.

(b) Explain and compare the RSS-based and CIR-based handoff algorithms in detail.

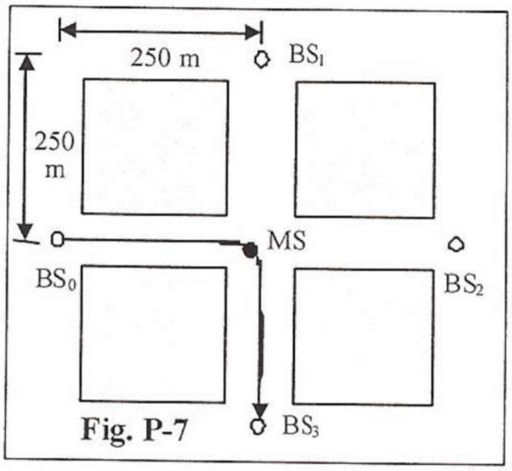


Fig. P-7

Ans：

(a) 要背圖。

0～250m：BS1 和 BS3 在一開始會有 corner effect，因此強度較弱，隨著慢慢移動強度會越來越高。因為離 BS0 越來越遠所以強度降低、離 BS2 越來越近所以強度變高。

250 ~ 500m：BS0 和 BS2 會有 corner effect 因此強度降低。因為離 BS1 越來越遠所以強度降低、離 BS3 越來越近所以強度變高。

(b) $RSS = C + I + N$ 包含 carrier、interference、noise，RSS 大不一定代表訊號強度較強，因此不易判斷 link 性能。

$CIR = \frac{C}{I+N}$ 是看 carrier 和 interference + noise 的比例，因此判斷上較準確。

比較：RSS 較簡單但不準，CIR 較複雜但準確。

16. If desired handoff cannot be applied, two schemes were proposed for achieving handoff priority to reduce the probability of forced termination.

(a) Explain the two schemes in detail.

(b) What is the impact on system performance when the two schemes are applied?

Ans：

(a) －Guard channel：保留一些 channel 專門給 handoff requests

－Handoff queuing：如果沒有 channel 來 handoff，則 handoff request 會在 target cell 排隊，等到有 channel 可用。等的同時 MS 和 serving cell 會維持 link。

(b) 因為分出了一些 channels 給 handoff 使用，所以使得 new call 的 blocking rate 增加。

17. Suppose that a binary sequence **x**, $x_n \in \{-1, +1\}$, is transmitted over an ISI channel with the channel gain vector **g** = (1.5, 0.5, 1) and the initial state (-1, -1).

(a) Illustrate the channel model by using a transversal filter.

(b) Illustrate the state and trellis diagram for an MLSE receiver.

(c) Explain the role of training sequences for MLSE receivers.

(d) What is the impact of the training sequence length for TDMA mobile cellular systems (such as GSM systems)?

Ans：

(a) 畫圖。

(b) 畫圖。

(c) training sequence：傳送接收端已知的 sequence，讓接收端收到後可以進行通道估測。

(d) training sequence 越長，估測越準，但頻寬消耗越大。

training sequence 越短，估測越不準，但節省頻寬。

18. Considering the two-branch switch and stay combing (SSC) scheme with two uncorrelated branches, the switching threshold is T, the average received bit energy-to-noise (ENR) for each diversity branch is $\bar{\gamma}_c$, and the distribution of the received ENR is $p_{\gamma_k}(x) = \frac{1}{\bar{\gamma}_c} e^{-x/\bar{\gamma}_c}$.

(a) Determine the probability q that the received ENR in a specific branch is below the threshold T.

(b) If the probability that the received ENR in a specific branch is below a value S is p, determine the probability that the ENR at output of the switched combiner is below S, i.e. $\Pr[\,\gamma_s^{SW} \le S\,]$, for $S < T$ and $S \ge T$.

Ans：

(a) 課本 P.100。

$$q = \Pr[\gamma_i < T] = 1 - e^{-T/\bar{\gamma}_c}$$

(b)

$$p = \Pr[\gamma_i \le S] = 1 - e^{-S/\bar{\gamma}_c}$$

$$\Pr[\gamma_s^{SW} \le S] = \begin{cases} qp, & S < T \\ p - q + qp, & S \ge T \end{cases}$$

22.

23. 名詞解釋

(a) Space diversity

(b) Angle diversity

(c) Polarization diversity

(d) Frequency diversity

(e) Field diversity

(f) Multipath diversity

(g) Time diversity

Ans：

(a) Space diversity：利用多天線實現，通常天線要距離夠遠，讓相關性夠小以得到 diversity。

(b) Angle diversity：利用指向行天線實現，每個天線會選擇從 narrow range of angle 來的平面波。

(c) Polarization diversity：利用極化方向不同來實現，scattering 環境通常可以 depolarize 訊號。

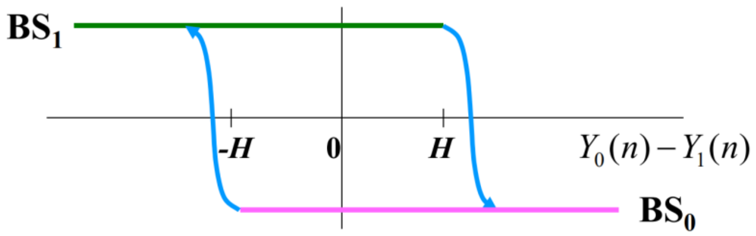
(d) Frequency diversity：利用多頻率通道來實現，channel 間隔要大於 channel 的 coherence bandwidth。

(e) Field diversity：利用電場和磁場來實現，電場和磁場的 components 在任意一點都是不相關的。

(f) Multipath diversity：以不同的 delay 來解析 multipath component，因此 time resolution 需要夠高。

(g) Time diversity：利用 multiple time slots，time slot 間隔至少要大於 channel 的 coherence time。

24. Signal strength based Handoff algorithms.



H：hysteresis (dB)、$Y_0(n)$ & $Y_1(n)$：BS0 與 BS1 的估測 signal strength (dBm)。

$$\begin{cases} Y_1(n) > Y_0(n) + H & \text{if the serving BS is } \mathrm{BS}_0 \\ Y_0(n) > Y_1(n) + H & \text{if the serving BS is } \mathrm{BS}_1 \end{cases}$$

2019、2020 新題目：

25. Suppose that a binary sequence $\mathbf{x}$, $x_n \in \{-1, +1\}$, is transmitted over an ISI channel with the channel gain vector $\mathbf{g} = (g_0, g_1, g_2) = (1.3, 0.7, 0.4)$ and the initial state $(-1, -1)$.

(a) Illustrate the state diagram and trellis diagram (until epoch 5) for an MLSE receiver.

(b) Determine the desired receiving signal for each possible branch in the trellis diagram.

(c) Determine all the branch metrics for the received signals 0.8 (1st symbol) and -1.3 (2nd symbol).

Ans：

(a) 背圖。

(b) 手算。

$$v_n = g_0 x_n + g_1 x_{n-1} + g_2 x_{n-2} = 1.3 x_n + 0.7 x_{n-1} + 0.4 x_{n-2}$$

$$state\ \ 0 = (-1,-1), state\ \ 1 = (1,-1), state\ \ 2 = (-1,1), state\ \ 3 = (1,1)$$

$$s_k^{(0)} \to s_{k+1}^{(0)} \Rightarrow v_{k+1} = -1.3 - 0.7 - 0.4 = -2.4$$
$$s_k^{(0)} \to s_{k+1}^{(1)} \Rightarrow v_{k+1} = 1.3 - 0.7 - 0.4 = 0.2$$
$$s_k^{(1)} \to s_{k+1}^{(2)} \Rightarrow v_{k+1} = -1.3 + 0.7 - 0.4 = -1$$
$$s_k^{(1)} \to s_{k+1}^{(3)} \Rightarrow v_{k+1} = 1.3 + 0.7 - 0.4 = 1.6$$
$$s_k^{(2)} \to s_{k+1}^{(0)} \Rightarrow v_{k+1} = -1.3 - 0.7 + 0.4 = -1.6$$
$$s_k^{(2)} \to s_{k+1}^{(1)} \Rightarrow v_{k+1} = 1.3 - 0.7 + 0.4 = 1$$
$$s_k^{(3)} \to s_{k+1}^{(2)} \Rightarrow v_{k+1} = -1.3 + 0.7 + 0.4 = -0.2$$
$$s_k^{(3)} \to s_{k+1}^{(3)} \Rightarrow v_{k+1} = 1.3 + 0.7 + 0.4 = 2.4$$

(c) 背 $\mu\left(s_0^{(0)} \to s_1^{(\ )}\right) = -\left|0.8 - (\text{上題結果})\right|^2$、 $\mu\left(s_1^{(\ )} \to s_2^{(\ )}\right) = -\left|1.3 - (\text{上題結果})\right|^2$。

$\Gamma = \mu_1 + \mu_2$ 兩者相加。

$\mathbf{v} = (0.8, -1.3)$

- Epoch 1

$$\mu(s_0^{(0)} \to s_1^{(0)}) = -|0.8 - (-2.4)|^2 = -10.24 \Rightarrow \Gamma(s_0^{(0)} \to s_1^{(0)}) = -10.24$$
$$\mu(s_0^{(0)} \to s_1^{(1)}) = -|0.8 - (0.2)|^2 = -0.36 \Rightarrow \Gamma(s_0^{(0)} \to s_1^{(1)}) = -0.36$$

- Epoch 2

$$\mu(s_1^{(0)} \to s_2^{(0)}) = -|-1.3 - (-2.4)|^2 = -1.21 \Rightarrow \Gamma(s_1^{(0)} \to s_2^{(0)}) = -10.24 - 1.21 = -11.45$$
$$\mu(s_1^{(0)} \to s_2^{(1)}) = -|-1.3 - (0.2)|^2 = -2.25 \Rightarrow \Gamma(s_1^{(0)} \to s_2^{(1)}) = -10.24 - 2.25 = -12.49$$
$$\mu(s_1^{(1)} \to s_2^{(2)}) = -|-1.3 - (-1)|^2 = -0.09 \Rightarrow \Gamma(s_1^{(1)} \to s_2^{(2)}) = -0.36 - 0.09 = -0.45$$
$$\mu(s_1^{(1)} \to s_2^{(3)}) = -|-1.3 - (1.6)|^2 = -8.41 \Rightarrow \Gamma(s_1^{(1)} \to s_2^{(3)}) = -0.36 - 8.41 = -8.77$$

26. The multi-antenna technique is used for performance improvement in wireless communications systems. The benefits of using multi-antenna systems include diversity, beamforming, and spatial multiplexing.

(a) Which parameter determine the mutual correlation between the radio-channel fading experienced by the signals at different antennas? What condition achieves high (low) mutual fading correlation?

(b) To achieve diversity gain, what is the requirement of antenna mutual fading correlation? Why?

(c) What are the two main purposes of beamforming? [Hint: maximizing/minimizing what metrics]

(d) Considering an antenna configuration consisting of N_{T} transmit antennas and N_{R} receive antennas, determine and explain the upper bound of the number of parallel signals that can be spatially multiplexed.

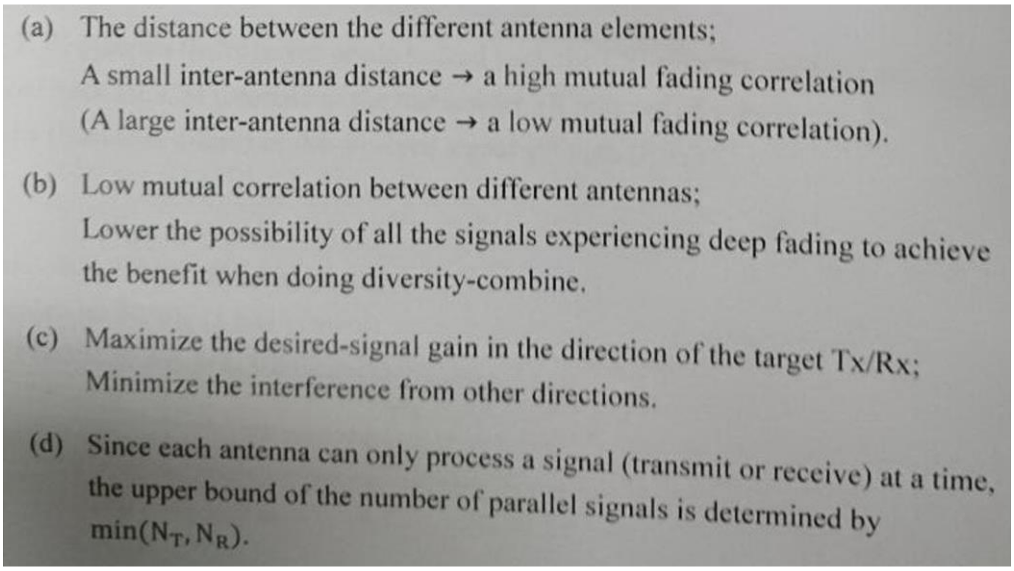
Ans：

(a) 不同 antenna elements 之間的距離。距離越近，mutual fading correlation 越高。

(b) 需要 low mutual fading correlation，因為做 diversity combining 時，correlation 越低效果越好。

(c) 最大化特定方向（Tx/Rx 方向）的 gain、最小化其他方向的干擾。

(d) 一個天線在某一時間上只能傳送或接收，因此 upper bound 為 $\min(N_T, N_R)$。


(a) The distance between the different antenna elements;
A small inter-antenna distance → a high mutual fading correlation
(A large inter-antenna distance → a low mutual fading correlation).

(b) Low mutual correlation between different antennas;
Lower the possibility of all the signals experiencing deep fading to achieve the benefit when doing diversity-combine.

(c) Maximize the desired-signal gain in the direction of the target Tx/Rx;
Minimize the interference from other directions.

(d) Since each antenna can only process a signal (transmit or receive) at a time, the upper bound of the number of parallel signals is determined by $\min(N_T, N_R)$.

27. Link adaptation is a technique used to improve the transmission efficiency in wireless communications.

(a) Explain in detail the link adaptation mechanism by adapting both modulation and coding.

(b) Link adaptation generally requires some channel state information (CSI) at the transmitter. Explain how to obtain the CSI for TDD systems and for FDD systems.

(c) If two modulation schemes GMSK and 8PSK (or QPSK and 16-QAM) are used and the available code rates are 1, 3/4, 2/3 and 1/2, show the applied modulation/coding and the corresponding throughput (information bits per transmitted (coded) symbol) in descending order with respect to the received SNR.

Ans：

(a) 傳送端會根據通道品質來選擇 modulation type 和 coding rate。
如果傳輸條件好，會採用 high-order modulation 和 high-rate coding，來提高吞吐量。
如果傳輸條件不好，則會降低 modulation order、code rate，來確保成功接收。

(b) TDD 系統：傳送端可以用 Rx-to-Tx link 的 CSI 來近似，得出 Tx-to-Rx link 的 CSI。
FDD 系統：接收端需要 feedback CSI 估計給傳輸端。

(c) 背 GMSK：1 bit/symbol

Modulation: GMSK (1 bit/symbol)

Modulation: 8-PSK (3 bits/symbol)

Code rate: 1.0, 3/4, 2/3, 1/2

	1	3/4	2/3	1/2
GMSK	1	3/4	2/3	1/2
8-PSK	3	9/4	2	3/2

Throughput gets worse when code rate drops(SNR ↓)

3 (8-PSK,code rate 1) > 9/4 (8-PSK,code rate 3/4) > 2 (8-PSK,code rate 2/3) > 3/2(8-PSK,code rate 1/2) > 1 (GMSK,code rate 1) > 3/4 (GMSK,code rate 3/4) > 2/3 (GMSK,code rate 2/3) > 1/2 (GMSK,code rate 1/2)

or

Modulation: QPSK (2 bit/symbol)

Modulation: 16-QAM (4 bits/symbol)

Code rate: 1.0, 3/4, 2/3, 1/2

	1	3/4	2/3	1/2
QPSK	2	3/2	4/3	1
16-QAM	4	3	8/3	2

Throughput gets worse when code rate drops(SNR ↓)

4 (16-QAM,code rate 1) > 3 (16-QAM,code rate 3/4) > 8/3 (16-QAM,code rate 2/3) > 2(16-QAM,code rate 1/2) = 2 (QPSK,code rate 1) > 3/2 (QPSK,code rate 3/4) >4/3 (QPSK,code rate 2/3) > 1 (QPSK,code rate 1/2)

28. Assume that a mobile cellular system has the following system parameters. Find the maximum allowable path losses in the forward-link (downlink, from a base transceiver station to a mobile station) and reverse-link (uplink, from a mobile station to a base transceiver station).

Tx power: BTS = 50 dBm; MS = 30 dBm;
RF loss: BTS = 3 dB; **Body loss:** MS = −3 dB;
Antenna gain: BTS = 17 dBi; MS = −2 dBi;
Margin: Interference = 6 dB & Fading = 5 dB;
Sensitivity: BTS = −110 dBm; MS = −100 dBm;
BTS Rx diversity gain: 2 dB.

Ans：

Forward-link:

Tx power(BTS) – RF loss + Antenna gain(BTS) – path loss – Interference margin – Fading margin + Antenna gain(MS) + Body loss >= Rx sensitivity(BTS)

50 – 3 + 17 - path loss -6 – 5 – 2 – 3 >= -100

The maximum allowable path loss is 148dB.

Reverse-link:

Tx power(MS) + Body loss + Antenna gain(MS) – Fading margin – Interference margin - path loss + Antenna gain(BTS) – RF loss +Diversity gain >= Rx sensitivity(MS)

30 - 3 - 2 - 5 - 6 - path loss + 17 – 3 + 2 >= -110

The maximum allowable path loss is 140dB.

29. Assume that an MS is in the handoff region between BS_0 and BS_1 with the received signal strength being Y_0 and Y_1, respectively. For signal strength based handoff algorithms, the following parameters are applied: the original hysteresis H, the upper threshold Ω_U, and the lower threshold Ω_L.

(a) Explain in detail the mobile assisted handoff (MAHO) procedure.

(b) Illustrate and explain in detail the handoff algorithm with upper and lower thresholds, i.e., the conditions that the handoff will be performed.

(c) Explain in detail why the hysteresis H is necessary.

(d) Assume that directed handoff cannot be applied. Propose two possible schemes, with detailed explanation, to reduce the probability of forced termination

Ans：

(a) MAHO：Mobile Assisted Handoff

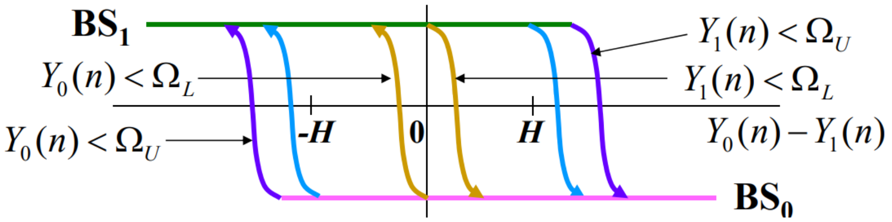
(1) MS 會監測鄰近的 cell，然後回傳至 serving cell。

(2) Serving cell 監測 MS 是否在 boundary。

(3) Network controller 找出最佳的 serving cell 和 frequency channel。

(b) 背 $Y_1(n) > Y_0(n) + H$ and $\square < Y_0(n) < \square$

$$
\begin{array}{ll}
\{Y_1(n) > Y_0(n) + H\} \text{ and } \{\Omega_L < Y_0(n) < \Omega_U\}, & \text{if the serving BS is } BS_0 \\
\{Y_1(n) > Y_0(n)\} \text{ and } \{Y_0(n) < \Omega_L\}, & \text{if the serving BS is } BS_0 \\
\{Y_0(n) > Y_1(n) + H\} \text{ and } \{\Omega_L < Y_1(n) < \Omega_U\}, & \text{if the serving BS is } BS_1 \\
\{Y_0(n) > Y_1(n)\} \text{ and } \{Y_1(n) < \Omega_L\}, & \text{if the serving BS is } BS_1
\end{array}
$$



(c) Hysteresis H 是為了避免發生「在短時間內來回切換的情況」。

(d) – Guard channel：保留一些 channel 專門給 handoff requests

– Handoff queuing：如果沒有 channel 來 handoff，則 handoff request 會在 target cell 排隊，等到有 channel 可用 。等的同時 MS 和 serving cell 會維持 link。

30. Considering the security issue in mobile communications, multiple hash algorithms are involved in user authentication and message privacy, such as A3 for authentication, A5 for message encryption and A8 for ciphering key generation.

(a) Is it possible that different network operators use different hash algorithms? Evaluate the possibility and explain in detail the reason why for each hash algorithm.

(b) In an authentication triplet, the lengths of RAND, SRES and Kc are 128 bits, 32 bits and 64 bits. Determine the probability that a fraud user can pass the authentication procedure based on random guess.

(c) Determine the probability that a fraud user can pass the authentication procedure and correctly transmit/receive messages based on random guess.

[Hint: $2^{10} \approx 10^3$ and express your answer in the form $a \times 10^{-b}$ for $1 < a < 10$ and $b \in \mathbb{N}$.]

Ans：

(a)

- Algorithm A3、A8
  - Different hash algorithms can be used according to different network operators。
  - Reason:
    SIM card(A3、A8、Ki) and AuC/HLR(Ki) are issued by the network operators.
    Hash algorithms can be set by the network operator.
- Algorithm A5
  - Must be common to all GSM PLMNs and all mobile station(in particular, to allow roaming).
    The hash algorithms must same all over the world.

(b)

RAND : 128 bits 、SRES : 32 bits 、Kc : 64 bits

Fraud user can pass the authentication procedure base on random guess

- ➢ SRES must be the same as BS

Probability of success

- ➢ $\frac{1}{2^{32}} = \frac{1}{(2^{10})^3 \times 2^2} = 0.25 \times \frac{1}{(2^{10})^3} \cong 0.25 \times \frac{1}{(10^3)^3} = 0.25 \times 10^{-9} = 2.5 \times 10^{-10}$

  Hint use $2^{10} \approx 10^3$

(c) Fraud user can pass the authentication procedure based on random guess and correctly transmit/receive message based on random guess

- ➢ SRES must be the same as BS
- ➢ Kc on both ends(MS 、BS) should be the same

Probability of success

- ➢ $P_{\text{success}} = P_{\text{SRES}} P_{\text{Kc}}$
  - ■ from (b) we get $P_{\text{SRES}} = 2.5 \times 10^{-10}$
  - ■ $P_{\text{Kc}} = \frac{1}{2^{64}} = \frac{1}{(2^{10})^6 \times 2^4} = 0.0625 \times \frac{1}{(2^{10})^6} \cong 0.0625 \times \frac{1}{(10^3)^6} = 0.0625 \times 10^{-18} = 6.25 \times 10^{-20}$

then $P_{\text{success}} = 2.5 \times 10^{-10} \times 6.25 \times 10^{-20} = 15.625 \times 10^{-30} = 1.5625 \times 10^{-29}$

P_{SRES} : the Probability of SRES on both ends are same

P_{Kc} : the Probability of Kc on both ends are same

(a) aa
(b) bb

(a) aa
(b) bb