

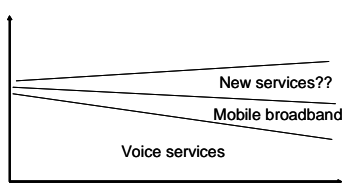


Wireless Infrastructure Economics: Capacity, cost and spectrum

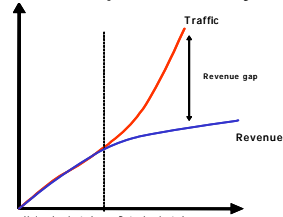
Jan Markendahl, Associate Professor,
Wireless Infrastructure Deployment and Economics
Communication Systems, KTH
March 2, 2016

Operator challenges – business related

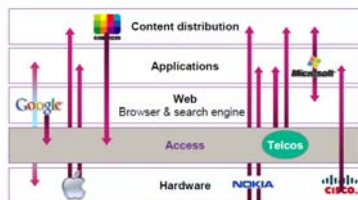
Revenue mix



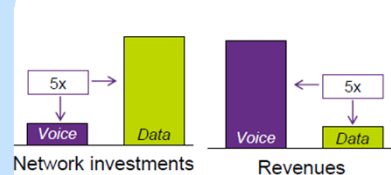
MBB profitability



The business landscape



Investments



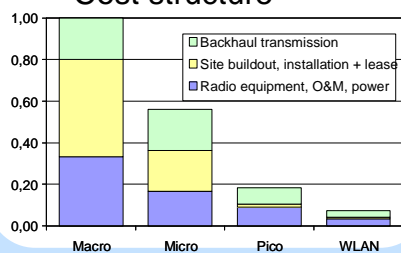
Traffic, prices and revenues



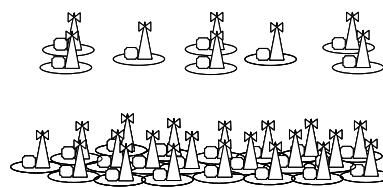
- Amount of voice data 10-20 MB per month
- Amount of mobile broadband data 1–20 GB per month
 - The number of mobile broad band bits are 100 – 1000 more than the number of voice bits
- But we pay more or less the same, i.e. the price per data bit is 100 – 1000 times lower => the cost per bit must be 100 – 1000 lower

Operator challenges – network related

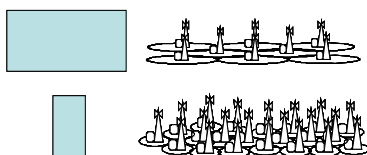
Cost structure



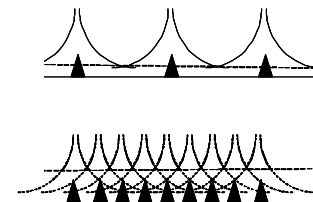
Scalability



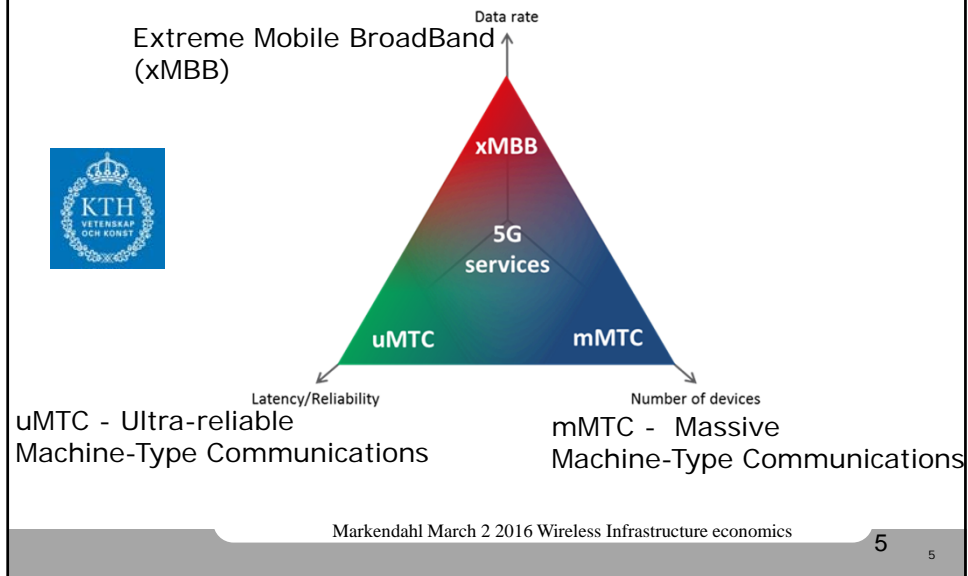
Spectrum allocation



Data rate depends on range



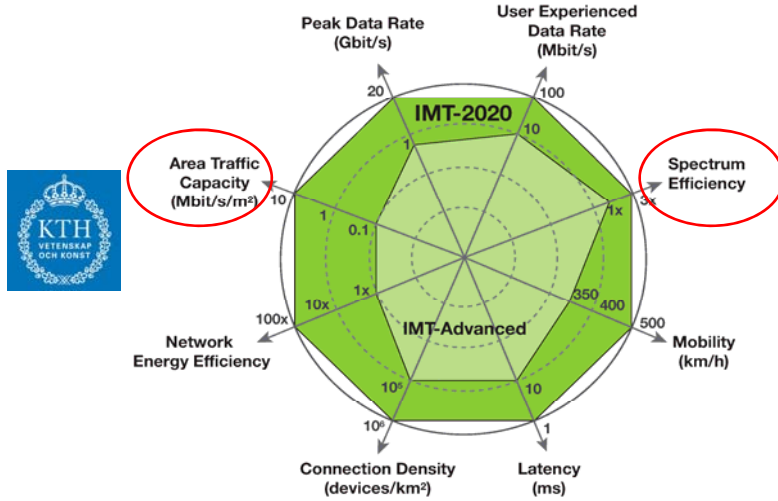
Utmaningar och inriktning för 5G



Vad vill man förbättra?



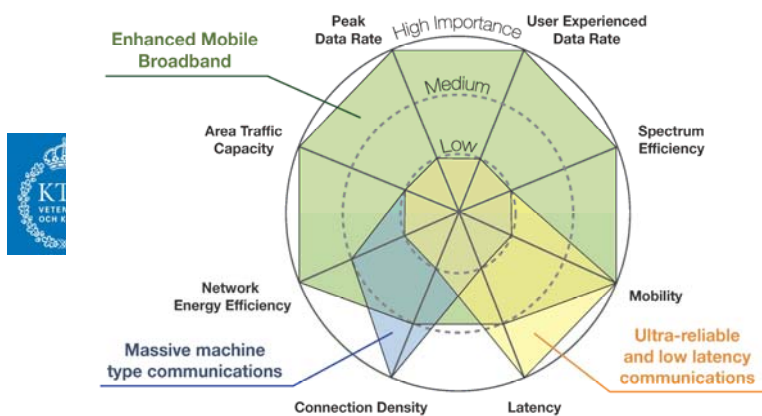
Vad vill man förbättra?



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7

Vad vill man förbättra?



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8

Today

I will deliver these "messages for xMBB"

- Capacity = function of
 - spectral eff
 - amount of spectrum
 - base station density
- Value of spectrum
- Dimensioning: What GB/month means in terms of kbps per user



ANDRES will talk about MTC next hour

The capacity may need to increase at least 1000 times the coming years

Contributions

- One enabler is "more spectrum"
- Another contribution comes from "better technology" (improved spectral efficiency)
- A third contribution is from "denser network"

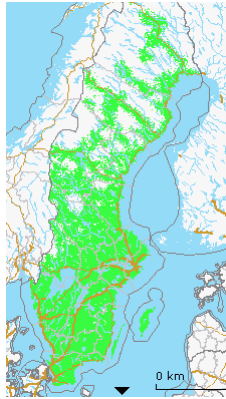


3 minute discussion – discuss in groups

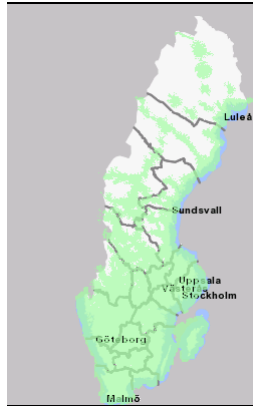
- How do you think the different aspects contribute?
- (More spectrum) * (improved spectral eff.) * (denser network) = 1000

GSM Coverage

Tele2 - Telenor - Telia



~70% covered area



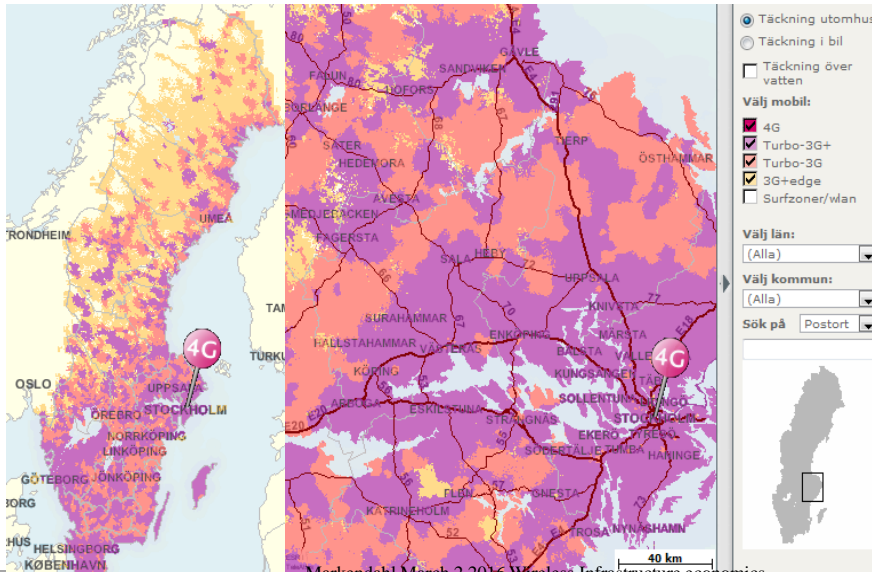
~65% covered area



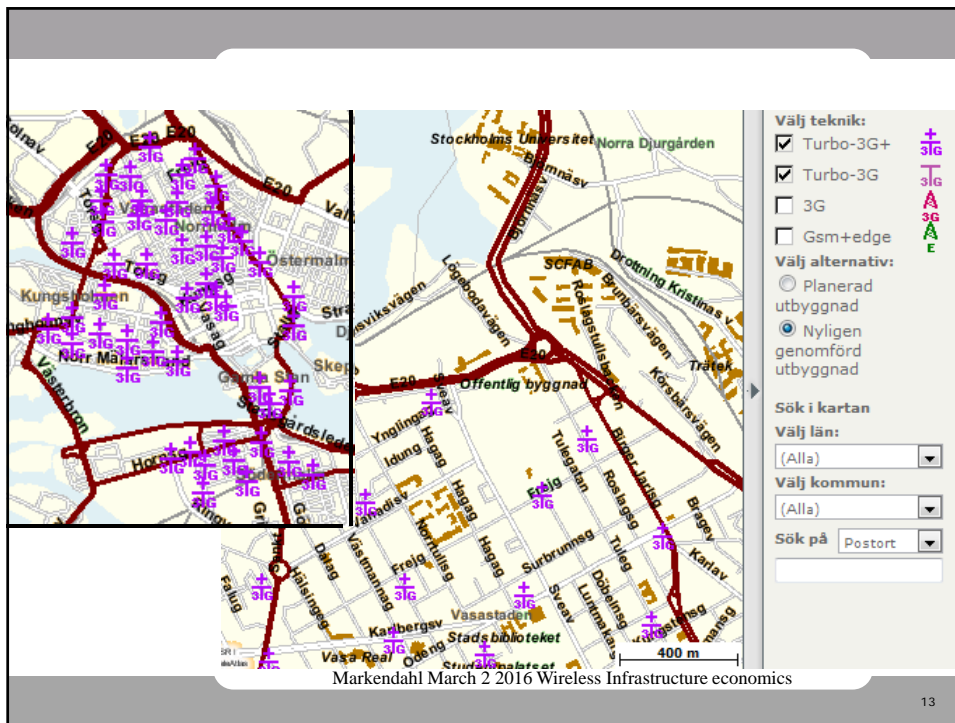
~90% covered area

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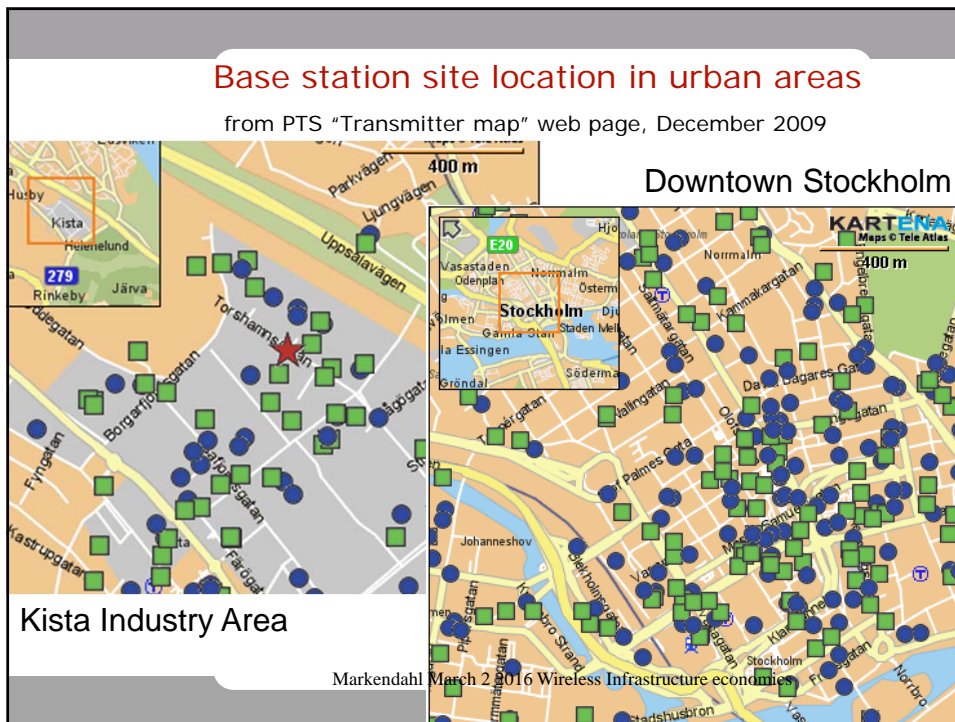
Coverage maps – Telia web page



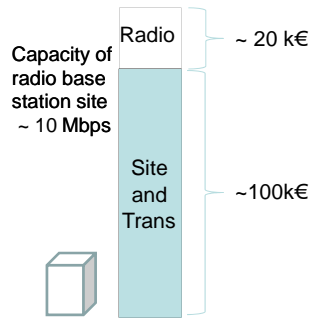
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13



Cost structure, bandwidth and capacity



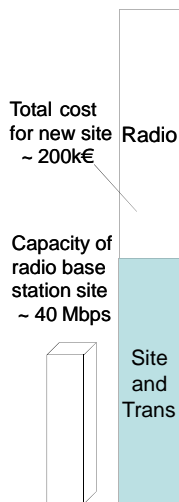
HSPA year 2008

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5 MHz

15

Cost structure, bandwidth and capacity



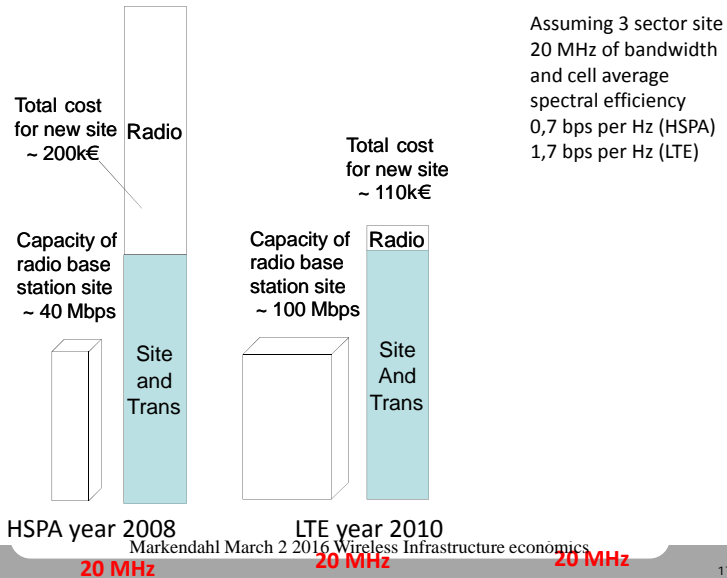
HSPA year 2008

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20 MHz

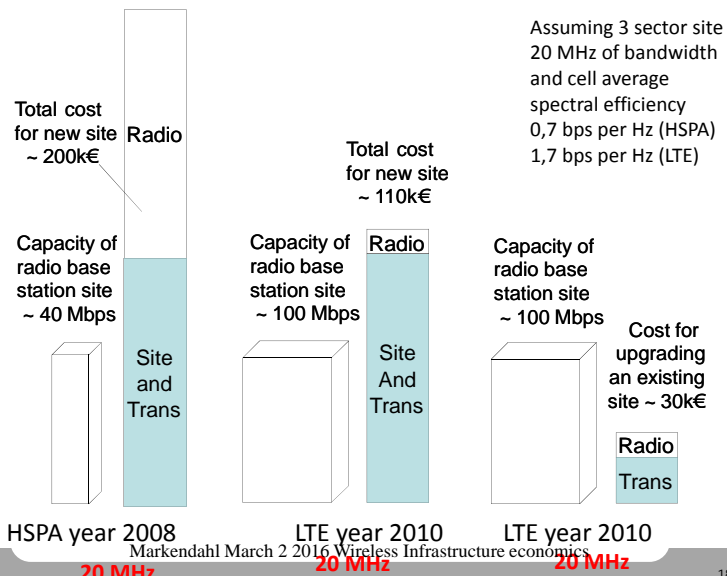
16

Cost structure, bandwidth and capacity



17

Cost structure, bandwidth and capacity

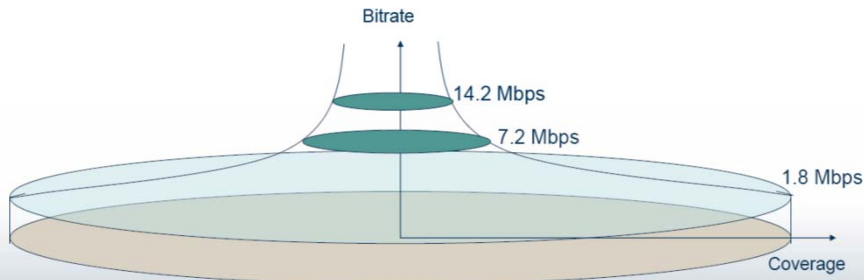


18

From Ericsson:
Capital markets day, May 2008



Coverage vs. bitrate



Double peak rate does not correspond to double capacity

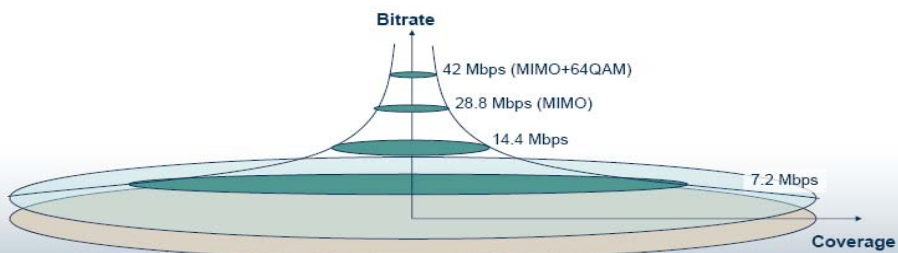
ERICSSON

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19

From Ericsson
Capital markets day
May 2009

Relation between Peak Rate & Coverage



Capacity does not scale with peak rate

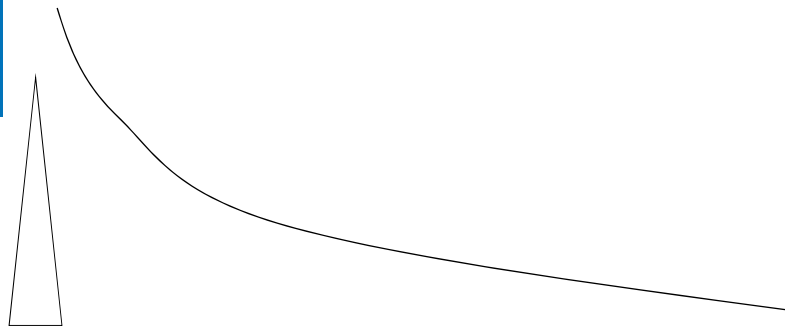
ERICSSON

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20

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

RAT 1 ———



Macro BS

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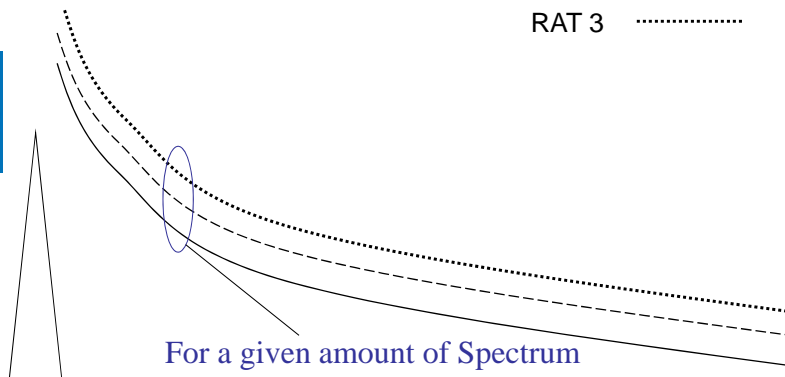
21

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

RAT 1 ———

RAT 2 - - - - -

RAT 3 ······

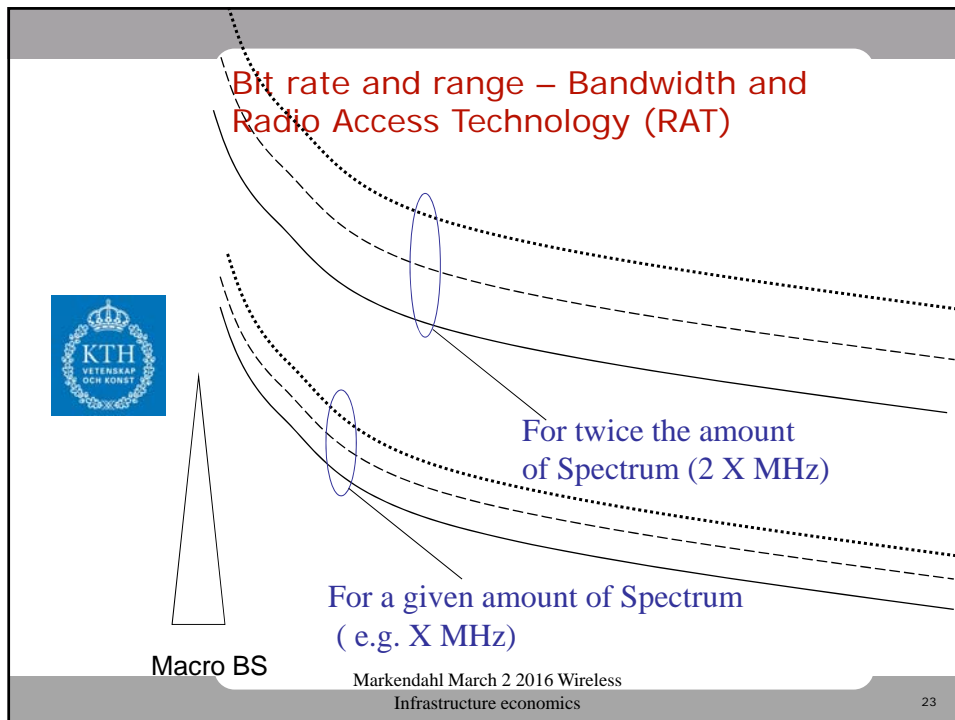


For a given amount of Spectrum
(e.g. X MHz)

Macro BS

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22



- Telenors löften helt orealistiska

KTH-professor dömer ut kampanj om nya mobilnätet
 Av: [Helen Ahlbom](#) 93 kommentarer
 Publicerad 20 maj 2009 00:00

KTH VETENSKAP OCH KONST

Telenor lovar hastigheter på 150 megabit/s till nästan hela svenska folket i sin senaste reklamkampanj. Det är fullständigt orealistiskt om man inte bygger 100 000-tals nya basstationer, anser Jens Zander, professor i radioteknik på KTH.

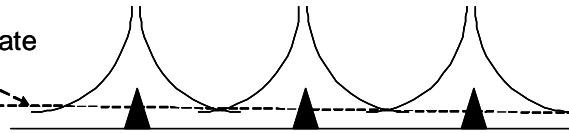
"Leve Allemansrätten!" utropar Telenor i reklamfilmer och stora affischer över hela landet. "Nu bygger vi Sveriges modernaste mobilnät. Det ger mer än 99 procent av svenska folket 150 Mbps via luften", utlovar bolaget på reklamplats.

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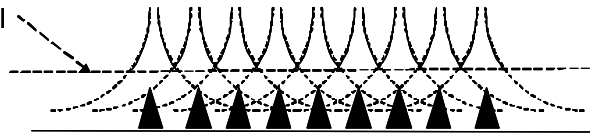
"Offered" bit rate vs coverage & load



"promised" data rate
at "low" level



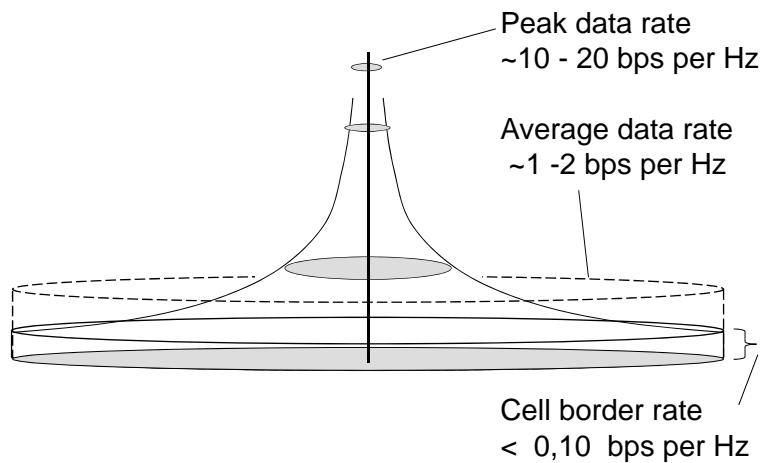
"promised" data rate
at "higher" level



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25

Spectral efficiency



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26

From Ericsson:
Capital markets day, May 2008

HSPA and LTE capacity evolution



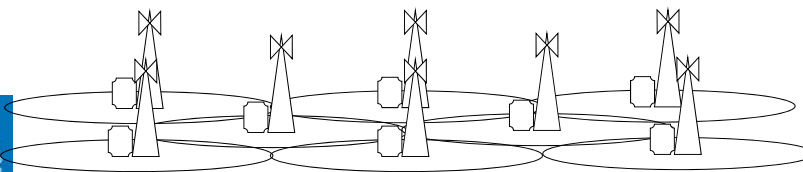
The capacity will double – but not 100 fold

B18_c

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ERICSSON

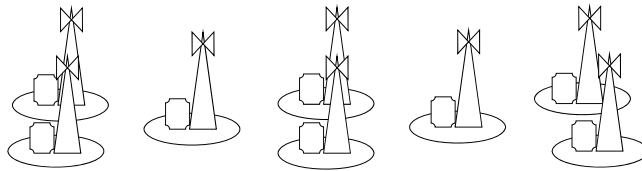
27



Cellular systems - low data rates

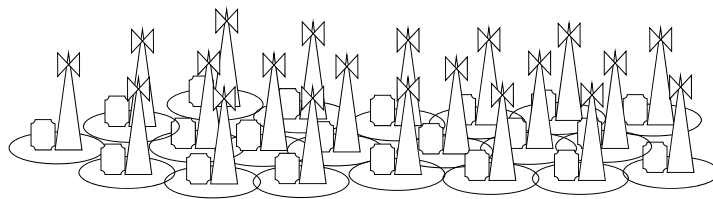
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28



Cellular systems – higher data rates, the same sites

Zander formula



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

N_{AP} the number of access points (base stations)

N_{user} the number of users

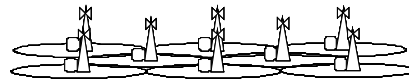
B_{user} the average data rate of the users

$A_{service}$ the service area covered (volume indoors)

$f(Q)$ is a function of the required Quality of Service.

Spectrum, capacity and cost

- High bandwidth means high capacity per site, i.e. less number of base station sites

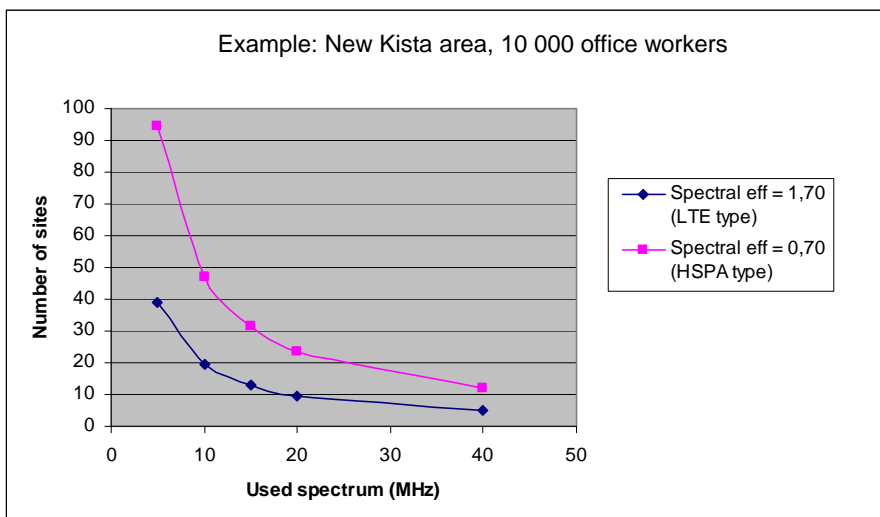


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31

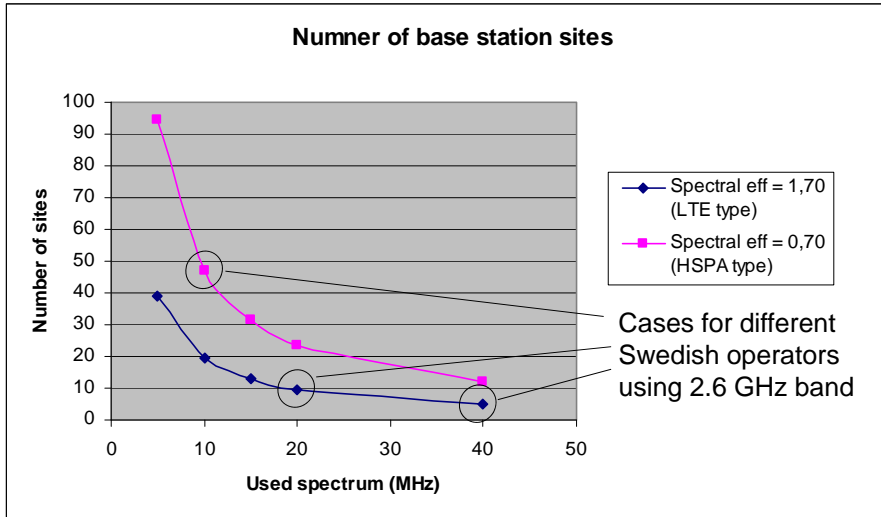
Amount of spectrum and number of sites

Example: New Kista area, 10 000 office workers



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32

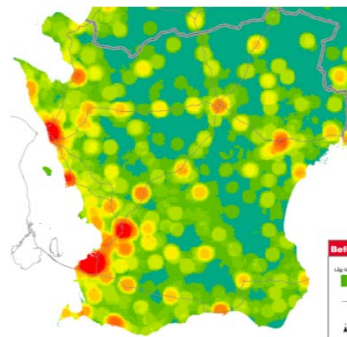


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33

Estimation of user demand

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



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34

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

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35

Geographical data for Sweden



	Km ²	Inabitants	Inh./km2	Share of area population	
Urban	2 109	5 197 620	2 464	0,5%	57%
Suburban	23 780	3 249 652	137	5,2%	35%
Rural	431 473	732 206	1,7	94,3%	8%
	457 362	9 179 478	20,1	100%	100%

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36

Geographical data for Sweden

	Km ²	Inabitants	Inh./km2	Share of area population	
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Rural	431 473	732 206	1,7	94,3%	8%
	457 362	9 179 478	20,1	100%	100%



92% of the population is living at 6 % of the total area

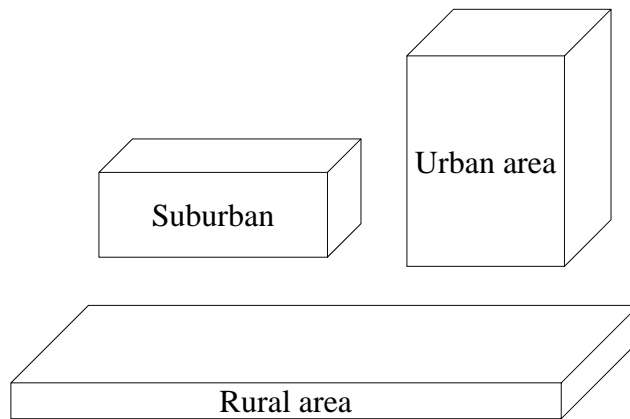
8% of the population is living at 95% of the total area

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

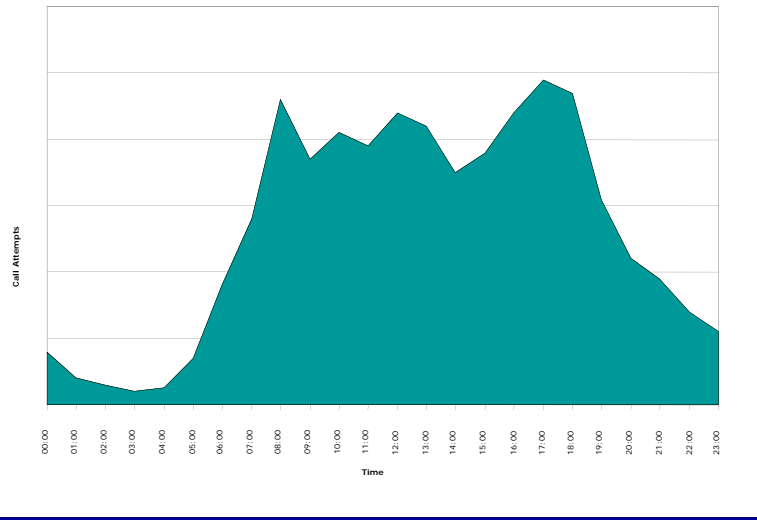


Dimensioning Real time services

- 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"



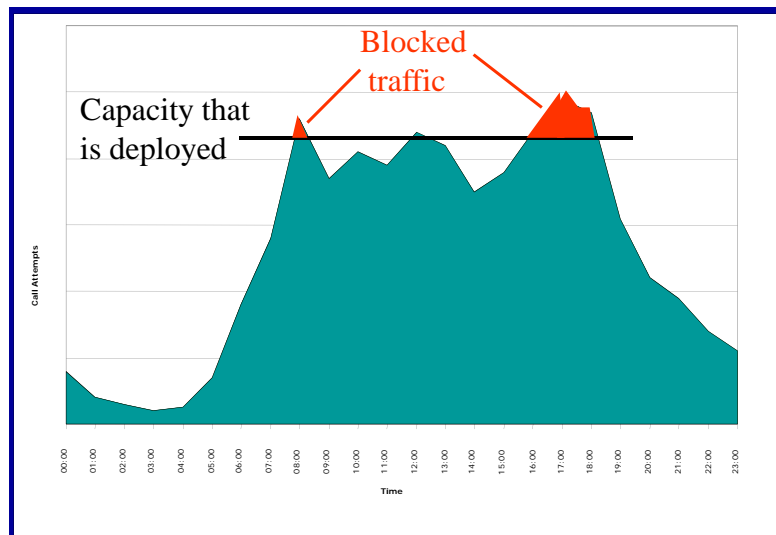
Capacity dimensioning – The busy hour



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41

Capacity dimensioning – The busy hour



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42

Capacity dimensioning – Mobile broadband

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



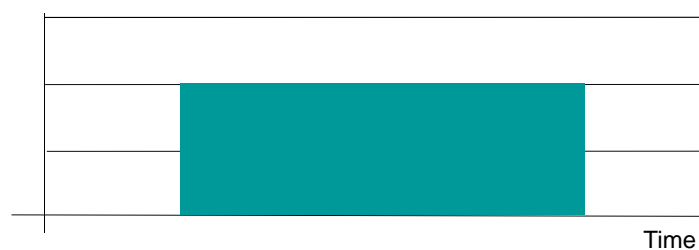
For data NRT data traffic the approach with "average data rate" per user can be used
X GB per user and month -> Y kbps per user

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43

Capacity dimensioning – Mobile broadband

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



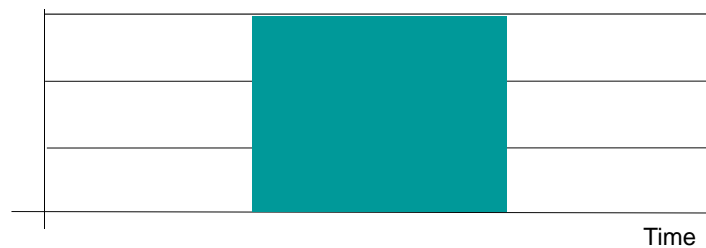
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44

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



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

Example of User demand – Mbps per sqkm



Number of active users per sqkm	Average data rate per user (Mbps)			
	0,01	0,1	1	10
10	0,1	1,0	10	100
100	1	10	100	1000

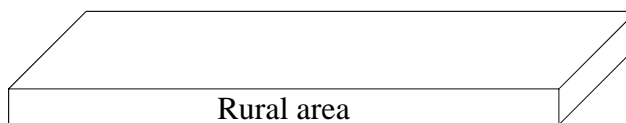
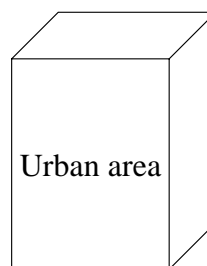
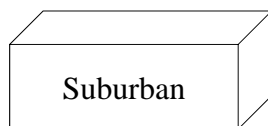
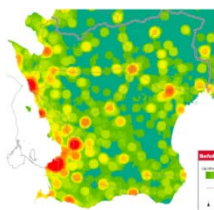
Implications for network deployment



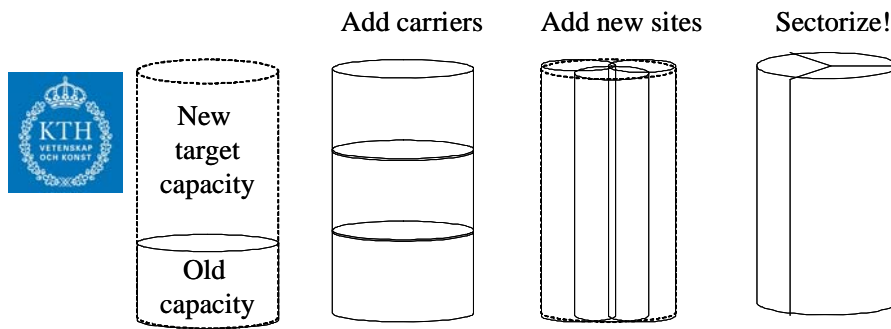
- 1000 active users/sqkm, 50% market share
=> deploy capacity for 500 users /sqkm
- 5 GB usage per month per user
~ 15 kbps per user 24 hours all days for one month
~ 50 kbps per user during "daytime" for one month
- Capacity estimates for 500 users
 - 5 GB users: ~ 25 Mbps/sqkm
- Compare with throughput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

Traffic density

- Estimate the demand
 - Number of users per area unit
 - Usage per user
 - Different types of users




What to do when the demand increases?



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51

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



Spectral efficiency	5 MHz of Spectrum	10 MHz of Spectrum	20 MHz of Spectrum
0,7 bps/Hz	3,5 Mbps	7,0 Mbps	14 Mbps
2,0 bps/Hz	10 Mbps	20 Mbps	40 Mbps

- 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

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52

A short exercise: how many users can be served,
- in a cell with capacities as below ?



Spectral efficiency	5 MHz of Spectrum	10 MHz of Spectrum	20 MHz of Spectrum
0,7 bps/Hz	3,5 Mbps	7,0 Mbps	14 Mbps
2,0 bps/Hz	10 Mbps	20 Mbps	40 Mbps

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

The capacity needs to be increase
at least 1000 times the coming years

Contributions

- One enabler is "more spectrum"
- Another contribution comes from "better technology" (improved spectral efficiency)
- A third contribution is from "denser network"



3 minute discussion – discuss in groups

- How do you think the different aspects contribute?
(More spectrum) * (improved spectral eff.) * (denser network) = 1000

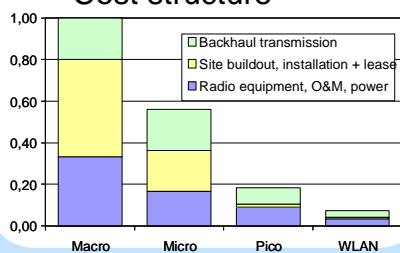
Cooper's law

- “the number of “conversations” that can theoretically be conducted over a given area in all of the useful spectrum is doubled every two-and-a-half years (www.arraycomm.com/technology/coopers-law)
 - The improvement in spectrum utilization has been over a trillion times in the last 90 years and a million times in the last 45 years.
- “Of the million times improvement in the last 45 years,
 - 25 times were the result of being able to use more spectrum
 - 5 times can be attributed to the ability to divide the radio spectrum into narrower slices
 - Modulation techniques like FM, SSB, time division multiplexing, another 5 times or so
 - The remaining **sixteen hundred times** improvement was the result of confining the area used for individual conversations to smaller areas, what we call spectrum re-use”.

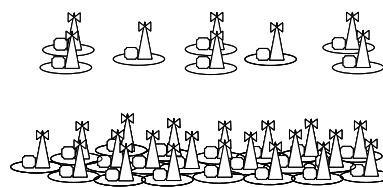


Operator challenges – network related

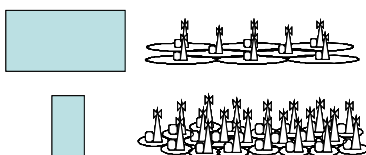
Cost structure



Scalability



Spectrum allocation



Data rate depends on range

