無線通訊系統期中考整理

1. 名詞解釋

① Frequency division duplex (FDD)

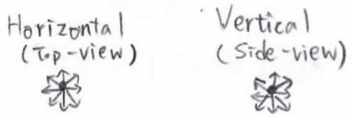
頻率雙向多工，BS 和 MS 使用不同的頻帶傳送

② Time division duplex (TDD)

時間雙向多工，uplink 和 downlink 使用不同 time slot 在相同頻段傳送

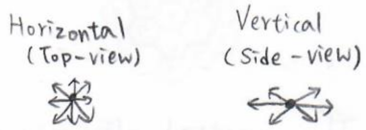
③ Isotropic antenna

均向型天線，在各個方向的強度皆相同，水平面及垂直面皆為均向性



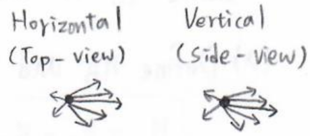
④ Omni-directional antenna

全向型天線，水平面為均向性，垂直面隨高度不同而改變



⑤ Directional antenna

指向型天線，僅在某些特定方向有較大強度的 main lobe 以及較小強度的 side lobe



⑥ Half power beamwidth

半功率波束寬度，在最大功率下降一半的地方 (-3dB)，角度展開的幅度

⑦ Full duplex

全雙工，同一時間內，雙向都可以傳送和接收

⑧ Half duplex

半雙工，任意時間內，只能同時有一方傳輸，另一方接收，無法同時傳送和接收

⑨ Frequency Division Multiple Access (FDMA)

分頻多工，將頻譜分成數段給不同人使用，若鄰近的 band 使用相同頻率，則頻段之間需要 guard band 避免干擾

⑩ Time Division Multiple Access (TDMA)

分時多工，將 1 個 frame 分成多個 time slot，1 個 time slot 獨佔所有頻段，每隔 1 個 frame 後都具有相同的 time slot 分佈，鄰近時段之間需要 guard time 避免干擾

⑪ Code Division Multiple Access (CDMA)

分碼多工，不同用戶使用不同的 code domain 傳送，需使用低相關 code 避免干擾

⑫ Main lobe / Side lobe

主瓣：包含較高功率的 lobe

旁瓣：不想要的方向上的輻射

2. Show the frequency reuse planning for a set of cells with a frequency reuse factor $N=3,4$, and 7.

$$\boxed{N=i^2+i\times j+j^2,\ i\ge 0, j\ge 0,\ i+j\ge 1}$$

$N=3 \Rightarrow (i,j)=(1,1)$，每個cell使用總頻寬的$\frac{1}{3}$，全部的通道被分成3組

$N=4 \Rightarrow (i,j)=(2,0)$ or $(0,2)$，每個cell使用總頻寬的$\frac{1}{4}$，全部的通道被分成4組

$N=7 \Rightarrow (i,j)=(2,1)$ or $(1,2)$，每個cell使用總頻寬的$\frac{1}{7}$，全部的通道被分成7組

3. The spectral efficiency of circuit switching systems can be expressed as $\eta_s=\eta_B\times\eta_c\times\eta_T$, where η_B is the bandwidth efficiency, η_c is the spatial efficiency, and η_T is the trunking efficiency.

(a) Define η_B and propose two approaches to improve η_B. What's the related cost?

$$\boxed{\eta_s=\eta_B\times\eta_c\times\eta_T=\frac{1}{W_c}\times\frac{1}{N\times A}\times G_c}$$

$\eta_B=\frac{1}{W_c}$ (W_c is the bandwidth per channel)

① 降低 source coding 的 bit rate $\longrightarrow$ 語音品質不好

② 使用 bandwidth efficient modulation $\longrightarrow$ high BER

(b) Define η_c and propose two approaches to improve η_c. What's the related cost?

$\eta_c=\frac{1}{N\times A}$ (A is the coverage area per cell)

①降低每個 cell的涵蓋區域 $\longrightarrow$ high frequency of cell-switching

② 使用較小的 reuse factor N $\longrightarrow$ 增加 co-channel 的干擾

權衡 Quality of Service 服務品質 阻塞

(c) Define η_T and explain the tradeoff between η_T and QoS (i.e., the blocking rate).

$\eta_T=G_c=\frac{\rho}{m}$ (G_c是每個通道提供的流量，ρ是總流量，m是總通道數目)

當增加ρ時，η_T也會跟著增加，the blocking rate 也會上升，QoS 就會下降

4. Considering a macrocellular system, the desired outage probability for thermal noise on cell fringe is $O(R)=0.5$. It is assumed that the propagation model is $L(d) = 131 + 40\log_{10}(d)$ dB with d in km, the channel bandwidth is 400 kHz, the threshold of carrier-to-noise power ratio (CNR) is $\Gamma_{th} = 5$ dB, and the noise power spectral density at the receiver is -160 dBm/Hz. $\boxed{\log_{10}2 = 0.3,\ \log_{10}3 = 0.4771,\ \log_{10}5 = 0.7,\ \log_{10}7 = 0.8451}$

(a) Find the sensitivity (the minimum signal power that achieves Γ_{th}) of the receiver in dBm.

$$\text{sensitivity} = -160 + 10\log_{10}400k + 5 = -160 + 10(0.6+5) + 5 = -99 \text{ dBm}$$

(b) If the maximum output power is 56 dBm and the standard deviation (due to the shadowing effects) in CNR is $\sigma_\Omega = 8$ dB, determine the cell radius. [Hint: $O(R) = Q\left(\frac{\mu_{\Gamma(R)} - \Gamma_{th(dB)}}{\sigma_\Omega}\right)$]

$$O(R) = 0.5 = Q(0) \Rightarrow \mu_{\Gamma(R)} - \Gamma_{th(dB)} = 0$$

$$56 - L(d) + 99 = 0 \Rightarrow 56 - 131 - 40\log_{10}(d) + 99 = 0$$

$$\log_{10}(d) = \frac{24}{40} = 0.6 \Rightarrow d \cong 4 \text{ km}$$

(c) If the channel bandwidth is changed to 6.4 MHz, determine the cell radius.

$$\text{sensitivity} = -160 + 10\log_{10}6.4M + 5 = -160 + 10(1.8+5) + 5 = -87 \text{ dBm}$$

$$56 - L(d) + 87 = 0 \Rightarrow 56 - 131 - 40\log_{10}(d) + 87 = 0$$

$$\log_{10}(d) = \frac{12}{40} = 0.3 \Rightarrow d \cong 2 \text{ km}$$

(d) According to (c), if the cell radius obtained in (b) shall be maintained, determine the required maximum output power in dBm.

$d = 4$ and sensitivity $= -87$

$$P - 131 - 40\log_{10}(d) + 87 = 0 \Rightarrow P - 131 - 40 \times 0.6 + 87 = 0 \Rightarrow P = 68 \text{ dBm}$$

5. (a) If the desired maximum effective isotropic radiated power (EIRP) is 24 dBW and a 5 W power amplifier is used, determine the required antenna gain in dBd.
[Hint: The gain of a half-wave dipole antenna is 2.15 dBi]

$$24\ (\text{dBW}) = 10\log(5) + G_i$$

$$G_i = 24 - 7 = 17 \text{ dBi} \rightarrow 17 = 10\log\frac{P_t}{P_i}$$

$$G_d = 17 - 2.15 = 14.85\ (\text{dBd})$$

(b) According to (a), determine the maximum effective radiated power (ERP) in dBW.

$$ERP = EIRP - 2.15 = 24 - 2.15 = 21.85\ (\text{dBW})$$

6. Consider two propagation environments with the corresponding delay spread 5 μs and 200 ns, respectively. Three systems are available with the channel bandwidth 100 kHz, 1 MHz and 10 MHz, and the packet duration 10 ms, 2 ms and 0.5 ms, respectively, operating in the 3 GHz (f_c) frequency band. There are three possible user velocities, including 5 m/s, 20 m/s and 60 m/s.

(a) In what situations (delay spread, channel bandwidth / packet duration, and user velocity), the observed channel is frequency selective or frequency non-selective. Why?

channel bandwidth ≪ coherence bandwidth → frequency non-selective fading
channel bandwidth ≥ coherence bandwidth → frequency selective fading
delay spread ≪ symbol duration → frequency non-selective fading
delay spread ≥ symbol duration → frequency selective fading

* Frequency (non-) selective fading is not related to packet duration & user velocity.

channel bandwidth		symbol duration
100 kHz	$\xrightarrow{\text{倒數}}$	10 μs
1 MHz	→	1 μs
10 MHz	→	0.1 μs

delay spread	10 μs	1 μs	0.1 μs ← symbol duration
5 μs	frequency non-selective	frequency selective	frequency selective
0.2 μs	frequency non-selective	frequency non-selective	frequency selective

(b) In what situations (delay spread, channel bandwidth / packet duration, and user velocity), the observed channel is time-variant or time-invariant for the reception of a packet. Why? [Hint: $f_m = \frac{v}{\lambda_c}$, $c = f_c \lambda_c$ and $c = 3\times10^8$]

packet duration ≪ coherence time → time-invariant
packet duration ≥ coherence time → time-variant

* Time-(in) variant is not related to delay spread & channel bandwidth

$$\text{coherence time } T_c \approx \frac{1}{\text{doppler spread} \leftarrow f_m}$$

$$\lambda_c = \frac{3\times10^8}{3\times10^9} = 0.1$$

$$\underset{\uparrow\ \text{doppler spread}}{f_m} = \frac{v}{0.1} = v\times10$$

user velocity

5 m/s → $f_m = 50\,\text{Hz}$, $T_c \approx \frac{1}{50} = 20\,\text{ms}$

20 m/s → $f_m = 200\,\text{Hz}$, $T_c \approx \frac{1}{200} = 5\,\text{ms}$

60 m/s → $f_m = 600\,\text{Hz}$, $T_c \approx \frac{1}{600} = 1.667\,\text{ms}$

	20 ms	5 ms	1.667 ms ← coherence time
packet duration	5 m/s	20 m/s	60 m/s ← V
10 ms	time invariant	time variant	time variant
2 ms	time invariant	time invariant	time variant
0.5 ms	time invariant	time invariant	time invariant

7. Considering two multi-path fading channels with the same average signal power, one is Rayleigh faded (channel A) and the other is Ricean faded (channel B). The crossing rates of the envelope level ρ are denoted as $L_{R,A}(\rho)$ and $L_{R,B}(\rho)$, respectively.

(a) Compare the two level-crossing rates $L_{R,A}(\rho=-5dB)$ and $L_{R,B}(\rho=-5dB)$, and explain the reasons in detail.

If $K=0$, Rayleigh faded (channel A) $\rightarrow$ Rapid variation
If $K>0$, Ricean faded (channel B) $\rightarrow$ LOS

Because channel B has LOS, so $L_{R,A}(\rho=-5dB) > L_{R,B}(\rho=-5dB)$

(b) Compare the average fade duration $\bar{t}_A(\rho=-5dB)$ and $\bar{t}_B(\rho=-5dB)$, and explain the reasons in detail.

Because channel A changes rapidly, so $\bar{t}_A(\rho=-5dB) < \bar{t}_B(\rho=-5dB)$

(c) Compare the two level-crossing rates $L_{R,A}(\rho=5dB)$ and $L_{R,B}(\rho=5dB)$, and explain the reasons in detail.

Because channel A changes rapidly, so $L_{R,A}(\rho=5dB) > L_{R,B}(\rho=5dB)$

(d) Compare the average fade duration $\bar{t}_A(\rho=-5dB)$ and $\bar{t}_A(\rho=5dB)$, and explain the reasons in detail.

因為 channel A 沒有 LOS，因此一旦 channel A envelope 降下去便很難回復到原本的 envelope 了

$\bar{t}_A(\rho=-5dB) < \bar{t}_A(\rho=5dB)$

8. The spatial correlation of the shadowing effects is modeled as a Gaussian white noise process filtered with a first-order low-pass filter, i.e., $\Omega_{k+1}(dBm) = \xi\Omega_k(dBm) + (1-\xi)V_k$, where k is the location index, Ω_k is the received signal power, ξ is the spatial correlation of the shadowing, and v is a zero-mean Gaussian random variable with variance σ_v^2. The variance of shadowing effects is assumed to be σ^2.

(a) Find the variance σ_v^2 in term of other system parameters.

$$\phi_{\Omega(dBm)\Omega(dBm)}(0) = E[\Omega_{k+1}(dBm)\Omega_{k+1}(dBm)] = E[(\xi\Omega_k(dBm) + (1-\xi)V_k)(\xi\Omega_k(dBm) + (1-\xi)V_k)]$$
$$= \xi^2\phi_{\Omega(dBm)\Omega(dBm)}(0) + (1-\xi)^2\sigma_v^2 \Rightarrow \sigma_v^2 = \left(\frac{1+\xi}{1-\xi}\right)\sigma^2$$

(b) Show that the spatial autocorrelation function is $\phi_{\Omega(dBm)\Omega(dBm)}(n) = \frac{1-\xi}{1+\xi}\sigma_v^2\xi^{|n|}$

$$\phi_{\Omega(dBm)\Omega(dBm)}(n) = E[\Omega_{k+n+1}(dBm)\Omega_{k+1}(dBm)] = E[(\xi\Omega_{k+n}(dBm) + (1-\xi)V_{k+n})\Omega_{k+1}(dBm)]$$
$$= \xi\phi_{\Omega(dBm)\Omega(dBm)}(n-1)$$

$\Rightarrow$ we know that $\phi_{\Omega(dBm)\Omega(dBm)}(n) = \xi\phi_{\Omega(dBm)\Omega(dBm)}(n-1) = \xi^2\phi_{\Omega(dBm)\Omega(dBm)}(n-2) = \cdots = \xi^n\phi_{\Omega(dBm)\Omega(dBm)}(0)$

$\because \phi_{\Omega(dBm)\Omega(dBm)}(n) = \phi_{\Omega(dBm)\Omega(dBm)}(-n)$, $\therefore \phi_{\Omega(dBm)\Omega(dBm)}(n) = \xi^{|n|}\phi_{\Omega(dBm)\Omega(dBm)}(0) = \xi^{|n|}\left(\frac{1-\xi}{1+\xi}\right)\sigma_v^2$

(c)

$$\phi(k) = \sigma_\Omega^2\xi_D^{(\frac{vT}{D})|k|} \text{ and } \phi(\Delta x) = \sigma_\Omega^2 e^{-\ln 2\frac{|\Delta x|}{d_{cor}}} \Rightarrow \xi_D^{(\frac{vT}{D})|k|} = e^{-\ln 2\frac{|\Delta x|}{d_{cor}}}$$

$$\left(\frac{vT}{D}\right)|k|\ln(\xi_D) = -\ln 2\frac{|\Delta x|}{d_{cor}}, \because vT|k| = |\Delta x|, \therefore d_{cor} = \frac{-D\ln 2}{\ln\xi_D}$$

(c) If an MS is traveling with velocity v, the envelope is sampled for every T seconds, and ξ_D is the shadow correlation of spatial distance D m, then the spatial correlation can be represented as $\phi(k) = \sigma_\Omega^2 \xi_D^{(\frac{vT}{D})|k|}$. By contrast, in the ITU channel model, the spatial correlation is defined as $\phi(\Delta x) = \sigma_\Omega^2 e^{\frac{-\ln 2|\Delta x|}{d_{cor}}}$. Find the parameter d_{cor} based on D and ξ_D.

$$\Rightarrow \xi_D^{(\frac{vT}{D})|k|} = e^{-\ln 2\frac{|\Delta x|}{d_{cor}}}, \quad \left(\frac{vT}{D}\right)|k| \ln(\xi_D) = -\ln 2 \frac{|\Delta x|}{d_{cor}}$$

$$\because vT|k| = |\Delta x|, \quad \therefore d_{cor} = \frac{-D\ln 2}{\ln \xi_D}$$

9. The average received signal power of a channel can be expressed as $\mu_{\Omega p}(d) = \frac{k\Omega_t}{d^a(1+\frac{d}{g})^b}$, where Ω_t is the transmission power, d is the propagation distance, g is the break-point, and a, b and k are constants related to the channel. The break-point g satisfies the relation $\sqrt{\Sigma^2+g^2} - \sqrt{\Delta^2+g^2} = \frac{\lambda_c}{2}$, where $\Sigma = h_b + h_m$ and $\Delta = h_b - h_m$ with h_b and h_m respectively representing the antenna heights of BS and MS. $\boxed{\Sigma^2-\Delta^2 = (\Sigma+\Delta)(\Sigma-\Delta) = 4h_b h_m}$ $\boxed{\Sigma^2+\Delta^2 = 2(h_b^2+h_m^2)}$

(a) Show that this channel has two-slope propagation loss (in dB scale) and find the two corresponding slopes.

If $d \ll g$, $\mu(dB) = 10\log_{10}(k\Omega_t) - 10a\log_{10}(d) - 10b\log_{10}(1+\frac{d}{g}) \approx 10\log_{10}(k\Omega_t) - 10a\log_{10}(d)$

If $d \gg g$, $\mu(dB) = 10\log_{10}(k\Omega_t) - 10a\log_{10}(d) - 10b\log_{10}(1+\frac{d}{g})$

$$\approx 10\log_{10}(k\Omega_t) - 10a\log_{10}(d) - 10b\log_{10}\left(\frac{d}{g}\right) = 10\log_{10}(k\Omega_t) - [10(a+b)\log_{10}(d) - 10b\log_{10}(g)]$$

當 $d \ll g$, path loss 以 $10a$ 的斜率變化
當 $d \gg g$, path loss 以 $10(a+b)$ 的斜率變化
} 故稱 two-slope model

(b) Derive the break-point g in terms of Σ, Δ and λ_c.

$$\left(\sqrt{\Sigma^2+g^2}\right)^2 = \left(\frac{\lambda_c}{2} + \sqrt{\Delta^2+g^2}\right)^2$$

$$\Rightarrow \Sigma^2+g^2 = \frac{\lambda_c^2}{4} + \lambda_c\sqrt{\Delta^2+g^2} + (\Delta^2+g^2)$$

$$\Rightarrow \left(\Sigma^2-\Delta^2-\frac{\lambda_c^2}{4}\right)^2 = \left(\lambda_c\sqrt{\Delta^2+g^2}\right)^2$$

$$\Rightarrow (\Sigma^2-\Delta^2)^2 - \frac{\lambda_c^2}{2}(\Sigma^2-\Delta^2) + \frac{\lambda_c^4}{16} = \lambda_c^2(\Delta^2+g^2)$$

$$\Rightarrow g^2 = \frac{1}{\lambda_c^2}\left[(\Sigma^2-\Delta^2)^2 - \frac{\lambda_c^2}{2}(\Sigma^2-\Delta^2) + \frac{\lambda_c^4}{16} - \lambda_c^2\Delta^2\right] = \left(\frac{\Sigma^2-\Delta^2}{\lambda_c}\right)^2 - \frac{\Sigma^2+\Delta^2}{2} + \frac{\lambda_c^2}{16}$$

$$\Rightarrow g = \sqrt{\left(\frac{\Sigma^2-\Delta^2}{\lambda_c}\right)^2 - \frac{\Sigma^2+\Delta^2}{2} + \frac{\lambda_c^2}{16}}$$

(c) If the carrier frequency is high enough (i.e., $\lambda_c \ll 1$), show that the break-point can be approximated as $g \approx 4h_b h_m/\lambda_c$.

$$g = \sqrt{\left(\frac{\Sigma^2-\Delta^2}{\lambda_c}\right)^2 - \frac{\Sigma^2+\Delta^2}{2} + \frac{\lambda_c^2}{16}} = \sqrt{\left(\frac{4h_b h_m}{\lambda_c}\right)^2 - (h_b^2+h_m^2) + \frac{\lambda_c^2}{16}}$$

$$= \frac{1}{\lambda_c}\sqrt{(4h_b h_m)^2 - \lambda_c^2(h_b^2+h_m^2) + \frac{\lambda_c^4}{16}} \quad \text{(後2項很小可省略)}$$

$$= \frac{4h_b h_m}{\lambda_c}$$

10. Consider three mobile communication systems applying FDMA, TDMA and CDMA multiple access schemes. For the FDMA system, the frequency reuse factor is 7 and the channel bandwidth is 25 kHz. For the TDMA system, the frequency reuse factor is 4 and the channel bandwidth is 200 kHz for supporting 8 users; while the channel bandwidth is 1.2 MHz for supporting 20 users in the CDMA system.

(a) Can the cell coverage be extended via increasing the transmission power? Why?

Yes, increase the transmission power also increase the carrier-to-noise ratio, so coverage can be extended.

(b) Can the frequency reuse factor be reduced via increasing the transmission power? Why?

No, because the co-channel interference will be increased, and carrier-to-interference ratio remains the same, the frequency reuse cluster size will not be reduced.

(c) Compare the system capacity of the three systems for the same bandwidth resource.

$$\begin{cases} \text{FDMA}: N=7,\ B_c=25\,\text{kHz} \\ \text{TDMA}: N=4,\ B_c=200\,\text{kHz},\ 8 \text{ users} \\ \text{CDMA}: \quad B_c=1.2\,\text{MHz},\ 20 \text{ users} \end{cases}$$

Assume total BW is M

$$\left.\begin{aligned} \text{FDMA}&: \frac{M}{7\times 25k} = \frac{M}{175k} \\ \text{TDMA}&: \frac{M}{4\times 200k}\times 8 = \frac{M}{100k} \\ \text{CDMA}&: \frac{M}{1200k}\times 20 = \frac{M}{60k} \end{aligned}\right] \therefore \text{capacities} \Rightarrow \text{FDMA}:\text{TDMA}:\text{CDMA} = \frac{1}{175}:\frac{1}{100}:\frac{1}{60}$$

$$= 12 : 21 : 35$$

(d) Assuming that the total available bandwidth is 16.8 MHz and the whole service area requires a total of 150000 user channels, determine the number of cells required for the three systems.

total available BW = 16.8 MHz
requires 150000 channels

① FDMA: $\dfrac{16.8\times10^6}{7\times25\times10^3} = \dfrac{16.8\times10^3}{175}$ (ch/cell)

$$\frac{15\times10^4}{\frac{16.8\times10^3}{175}} = \frac{15\times10^4\times175}{16.8\times10^3} = 1562.5 \approx 1563 \text{ (cell)}$$

② TDMA: $\dfrac{16.8\times10^6\times8}{4\times200\times10^3} = 168$ (ch/cell)

$$\frac{15\times10^4}{168} \approx 893 \text{ (cell)}$$

③ CDMA: $\dfrac{16.8\times10^6\times20}{1200\times10^3} = \dfrac{16.8\times10^2}{6}$ (ch/cell)

$$\frac{15\times10^4}{\frac{16.8\times10^2}{6}} = \frac{15\times10^4\times6}{16.8\times10^2} \approx 536 \text{ (cell)}$$

[Hint: $f_m = \frac{v}{\lambda_c}$, $L_R = \sqrt{2\pi} f_m \rho e^{-\rho^2}$, $\bar{t} = (e^{\rho^2}-1)/(\rho f_m \sqrt{2\pi})$, $e^{0.25} = 1.284$ and $e^x \approx 1+x$ for $x \ll 1$.]

11. Considering a communication system under a Rayleigh fading channel, the carrier frequency is 2 GHz and a coding scheme with interleaving (the interleaving interval is assumed to be 5 ms) is applied. Good radio link can be maintained for a normalized level $\rho \geq 0.1$.

$\boxed{\lambda_c = \frac{c}{f_c} = \frac{3\times10^8}{2\times10^9} = 0.15\ (m)}$ $\boxed{\sqrt{2\pi} \approx \sqrt{6.28} \approx 2.5}$

(a) Find the level crossing rates and average fade durations for $\rho = 0.1$ with user mobility $v = 72$ and 4 km/hr.

① $v = 72\ km/hr = 20\ m/s$

$$f_m = \frac{v}{\lambda_c} = \frac{20}{0.15} = \frac{400}{3}\ (Hz)$$

$$L_R = \sqrt{2\pi} f_m \rho e^{-\rho^2} = \sqrt{2\pi}\cdot\frac{400}{3}\times0.1\times e^{-0.01} \approx 2.5\times\frac{400}{3}\times0.1\times0.99 = 33\ (Hz)$$

$$\bar{t} = \frac{e^{0.01}-1}{0.1\times\frac{400}{3}\times\sqrt{2\pi}} = \frac{0.01}{0.1\times\frac{400}{3}\times2.5} = 0.3\ (ms)$$

② $v = 4\ km/hr = \frac{10}{9}\ m/s$

$$f_m = \frac{v}{\lambda_c} = \frac{\frac{10}{9}}{0.15} = \frac{200}{27}\ (Hz)$$

$$L_R = \sqrt{2\pi}\cdot\frac{200}{27}\times0.1\times e^{-0.01} = \frac{5.5}{3} \approx 1.83\ (Hz)$$

$$\bar{t} = \frac{0.01}{0.1\times\frac{200}{27}\times2.5} = 5.4\ (ms)$$

(b) Does the system perform well for $v = 72$ and 4 km/hr? Why?

If the average fade duration is shorter than the interleaving interval, the system can perform well, Otherwise, it cannot.

① $v = 72\ km/hr$, $\because$ 0.3 ms < 5 ms, $\therefore$ it can perform well

② $v = 4\ km/hr$, $\because$ 5.4 ms > 5 ms, $\therefore$ it cannot perform well

(c) If the interleaving interval is now changed to 20 ms, does the system perform well for $v = 72$ and 4 km/hr? Why?

Both average fade duration are shorter than 20 ms, so both systems can perform well.

(d) If an additional power margin of 14 dB is required (i.e., a higher normalized level ρ is required) for a specific performance requirement, find the average fade duration for $v = 72$ and 4 km/hr. Does the system perform well for $v = 72$ and 4 km/hr? Why?

Power = 14 dB $\Rightarrow$ Gain = 7 dB = 10 dB − 3 dB = $\frac{10}{2} = 5$ $\Rightarrow \rho = 0.1\times5 = 0.5$

① $v = 72\ km/hr \Rightarrow \bar{t} = \frac{e^{0.25}-1}{0.5\times\frac{400}{3}\times2.5} = \frac{0.284}{0.5\times\frac{400}{3}\times2.5} \approx 1.7\ (ms)$

$\because$ 1.7 ms < 5 ms, $\therefore$ it can perform well

② $v = 4\ km/hr \Rightarrow \bar{t} = \frac{0.284}{0.5\times\frac{200}{27}\times2.5} \approx 30.7\ (ms)$

$\because$ 30.7 ms > 5 ms, $\therefore$ it cannot perform well

12. The received signal power in free space can be represented as $P_r = P_t\left(\frac{\lambda_c}{4\pi d}\right)^2$. In land mobile radio applications, it is assumed that the propagation is over a flat reflecting surface as shown in Fig. 1. Please show that P_r is inversely proportional to d^4 for $d \gg h_b h_m$. [Hint: the reflection coefficient is $\alpha_v = -1$, and $\Delta\phi = \frac{2\pi\Delta d}{\lambda_c}$ is the phase difference of the two paths.]

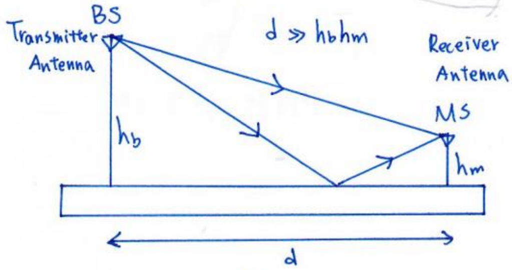


Fig. 1.

$$P_r = P_t\left(\frac{\lambda_c}{4\pi d}\right)^2 \left|1+\alpha_v e^{j\Delta\phi}\right|^2$$

$$= P_t\left(\frac{\lambda_c}{4\pi d}\right)^2 (1-e^{j\Delta\phi})(1-e^{-j\Delta\phi})$$

$$= P_t\left(\frac{\lambda_c}{4\pi d}\right)^2 4\sin^2\left(\frac{\Delta\phi}{2}\right) \cdots ☆$$

$$\begin{cases} d_1(\text{LOS}) = \sqrt{(h_b-h_m)^2+d^2} = d\sqrt{1+\left(\frac{h_b-h_m}{d}\right)^2} \overset{d\gg h_b h_m}{\approx} d\left(1+\frac{(h_b-h_m)^2}{2d^2}\right) \\ d_2 = \sqrt{(h_b+h_m)^2+d^2} = d\sqrt{1+\left(\frac{h_b+h_m}{d}\right)^2} \approx d\left(1+\frac{(h_b+h_m)^2}{2d^2}\right) \end{cases}$$

$$\Rightarrow \Delta d = d_2 - d_1 = \frac{1}{2d}\times 4 h_b h_m = \frac{2h_b h_m}{d}$$

$$\Rightarrow \Delta\phi = \frac{2\pi\Delta d}{\lambda_c} = \frac{4\pi h_b h_m}{\lambda_c d} \text{ 代入 } ☆$$

$d \gg h_b h_m \Rightarrow \frac{2\pi h_b h_m}{\lambda_c d}$ is small $\Rightarrow \sin^2\left(\frac{2\pi h_b h_m}{\lambda_c d}\right) \approx \left(\frac{2\pi h_b h_m}{\lambda_c d}\right)^2$

$$P_r = P_t\left(\frac{\lambda_c}{4\pi d}\right)^2 4\sin^2\left(\frac{2\pi h_b h_m}{\lambda_c d}\right) \approx P_t\left(\frac{\lambda_c}{4\pi d}\right)^2 \cdot 4 \cdot \left(\frac{2\pi h_b h_m}{\lambda_c d}\right)^2$$

$$= P_t \cdot \frac{(h_b h_m)^2}{d^4} \propto \frac{1}{d^4}$$

13. Some parameters are used to characterize a frequency-selective fading channel, including ① multipath intensity profile (σ_τ), ② Doppler spread (B_d), ③ coherence bandwidth (B_c; $\updownarrow$ delay spread), and ④ coherence time (T_c).

(a) Determine which parameters rely on the propagation environments, such as urban, suburban or open area. Why?

①, ③, multipath intensity profile σ_τ 和 coherence bandwidth B_c 跟傳輸環境有關，因為 σ_τ 是 delay time τ 所推得的，又在不同環境干擾下，delay time τ 也會不同，σ_τ: urban > suburban > open area，而 B_c 正比於 σ_τ 之倒數，i.e., $B_c \propto \frac{1}{\sigma_\tau}$，因此不同環境傳輸所形成不同的 delay time τ，也會有不同 B_c

(b) Determine which parameters rely on user mobility. Why?

②, ④, Doppler spread $B_d = f_D = \frac{V}{\lambda_c}\cos\theta$，因此不同速度所產生 f_D 不同，即 B_d 不同，而 coherence time T_c 正比於 doppler spread 之倒數，i.e., $T_c \approx \frac{1}{B_d}$，所以不同 mobility 下，會形成不同 doppler spread B_d，也會有不同的 coherence time T_c

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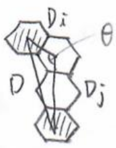
(a). With the different environment, the multipath effect will be different as well. Therefore, delay spread depends on the propagation environment. Moreover, Coherence bandwidth is inverse to the delay spread, and thus depends on the propagation environment, too.

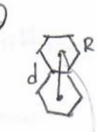
(b) When the user is moving, there will be Doppler effect. When the user moves faster, coherence time will be smaller.

14. For hexagonal cells, show that $D=\sqrt{3N}R$ by using law of cosines (cosine formula) where D is co-channel reuse distance, N is frequency reuse factor, and R is cell radius.

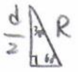
六角形

① 

斜線cell為同類

② 

$d=2(\frac{\sqrt{3}}{2})R = \sqrt{3}R$



由圖① ：令 $D_i = id$, $D_j = jd$

$$\Rightarrow D^2 = D_i^2 + D_j^2 - 2D_iD_j\cos\theta,\ \theta = 120^\circ$$
$$= i^2d^2 + j^2d^2 - 2\times(-\tfrac{1}{2})\,ij\,d^2$$
$$= d^2(i^2+j^2+ij) = d^2 \cdot N$$
$$\overset{\boxed{d=\sqrt{3}R}}{=} 3R^2N$$
$$\Rightarrow D = \sqrt{3N}R$$

15. Consider a mobile communication system using a specific frequency band in a specific environment.

(a) Is it possible for a receiver to reduce the experienced coherence time (T_c)? Why?

Yes, since $T_c \propto \frac{1}{D_s}$, if receiver move faster, then D_s will be increased and T_c will be reduced.

(b) Is it possible for a receiver to reduce the experienced coherence bandwidth (W_c)? Why?

No, since $W_c \propto \frac{1}{T_d}$ (delay spread) and T_d is related to specific propagation environment, the receiver can't change this specific propagation environment, then T_d will not changed if specific propagation environment is not changed. So, W_c will not changed.

(c) How to assure that the experienced communication channel is frequency non-selective (flat)?

In time domain, need symbol duration >> delay time spread

In frequency domain, need signal bandwidth << coherence bandwidth

(d) How to assure that the experienced communication channel is frequency selective (non-flat)?

In time domain, need symbol duration << delay time spread

In frequency domain, need signal bandwidth >> coherence bandwidth

16.

(a).
$$y^{(a)} = U_r^H y = U_r^H G x + U_r^H w$$
$$= U_r^H G U_t x^{(a)} + U_r^H w$$
$$\triangleq G^{(a)} x^{(a)} + w^{(a)}$$

$\boxed{G^{(a)}: \text{the angular-domain channel matrix}}$

故 $G^{(a)} = U_r^H G U_t$

(b) 由上式可知，$G^{(a)}$ 維度為 $N_r \times N_t$

非零 element 個數即為不同路徑的數量 $= L$

17. 定義

(a) Delay spread

The distance between the time of anival of the earliest significant multipath component and the time of arrival of the last multipath components.

(b) Doppler spread

The range of frequencies over which the received Doppler spectrum is essentially non zero.

(c) Coherence time

The time duration over which the channel impulse response is considered to be not varying.
通道脈衝響應被認為沒有變化的時間間隔

(d) Coherence bandwidth

The bandwidth or frequency interval over which two frequencies of a signal are likely to experience comparable or correlated amplitude fading.
信號的兩個頻率可能 experience comparable or correlated amplitude fading 的最大頻寬

(e) Relationship among the four channel characteristics

$$\text{coherence time} \approx \frac{1}{\text{Doppler spread}}$$

$$\text{coherence bandwidth} \propto \frac{1}{\text{delay spread}}$$

18. (a) BS → MS in macrocellular

BS → MS in macrocellular : isotropic scattering

The MS is surrounded by many objects so that there are a lot of reflection paths in different directions. The arriving plane waves arrive from all directions with equal probability. In general, no direct LOS path exists between an MS and the BS.

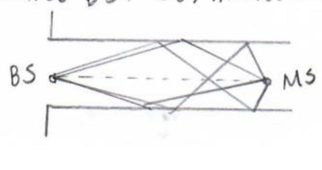
(b) MS → BS in macrocellular

MS → BS in macrocellular : not isotropic scattering

Usually, the BS is located at a high position, where does not have a lot of objects around it. The plane waves tend to arrive from one general direction.

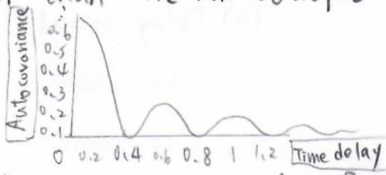
(c) Microcelluar system

In a microcellular environment, the plane waves may be channeled by the buildings along the streets and arrive at the receiver from just one direction. The BS antennas are only moderately elevated above the local scatterers. A direct LOS path may exist between the MS and the desired BS. So, microcellular is not isotropic scattering.
適度地 提高



(d) Macrocell system

For isotropic scattering, the spatial correlation decreases much faster than the non-isotropic scattering's.



MS: The signal is istropic scattered

BS: The arriving plane waves at the BS tend to be concentrated in a narrow angle of arrival (non-isotropic scattering). The spatial correlation is higher than isotropic scattering

19. (a) $\rho = \dfrac{100000 \times 1.8 \times 3}{60 \times 200} = 45$ Erlangs/cell

$N = 273/7 = 39$ (The maximum number of channels per cell)

By the table, the maximum cell blocking rate is about 20%

(b) For $N=39$ and blocking rate is 2%,

$\rho = 30.1 = \dfrac{100000 \times 1.8 \times 3}{60 \times \text{cells}} \Rightarrow \text{cells} \approx 300$

(c) $\rho = \dfrac{120000 \times 1.8 \times 3}{60 \times 300} = 20 \times 1.8 = 36$

By the table, the number of channels needed is $46 \times 7 = 322$ channels

20. Frequency selective 和 Frequency non-selective 比較

(a) Frequency selective: signal bandwidth > coherence bandwidth

信號在不同頻率遇到的 fading gain 及 random phase 差異大

Frequency non-selective: signal bandwidth ≪ coherence bandwidth

信號在各頻率成份遇到的 fading 狀況大致相同

(b) Frequency selective: time spread ($= \tau_i - \tau_j$) 相對於 symbol duration 而言是明顯的，此時 inter-symbol interference 發生，∴設計 Receiver 時可能需要 equalizer 或 RAKE RX.

Frequency non-selective: time spread 相對於 symbol duration 而言是不明顯的，∴ Receiver 的設計較簡單

21. Consider an antenna with gain 17dBi; If the required output signal power is 29dBW, determine the input signal power in W.

(dB) = 10 log (W)

$\because 29\,dB = 10\log_{10}(P_o)$, $\therefore P_o = 10^{2.9}$ W

$\because 17\,dB = 10\log_{10}\left(\frac{P_o}{P_i}\right)$, $\therefore P_i = \dfrac{10^{2.9}}{10^{1.7}} = 10^{1.2}$ W