"Towards Green Techniques for Wireless"

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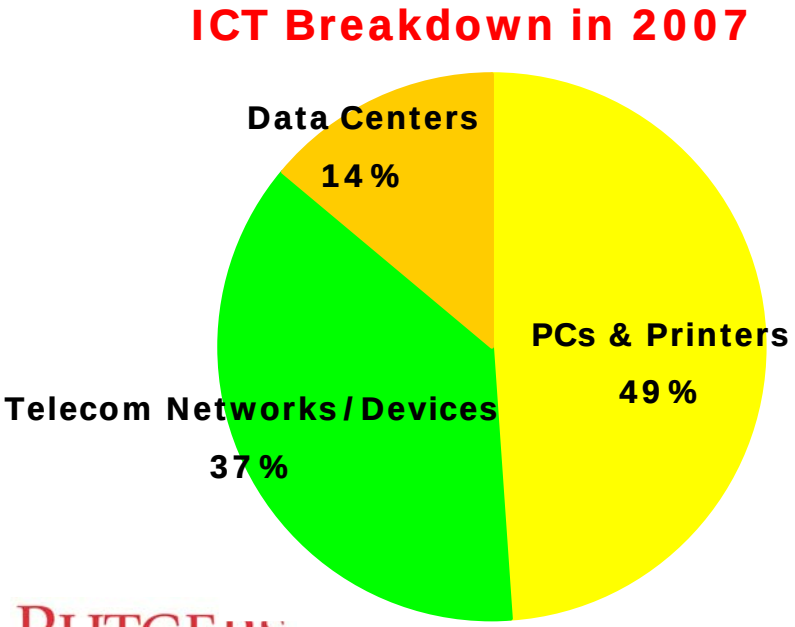
Mobile/Cellular Systems: Green Outlook?

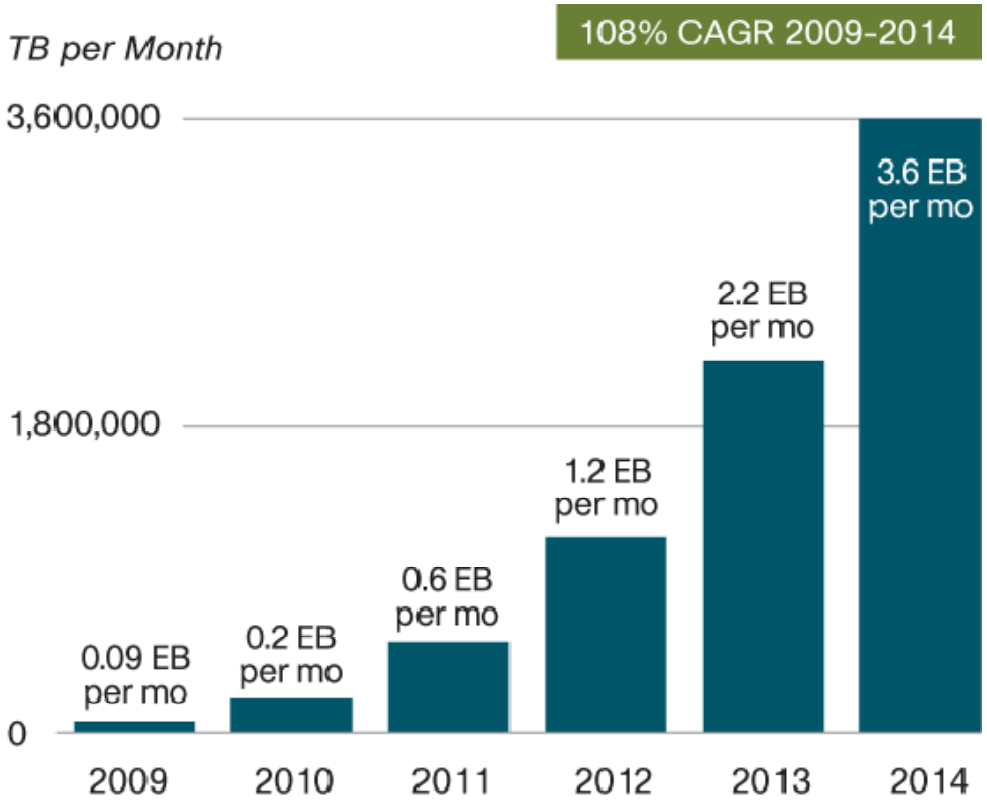
- Carbon footprint of ICT industry ~ 2-4% of human carbon footprint
  - PCs, printers, telecom networks/devices, data centers
- ~ 25% of all car emissions
- ~ equal to airplane emissions



Should we bother with Green Wireless?

Mobile/Cellular Systems: Wireless Data?

- Data volume doubling annually!
  - 3G, 4G, LTE-Advanced rollout, WiFi
  - Reported 5000% increase in mobile traffic in last 3 years



3.6 ExaBytes/month in 2014

1 EB = 10^{18} Bytes

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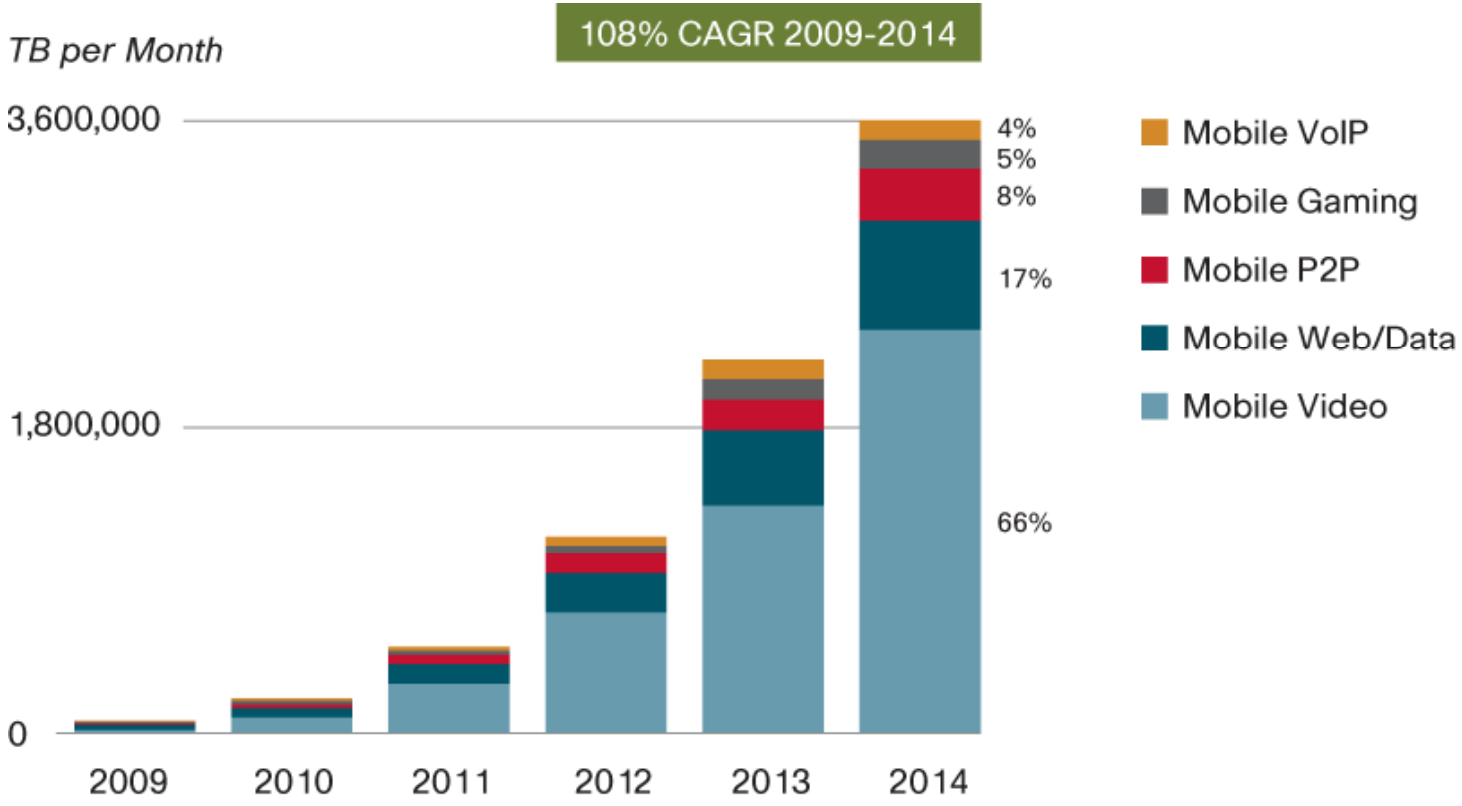
Mobile Video Growth

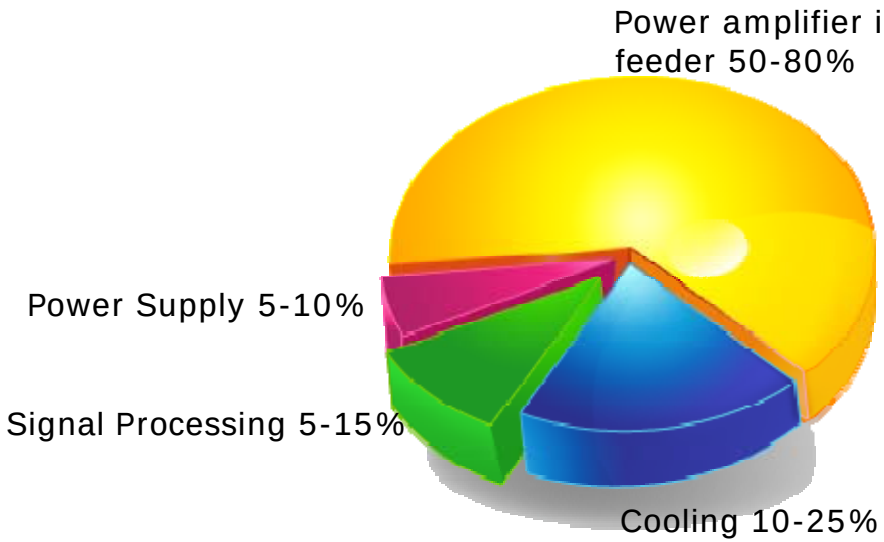
- Mobile video ~ 66% of volume
  - Smart phones, iPAD, etc.
  - Social networking



Source: Cisco VNI Mobile, 2010

Power Consumption in Cellular

- 80% of total power in cellular systems is consumed at the base stations

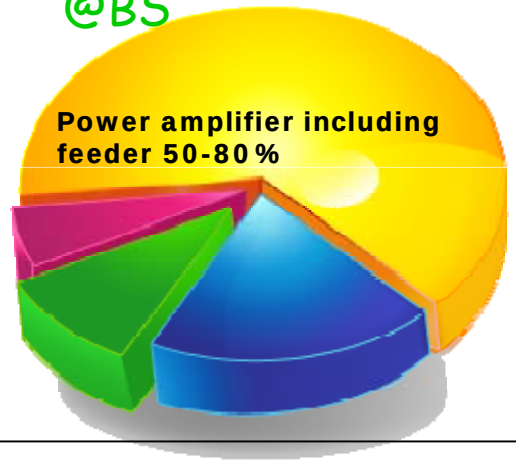


80-80

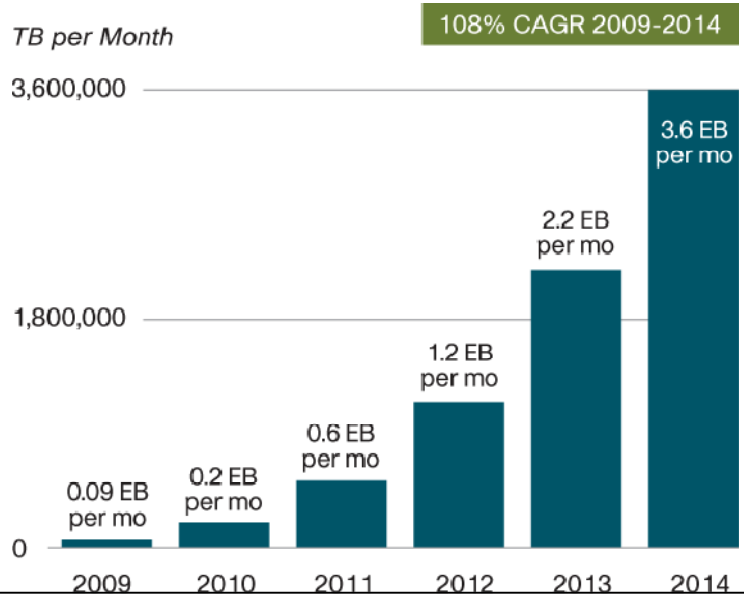
Source: *"EARTH research project", U. Barth, Alcatel-Lucent Bell Labs, Stuttgart*

Case for Green Wireless?

- Evidence at hand
  - ICT industry ~ 2- 4% of human carbon footprint
  - 80-80 energy costs @BS



  - Pervasive computing
  - Sensor networks
  - Cyber-physical systems
  - Growth of wireless data



Should we bother with Green Wireless?

We reserve the right to remain Energy Efficient!

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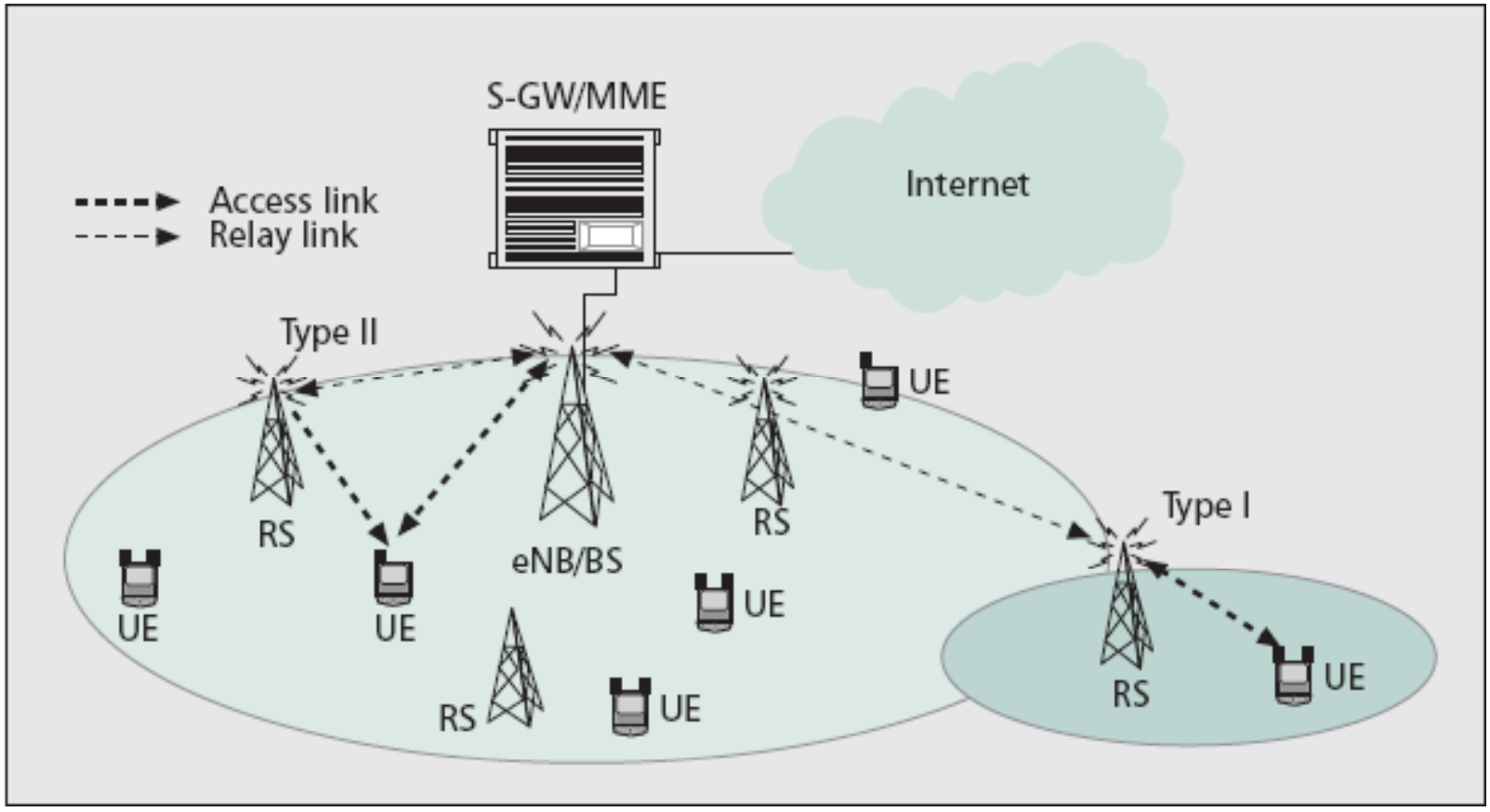
What can Relays do?

- Can relays reduce 80-80 energy costs?

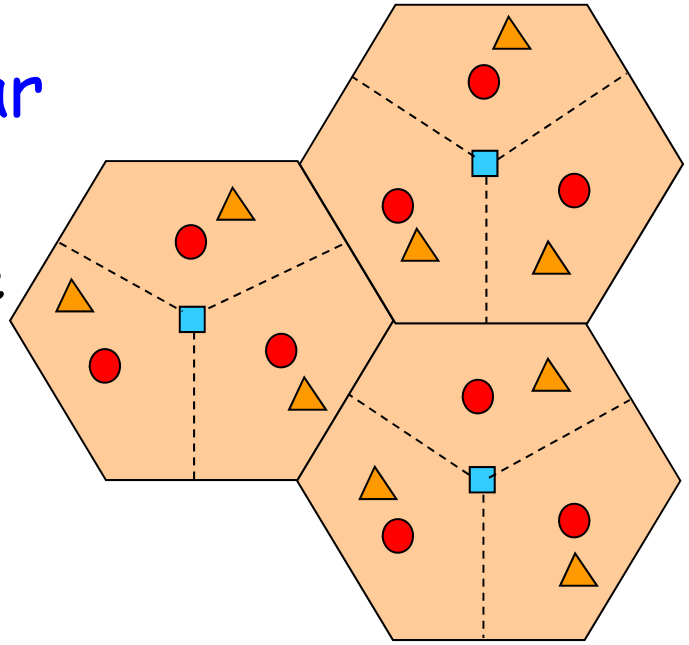


Reference : " Relay Technologies for WIMax and LTE-A Relaying Systems", IEEE Commun. Mag. Oct 2009

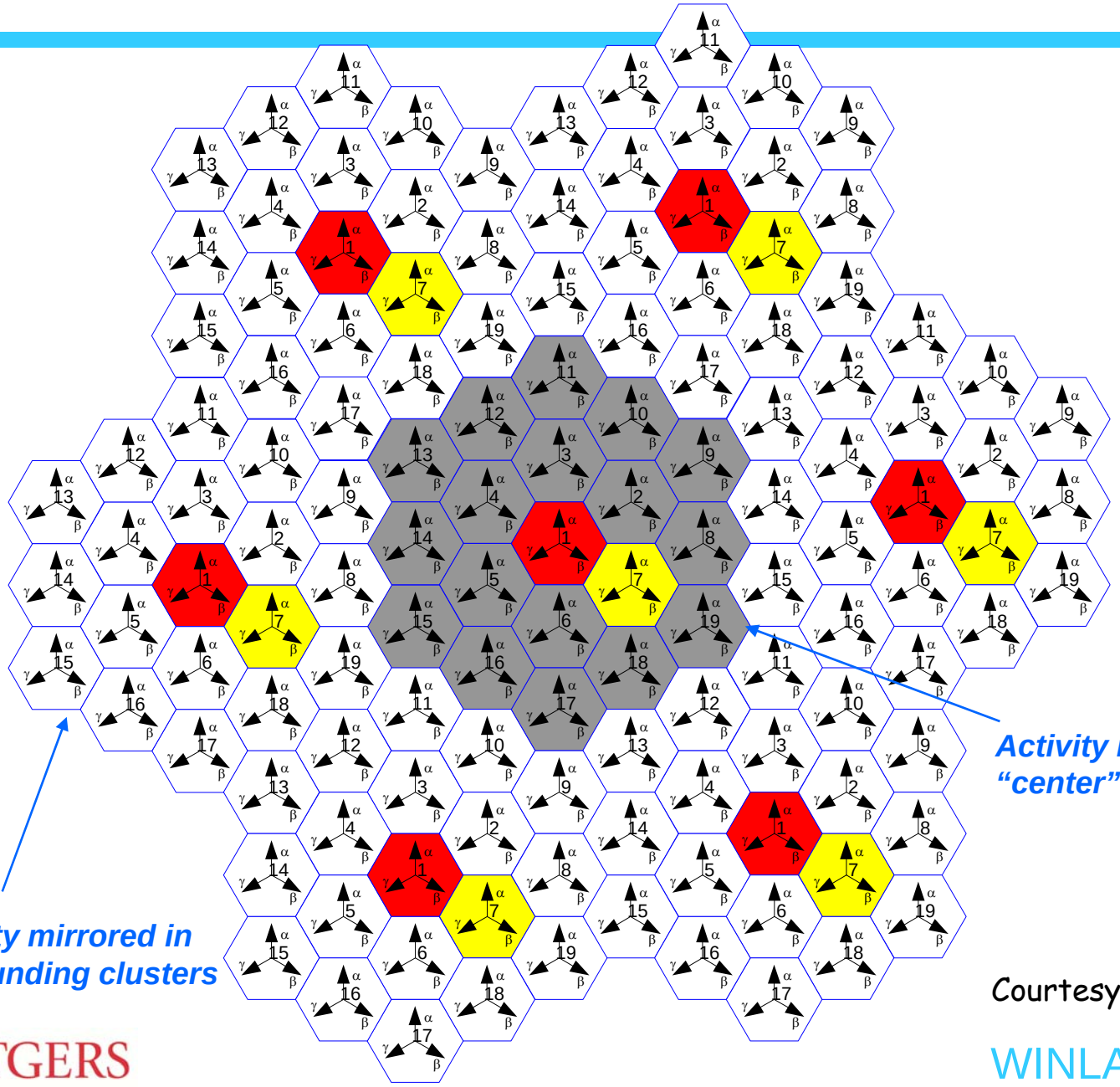
Reducing Power via Downlink Relaying

joint work with C. Raman, R. Yates, G. Foschini, R. Valenzuela
WINLAB, Rutgers & Bell Labs, Alcatel-Lucent

- Do relays help in (interference limited) cellular systems?
  - PRO – effective power gain due to reduction in distance-based attenuation
  - PRO – diversity benefit due to relay transmissions
  - CON – increase in effective interference due to in-band relay transmissions



Hexagonal Cell Layout with Wraparound



Activity in all sectors of "center" cluster

Activity mirrored in surrounding clusters

Courtesy: WiMax Forum

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Power Savings with Relays

SCENARIO: 57 sectors, one relay per sector, one user per sector. Base station and relays transmit just enough power to maintain uniform rate using power control.

Peak power required to guarantee 1 bps/Hz @ 10% outage Base station only (No relays)	Peak power required to guarantee 1 bps/Hz @ 10% outage Base station with relays	Savings in dB
10 W	5.5 W	2.6
Common rate for 90% users Base station only (No relays)	Common rate for 90% users Base station with relays	Percentage rate increase
1 bps/Hz	1.35 bps/Hz	35%

Avg savings in total energy : 3 dB

Marginal Utility of Bandwidth vs Power ?

- Power and bandwidth limited systems
- What does information theory tell us?

Shannon Capacity

$$C = W \log_2\left(1 + \frac{P^t}{N_0 W}\right)$$

$$\left.\frac{\partial C}{\partial P^t}\right|_{P^t \to 0} = \frac{1}{N_0 \log 2}$$

Marginal gain with Power

$$\left.\frac{\partial C}{\partial W}\right|_{W \to 0} = \infty$$

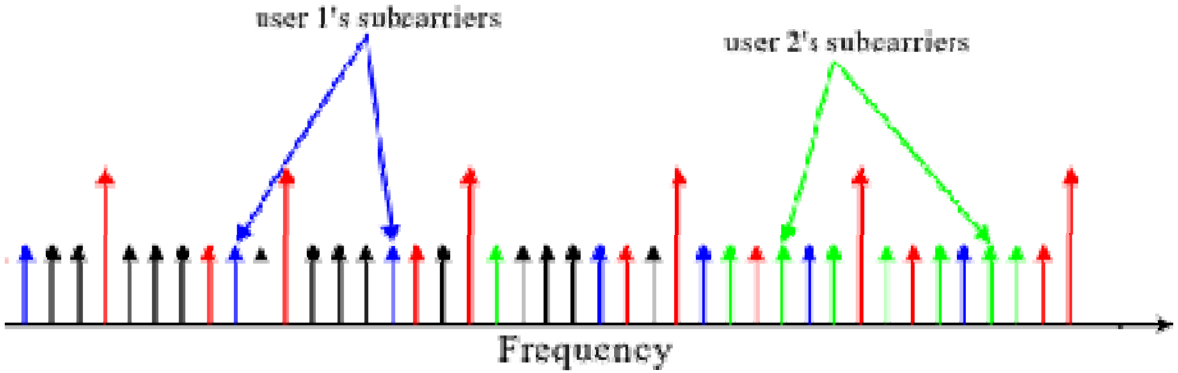
Marginal gain with BW

Bartering bandwidth is more efficient

Bandwidth Exchange in OFDMA

joint work with D. Zhang, R. Shinkuma
WINLAB, Rutgers and Kyoto University

- Non-contiguous OFDMA
  - Enables effective direct exchange of orthogonal bands

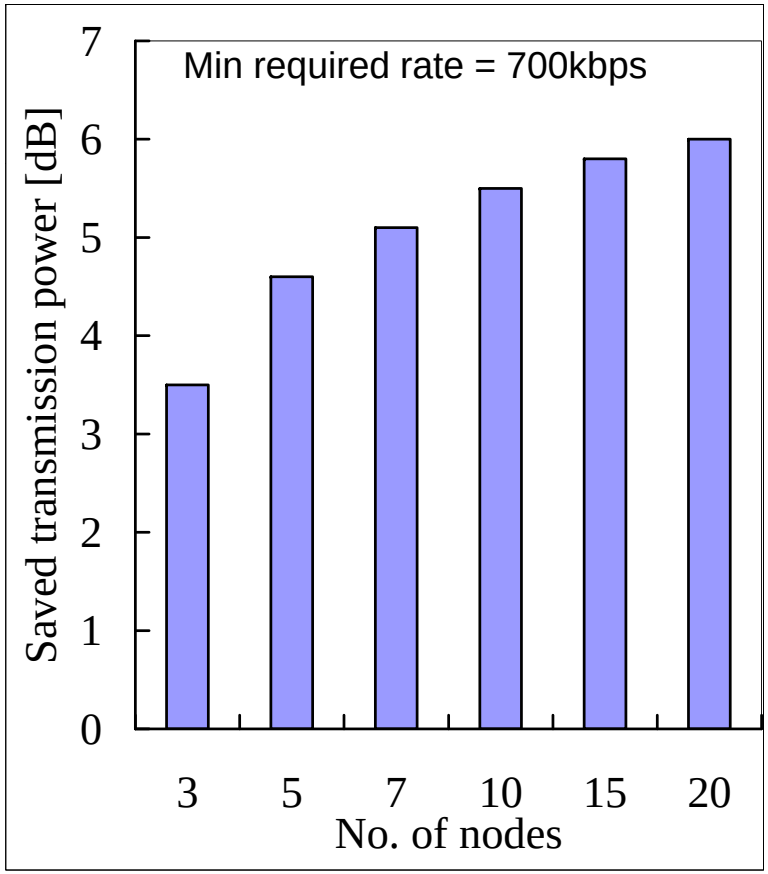


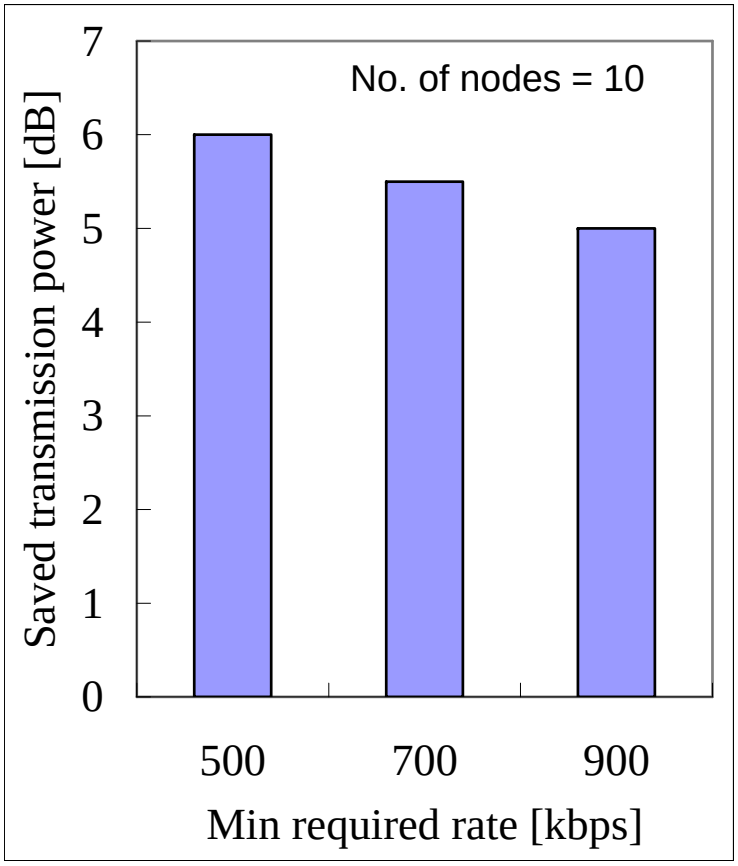
- Alternate implementations
  - Delegate time slots
  - Use spreading codes of different length
  - Use different backoff parameters

Transmit Power Savings via BE

- Keep outage probability ~0.1

- Required Tx power for NoBE [dBm]- Required Tx power for BE with NBS [dBm]





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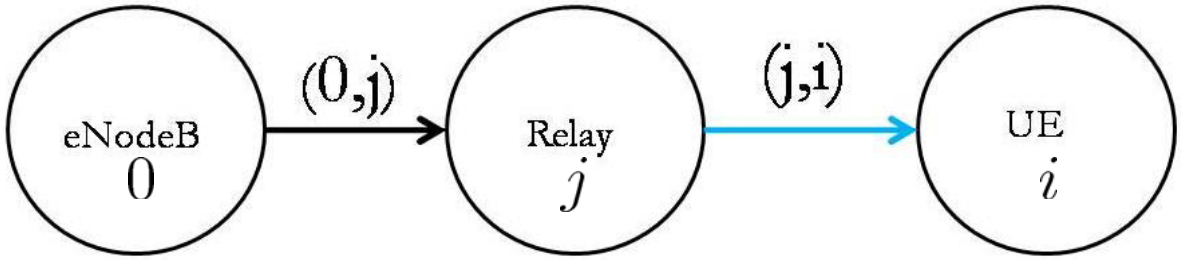
Bandwidth Sharing in LTE-A Relaying

joint work with C. Raman, R. Yates
WINLAB, Rutgers

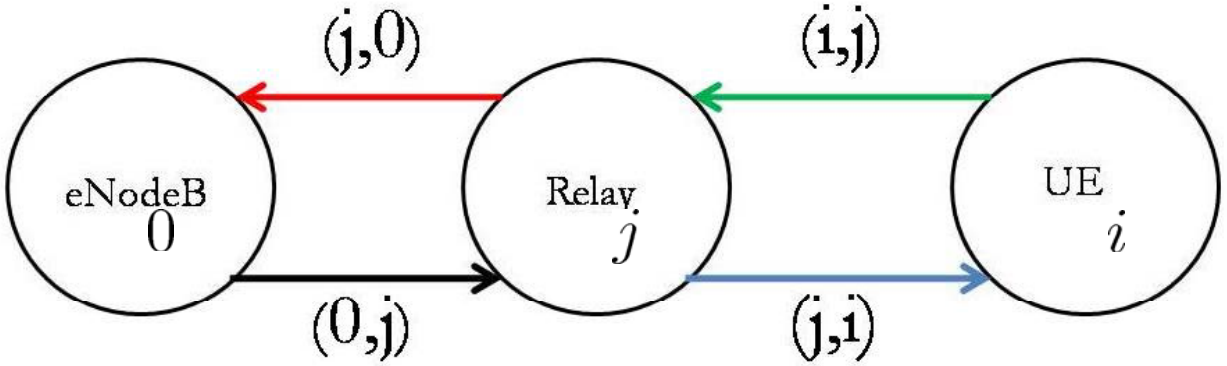
- Relays aid eNodeB and UE in forwarding data.
- Type - I Relays
  - Extends coverage beyond service range of eNodeB
  - Provides wireless backhaul to remote areas.
  - Access link between eNodeB to UE not used.
- Type - II Relays
  - Improve service quality and link capacity.
  - Uses the access link between eNodeB and UE.
- What if node/relay can flexibly share bandwidth?

Two Scenarios for Type-I Relaying

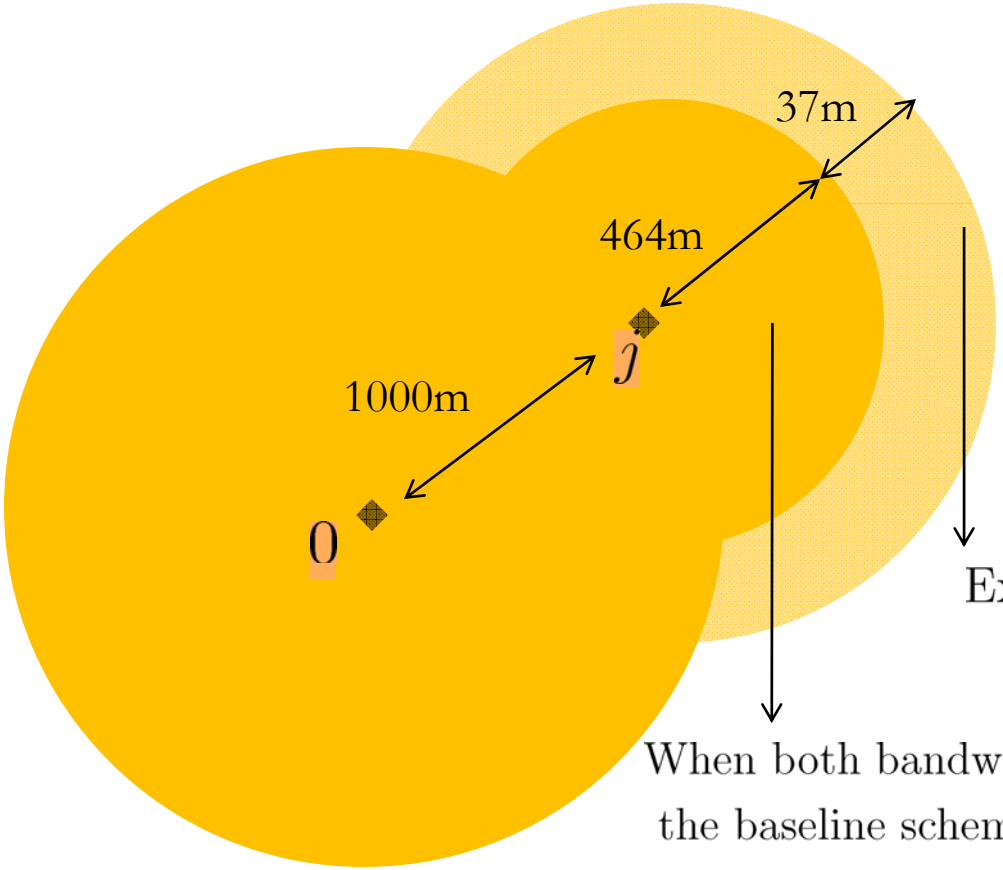
- We consider two scenarios
  - Case I - No uplink data for UE i



  - Case II – UE i has uplink data as well to send



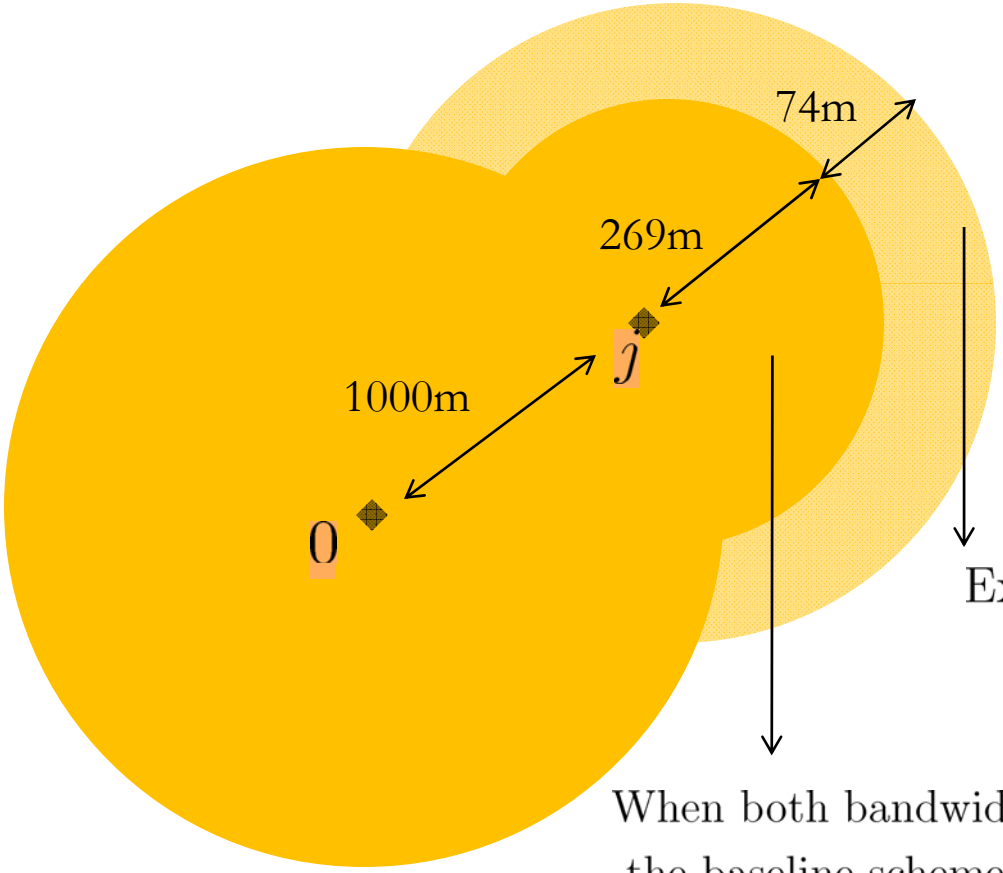
Case I: Coverage Area Improvement



Extends coverage area to UE i

When both bandwidth sharing and the baseline scheme is feasible sharing consumes $2.5dB$ less power

Case II: Coverage Area Improvement

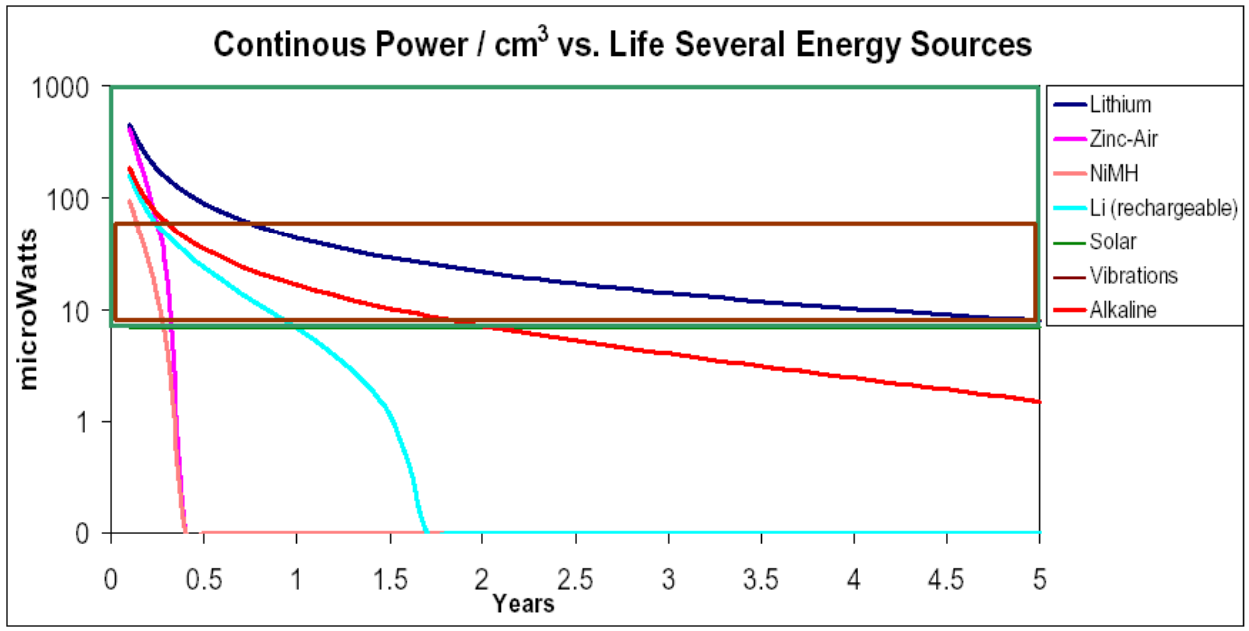


Extends coverage area to UE i

When both bandwidth sharing and the baseline scheme is feasible sharing consumes $3dB$ less power

Rechargeable Networks: Optimal Retransmission Policies

Jing Lei, Zhuo Chen, Roy Yates



Picture Courtesy of S. Roundy, UC Berkeley

- Energy replenishment rate is stochastic and environment-constrained
- Rechargeable battery has a long life but its energy should not be abused
- Message transmission carries different rewards

Our goal is to maximize the average reward rate by selective transmission .

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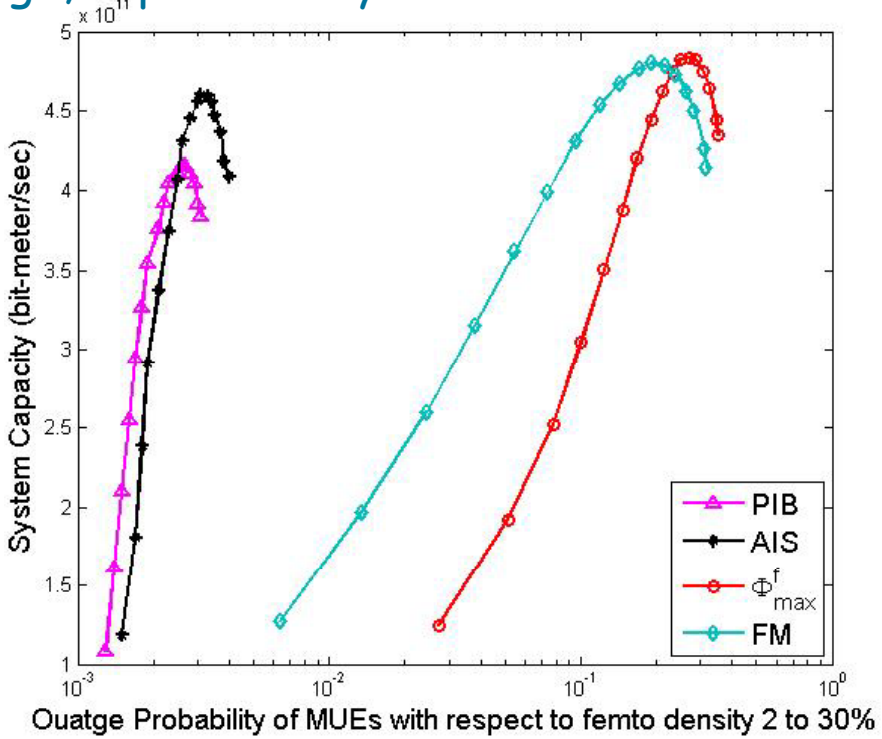
Adaptive Geo-location Based Interference Control for Hierarchical Cellular Network with Femtocells

Shweta Sagari, Gautam Bhanage, Dipankar Raychaudhuri

Interference mitigation strategies:

- Proximity Based Iterative (PBI) scheme
- Adaptive Interference Scaling (AIS) scheme
  - Avoids over-the-air interference estimation by using geo-location information and backhaul signaling
  - Both the schemes initiated by MBS



- Femtocell density above 20%: degradation in system capacity for all schemes due to large increased in femtocell interference

Other Directions: Recycling?

- Estimated ~200M mobile devices disposed of or decommissioned annually
  - Advances in wireless technology lead to upto ~3M mobile devices becoming "unwanted" every week (avg. life of cell-phone ~18 mo)
  - > 500M unused cell phones in U.S. alone!

- Lots of challenges and opportunities in new materials for wireless devices, batteries, etc.

Source: *"Wireless Logic" http://www.wireless-logic.com*