Models for Wireless Infrastructure economics
&
Mobile Broadband deployment

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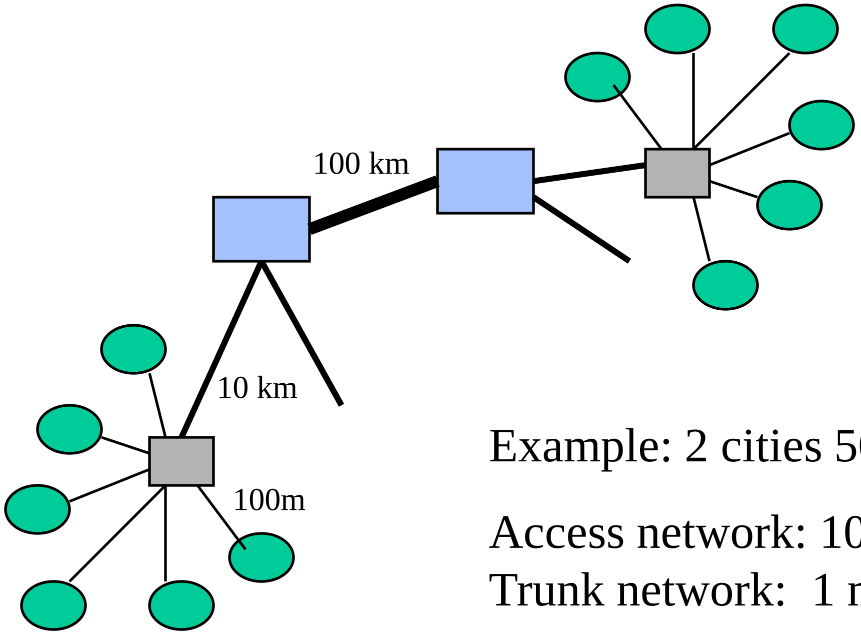
Outline

- Some fundamental problems in infrastructure provisioning
- Wireless Network design fundamentals
- Wireless Broadband dimensioning & deployment

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)

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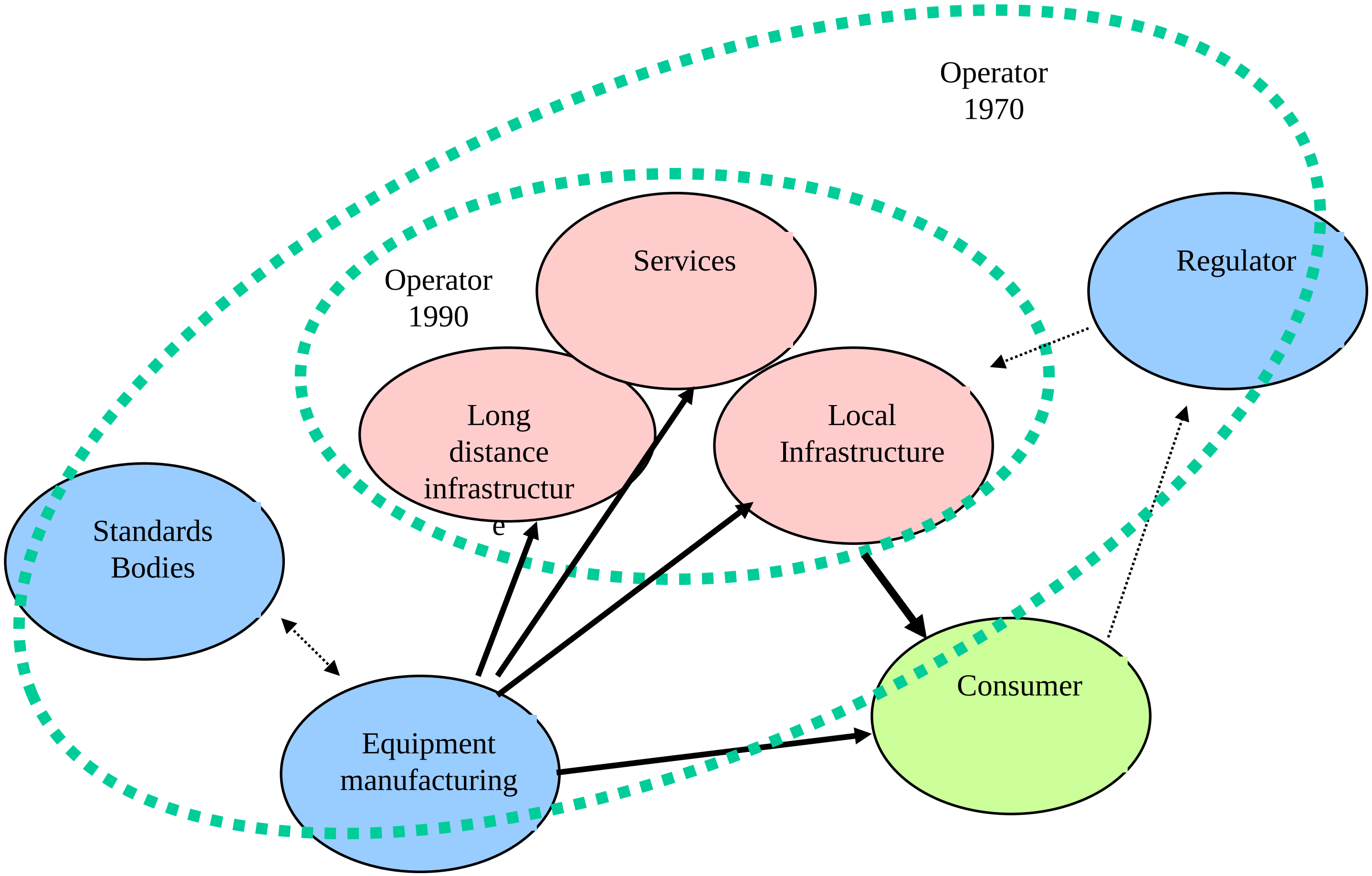
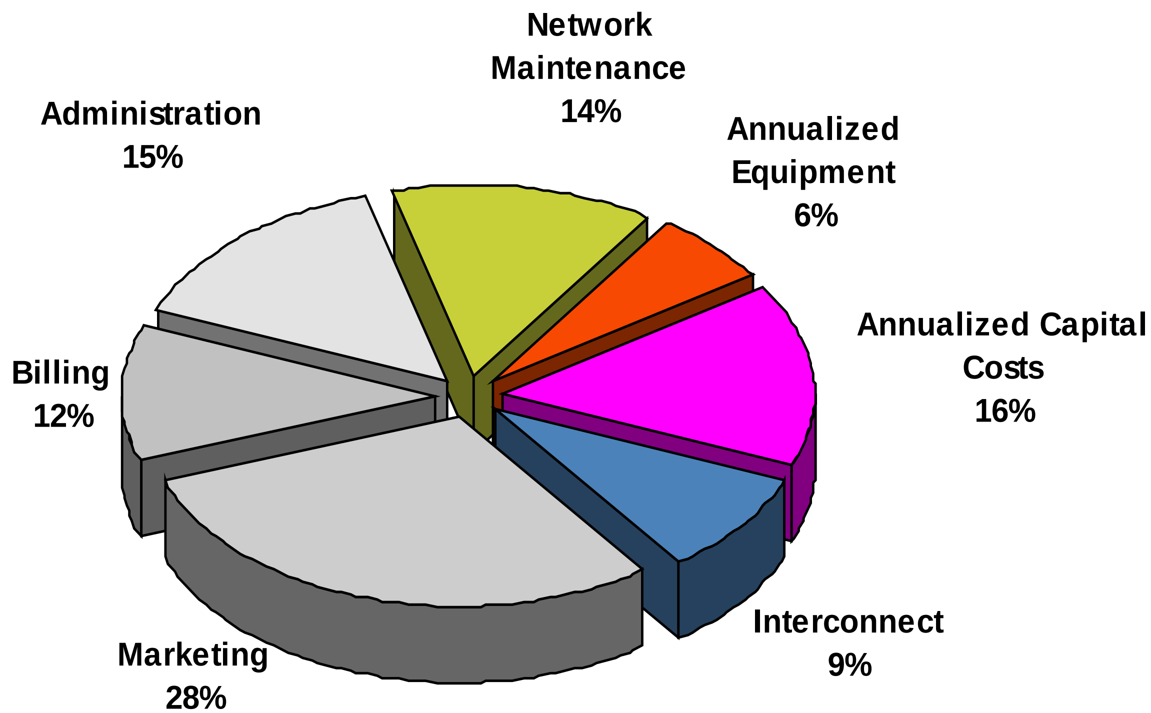
Fragmentization of Actor Roles on the wireless scene



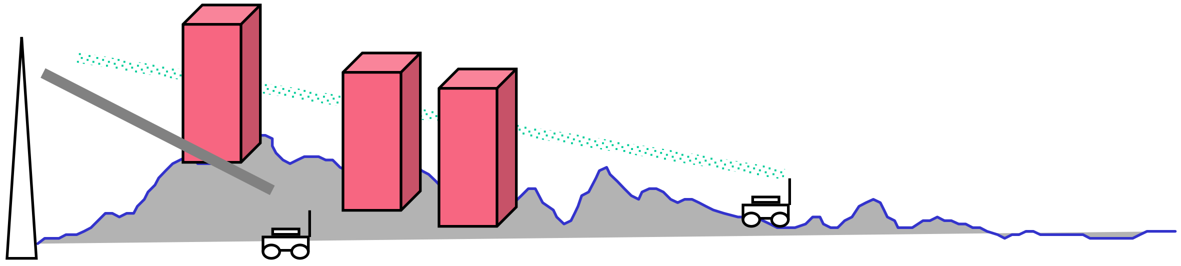
Wireless operator costs



Wireless Network Dimensioning
- a recap

Wireless Networks - problems

- Range
- Coverage



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

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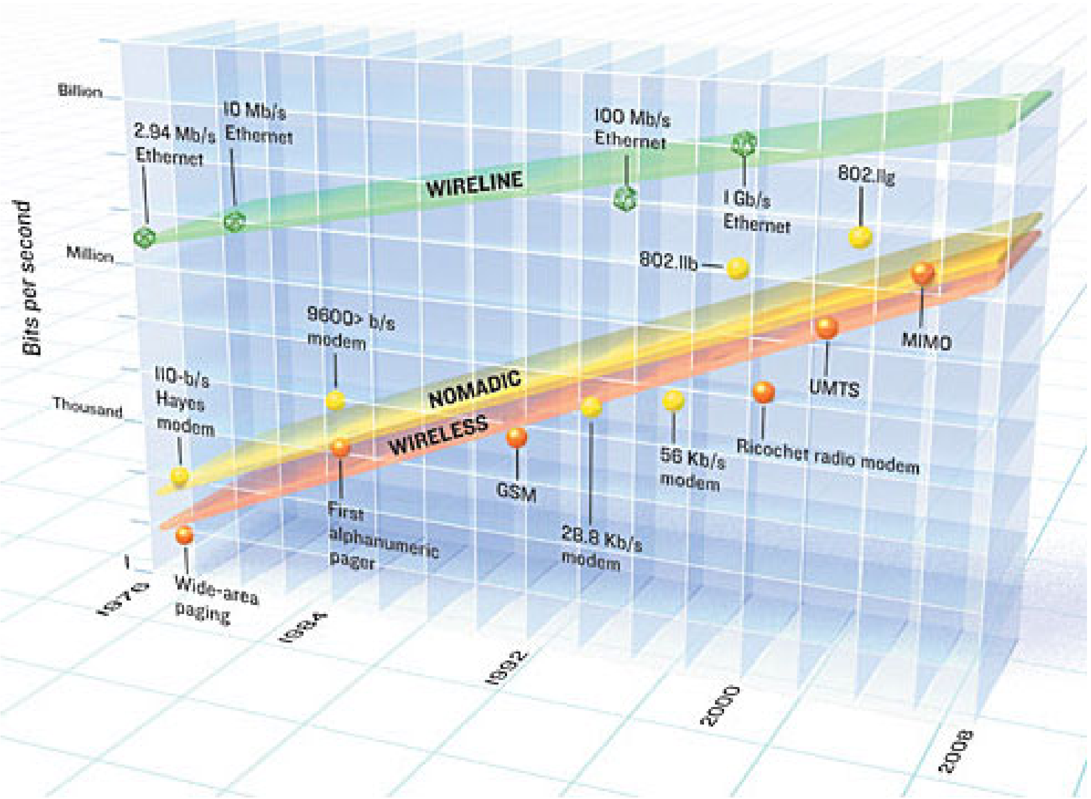
Peak rates & PHY-technology is no longer THE issue ..



"Edholms law"

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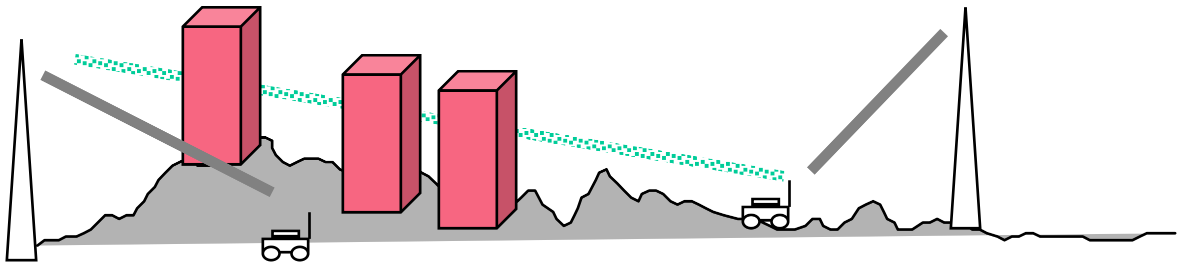
Wireless Networks - problems cont.



- Interference due to spectrum reuse
- Capacity limitation

The infrastructure cost

- Spectrum limitation
  - Btot available bandwidth
  - Spectral /reuse efficiency K

$$Cost \propto N_{BS} \propto \frac{N_{user} B_{user} K}{B_{tot}} A_{tot}$$

- Coverage limitation

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

Mobile broadband deployment

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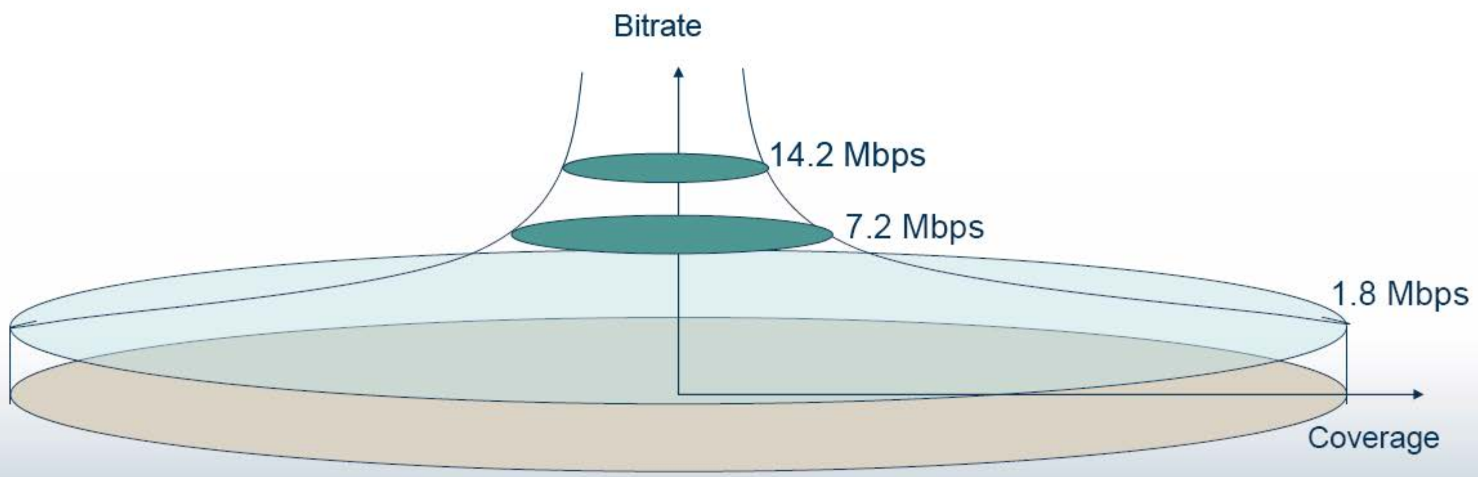
Coverage & Bit rate

Coverage vs. bitrate



Double peak rate does not correspond to double capacity

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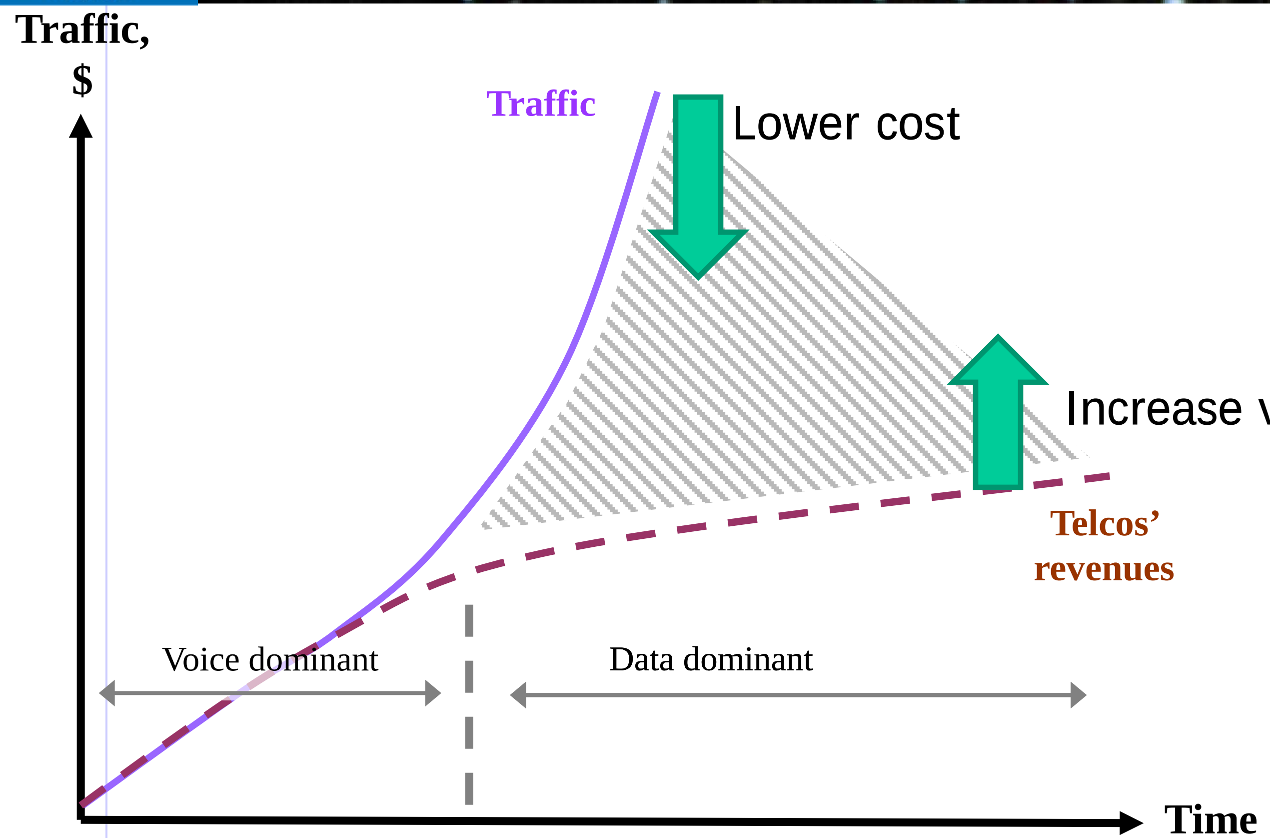
What can be done about the revenue gap ?

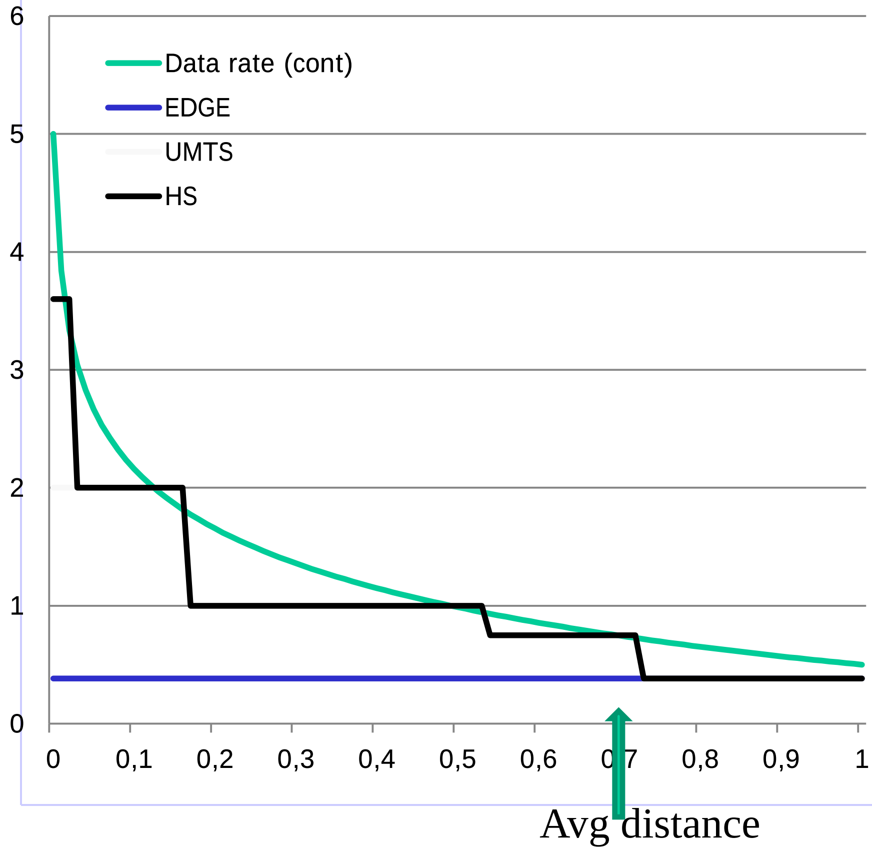


In a world dominated by data,
traffic growth is not anymore correlated with revenue growth!

Design Example: Rural deployment –

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

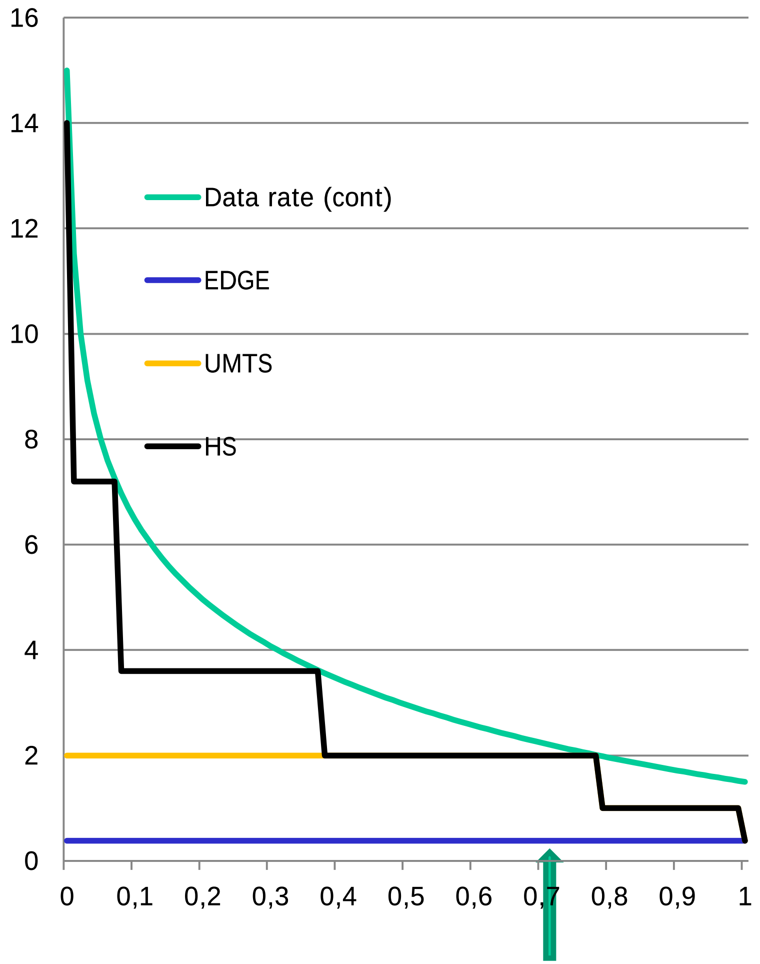
$$\overline{R} = E[R] = W\int R'(r) f(r) dr$$



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

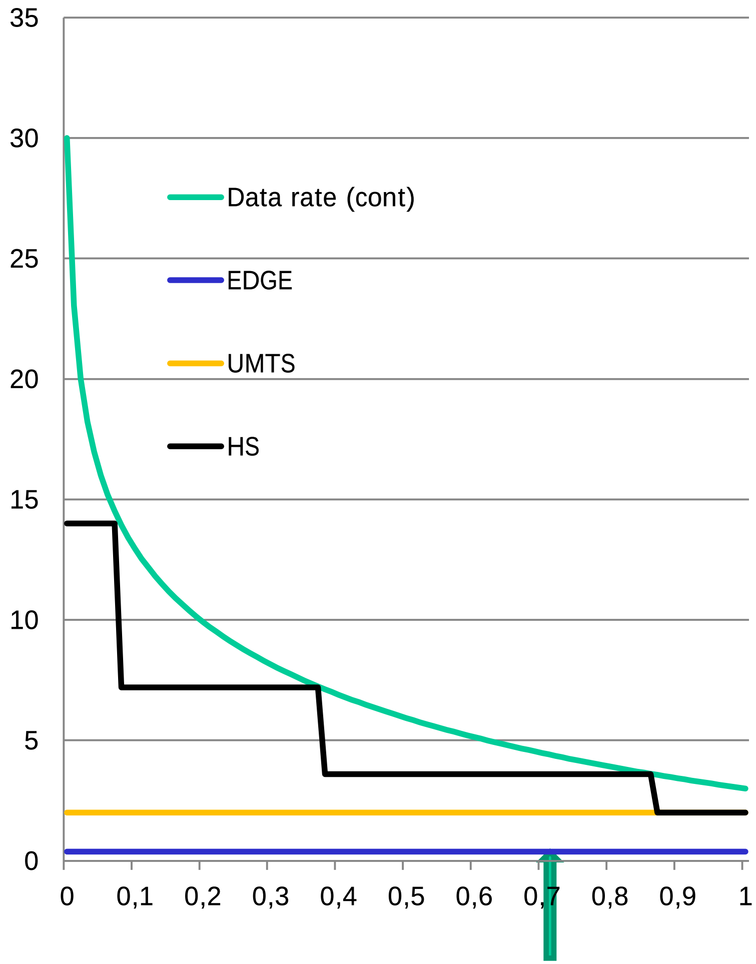


Avg distance

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



Avg distance

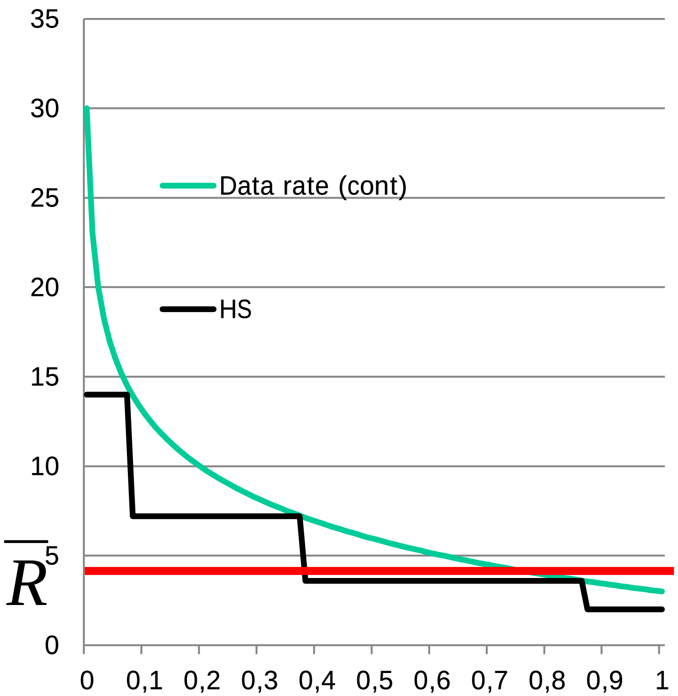
Cell radius: <500 m

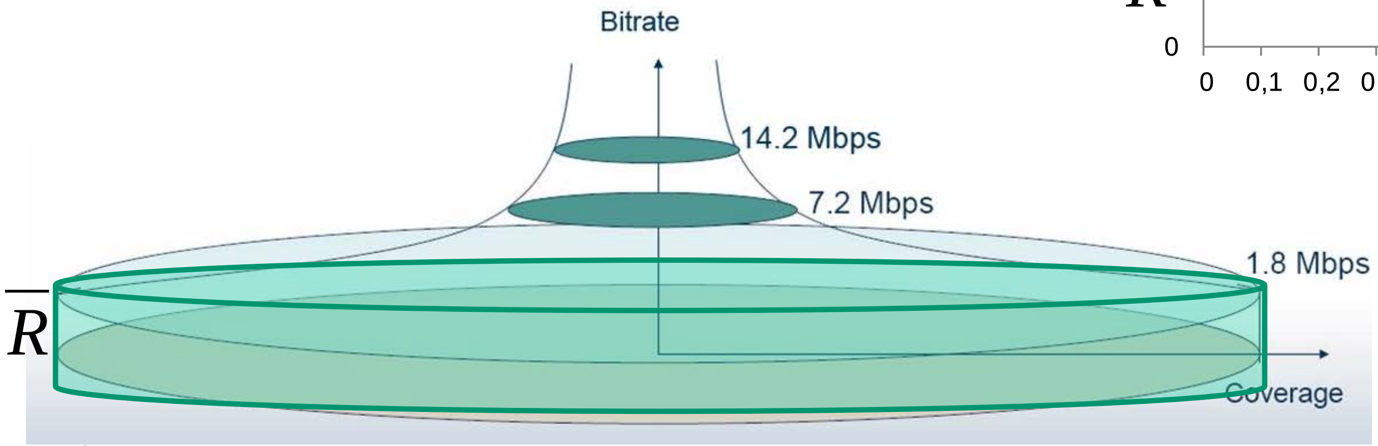
	Peak Rate (Mbps)	Avg. Rate (Mbps)
Continous	N/A	5,1
HS	7.2	3,8
UMTS	2	2
EDGE	0.38	0.38

Single cell capacity & approximation

Single cell capacity

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





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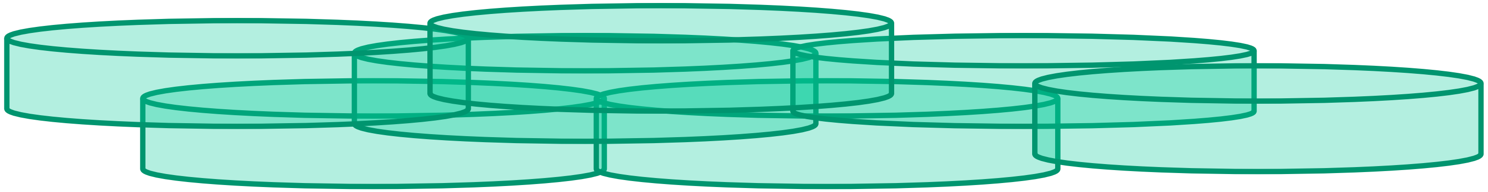
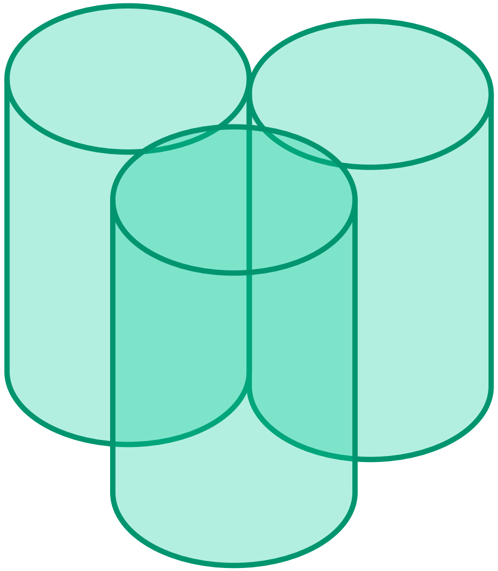
Deployment strategies



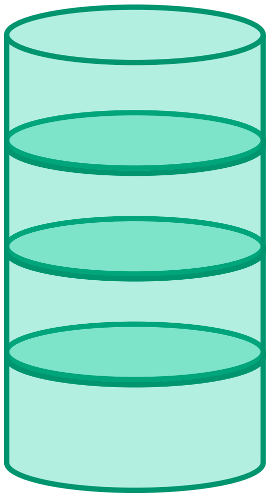
- Wide area ”blanket coverage”
- Low Capacity

Deployment strategies



- Limited ”Hot spot” coverage
- High capacity Capacity

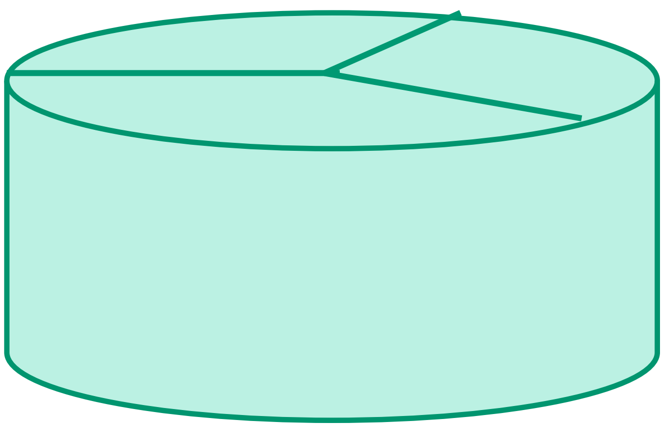
Capacity enhancement



- More spectrum (channels)

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

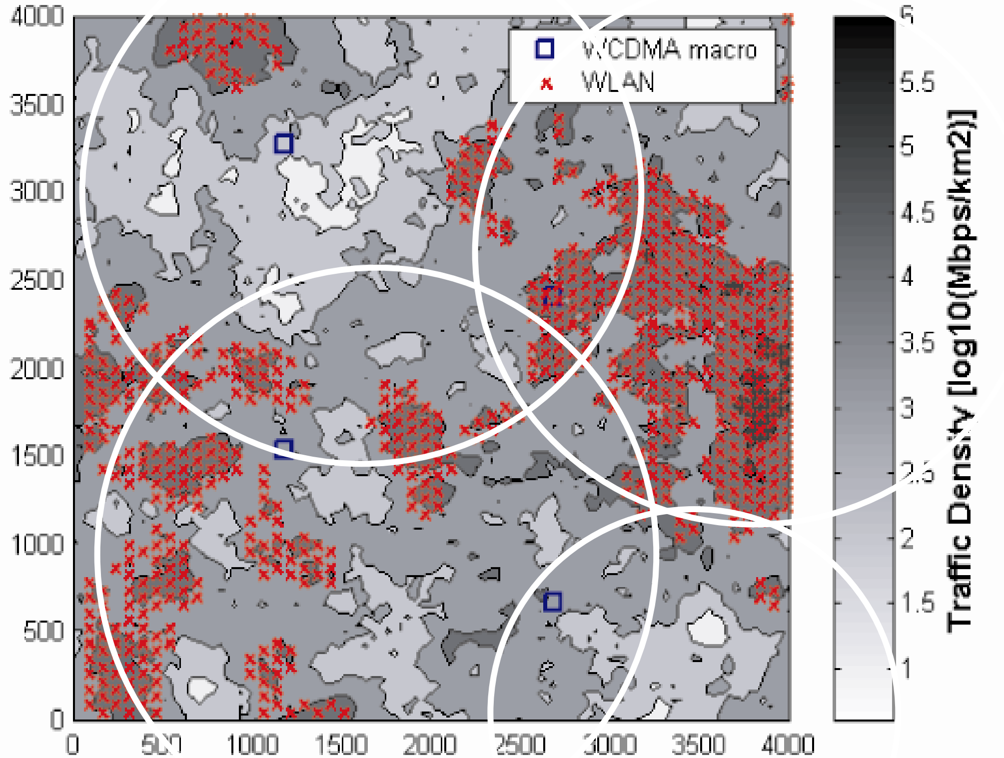
$$R_{tot} = N_{ch} \overline{R}$$



- Sectorization
- Improved spatial reuse

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

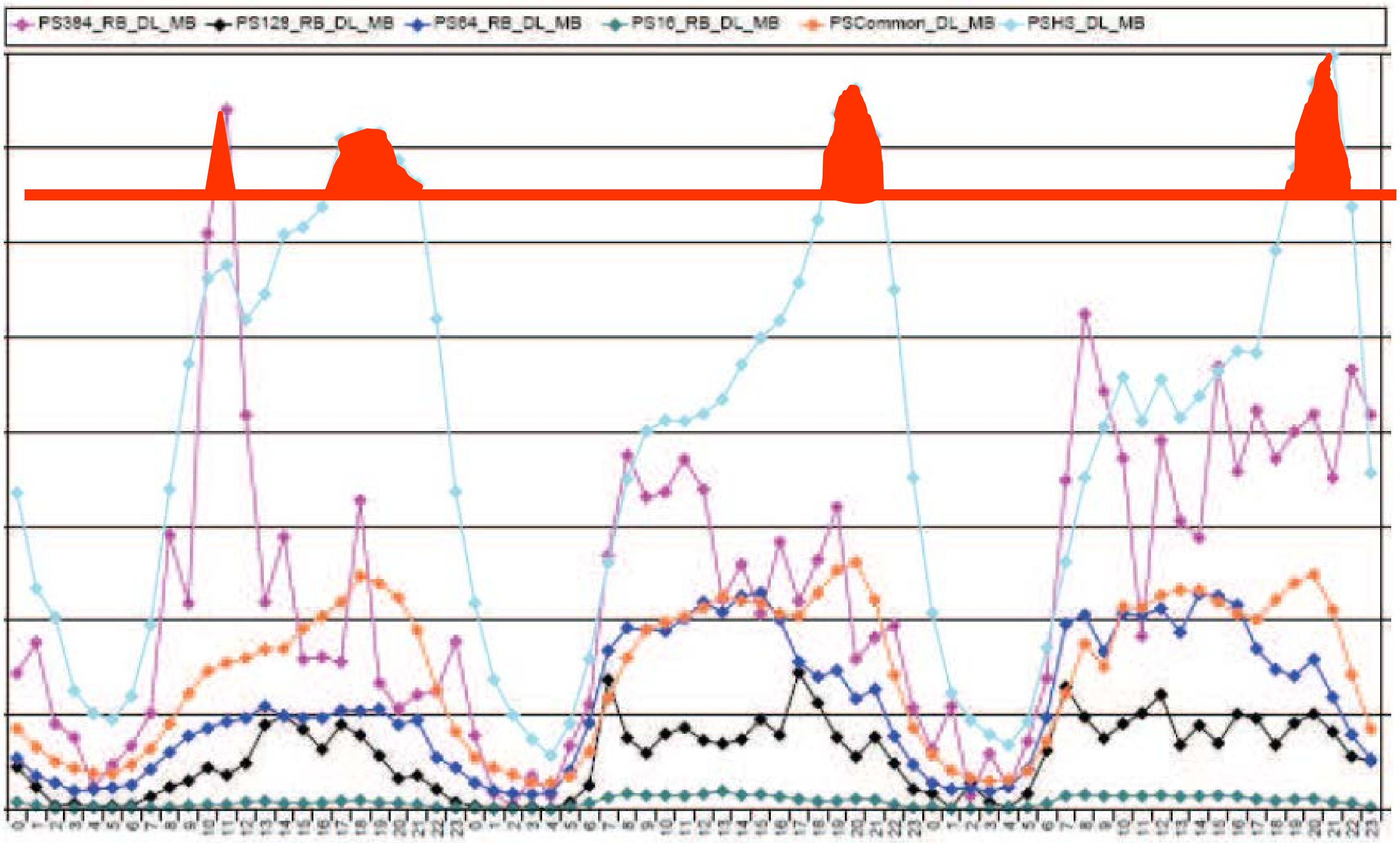
"HET NETS" – from "blanket coverage" to selective capacity



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

Temporal design – peak capacity

- Networks designed for ”peak/busy hour”



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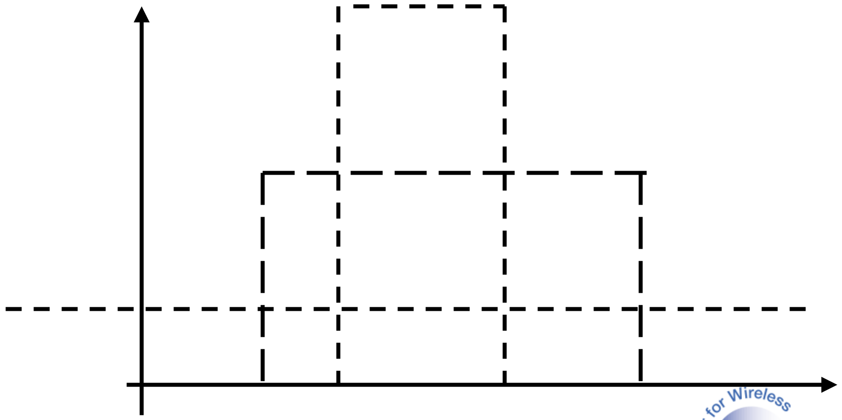
Dimensioning

- 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

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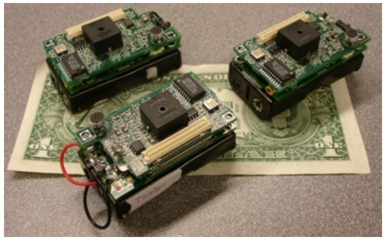
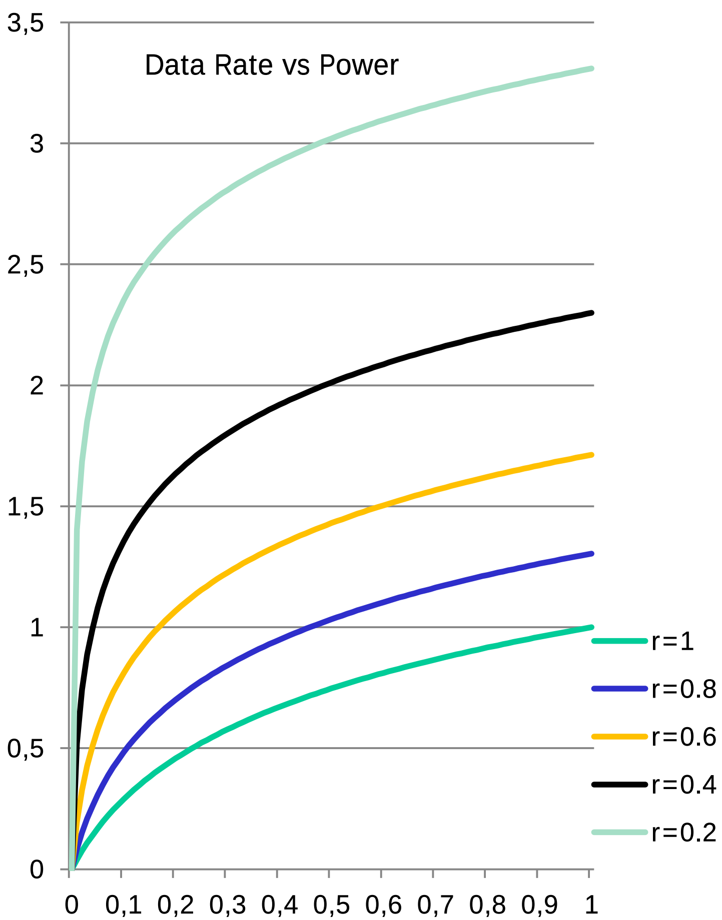
Energy constraints

- **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 ?



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

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

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

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

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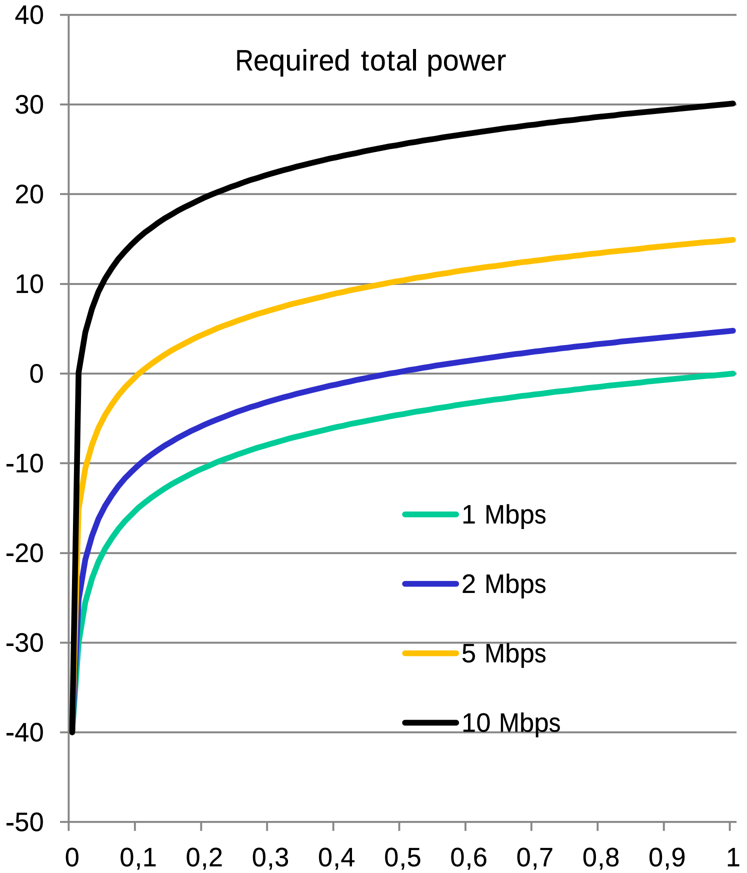
What cell size to use ?



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

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

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