Energy Efficient Architectures and Techniques for Green Radio Access Networks

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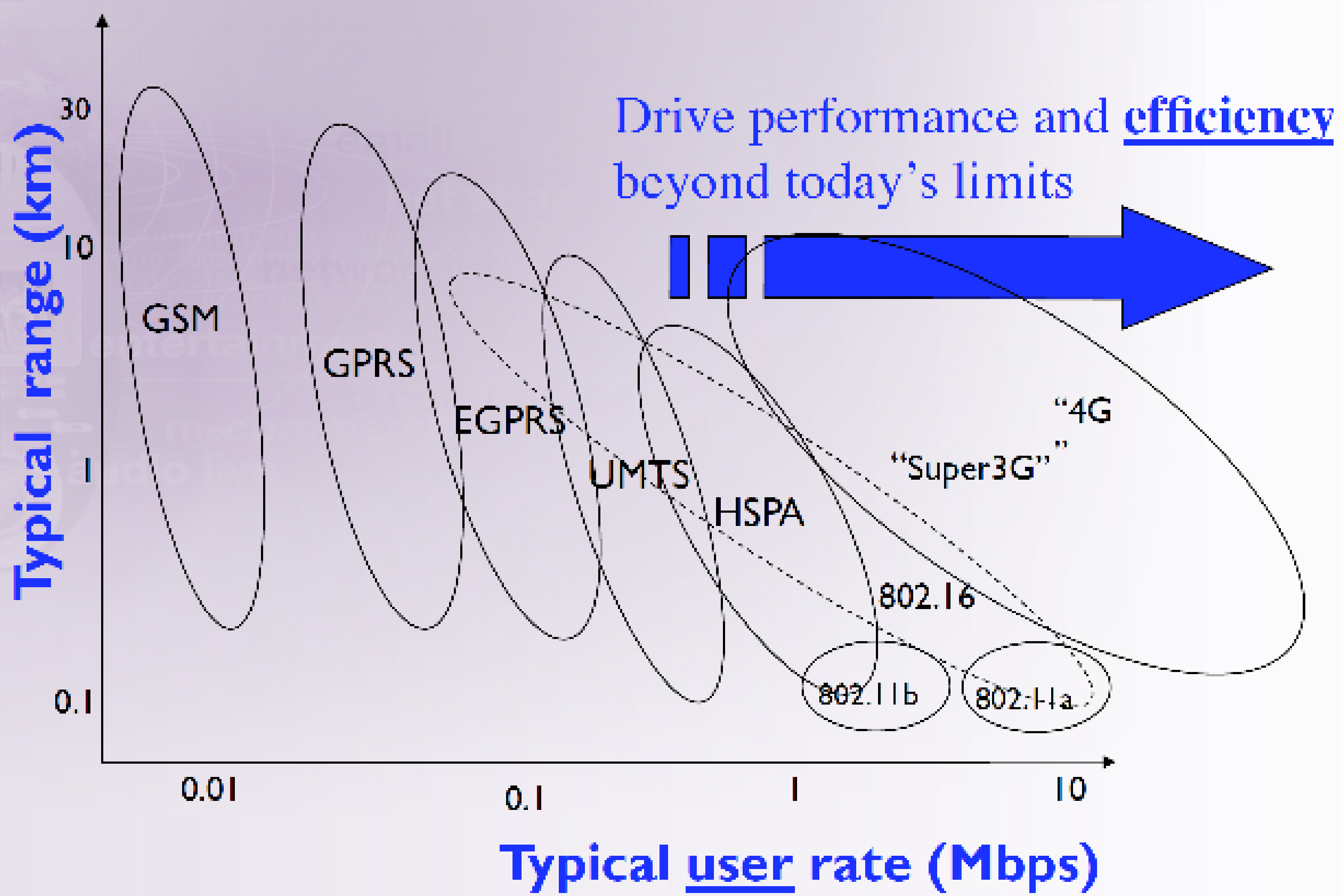
Presentation Overview

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

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 4 UK Research Intensive Universities
  - Kings College
  - Edinburgh
  - Bristol
  - Swansea

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

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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 40-50 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

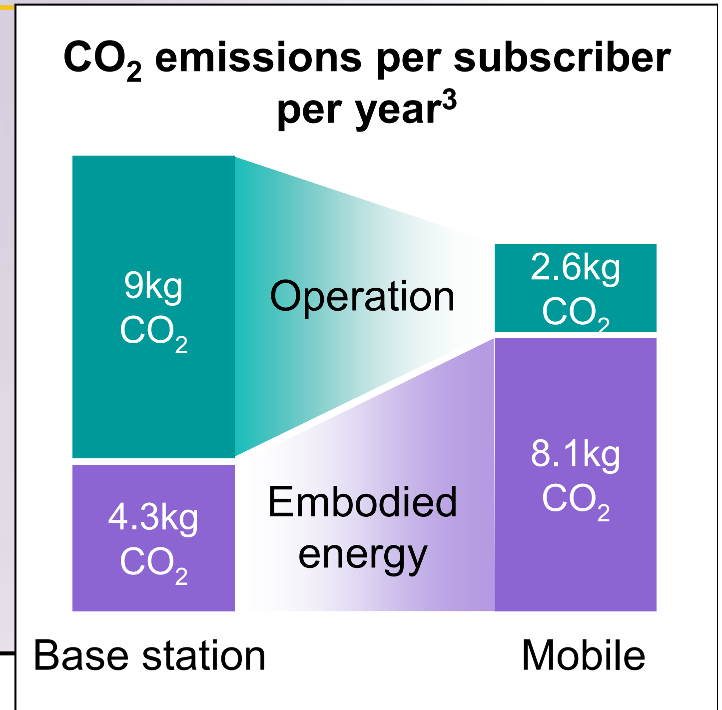
Two types of Energy

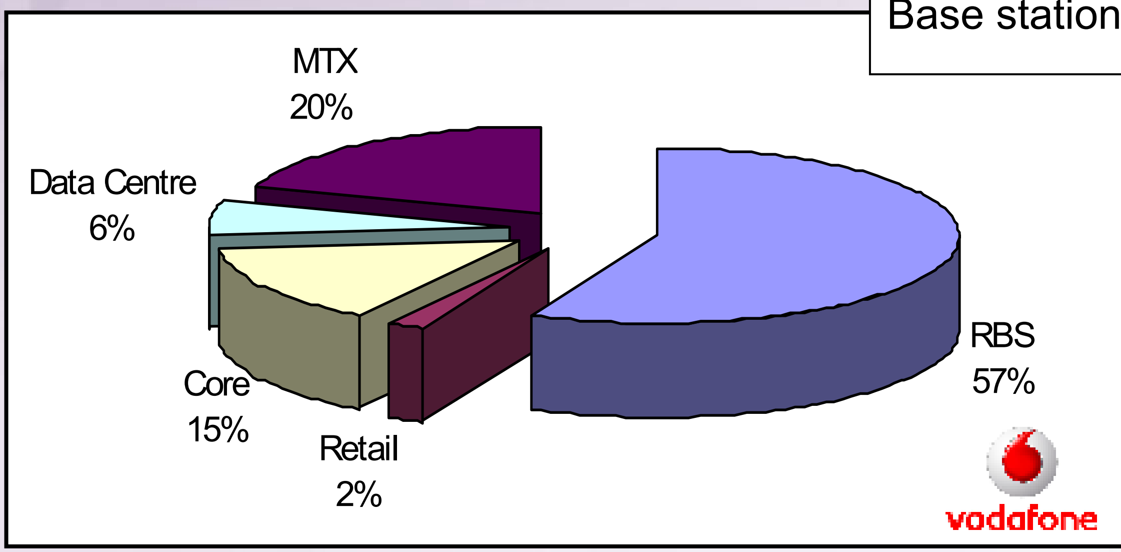
- **Embodied energy**
  - **Energy used in raw material extraction, transport, manufacture, assembly, installation of a product or service including disassembly, deconstruction and decomposition.**
  - **Forms part of Capital Expenditure (CAPEX)**

- **Operating energy**
  - **Energy expended over the operational lifetime of the product.**
  - **Forms part of Operational Expenditure (OPEX)**

Where is the Energy Used[3]?

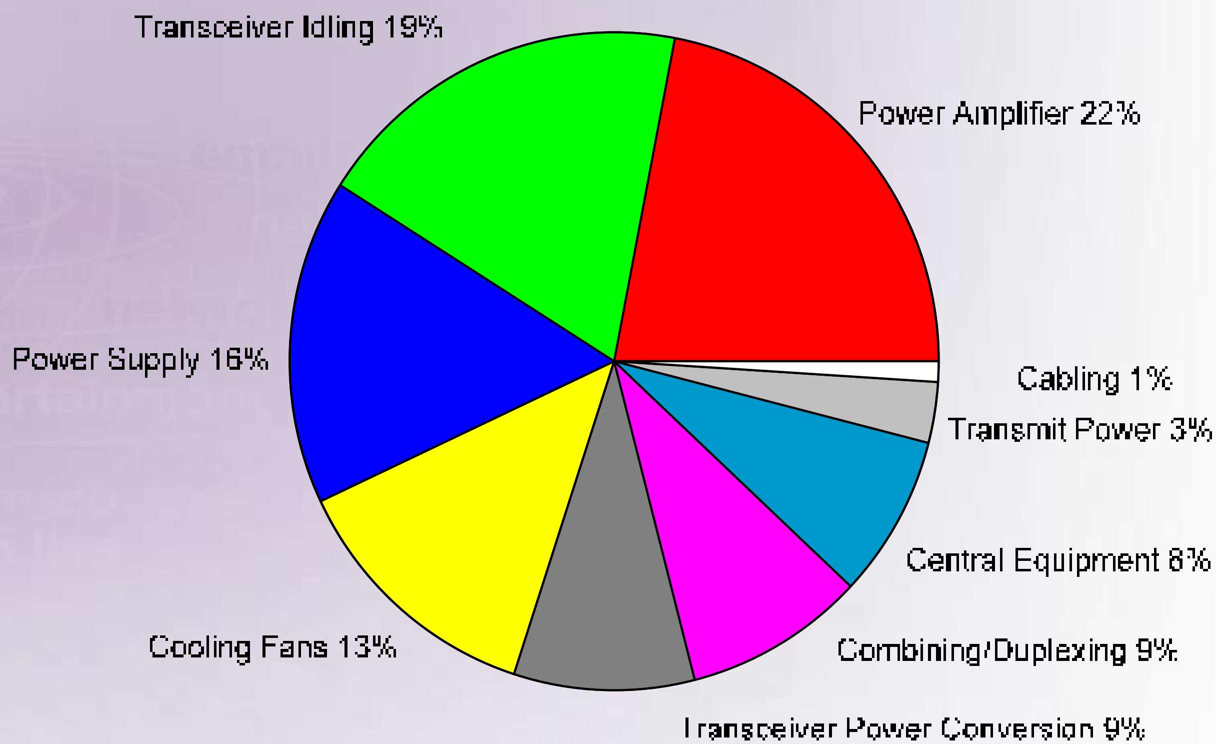
- For the operator, 57% of electricity use is in radio access
- Operating electricity (OPEX) is the dominant energy requirement at base stations
- For mobile user devices, most of the energy is expended during manufacture





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

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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Power Consumption Reductions

Power Consumption per Base Station

	GSM	WCDMA
2008	800W	500W
2010	650W	300W

Source: Nokia Siemens Networks

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 of CO_2 emissions but also increases the system OPEX.
- In mobile markets such as India and China, there are 10-20 times number of mobile subscribers vs UK and much larger geographic areas to cover!

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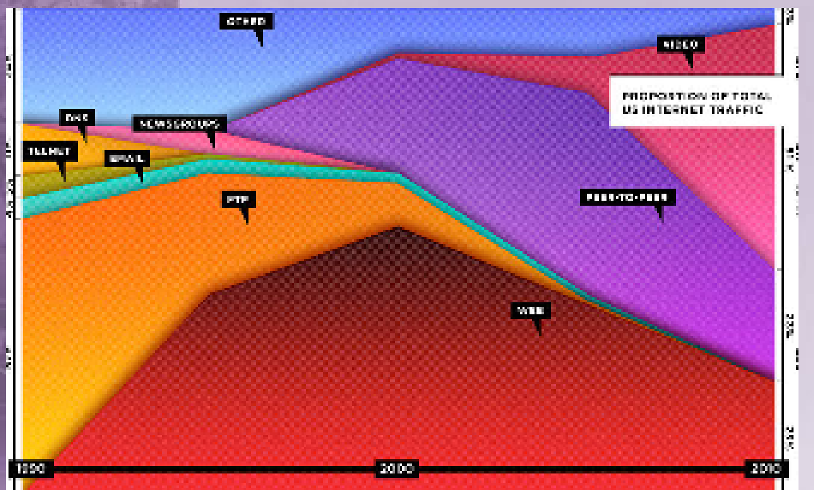
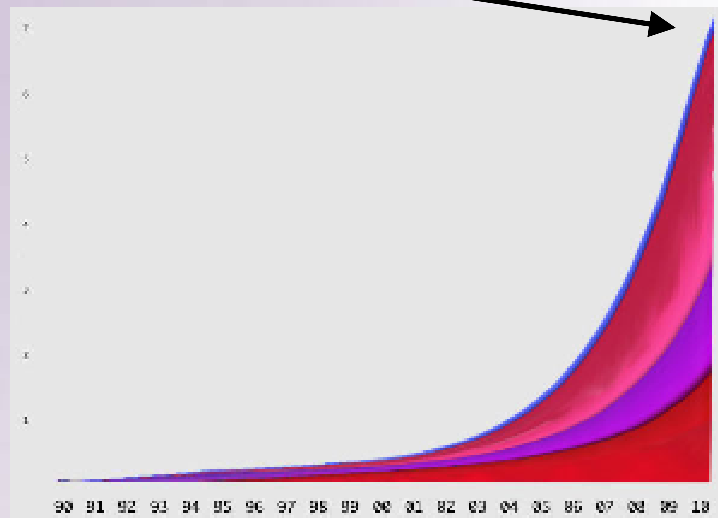
Internet Traffic Statistics

7 Exabytes = 7 Million Terabytes



Proportions of Traffic from 1990-2010
(Source: Wired Magazine)

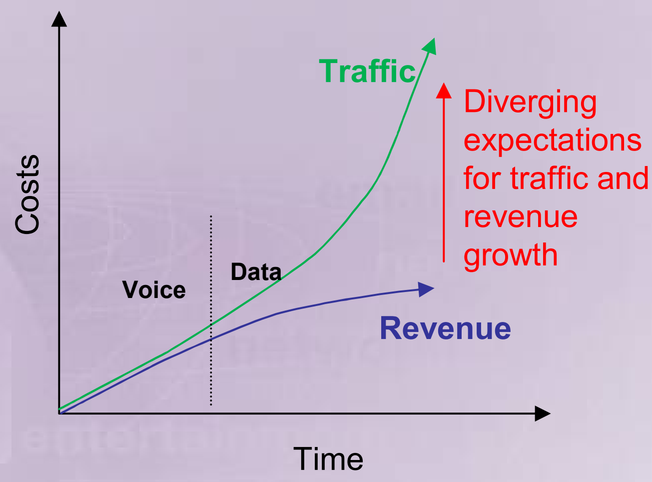


Traffic Volumes from 1990-2010
(Source: boingboing.net)

Trends:

- Traffic types varying→ **Video traffic** currently growing rapidly
- Observe exponential growth in traffic over time

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

Broadband Traffic on Mobile Networks

Revenue increase is not in line with traffic growth[9]

- Average annual increase in traffic: 400%
- Average annual increase in revenue: 23%

With the launch of High Speed Downlink Packet Access (HSDPA), the future move to adopt LTE and the introduction of flat-rate pricing, data traffic is increasing

Traffic is growing faster than the revenue increase with the biggest growth at operators whose pricing is more aggressive than the average

In the UK on O_2 97% of smartfone users download <500MB/month but remaining 3% of users use 30% of network capacity!

Now operators are varying monthly user charges between low (500MB) and high (1GB) download capability per month.

9. S. Chia, Workshop on "As the Internet takes to the air, do mobile revenue go sky high?," IEEE Wireless Communications and Networking Conference, April 2008.

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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
- Femtocell deployment
- Multi-hop routing / Relaying
- Improved resource allocation
- Dynamic spectrum access
- Interference Management and Mitigation

Required Target Innovations

Deployment Scenarios

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

Overall Base Station Efficiency

Techniques to deliver significant improvements in overall efficiency for base stations, measured as RF output power to total input (AC) power

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 techniques to scale power consumption with load

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

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

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

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

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

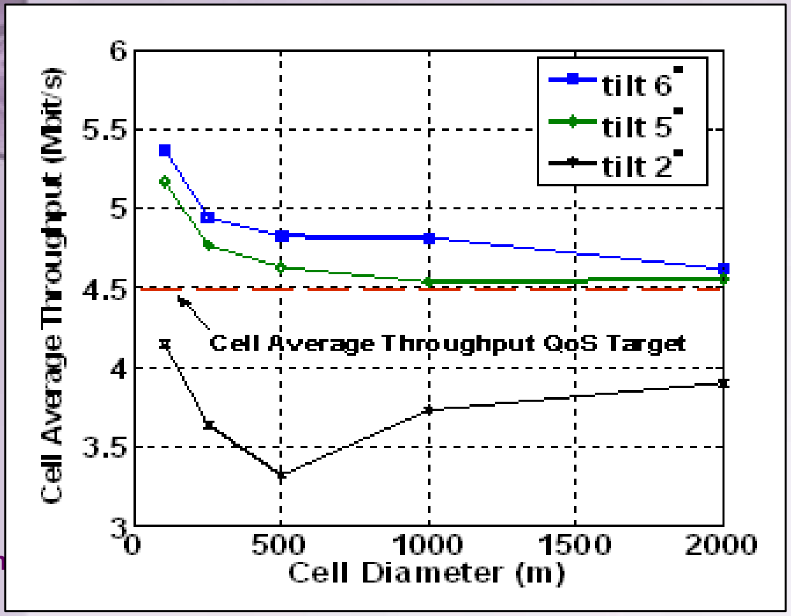
Case Studies

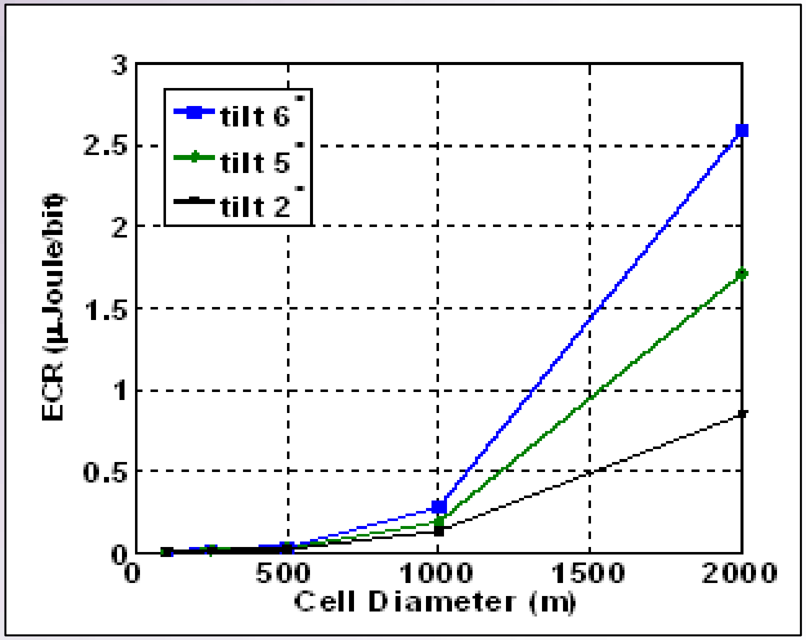
- Cell depoyment strategies
- Delay-tolerant networking
- Resource Allocation Strategies
- Interference Management & Mitigation

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.

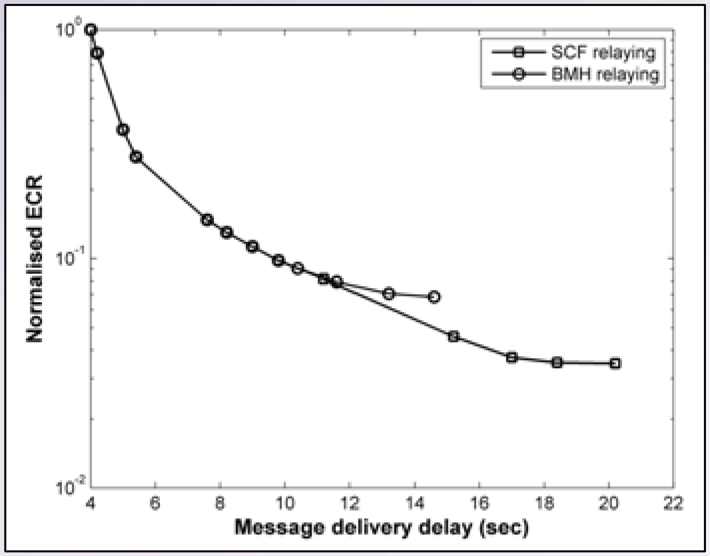




ECR decreases monotonically with cell diameter and downtilt angle under a throughput-coverage constraint.

Store, Carry and Forward (SCF) Delay-Tolerant Networking

- SCF relaying provides a generalization of previous relaying techniques that transmit an information message as soon as received.
- informed routing decisions are made both in space & time.
- A single cell scenario with 20 uniformly distributed active source nodes and 40 candidate mobile relays.
- Each source node has a file of 4 Mbits to send to BS.
- Compared to a basic multihop (BMH) relaying strategy where messages are forwarded as they become available.



Traffic Aware Resource Allocation

- **Under low traffic load conditions, BS likely to have more bandwidth to 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 function of SINR required at the mobile receiver for a given data rate. Alpha specifies permitted bandwidth expansion

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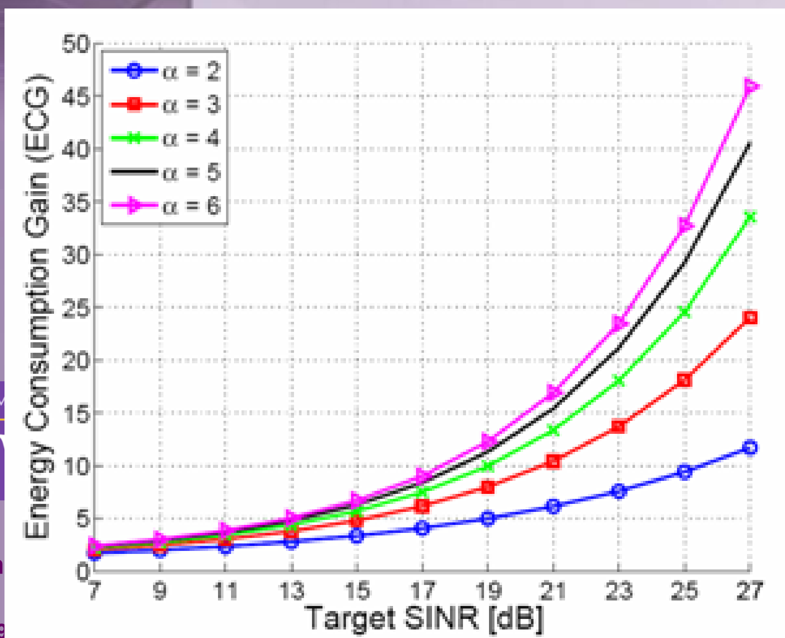

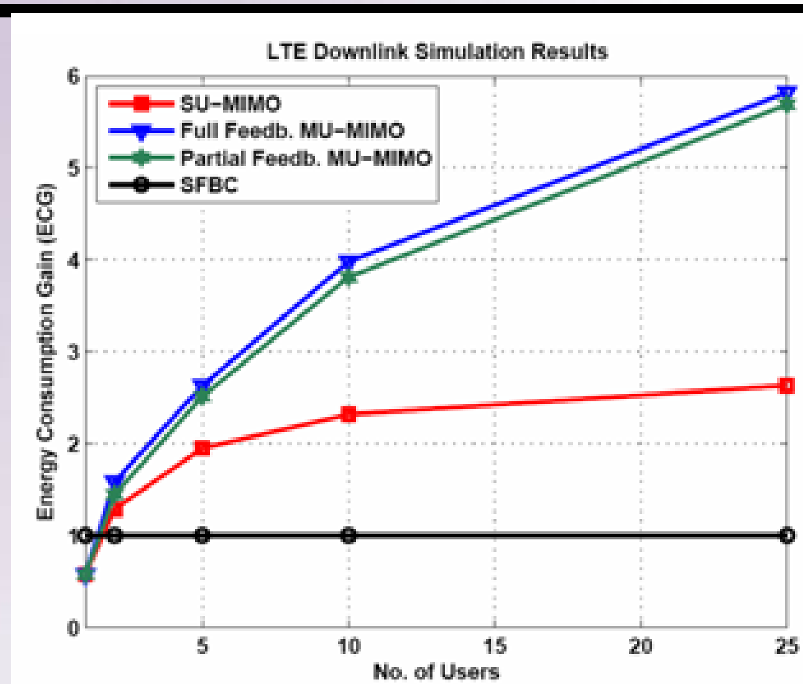

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ECG of various MIMO schemes, relative to SFBC, all at 3bits/s/Hz spectral efficiency. At high traffic load BS may exploit multi-user diversity by possibly using MIMO techniques.

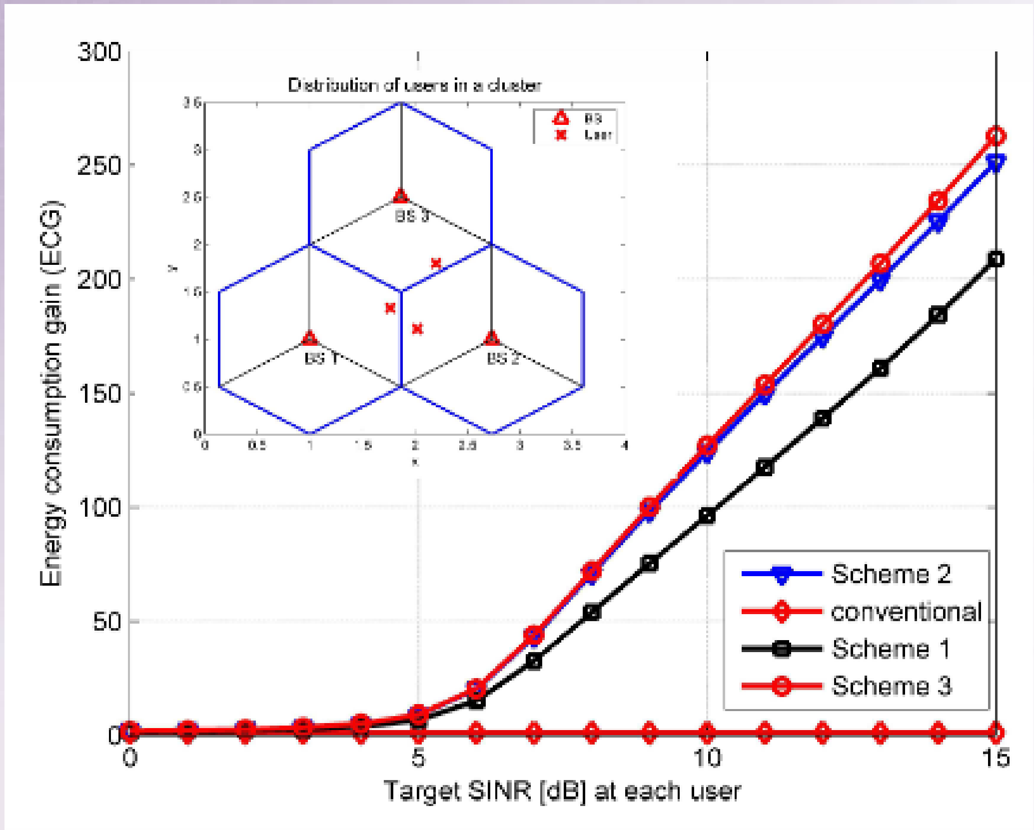
DAS for Interference Control

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

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 must research and investigate the changes to the system architecture and develop advanced networking techniques to deliver more efficient, Green Radio systems.