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Energy Efficient Architectures and Techniques for Green Radio Access Networks

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Presentation Overview

- The Need for Green Radio (GR)
- Defining the Green Radio Issues
- Current Research Advances
- Conclusions

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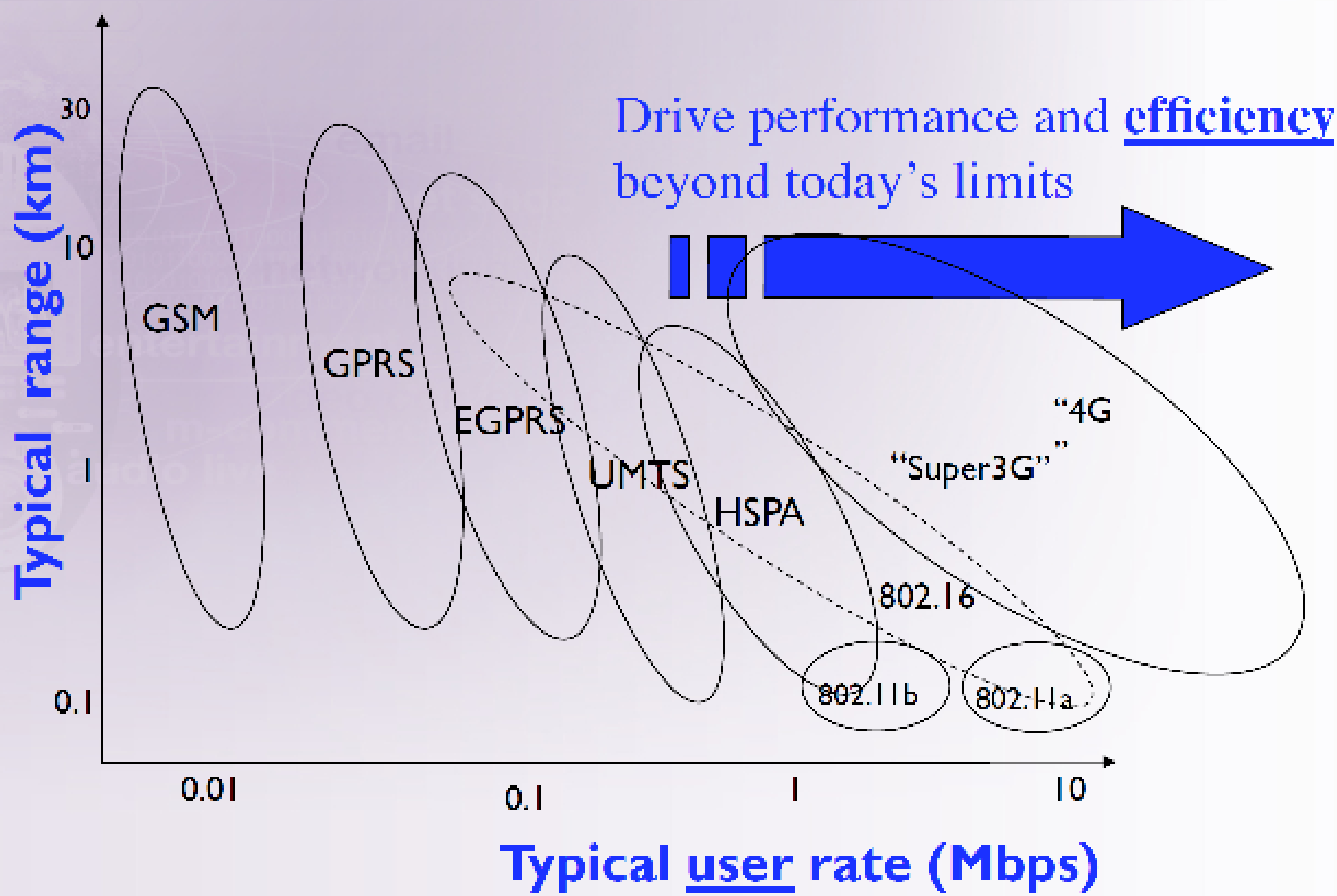
Mobile System Evolution



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Green Radio

- Reflections from a UK Research programme

- Funded by Industry and Government (EPSRC)
- Program driven by the INDUSTRIAL requirement
- £2M or $3M total three year research spend
- Research program defined jointly by industry and academia

- Delivered by 5 UK Research Intensive Universities
  - Bristol
  - Edinburgh
  - Kings College London
  - Southampton
  - Swansea

- Research monitored and steered and publications reviewed by industrialists at quarterly progress meetings

- Programme started Oct 2008 and ends 2012

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Why need for Green Radio?
Operator & Manufacturer Perspective

- Increasing energy costs with higher base station site density and energy price trends
  - A typical UK mobile network consumes 40 MW
    - Overall this is a small % of total UK energy consumption, but efficient communications saves energy in other industries
  - Energy cost and grid availability limit growth in emerging markets (high costs for diesel generators)
- Corporate Responsibility targets set to reduce CO_2 emissions and environmental impacts of networks
  - Vodafone[1] - “Group target to reduce CO_2 emissions by 50% by 2020, from 2006/07 levels”
  - Orange[2]: “Reduce our greenhouse emissions per customer by 20% between 2006 and 2020”

1. http://www.vodafone.com/etc/medialib/attachments/cr_downloads.Par.25114.File.tmp/CR%20REPORT_UK-FINAL%20ONLINE_180908_V6.pdf
2. http://www.orange.com/en_EN/tools/boxes/documents/att00005072/CSR_report_2007.pdf

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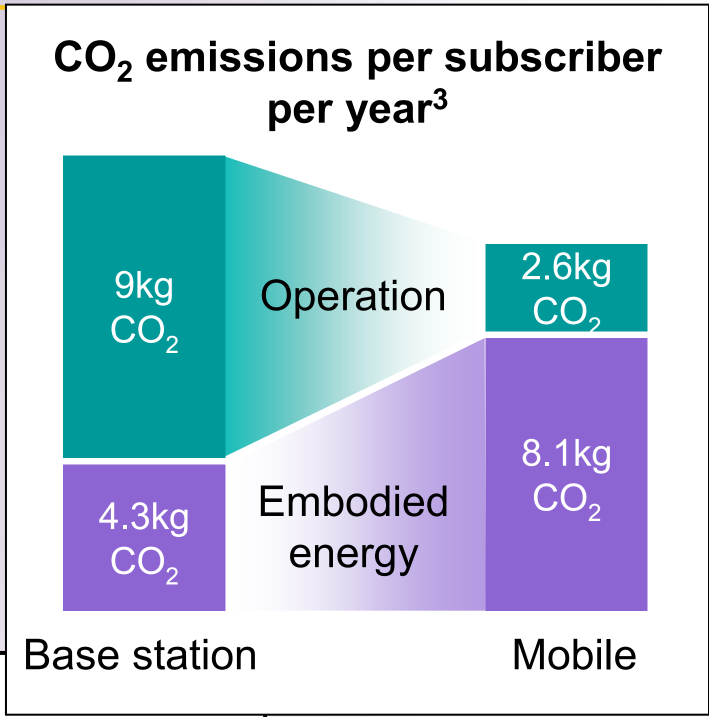
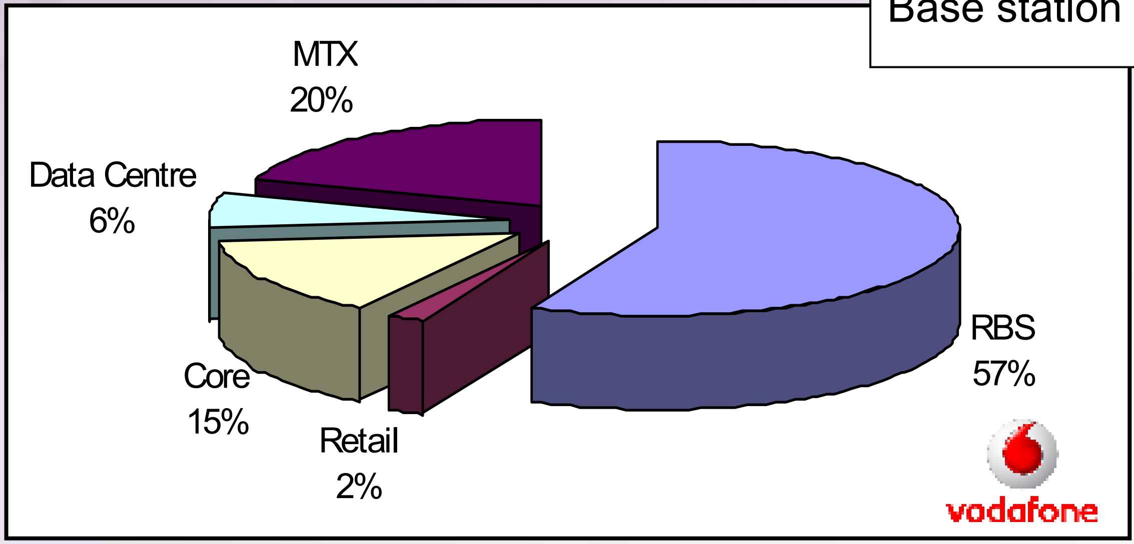
Where is the Energy Used[3]?

- For the operator, 57% of electricity use is in radio access
- Operating electricity (OPEX) is the dominant energy requirement at base stations
- For mobile user devices, most of the energy is expended during manufacture





3. T. Edler, Green Base Stations – How to Minimize CO_2 Emission in Operator Networks, Ericsson, Bath Base Station Conference 2008

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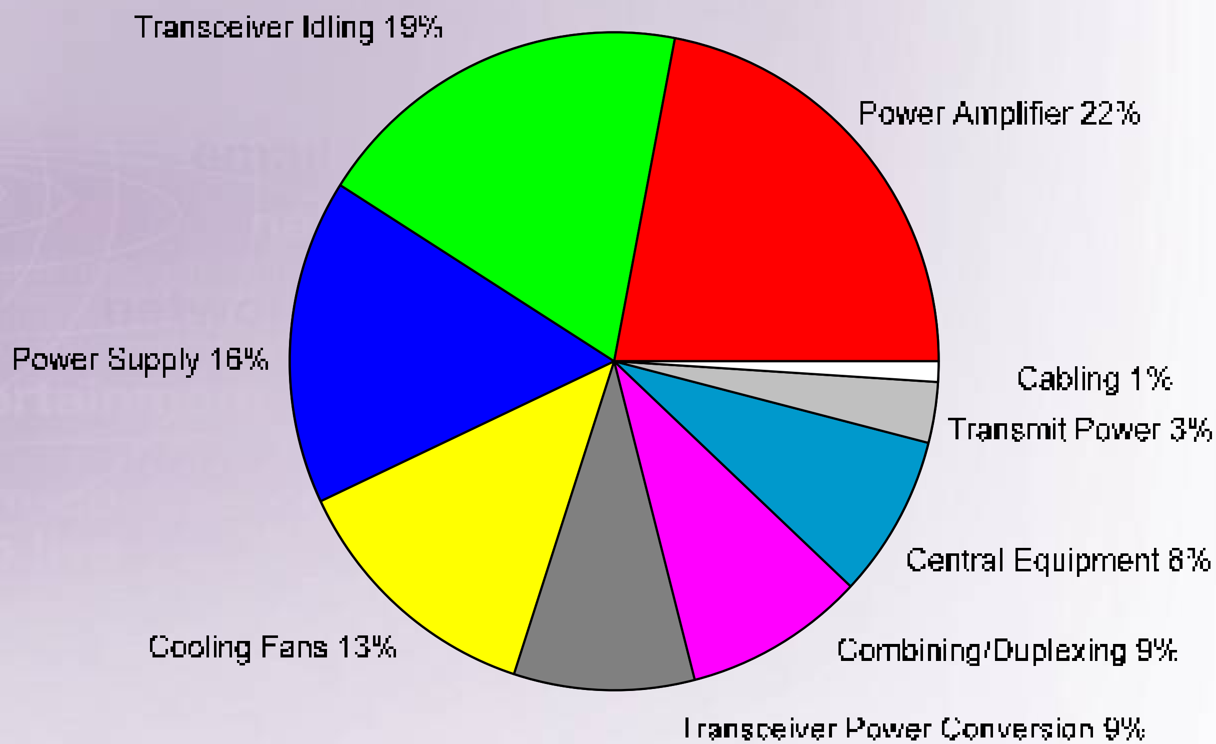
Base Station Power Use @ 2003[5]



5. H. Karl, "An overview of energy-efficiency techniques for mobile communication systems," Telecommunication Networks Group, Technical University Berlin, Tech. Rep. TKN-03-XXX, September 2003. [Online]. Available: http://www-tkn.ee.tu-berlin.de/~karl/WG7/AG7Mobikom-EnergyEfficiency-v1.0.pdf

3.8 kW AC > 120 W RF

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Energy Consumption

- The Base Station (BS) is the most energy–intensive component in a 3G mobile network.
- A typical 3G Base Station consumes about 500 W with a output power of ~40 W. This makes the average annual energy consumption of a BS around 4.5 MWh (which is lower than a GSM BS).
- A 3G mobile network with 12,000 BSs will consume over 50 GWh p.a. This not only responsible for a large amount CO_2 emission it also increases the system OPEX.
- This is worse in developing mobile markets such as India and China which have 10-20 times number of mobile subscribers!

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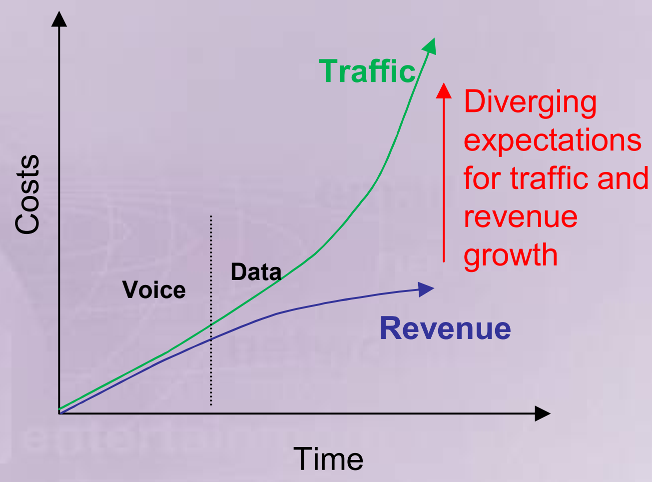
Green Radio as an Enabler[8]



Trends:

- Exponential growth in data traffic
- Number of base stations / area increasing for higher capacity
- Revenue growth constrained and dependent on new services

Energy use cannot follow traffic growth without significant increase in energy consumption

- Must reduce energy use per data bit carried

Number of base stations increasing

- Operating power per cell must reduce

Green radio is the key enabler for cellular growth while guarding against increased environmental impact

8. Traffic / revenue curve from "The Mobile Broadband Vision - How to make LTE a success", F. Meywerk, Senior Vice President Radio Networks, T-Mobile Germany, LTE World Summit, November 2008, London

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GR Research Objectives

Strive to improve efficiency of BS operation with improved component designs:

- Power amplifier
- Power efficient processing, e.g. DSP
- Sleep modes
- Backhaul redesign

Improve overall system operation:

- Small cell deployment outdoors
- Heterogeneous deployments (macro over micro/pico/femto)
- Femtocells for Enterprise & Home networks
- Multi-hop routing / Relaying
- Improved resource allocation
- Spectrum balancing
- Interference Management and Mitigation

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Target Innovations: Architecture

Establishing Baselines

To develop a clear understanding of energy consumption in current networks and the network elements, base sites, mobiles, etc for prevailing scenarios

Deployment Scenarios

To determine what is the optimum deployment scenario for a wide area network given a clearly defined energy efficiency metric

Backhaul Options

To determine the best backhaul strategy for a given architecture

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Target Innovations: Techniques

Overall Base Station Efficiency

Techniques to deliver significant improvements in overall efficiency for base stations, measured as RF power out to total input power

Improving the QoS/RF Power Ratio

Reduce the required RF output power required from the base station whilst still maintaining the required QoS

Optimization of a Limited Energy Budget

Given a base station nominal daily energy requirement derived from renewable energy sources (e.g. 2.4 kWh - 100W x 24hrs) determine how this would be best used for communication

Scaling of Energy Needs with Traffic

Sleep mechanisms that deliver substantial reduction in power consumption for base stations with low loads and develop techniques that allow power consumption to scale with load

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Key Energy Metrics

Energy Consumption Ratio (ECR)

This is measurement of a single system in Joules per bit and is simply the Energy consumed by the system divided by the number of data bits communicated

$$\mathrm{ECR} = \frac{\text{Energy Consumed}}{\text{Data Bits Communicated}}$$

Energy Consumption Gain (ECG)

This compares the energy consumed by a system under test, relative to a reference system, where both communicate the same number of data bits

$$\mathrm{ECG} = \frac{\text{Energy Consumed by Reference System}}{\text{Energy Consumed by System Under Test}}$$

An ECG >1 indicates the system under test is more efficient than the reference system

$$E_{Total} = E_{Embod} + E_{Opex}$$

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Case Studies

- Cell deployment strategies
- Delay-tolerant networking
- Resource Allocation Strategies
- Interference Management & Mitigation

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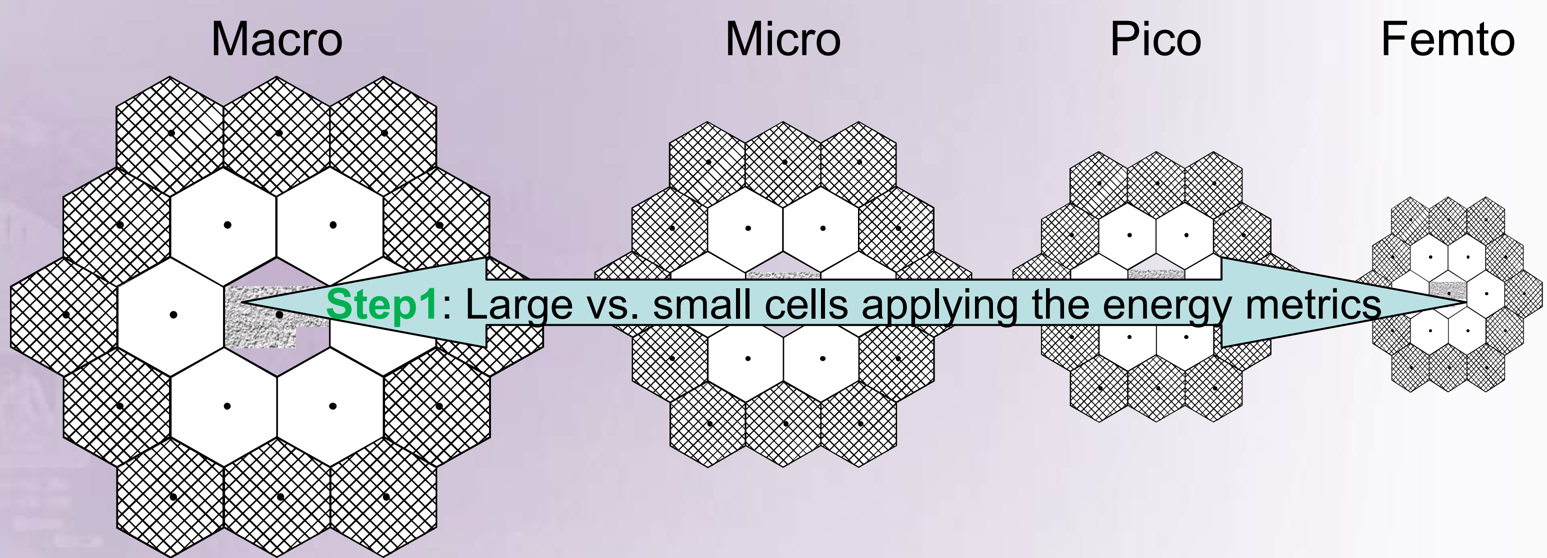
Cell Deployment Strategies



Step2: Overlay Source & Network Coding and/or Cooperative Networking

Step3: Evaluate optimum cell size from the following perspectives…….

RRM	Packet scheduling, handover, power and load control
BER/FER vs Eb/No	Differentiated QoS, fast fading effects, UE speed, MIMO
Link Budget	Energy consumption is proportional to distance
Mobility/Traffic Models	User Equip (UE) movement, traffic types & mixes

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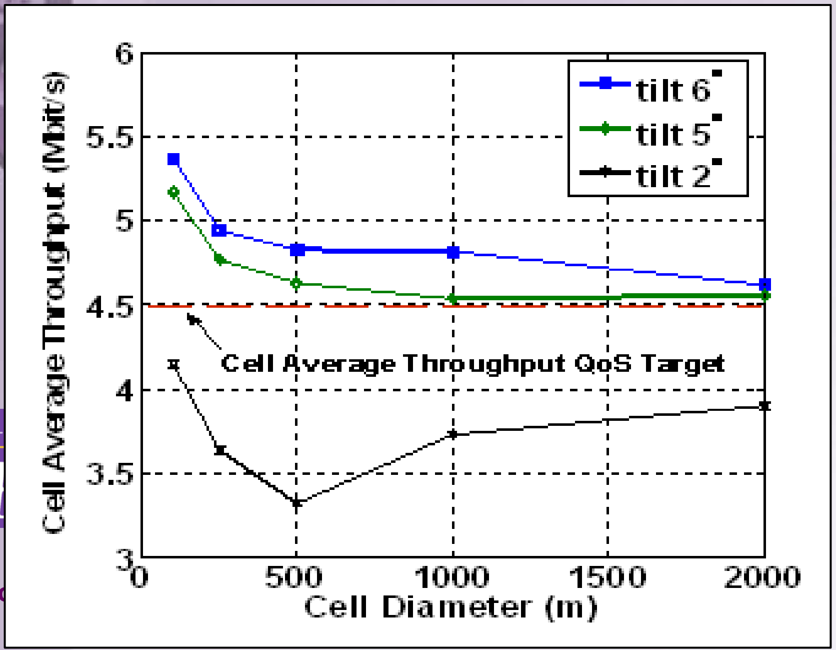
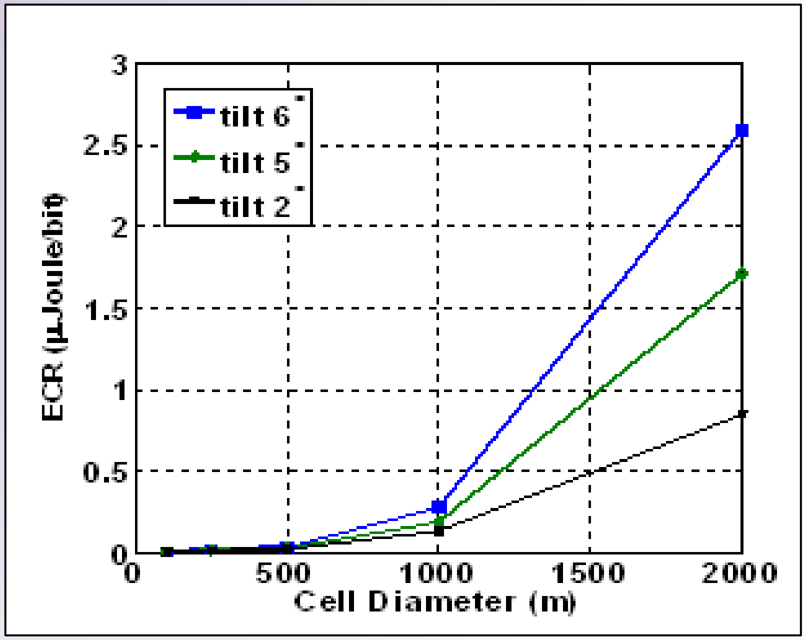
Cell Deployment Strategies

Impact of cell size and antenna downtilt on RF energy consumption of an LTE RAN while accounting for intercell interference

Cell throughput-coverage target set to 1 Mbit/s over 95% of cell area while cell average throughput target set to 4.5 Mbit/s.





ECR decreases monotonically with cell diameter and downtilt angle under a throughput-coverage constraint.

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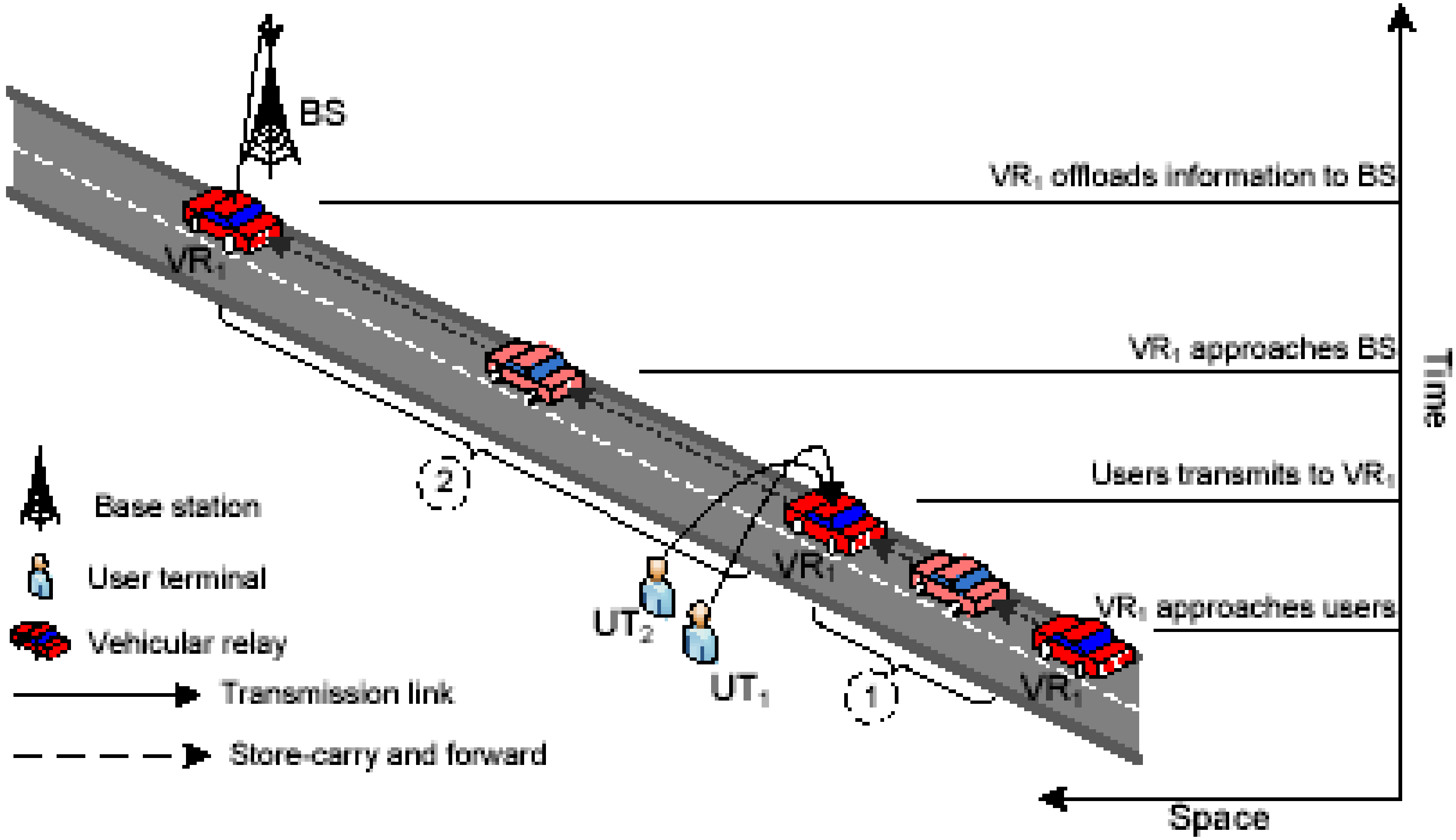
Store-Carry and Forward (SCF) Relaying



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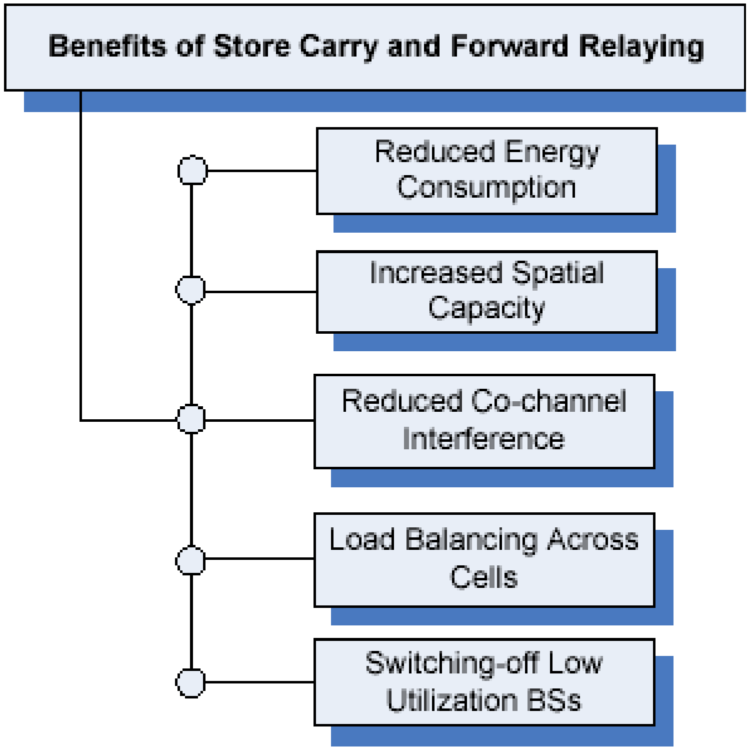
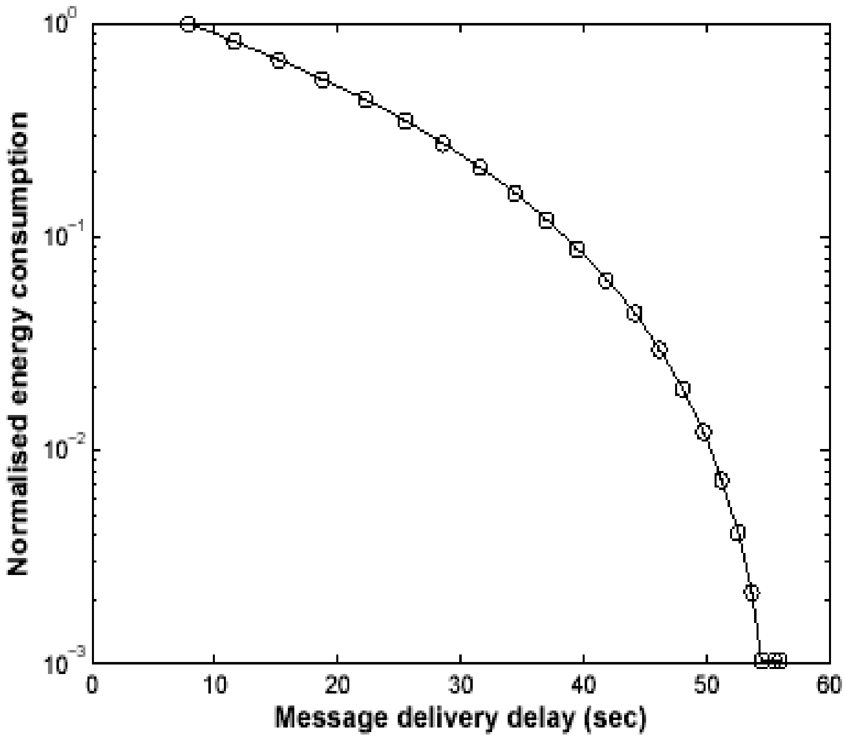
Benefits of SCF Relaying





The graph above shows the normalized energy consumption gains for the 2-hop relaying scheme (compared to single hop communication).

Considerable reductions (up to 1000 times) in the communication energy consumption can be achieved by postponing communication for preferable transmit locations (note that the y-axis is logarithmic).

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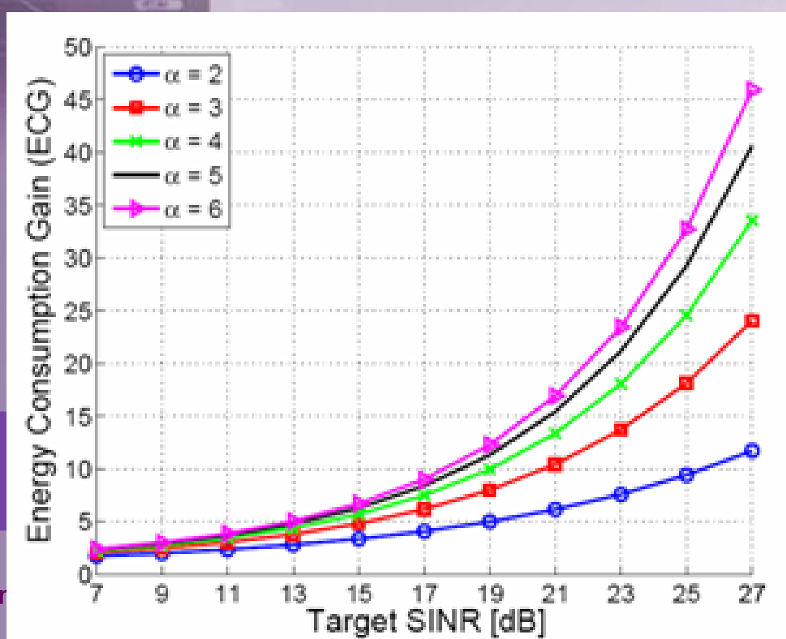
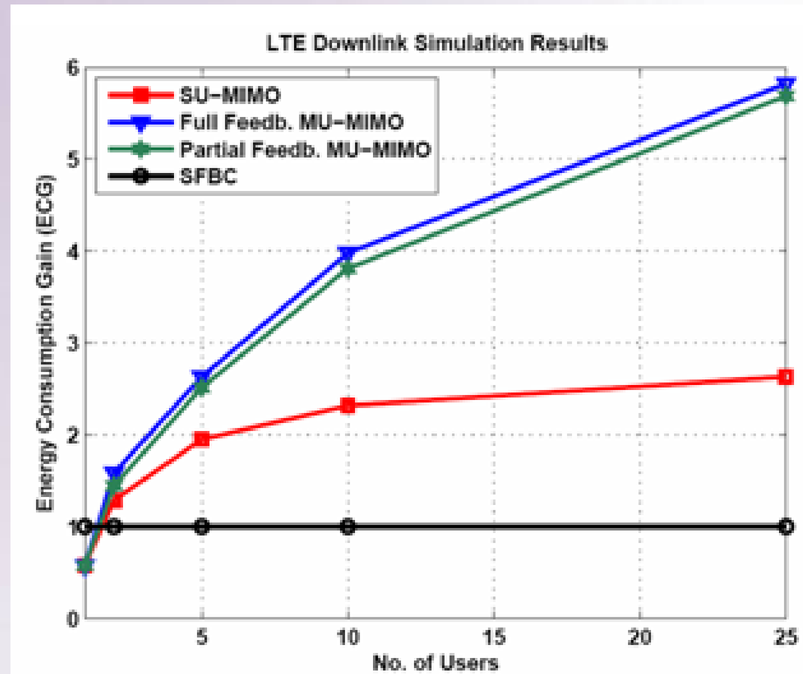
Traffic Aware Resource Allocation

Under low traffic load conditions, BS likely to have more bandwidth for users than actually required. Can we exploit trade off between spectral and energy efficiency to achieve the energy savings while retaining QoS?

Predicted ECG gains versus SINR required at the mobile receiver for a given data rate. Alpha specifies permitted bandwidth expansion





ECG of various MIMO schemes, relative to SFBC, all at 3bits/s/Hz spectral efficiency. At high traffic load BS may exploit multi-user diversity by possibly using MIMO techniques.

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DAS for Interference Control

- Coordinate multiple antennas of adjacent BS to form a Distributed Antenna System (DAS).
- Each cell edge user is collaboratively served by its surrounding base station with effective interference control and mitigation by coordinated beamforming among the DAS antennas.

- Three schemes compared
  - Scheme-1: User served by only one BS while other BSs avoid transmitting energy towards that user;
  - Scheme-2: All users served by multiple BSs using multiple antenna beam-forming & coherent user-end combining
  - Scheme-3: Users allocated to one or more BSs based on their position

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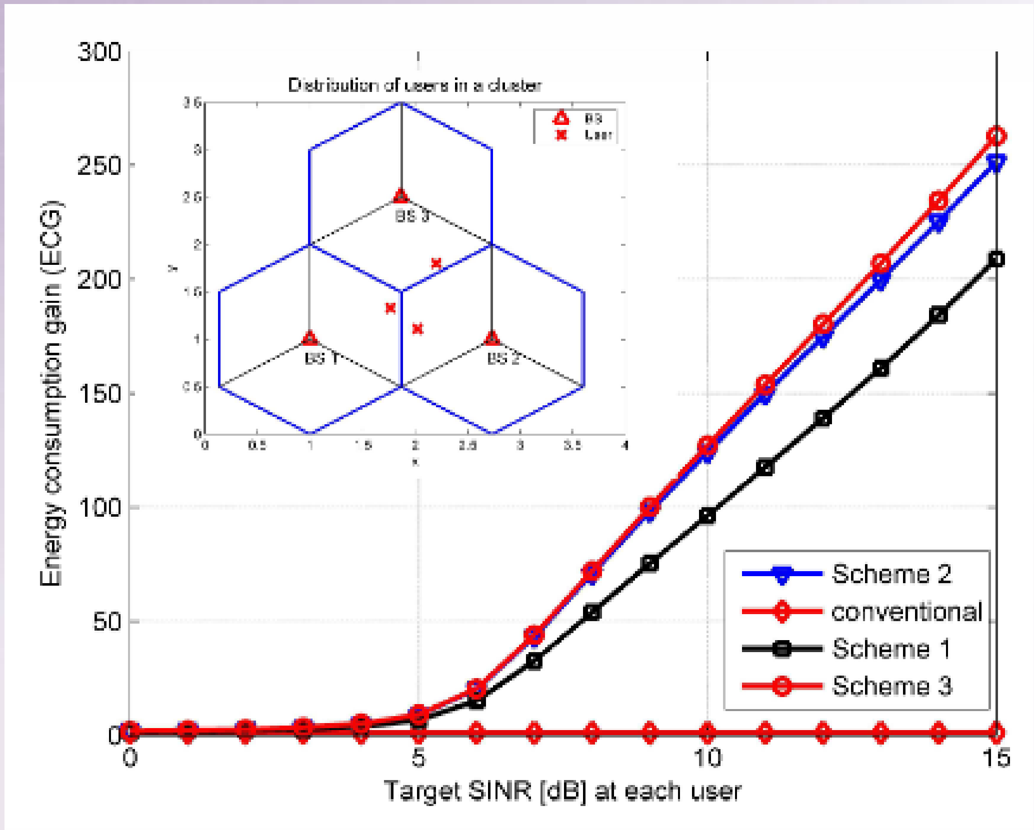
DAS for Interference Control

- **Configuration: a cluster of 3 cells with one user per cell.**
- **All three schemes significantly outperform the conventional system at high SINRs**



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Conclusions

- **Growth in data transmission requirements for mobile broadband will not bring major revenue increase.**
- **Every industry has published CO_2 reduction targets and the mobile and IT communities are not exempt.**
- **Power drain in base-station or access point is the major issue in many wireless systems.**
- **Green Radio promises to deliver benefit to the Cellular network Operators via the equipment supply chain vendors.**
- **We are researching the changes to the system architecture and developing advanced networking techniques to deliver more efficient, Green Radio systems.**

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Papers

- **IEEE Communications Magazine – "Green Radio: Radio Techniques to Enable Energy Efficient Wireless Networks", to appear 2010**
- **Several IEEE Transactions in Wireless Communications in review**
- **Papers in:**
  - IEEE VTC-2009 (Fall & Spring), 2010 (Fall)
  - IEEE ICC-2009, 2010
  - IEEE Globecom 2010 (to appear)
  - Many others
- **Springer, Annals of Telecommunications, Special issue on Green Mobile Network (MVCE is Guest editor)**
- **MVCE plan several workshops 2011: Green Basestations (industry led workshop) and at VTC 2011-Spring (academic).**

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