Models for Wireless Infrastructure economics & Mobile Broadband deployment

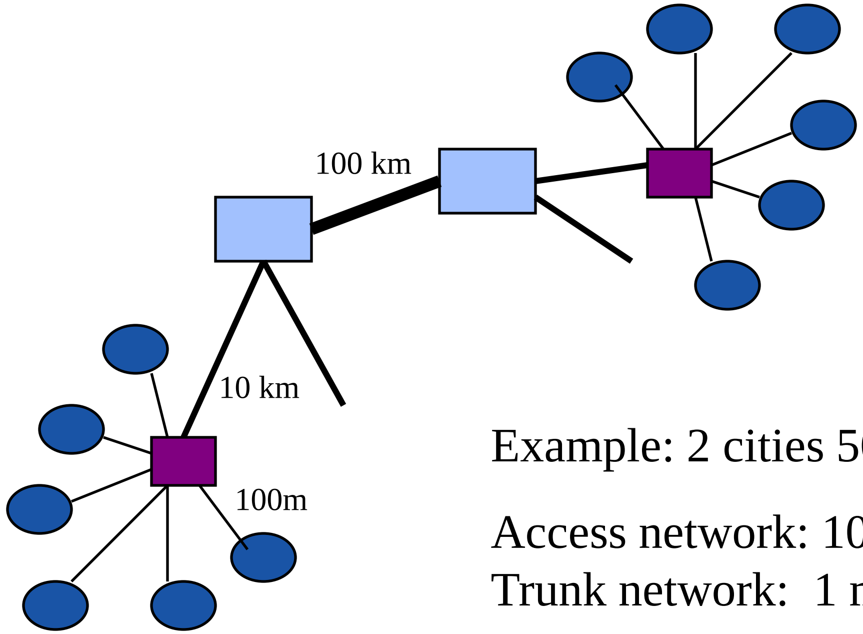
Jens Zander

Outline

- Some fundamental problems in infrastructure provisioning
- Wireless Network design fundamentals
- Recent trends in Wireless Access
- Wireless Broadband dimensioning & deployment models

Some fundamental questions

The “last mile” problem:
Most investments in Access Networks



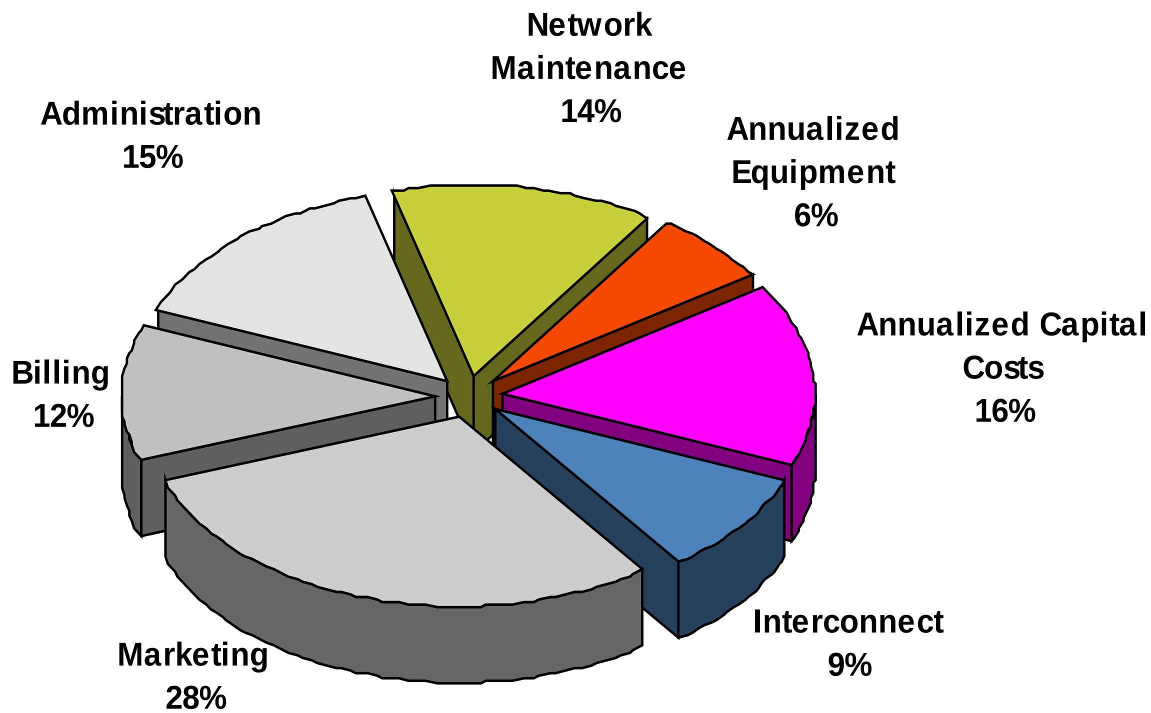
Backbone network shared by many

Access network individual

Example: 2 cities 50.000 user each

Access network: 100 m/user
Trunk network: 1 m/user (=100 km/100.000 users)

Traditional Wireless operator costs



Quiz 1:

Where are infrastructure equipment manufacturers making money ?

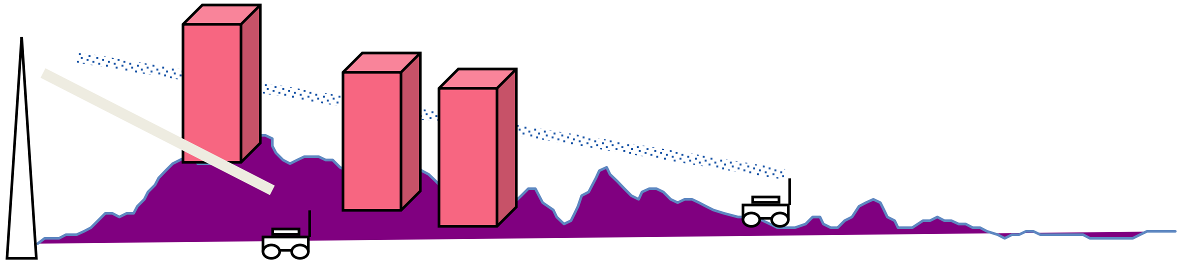
A. Selling equipment (basestation)
B. Installing optical fiber connections
C. Operating & maintaining wireless networks (services)

Wireless Network Dimensioning
- a recap

Wireless Networks - problems

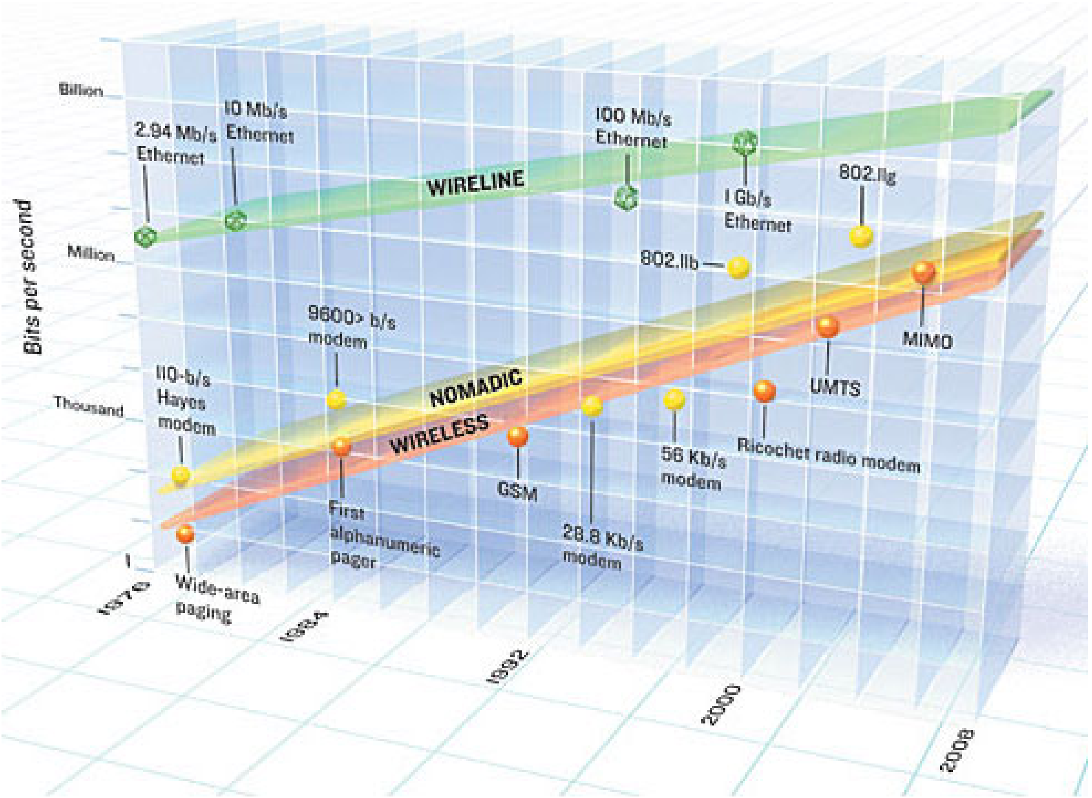
Range

Coverage



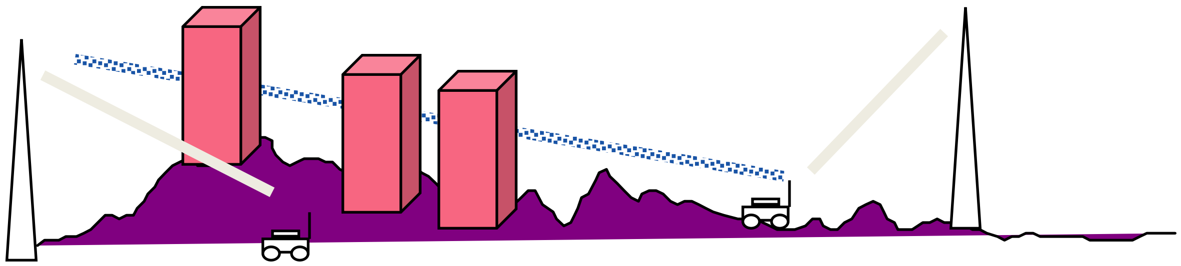
$$\frac{E_{rx}}{N_0} \propto \frac{P_{tx} G_{ant}}{B_{user} R^{\alpha}} \geq \gamma_0(\eta_{eff})$$

Peak rates & PHY-technology is no longer THE issue ..



"Edholms law"

Wireless Networks - problems cont.



Interference due to spectrum reuse

Capacity limitation

Quiz 2a:

How can improve coverage ?

A. Increase transmit power
B. Use directional antennas
C. Use higher towers
D. More sensitive terminal receivers
E. Use higher frequency band

Quiz 2b:

How can improve capacity ?

A. Increase transmit power
B. Use directional antennas
C. Use higher towers
D. More sensitive terminal receivers
E. Use higher frequency band

The infrastructure cost

$$C_{\text{infra}} = c_1 + c_{BS} N_{AP} \approx c_{BS} N_{AP}$$

Spectrum limitation

- W_{sys} available bandwidth
- Spectral /reuse efficiency K

$$C_{\text{infra}} \approx c_{BS} \frac{B_{tot}}{\eta W_{sys}} = c_{BS} \frac{N_{user} B_{user}}{\eta W_{sys}} = c_{BS} \frac{\omega_{user} A_{tot} B_{user}}{\eta W_{sys}}$$

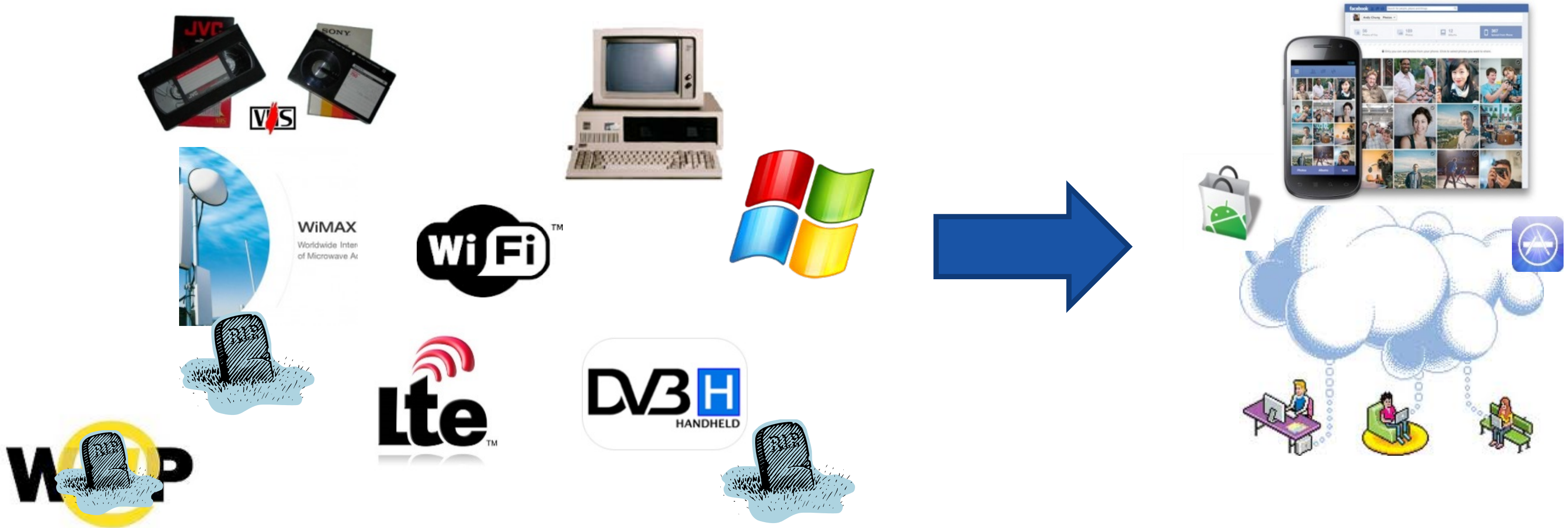
Coverage limitation

$$N_{BS} \propto \frac{1}{R_{cell}^{\ 2}} \propto \left(\frac{\gamma_0 N}{P} \right)^{2/\alpha} \propto B_{user}^{2/\alpha}$$

wireless @kth

Recent Trends

A lessons from History - Dominant designs

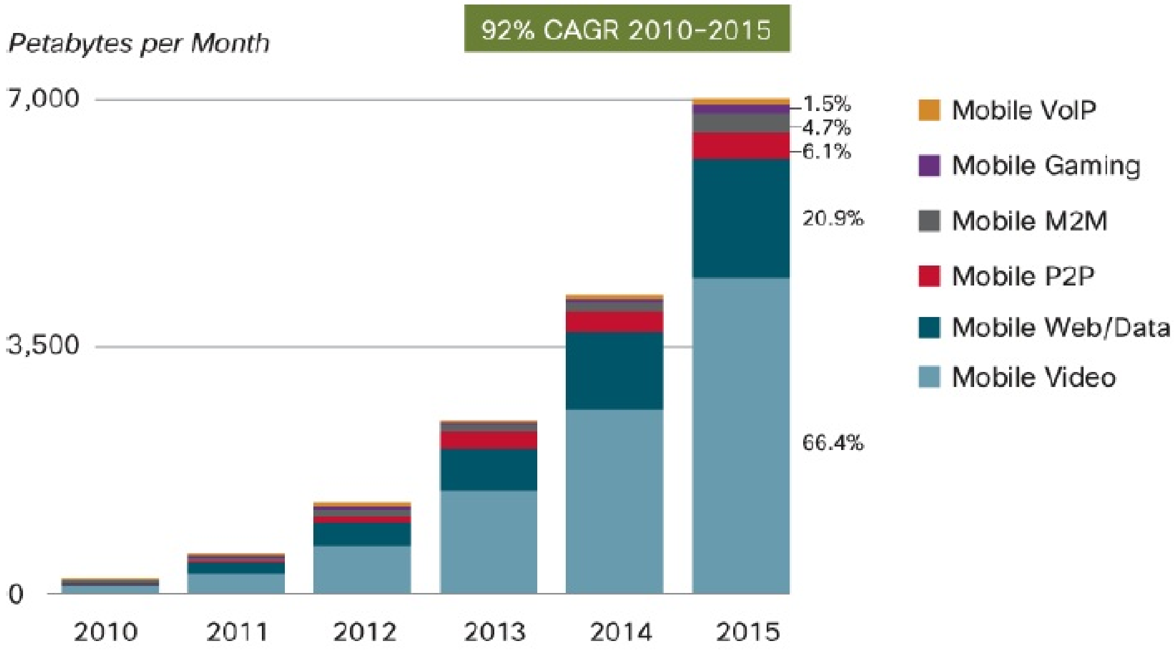


- From infrastructures driven by ”killer apps” and ”one-trick ponies”
  → general IP-based access infrastructures
- Internet access = dominant design for ALL services (fixed & mobile)
- Marginalizes other technical solutions – e.g. Wireless P2P, Mesh, ...
- Story sounds familiar ...?

> ”IP is the answer - now, what was the question ?”
>
> G Q Maguire

wireless @kth

Mobile Data Tsunami



VoIP traffic forecasted to be 0.4% of all mobile data traffic in 2015.

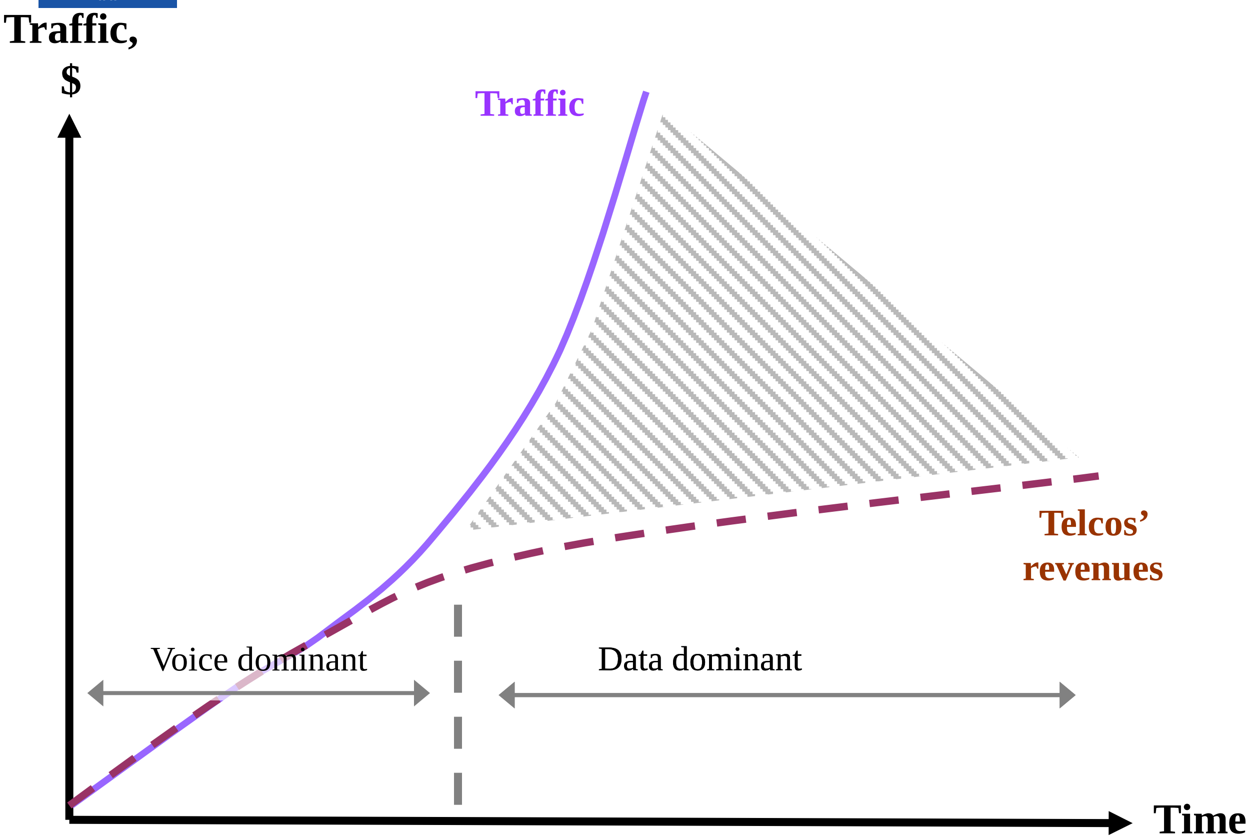
Source: Cisco VNI Mobile, 2011

Cisco forecast: 2015 – 26x

Extrapolation: 2020 - 1000x

wireless @kth

What can be done about the revenue gap ?



In a world dominated by data,
traffic growth is not anymore correlated with revenue growth!

Lowering the system cost

$$C_{sys} \approx c_2 \frac{B_{tot}}{\eta W_{sys}} + c_3 W_{sys} = c_2 \frac{\omega A_{tot} B_{user}}{\eta W_{sys}} + c_3 W_{sys}$$

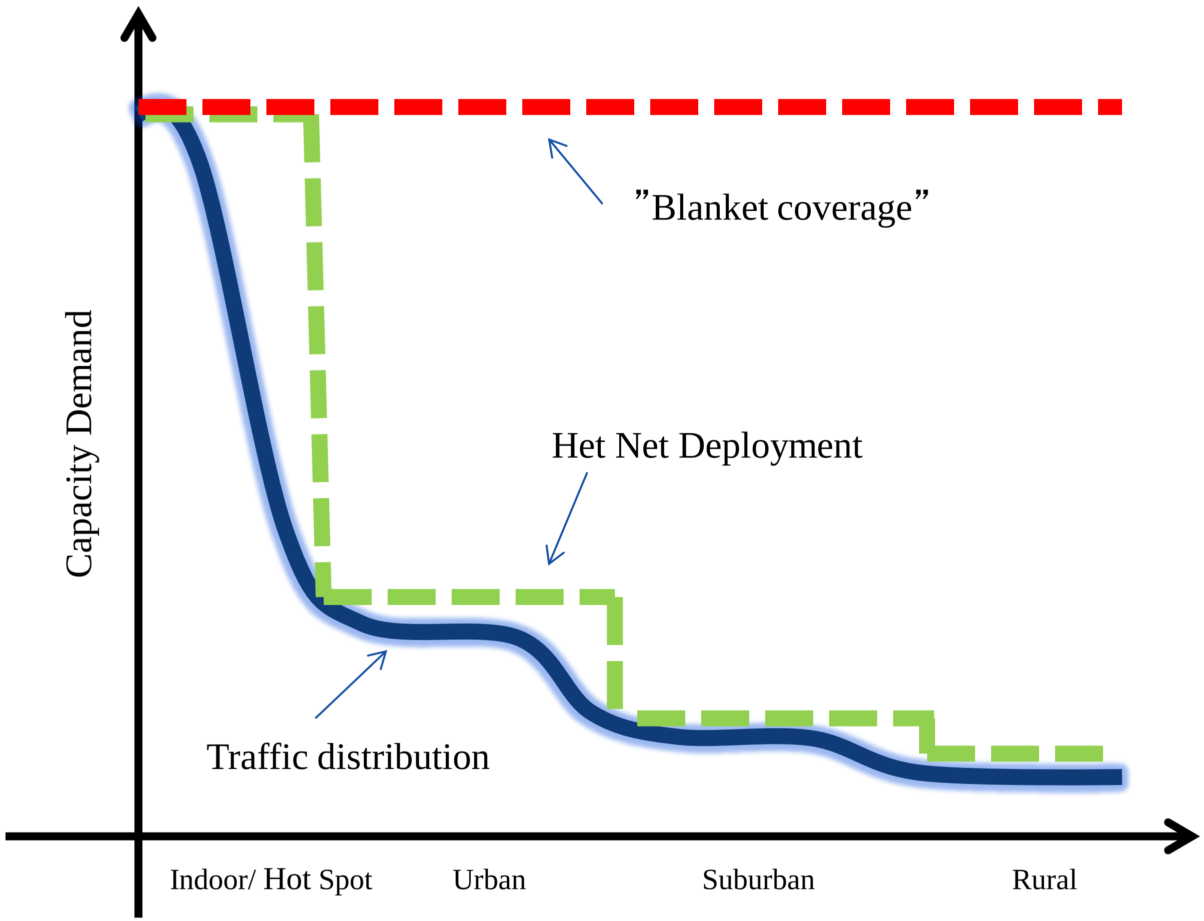
- Improving the efficiency of the modulation and RRM system, i.e. increasing η
- Reducing the coverage area A_{tot}.
  The required data rate is only provided in parts of the area
- Buying more spectrum ?
- Reducing the cost per base station

$$c_2 = C_{AP} = C_{site} + C_{backhaul} + C_{equipment} + C_{deployment} + C_{\mathrm{maint}}$$

wireless @kth

How to lower the cost:

”HET NET”s – deploy according to demand



HET NETs - The Light Analogy -

Outdoor – Wide Area

- Indoor – Short Range

A World Divided

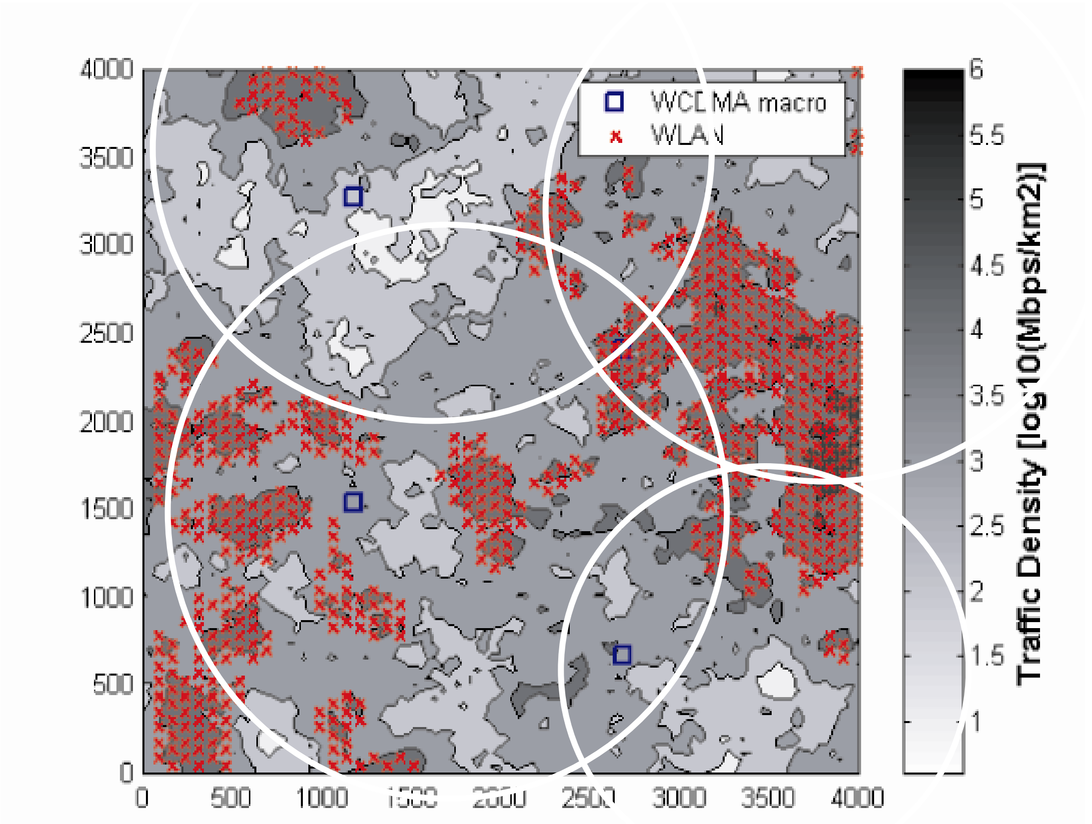
The coverage world

Industry grade equipment
High power/Wide area
24-7 availabilty
High **system** complexity

The capacity world

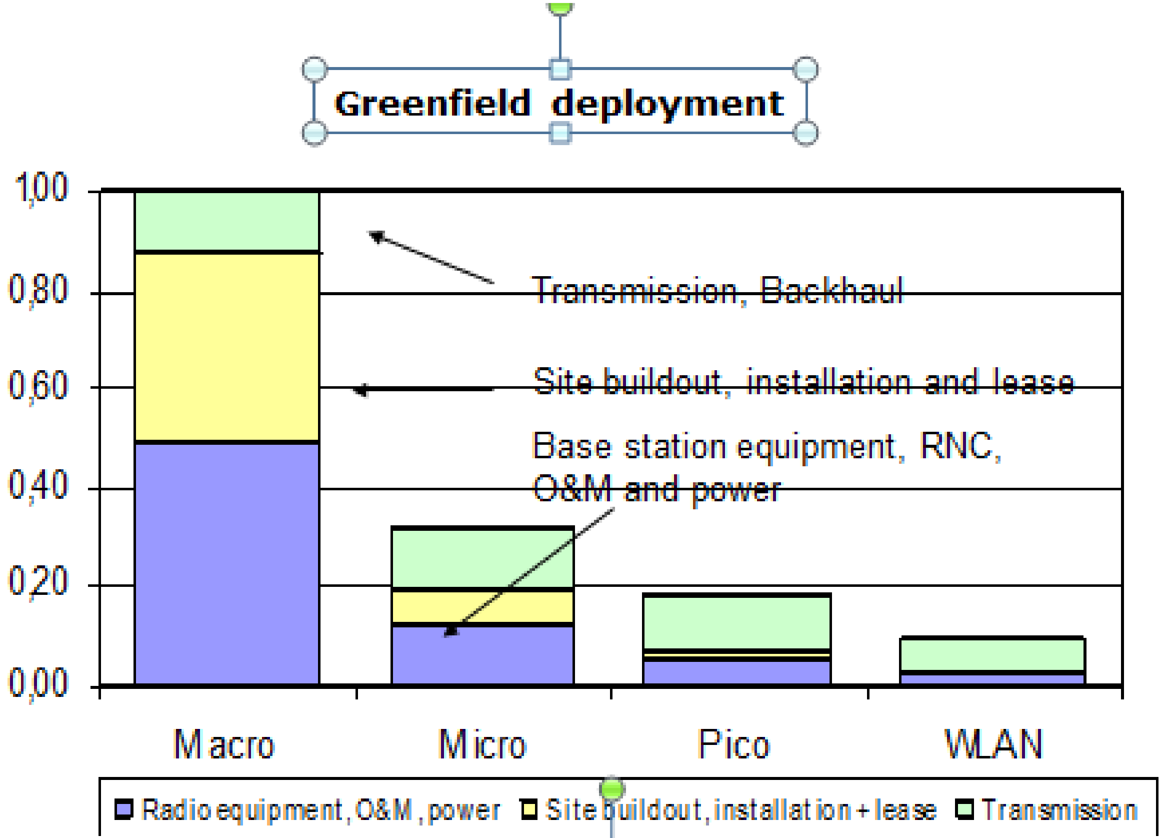
Consumer grade equipment
Low power/Short range
Reliability through redundancy
Deploy where backhaul available
Low **system** complexity

“HET NETS” – from “blanket coverage” to selective capacity



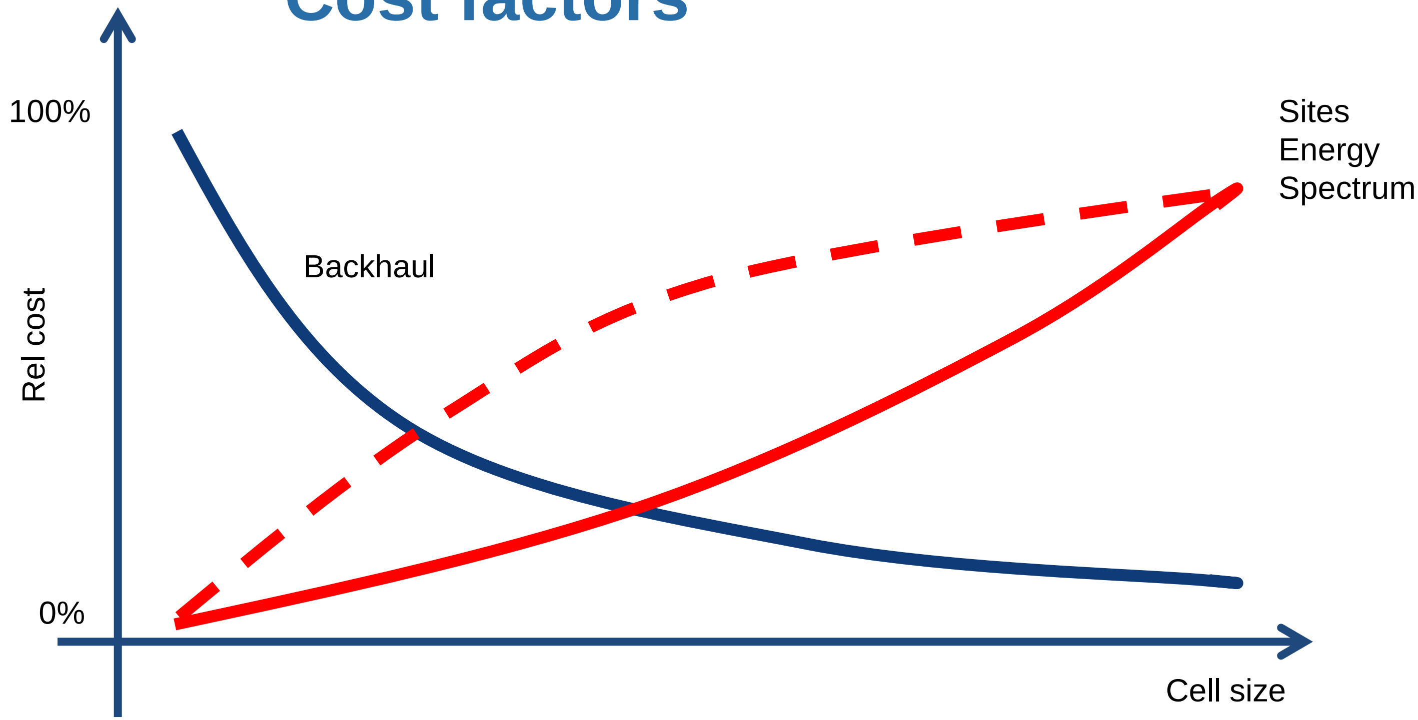
(Klas Johansson, ”Cost Effective Deployment Strategies for Heterogeneous Wireless Networks”, Doctoral Thesis, KTH 2007)

Cost drivers



(Klas Johansson, "Cost Effective Deployment Strategies for Heterogeneous Wireless Networks", Doctoral Thesis, KTH 2007)

Cost factors



Quiz 3:

How can we lower the infrastructure cost?

A. Increase transmit power
B. Improve coding and modulation
C. Use higher towers
D. More spectrum
E. Use higher frequency band

The cost of spectrum

$$R_{tot} \approx \frac{C_{sys}}{c_{BS} A} \eta W_{sys} = \frac{\eta}{A} N_{BS} W_{sys}$$

More base stations

More spectrum

$$R_{tot} + \Delta R \approx \frac{\eta}{A} N_{BS} W_{sys} + \frac{\eta}{A} \Delta N W_{sys} + \frac{\eta}{A} N_{BS} \Delta W$$

Spectrum Upgrade cost

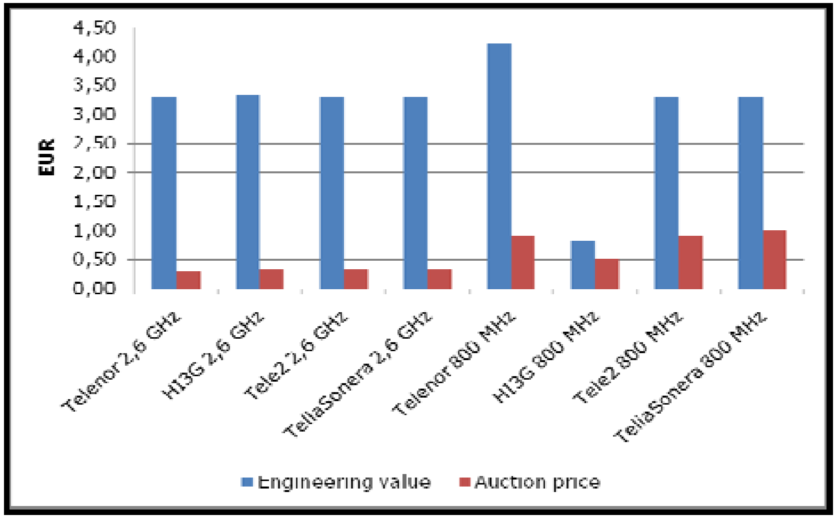
$$C_{sys} + \Delta C \approx C_{sys} + c_{BS} \Delta N + \Delta c_{BS} N_{BS} + c_{sp} \Delta W$$

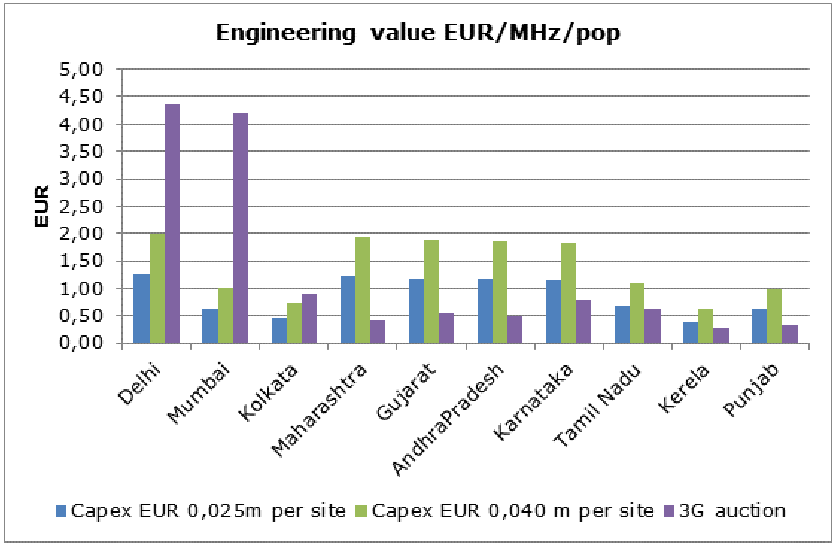
$$\min \Delta C = \min\left(c_{BS} \frac{\Delta R}{\eta W_{SYS}} A, \Delta c_{BS} N_{BS} + c_{sp} \frac{\Delta R}{\eta N_{BS}} A \right)$$

$$c_{sp}^{*} = \left(\frac{c_{BS}}{W_{SYS}} - \Delta c_{BS} N_{BS} \right) N_{BS}$$

Engineering value of spectrum

Is mobile spectrum still ”cheap” ?





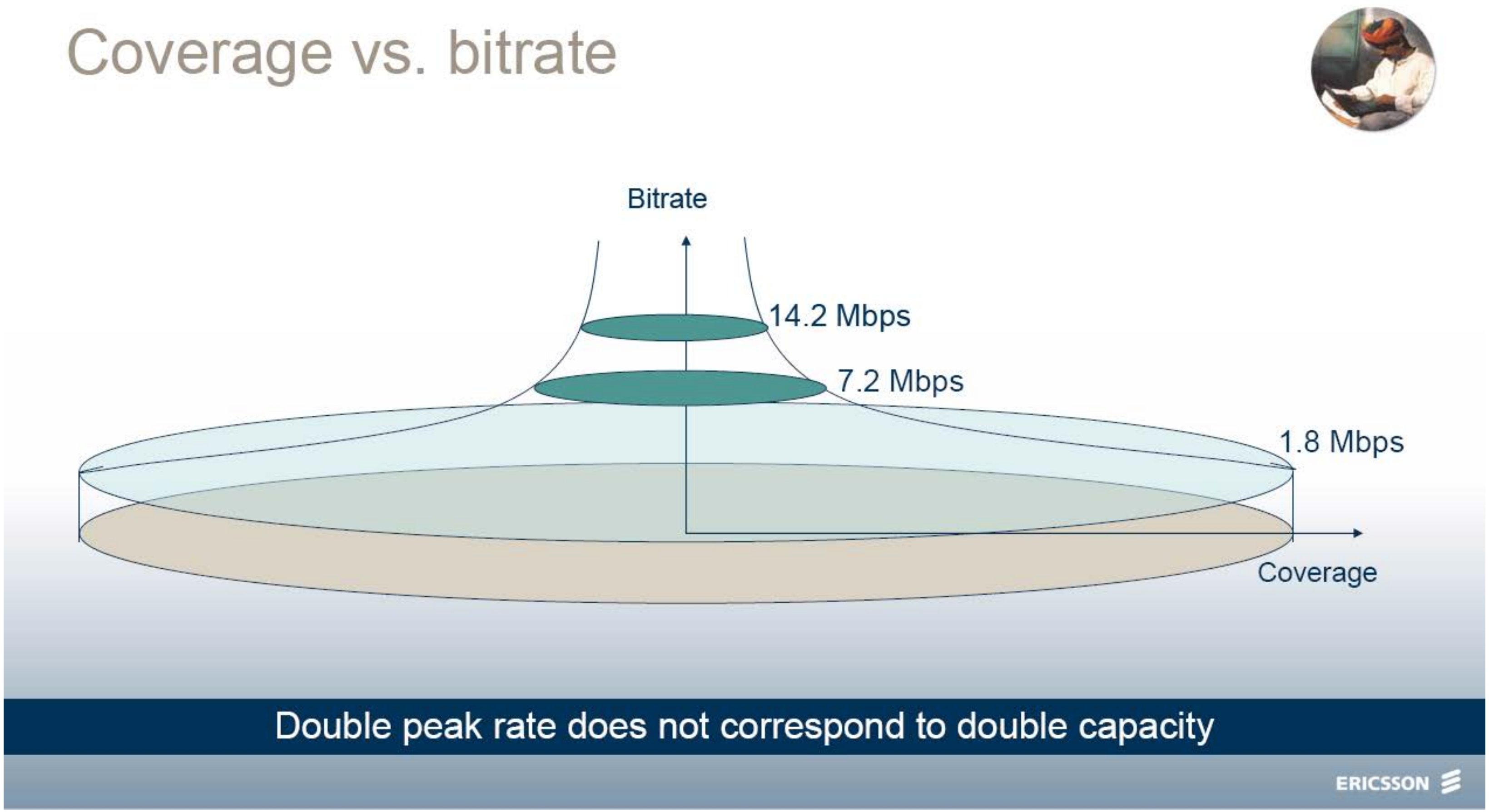
Source: B G Mölleryd and J Markendahl

Valuation of spectrum for mobile broadband services - The case of Sweden and India

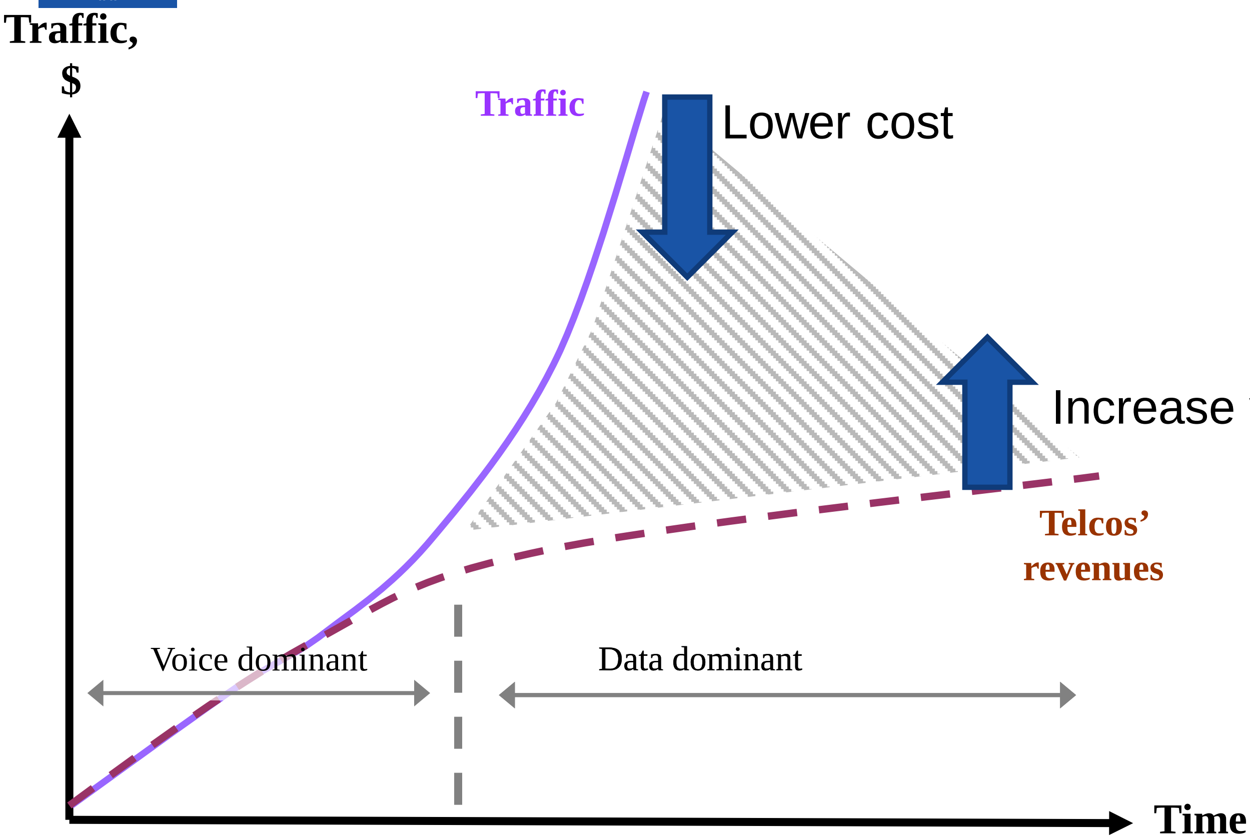
ITS Regional Conference, New Dehli, Feb 2012

Mobile broadband deployment

Coverage & Bit rate



What can be done about the revenue gap ?

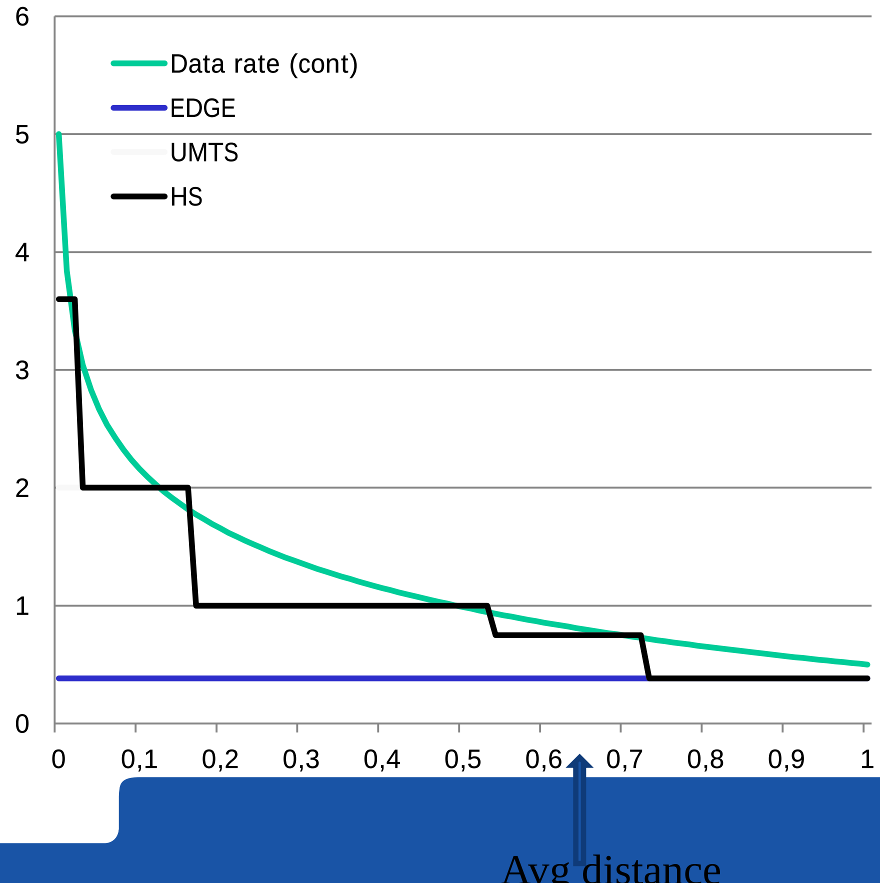


In a world dominated by data,
traffic growth is not anymore correlated with revenue growth!

Design Example: Rural deployment –

$$R_{cont}(r) = cW\log_2\left(1+\frac{cP_{tx}}{N_0 r^{\alpha}}\right) = WR'(r)$$

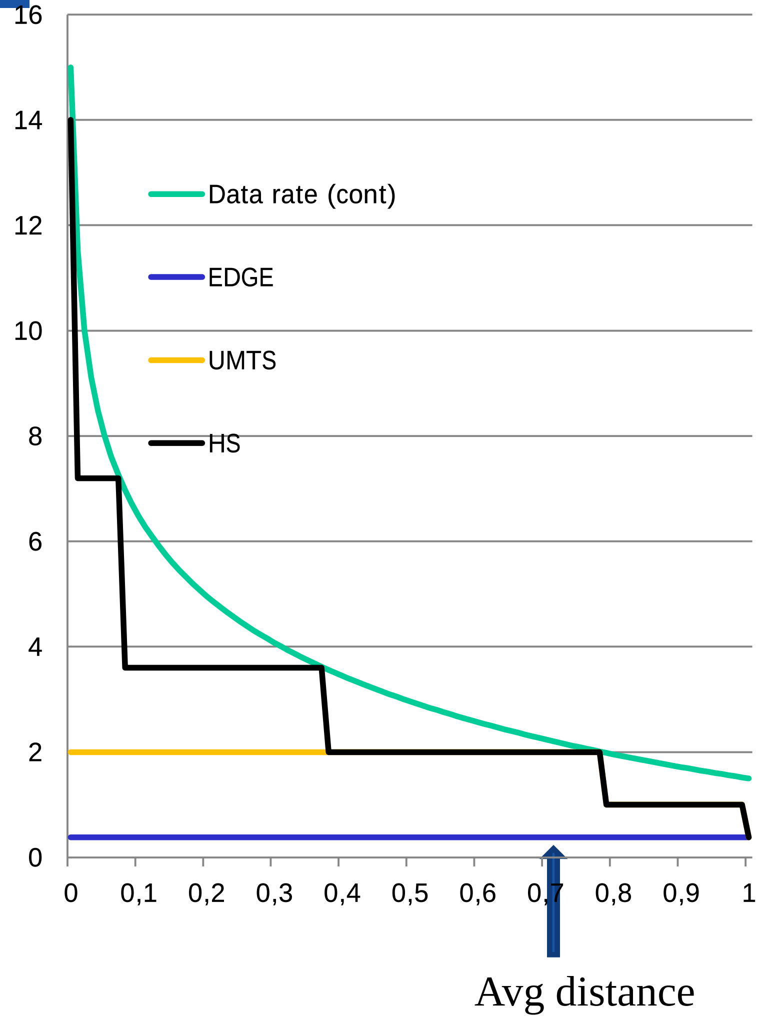
$$\overline{R} = E[R] = W\int R'(r)f(r)dr$$



Cell radius: 5000 m

	Peak Rate (Mbps)	Avg. Rate (Mbps)
Continous	N/A	0,84
HS	7.2	0.68
UMTS	2	0.66
EDGE	0.38	0.38

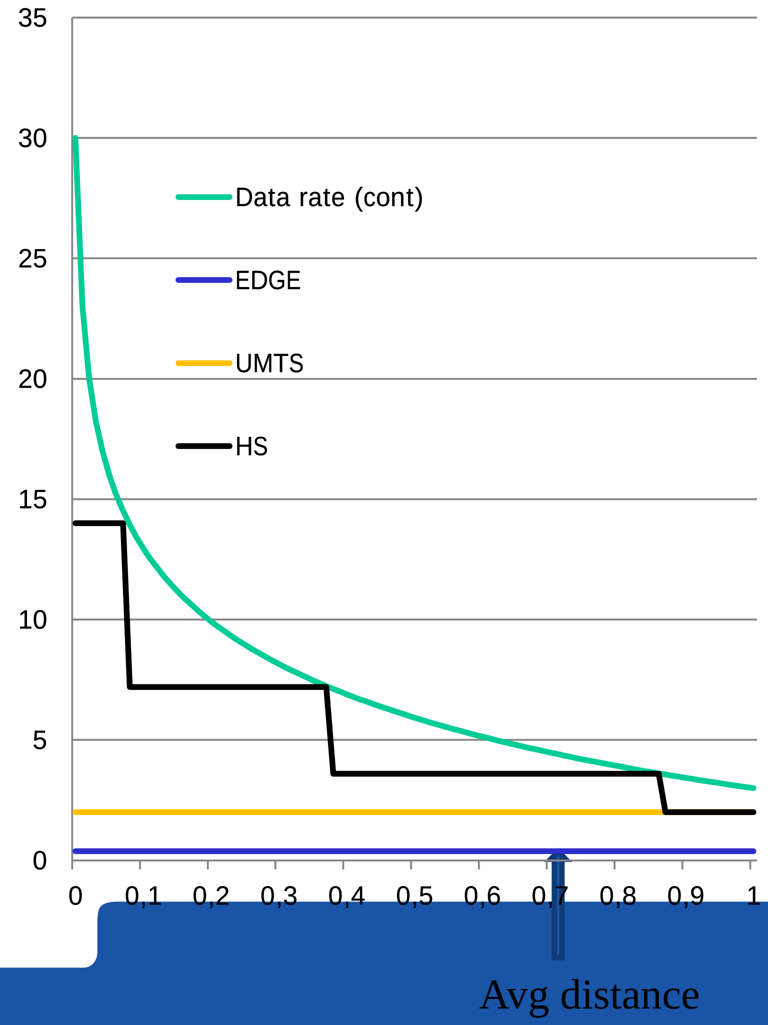
Design Example: Urban deployment



Cell radius: 1500 m

	Peak Rate (Mbps)	Avg. Rate (Mbps)
Continous	N/A	2,5
HS	7.2	1,9
UMTS	2	1,6
EDGE	0.38	0.38

Design Example:
Very dense deployment



Cell radius: <500 m

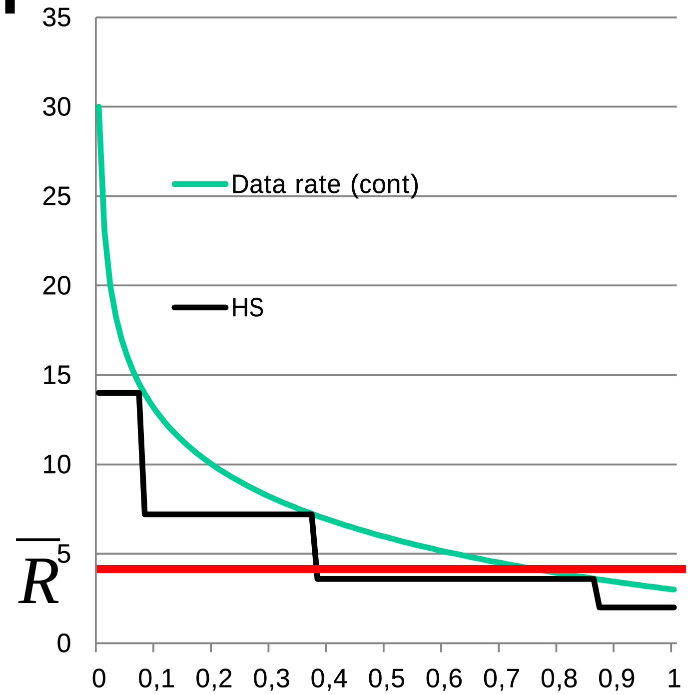
	Peak Rate (Mbps)	Avg. Rate (Mbps)
Continous	N/A	5,1
HS	7.2	3,8
UMTS	2	2
EDGE	0.38	0.38

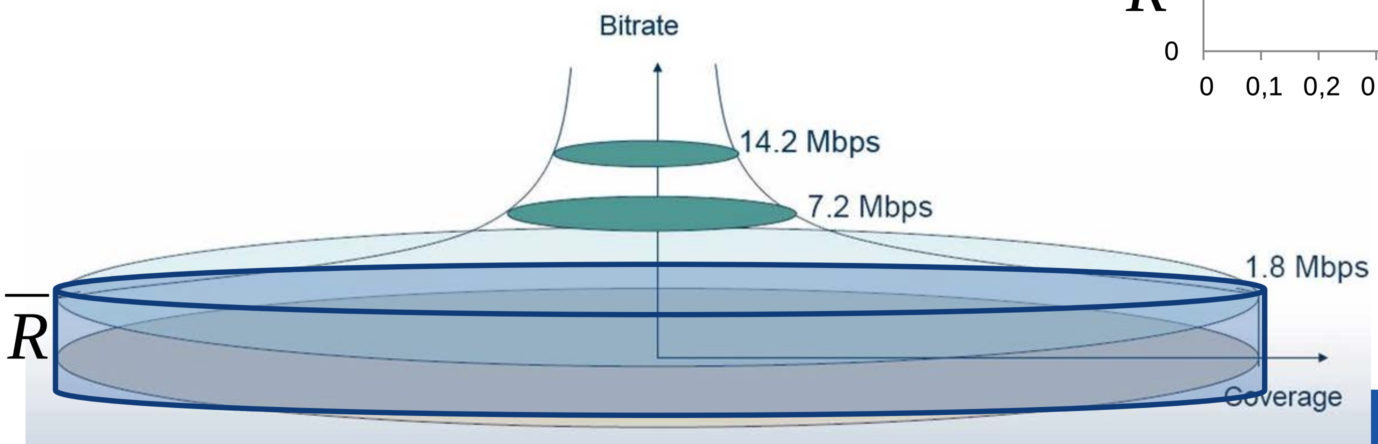
wireless @kth

Single cell capacity & approximation

Single cell capacity

$$\overline{R} = E[R] = W\int R'(r)\,f(r)\,dr$$



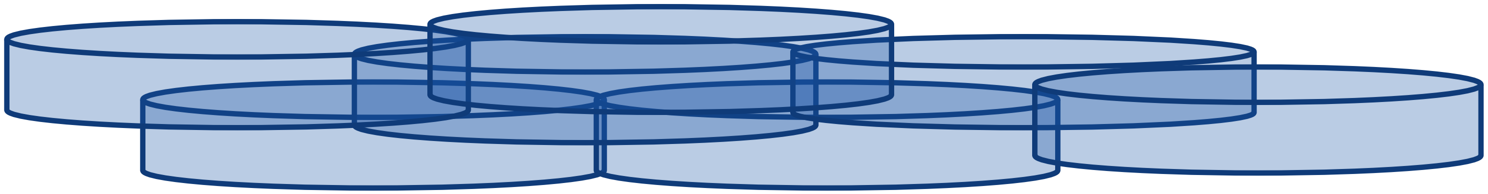


Quiz 4:

What is true?

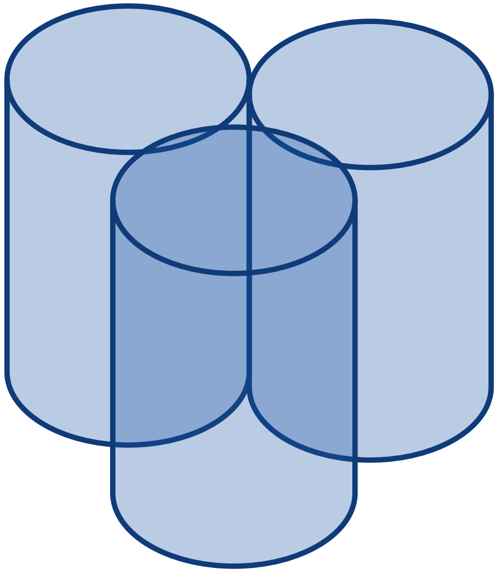
A. The peak data rate determines the capacity
B. The average data rate can never exceed the peak rate
C. In large cells the capacity is close to the peak rate
D. In small cells the capacity is close to the peak rate

Deployment strategies



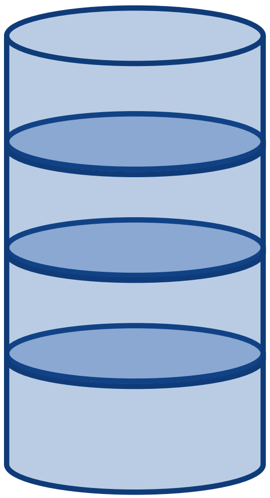
- Wide area ”blanket coverage”
  - Low Capacity

Deployment strategies



- Limited ”Hot spot” coverage
  - High rate/capacity

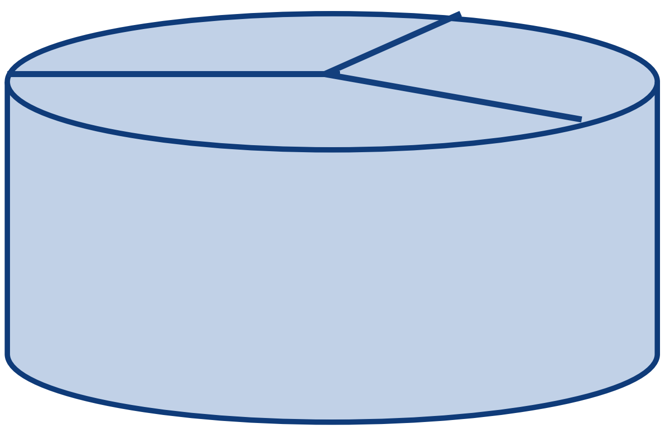
Capacity enhancement



- More spectrum (channels)

$$\overline{R} = E[R] = W\int R'(r)\, f(r)\, dr$$

$$R_{tot} = N_{ch}\,\overline{R}$$



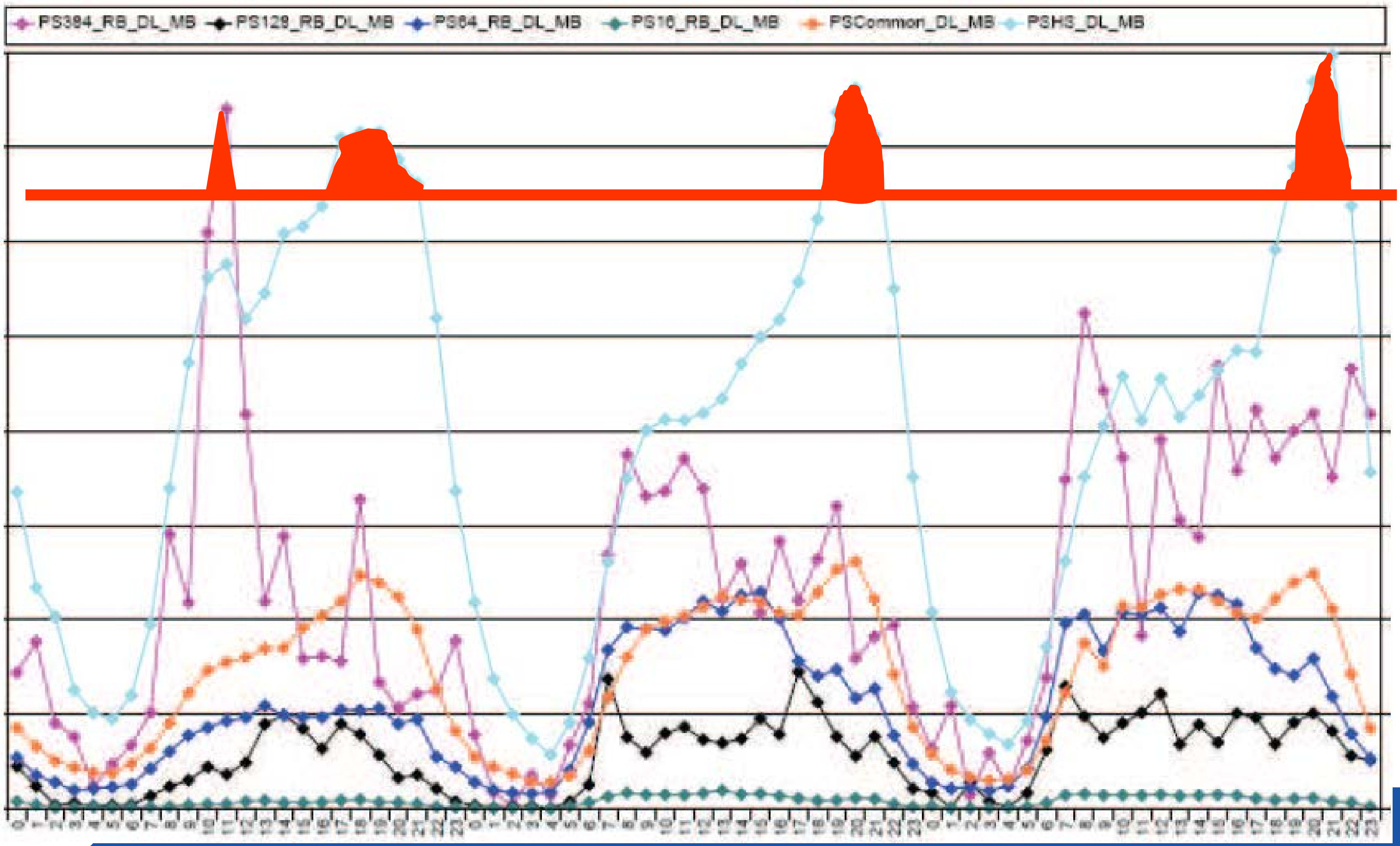
Sectorization

Improved spatial reuse

$$\overline{R_{tot}} \approx N_s\,\overline{R}$$

Temporal design – peak capacity

Networks designed for ”peak/busy hour”



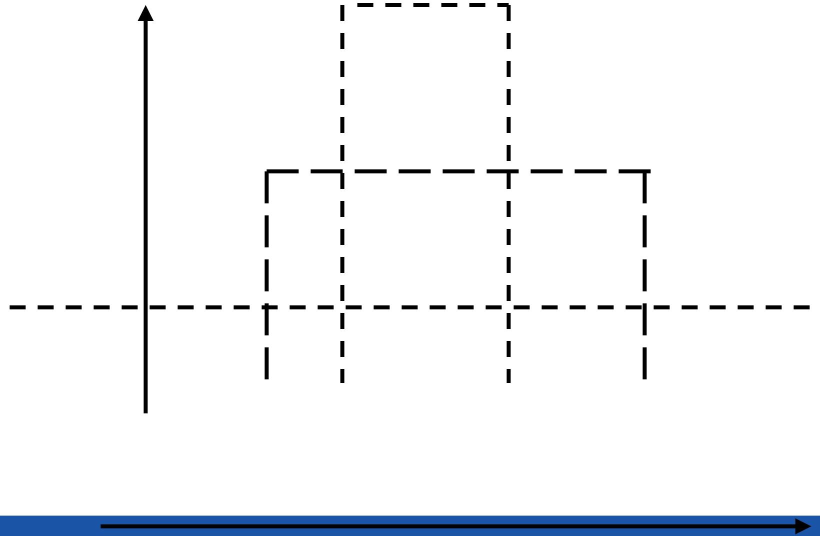
Dimensioning

For voice and RT data you need to estimate the maximum number of ongoing calls or sessions

- Depends on the arrival rate and the duration of ”calls”
- Is based on the traffic during the ”busiest hour”

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
  - During 24 hrs all day(s)
  - During 2 - 8 hours per day



Numerical example

1 Gbyte/month = 30 Mbyte/day

(= 1.3 Mbyte/h average)

= 4-5 Mbyte/h peak hour (all daily traffic in 6-8h)

= 4800Kbyte/3600 s = 1.5 Kbyte/s = 12 Kbps

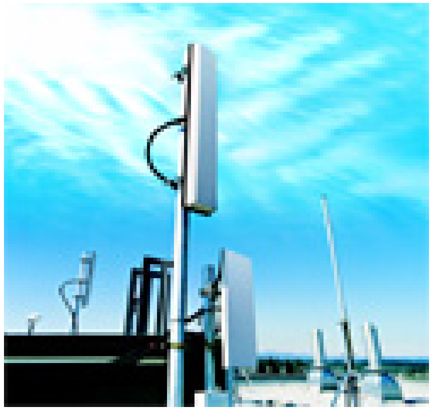
Population density: 100 pop/sqkm

Cell size: 1.500 m = 6,8 sqm => 680 pop/cell

Capacity demand: 12 * 680 =8,5 Mbps /cell

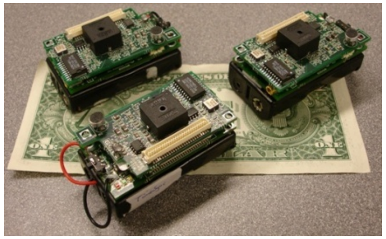
=> 8,5/3 = 2 Mbps/sector

Energy constraints

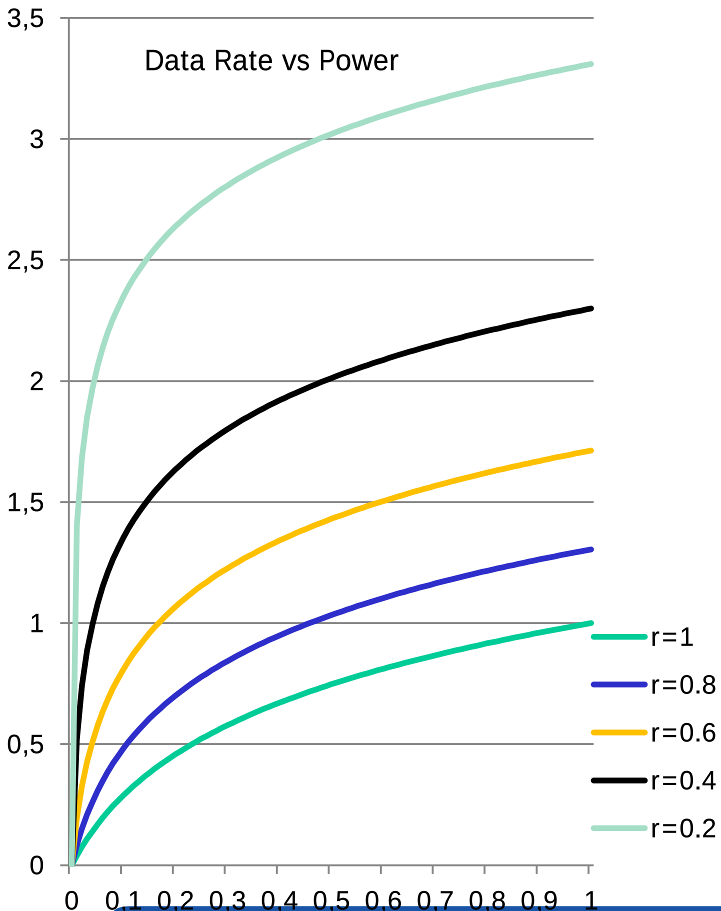


Global scale:

- **Energy consumption of IT-technology not neglectable (2% of CO_2-emission)**
- **3G technology example**
  - **Base station RF output (at antenna): 60 W**
  - **Power input: 3-6 kW (Efficiency 1-2%)**
  - **Reason Spectrum efficient – not power efficient**
- **ELECTRICITY BILL**
  - **30.000 BS = 1 GWh/day = 1 MSEK/day**
  - **30 MSEK/month / 1 M Users**
  - **30 SEK/month (@1 SEK/KWh)**
  - **60 SEK/month (@ 2 SEK/kWh)**



What Power to use ?



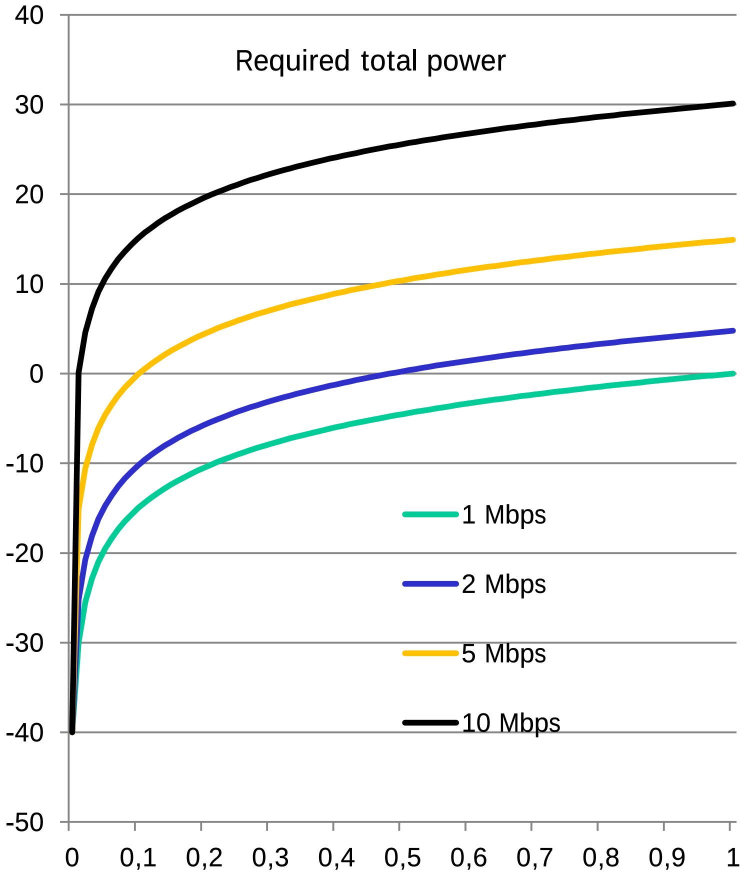
$$\overline{R} \approx R(\overline{r}) = cW \log_2\left(1 + \frac{cP_{tx}}{N_0 \overline{r}^{-\alpha}}\right) =$$

$$= cW \log_2\left(1 + \frac{cP_{tot}}{N_0 \overline{r}^{-\alpha} N_{BS}}\right) =$$

$$= cW \log_2\left(1 + \frac{c' P_{tot}}{N_0 \overline{r}^{-\alpha-2}}\right)$$

$$N_{BS} \propto \frac{1}{r^2}$$

What cell size to use ?



$$\overline{R} \approx c_0 W \log_2\left(1 + \frac{c' P_{tot}}{N_0 \overline{r}^{-\alpha-2}}\right)$$

$$P_{tot} \approx c_1 \overline{r}^{-\alpha-2}\left(2^{\frac{\overline{R}}{c_0 W}} - 1\right)$$

Some conclusions

Peak & average data rates differ a lot

Cell capacity = Average data for user in cell

Increase capacity by more channels & Sectors

Dimensioning for peak-hour traffic

Total energy consumption decrease with cell size