Network dimensioning and cost structure analysis
+ Introduction to HW3

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Topics today

• The network dimensioning part of the course
• How to estimate user demand
• Network dimensioning
• Cost structure analysis
• About HW3
About network dimensioning, deployment and cost structure analysis

- Economics of wireless infrastructure, scalability cost-capacity trade-offs, spectrum allocation
- Network dimensioning, deployment and configuration strategies, impact of user demand
- Cost structure modeling & analysis of network, to calculate CAPEX, OPEX, Net present value
- Homework 3: Dimensioning and high level design of a wireless network incl. cost structure analysis
Homework 3

- For a specific user and traffic scenario you will
  - Make the dimensioning of a radio access network
  - Analyze the cost structure for different options

Agenda items

- To estimate demand
- Dimensioning of radio access network
- Capacity, data rates and spectral efficiency of radio access technologies (RAT)
- Trade offs using
  - Number of base station sites
  - Spectrum
  - Cell structure
- What to do when the demand increases?
- Cost structure analysis
Estimation of user demand

• How to describe demand
  – Location of users
  – Number of users
  – Service mix
  – Traffic per user

• How to estimate demand for dimensioning

Population density in Skåne
Population density (persons per sqkm)

- Sweden average: 20
- Sweden rural areas: 1 – 10
- Sweden suburban areas: 100-1000
- Sweden urban areas: 1000 -10 000
- EU region rural areas: 100-200
- Malmö average: 2000
- Stockholm average: 4000
- Stockholm city: 25 000

Geographical data for Sweden

<table>
<thead>
<tr>
<th>Km²</th>
<th>Inhabitants</th>
<th>Inh./km²</th>
<th>Share of area</th>
<th>Share of population</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban</td>
<td>2 109</td>
<td>5 197 620</td>
<td>2 464</td>
<td>0,5% 57%</td>
</tr>
<tr>
<td>Suburban</td>
<td>23 780</td>
<td>3 249 652</td>
<td>137</td>
<td>5,2% 35%</td>
</tr>
<tr>
<td>Rural</td>
<td>431 473</td>
<td>732 206</td>
<td>1,7</td>
<td>94,3% 8%</td>
</tr>
<tr>
<td></td>
<td>457 362</td>
<td>9 179 478</td>
<td>20,1</td>
<td>100% 100%</td>
</tr>
</tbody>
</table>

92% of the population is living at 6 % of the total area
8% of the population is living at 95% of the total area
Estimation of user demand

- The network dimensioning part of the course
- How to describe demand
  - Location of users
  - Number of users
- Service mix
  - Traffic per user
- How to estimate demand for dimensioning

Traffic, prices and revenues

Traffic and revenue for different services at the Swedish market Q4 2008

<table>
<thead>
<tr>
<th>EUR per MB</th>
<th>2007</th>
<th>2008</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voice</td>
<td>1.46</td>
<td>1.36</td>
</tr>
<tr>
<td>SMS</td>
<td>439.5</td>
<td>351.6</td>
</tr>
<tr>
<td>Mobile data (laptop)</td>
<td>0.014</td>
<td>0.011</td>
</tr>
</tbody>
</table>

Estimated price per MByte for voice, SMS and data for one Swedish operator
Amounts of data – orders of magnitude
(GB per month and person, 2010 Northern Europe)

- Voice traffic: 0.01-0.02 GB
- Smartphones: 0.10-0.20 GB
- Laptop MBB as complement: 1 – 5 GB
- Laptop MBB as substitute: 2 – 20 GB
- Fiber to the home (house hold): 100-200 GB

Distribution of mobile broadband usage
and subscriptions in Sweden Q4 2099

- Share of subscriptions:
  - < 0.1 G byte: 68%
  - 0.1 - 1 G Byte: 20%
  - 1 - 5 G Byte: 5%
  - > 5 G Byte: 7%

- Share of data usage:
  - < 0.1 G byte: 6%
  - 0.1 - 1 G Byte: 3%
  - 1 - 5 G Byte: 11%
  - > 5 G Byte: 80%
Estimation of user demand

- The network dimensioning part of the course
- How to describe demand
  - Location of users
  - Number of users
  - Service mix
  - Traffic per user

How to estimate demand for dimensioning

Demand estimates as input for dimensioning of network capacity

- Amount of data
  - per user, per time unit, per area unit
- Usage:
  - Amount of data per user and time unit
  - Example 1: 100MB per day
  - Example 2: 5 GB per month
  - needs to be expressed as kbps/Mbps per user
Demand estimates as input for dimensioning of network capacity

- Traffic
  - Amount of data per time unit per area unit
  - Depends on user density and usage per user
  - Example 1: 10 Mbps per sqkm
  - Example 2: 100 GB per day in a 2* 2 km area

Traffic density

- Suburban
- Urban area
- Rural area
Dimensioning Real time services

- For voice and RT data you need to estimate the maximum number of ongoing calls or session
  - Is based on the traffic during the “busiest hour”

Capacity dimensioning – The busy hour

[Diagram showing capacity deployment over time with blocked traffic highlighted]
Capacity dimensioning – Mobile broadband

Monthly demand of MBB spread out
- all days of the month
- all 24 hours of the day

For data NRT data traffic the approach with “average data rate” per user can be used
X GB per user and month -> Y kbps per user

Capacity dimensioning – Mobile broadband

Monthly demand of MBB spread out
- all days of the month
- 12 out of 24 hours of the day
Capacity dimensioning – Mobile broadband

Monthly demand of MBB spread out
- all days of the month
- 8 out of 24 hours of the day

Short exercise

- What is the average data rate per user?
  Example A.
  - Monthly usage 5.4 GB per user
  - Assume 30 days per month
  - Assume data used during 8 hours per day
  Example B.
  - Monthly usage 14.4 GB per user
  - Assume 20 (office) days per month
  - Assume data used during 4 hours per day

- What is the average data consumption per month for these cases?
  Example C.
  - The operator promises at least 1 Mbps
  - Assuming data usage 1 hour per day
  Example D.
  - The operator promises at least 8 Mbps
  - Assuming data usage 4 hours per day
Example of User demand – Mbps per sqkm

<table>
<thead>
<tr>
<th>Number of active users per sqkm</th>
<th>0,01</th>
<th>0,1</th>
<th>1</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>0,1</td>
<td>1,0</td>
<td>10</td>
<td>100</td>
</tr>
<tr>
<td>100</td>
<td>1</td>
<td>10</td>
<td>100</td>
<td>1000</td>
</tr>
</tbody>
</table>

Average data rate per user (Mbps)

Are these numbers realistic?

- Population density
  - Stockholm average: 4000/ sqkm
  - Malmö average: 2000/ sqkm
  - Stockholm city: ~25 000/ sqkm

- Penetration of mobile dongles
  - 20 % 2010 (may be 50% in the future)

- Market share of operator ~ 40 %
  - Share of all users in an area: 0.2 * 0.4 = 8%

- Check Mbps per sqkm!! - With 8% of all users
  - In area with 25 000 / sqkm => 2000 / sqkm
  - In area with 2 500 / sqkm => 200 / sqkm
  - In area with 250 / sqkm => 20 / sqkm
Capacity of a base station?

I. Bandwidth * spectral efficiency * No sectors / spectrum reuse

II. Bandwidth * No sectors / (spectrum reuse * spectral efficiency)

III. Bandwidth * No sectors * spectrum reuse / spectral efficiency

IV. Bandwidth * No sectors * Spectral efficiency
Capacity of a base station – type?

- Bandwidth * No sectors * Spectral efficiency

A. 5 MHz * 1 * 1 = 5 Mbps
B. 10 MHz * 3 * 1 = 30 Mbps
C. 20 MHz * 3 * 2 = 120 Mbps
D. 20 MHz * 1 * 10 = 200 Mbps

Implications for network deployment

- 1000 active users/sqkm, 50% market share => deploy capacity for 500 users /sqkm
- 5 GB usage per month per user
  ~ 15 kbps per user 24 hours all days for one month
  ~ 50 kbps per user during “daytime” for one month
- Capacity estimates for 500 users
  - 5 GB users: ~ 25 Mbps/sqkm
- Compare with throughput for one “cell”
  - “3G” using 5 MHz ~ 3.5 Mbps
  - “4G” using 20 MHz ~ 35 Mbps
Agenda items

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Traffic density

- Estimate the demand
  - Number of users per area unit
  - Usage per user
  - Different types of users
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**The dimensioning problem**

- Urban area
- Rural area
- HSPA
- UMTS
- GSM
The dimensioning problem

- To satisfy the demand
  - To “fill the demand box” with “resource cylinders”

Agenda items

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From Ericsson:
Capital markets day, May 2008

Coverage vs. bitrate

Double peak rate does not correspond to double capacity

Bit rate and range – Bandwidth and Radio Access Technology (RAT)

For a given amount of Spectrum (e.g. X MHz)
Bit rate and range – Bandwidth and Radio Access Technology (RAT)

For a given amount of Spectrum (e.g. X MHz)

For twice the amount of Spectrum (2 X MHz)
Deployment Downtown Stockholm
About promised data rates

"promised" data rate at "low" level

"promised" data rate at "higher" level

About promised data rates

"promised" data rate at "low" level

"promised" data rate at "higher" level
Base station site locations in urban areas
from PTS “Transmitter map” web page, December 2009

Downtown Stockholm

Kista Industry Area
Simple "cylinder" model

Spectral efficiency

Peak data rate
~10 - 20 bps per Hz

Average data rate
~1 - 2 bps per Hz

Cell border rate
< 0.10 bps per Hz
Spectral efficiency and cylinder model

Spectral efficiency and cylinder model
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Cellular systems - low data rates
Cellular systems – higher data rates, the same sites

Zander formula

\[ C_{\text{system}} \approx c_{AP} N_{AP} \approx c' N_{\text{user}} B_{\text{user}} A_{\text{service}} f(Q) \]

- \( N_{AP} \): the number of access points (base stations)
- \( N_{\text{user}} \): the number of users
- \( B_{\text{user}} \): the average data rate of the users
- \( A_{\text{service}} \): the service area covered (volume indoors)
- \( f(Q) \) is a function of the required Quality of Service.
Amount of spectrum and number of sites

Example: New Kista area, 10 000 office workers

- Spectral eff = 1.70 (LTE type)
- Spectral eff = 0.70 (HSPA type)

Short exercise – work in 4 groups

- How many base station sites need to be deployed in the following cases?
  - Operator A, LTE in the 2.6 GHz
  - Operator B, HSPA in the 2.6 GHz
  - Operator C+D, LTE in the 2.6 GHz band and share network
  - Operator E, LTE using unlicensed 1800 MHz band
- You are allowed to ask me one question per group
Cases for different Swedish operators using 2.6 GHz band

Cases for different Brazilian operators

Cases for different UK operators
What to do when the demand increases?

- Deploy a denser network
  - Add more sites (number of AP´s)
- Increase the bandwidth
  - Add more carriers
- Add sectors at existing sites
  - Add antennas and radio equipment
What to do when the demand increases?

![Diagram showing options to increase capacity: Add carriers, Add new sites, Sectorize!]

- **New target capacity**
- **Old capacity**

Add carriers  Add new sites  Sectorize!

**Capacity of a cell as function of Spectral Efficiency and amount of spectrum**

<table>
<thead>
<tr>
<th>Spectral efficiency</th>
<th>5 MHz of Spectrum</th>
<th>10 MHz of Spectrum</th>
<th>20 MHz of Spectrum</th>
</tr>
</thead>
<tbody>
<tr>
<td>0,7 bps/Hz</td>
<td>3,5 Mbps</td>
<td>7,0 Mbps</td>
<td>14 Mbps</td>
</tr>
<tr>
<td>2,0 bps/Hz</td>
<td>10 Mbps</td>
<td>20 Mbps</td>
<td>40 Mbps</td>
</tr>
</tbody>
</table>

- Using a base station site with 3 sectors (cells) will result in a site capacity 3 times higher
- Example:
  - With a radio access technology with spectral efficiency = 2 bps/Hz and 20 MHz of spectrum
  - the site capacity = 120 Mbps
A short exercise: how many users can be served, in a cell with capacities as below?

<table>
<thead>
<tr>
<th>Spectral efficiency</th>
<th>5 MHz of Spectrum</th>
<th>10 MHz of Spectrum</th>
<th>20 MHz of Spectrum</th>
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<td>7,0 Mbps</td>
<td>14 Mbps</td>
</tr>
<tr>
<td>2,0 bps/Hz</td>
<td>10 Mbps</td>
<td>20 Mbps</td>
<td>40 Mbps</td>
</tr>
</tbody>
</table>

- Use the “user demand” A, B C or D from before

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Cost structure analysis
Cost structure of radio access networks

- It is not only costs for the base station equipment (the radio) but also for the transmission & sites

Cost and capacity - examples

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Cost [kEuro]</th>
<th>Capacity [Mbps]</th>
</tr>
</thead>
<tbody>
<tr>
<td>EDGE Macro BTS, 3 TDMA carriers</td>
<td>10</td>
<td>0,7</td>
</tr>
<tr>
<td>EDGE Macro BTS, additional sector</td>
<td>5</td>
<td>0,7</td>
</tr>
<tr>
<td>EDGE upgrade for existing GSM Macro</td>
<td>5</td>
<td>0,7</td>
</tr>
<tr>
<td>WLAN AP (1 AP per site)</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>UMTS Macro BTS, first cell at site</td>
<td>20</td>
<td>1</td>
</tr>
<tr>
<td>UMTS Macro BTS, additional cells (sectors or carriers)</td>
<td>10</td>
<td>1</td>
</tr>
<tr>
<td>UMTS Micro BTS, one cell only (i.e. no build out)</td>
<td>10</td>
<td>1</td>
</tr>
<tr>
<td>HSDPA Macro BTS, first cell at site</td>
<td>25</td>
<td>3</td>
</tr>
<tr>
<td>HSDPA Macro BTS, additional cells (sectors or carriers)</td>
<td>15</td>
<td>3</td>
</tr>
<tr>
<td>HSDPA Micro BTS, one cell only (i.e. no build out)</td>
<td>15</td>
<td>3</td>
</tr>
</tbody>
</table>
Financial aspects

- Price erosion
- Discounted cost model
  - We need to consider the time and how the value of changes over time
  - Net Present Value calculation

Price erosion

- All costs; equipment, leases, labour etc have an associated “cost trend”
- One example is Moore law for electronics
  - The performance/cost ratio is doubled every 18th month
- For price erosion 5 % you get

<table>
<thead>
<tr>
<th>Year</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>1</td>
<td>95</td>
</tr>
<tr>
<td>2</td>
<td>90.25</td>
</tr>
<tr>
<td>3</td>
<td>85.7375</td>
</tr>
<tr>
<td>4</td>
<td>81.45063</td>
</tr>
<tr>
<td>5</td>
<td>77.37809</td>
</tr>
<tr>
<td>6</td>
<td>73.50919</td>
</tr>
</tbody>
</table>
NPV calculation

- We need to consider the time and how the value of changes over time
- Net Present Value calculation (NPV in Excel)

<table>
<thead>
<tr>
<th>Year</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value</td>
<td>V1</td>
<td>V2</td>
<td>V3</td>
<td>V4</td>
</tr>
</tbody>
</table>

V1_1
V2_1
V3_1
V4_1
Homework 3

- For a specific user and traffic scenario you will
  - Make the dimensioning of a radio access network
  - Analyze the cost structure for different options