Green Radio

Centre for Communication Systems Research

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Outline

- Energy efficiency of ICT & mobile communications
- EE Metrics
- Important concepts for EE and SE
- EARTH approaches to sustainable mobile networks
  - Holistic approach
  - Green radios
  - Green networks

The Issue (1/2)

- Currently, 3 % of the world-wide energy is consumed by the ICT infrastructure
  - Contributing ~ 2 % of the world-wide CO_2 emissions
  - comparable to the world-wide CO_2 emissions by airplanes or ¼ of the world-wide CO_2 emissions by cars
- The transmitted data volume increases approximately by a factor of 10 every 5 years

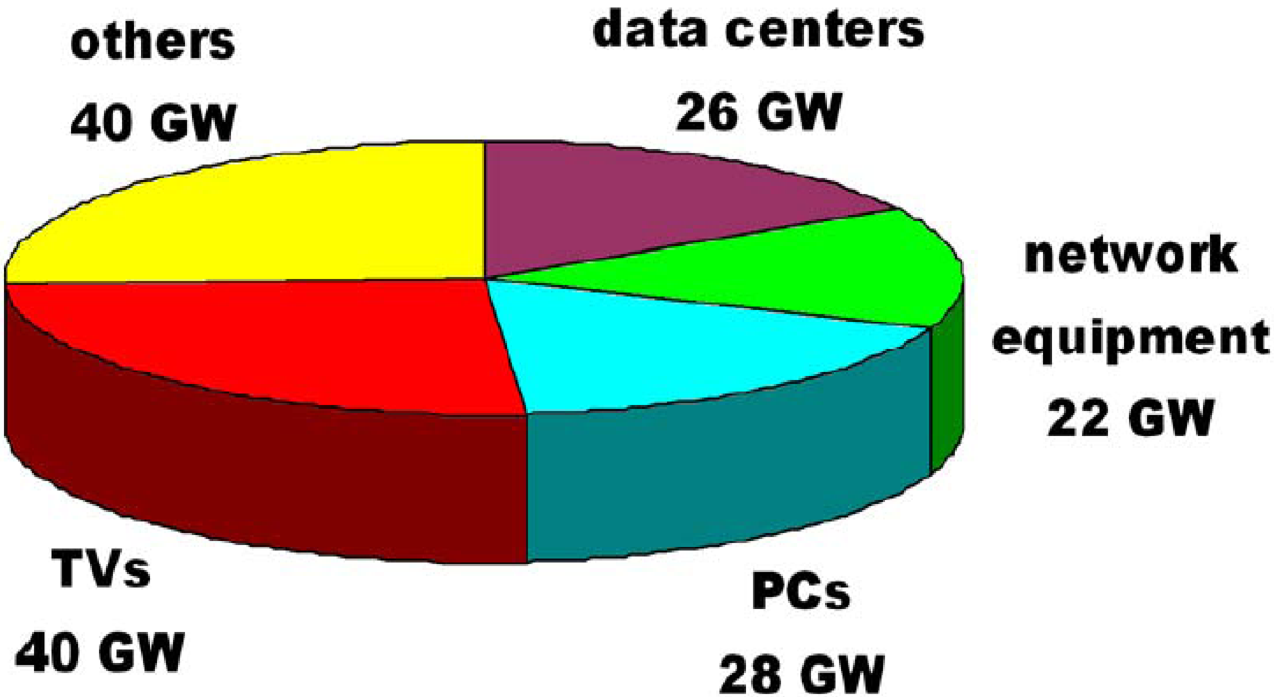
The Issue (2/2)

- ICT: 10% of electrical energy in industrialized nations
  - 900 Bill.. kWh / year = Central and South Americas

- Power consumption of ICT is currently rising at 16-20% / year
  → Doubling every 4-5 years

- Wireless communications can be used extensively to save energy in other industrial sectors.

ICT use: worldwide today



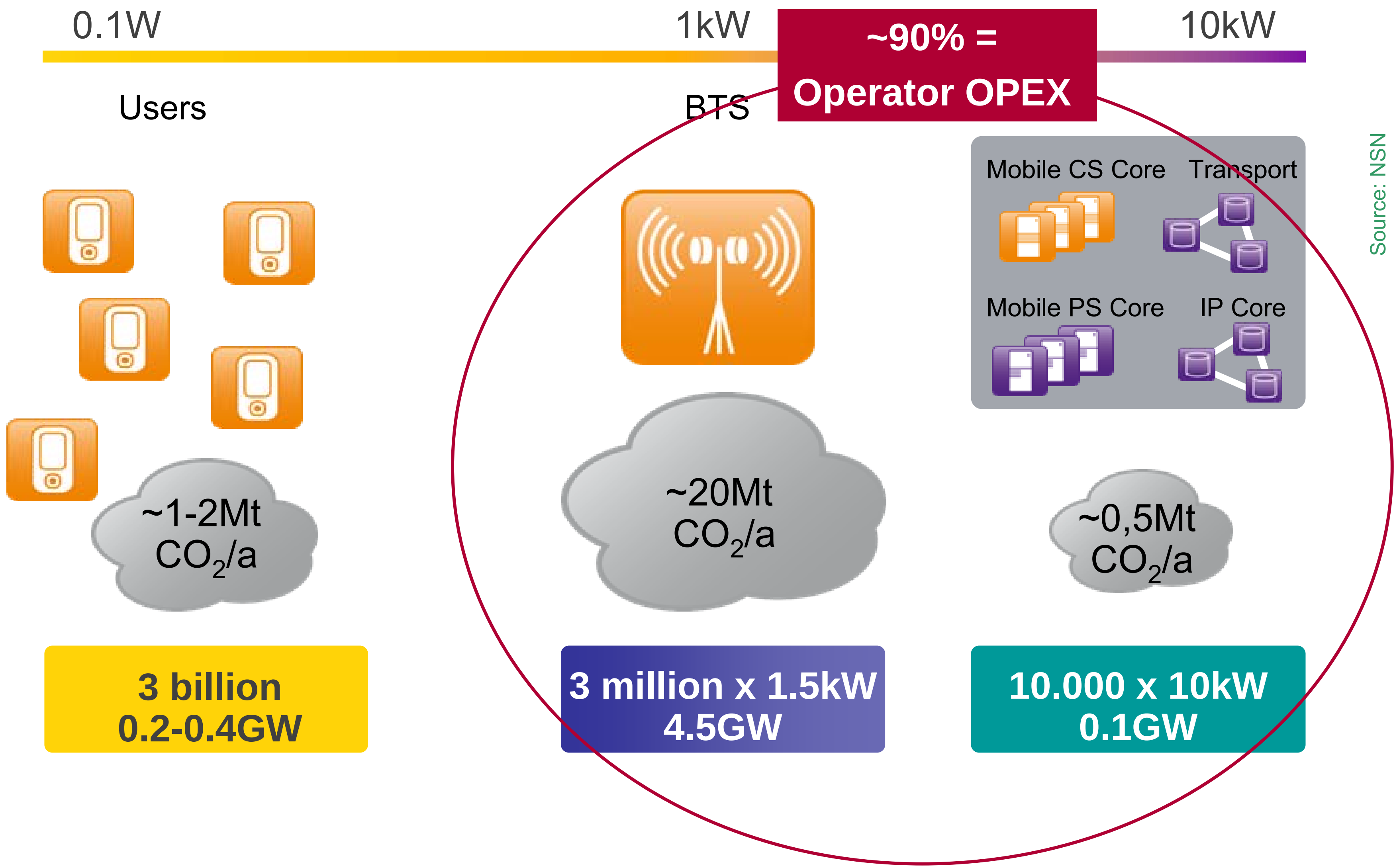
Source: Ghent University/IBBT

- **Total = 156 GW ~ 8% of the global electricity consumption**
- **No dominating front**

EE & PE Mobile networks

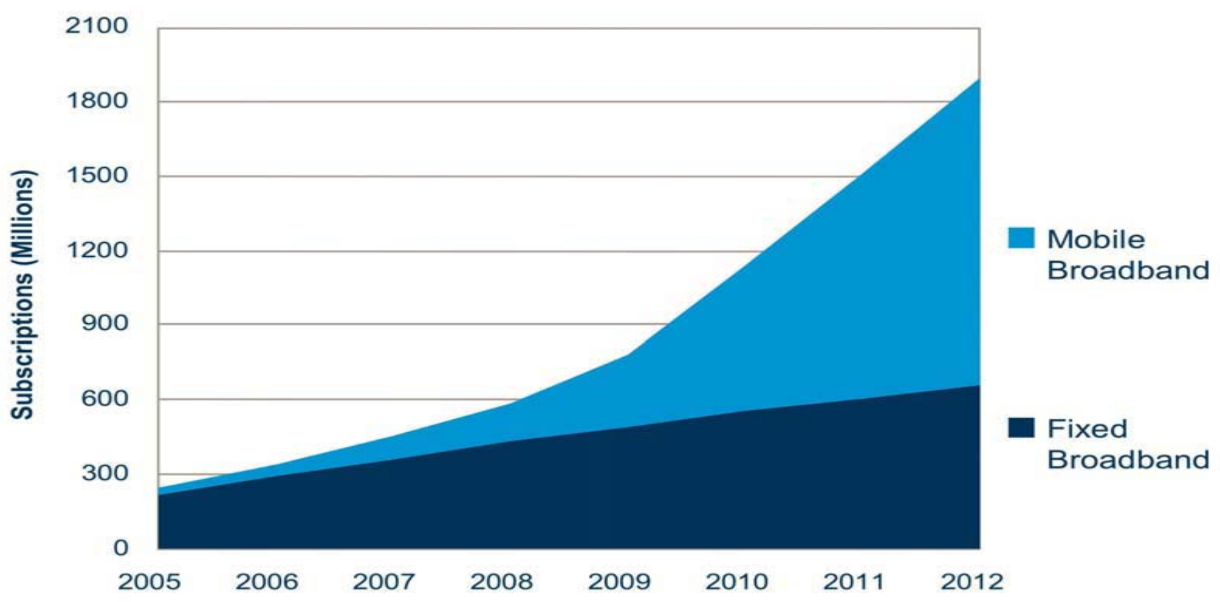
- **So far, mobile networks standards and design rules have ignored EE**
  - Cellular networks have been optimized in terms of spectral efficiency, **Max** capacity, not really in terms of Energy Efficiency!
  - EE considered only for **high load** scenarios
  - PE of equipments/components (mainly terminals)
- **Emerging IoT / RWI raises green challenges**

Power consumption of cellular networks



EE & Mobile networks

- **Mobile operators are already today among the top energy consumers**
  - Telecom Italia (fixed & mobile) is the 2nd largest energy consumer in Italy
- **Energy consumption of Mobile Networks is growing much faster than ICT on the whole**
  - Rapid traffic growth and build-up of broadband coverage
  - Mobile replacing fixed in many areas (only telecom infrastructure in many countries)
  - Enabling ICT services for energy saving in other sectors (teleconferencing,...) further increases mobile networks growth

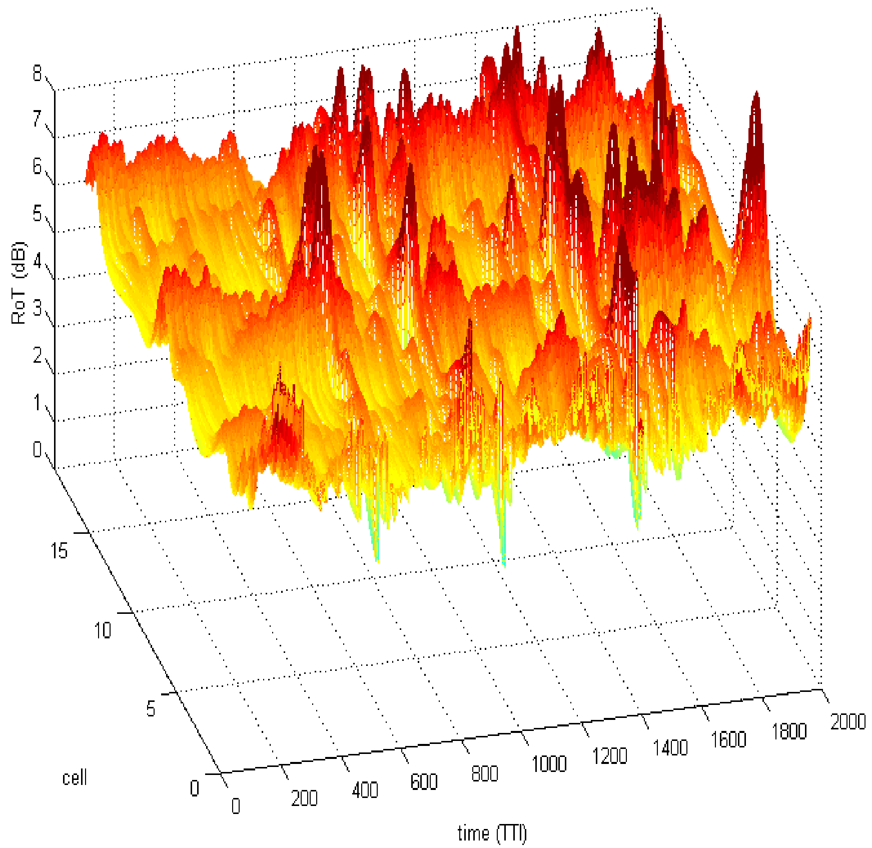


Source: OVUM, Strategy Analytics & Internal Ericsson

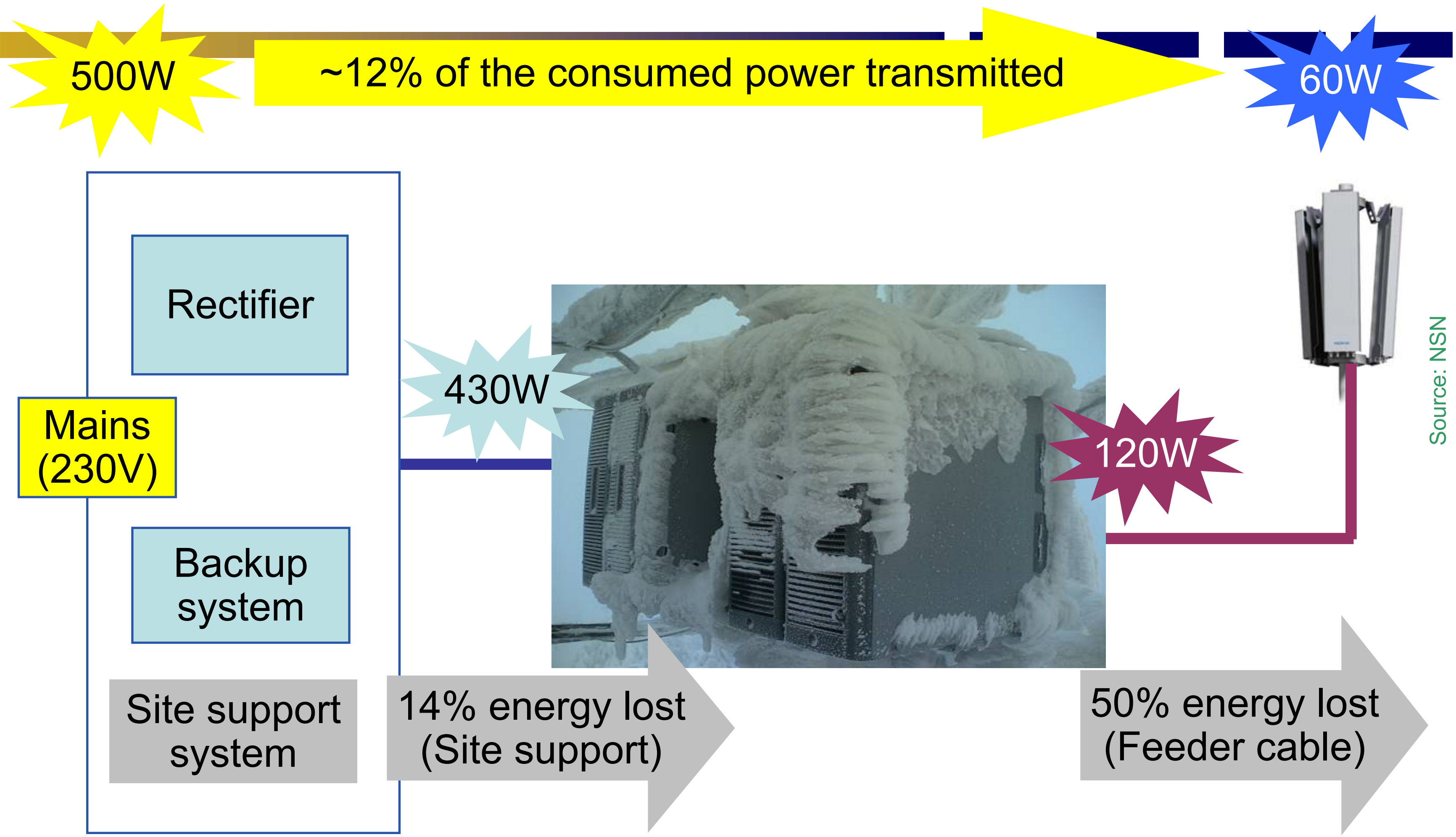
Annual growth rate of internet traffic is 85%.

Mobile networks

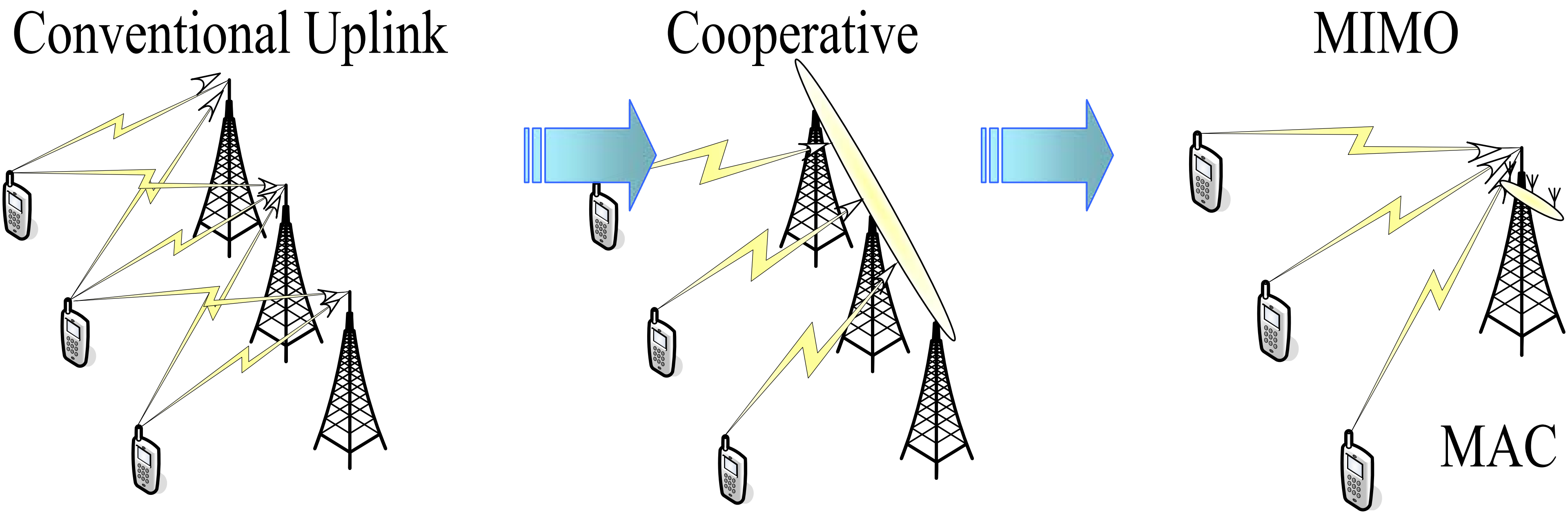
- **Large savings potential not only for quiet hours**
- **Network load is not evenly distributed**
  - Typically 10% of the sites carry 50% of all traffic.
  - 50% of sites are lightly loaded, carrying only 5% of the traffic.
- **Are protocols and algorithms developed are scalable in EE?**



Power consumption of a modern cellular site

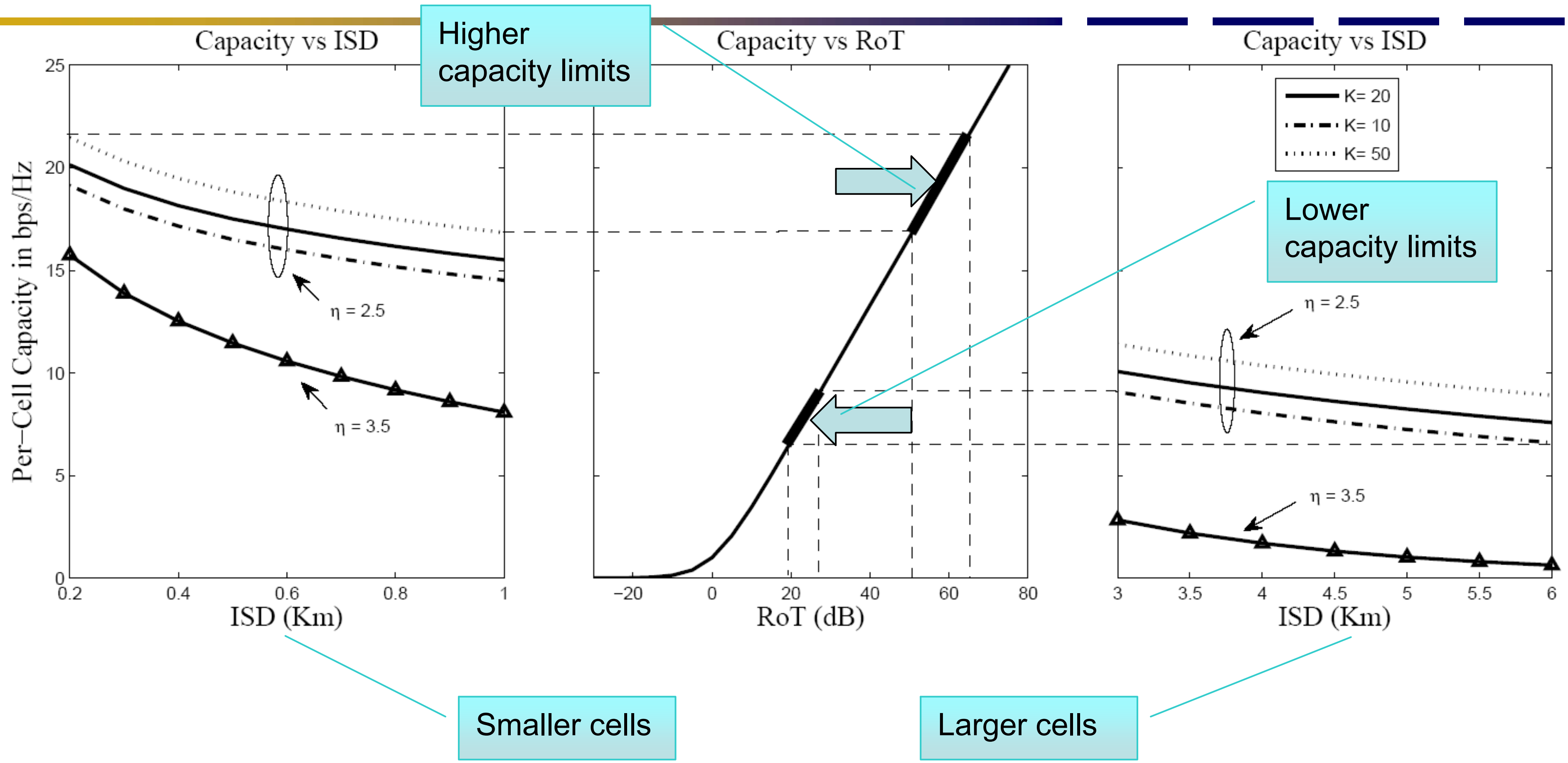


Important Concepts



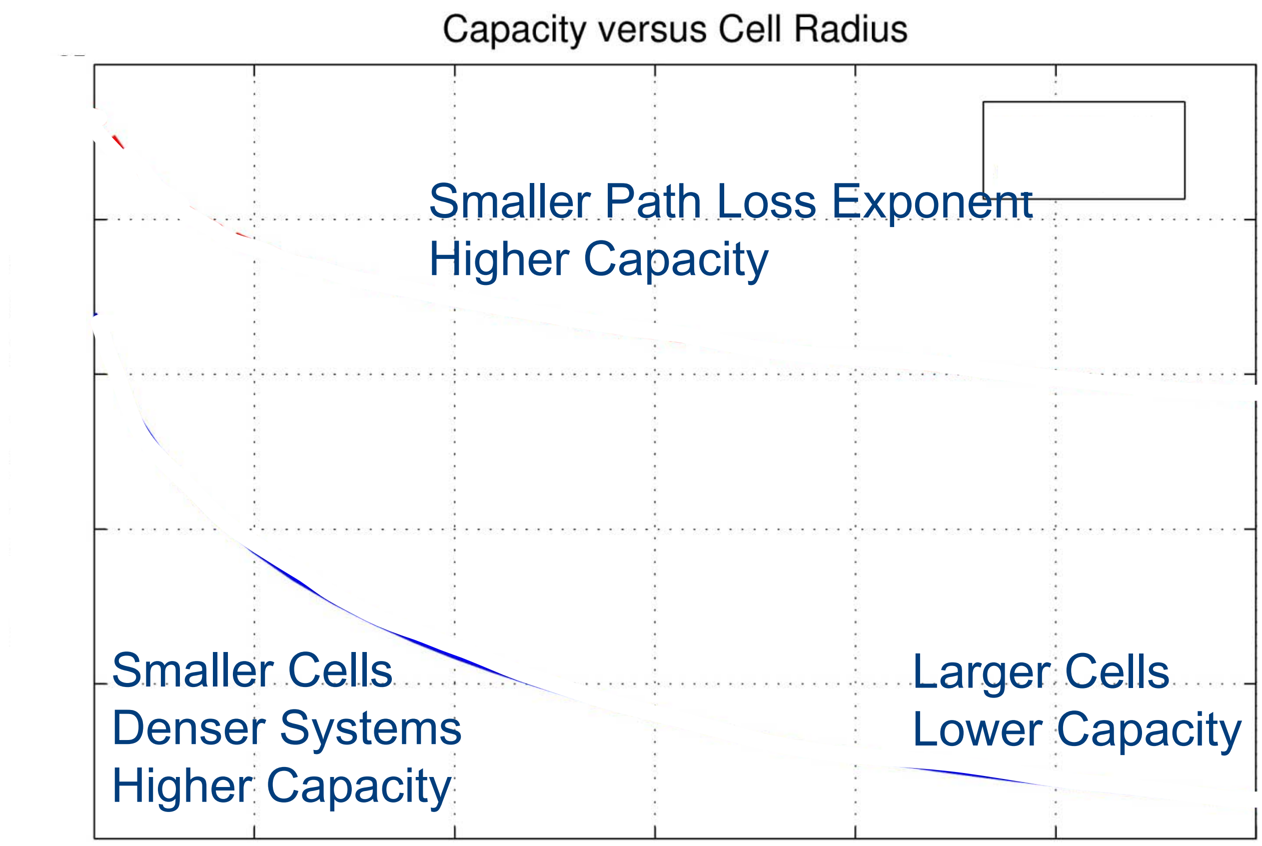
Cooperation converts the distributed cellular system into a MIMO system with distributed antennas

Effect of inter-site distance



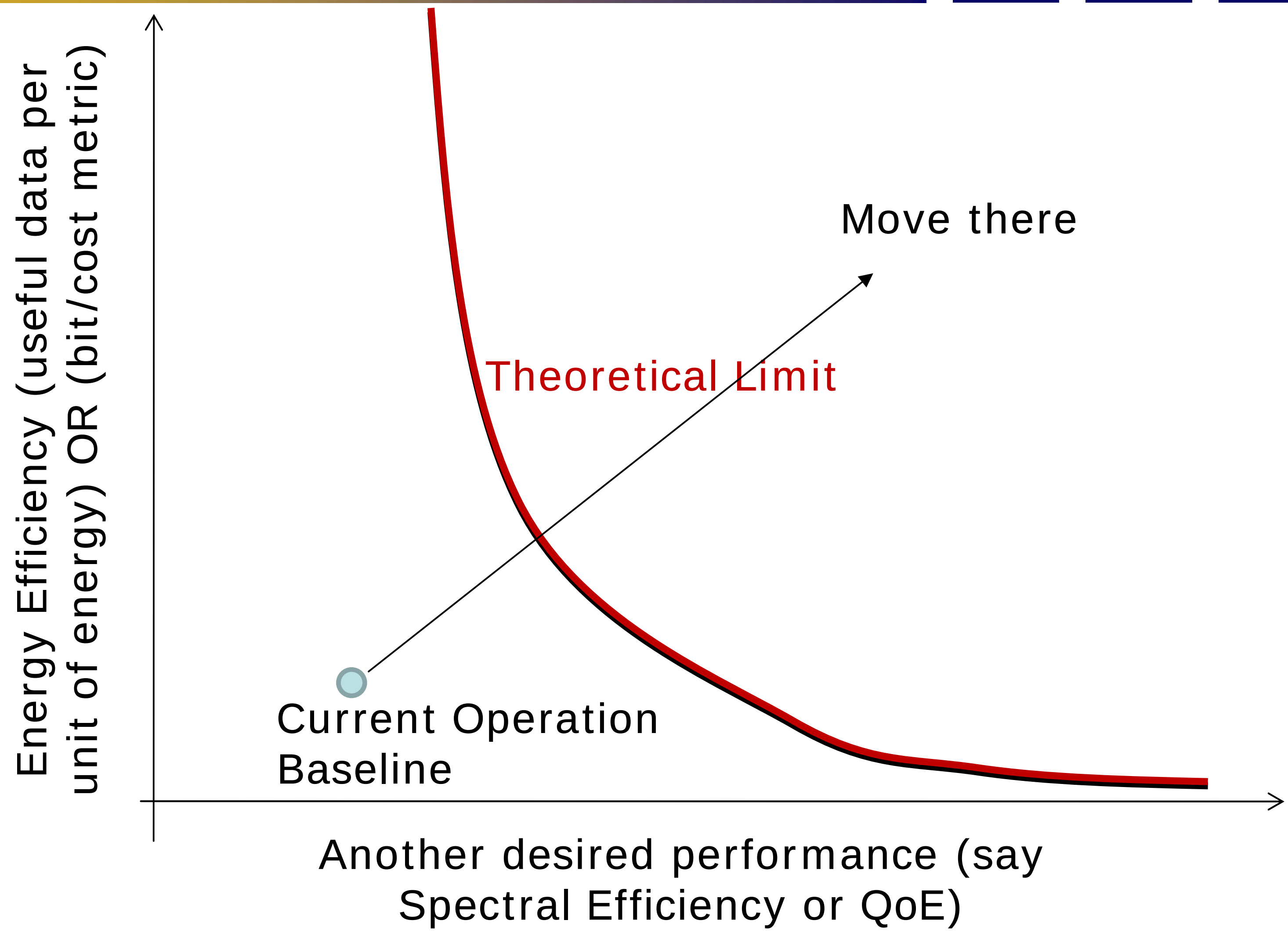
- Change in power constraint, path loss exponent and cell size changes the RoT and hence capacity-range moves over the “Capacity vs. RoT curve”

Small Cells Effects

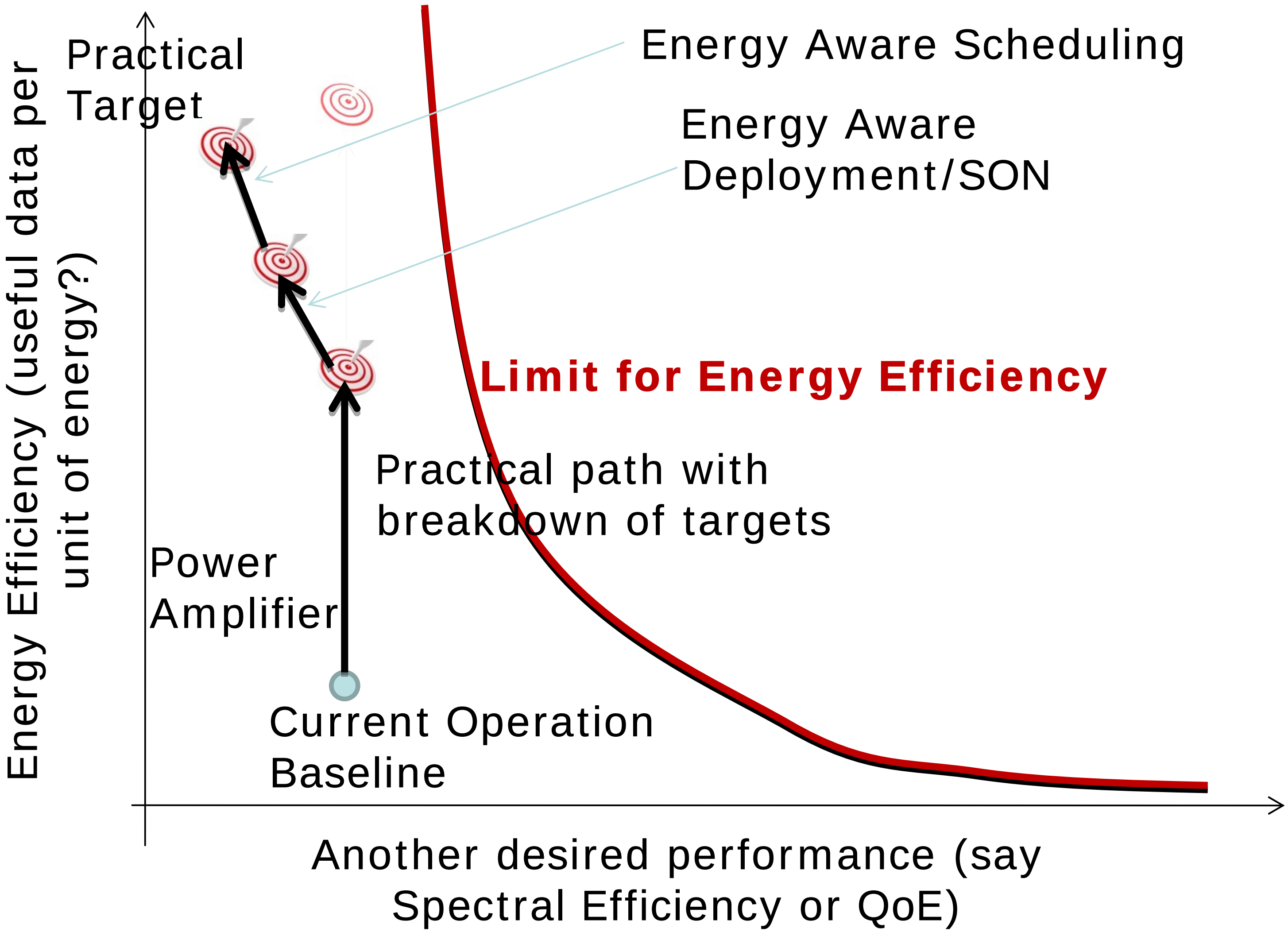


UT transmit power constraint is 200mW. Path loss at reference distance of 1m is 38dB, Pathloss exponent η. Carrier Frequency 1.9GHz, Bandwidth 5MHz, Thermal Noise Density -169dBm/Hz. Rayleigh Fading assumed. For simulation verification, 20 uniformly distributed users in each cell.

EE – SE trade-off



EE – SE trade-off



EARTH

Energy Aware Radio and neTwork tecHnologies

EARTH in a Nutshell

- Overall goal
  - to address the global environmental challenge by improving the **energy/power efficiency** of existing and future communication systems.
  - The main focus is **mobile cellular networks** and their evolutions.
  - Development of a new generation of energy/power efficient products, components, deployment strategies and energy-aware network management solutions
- Expected Impact
  - Enabling unprecedented energy efficiency
    - significant reduction in environment pollution and
    - Significant reduction in **operating cost**.
  - Strengthening European industry and infrastructure
    - contribution to **standardization, regulations** processes
    - foundation for a competitive new generation of European products
    - enabling cost-efficient provisioning of broadband access in Europe

EE mobile networks require a holistic approach

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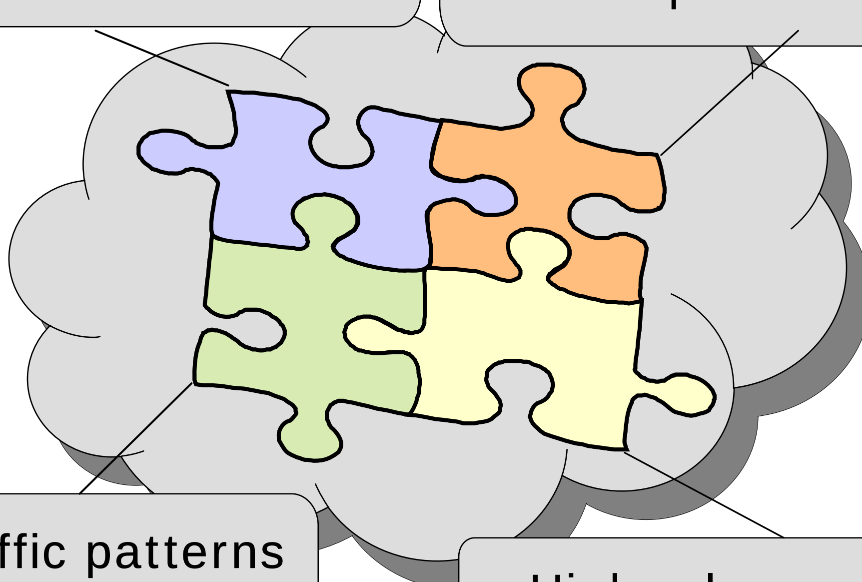
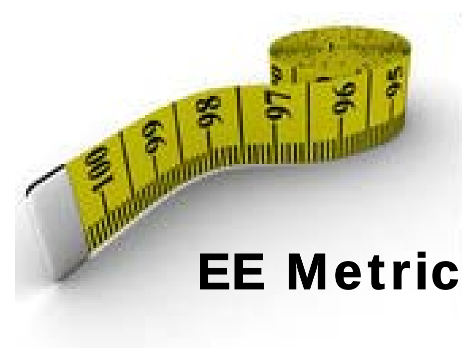
… from semiconductor technology to radios and networks

- Deployment strategies
- Cooperation schemes

- PHY layer parameters
- Transceiver architectures & components

Reference scenarios





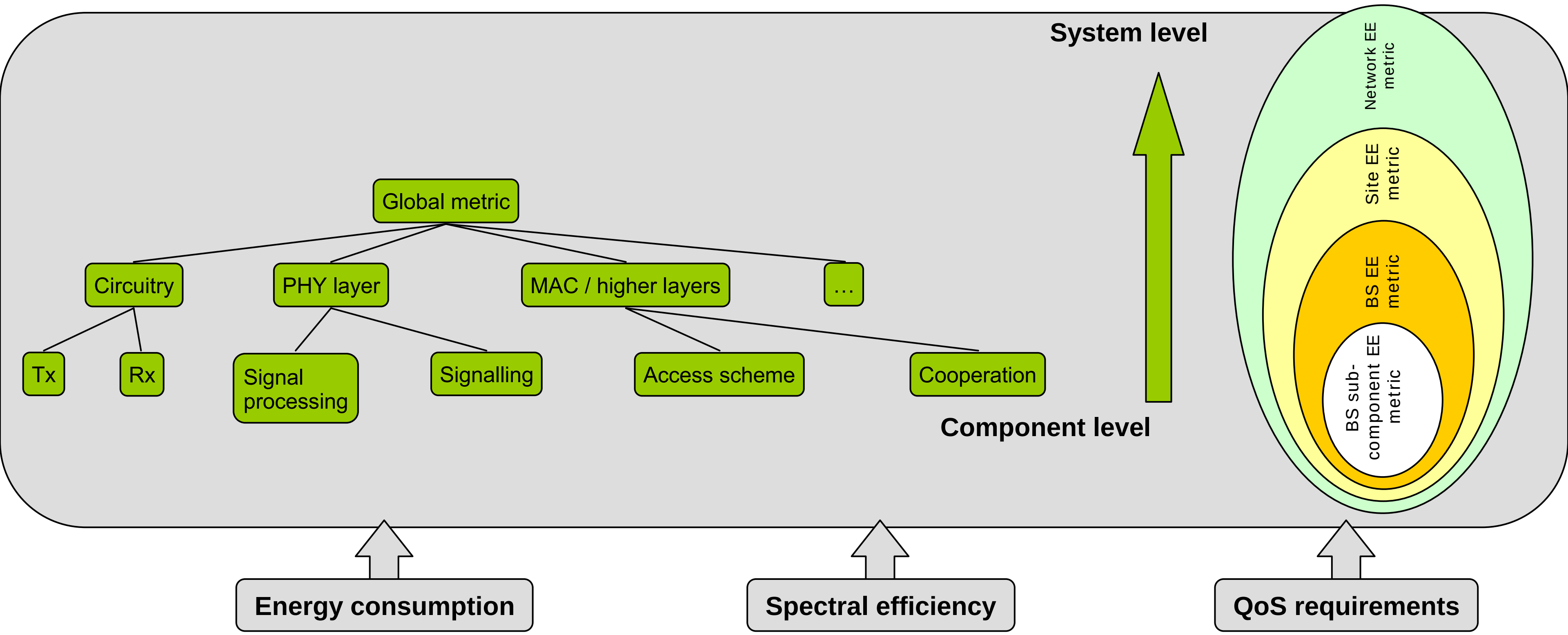
EE Metrics?

- Traffic patterns
- User densities

- Higher layer strategies

EE Metrics

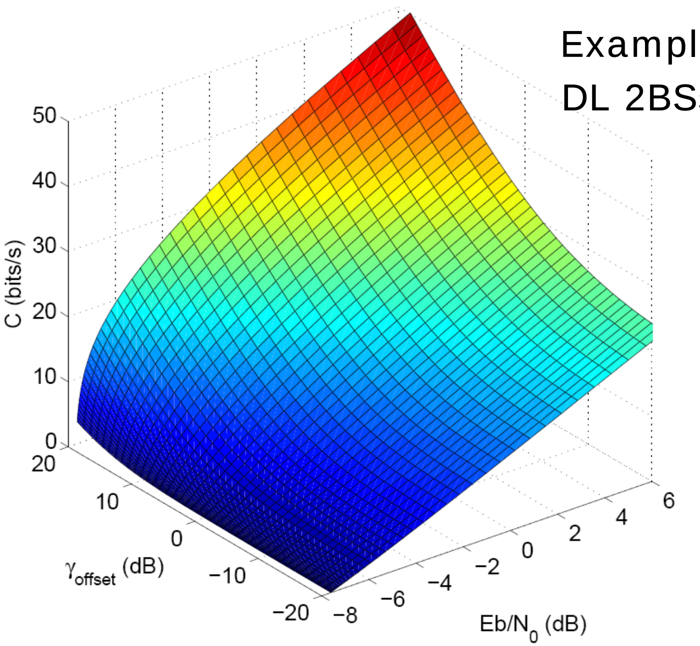
- Metrics should be defined to measure energy consumption (in e.g. Wh or Joule) on component, node and system/network levels, in relation to delivered QoS and system spectral efficiency



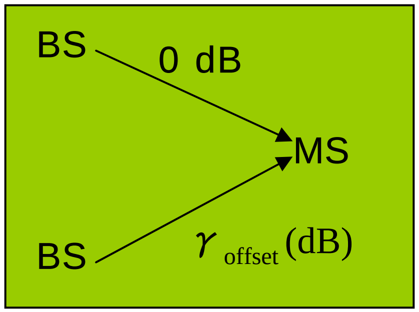
Some Metrics

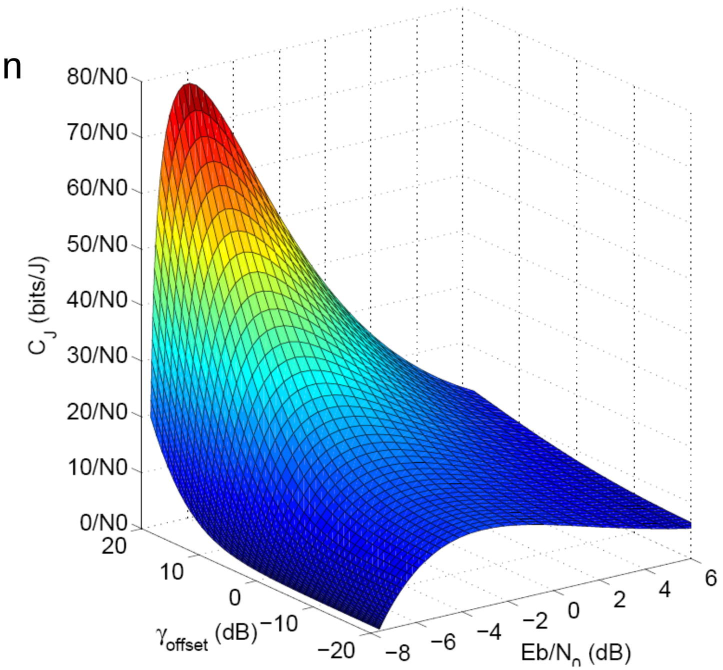
Metric to measure energy efficiency:

- Capacity function (fct.) of the energy consumption: **C=f(Eb)**
- Transport Capacity CT (bits-m) fct. of the energy consumption: **CT=f(Eb)**
- Bit per joule capacity CJ (bits/J): fct. of the energy consumption **CJ =f(Eb)**



Example: Monte-Carlo simulation
DL 2BSs-1MS scenario





Towards Green Radios

EE Technologies and Components

Power scalable transceivers

Power control on component, front - end and system level

Adaptable matching networks

Energy Efficiency Enabling Radio Interface Techniques

Integrated optimisation considering component, radio and interface to network -level

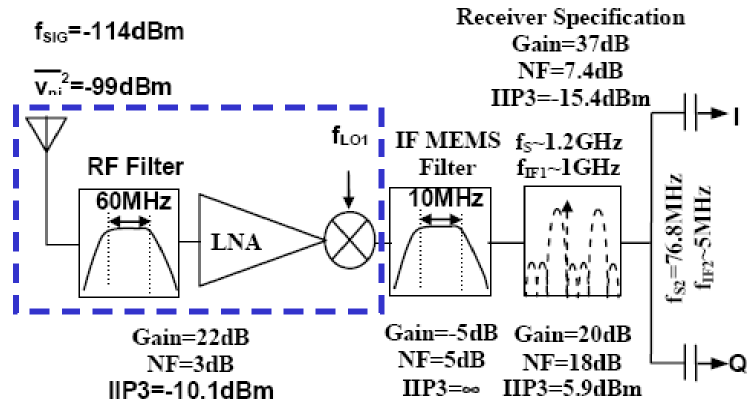
- Base station power adaptation
- Sleep mode and associated signalling
- Transmission mode adaptation
- Dynamic load adaptation
- Cross layer optimisation

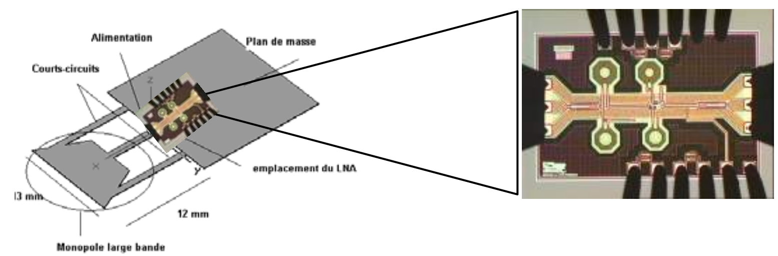
EE Application of Innovative Radio Transmission Techniques

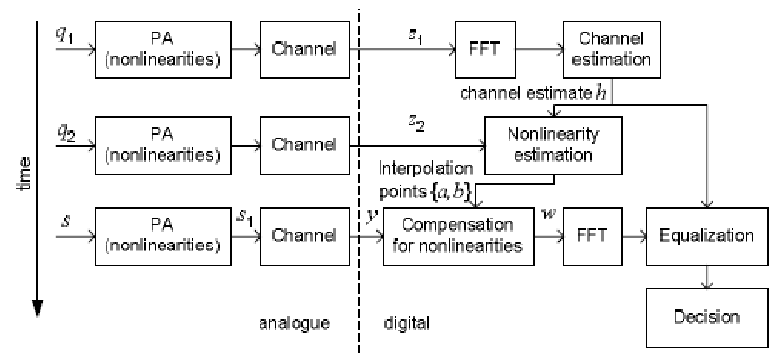
- MIMO
- Adaptive antennas
- Coordinated multi -points
- Advanced retransmission

Innovations in RF front-end architectures

- **Design flexible architectures with new components**
  - MEMS to have better perf. (filtering) with lower consumption
- **Tune performances at run time to the required flexibility & reconfigurability**
- **Co-design of PAs and LNAs**
  - Better performance (BW, Gain) for a given current
  - Lower current for given performance
- **Avoid losses in the chain**
  - Best matching between amplifiers and the antenna
  - Use of PA in their non linear domain + pre-distortion techniques & digital compensation (Tx or Rx)

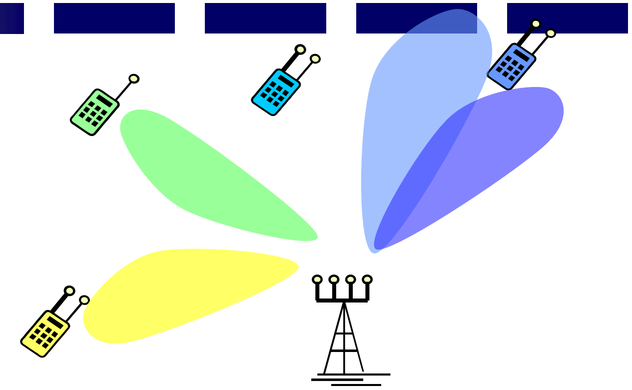






Innovations in digital BB architectures

- **Multi-User MIMO**

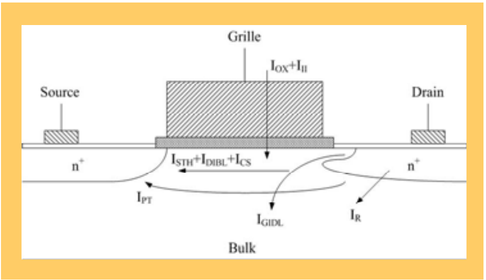


- Spatial dimensions assigned to **several** users.
- Separation of users by TDMA, FDMA **and** SDMA.

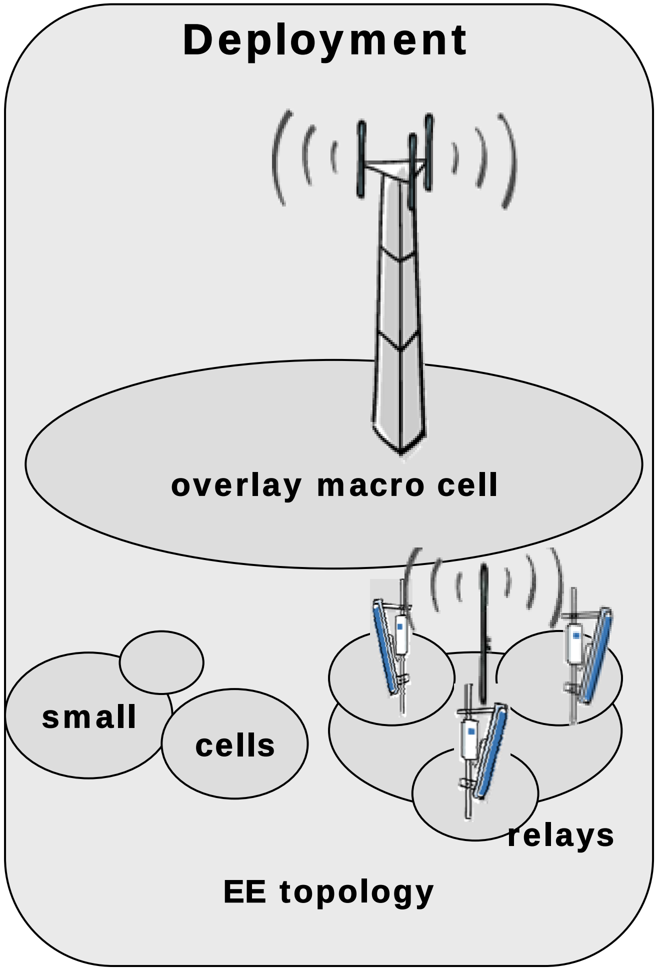
- **Manage multiple standards in the terminal**
  - **Complex & dense digital partitioned NoC (network on chip / multi-cores)**
  - **Use of DFVS in GALS systems, i.e. Tuning of local power supply units & clock generators**

- **Run full frequency only when required**

- **Master leakages**
  - **Leakage currents represent up to 25% of the power consumption with submicron technologies**



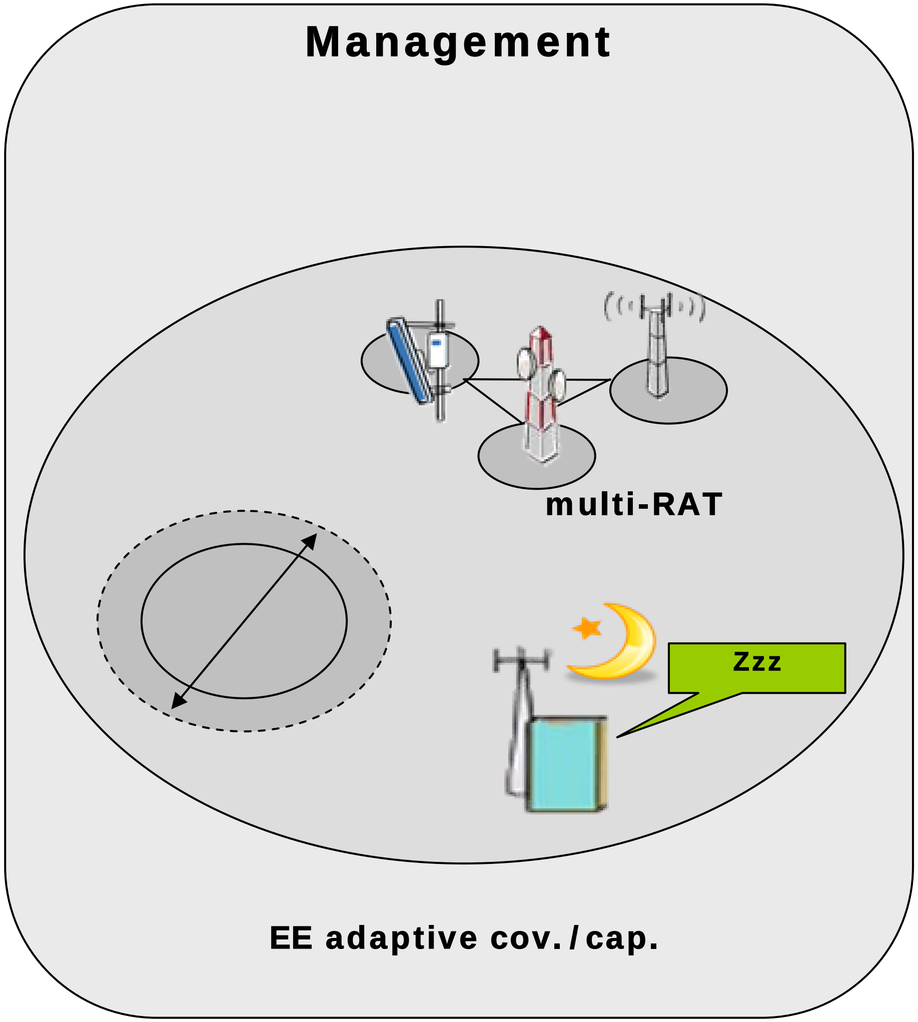
Towards Green Networks (1/4)



Design of green networks for efficient operation **not only at high load** but **low** and **medium** load conditions

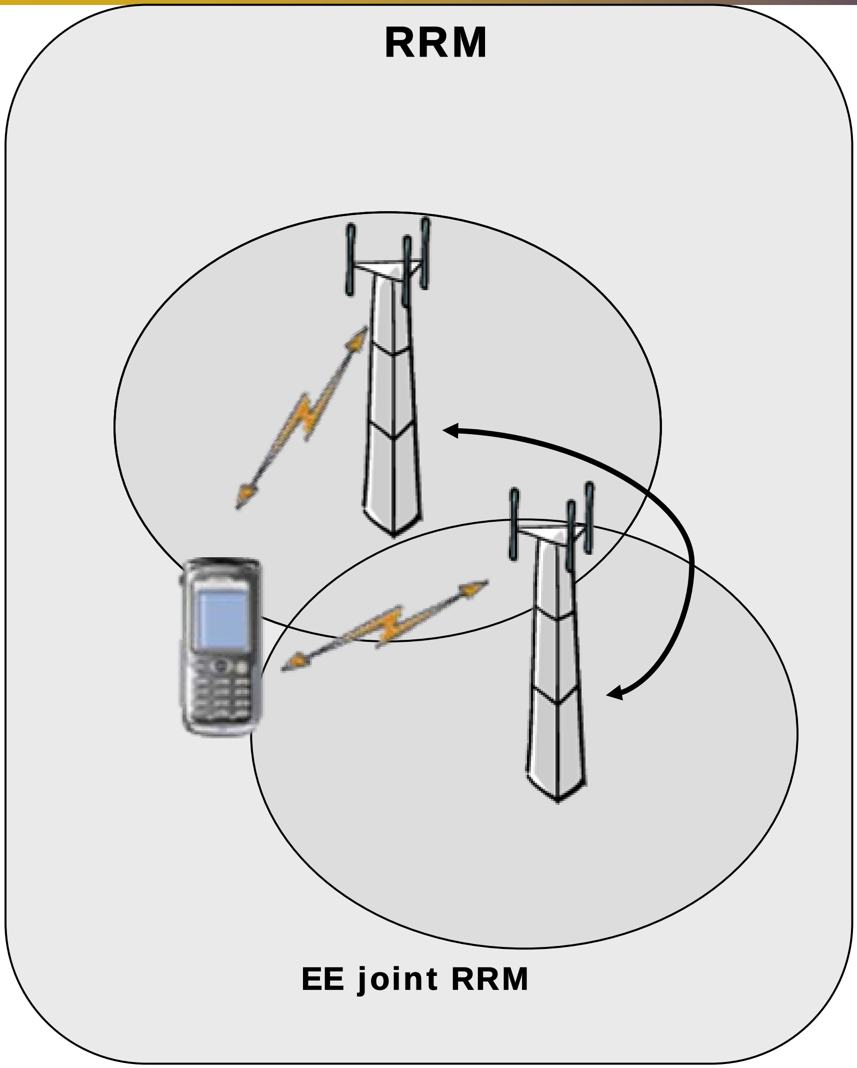
- **Deployment scenarios:**
  - optimum cell sizes
  - Optimum mix of cell sizes
  - hierarchical deployments
  - multi-RAT deployments
  - relays & repeaters

Towards Green Networks (2/4)



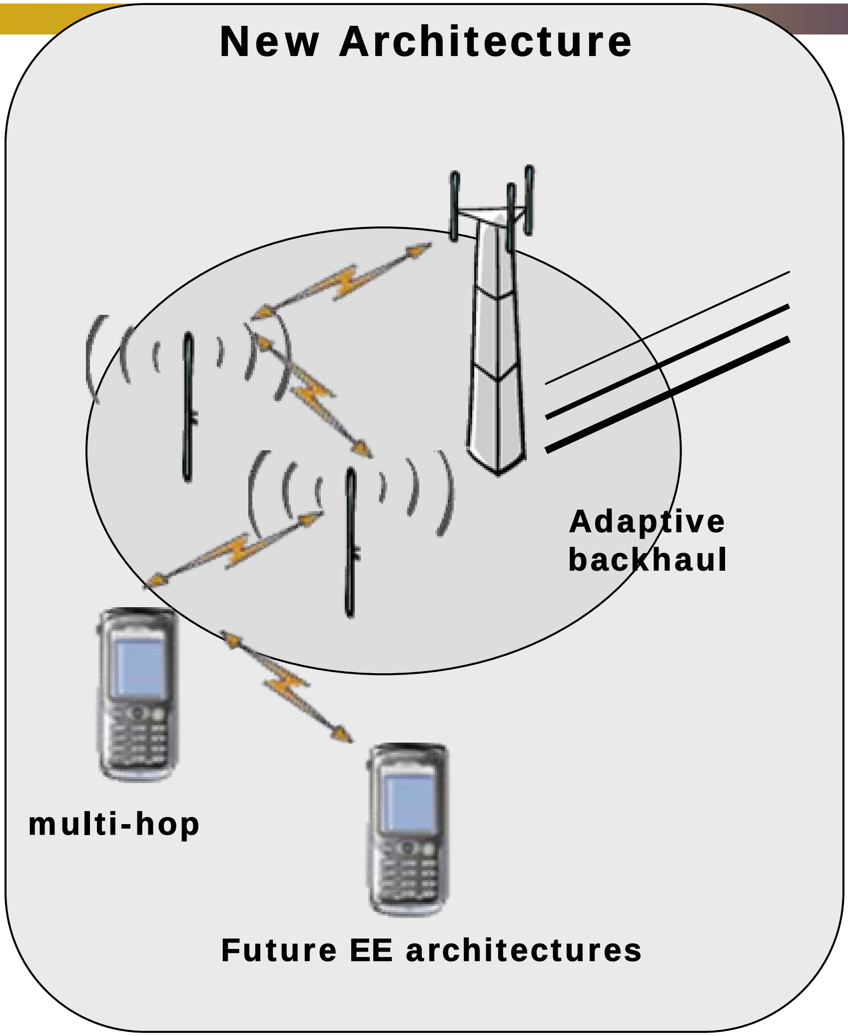
- **Management algorithms:**
  - coverage adjustment
  - capacity management
  - multi-RAT coordination
  - base station sleep mode
  - protocol design

Towards Green Networks (3/4)



- **RRM algorithms:**
  - cooperative scheduling
  - interference coordination
  - joint power allocation and resource allocation

Towards Green Networks (4/4)

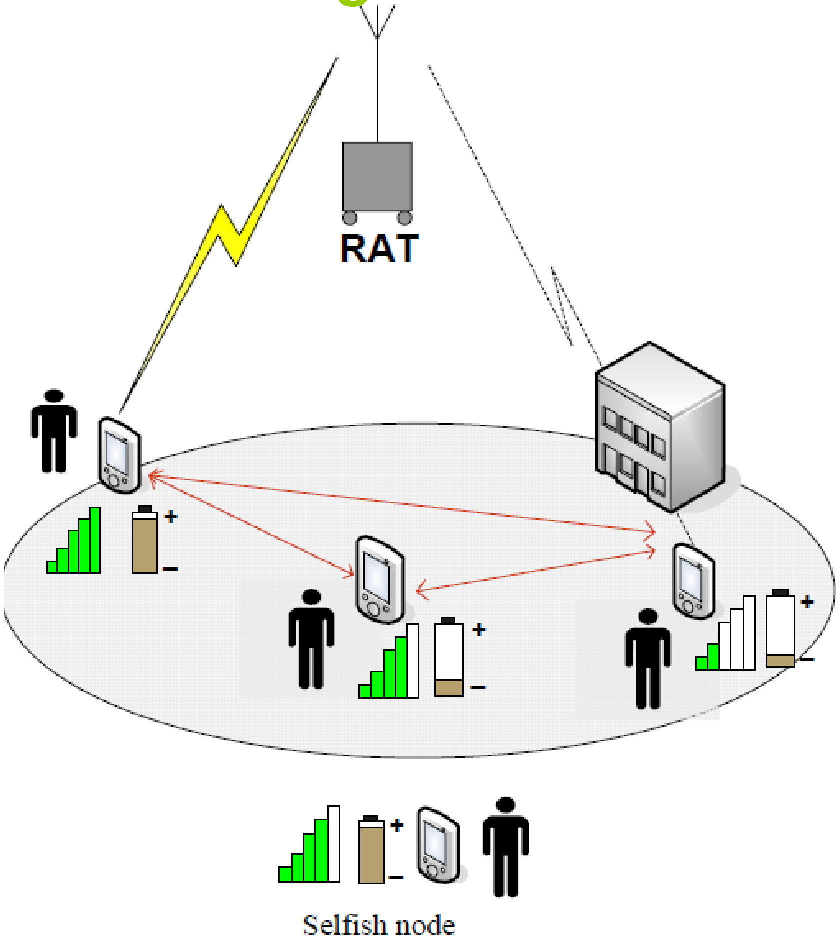


Disruptive approaches:

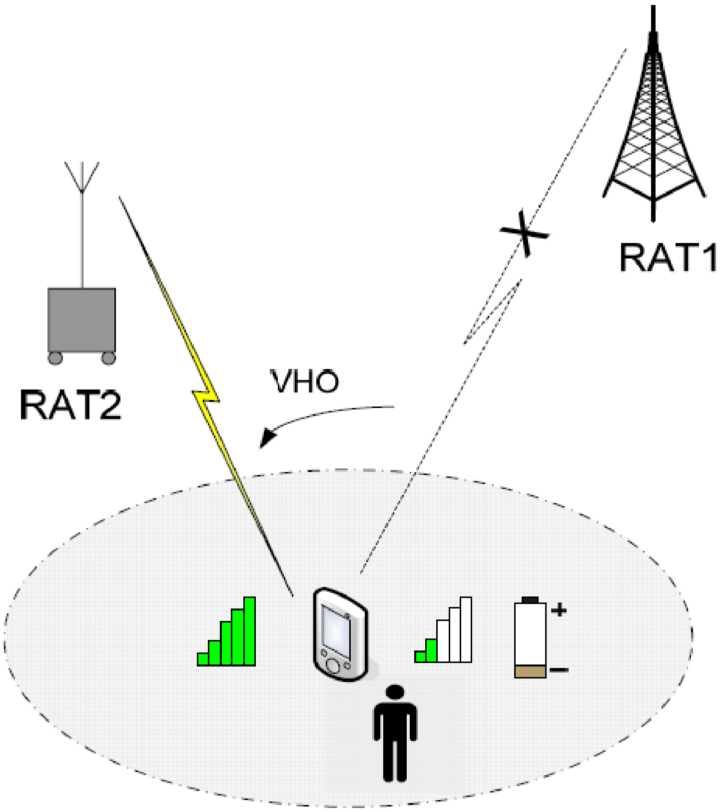
- multi-hop transmission
- ad-hoc networks
- terminal-terminal-transmission
- cooperative multipoint arch.
- EE adaptive backhauling
- cognitive/opportunistic radios & networks

Some disruptive power saving strategies

- Use of cognitive radios and networks

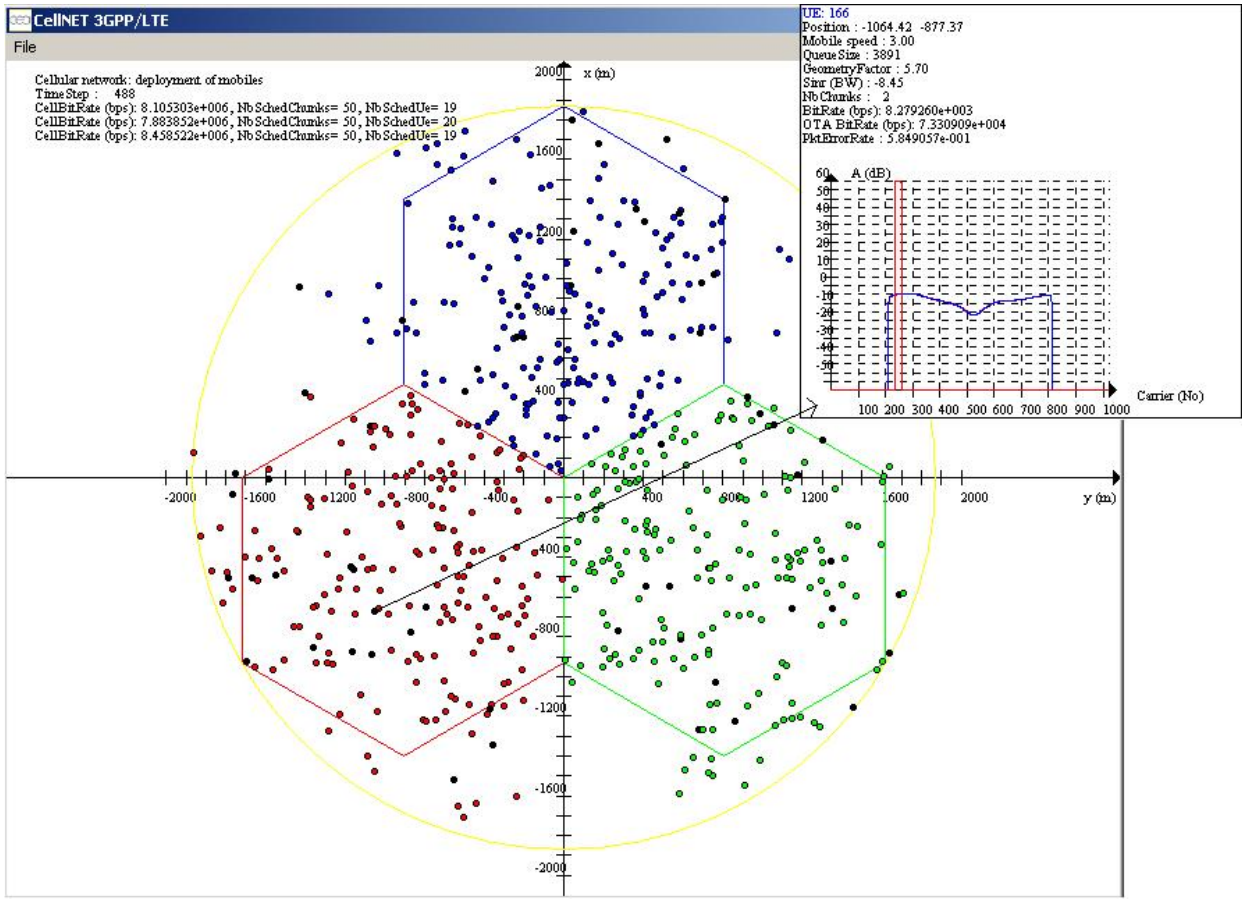


short range cooperative clusters in homogeneous networks



exploiting heterogeneous RATs

Extensive System level simulations



- Green metrics
- Evaluation of green algorithms & protocols

Integration and testing

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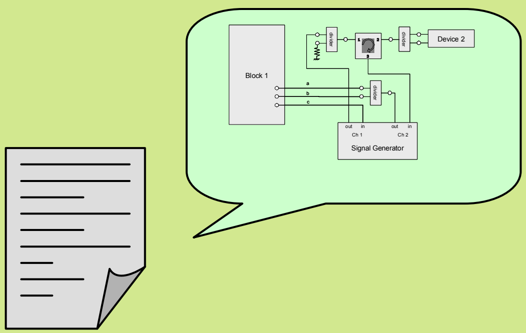
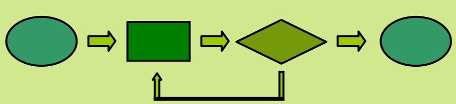
Definition of the validation procedures

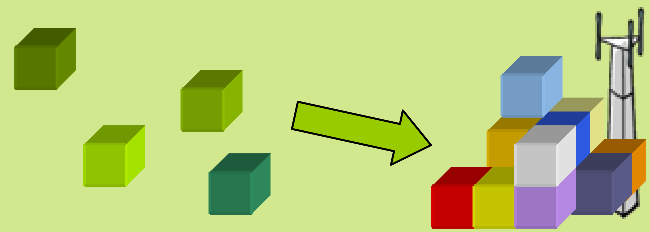
Define the validation platform

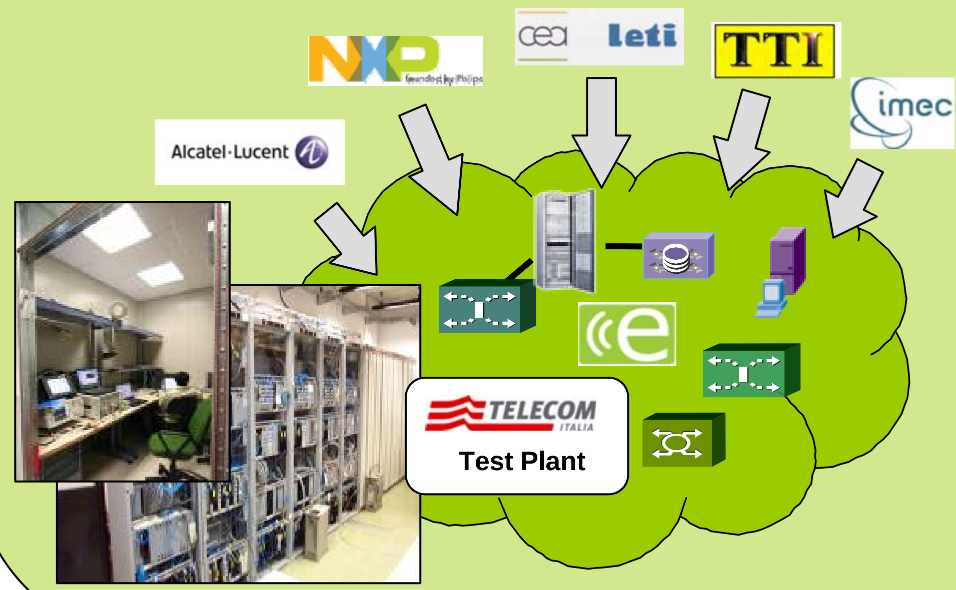


Define the rules and the activities for the integration in the test bed

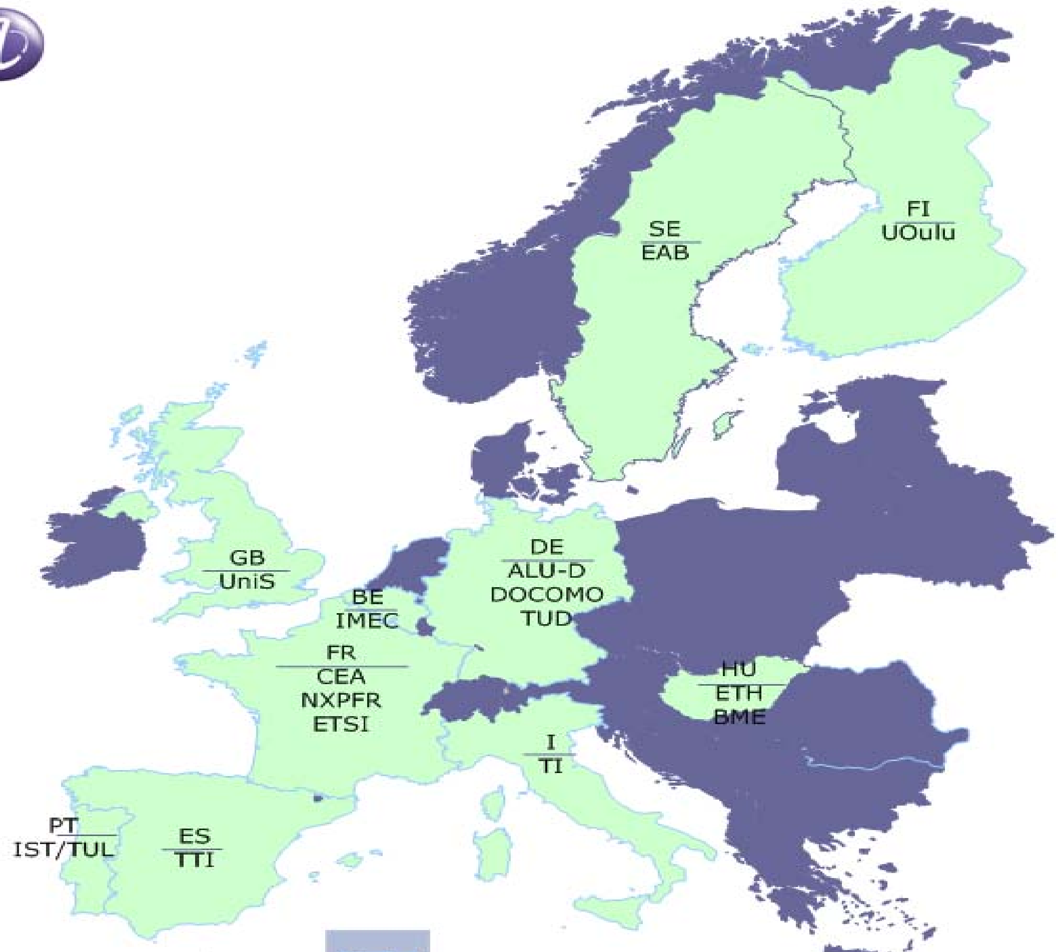


Integration and testing





EARTH Consortium



Industrials, Operators
ALUD, EAB, DOCOMO, TI, NXPFR, ETH

Research centre
CEA, IMEC

Higher education
UNIS, TUD, UOulu, BME, IST/TUL

SME
TTI

Other
ETSI

Thank you for your attention

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