



# Green Radio – The Case for more Efficient Cellular Basestations

*Globecom 2010*

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# Green Radio

- **A global industrial perspective on achieving access network (system level) efficiency, including backhaul and .11n offload.**
- **Program driven by the INDUSTRIAL requirement**
- **£2M (or \$3M) three year research spend**
- **Funded by 14 Companies and Government (EPSRC)**
- **Research program defined jointly by industry and academia**
- **Delivered by 5 UK Comms Research Universities**
  - **Kings College London**
    - **Edinburgh**
    - **Bristol**
    - **Swansea**
  - **Southampton**
- **Research monitored and steered and publications all reviewed by industrialists at quarterly progress meetings**

# Presentation Overview

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- The Current Status on Cellular Systems
- The Business Case for **Green Radio (GR)**
- The Green Radio Issues
- Discuss **likely GR** research advances in:
  - High Load scenario
  - Low Load scenario
  - Delay tolerant scenario
  - Independent of traffic load
- Conclusions



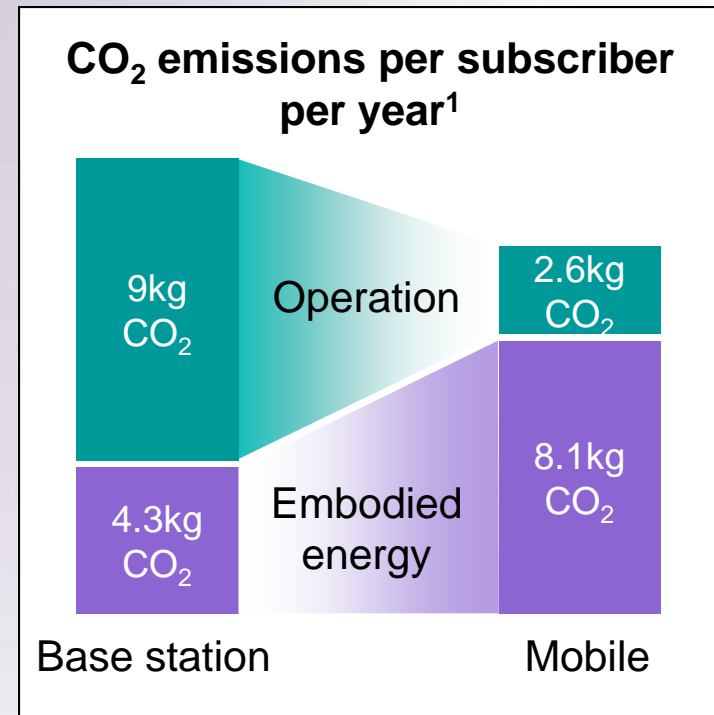
# Two types of Energy

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- **Embodied energy**
  - Energy used in raw material extraction, transport, manufacture, assembly, installation of a product or service **including** disassembly, deconstruction and decomposition. (Part of CAPEX)
- **Operating energy**
  - Energy expended over the operational lifetime of the product. (Contributes to OPEX)

# Where is the Energy Used?

- For the operator, 57% of electricity use is in radio access
- **Operating electricity** is the dominant energy consumed at a radio base station (RBS)
- For mobile user devices, with ~2 year lifetime, most of the energy is expended during manufacture



1. T. Edler, Green Base Stations – How to Minimize CO<sub>2</sub> Emission in Operator Networks, Ericsson, Bath Base Station Conference 2008

# Continuous Power Reductions

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## Power Consumption per Radio Base Station (RBS)

	<b>GSM</b>	<b>WCDMA</b>
<b>2008</b>	<b>800W</b>	<b>500W</b>
<b>2010</b>	<b>650W</b>	<b>300W</b>

Nokia Siemens Networks



# Energy Consumption

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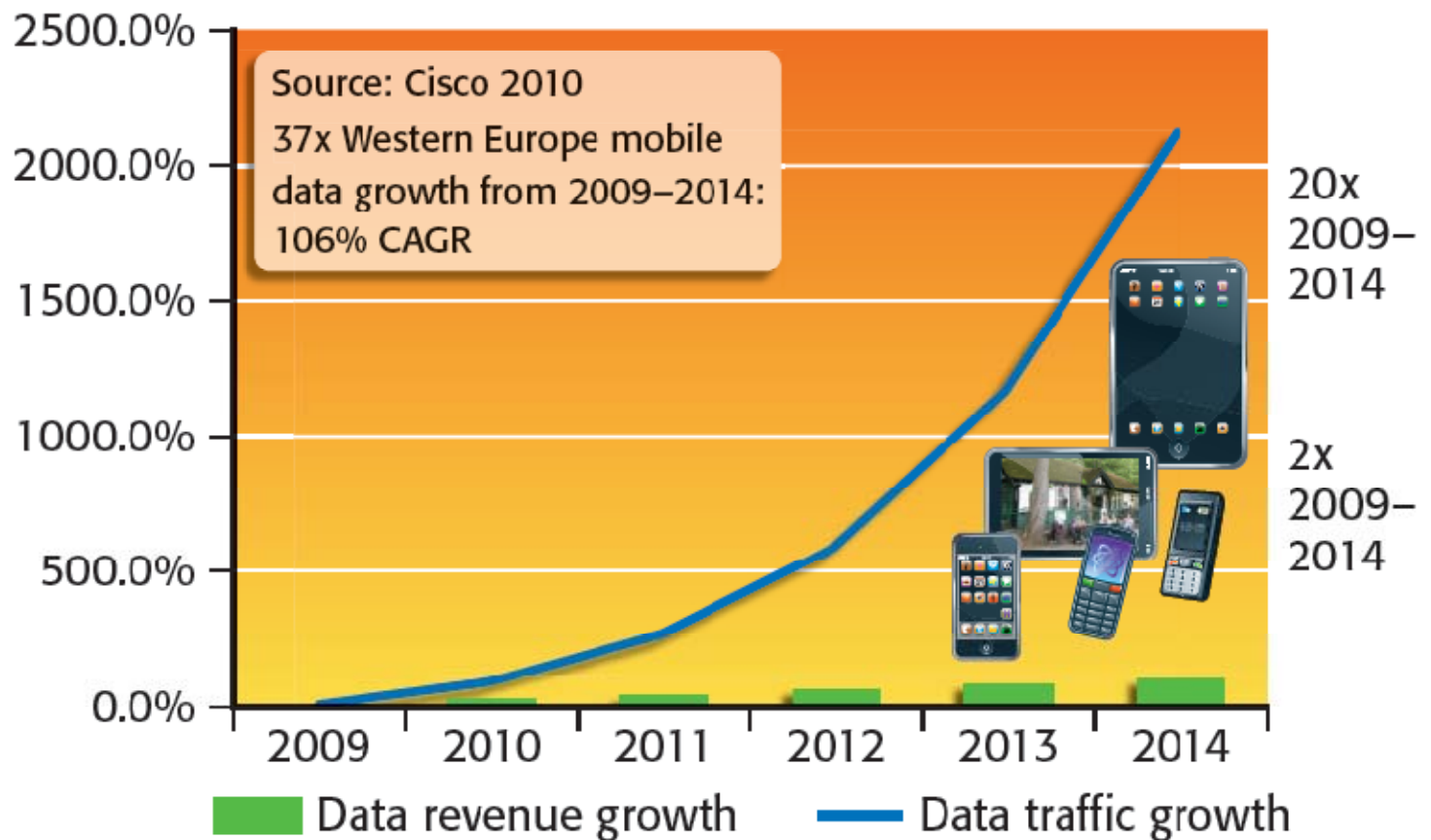
- **The cellular Radio Base Station (RBS) is the most energy-intensive component in a 3G mobile network.**
- **A typical 3G RBS consumes about 500 W with a output power of ~40 W. This makes the average annual energy consumption of a RBS around 4.5 MWh (note 3G RBS energy < GSM).**
- **A 3G mobile network with 12,000 BSs will consume over 50 GWh p.a. This not only responsible for a large amount CO<sub>2</sub> emission it also increases the system OPEX.**
- **This is worse in developing mobile markets. China Mobile has 500M mobile subscribers and a network comprising 0.5M GSM/EDGE plus 0.2M 3G CDMA RBS!**



# Data Traffic & Revenue Growth

## Exponential Mobile Data Growth - But Linear Data Revenue Growth

Global data revenue and traffic growth, 2009–2014

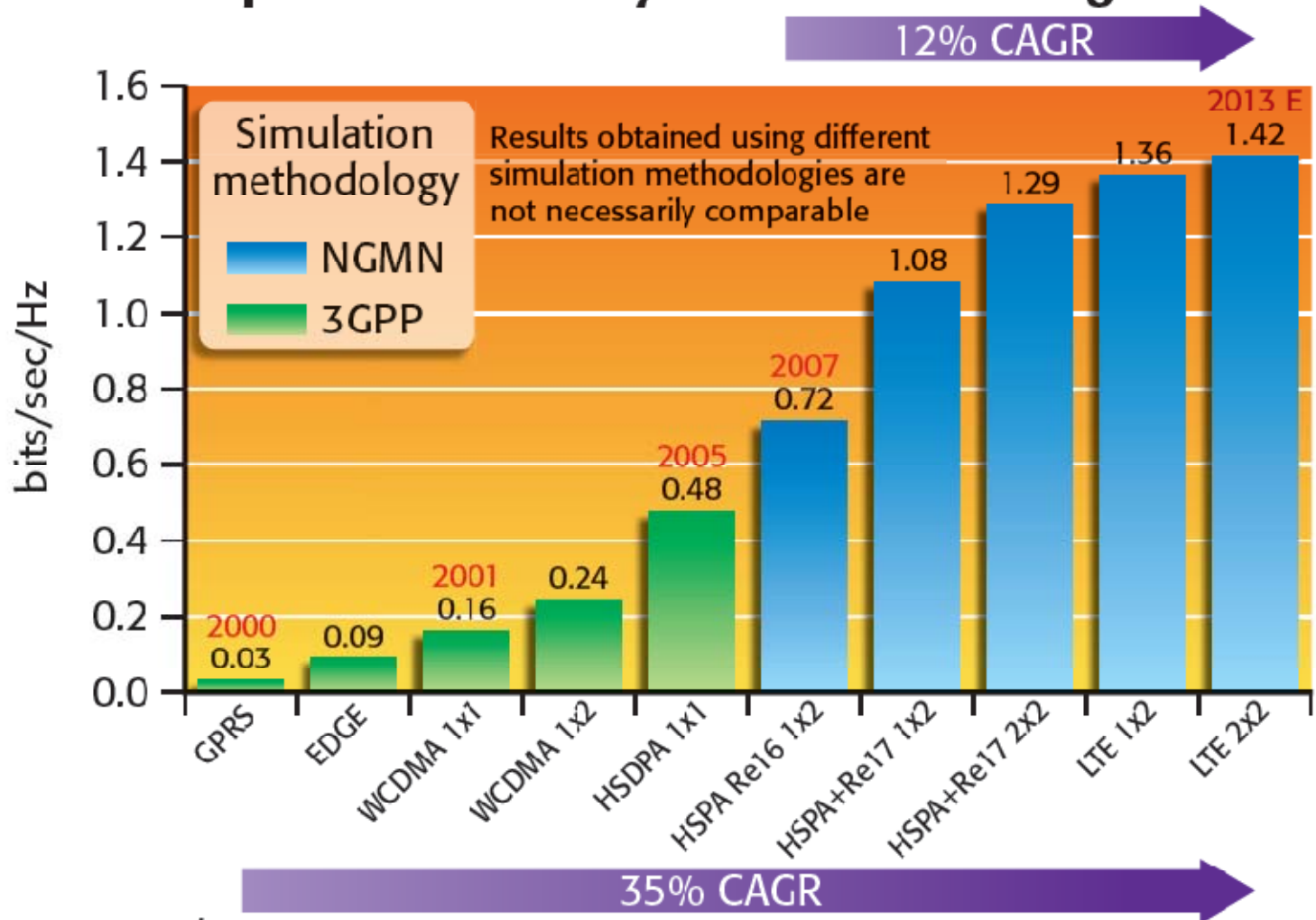


Source: Informa Telecoms & Media

© Informa UK Ltd 2010

# Data Throughput

## Spectral Efficiency Gains are Slowing



Source: Qualcomm

# Energy Consumption – **The Challenge**

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- **High Speed Downlink Packet Access (HSDPA), the move to LTE and flat-rate pricing are all increasing the demand for data traffic**
- **Since 2006, the growth rate of data traffic on mobile networks has been approximately 400% p.a..**
- **Largest growth is at operators whose pricing is more aggressive than the average**
- **14% of handset sales in 2009 were smartfone (iphone, blackberry, android)<sup>2</sup>.**
- **More Facebook users are using mobile, rather than fixed lines.**
- **2014: monthly mobile data traffic predicted to exceed all of traffic carried in 2008**

2. <http://www.mobile-computing-news.co.uk/industry-news/2372/gartner-report-shows-smartphones-growth.html>



# Energy Consumption – The Issues

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**Traffic growth will demand a much higher future energy consumption than today.**

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

- Must reduce energy use per data bit carried

**Number of base stations must increase to service traffic growth**

- Thus operating power per cell must reduce

**How do we design future mobile networks to be more energy efficient while also accommodating the growth in data traffic?**



# Green Radio Scenarios

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## Two Market Profiles:

### 1. Developed World

- Developed Infrastructure
- Saturated Markets
- Increase in data traffic
- Quality of Service Key Issue
- Drive is to Reduce Costs

### 2. Emerging Markets

- Less Established Infrastructure
- Rapidly Expanding Markets
- Large Geographical Areas
- Often no mains power supply  
– power consumption a major issue

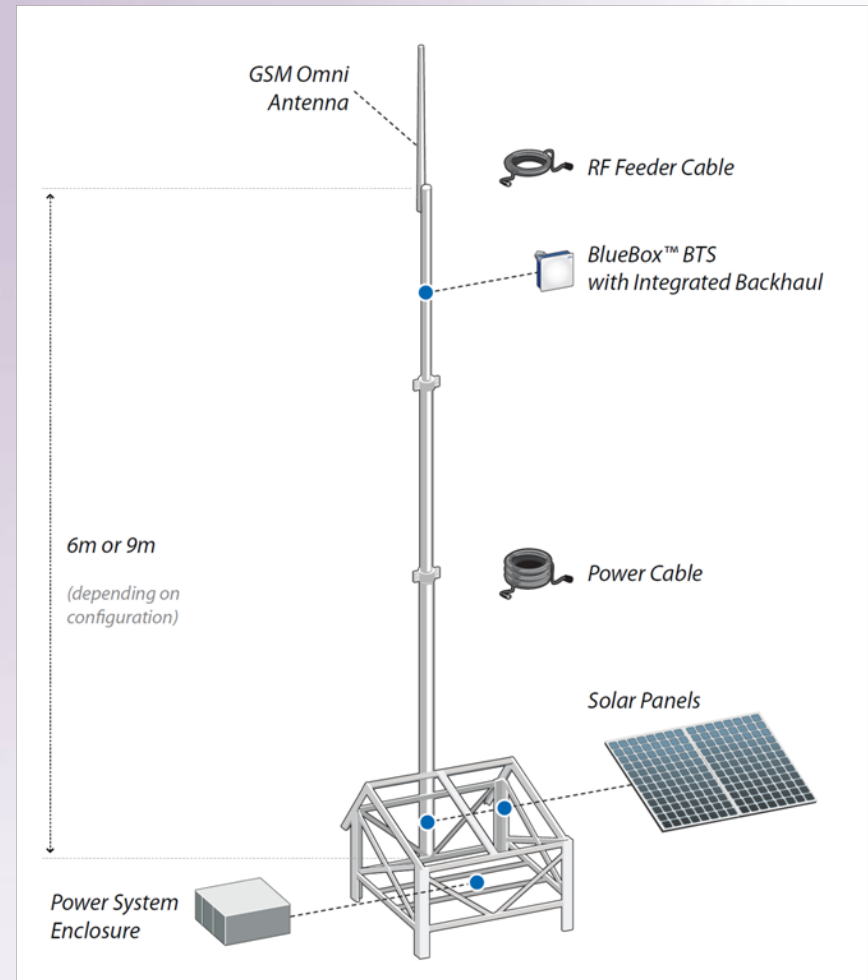


# Solar Energy for Green Radio

Over a year, 1m<sup>2</sup> solar panel produces ~400 kWh energy, or about 10% of a 3G macrocell RBS requirement (in London, < 5%).

Solar panels in locations now provide the energy requirement for a small “rural or village” RBS, e.g., the WorldGSM™ 100 W VNL<sup>3</sup> Indian RBS.

3. <http://www.vnl.in/technology/sites/>



# GR Research Objectives

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## Improve RBS efficiency at high load:

- Achieve high bit/s/Hz with low power drain
- MIMO scheduling
- Femtocells or relays?

## Improve RBS efficiency at low load:

- Sleep modes
- Spectrum sharing

## Improve efficiency under other conditions:

With Delay:

- Store and carry forward (SCF) relaying

## For all scenarios:

- Increase component integration
- More efficient power amplifier (PA)
- Power efficient processing, e.g. DSP

# Key Metrics for Energy Use

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## 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)

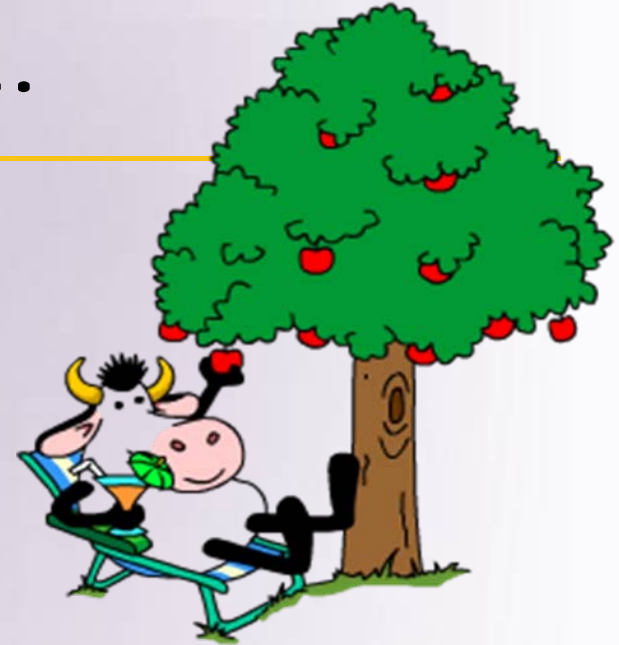
This compares the energy consumed by a system under test, relative to a reference system, where both communicate the same number of data bits

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

An **ECG >1** indicates an improvement in **efficiency**.

# Low hanging fruit ..

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- Optimise power supply rectifier
- Cut-off 1.8 GHz higher band at night
- Upgrade 2G to more efficient Tx's, e.g. GPRS to Evolved EDGE
- Power Saving (software controlled PA bias)
- Increase integration with remote radio heads (RRH)
- Employ more free air cooling rather than air conditioning and operate at high thermostat settings

# Scenario 1

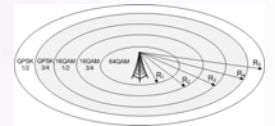
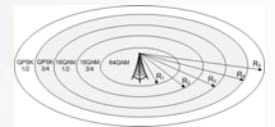
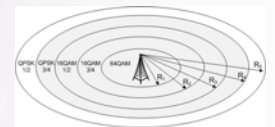
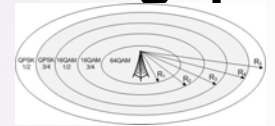
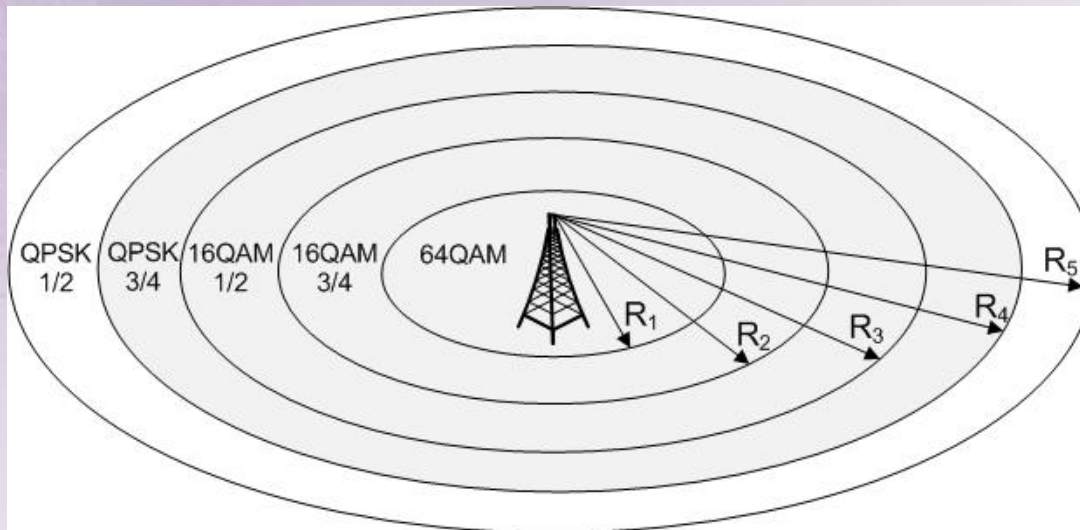
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## High Traffic Load

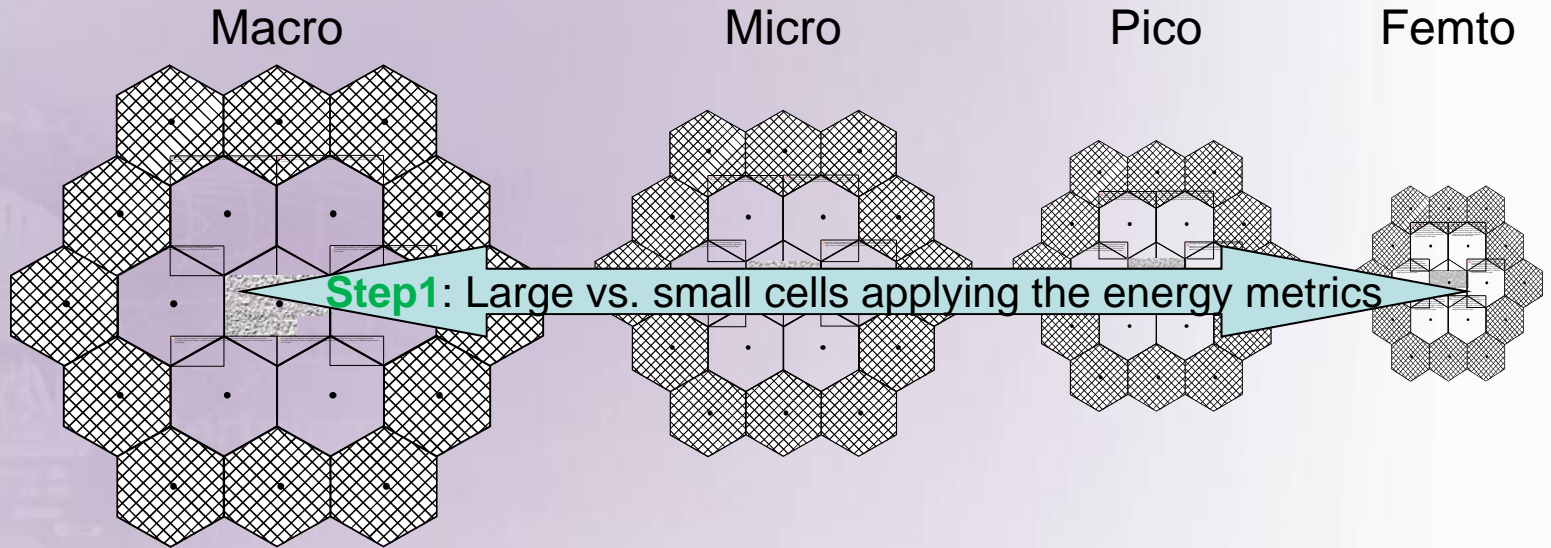


# Macrocell transmission data rates

- High SNR, close to RBS, will support 64 QAM
- Reduced SINR at cell edge permits only QPSK Tx
- Smaller cells will thus provide high data throughput
- Array of small cells secures overall high throughput



# Cell Size Analysis



**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

# What is a Femtocell?

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The Femtocell (HomeNodeB) is a low power cellular [base station](#) access point for a home or small business.

Connects to the service network via ([DSL](#) or [cable](#)) broadband.

ABI research predicts worldwide 45m femtocell deployments by 2014.

Unlike unlicensed IEEE 802.11 Wi-Fi - Femtocells interface to **existing mobile handsets** via [licensed](#) spectrum.

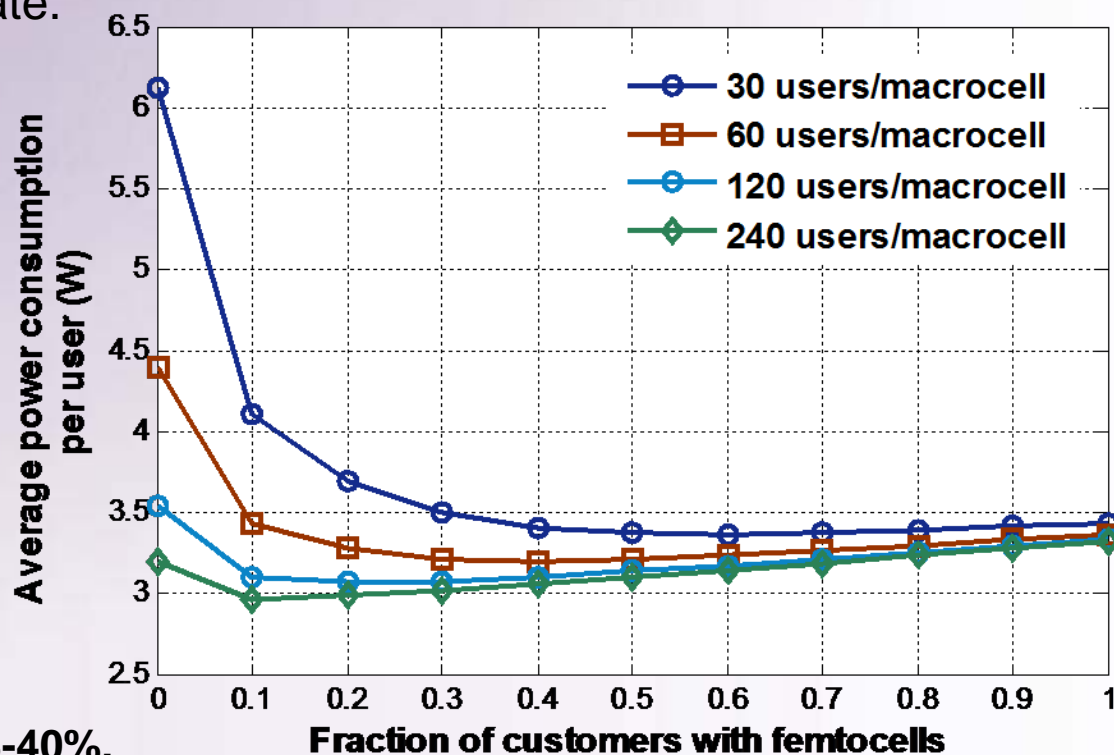
Use [GSM](#), [CDMA2000](#), [TD-SCDMA](#), [WiMAX](#), [WCDMA](#) or [LTE](#) system.

Key attractions are better coverage and capacity, especially indoors, with superior voice quality and handset battery life.



# Power Consumption Analysis based on the Penetration of Femtocells

- Relationship between fraction of customers with femtocells and the power consumption per user, for different user densities.
- Evaluation metric: System power consumption per user; includes CAPEX and OPEX energies, with unused femtocells switched off.
- System power consumption decreases with the initial increase in femtocell adoption rate.
- When femtocells' deployment rate is greater than 60%, system power consumption increases again.
- A lower user density leads to increased power saving.
- Energy reduction of 3-40%.



# SISO vis MIMO with Packet Scheduling

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- Compared SISO and MIMO techniques with fast packet scheduling.
- Determine ECR of LTE as a function of required spectral efficiency in different channel scenarios.
- Study the impact of control signalling overhead on  $ECR_{RF}$  for MIMO and SISO.
- Investigating different MIMO transmission and precoding techniques in combination with multi-user diversity.
- Conclude that a MU-MIMO can achieve up to 80% energy reduction over a single-user SISO scheme.

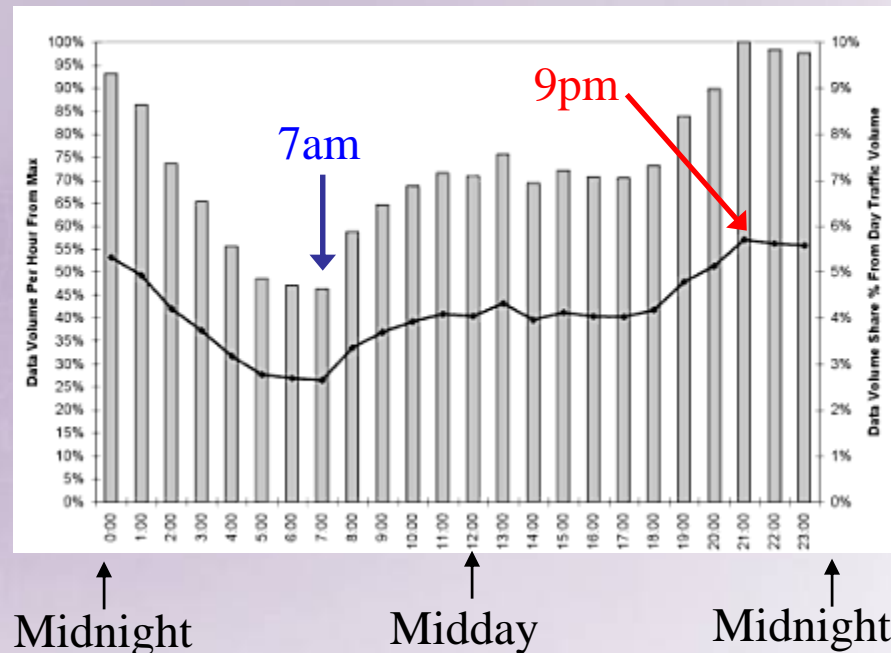
# Scenario 2

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## Low Traffic Load



# Daily Traffic Variation<sup>4</sup>



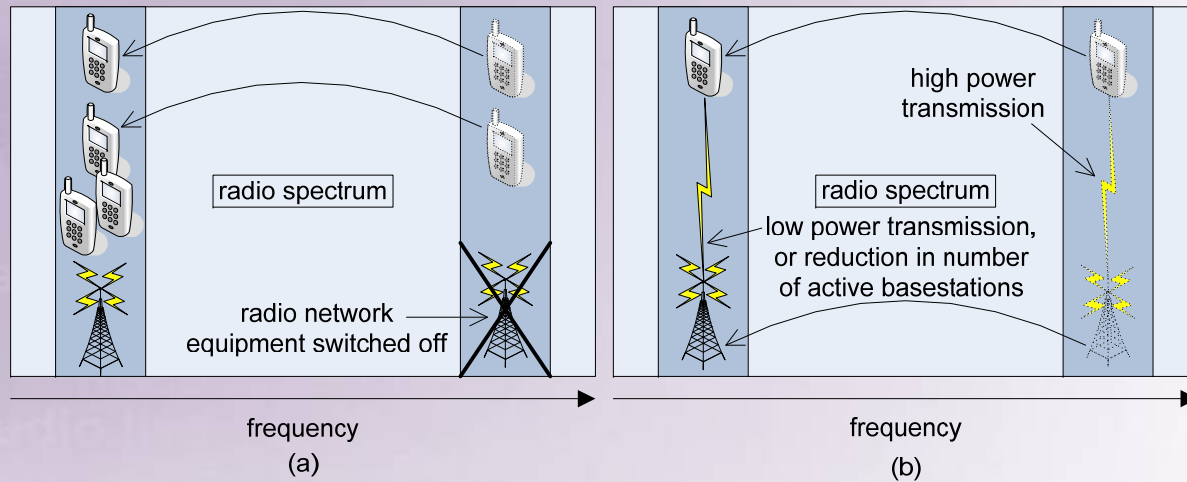
Vertical bars show traffic load over 24 hour period, averaged over 100 cells

- Change by factor of ~2 from lowest load at 7am to highest at 9pm
- Significant periods of low network utilisation
- Expect major load variations between cells

Further analysis shows that 90% of data traffic is carried in only 40% of network cells

4. H Holma and A Toskala, "LTE for UMTS - OFDMA and SC-FDMA Based Radio Access" John Wiley 2009

# Spectrum Sharing Techniques



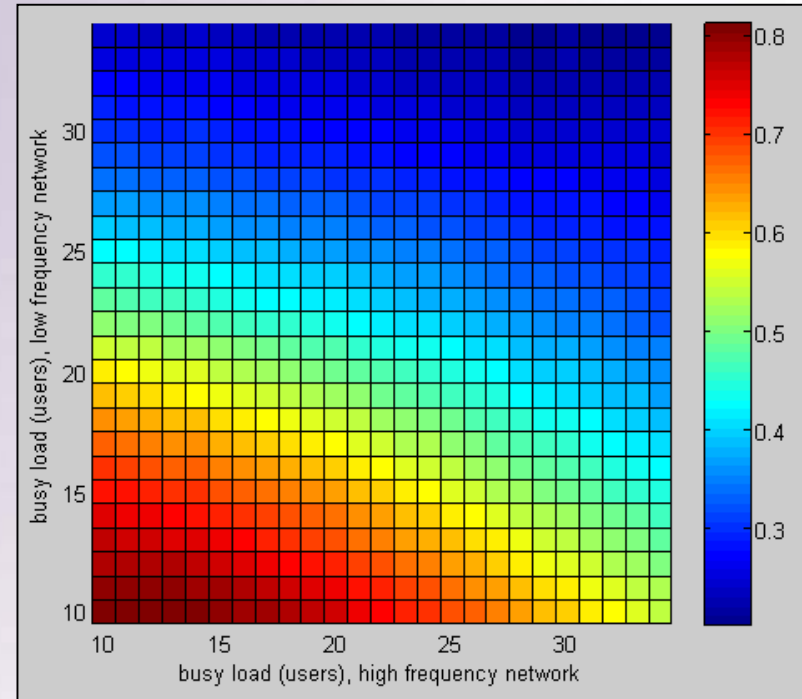
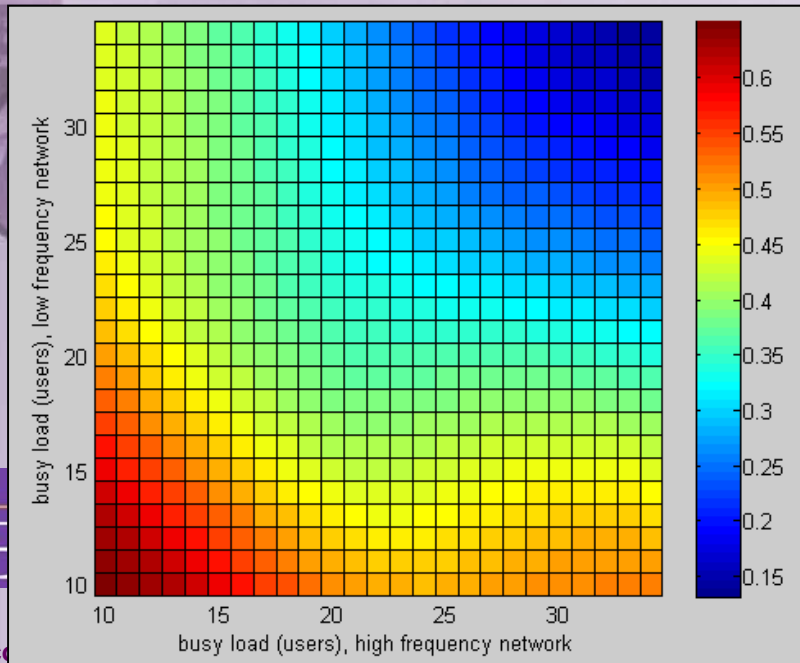
**Dynamic intra-operator cross-band spectrum management concepts:**

- (a) power down of selected radio equipments,
- (b) to take advantage of band with superior propagation characteristics.

# Spectrum Sharing Simulations

- Saving by disabling and/or changing transmission frequencies

**AC** power saving by switching of parts of networks at a frequency, or reducing network sectorisation, by reallocating users as in (a) to other frequencies, when under low load.



**RF** transmission power saving by reallocating links to a lower frequency band as in (b) to improve propagation, whenever transmission capacity is available.

# Scenario 3

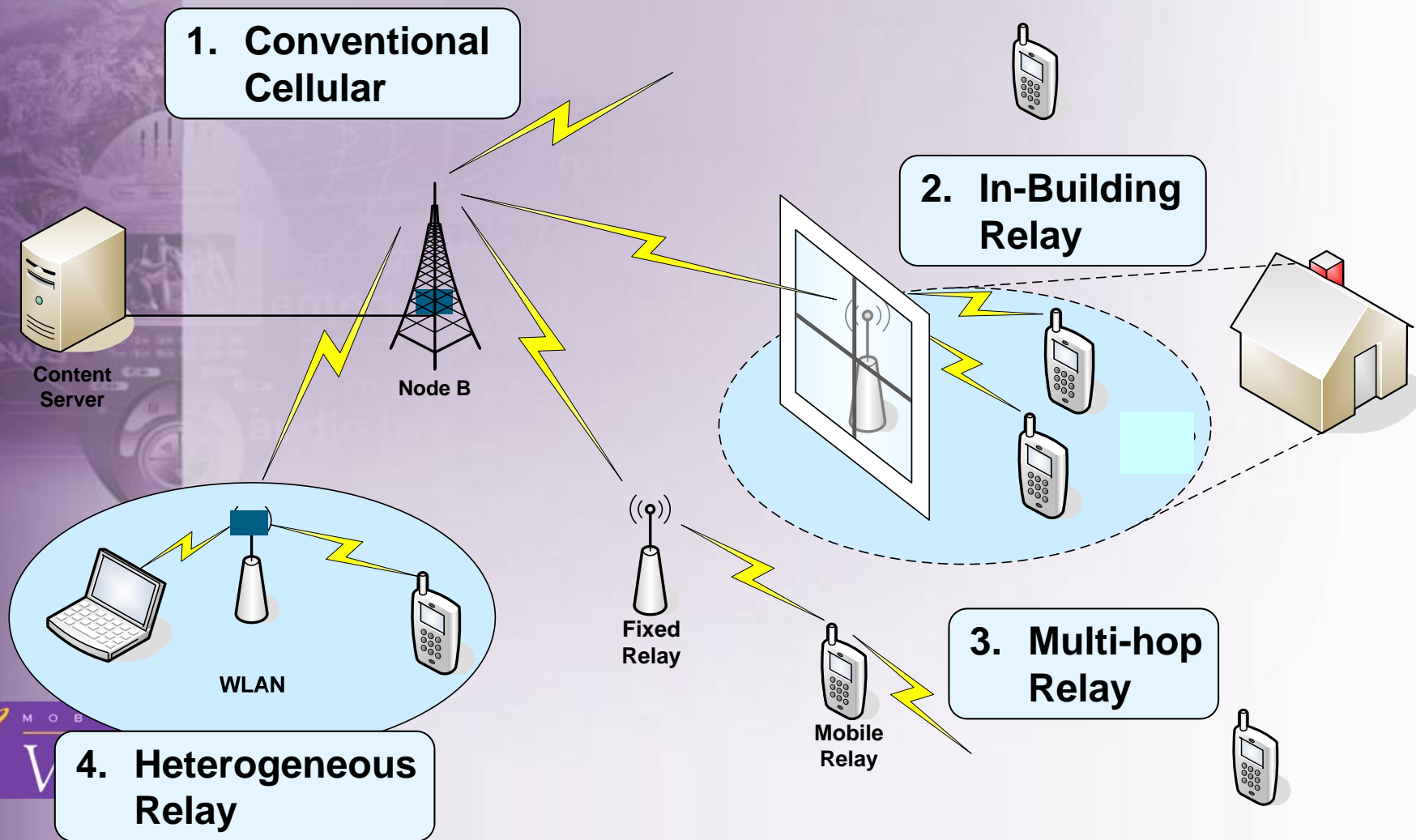
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## Delay tolerant System

e.g. for FTP or email



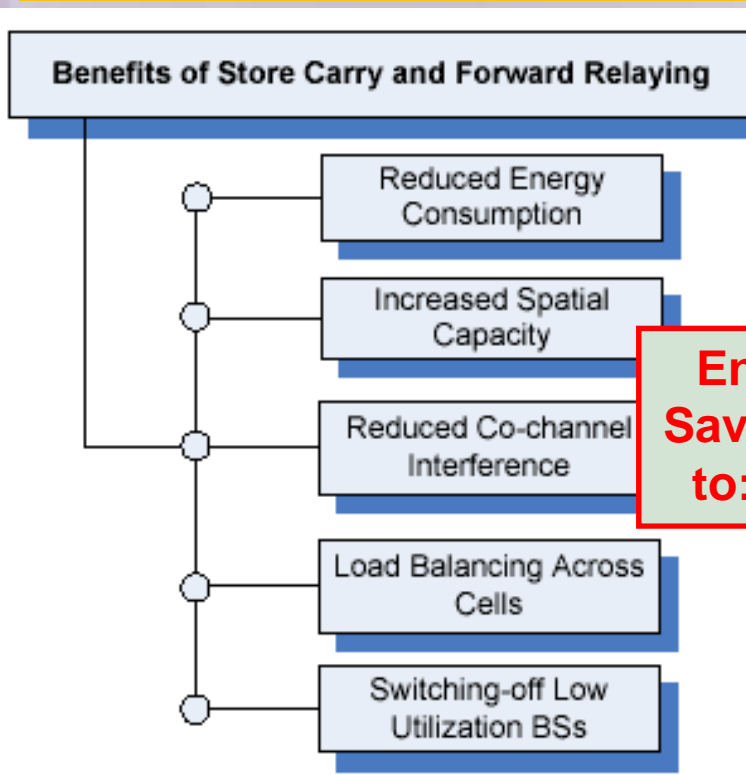
# Can We Reduce Power Consumption Through Delay-Tolerant Networking?



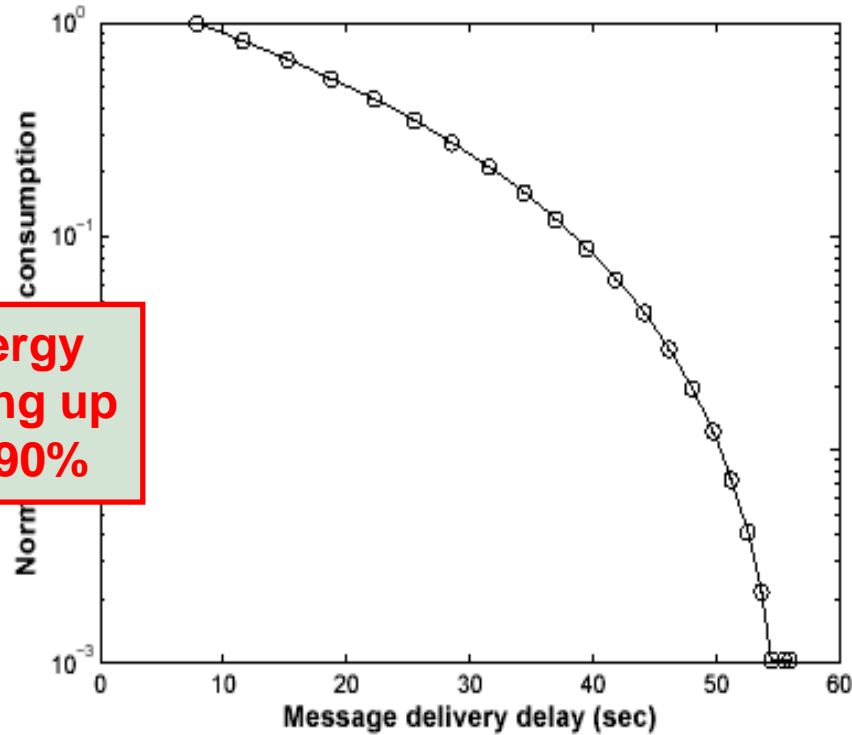
**4. Heterogeneous Relay**



# Benefits of SCF Relaying



**Energy Saving up to: 90%**



- Graph shows the normalized energy consumption gain (ECG) (on logarithmic y-axis) for a 2-hop relaying scheme, compared to single hop communication.
- Considerable reductions in energy consumption can be achieved by delaying comms to preferable transmit locations, but reduction by 90% is a more practically achievable value.

# Scenario 4

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## All Systems – Load Independent



# Power Efficient BS Hardware

## 3G Base station efficiency

- Climate control 65%
  - Power supply 85%
  - PA / transceiver 45%
  - Feeder cables 50%
- Baseline overall efficiency now 12%**

## Advanced base station architectures

- Multi-mode and multi-standard
- Maximise equipment and base station re-use

## Integration allows energy reductions

- Masthead electronics avoids cable losses
- Some security issues
- Target > 20% overall efficiency

## Advanced power amplifier techniques

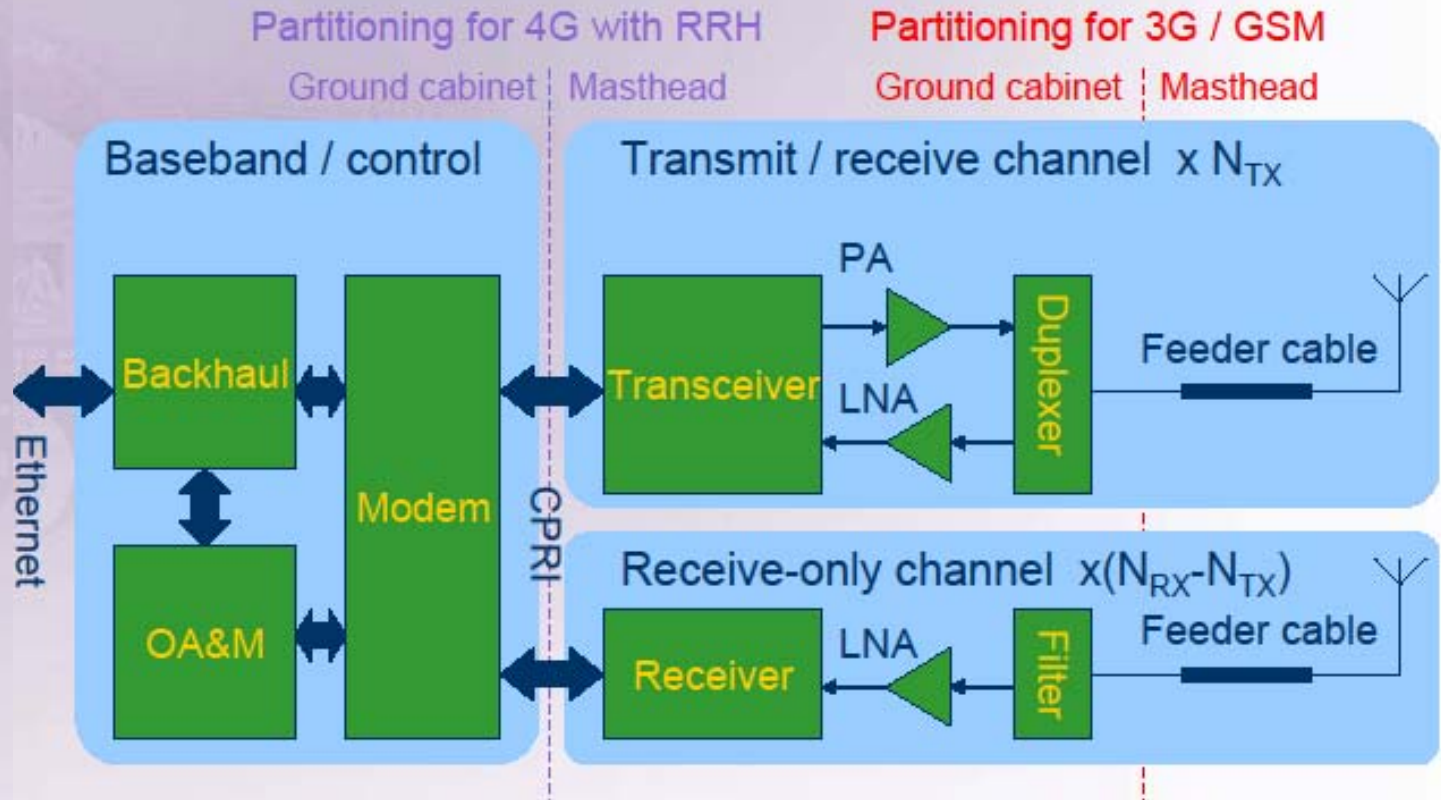
- Target: > 60% PA efficiency
- Current industry PAs, 20-40% efficient

## Integrated remote radio antenna

- Masthead PA eliminates feeder loss
- Integration avoids interconnect losses
- Passive thermal cooling



# Increase Integration: 3G > 4G



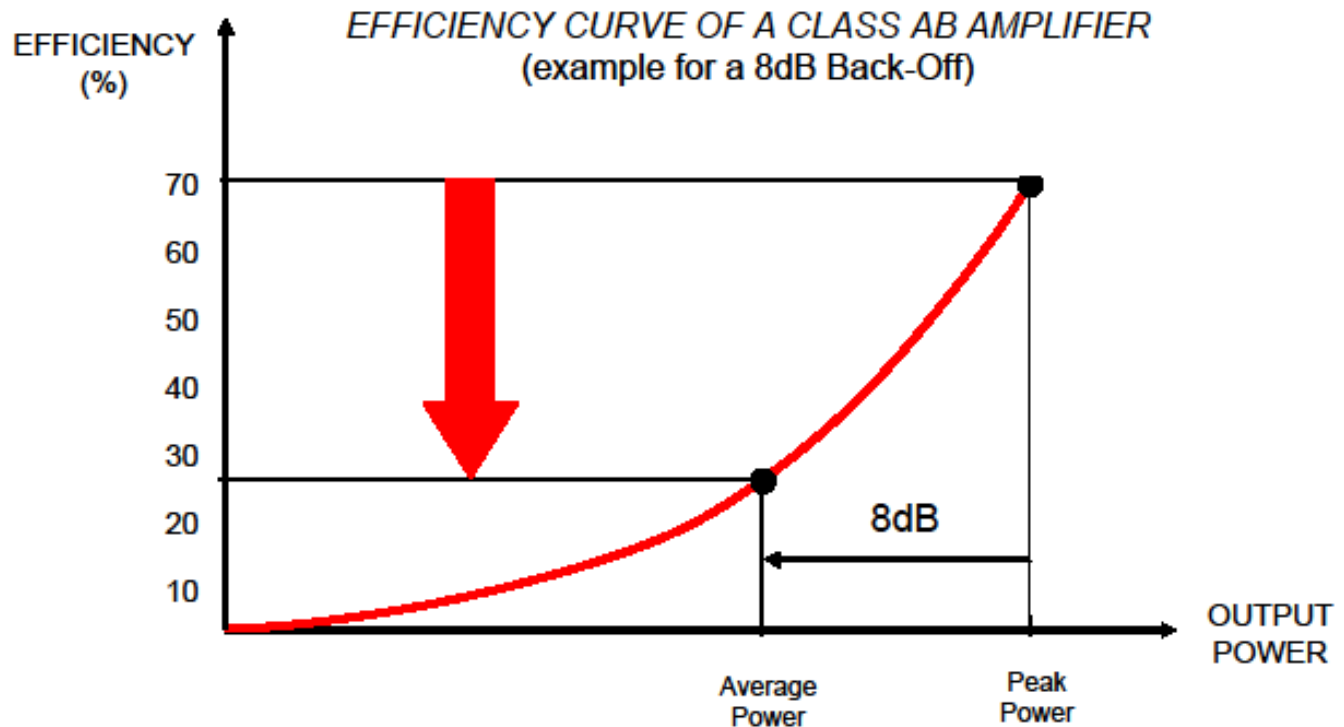
CPRI interface between digital and RF modules <http://www.cpri.info>

# Power Amplifier Efficiency



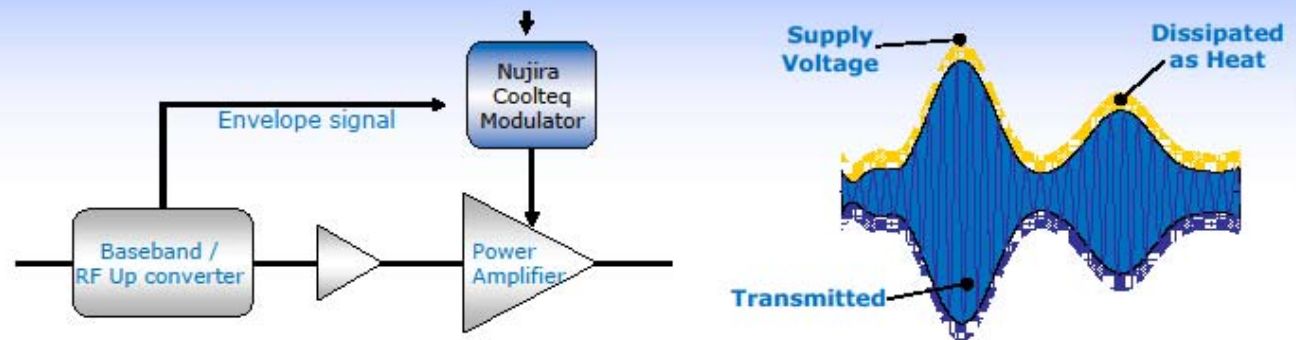
## Energy Efficiency $\neq$ Peak Efficiency!

- Classical power amplifier architectures have low efficiency at low power levels



# High Efficiency Power Amplifier

## Technology – High Accuracy Tracking

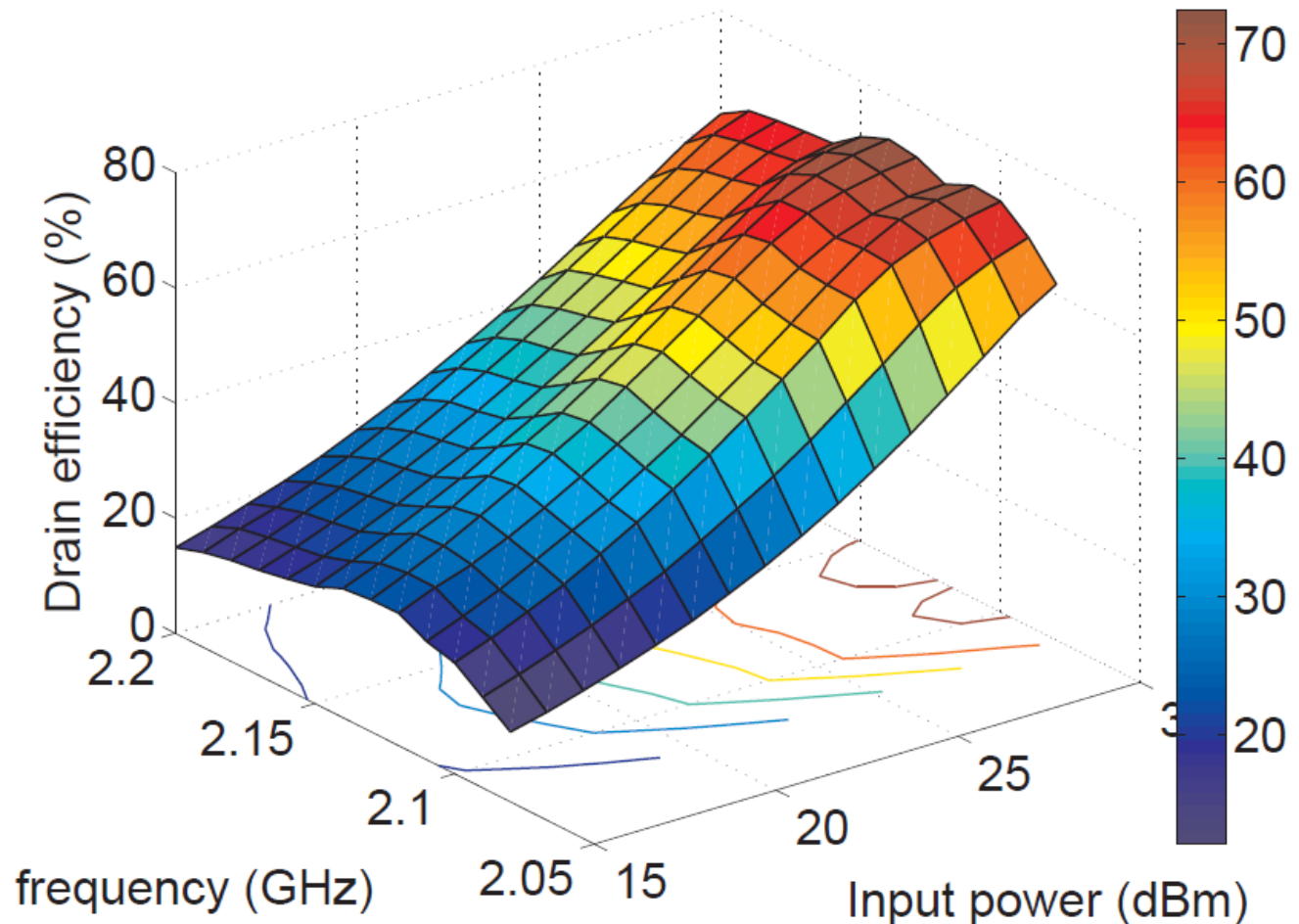


- In a High Accuracy Tracking PA, the power supply is modulated in unison with the RF envelope
- PA device is in compression and therefore efficient for the majority of envelope
- High Accuracy Tracking offers excellent efficiency, RF device power dissipation drops considerably

# New Class J Power Amplifier Designs

>60% efficiency, 140 MHz RF bandwidth

Drain efficiency over  $P_{in} = 15-30\text{dBm}$  and  $f = 2.08-2.20\text{GHz}$



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# Conclusions



# Energy Reduction Techniques

- RBS overall efficiency (RF / AC) is increasing year-on-year:
  - 2003 – 3%
  - 2009 – 12%
  - 2015 – ?25%?
- We can significantly reduce power requirement by employing many different individual techniques:

Store-Carry-Forward	MIMO vis SISO	Class J Amplifier	Spectrum Sharing	Small Cells	Bandwidth Expansion	Sleep Modes	Scheduler
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- We must now further combine, as appropriate, the above techniques to reduce the overall required AC power.
- Attempting to extrapolate from today's distributed architecture to well beyond Release 8 i.e. to LTE-Advanced ~Release 10+
- Tenfold power reductions (i.e. to 90%) are available, (e.g. SCF) at the expense of a significant increase in latency!



# Future Developments

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- Establish optimum cell size design: macro vis femto taking into account backhaul power requirements.
- Ascertain if femtocell or relay is most energy efficient method of extending the cell range or coverage.
- Can better knowledge of propagation channel and interference signals assist us in achieving energy reduction?
- Conclude optimisation of RBS hardware and integration!
- Our technical meetings are rich in industrial feedback and **we welcome industrial organisations, who are active in these areas, to join the Mobile VCE GR programme.**

# Some **Green Radio** Programmes

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## **Earth – Energy Aware Radio and neTwork technologies**

Component and System level energy improvements

15MEuro EU project, 7 industrial, 7 academic & standards partners

2010 – 2012, aim for 50% power reduction in 4G nets

## **OPERA-Net – Optimising Power Efficiency in mobile Radio Networks**

EU Project led by France Telecom, 2008-2011

7 industrial, 3 academic partners

## **Cool BS – Regenerative and Autonomous Femtocell BS**

Improved energy supply, multiprocessors, PA

5 Industry partners with TU Dresden

## **eWIN – Energy-efficient wireless networking**

Partners: KTH, ACREO, Ericsson, Huawei

Funding: [TNG Strategic Research Area](#), Industry

## **GreenTouch – Energy Efficient, Sustainable communication networks**

AT&T, China Mobile, Portugal Telecom, Swisscom, Telefonica, ATT Bell Labs,

Samsung, Freescale, Huawei, IMEC, MIT, Stanford, Melbourne, etc

## **GREENET - Analysis, design and optimization of energy efficient wireless networks**

EU Marie Curie PhD training network

Lead by UPC in Barcelona, 5 academic and 4 industrial partners



# Acknowledgments

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## Industrial and Academic Colleagues in UK Virtual Centre of Excellence in Mobile Communications ([www.mobilevce.com](http://www.mobilevce.com))

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