Core 5 Programme

Green Radio – Sustainable Wireless Networks

Simon Fletcher GR Industrial Chair

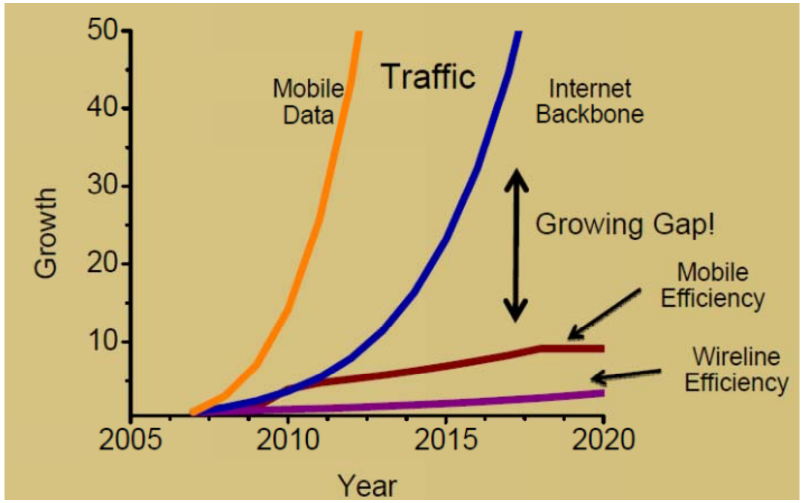
For COST in Bristol

2012.09.25

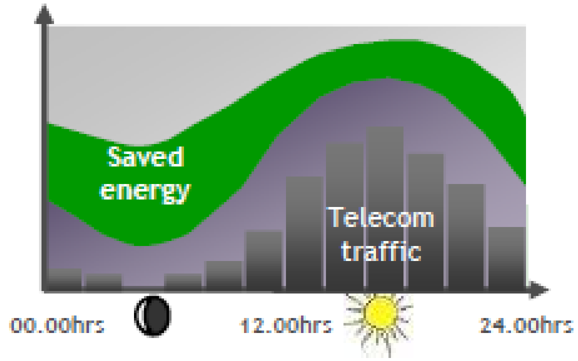
V0.2

Outline

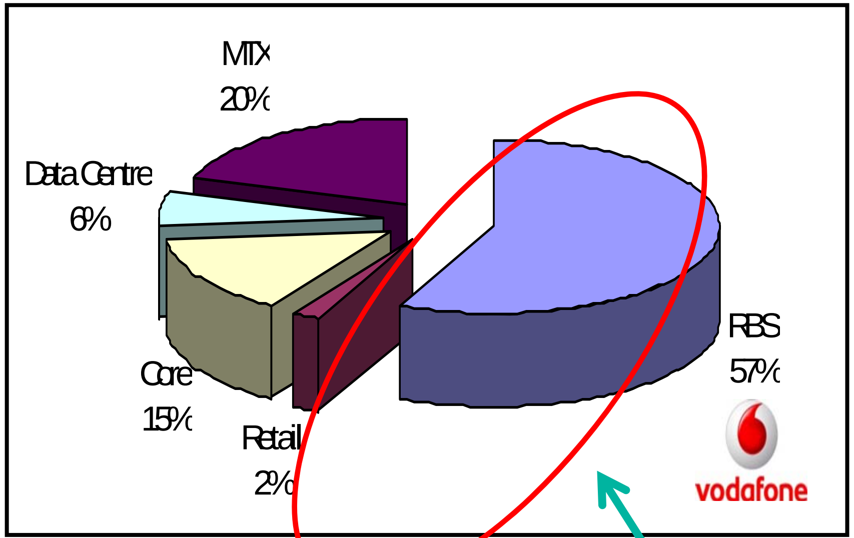
1. Introduction – GR Aim and Objectives

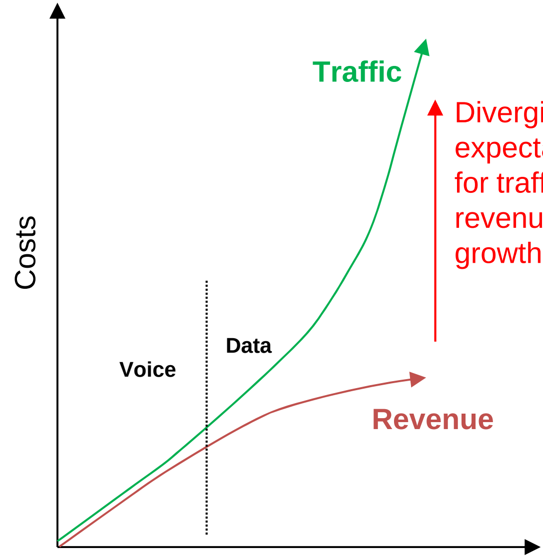


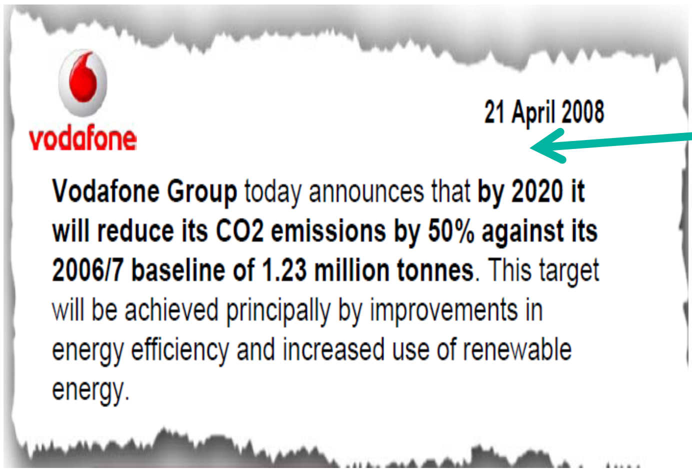
2. Our Technical Approach
   - Energy Models & Metrics
   - Architectures
   - Techniques
3. Number Crunching the Approaches
4. Integration
   - Scenarios
   - VCEsim
5. The Green RAN
6. Key Conclusions, Achievements & Future Trends



The Motivation for Green Radio Research






vodafone

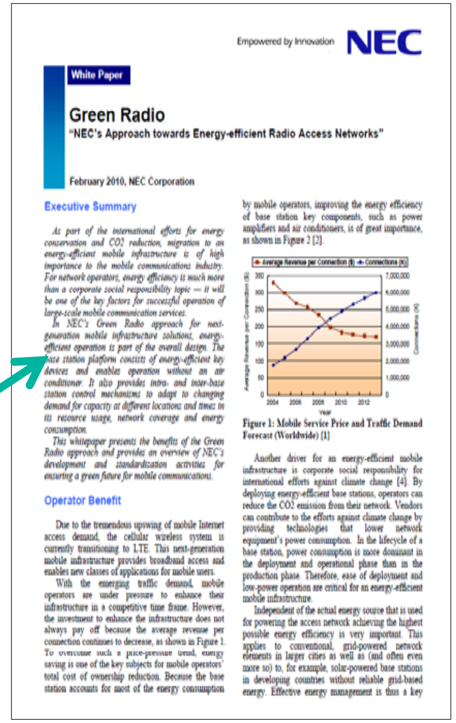
21 April 2008

Vodafone Group today announces that **by 2020 it will reduce its CO2 emissions by 50% against its 2006/7 baseline of 1.23 million tonnes**. This target will be achieved principally by improvements in energy efficiency and increased use of renewable energy.

Consortium

mobile vce : research innovation application :

EPSRC
Nokia Siemens Networks
Alcatel·Lucent
NEC
vodafone
orange
TOSHIBA
HUAWEI
FUJITSU
THALES
Turner A TimeWarner Company
BBC
The University Of Sheffield.
University of BRISTOL
KING'S College LONDON
University of Southampton
The University of Edinburgh



http://www.nec.com/en/global/solutions/nsp/lte/pdf/greenradio.pdf

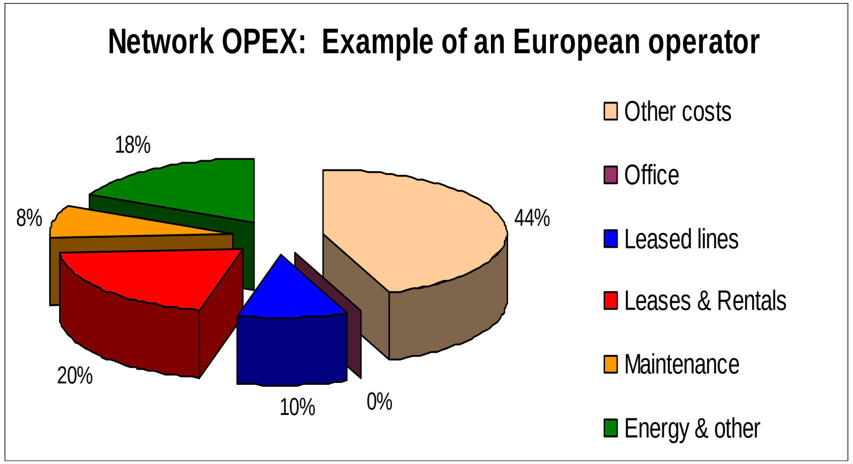
Aim & Objectives

- The fundamental research question
  - How can a significant reduction in energy consumption be achieved in future wireless communication networks, in particular cellular mobile networks based on the LTE standard, through interventions in
    - RAN Architectures & Cell Deployments
    - Radio Techniques across the Protocol Stack
- Target a 100x reduction is energy consumption
  - Achieved Energy Reduction Gains (ERGs) from
    - 85% at high traffic loads
    - 92% at low traffic loads
  - On average ~10x energy reduction by integrating solutions

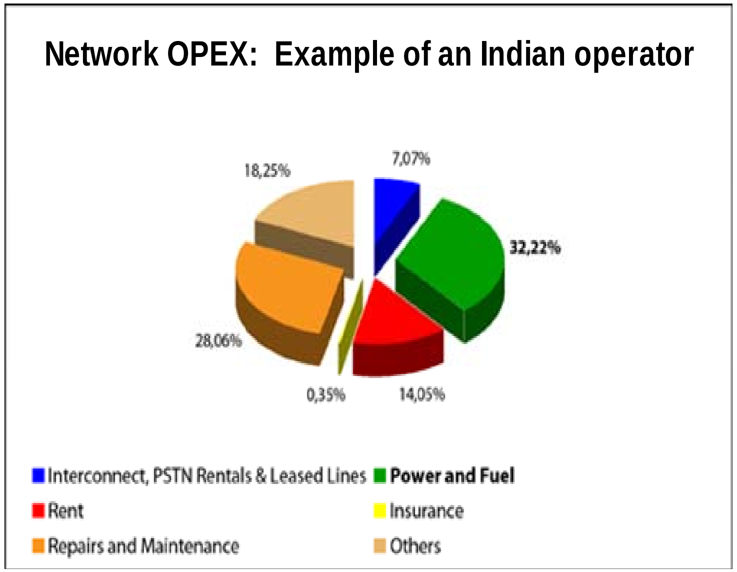
Green Radio Market Characterisation

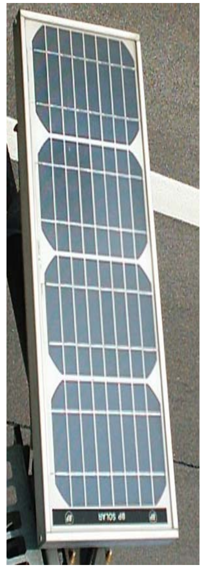
different CAPEX and OPEX Ratios…..

- Developed Regions
  - Developed Infrastructure
  - Saturated Markets
  - Quality of Service Key
  - Drive to Reduce Costs



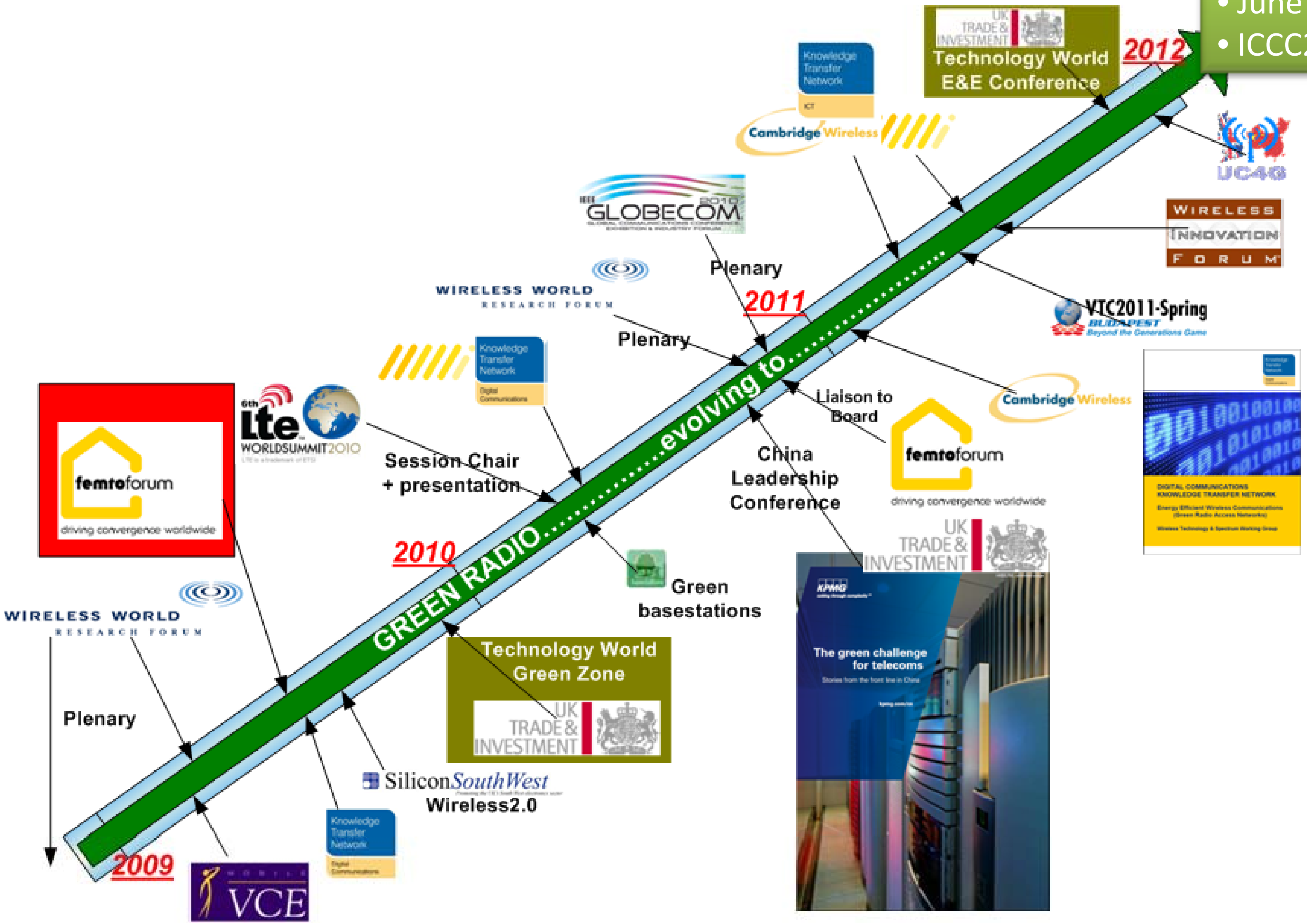
- Emerging Regions
  - Less Established Infrastructure
  - Rapidly Expanding Markets
  - Large Geographical Areas
  - Often no mains power supply – power consumption a major issue





Building Global Linkage

- Book opportunity
- June Smallcell forum
- ICCC2012 in Beijing



Linkage to China

High common interest in the area of Green Technologies in the UK and China

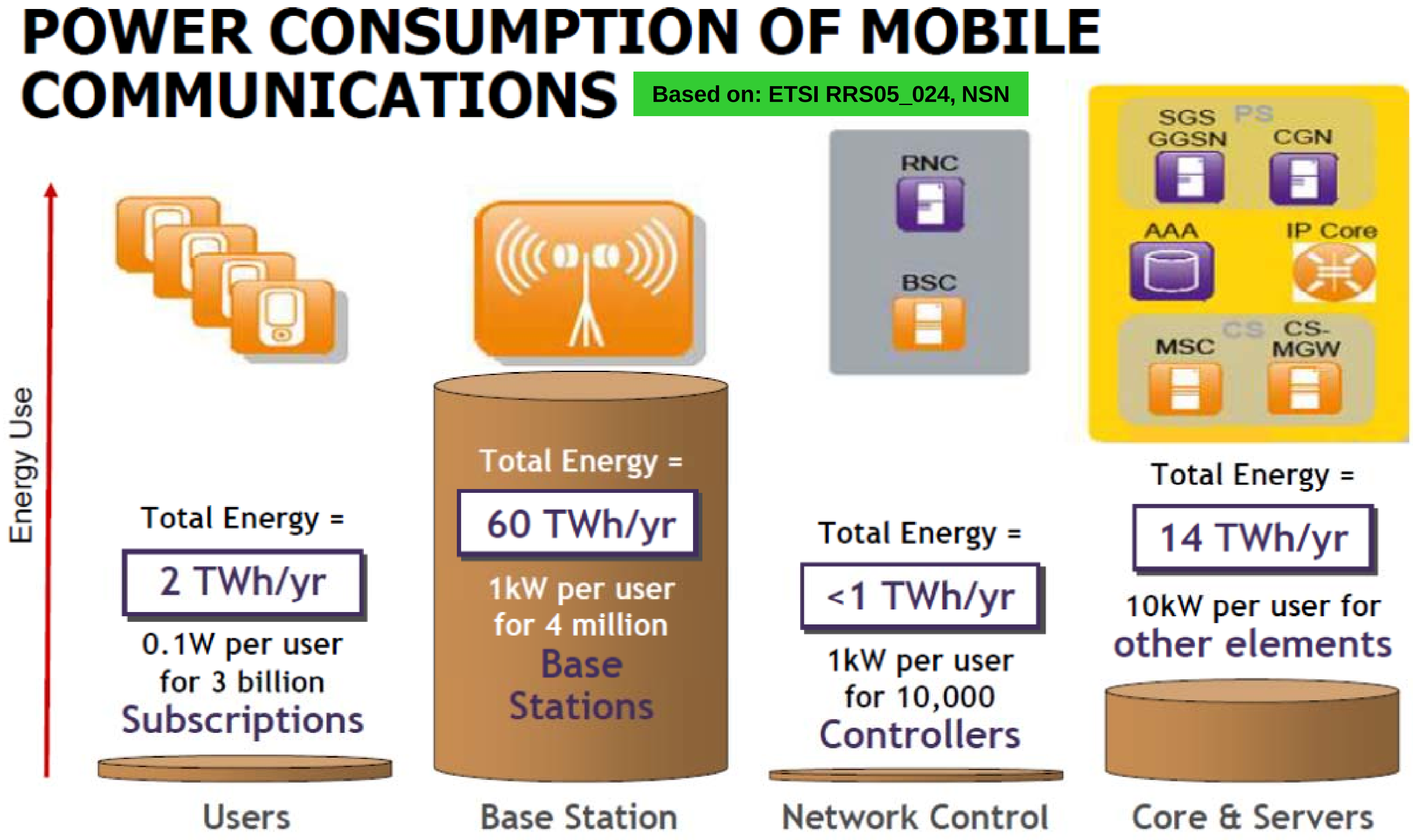
- **2009: Tour of Universities and Industrial partners, Green Radio was clearly a common interest.**
- **2010: Green Communications Leadership Forum at Huawei, Shanghai**

Continues to seed engagement opportunities in partnership with UKTI

RESEARCH COUNCILS UK

UC4G

Our Approach



The greatest opportunity to reduce energy was to focus on the *Radio Access Network* where the BS power consumption dominated

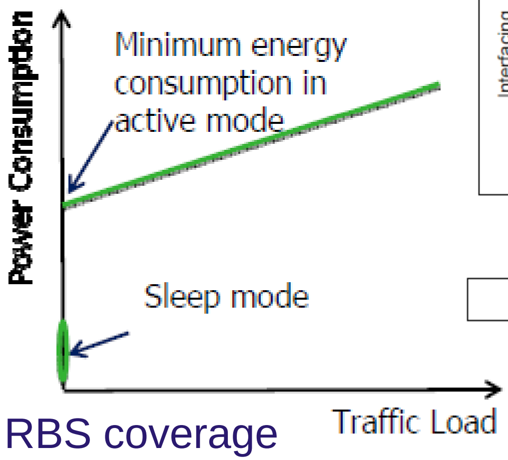
RBS Power Models

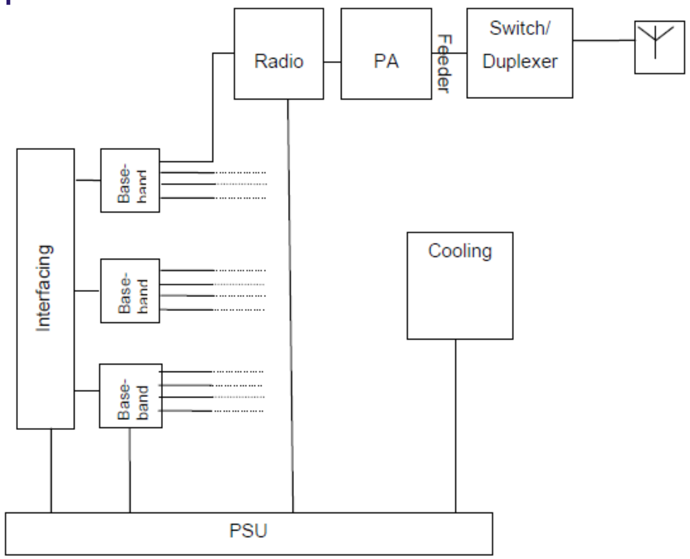
Developed base-station **Operational (OP)** power consumption model that is a function of:

- **Radiohead (RH)** power (Load ***L*** dependent)
- **Overhead (OH)** and **Backhaul (BH)** power (Load independent)

$$P_{OP} = N_a[\underbrace{\frac{P_{TX}}{\mu}L}_{\text{Radiohead}} + \underbrace{(P_{OH} + P_{BH})}_{\text{Overhead \& Backhaul}}]$$

No. Antennas



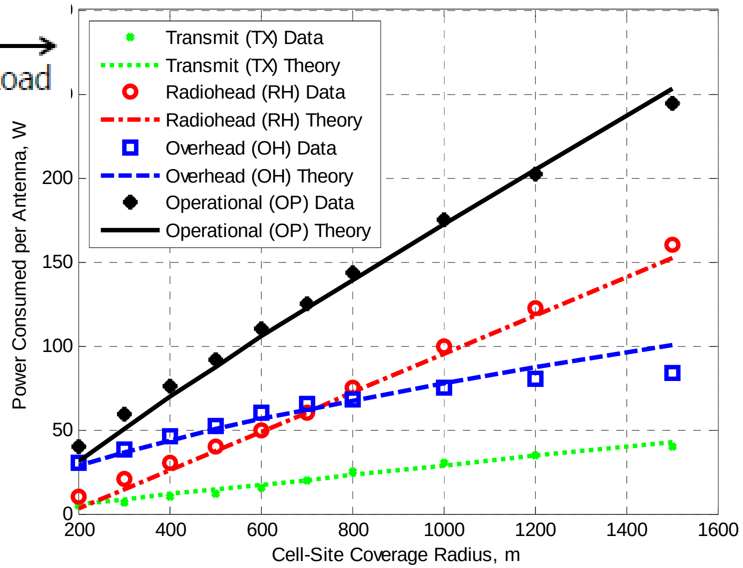


There is a relationship between the RBS coverage radius and the power consumption of the RBS:

- Power amplifier efficiency decreases with RBS size
- Overhead power varies slowly with RBS size
- Backhaul power is roughly constant

This yields an approximate empirical formula between operational power and coverage radius (***r***):

$$P_{OP} \approx N_a[0.1rL + (r^{0.62} + P_{BH})]$$



Achievement: Energy Metrics

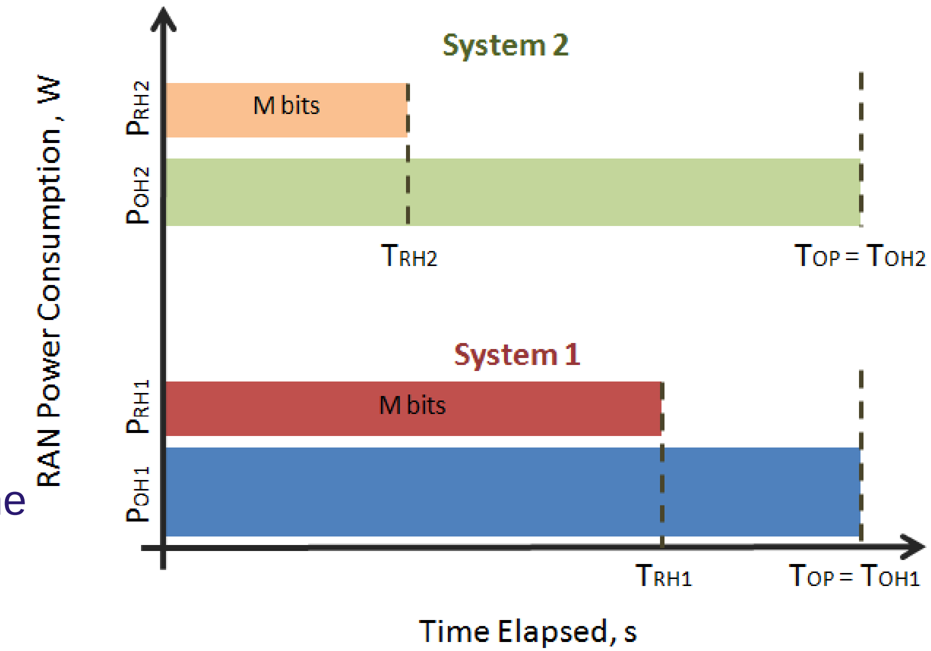
Energy (E) = Power (P) x Time (T):

$$E = P_{RH}T_{RH} + P_{OH}T_{OH}$$

ECR = Energy (E) / M bits delivered:

$$ECR = \frac{E}{M} = \frac{P_{RH}\dfrac{M/T_{OH}}{M/T_{RH}} + P_{OH}}{M/T_{OH}} = \frac{P_{RH}\dfrac{R}{C} + P_{OH}}{R}$$

where ***R*** is the *offered* ***traffic rate***, and ***C*** is the achievable ***system throughput***. ***R/C*** can be seen as the system ***load***, ***L*** (proportion of transmit period to total operational period).



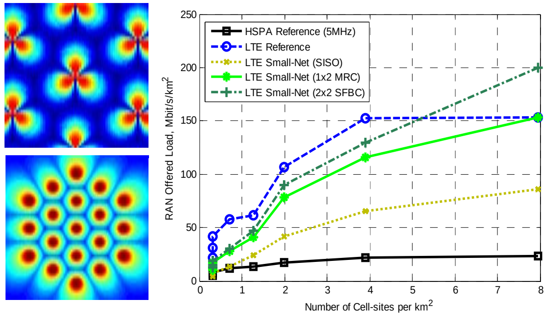
ECG = Sys 2 Energy (E2) / Sys 1 Energy (E1):

$$ECG = \frac{E_2}{E_1} = \frac{P_{RH,2}T_{RH,2} + P_{OH,2}T_{OP}}{P_{RH,1}T_{RH,1} + P_{OH,1}T_{OP}} = \frac{P_{RH,2}\dfrac{R}{C_2} + P_{OH,2}}{P_{RH,1}\dfrac{R}{C_1} + P_{OH,1}} = \frac{P_{RH,2}L_2 + P_{OH,2}}{P_{RH,1}L_1 + P_{OH,1}}$$

ERG = (1 – 1 / ECG) x 100%:

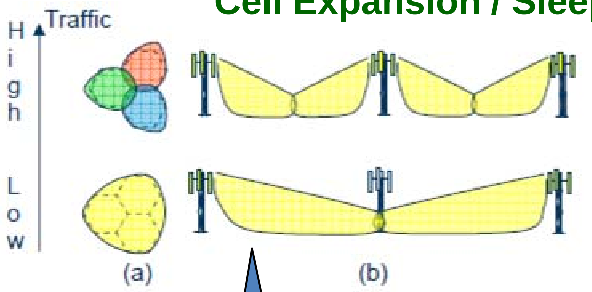
$$ERG = (1 - \frac{P_{RH,1}L_1 + P_{OH,1}}{P_{RH,2}L_2 + P_{OH,2}}) \times 100\%$$

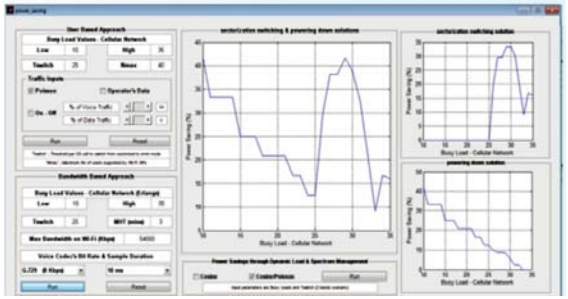
Architectures



Cell Size

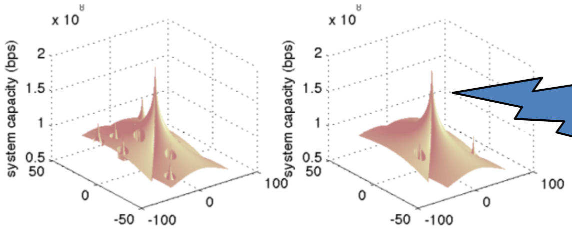
Cell Expansion / Sleep Mode



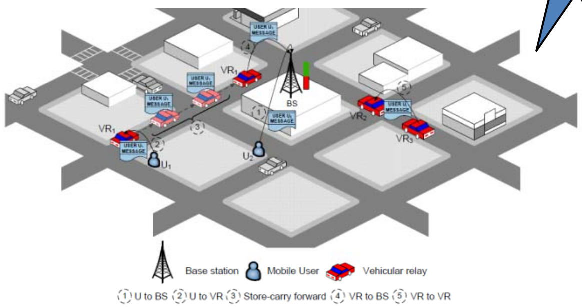


Traffic Off-loading to Wi-Fi

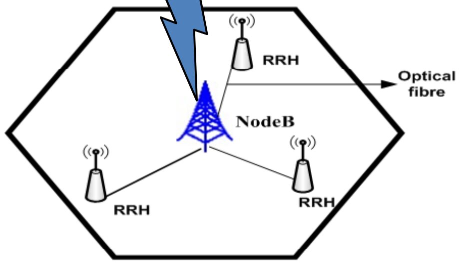
Architectures Research Approaches



Femto Cells



Mechanical Relaying



1. Distributed antenna system with 3 RRH in a single cell

Distributed Antenna System For Cell Edge Users

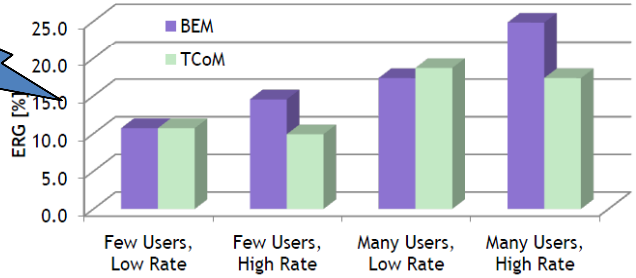


Fig 1. Theoretical gains from manipulating bandwidth

Bandwidth Expansion for High User Density

Techniques

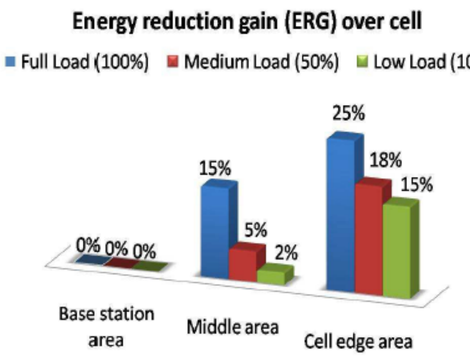


Fig.1: Average ERG for R-NC vs. HARQ in downlink LTE-A with different traffic load

Random Network Coding

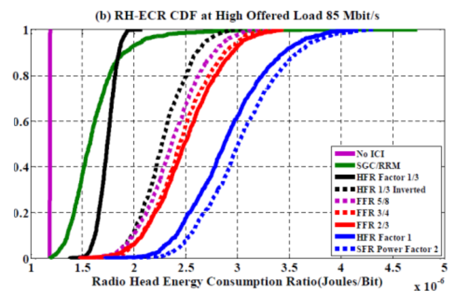
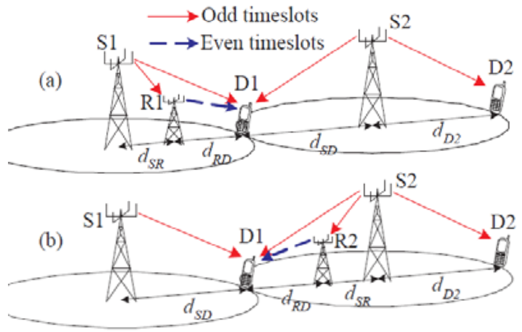
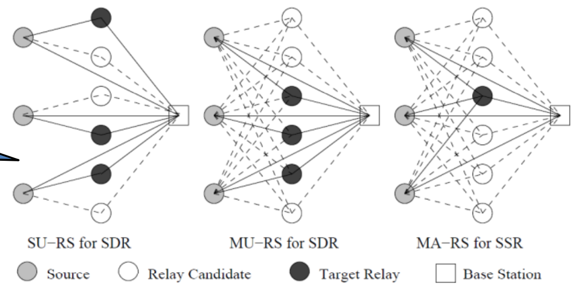


Figure 4. Radio Head Energy Performance

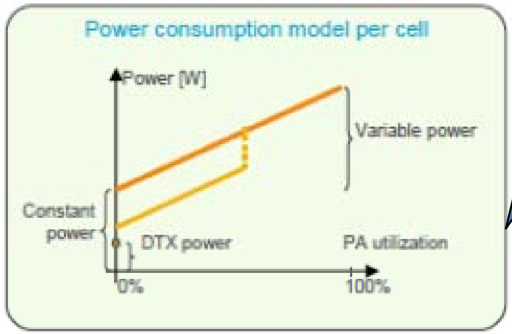
EE Scheduling



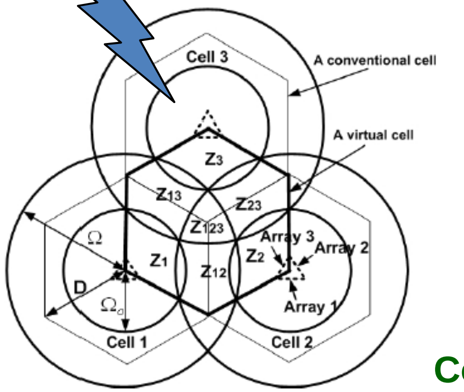
Interference Cancellation



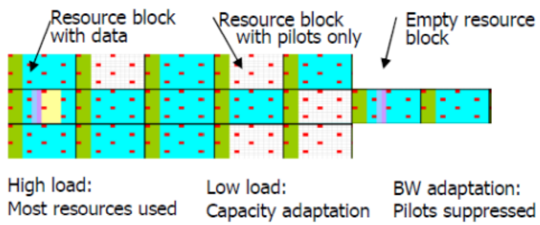
Cooperative Relaying and Backhauling



Power Amplifier Efficiency



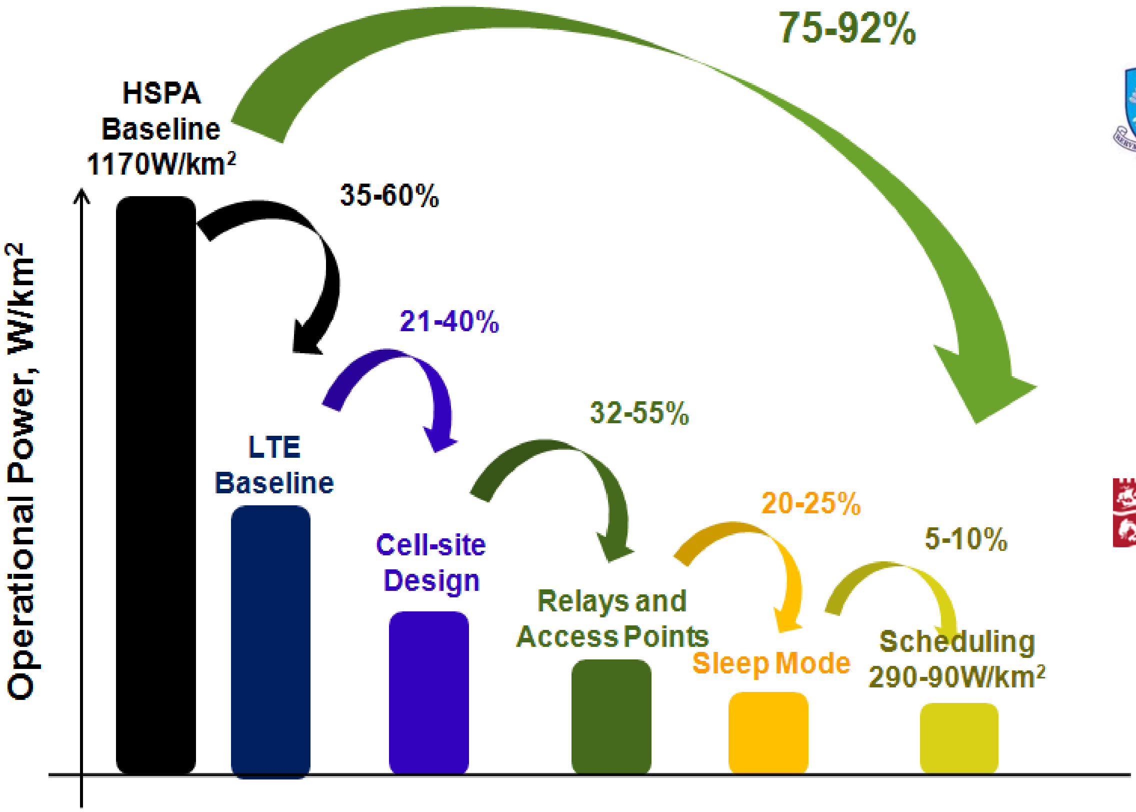
CoMP



Sleep-modes

Integration

- **No one solution cured all**
- **Three Integration Scenarios Investigated**
  - **Wide Area Macro**
  - **Enterprise – WiFi/Small Cell**
  - **Dense Urban HetNets**
- **Integration of Architecture and Techniques into a Green RAN saves 75-92% energy; and *economic costs evaluated***



The University Of Sheffield. — **Integration** Dynamic Cells, Sleep Mode, Interference Avoidance, Relaying, Indoor Network

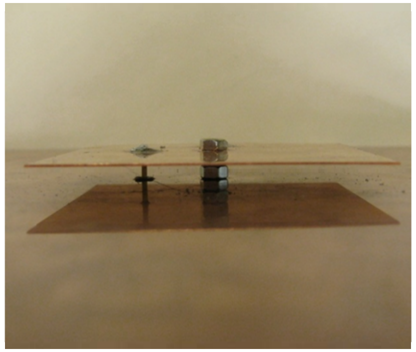
King's College London — Mechanical Relaying, Wi-Fi offloading.

University of Bristol — Hardware and Energy Efficient Scheduling

The University of Edinburgh — Femto-cell Deployment, sleep modes, 2 Layer Het-Nets

High efficiency Base Station antenna design for LTE

Suspended plate antenna showing 95% efficiency due to air substrate between patch and ground plane can serve as a reference.



New mechanical approaches to achieve wideband antennas

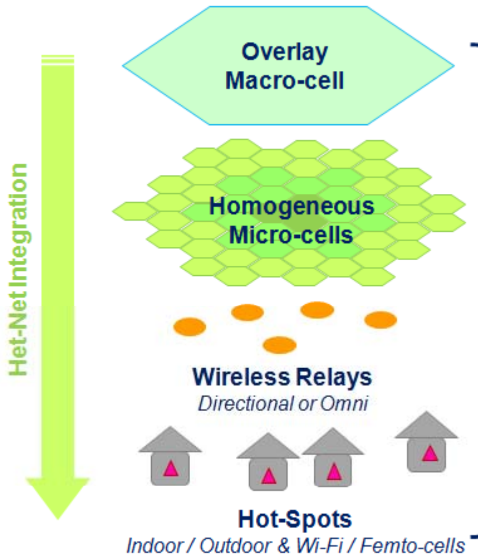
New Materials?

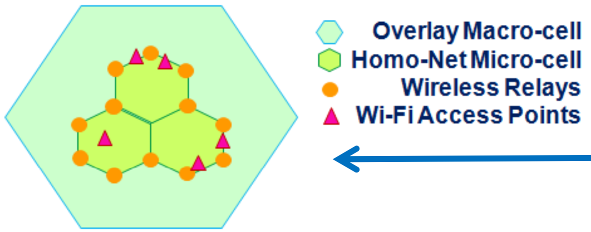
•Antenna efficiency varies significantly with the selection of dielectric materials.

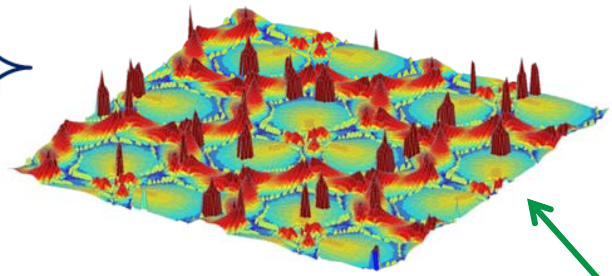
•Arlon and Duroid out performing FR4….but more expensive.

Dielectric \ Frequency(GHz)	2.15	2.4	5.25
	η	η	η
FR4 (ε_r =4.7)	29±2%	37±2%	55±2%
Arlon (ε_r =3.2)	56±2%	55±2%	93±2%
Duroid (ε_r =2.2)	83±2%	83±2%	95±2%
Air (ε_r =1)	reference	reference	reference

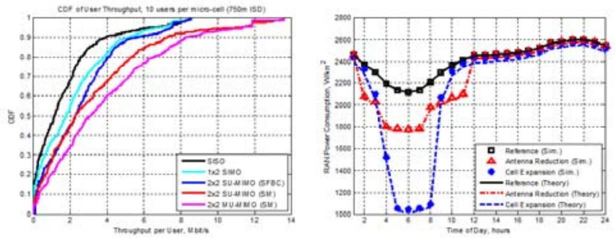
VCEsim

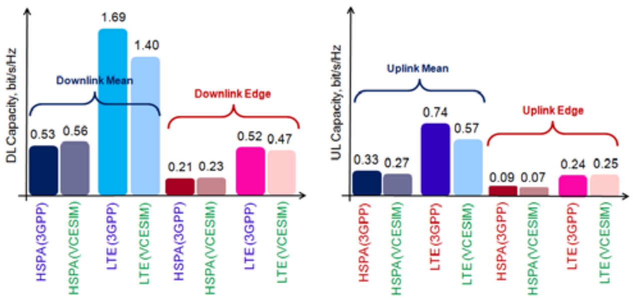


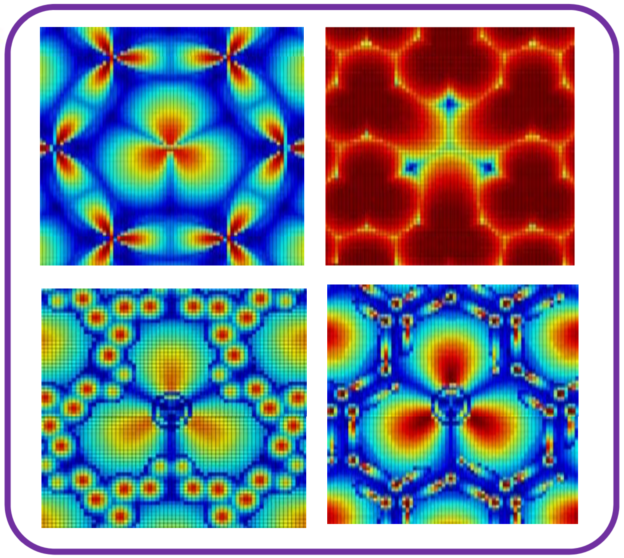




Het-Net with Relays and Indoor Wi-Fi







Heterogeneous RAN (wrap around)
2-hop RS, 802.11n AP, Femto-BS, Macro/Micro-BS, DAS/RRH

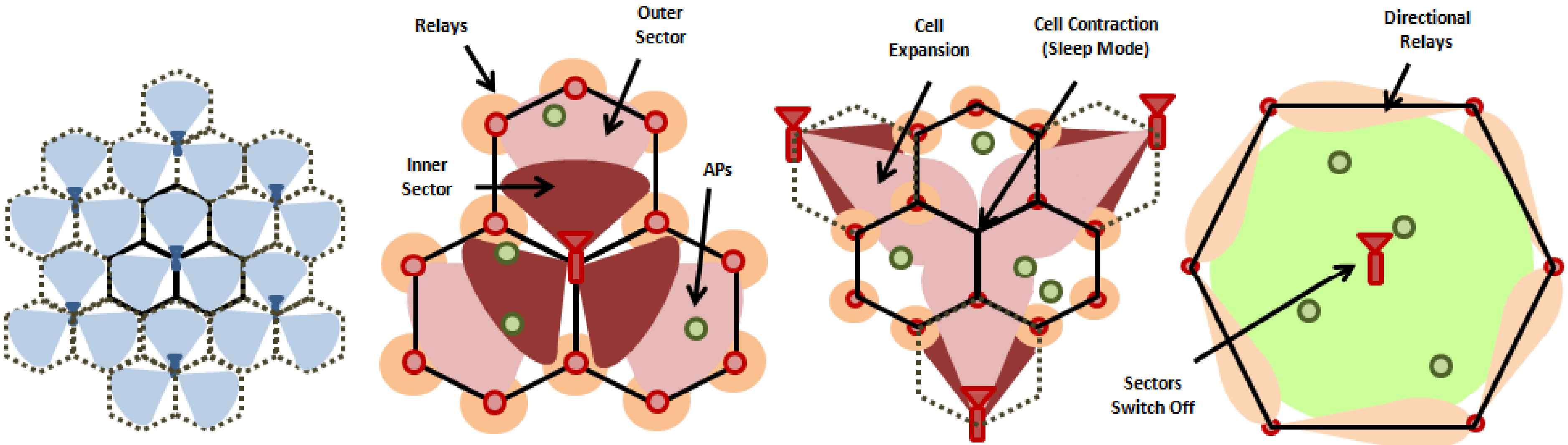
Dynamic Base-stations
Antenna beam tilt/pan/fan, Sleep Mode Management and Cell Expansion

Efficient Transmit Techniques
Interference avoidance, MIMO, Mechanical relaying, CoMP, PA Efficiency

Self-Organising
Dynamic Programming, Self-Organizing-Network (SON)

Geographic Specific Test Case
London Traffic and RAN model

Green RAN: Reconfigurable, Adaptable & Scalable

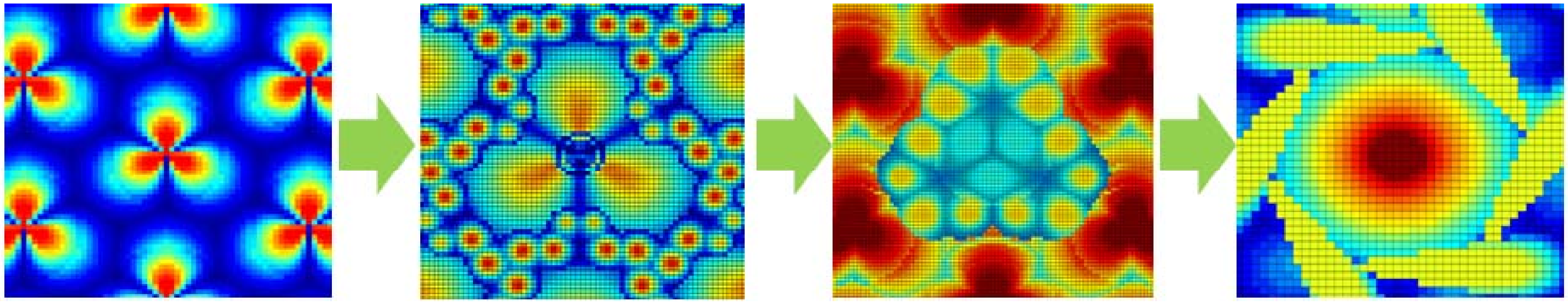


ISD: 750m
Capacity: 120Mbit/s/km^2

ISD: 2100m
Capacity: 120Mbit/s/km^2

ISD: 2100m
Capacity: 60Mbit/s/km^2

ISD: 2600m
Capacity: 20Mbit/s/km^2



HSPA/LTE Reference

Green LTE-A RAN (High Load 87% ERG to Low Load 92% ERG)
Also reduces 39-75% OPEX

Conclusions

- A reconfigurable, adaptable & scalable RAN to support changing loads
- Integration and antenna/radio densification are driving principles
- Overhead and Backhaul energy consumption remain limiting factors

Achievements

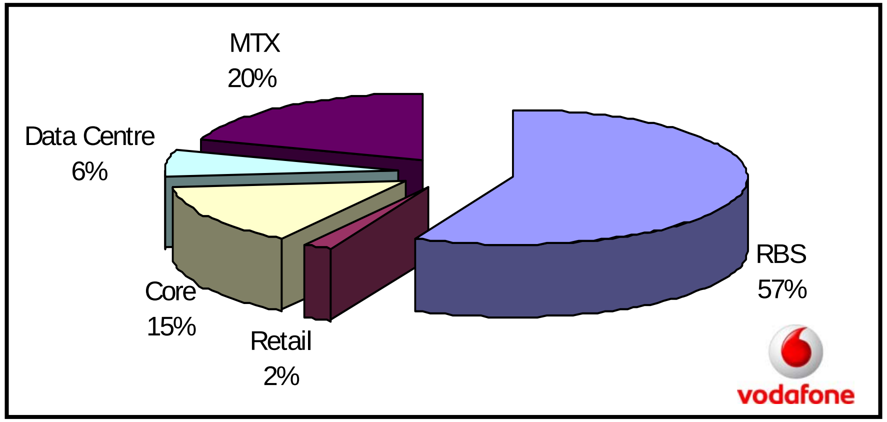
- On average, 10x energy reduction
- Leading edge research (PA, Network Coding, Mechanical Relay, Stochastic Geometry…)
- VCEsim – open source system level simulator, currently validating for a London case

Green Radio is now established as a rapidly expanding research field.

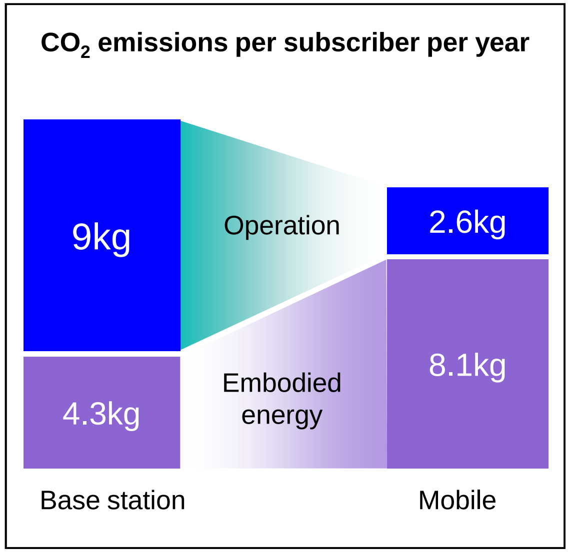
Emerging Opportunities…….

Two types of Energy

- **Operating energy**
  - Energy expended over the operational lifetime of the product (part of Opex).



- **Embodied energy**
  - Energy used in raw material extraction, transport, manufacture, assembly, installation of a product or service including disassembly, deconstruction and decomposition.



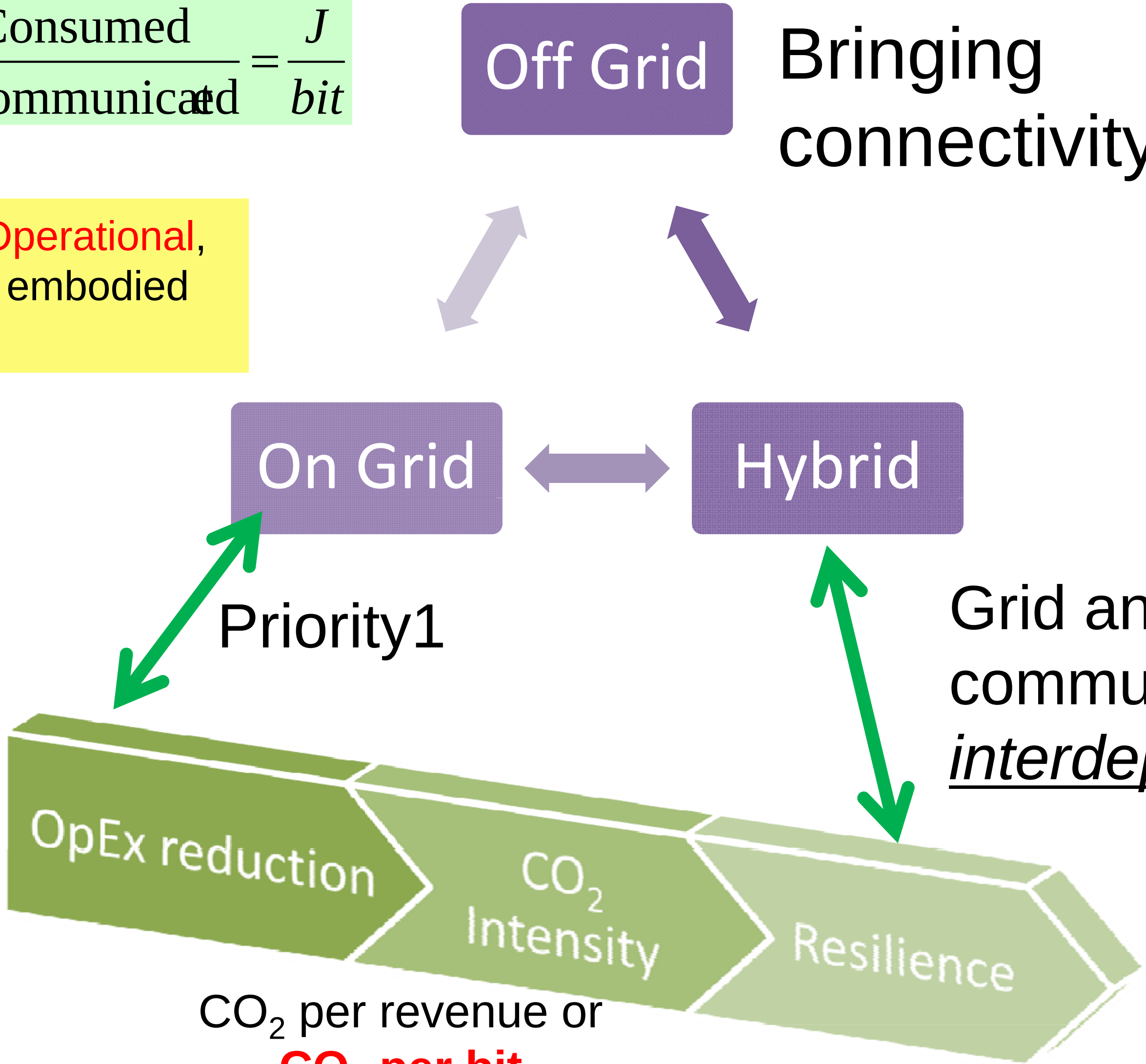
In VLSI devices the embodied energy can be 2.5 – 3 times the operating energy, recycling helps

Connectivity - Design for Sustainability
Portability of GreenTech Innovations

$$ECR = \frac{EnergyConsumed}{DataBitsCommunicated} = \frac{J}{bit}$$

Quantified as RF, Operational, and Total (includes embodied energy)

Bringing connectivity to all



Grid and communications *interdependence*

Business Drivers

CO_2 per revenue or **CO_2 per bit**

TARGETED INNOVATIONS

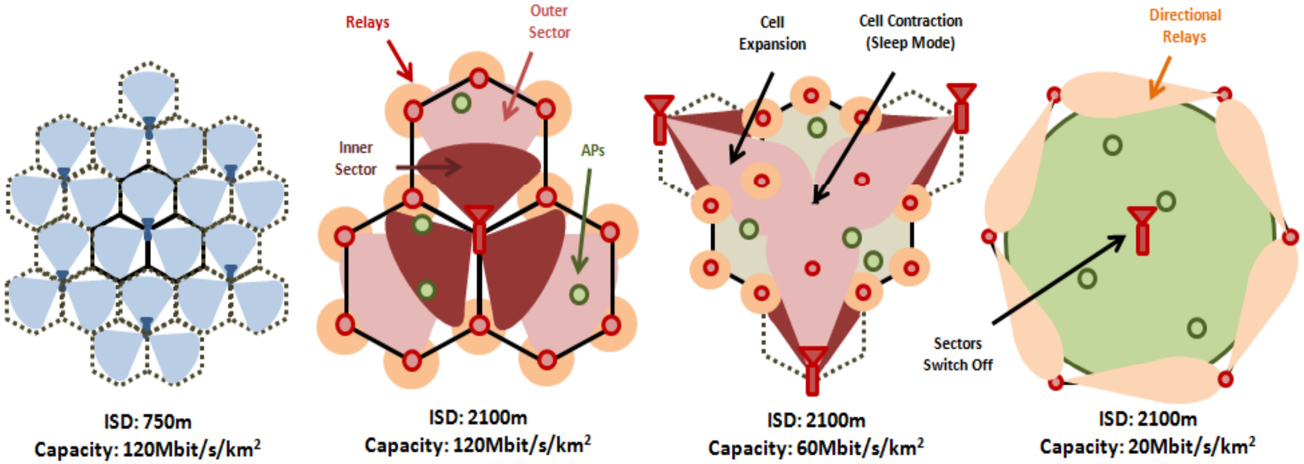
- Techniques for Optimization of a Limited Energy Budget

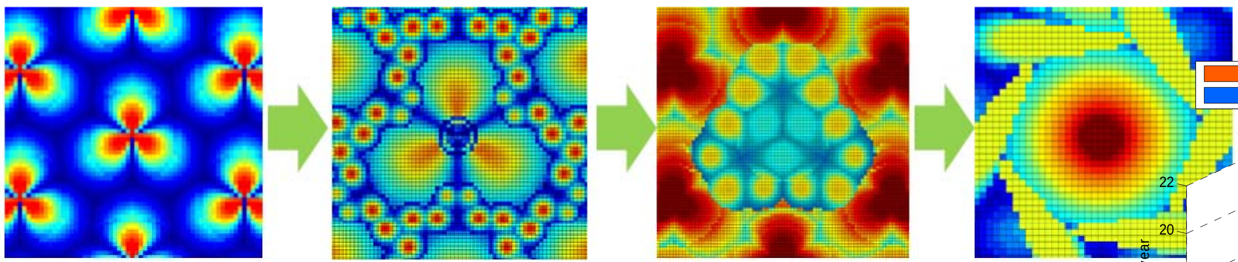
Given a base station nominal daily energy requirement derived from renewable energy sources (eg 2.4 kWh - 100W x 24hrs) to determine how this would be best used for communication

- Backhaul Architectures

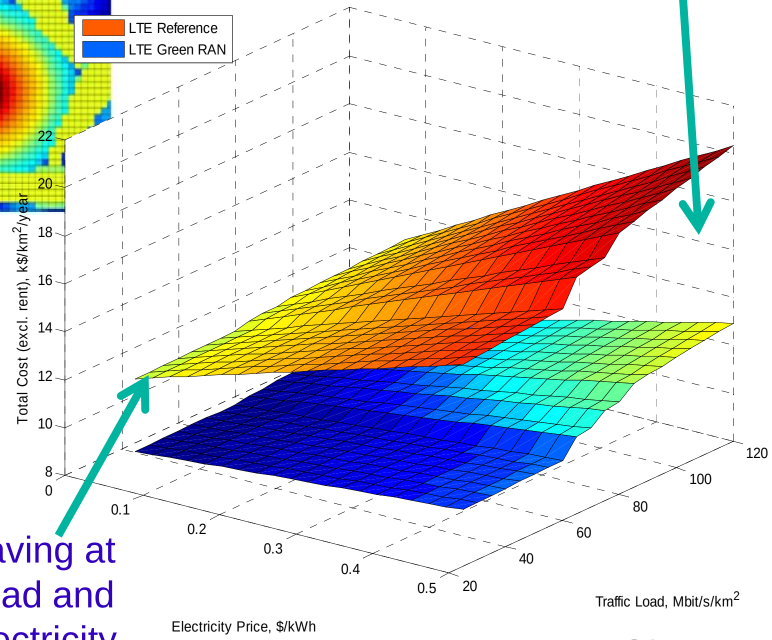
To determine the best backhaul strategy for a given architecture

Economic Study of Green Radio
Integration of Architecture and Technique Principles





Max. Saving at High Load and High Electricity Prices.

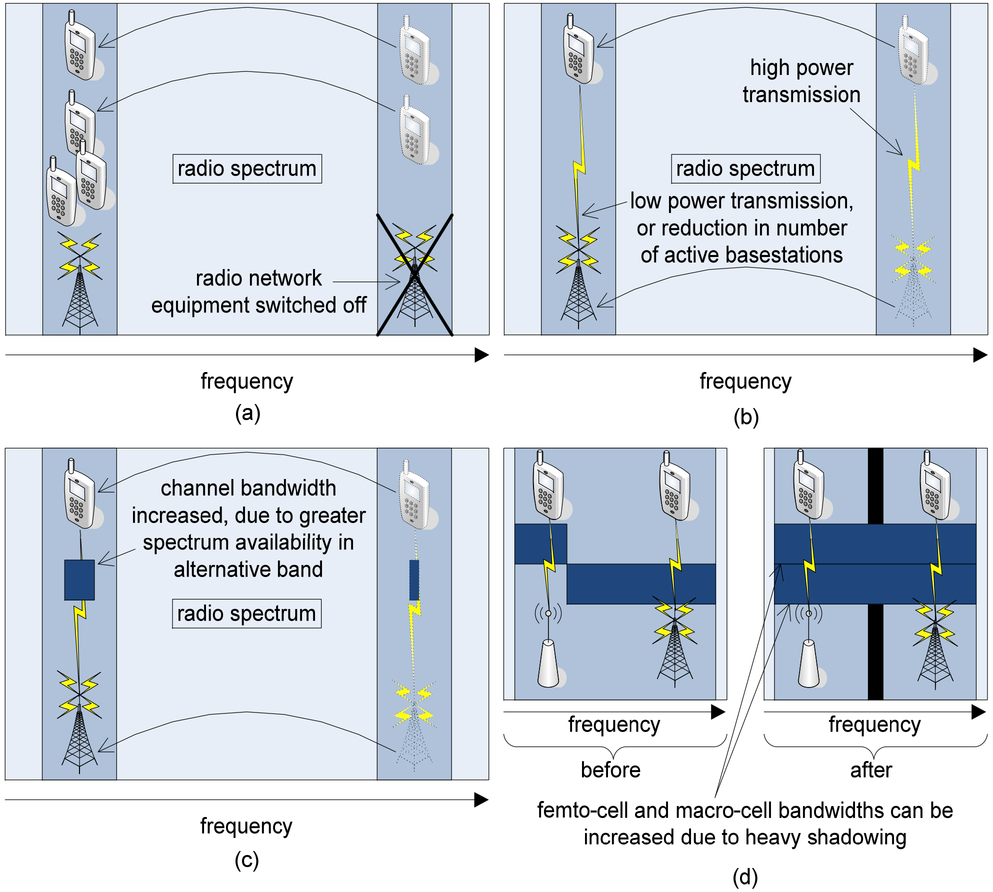


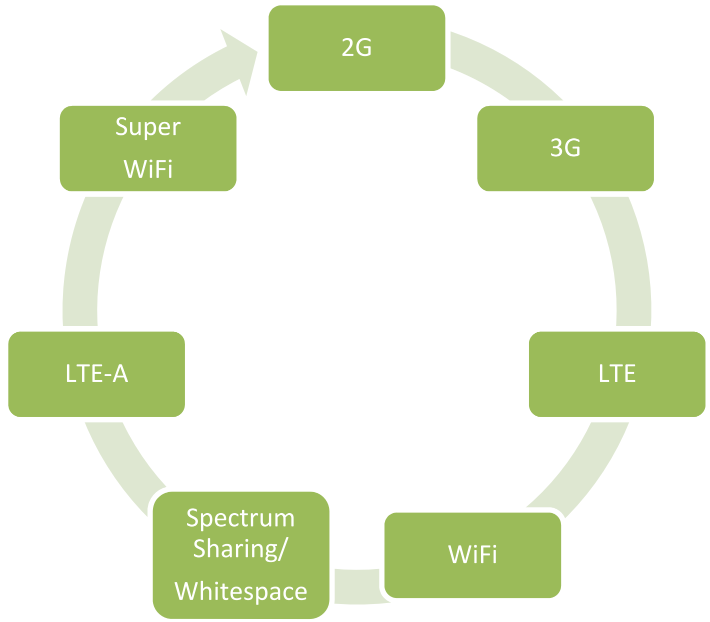
Min. Saving at Low Load and Low Electricity Prices

Managed appropriately smallcells will improve J/bit metric, but further study of the economic aspects would be beneficial.

Move closer to real deployment modelling

Dynamic intra-operator cross-band spectrum management (network/spectrum sharing)





- power down selected radio equipment
- take advantage of band with superior propagation characteristics
- **increase channel bandwidths**
- **Improve the hierarchical spectrum management.**

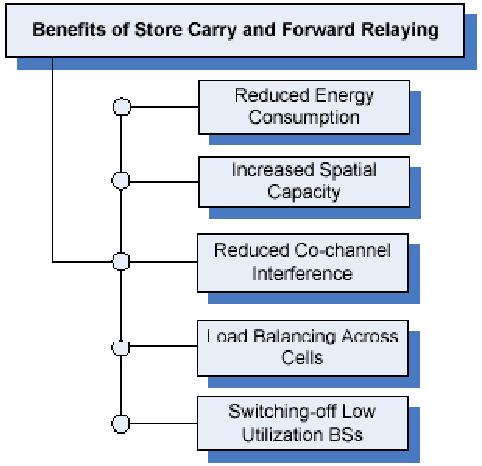
Carrier-off during quiet periods is deployed in networks today.

Can we further expand and refine efficient network protocols – across ALL RATs?

Traffic Management

Store-Carry Forward (SCF), Mechanical Relay, Delay tolerant networking, etc.

For some services reductions in energy consumption can be achieved by delaying communication for preferable transmit locations.

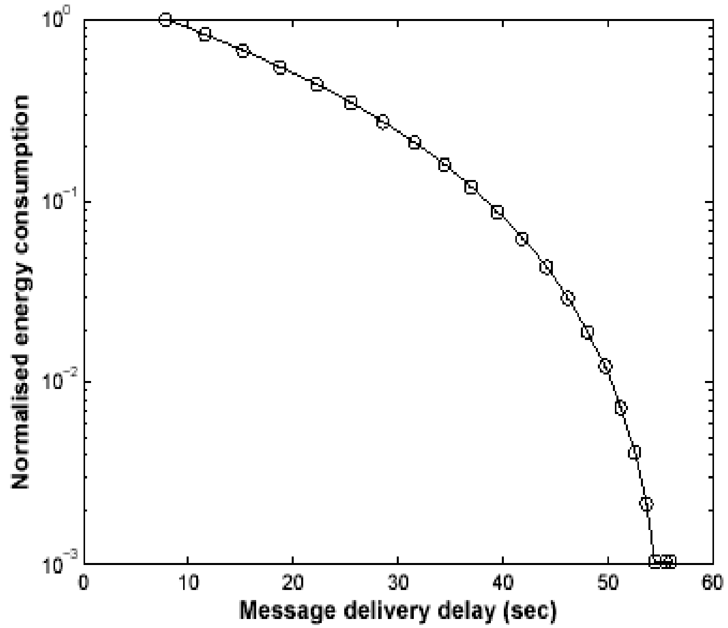


signalling overheads?

Which applications can tolerate U-Plane delays, and how much?

How to tame chatty and non-J/bit friendly smart phone apps?

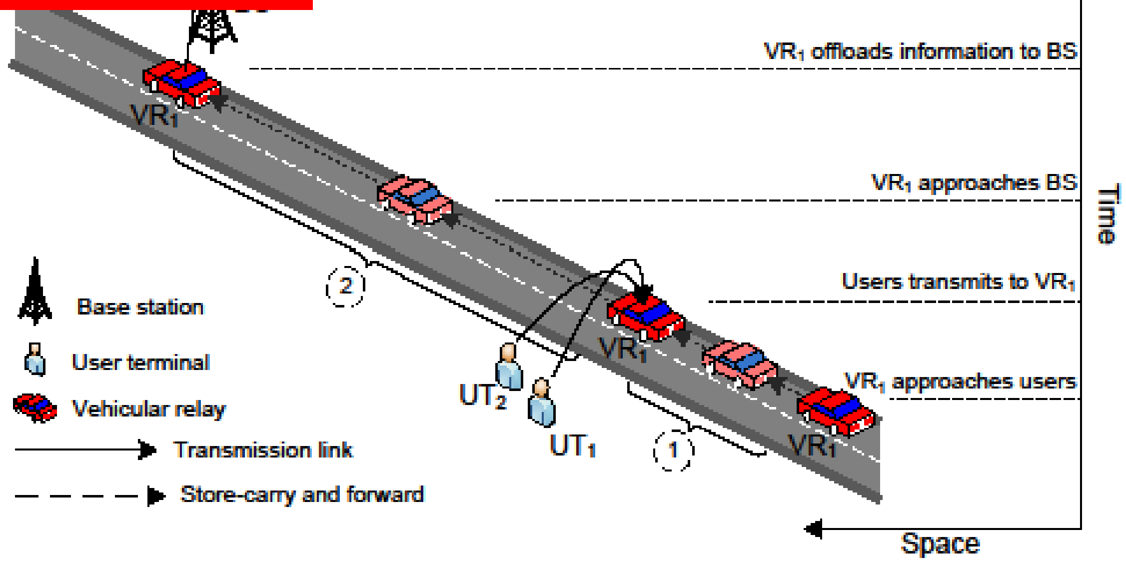
Backhauling options




Meet Clarence, the homeless, walking, talking wi-fi hotspot

Will Pavia New York

The Times: 13.03.2012



Opportunities for new Research

- **Protocols and protocol stacks that are efficient in a system where nodes are powering on and off at relatively high frequency (sleep modes)**
- **Backhaul power reduction (we can’t always assume fibre)**
- **Mobile devices are back to 1day charge cycle….need to extend.**
- **Reverse innovation – off-grid only solutions and hybrid not fully addressed yet.**
- **How to “densify” the RAN with more antennas/radios – small cells vs high-order MIMO vs relays……..efficient “RF”**
- **HetNets/Edge RAN/Cloud RAN – flexible spectrum, SON, virtualisation & co-location**
- **Is there a fundamental theory of network energy efficiency of equivalence to network information theory.**
- **Reduce overheads to gear energy harvesting**

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