Q1 [70 pts] – Miscellaneous Questions

a) **[20 pts]** In a wireless system, when the path-loss is measured as 70 dB, the corresponding spectral efficiency is calculated as 2.7 bits/sec/Hz according to Shannon's channel capacity formula. Find the spectral efficiency when the path-loss is 80 dB.

(*) $SE_1 = 2.7 = \log_2(1+SNR_1) \Rightarrow SNR_1 = 2^{2.7} - 1 = 5.5$

$\Rightarrow SNR_2 = 0.55$

$SE_2 = \log_2(1+0.55) = 0.63$ bps/Hz

b) **[50 pts]** Provide short yet accurate answers.

- **[10 pts]** Why is "**co-channel interference**" observed in cellular networks?

(*) Reuse of same freq channel in other cells.

- **[10 pts]** Briefly describe "**inter-cell interference coordination (ICIC)**". Why has this concept become important in 4G cellular networks?

(*) Main Elements of ICIC:

→ A neighboring BSs collaborate for resource allocation or interference management.

→ Each RB can have separate reuse pattern.

(*) ICIC has become important due to desire for increased reuse.

- **[10 pts]** What is the main benefit of the "**small cell deployment**" concept which is an emerging technology in cellular networks?

(*) Area capacity.

Partial mark for lower pathloss, higher reuse.

- **[10 pts]** What is the difference between FDD and FDMA?

FDD:

(*) All the signals to share a common medium reside at ~~all~~ the same location → downlink in wireless.

FDMA:

Signals to share a common medium are distributed → uplink in wireless.

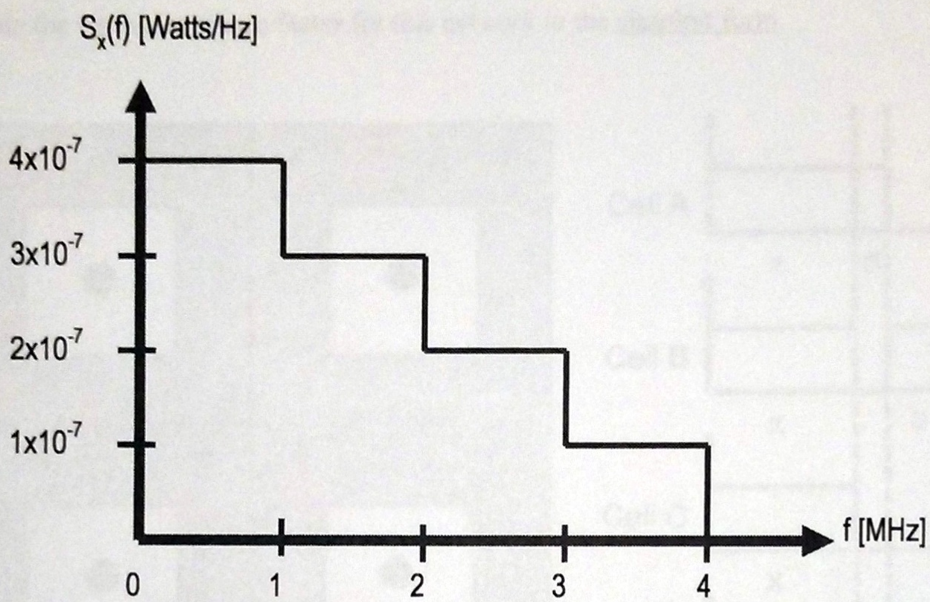
- **[10 pts]** Why is SATCOM (satellite communications) not commonly used in 4G cellular networks?

(*) large footprint is the main problem.

The footprint is analogous to cell size; in a capacity limited network, large cell is not good.

Q2 [40 pts] – Power Spectal Density (8pt x5)

The power spectral density, $S_x(f)$, for a digital signalling scheme is given below:



a) Find the total power of this signalling scheme.

b) How much power does this signalling scheme has between 2 MHz and 3 MHz?

c) How much power does this signalling scheme has at 3 MHz?

d) Find the absolute bandwidth of this signalling scheme.

e) $BW_{90\%}$ (90%-bandwidth) is defined as the frequency below which 90% of the total power is confined to. Find $BW_{90\%}$ for this signalling scheme.

(a) $\int_{-\infty}^{+\infty} S_x(f)\,df = 2\int_0^{\infty} S_x(f)\,df = 2\times10^6\times(4+3+2+1)\times10^{-7} = 2\ W$

(symmetry) ← PSD is double sided symmetric function.

(b) $2\int_{2\times10^6}^{3\times10^6} 2\times10^{-7}\,df = 0.4\ W.$

(c) Zero

(d) 4 MHz

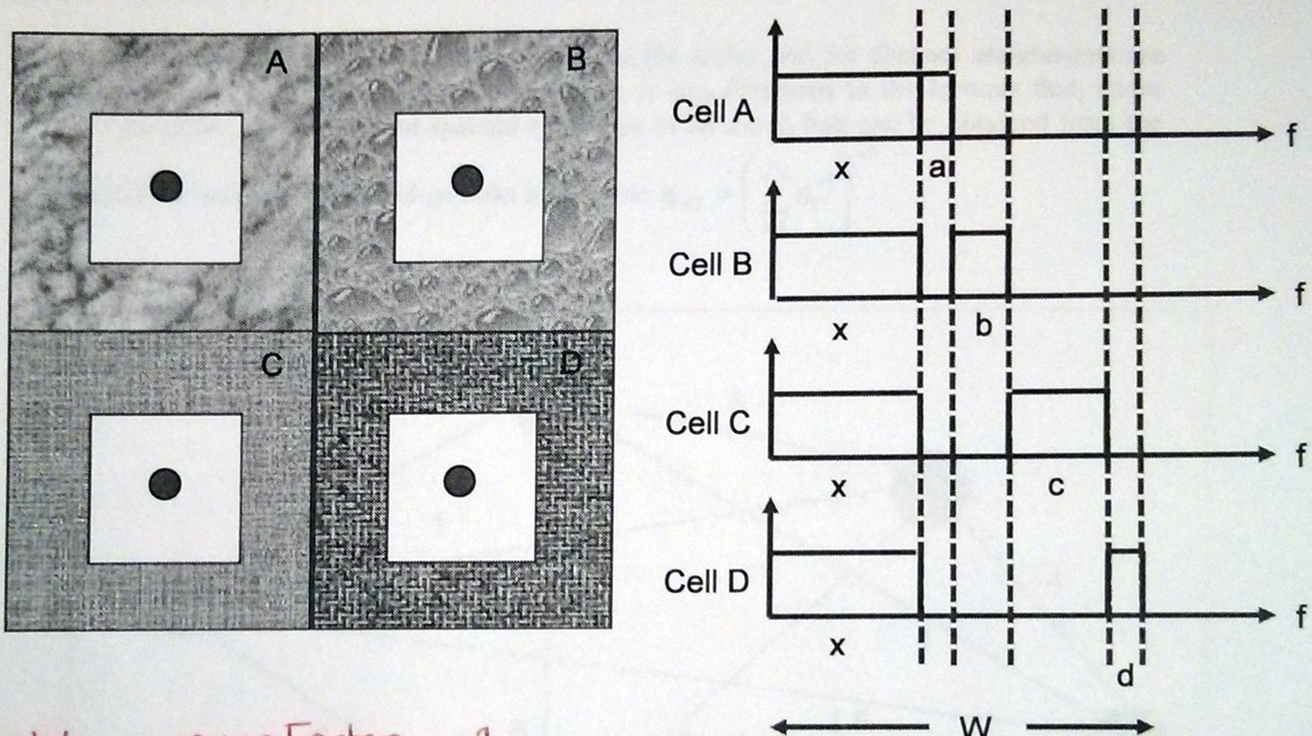
(e) Find f_c such that $\int_0^{f_c} S_x(f)\,df = 0.9\times BW$

$\Rightarrow f_c = 3\ MHz.$

Q3 [35 pts] – Fractional Frequency Reuse (FFR)

In a cellular network the fractional frequency reuse pattern is shown in the below. The total bandwidth is W Hz. A fraction of this (xW Hz) is used in the centre of each cell. The remaining portion is used in an orthogonal manner among the four cells. Note that x, a, b, c, d are fractions in the range [0, 1].

Obtain the equivalent reuse factor for this network in the simplest form.



For xW reuse Factor $= 1$

For aW, bW, cW, dW reuse Factor $= \frac{1}{4}$

Eq. reuse Factor $= x + \frac{1}{4}(a+b+c+d) = x + \frac{1}{4}(1-x)$

$= \frac{4x - x + 1}{4}$

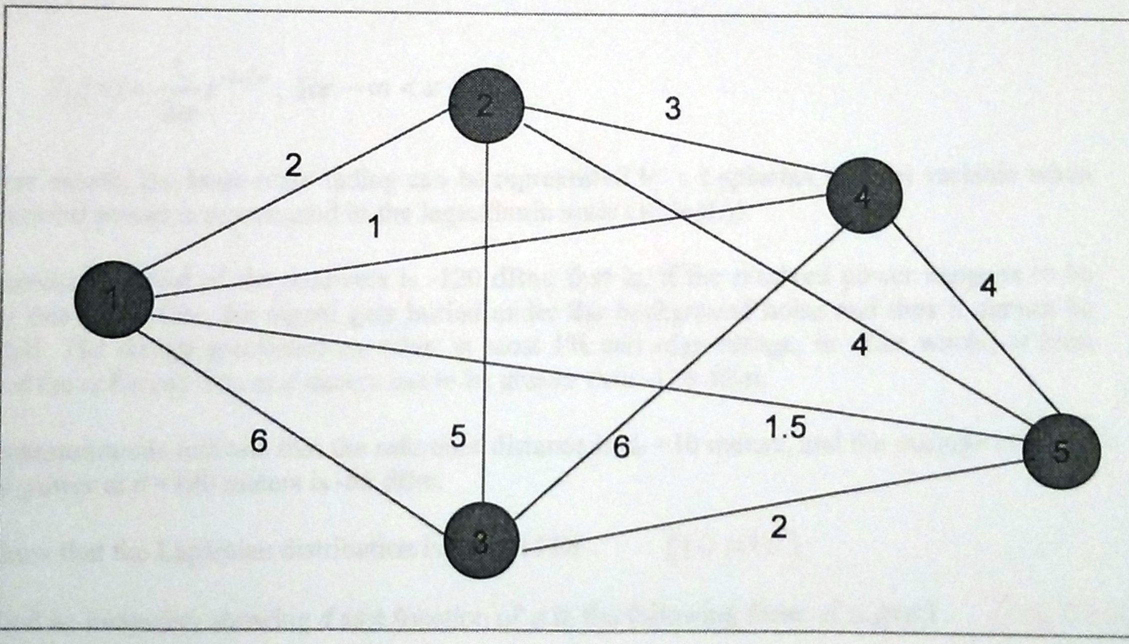
$\Rightarrow \frac{3x+1}{4}$

Q4 [35 pts] – Wireless Multihop Networks

The below figure shows a wireless network with five nodes. Node 1 is the source and Node 5 is the destination; the other three nodes denote the potential relays. The spectral efficiency value of each link is shown in the figure. The source and destination can be connected directly (single-hop), or through n hops with $n = 2, 3, 4, \ldots$

How should source and destination be connected if the main goal is to maximize the link rate? Substantiate your answer.

Help: Assume that there is no scheduling delay at the nodes and the channel assignments are done in an orthogonal manner (no channel reuse). It was discussed in the lectures that, under these assumptions, the equivalent spectral efficiency of an n-hop link can be obtained from the spectral efficiencies of the individual links as follows: $\eta_{nH} = \left(\sum_{i=1}^{n} \eta_i^{-1}\right)^{-1}$.



Max $\frac{1}{\sum \eta_i^{-1}} \equiv$ Min $\sum \eta_i^{-1}$

The efficient method is to use shortest Path Alg.

Briefly, starting from dest or source, each time find single hop shortest $\frac{1}{\eta_i}$ (or highest η_i) and eliminate all other Paths.

Therefore, ① → ③ → ④ → ⑤ $\eta = \frac{1}{\frac{1}{4}+\frac{1}{6}+\frac{1}{6}} = \frac{24}{14} = 1.7$

Q5 [40 pts] – Coverage in Cellular Networks

In a suburban cellular network, the coverage region of a single base station has to be found in order to determine the total number of base stations needed to be deployed.

Consider a circular region with a radius of d meters; a base station is located at the centre of this region to provide coverage.

Local average received power measurements are made, and it is found that the measured data fits a distant-dependent mean power law model (with a propagation exponent of 4) having a "log-Laplacian" distribution about the mean:

$$P_r(d)\ [\text{dBm}] = \overline{P_r(d)}\ [\text{dBm}] + X_\sigma\ [\text{dB}],$$

$$\overline{P_r(d)}\ [\text{dBm}] = P_r(d_0)\ [\text{dBm}] + 40\log(d_0/d)\ [\text{dB}].$$

In the above X_σ represents a Laplacian random variable, with parameter $\sigma > 0$, which has the following PDF:

$$f_X(x) = \frac{1}{2\sigma} e^{-|x|/\sigma}, \text{ for } -\infty < x < \infty.$$

In other words, the large-scale fading can be represented by a Laplacian random variable when the received power is represented in the logarithmic scale (10 log(.)).

The sensitivity level of the receivers is -120 dBm; that is, if the received power happens to be below this level, then the signal gets buried under the background noise and thus it cannot be detected. The design specifications allow at most 1% cell edge outage; in other words, at least 99% of the collected data at d meters has to be greater than -120 dBm.

The measurements indicate that the reference distance is d_0 =10 meters, and the average received signal power at d=100 meters is -55 dBm.

(a) Show that the Laplacian distribution is a valid PDF. (10 pts)

(b) Find an inequality showing d as a function of σ in the following form: $d \le g(\sigma)$. (25 pts)

(c) If the measurements indicate that σ = 4.2, find the maximum area that can be given service with a single base station. (5 pts)

ⓐ $\int_{-\infty}^{+\infty} \frac{1}{2\sigma} e^{-|x|/\sigma} = \frac{1}{2\sigma}\left(\int_{-\infty}^{0} e^{x/\sigma} dx + \int_{0}^{\infty} e^{-x/\sigma} dx\right)$

$= \frac{1}{2\sigma}\left(\sigma e^{x/\sigma}\Big|_{-\infty}^{0} - \sigma e^{-x/\sigma}\Big|_{0}^{\infty}\right) = 1$

ⓑ $Pr(d) = Pr(d_0) + 40 \log d_0/d + X_\sigma$

1st requirement $Pr(100) = -55 \Rightarrow Pr(d_0) = -15$

2nd requirement $Prob(Pr(d) < -120) \leq 0.01$

$\Rightarrow Prob(-15 + 40 \log 10 - 40 \log d + X_\sigma < -120) \leq 0.01$

$\Rightarrow Prob(X_\sigma < 40 \log d - 145) \leq 0.01$

$\Rightarrow \int_{-\infty}^{40 \log d - 145} \frac{1}{2\sigma} e^{\frac{-|x|}{\sigma}} dx \leq 0.01$ Assume $40 \log d - 145 \leq 0$

$\Rightarrow \frac{1}{2\sigma}\left(\int_{-\infty}^{40 \log d - 145} e^{+x/\sigma} dx\right) \leq 0.01$

$\Rightarrow \frac{1}{2\sigma}\left(+\sigma e^{+\frac{x}{\sigma}}\Big|_{-\infty}^{40 \log d - 145}\right) \leq 0.01$

$\Rightarrow e^{\frac{40 \log d - 145}{\sigma}} \leq 0.02$

$\Rightarrow d \leq \frac{145 + \sigma \ln(0.02)}{40}$

ⓒ $d_{max} = 10^{\frac{145 - 3.91 \times 4.2}{40}} \simeq 1638\ m$

$A = \pi d^2 \simeq 8,429,031\ m^2$