KUNGL TEKNISKA HÖGSKOLAN
Radio Communication Systems

Ik2502 Wireless Networks

Proposed Solution for Exam 100503:

Problem 1

a) From lecture notes (page 17) the assignment failure rate is written as follows:

$$\nu = \Pr\left(M \geq K_0\right) = e^{-F\rho} \sum_{n=K_0}^{+\infty} \frac{(F\rho)^n}{n!} = 1 - e^{-F\rho} \sum_{n=0}^{K_0-1} \frac{(F\rho)^n}{n!} = 20\%$$

With $F = 1.6$ and $\rho = 4$ we get $K_0 = L\left(1 + \frac{W}{R}\frac{1}{\gamma_t}\right) = 9$. With a load $L = 0.5$, this gives a required signal energy-to-noise power spectral density $\gamma_t = \frac{128}{1.6*(18-1)} = 6.72$ dB.

b) With a voice detection factor q the assignment failure rate becomes

$$\nu = \Pr\left(M \geq K_0\right) = e^{-qF\rho} \sum_{n=K_0}^{+\infty} \frac{(qF\rho)^n}{n!} = 1 - e^{-qF\rho} \sum_{n=0}^{9-1} \frac{(qF\rho)^n}{n!} = 5.7\%$$

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a

Assuming that the not-handover circle is completely inside the hexagon, the probability of soft handover can be written

$$P_{\text{soho}} = P(\text{outside circle}) = 1 - \frac{A_{\text{circle}}}{A_{\text{hexagon}}} = 1 - \frac{\pi r^2}{\frac{3}{2}\sqrt{3}\ R^2} = 1 - \frac{2\pi}{3\sqrt{3}}\rho^2$$

where $\rho = r/R$ is the normalized distance, $\rho = 1$ at a cell corner.

$$P_{\text{soho}} < 20\,\% \Rightarrow 1 - \frac{2\pi}{3\sqrt{3}}\rho^2 < 0.2 \Rightarrow \rho \gtrsim 0.81$$

Notice that $0.81 < \sqrt{3}\,/\,2$ so the circle *is inside* the hexagon. At distance r the received SIR is

$$\Gamma \approx \frac{\frac{1}{r^4}}{0.50 \times 7.7\ \frac{1}{\left(\sqrt{3K}\ R\right)^4}} \approx 2.3\,\frac{K^2}{\rho^4}$$

$$\Gamma = 10^{2.5},\ \rho \gtrsim 0.81 \Rightarrow K \gtrsim 7.7$$

The next Loeschian number is $K = 9$ so the cell capacity is

$$\eta = \left\lfloor \frac{C}{K} \right\rfloor = \left\lfloor \frac{120}{9} \right\rfloor = 13\,\text{ch./cell}$$

b

Since G_s and G_I are independent we have

$$G_{\text{dB}} = 10\log_{10}(G) = 10\log_{10}\left(\frac{G_s}{G_I}\right) = 10\log_{10}(G_s) - 10\log_{10}(G_I)$$

$$G_{\text{dB}} \in N\left(\mu_s - \mu_I,\ \sqrt{\sigma_s^2 + \sigma_I^2}\right) = N(\mu,\ \sigma)$$

Using the given values, we have

$$\Rightarrow \mu = 0 - 5 = -5\,\text{dB},\ \sigma = \sqrt{6^2 + 4.5^2}\ = 7.5\,\text{dB}$$

If $\rho = r/R = 1$ we can write, since $K = 9$

$$\Gamma = \frac{G_s\ \frac{1}{r^4}}{G_I\ \frac{1}{\left(\sqrt{3K}\ R\right)^4}} = G\,\frac{(3K)^2}{\rho^4} = G \times 3^6 \Rightarrow \Gamma_{\text{dB}} = G_{\text{dB}} + 60\log_{10}(3)$$

$$\Rightarrow \Pr(\Gamma_{\text{dB}} < 25\,\text{dB}) = \Pr\left(G_{\text{dB}} < 25 - 60\log_{10}(3)\right) = \Pr\left(\frac{G_{\text{dB}} - \mu}{\sigma} < \frac{25 - 60\log_{10}(3) - (-5)}{7.5}\right)$$

$$= \ \Phi\left(4 - 8\log_{10}(3)\right) \approx 0.57\ \text{(BETA)}$$

So, the probability of soft handover at the cell corner is 57 %.

IK2502 2010; Problem 5 Deployment and cost

Problem background:

A facility owner will build a new office area called Kista 2.0 with an estimated number of 10 000 workers from start. The facility owner wants to investigate the possibility to offer Internet over wireless connections and need to estimate the cost for deploying a new radio access networks. The facility owner has been in contact with 3 different operators that will offer different solutions. From the initial discussions the facility owner has some information about the three operators and now wants to get an initial cost estimate.

Your task is to help the facility owner and make this initial cost estimate for the estimated low and the high demand levels and based on the information provided below.
Which operator will most likely be able to offer the services at the lowest cost?

The demand

10 000 workers are to be served from year 1 in the 1 km2 area. Two levels of demand are of interest; 1,44 GB and 7,2 GB per month and user for low and high level respectively. For the dimensioning assume that the data is consumed during 8 busy hours (all equally busy) for 20 work days per month.

Data for operator A deployment

The incumbent operator A has 4 macro base stations sites in the area that can be re-used. In case new macro base station sites are needed the operator A has all necessary building permits. Operator A has access to 10 MHz of spectrum in this frequency band and will use the radio access technology WAD suitable for wide area deployment.

Data for operator B deployment

Operator B has no base stations sites at all in the area. New sites are needed and operator B has all necessary building permits. Operator B has access to 20 MHz of spectrum in this frequency band and will also use the radio access technology WAD.

Data for operator C deployment

The new operator C will offer an indoor solution based on deployment of a number of small pimentocell access points using the LAD radio access technology. The operator has a 20 MHz license for operating LAD equipment in this frequency band; hence cell planning can be made in order to avoid inter-cell interference. All access points and required transmission need to be installed from the beginning.

The radio access technology

The technical data and performance is shown in table 1. WAD has a re-use factor of 1. One WAD TRX module supports a three sector site and system bandwidth up to 20 MHz. The link budget for WAD is calculated to allow for 20 dB wall penetration losses which are sufficient for all locations in all buildings in the area.
In order to satisfy the coverage requirements in the buildings one pimentocell access point need to be deployed for every 10 user as long as the capacity requirements are met.

Table 1: Technical data for radio access technologies

Type of deployment	Radio access technology	System bandwidth	Spectral efficiency	Max cell range (for all bandwidths)
Indoor pimentocell	LAD	1 – 5	3	50 m
Outdoor macro site	WAD	5 – 20	1,67	600 m

Cost calculation

Estimate the total cost as the CAPEX plus the OPEX for years 1 to 5 assuming a discount rate of 0 %. All network build out is made year 0. Derive CAPEX numbers from data in tables 2. For macrocell deployment the annual OPEX is estimated to be 10 % of the total CAPEX including radio equipment, installation and all *new* macro base stations sites. For the pimentocell deployment the annual OPEX is estimated to be 20% of the total CAPEX including access point equipment, cabling, planning and installation.

Table 2: Cost estimates

WAM Radio equipment and installation	**Costs**
TRX supporting 3 sectors and up to 20 MHz, first TRX	10 k€
TRX supporting 3 sectors and up to 20 MHz, additional TRX	10 k€
Installation of the first TRX	10 k€
Deployment and macros site build out	
Site construction	70 k€ per site
Non-telecom equipment	20 k€ per site
Transmission costs	10 k€ per site
Pimentocell equipment and installation	
One access point, omnidirectional antenna, supports 5 MHz	300 €
Planning and installation of one access point	300 €
Cabling for one access point	400 €

SOLUTION

Demand
Compute demand as Mbps per person (8 busy hours and 20 days per month)
and for all 10000 persons
Low level: 1,44 GB per month => 20 kbps per person => 0,20 Gbps in total
High level: 7,20 GB per month => 100kbps per person => 1,00 Gbps in total

What can the solutions offer?
Wide area deployment
WAD with 10 MHz: 10*1,67*3 sectors = 50 Mbps per site
WAD with 20 MHz: 20*1,67*3 sectors = 100 Mbps per site
Coverage not a problem since one WAB can cover > 1 sqkm, i.e. the total area

Local area deployment
LAD with 5 MHz: 5*3*1 (omni) = 15 Mbps per access point
One pimentocells need to be deployed per 10 users
=> in total 1000 access points => 15 Gbps demand, i.e. >> demand

How many base station sites are needed?
Operator A (WAD with 10 MHz):
Low demand (0,2 Gbps) is met with 4 base station sites => already have 4 sites
High demand (1,0 Gbps) is met with 20 base station sites => 16 new sites are needed

Operator B (WAD with 20 MHz):
Low demand (0,2 Gbps) is met with 2 base station sites => 2 new sites are needed
High demand (1,0 Gbps) is met with 10 base station sites => 10 new sites are needed

Cost input
Deployment cost for one new macro site: 100 k€ (70k€+20k€+10k€)
Cost for one WAD TRX with installation: 20 k€ (10k€ +10 k€); just one TRX per site
Deployment and equipment cost for one pimentocell: 1k€ (300€+300€+400€)

Cost analysis

Solution	No sites = Existing + new	Costs for new sites (M€)	No TRX	Costs TRX (M€)	CAPEX year 0 (M€)	OPEX year1-5 (M€)	Total cost (M€)
WAD 10 MHz Low demand	4 = 4 + 0	0	4	4*0,02 = 0,08	= 0,08	5*0,008 = 0,04	0,12
WAD 10 MHz High demand	20 = 4+16	16* 0,1 = 1,60	20	20*0,02 = 0,40	= 2,00	5*0,20 = 1,00	3,00
WAD 20 MHz Low demand	2 = 0 + 2	2* 0,1 = 0,20	2	2*0,02 = 0,04	= 0,24	5*0,024 = 0,120	0,36
WAD 20 MHz High demand	10 = 0+10	10* 0,1 = 1,00	10	10*0,02 = 0,20	= 1,20	5*0,12 = 0,60	1,80
Pimentocell both low/high	1000 = 0 +1000	= 0,70	1000	= 0,30	= 1,00	5*0,2 = 1,00	2,00

Conclusions and recommendations

If the demand is believed to remain at the low level Operator A (10 MHZ and 4 existing sites) can be chosen. Lowest costs since no new sites need to be built.

If the demand is believed to be close to but not larger than the “high” level Operator B (20 MHZ and 10 new sites) provides the lowest cost due to less number of new sites.

If the demand is likely to be higher than the “high” level (1 Gbps) then Operator C with the indoor pimentocell solution should be chosen. The pimentocells provide almost the same cost as the WAD 20 MHz solution but provide a substantially higher capacity and hence is more future proof if the demand will increase.