







### Mobile Data avalanche

92% CAGR 2010-2015

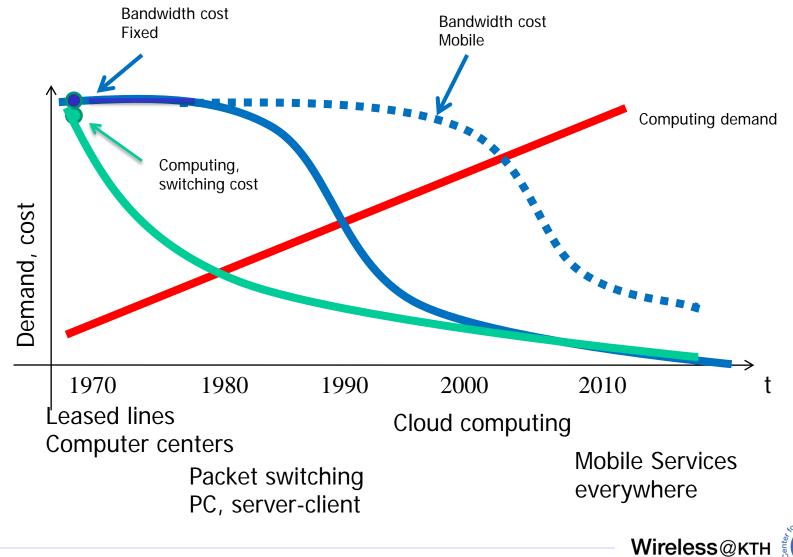


VoIP traffic forecasted to be 0.4% of all mobile data traffic in 2015. Source: Cisco VNI Mobile, 2011





### Compution & Communication Paradigms







# World wide proliferation of Mobile Data

Key Global Telecom Indicators for the World Telecommunication Service Sector in 2011 (all figures are estimates)

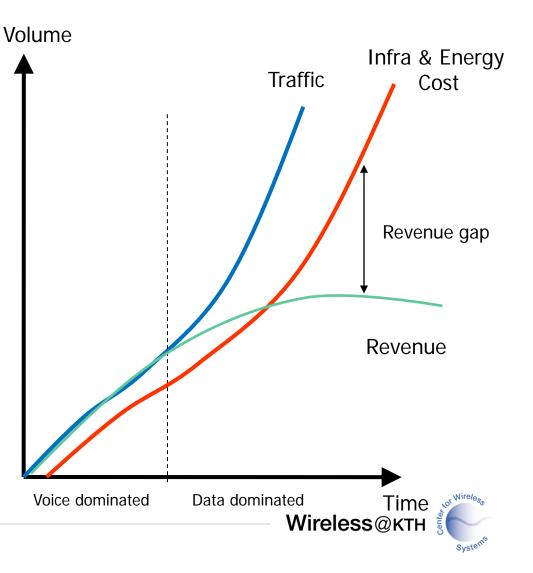
	Global	Developed nations	Developing nations	Africa	Arab States	Asia & Pacific	CIS	Europe	The Americas
Mobile cellular subscriptions (millions)	5,981	1,461	4,520	433	349	2,897	399	741	969
Per 100 people	86.7%	117.8%	78.8%	53.0%	96.7%	73.9%	143.0%	119.5%	103.3%
Fixed telephone lines (millions)	1,159	494	665	12	35	511	74	242	268
Per 100 people	16.6%	39.8%	11.6%	1.4%	9.7%	13.0%	26.3%	39.1%	28.5%
Active mobile broadband subscriptions (millions)	1,186	701	484	31	48	421	42	336	286
Per 100 people	17.0%	56.5%	8.5%	3.8%	13.3%	10.7%	14.9%	54.1%	30.5%
Fixed broadband subscriptions (millions)	591	319	272	1	8	243	27	160	145
per 100 people	8.5%	25.7%	4.8%	0.2%	2.2%	6.2%	9.6%	25.8%	15.5%
Source: International Telecommunication Union (November 2011)						via: mobiThinking			





### More for less money

- Spending capability of user increases with GNP growth (<10% annually)</li>
- Capacity requirements increase by 100% annually

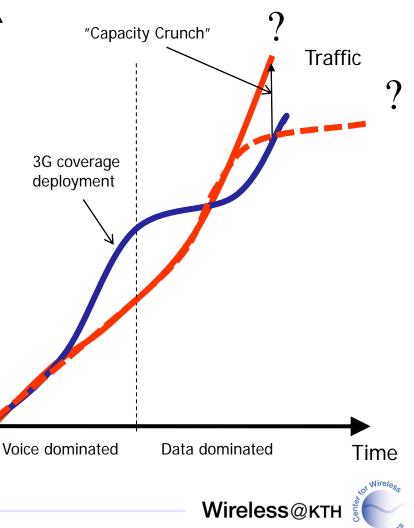




### but will operators keep up '



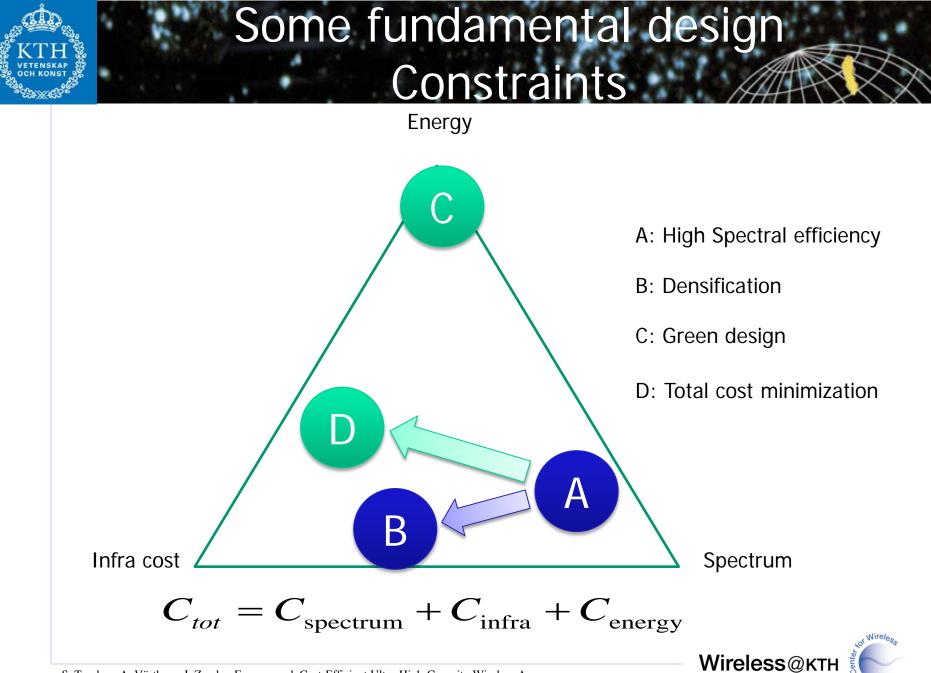
- Excess capacity when 3G was deployed to meet coverage constraints
- "Hidden traffic" ("App-App", "Cloud based") causes severe problems ("Control plane overload")
- Rapid LTE Deployment medium term solution since terminal market still dominated by WCDMA/HSPA terminals





# How can we achieve the target ?





Syster

S. Tombaz, A. Västberg, J. Zander, Energy- and Cost-Efficient Ultra-High-Capacity Wireless Access, IEEE Wireless Communications, October 2011.



### Candidate Technologies

- Improved Spectral Efficiency (Moore's Law)
  - PHY-layer (Modulation, MIMO)
  - Interference Management (COMP/ICIC)
- Denser infrastructure
- More Spectrum





### In search for 5 G 1000 times more capacity ...but how?

### What does the "market" think ?

Company	Spectrum	Spectral efficiency	Densification	Total capacity increase
Nokia Siemens	10x	10x	10x	1000x
Huawei	3x	3.3x	10x	100x
NTT Docomo	2.8x	24x	15x	1000x

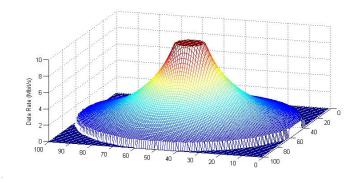
What does capacity mean?

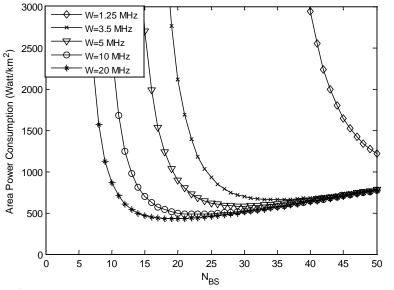
$$R_{tot} = N_{user} R_{user}$$





### Spectral efficiency & PHY Layer improvements





 Operation today almost at Shannon limit

$$R = nW \log\left(1 + \frac{P}{I_0 W}\right)$$

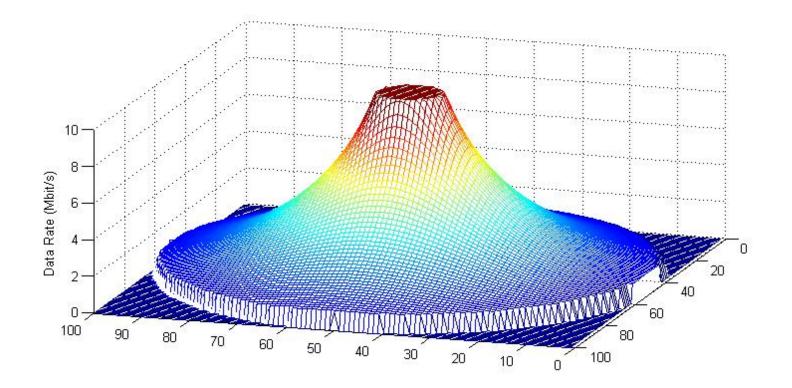
- Increased peak rates have limited effect on average or guaranteed rate if BS density is too small
- Too high <sup>R</sup>/<sub>W</sub> leads to poor energy efficiency
- Conclusion:
  - Further increase in spectral efficiency not feasible/desirable
  - Multiple antenna (MIMO) gain feasible (factor n in peak rate)

S. Tombaz, A. Västberg, J. Zander, Energy- and Cost-Efficient Ultra-High-Capacity Wireless Access, IEEE Wireless Communications, October 2011.





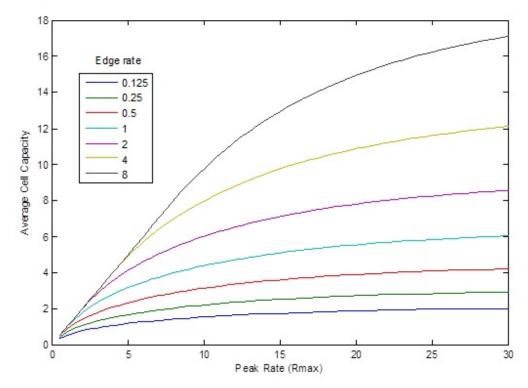
### Capacity and Peak Rate are not simply related



### Capacity ≠ Peak Rate Moore's law not applicable to concrete and steel Wireless@ктн



### Peak vs Edge Rates



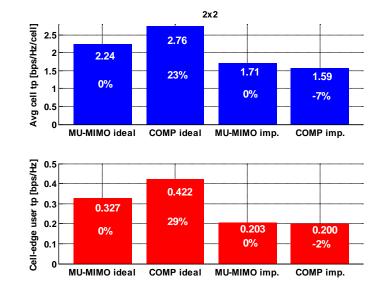
- Edge rates dominate
- High peak rates make sense only in dense deployment
- Cost/Tech drivers:
  - Peak rates: Replace base station equipment
  - Edge rate: More Base stations sites





### Interference Management

- Ideal COMP/ICIC ("Crazy COMP")
  - Completely Noise limited
  - Some additional diversity gain
  - Theoretical gains 3-4 (?) in SE (reduced reuse factor)
- Practically achievable gains significantly less
  - CSI estimation errors/quatization
  - CSI feedback capacity & processing



Source: 3GPP TSG RAN WG1, R1-100855 "Performance evaluation of intra-site DL CoMP"



### Cooper's law

Cooper's Law of Spectral Efficiency 1 Trillion Conversations per Location 10 Billion 100 Million 1 Million 1 Million Times Improvement 10,000 in 45 Years 100 1 1900 1940 1980 2020

- 1.000.000 times more capacity over last 45 year
  - 25x more spectrum
  - 25x better modulation/signal processing
  - 1600x densification (more base stations)



Source: http://www.arraycomm.com/technology/coopers-law



# Cost for densification

$$C_{\rm infra} \propto C_{BS} \, rac{N_{user} R_{user} A_{service}}{\eta W_{sys}}$$
 "Zander's Law"

$$C_{BS} = C_{site} + C_{backhaul} + C_{Equipment}$$





# Densification: Technology shift



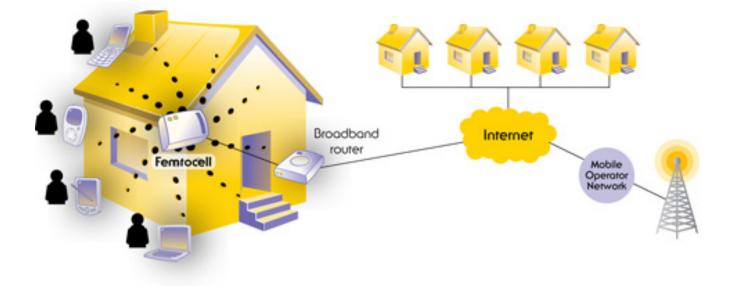
- Industry grade eq
- High power
- 24-7 availabilty
- High system complexity
- COST = equipment, site, spectrum, energy

- Consumer grade eq
- Low power/Short range
- Low system complexity (P&P, SON)
- Massive deployment mainly indoor
- Reliability through redundancy
- Deploy where backhaul available
- COST = Deployment









- Technology: Not an issue !
- Business model: Cooperation !

### "HET NETs"



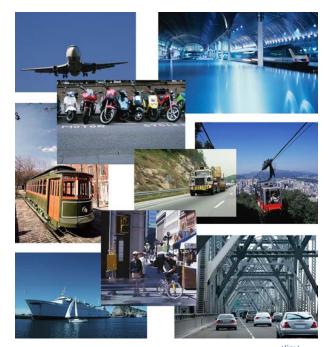


### Infrastructure sharing

Multiple competing parallel infrastructures



- Multimode shared infrastructure
  - Explicit sharing
  - Coopetition

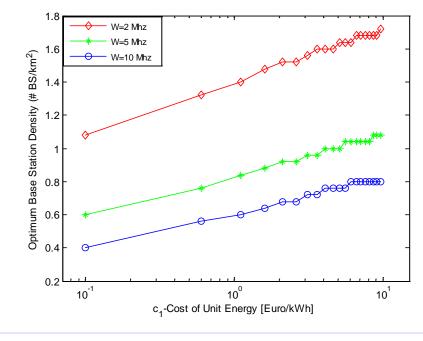






### Why do we need more spectrum?

- More data rate / Capacity ?
  - For very high data rates (>100 Mbit/s user rate)
- Lower deployment cost (fewer base stations)
- Lower energy consumption (lower spectral efficiency)





S. Tombaz, A. Västberg, J. Zander, Energy- and Cost-Efficient Ultra-High-Capacity Wireless Access , IEEE Wireless Communications, October 2011. 20

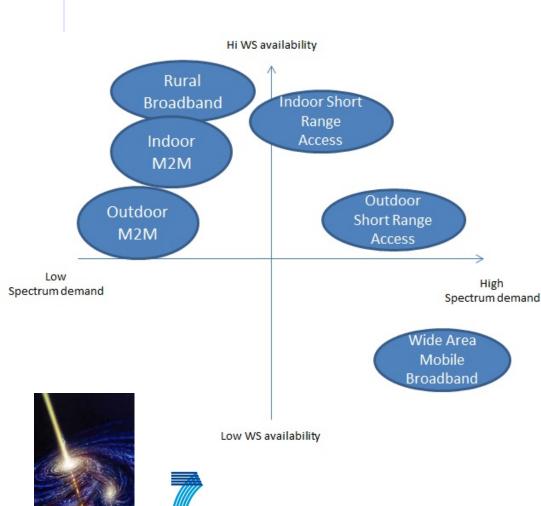


# Spectrum options ?

	Exclusive <6 GHz	Shared < 6 GHz	Secondary <6 GHz	Exclusive > 10 GHz	
Availability	Very Low	Low (100 MHz)	Good (>1 GHz) for <u>indoor use</u>	Very good	
Advantages	<ul> <li>Guaranteed QoS</li> <li>Long-term investments</li> </ul>	<ul> <li>Spectrum available</li> <li>Low cost equipment/deploy ment</li> </ul>	<ul> <li>Spectrum available</li> <li>Low cost equipment/deploy ment</li> </ul>	Very high capacity Low interference	
Disadvantages	High deployment cost	<ul><li>No QoS guarantees</li><li>Low availability</li></ul>	<ul><li>Limited QoS guarantees</li><li>Regulatory uncertainty</li></ul>	LOS propagation, antennas Dedicated Deployment	



### Commercial Feasability of Secondary Spectrum Use (FP7 QUASAR)



SEVENTH FRAMEWORK

- Plenty of spectrum for secondary use, in particular short range indoor
- Availability very scenario & location specific
- Sensing useless in many popular scenarios – yields very low utilization
- Key challenges in business scalability:
  - Assessing impact of multiple interferers
  - Strong Coupling to infrastructure lifetime





### Some conclusions

- Moore Law is not going to save the day (not this time either)
- Denser infrastructure still the key to higher capacity
  - Infrastructure sharing "disruptive" business model
  - Cost dominated by deployment & fixed infrastructure not equipment, spectrum
  - Challenge: Ad-hoc, Out-of-the-box deployment (P&P, SON)
- More <u>low-band</u> spectrum → lower cost, lower energy consumption
- Several new spectrum options available





### Read more & Interact !

### wireless.kth.se



Heterogeneous Networks in **Diverse Traffic Distribution** 

Ultra-High Capacity Wireless

URSI General Assembly 2011, Politics and Spectrum usage LightSquared - even more money down the drain?



### theunwiredpeople.com

### LET'S TALK WIRELESS NWORED PEOPLE

### Technology Neutral Spectrum Assignment – a nice concept but is it realistic ?

Posted on September 9, 2011 by Jens Zander

**1**. (1. )

Login

Rekommendera

We learn from Economics theory that if you want to trade goods effectively, these shall be as general as possible, usable by anyone an preferably for many purposes. In this way we attract a large crowd of willing buyers and the market becomes an effective instrument to share these goods. However, if the goods are very specific (like left lady's high-heels shoes in pink, size 49) the demand is very limited and few buyers will show up to facilitate effective trading.

This exactly the concept behind technology neutral spectrum licensing .. instead of prescribing in detail when, where and how to use the spectrum, the new policy (e.g. "WAPECS") is to provide a "block edge mask", restricting what emission are allowed outside the allocated band. Any system conformant with these rules will be allowed and the market for licenses is now large

What's the ratch 2 Well, its what in the business is called "Lenacy Environment", i.e. anything that is get there before these new regulations are put into place. We have already numerous examples of interference problems. Air-out radars, GSM-R (railway) systems, TV-receivers are facing interference from new LTE/UMTS systems that are put into operation in neighboring bands. Is something wrong with these systems 7 No. Are they violating the spectrum mask rules ? Not likely, Would the problems on away with perfect new equipment? Unfortunately 200

You see, most of this equipments was not designed to have a LTE or UMTS base station next door. The were designed with the implicit assumption that the neighboring band was empty or used in a very specific way. In this way receiver designers could cut some corners and save a few bucks in production cost. So it's clear where to put the blame. But will the airport-radar uses, the television set manufacturers or railways modify their systems 7. Not likely. There seems to be "souratters rights" in the spectrum domain - the guys that where there first (and have significant investments made) are protected and the new users have to modify their equipment, restrict their use or even pay for the modification of legacy equipment. In Sweden a recent study show that using UMTS in the 900 MHz band is OK as long a you stay a kilometer away from the nearest railroad (i.e. where the highest condition density are likely to be). If a different system is used LTE GSM there may be different restrictions. Instead of having a technology neutral spectrum, specific rules apply for each technology and exact how close to the band edge the spectrum chunk is located. Will the bidders in a spectrum auction need to take this into account - yes of course, with a significantly lower valuation as consequence

So Tech Neutrality is a nice concept but difficult in practice. It again exposes the shortcomings of our current paradigm of transmitter licensing. Here (and in many similar cases) its the receivers that cause the problems. The concept of Spectrum Usage Rights is a step in the right direction, but not a solution to these problems.



Posted In Spectrum, Systems | 2 Comments and 1 Reaction

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 Technology Neutral Spectrum Assignment - a nice concept but is it realistic 7

Search

- Chinacom 2011-Some notes URSI General Assembly 2011, Politics and Spectrum usage
- LightSquared even more more down the drain?
- "Big Brother" says streaming more than 10 times is illegal

### Categories

### Business Conterence

- Devices and Gadnets
- Education
- Green radio
- Job openings
- Security
- Spectrum Systems
- Uncategorized

### PEOPLE RECENT POPULAR

jzander Absolutely, I think this is one of the problematic areas for secondary spectrum use ("cognitive radio") in densely populated areas. There is plenty of spectrum in many places on paper but when you Technology Neutral Spectrum Assignment - a nice concept but is it realistic ? 1 day ago

Syed Fahad Yunas Hi, If I am not wrong, Spectrum Sensing Cognitive Radio also work almost on the same spectrum neutral principles isn't it? Do you think their usage will also be limited by









### Additional slides





# Cellular Design for Power/Total Cost minimization





### Energy consumption modelling

- Assumptions:
  - Homogenous network, (real network composed of homogeneous "islands")
- Power consumption

$$\mathbf{P} = N_{BS} \left[ aP_{tx} + b_{radio} + b_{backhaul} + y \frac{\overline{R}_{tot}}{N_{BS}} \right] + d$$

Proportional to #base stations

Independent of #base stations





### Energy consumption modelling (2)

• Spectrum-Infrastructure Cost-Power Trade-off (Shannon Bound)

$$P_{rx}(d) = \frac{c'GP_{tx}}{d^{\alpha}} \qquad P_{tx} = \left[2^{\frac{\overline{R}}{W}} - 1\right] \frac{N_0 W}{cG} R_{cell}^{\alpha}$$

• Average spectral efficiency  $S = \frac{\overline{R}}{W}$ 

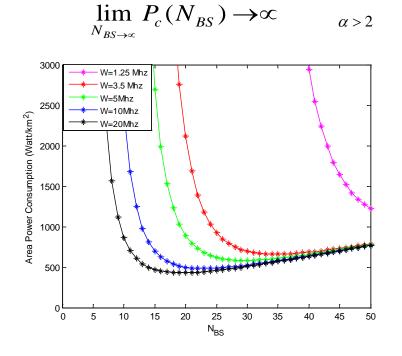
$$\mathbf{P}_{c} = \left(N_{BS}\left[a\left\{\frac{N_{o}W}{cG}\left(2^{\frac{\overline{R}_{t_{tot}}}{N_{BS}W}} - 1\right)\left(\frac{A}{\pi N_{BS}}\right)^{\alpha/2}\right\} + b_{radio} + b_{backhaul} + y\frac{\overline{R}_{tot}}{N_{BS}}\right] + d\right)/A$$





### "Green" Architecture

• If power/energy is the dominant constraint;



There is always a non-null and finite that minimizes the areapower consumption.

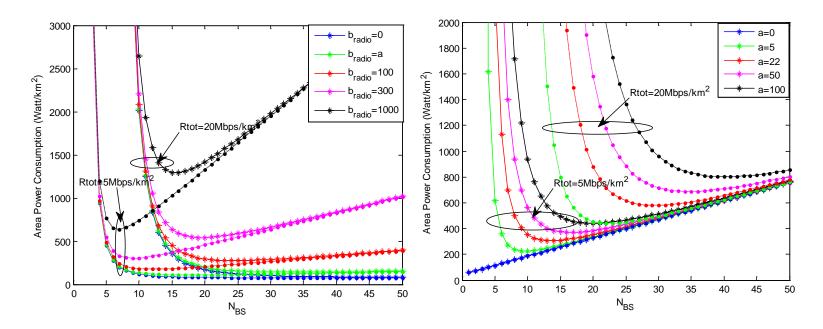




### Green Architecture

• Idle power

PA - efficiency







### Deployment of Minimal Total Cost

• Total Network Cost as a function of main drivers of the network:

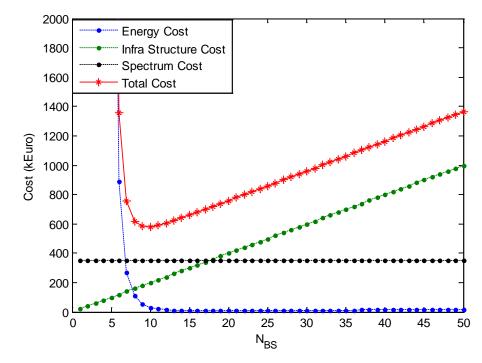
$$Cost = c_o * N_{BS} + c_1 \left\{ N_{BS} \left[ a \left\{ \frac{N_o W}{cG} \left( 2^{\frac{\overline{R}_{t_{tot}}}{N_{BS}W}} - 1 \right) \left( \frac{A}{\pi N_{BS}} \right)^{\alpha/2} \right\} + b_{radio} + b_{backhaul} + y \frac{\overline{R}_{tot}}{N_{BS}} \right] + d \right\} + c_2 W$$

- Co[€/BS]: Annual cost per base station
- C1 [€/Energy Unit]: Annual energy cost
- C2 [€/Mhz]: Annualized spectrum cost





# **Deployment of Minimal Total Cost**

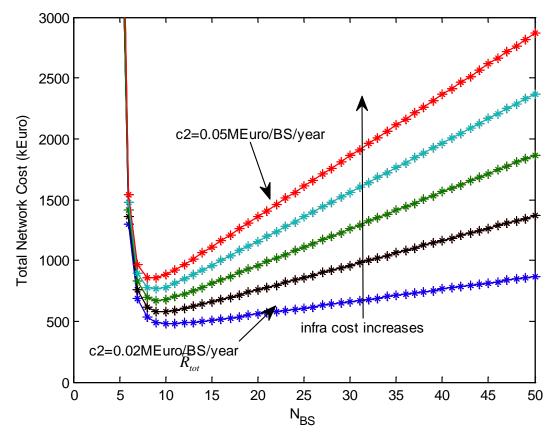


- Minimum total cost now occurs at a much lower number of base stations than in the energy-only minimization.
- Spectrum cost constant provides only a level shift of the total cost;





### Increasing infrastructure cost

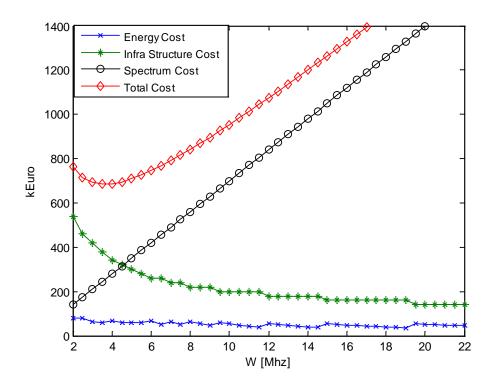


- Total cost increases
- Optimal number of base station is not that much affected.





### Spectrum cost impact



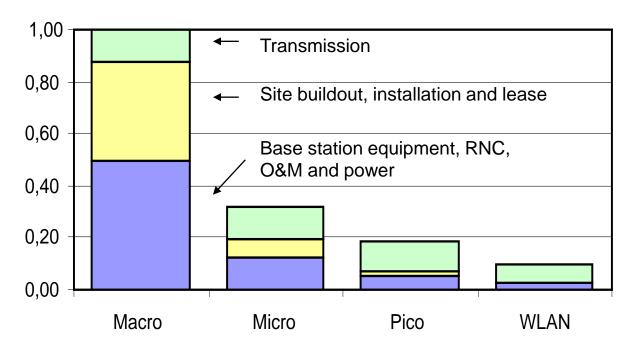
• As the spectrum cost increases, optimum spectrum expenditure moves closer to the "energy asymptote"





### Cost drivers

### Greenfield deployment



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



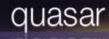
### **QUASAR** Technical findings





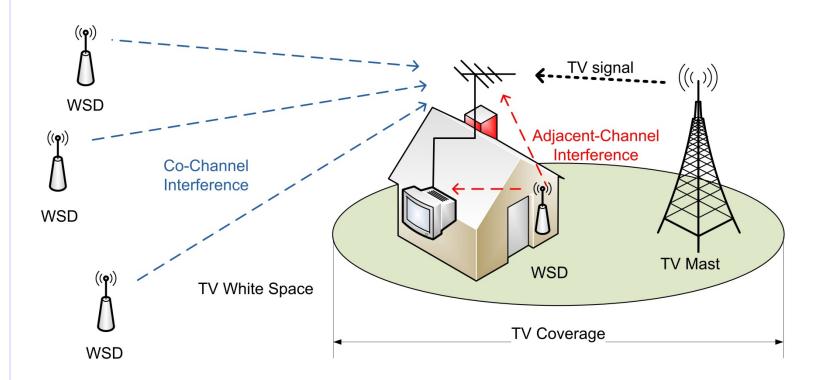
# **QUASAR Key technical findings**

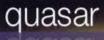
- Plenty of spectrum available but very scenario & location specific
   commercial success is where we can live with this
- Aggregate interference critical for the scalability massive use of secondary spectrum
  - Both co-channel & and adjacent channel interference has to be considered
- "Cognitive" sensing is not very effective in most popular scenarios geolocation based techniques are preferable
  - Limited knowledge of victim receiver location
  - Difficult to assess aggregate interference
  - Sensing interesting to improve/calibrate database propagation models





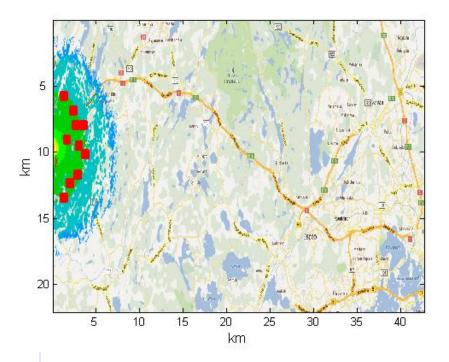
### Co-channel & Adjacent channel interference

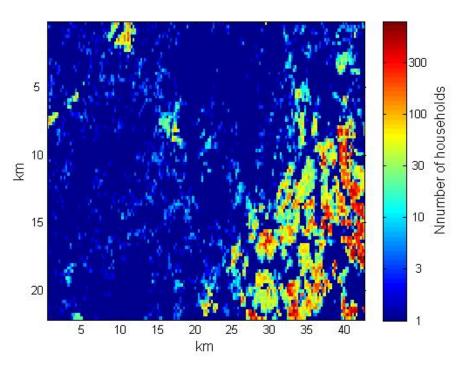






### Aggregate interference due to "massive" use





TV coverage area, TV test points and secondary deployment area

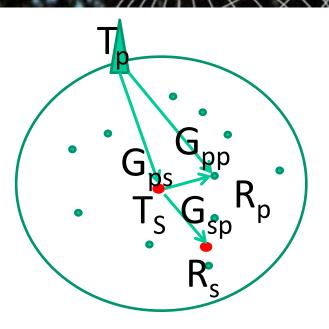
Density of the households Each household  $\rightarrow$  1 transmitter





# (Un-)Reliability of sensing

- Opportunity (not signal) Detection problem
- Even with "perfect" signal detection uncertainty remains about
  - Primary receiver location
  - Primary system path loss
  - Aggregate interference
- Maps into high interference margins and (very) inefficient spectrum use



Scenario	Standard deviation	<i>IM</i> (95%)	<i>IM</i> (99%)	Rate ( <i>IM</i> =95%)	Rate ( <i>IM</i> =99%)
Low detection correlation ( =0)	23,0	37,8	53,5	1,66E-04	4,51E-06
High detection correlation ( =1)	21,5	35,4	50,1	2,86E-04	9,75E-06
Known primary receiver position	11,3	18,6	26,3	1,38E-02	2,33E-03
Known path gain	8,0	13,2	18,6	4,83E-02	1,38E-02
Genie aided access (full knowledge)	0	0	0	1	1

