EEEN3008J: Advance wireless communications

Tutorial 1

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Problem 1

You are asked to design a cellular system for a tropical island with 60,000 total users. You will deploy 100 base stations with Omni-directional antennas. The average user makes 1 call per hour of length 2 minutes, and you may assume that users are distributed equally in all base stations. Due to the dense tropical vegetation, the path loss exponent is 4.2. The required S/I is 19 dB and assume a blocked-calls cleared system with $P_{r,block}$ of 5%. What is the minimum number of unique channels required to be allocated to this cellular system?

Solution to Problem 1

Hexagonal plan:

$$\frac{S}{I} \leq \frac{(3N)^{n/2}}{6}, 10^{19/10} \leq \frac{(3N)^{n/2}}{6}, 79.4 \leq \frac{(3N)^{n/2}}{6}, 476.4 \leq (3N)^{4.2/2}, 476.4 \leq (3N)^{2.1}, 18.8 \leq 3N,$$

$N \geq 6.3$, minimum $N = 7$

User number for each cell:

$$n_{\text{user}} = \frac{60000}{100} = 600$$

User traffic intensity:

$$A_u = \lambda H = \frac{2}{60}$$

Total offered traffic intensity per cell:

$$T_{\text{tr}} = n_{\text{user}} A_u = 20$$

From Erlang B chart, use $T_{\text{tr}} = 20$ and $\mathrm{Pr}_{block} = 0.05$, we get $N_C = 25$

Minimum number of unique channels:

$$NN_C = 7(25) = 175$$

Problem 2

A cellular system requires S/I ratio of only 12 dB. The path loss exponent is found to be 2.9.

(a) What N is required for omni-directional antennas?

(b) What N is required for 120^o sector antennas?

Solution to Problem 2

What we have are:

Required $\mathrm{SIR} = 12\mathrm{dB}$

$n = 2.9$

We assume it's hexagonal cell planning

(a) Omin antenna

$$\frac{S}{I} \leq \frac{(3N)^{n/2}}{6},\quad 10^{12/10} \leq \frac{(3N)^{2.9/2}}{6},\ 15.8 \leq \frac{(3N)^{2.9/2}}{6},\ 94.8 \leq (3N)^{2.9/2},\ 23.1 \leq 3N$$

$N \geq 8$, since we don't have $N = 8$, we have to increase to $N = 9$

(b) Sector antenna

$$\frac{S}{I} \leq \frac{(3N)^{n/2}}{2},\quad 10^{12/10} \leq \frac{(3N)^{2.9/2}}{2},\ 15.8 \leq \frac{(3N)^{2.9/2}}{2},\ 31.6 \leq (3N)^{2.9/2},\ 10.8 \leq 3N$$

$N \geq 4,\ N = 4$

Problem 3

A cellular service provider decides to use a digital TDMA scheme which can tolerate a signal-to-interference ratio of 15dB in the worst case. Find the optimal value of N for (a) omnidirectional antennas (b) 120◦ sectoring, and (c) 60◦ sectoring. Should sectoring be used? If so which case should be used? Let the path loss exponent n = 4 and consider *trunking efficiency*.

Solution to Problem 3

$\boxed{3\text{-}5}$ (a) Let i_0 be the number of co-channel interfering cells, <u>for omni-derectional antennas</u>, $i_0 = 6$. Assume $n = 4$, we have

$$\frac{S}{I} = \frac{(\sqrt{3N})^n}{i_0} > 15\,dB = 31.623 \Rightarrow N > 4.59$$

$$\Rightarrow \underline{\underline{N = 7}}$$

(b) <u>For 120° sectoring</u>, $i_0 = 2$.

$$\frac{S}{I} = \frac{(\sqrt{3N})^n}{i_0} > 31.623 \Rightarrow N > 2.65 \Rightarrow \underline{\underline{N = 3}}$$

(c) <u>For 60° sectoring</u>, $i_0 = 1$.

$$\frac{S}{I} = \frac{(\sqrt{3N})^n}{i_0} > 31.623 \Rightarrow N > 1.87 \Rightarrow \underline{\underline{N = 3}}$$

From (a), (b) and (c) we can see that using 120° sectoring can increase the capacity by a factor of 7/3, or 2.333. Although using 60° sectoring can also increase the capacity by the same factor, it will decrease the trunking efficiency therefore we choose the 120° sectoring.

Decreased Trunking Efficiency due to Sectoring

- The decreased trunking efficiency due to sectoring can be shown by comparing the probability of blocking for both the sectored and unsectored case
- Probability of blocking for a six sector case is

$$P_B(60^o) = \frac{\frac{(A/6)^{N/6}}{(N/6)!}}{\sum_{x=0}^{N/6} \frac{(N/6)^x}{x!}}$$

- Probability of blocking for a three sector case is

$$P_B(120^o) = \frac{\frac{(A/3)^{N/3}}{(N/3)!}}{\sum_{x=0}^{N/3} \frac{(N/3)^x}{x!}}$$

Decreased Trunking Efficiency due to Sectoring

- Probability of blocking for an unsectored case is

$$P_B(360^o) = \frac{\frac{(A)^N}{(N)!}}{\sum_{x=0}^{N} \frac{(N)^x}{x!}}$$

- From the above expressions we can see that

$$P_B(360^o) < P_B(120^o) < P_B(60^o)$$

Problem 4

Consider a cellular system in which an average call lasts two minutes, and the probability of blocking is to be no more than 1%. Assume that every subscriber makes one call per hour, on average. If there are a total of 395 traffic channels for a seven-cell reuse system, calculate the trunking efficiencies for (a) 60^{o} sectoring and (b) 120^{o} sectoring. Assume that blocked calls are cleared so the blocking is described by the Erlang B distribution.

Solution to Problem 4

If there are a total of 395 traffic channels for a seven-cell reuse system, there will be about 57 traffic channels per cell. Assume that blocked calls are cleared so the blocking is described by the Erlang B distribution. From the Erlang B distribution, it can be found that the unsectored system may handle 44.2 Erlangs or 1326 calls per hour.

Now employing 120° sectoring, there are only 19 channels per antenna sector (57/3 antennas). For the same probability of blocking and average call length, it can be found from the Erlang B distribution that each sector can handle 11.2 Erlangs or 336 calls per hour. Since each cell consists of three sectors, this provides a cell capacity of $3 \cdot 336 = 1008$ calls per hour, which amounts to a 24% decrease when compared to the unsectored case. Thus, sectoring decreases the trunking efficiency while improving the S/I for each user in the system.

It can be found that using 60° sectors improves the S/I even more. In this case, the number of first tier interferers is reduced from six to only one. This results in S/I = 29 dB for a seven-cell system and enables four-cell reuse. Of course, using six sectors per cell reduces the trunking efficiency and increases the number of necessary handoffs even more. If the unsectored system is compared to the six sector case, the degradation in trunking efficiency can be shown to be 44%

Problem 5

A total of 24 MHz of bandwidth is allocated to a FDD cell system that uses two 30 kHz simplex channels to provide full duplex voice and control channels. Assume each user generates 0.1 Erlangs of traffic (assume Erlang B is used).

a) Find the number of channels in each cell for a four-cell reuse system.
b) If each cell is to offer capacity that is 90% of perfect scheduling, find the maximum number of users that can be supported per cell where omnidirectional antennas are used at each base station.
c) What is the blocking probability of the system in (b) when the maximum number of users are available in each pool?
d) If each new cell now uses 120◦ sectoring instead of omnidirectional for each base station, what is the new total number of users that can be supported per cell for the same blocking probability as in (c)?
e) If each cell covers five square kilometers, then how many subscribers could be supported in an urban market that is 50 km × 50 km for the case of omnidirectional base station antennas?
f) If each cell covers five square kilometers, then how many subscribers could be supported in an urban market that is 50 km × 50m for the case of 120◦ sectored antennas?

Solution to Problem 5

(a) $\frac{24 \text{ MHz}}{2 \cdot 30 \text{ kHz}} = 400$ channels

$\frac{400 \text{ channels}}{4 \text{ cells}} = 100$ channels/cell

(b) 90% of 100 Erlangs = 90 Erlangs

$90 = U A_u = U(0.1) \Rightarrow U = 900$ users

(c) offered: 90E ; $C = 100 \Rightarrow 0.03$ from graph (Fig. 3-6)

3% GOS

(d) Each sector has 33.3 channels ; GOS = 3%

from graph (Fig. 3-6) $\Rightarrow \approx 25$ Erlangs/sector

$25 = U A_u$ (per sector)

$\Rightarrow U = 250 \times 3$ sectors

$U = 750$ users

(e) $\frac{2500 \text{ km}^2}{5 \text{ km}^2} = 500$ cells $\Rightarrow 500 \times 900$ users/cell $= 450{,}000$ users

(f) 500 cells $\Rightarrow 500 \times 750$ user/cell $= 375{,}000$ users