GreenTouch Open Forum, Seoul, Korea, 8 April, 2011

TANGO: Traffic-Aware Network Planning and Green Operation

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Network Integration for Ubiquitous Linkage and Broadband (NiuLab)

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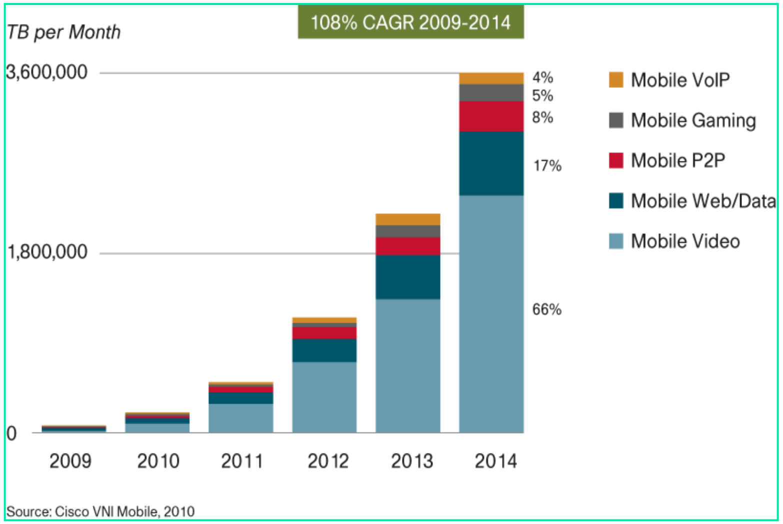
Content

- **Why and What's GREEN?**
  - ***Grand Challenge of Mobile Communication in 2020***
  - ***GREEN: Globally Resource-optimized and Energy-Efficient Networks***
- **Paradigm Shift to GREEN**
  - ***TANGO: Traffic Aware Network planning and Green Operation***
  - ***CHORUS: Collaborative & Harmonized Open Radio Ubiquitous System***
- **Dynamic Cell Planning for GREEN**
  - **Energy-aware network planning with inter-cell cooperation**
- **Self-Organization for GREEN**
  - **Cell Zooming and Dynamic BS Sleeping Control**
- **Conclusion**

Mobile Communication in 2020

- **All objects will be connected**
  - **Trillion's wireless devices *(mobile things)***
  - ***Traffic will increase by 100-1000 times***
- **Mobile data/video will dominate**
  - **Mobile Internet booms**
  - **Smart phones with DTV reception**
- **Personalized services**
  - **1G (80s) → 2G (90s) → 3G (00s) → 4G (10s) → mG? (20s)**
  - **mG = MY (*personalized*) services?**

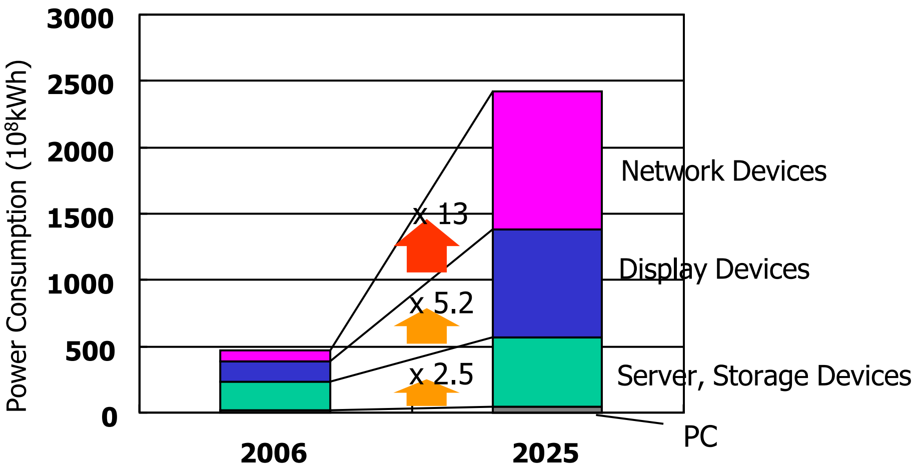
Trillion's Wireless devices



Global Mobile Traffic Forecast by Cisco

But, energy consumption is a grand challenge

- ICT's energy consumption ~ Global aviation industry (No.5)
  - world population is expected to reach 9.15bn in 2050
- China is the largest ICT market in the world
  - 860m mobiles and 450m Internet users, 300m mobile Internet users (2010)
  - penetration rates are only 67% (mobile), 33% (Internet)
- Chinese operators consumed 29bn KWh! (2009), 25% up than 2008
  - 6.4bn'06 → 8.1bn'07 → 9.4bn'08→11.2bn'09 (China Mobile)
  - 5.4bn'06 → 6.0bn'07 → 6.9bn'08 → 9.8bn'09 (China Telecom)
  - Total #BS > 1.3m, while 3G users is only 47m

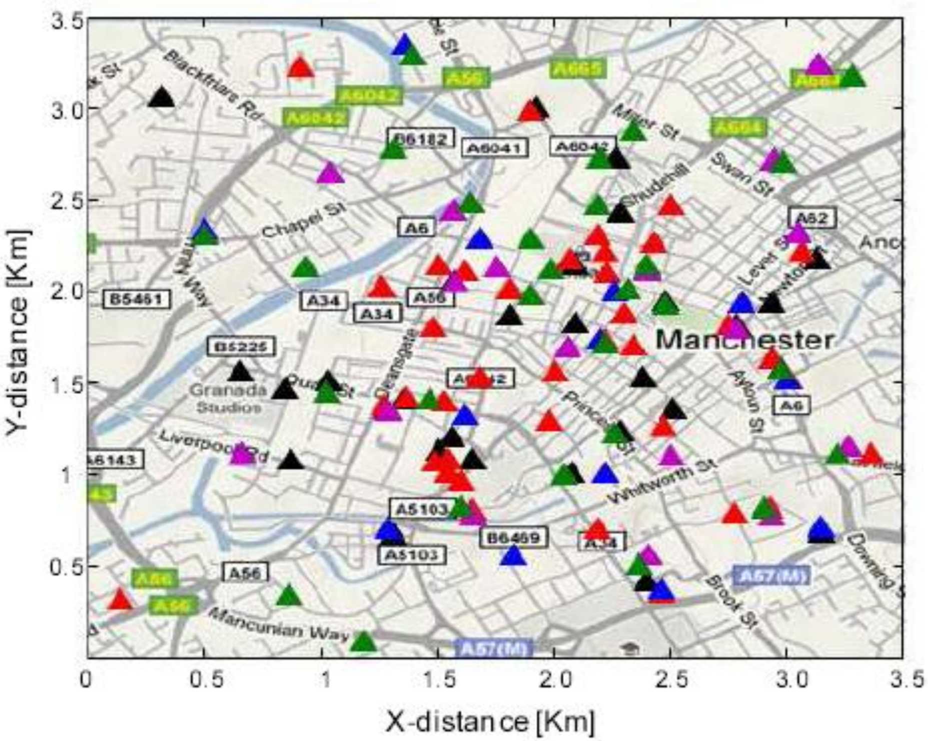


Power Consumption by IT Devices in Japan

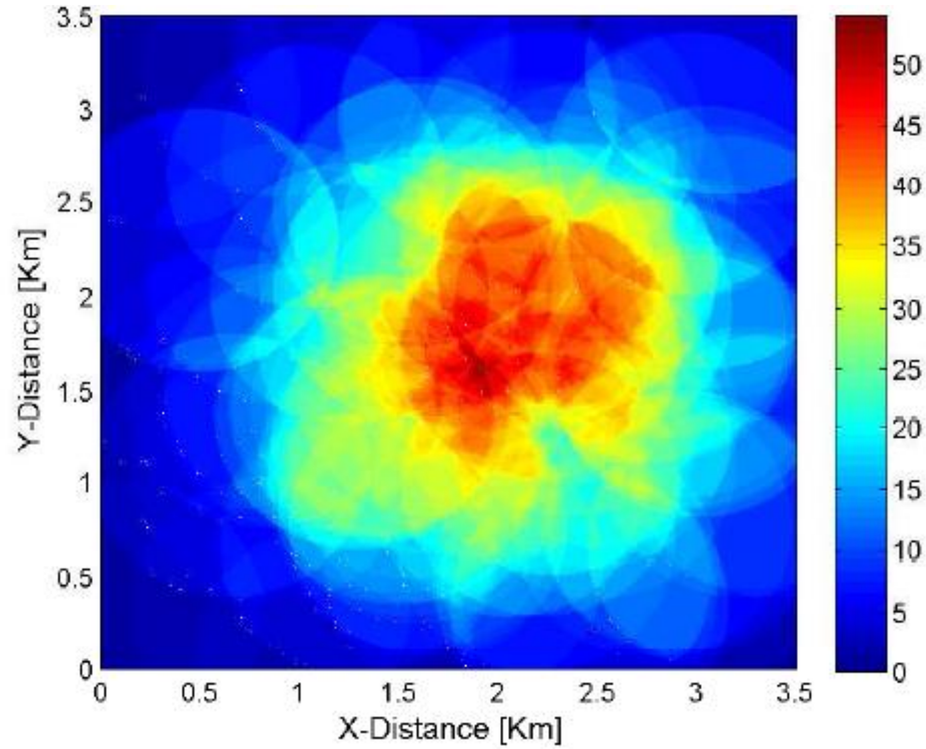
Where has Energy Gone?

- **Roughly speaking**
  - **~80% energy consumed by BSs in a cellular network**
  - **~70% energy consumed by signal processing, power amplifier, and cooling system inside a BS**
  - **~50% energy consumed for coverage guarantee (*BSs are always on and multiple networks are densely deployed and overlapping*)** – *next slide*
- **Key challenge**
  - **In order to dramatically reduce energy consumption, switching off (sleeping) lightly loaded BSs as many as possible is most effective**
  - **but how to guarantee the coverage and QoS?**
- **Hence, Green is not just low (transmitting) power, or high energy-efficiency (EE), but a holistic approach with paradigm shift**
  - **GREEN: Globally Resource-optimized & Energy-Efficient Networks**

Redundant Overlap in Coverage



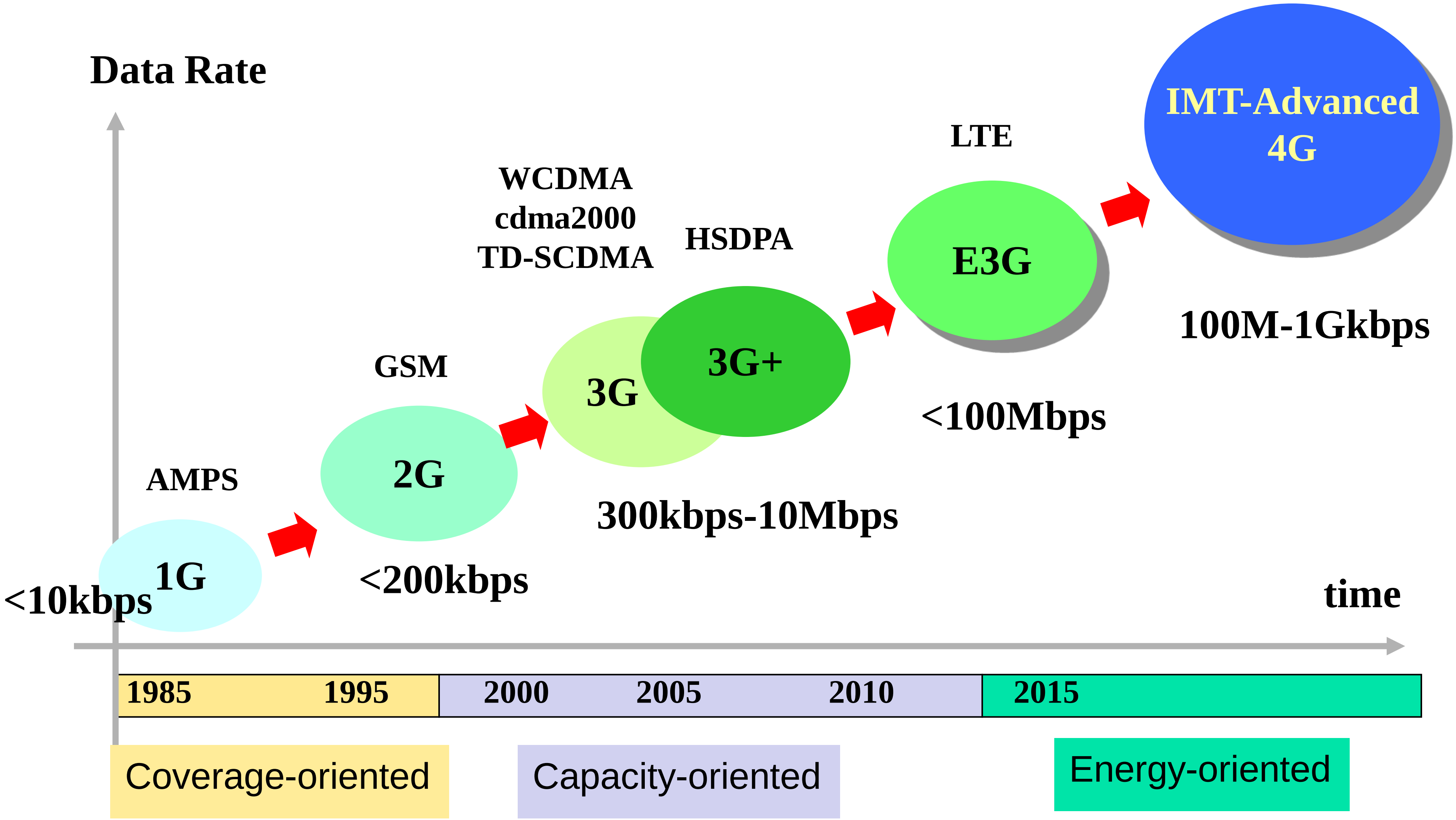
BS location data from a part of Manchester, UK. (*Some base stations are collocated, in which case just one triangle is shown on the map*.)



Redundancy in the cellular coverage of Manchester at 700m base station coverage

E. Oh, B. Krishnamachari, X. Liu, and Z. Niu, "**Towards Dynamic Energy-Efficient Operation of Cellular Network Infrastructure**", to appear in ***IEEE Commun. Mag.,*** June 2011

Evolution of Mobile Networks



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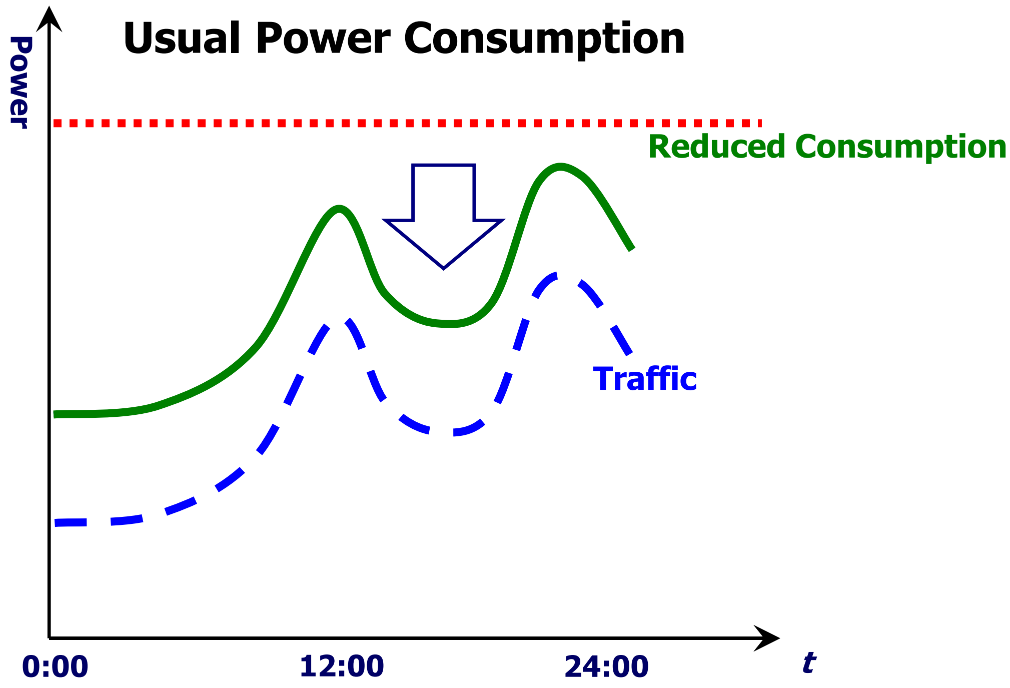
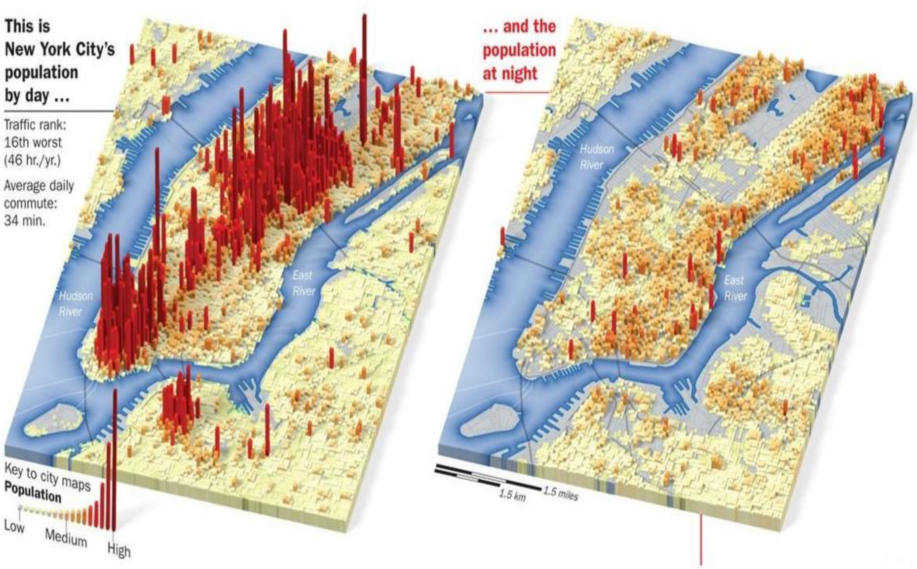
Paradigm Shift to GREEN (2)

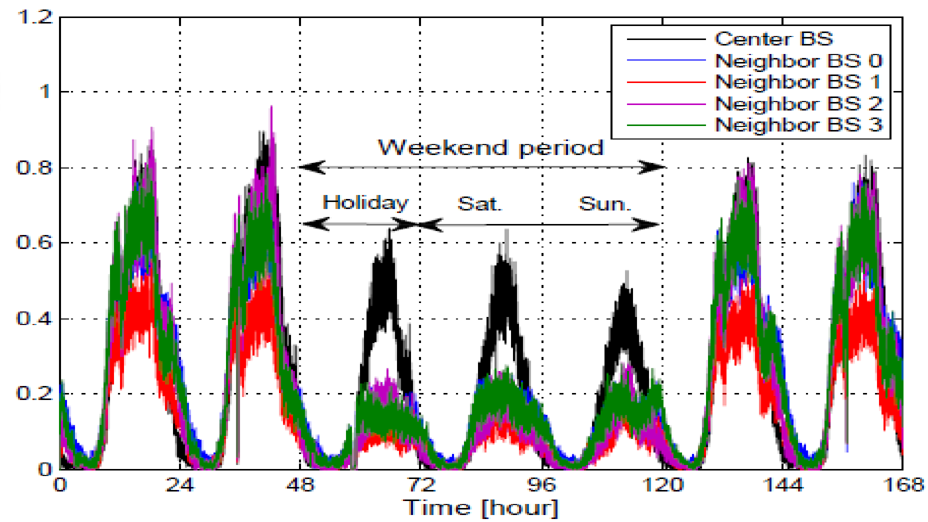
- **Tango: Traffic-aware network planning & green operation**
  - **Adapted to traffic volume (*dayly and weekly*)**
  - **Adapted to traffic characteristics (*unicast, multicast, broadcast*)**
  - **Adapted to QoS requirements (*realtime, nonrealtime*)**



Understanding the Traffic

- **Dynamics in time-domain (*large- and small-scale*)**
  - **day and night, weekday and weekend**
- **Dynamics in spatial domain (*getting worse as cells are getting smaller*)**
  - **hot cells and cool cells**

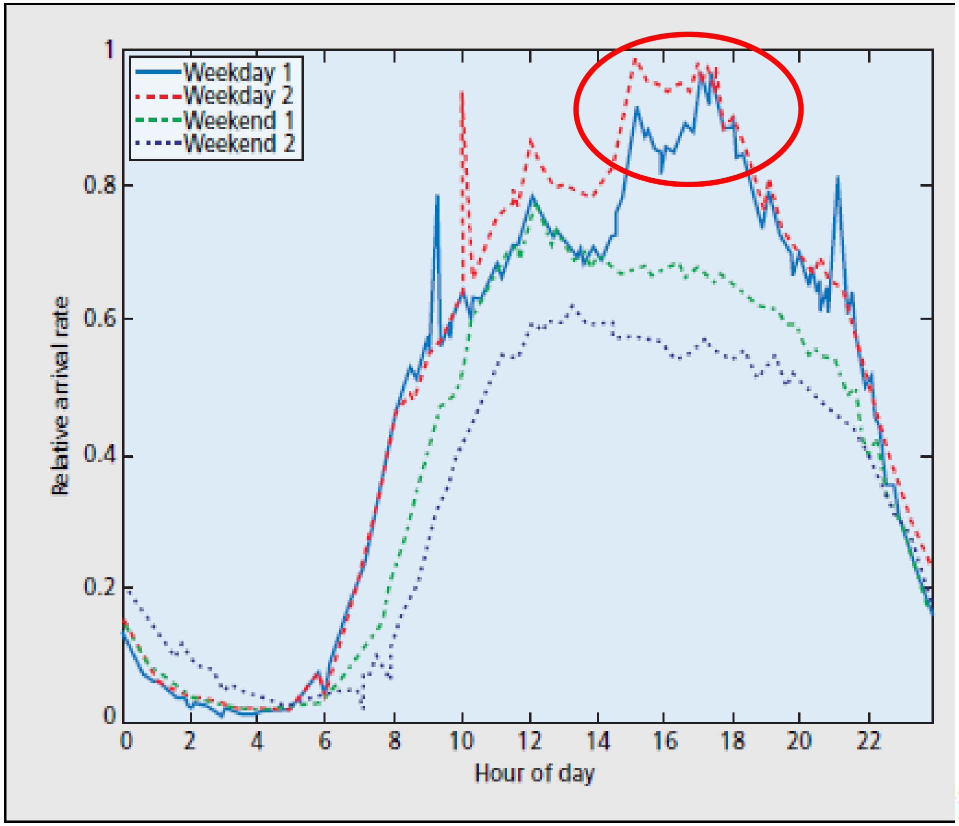




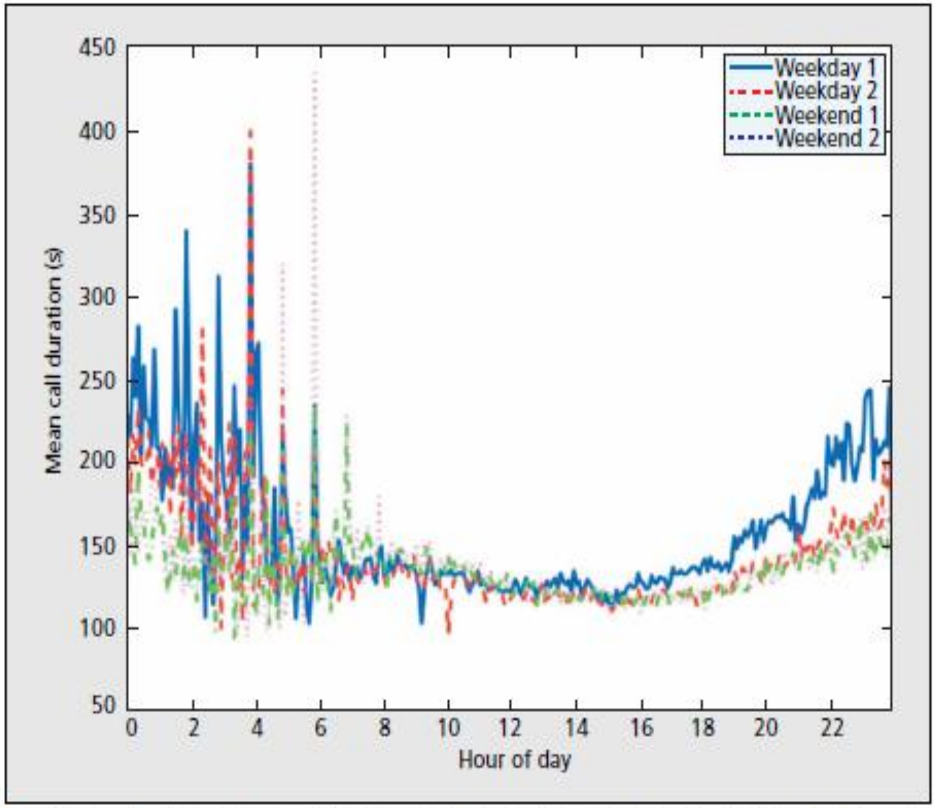
E. Oh, B. Krishnamachari, X. Liu, and Z. Niu, "**Towards Dynamic Energy-Efficient Operation of Cellular Network Infrastructure**", to appear in ***IEEE Commun. Mag.***, June 2011

Time-Variation of Mobile Traffic

- **The range of variability in mean call duration is much smaller than that of arrival rates**
- **The variation is larger during the day, when the load is higher!**



■ Figure 2. *Distribution of system-wide average call arrival rates during four different days. The arrival rates are averaged over 5-min slots.*

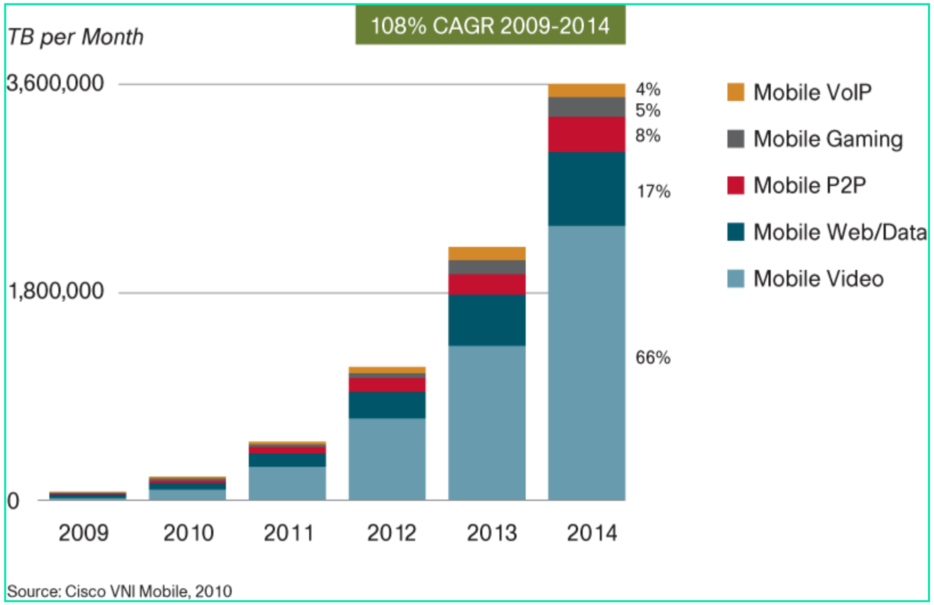


■ Figure 3. *Distribution of average call duration over 5-min periods during four different days. The large spikes during the mornings are due to small gaps in collection.*

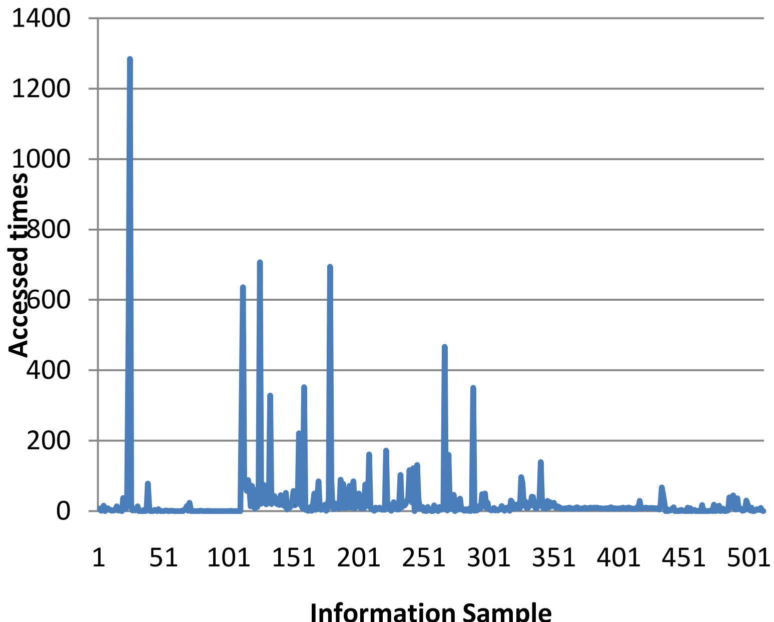
*D. Willkomm, S. Machiraju and J. Bolot, Adam Wolisz, "**Primary User Behavior in Cellular Networks and Implications for Dynamic Spectrum Access**", **IEEE Com. Mag**., March 2009*

Understanding Traffic

- Non-realtime traffic will dominate mobile applications
  - Use *delay* to trade for *energy*?
  - Use *multicast/broadcast* to save energy?



Global Mobile Traffic Forecast by Cisco



Experimental data from sina.com.cn

Understanding QoS

- **ITU Definition**: ***"QoS is the collective effect of service performance which determine the degree of satisfaction of a user of the service"***
  - a measure of the **satisfaction** experienced by a person while receiving a service
  - **it is a user perception and different from network performance**
- **IETF Definition:** ***"A set of service requirements to be met by the network while transporting a flow"***
  - it is closely equivalent to the network performance (much easier!)
  - it is a measure of network performance rather than the user QoS
- **Technically, we usually transfer QoS level into**
  - Bit Rate (bandwidth)
  - Blocking Prob. and/or Packet Loss Rate
  - Delay (mean and/or maximum) time,
  - Jitter
- **For mobile networks, coverage guarantee (connectivity) is one of the major QoS**

QoS: It's not Free

- **QoS is not only bandwidth, but more traffic control and management**
  - ***Traffic control and management is not cheap***
- **QoS is not only in the core, but more on the edges**
  - ***End-end QoS is expensive***
- **Cost of Wireless Bandwidth**

$$C = N_{user} \times B_{user} \times \rho \times A_{service} \times f(Q)$$

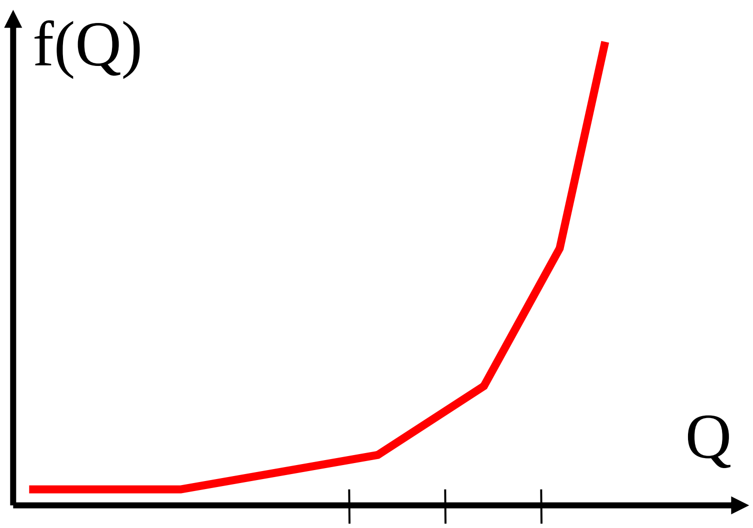
Where N_{user} = number of users;

B_{user} = bandwidth/user;

ρ = bandwidth utilization ratio

$A_{service}$ = service area (coverage);

$f(Q)$ = QoS guarantee level

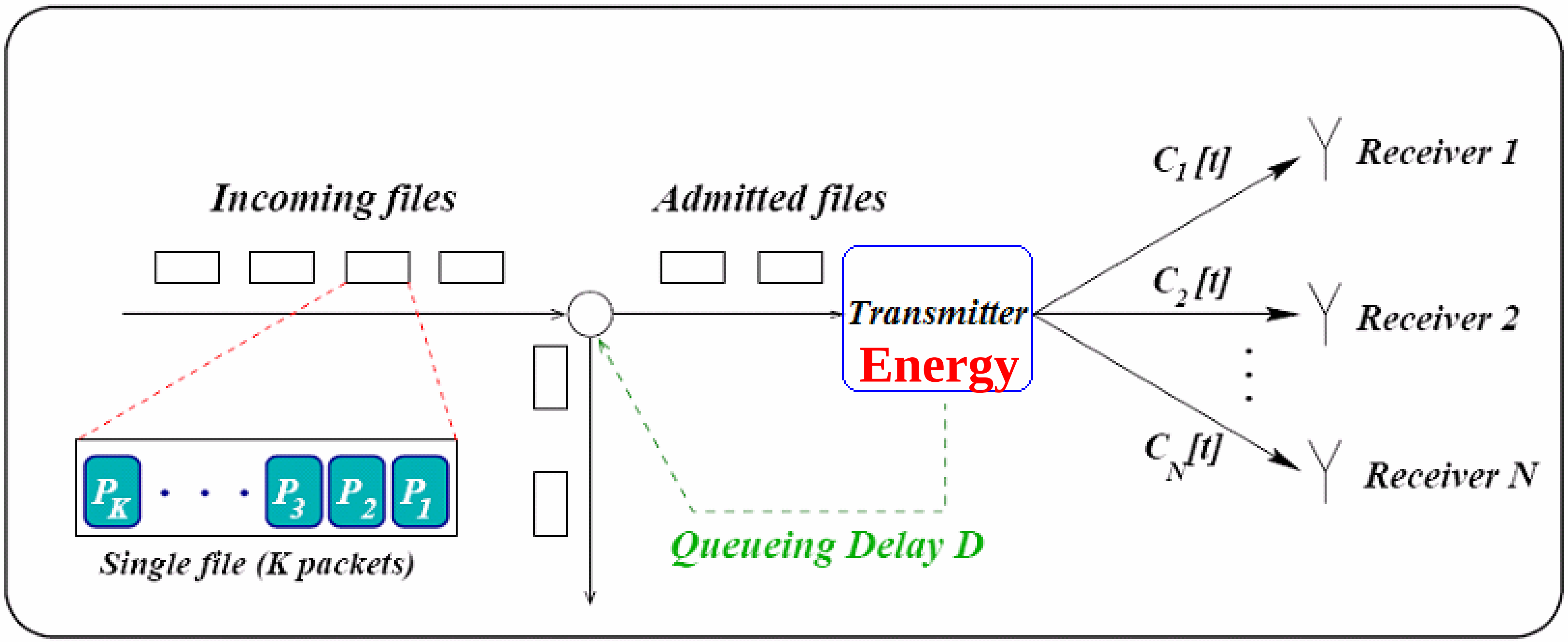


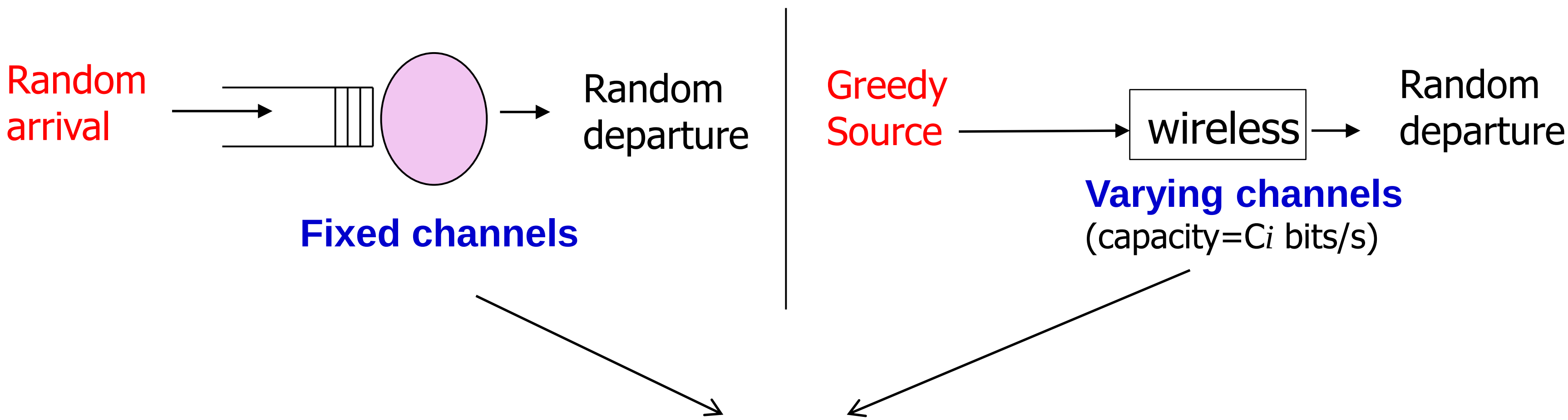
Performance Metrics of Typical Applications

Application	CLR	CDV	Max CTD	Mean CTD	MCR
video conf	10^{-5}	50 ms	120 ms	100 ms	NA
telephone	10^{-5}	2 ms	41 ms	40 ms	NA
Email	10^{-5}	Not spec	Not spec	Not spec	NA
File transfer	10^{-8}	Not spec	Not spec	Not spec	20 cells/s

- Cell loss ratio (CLR): fraction of cells host during transmission.
- Cell delay variation (CDV): maximum difference between e2e cell delays
- Maximum cell transfer delay (max CTD): maximum end-to-end cell delay.
- Mean cell transfer delay (mean CTD): average end-to-end cell delay.
- Minimum cell rate (MCR): minimum rate at which the network delivers cells.

Information Theory and Queueing Theory

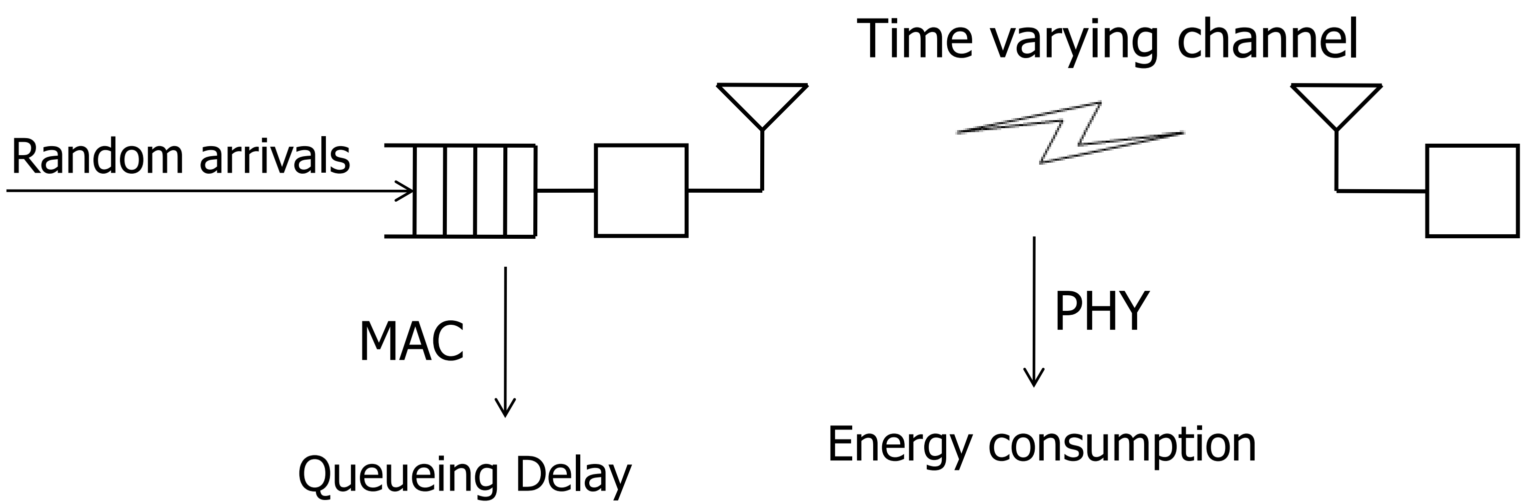




How to combine?

Tradeoff between EE and Delay

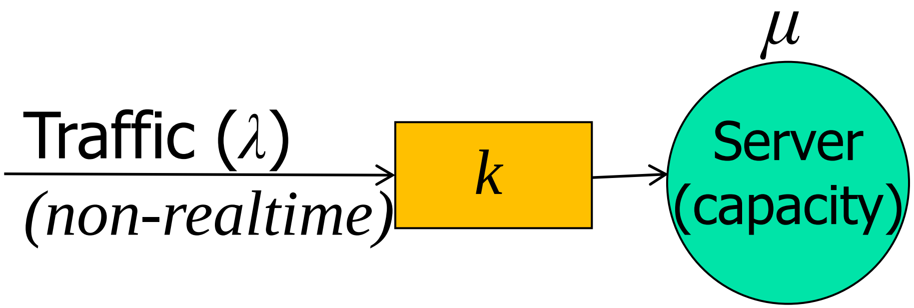
- **From queueing theory:** ***Constant rate minimizes the delay***
  - ***W_M/D/1 = ½ x W_M/M/1***
- **From information theory:** ***Variable rate minimizes the energy***
  - ***Water-filling maximizes the capacity***

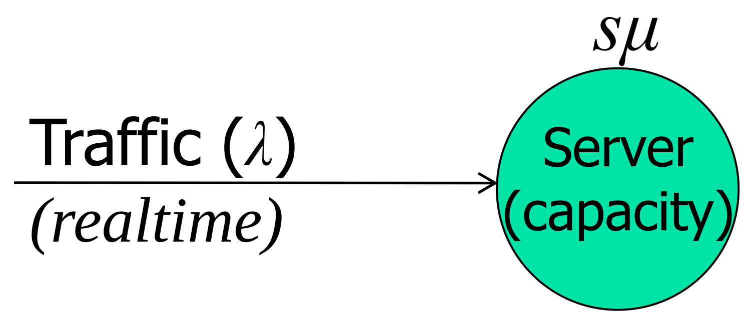


Variation of channels

$$\boxed{\bar{W}_q = \frac{\rho h (1 + c_b^2)}{2(1-\rho)}}$$

Use *delay* to trade for *energy*?





M/M/1(k) – *soft realtime*

$$P_B^{(2)}=\rho_2^{k+1}(1-\rho_2)/(1-\rho_2^{k+2})$$

where $\rho_2=\lambda/\mu$

M/M/1(0) - *Realtime*

$$P_B^{(1)}=\rho_1/(1+\rho_1)$$

where $\rho_1=\lambda/s\mu$

$$P_B^{(1)}=P_B^{(2)}$$

$$\downarrow$$

$$\boxed{s=(1-\rho_2^{k+1})/[(1-\rho_2)\rho_2^{k}]}$$

For $k=2$ *and* $\rho_2=0.5$, then $s=7$

For $k=8$ *and* $\rho_2=0.5$, then $s=511$!

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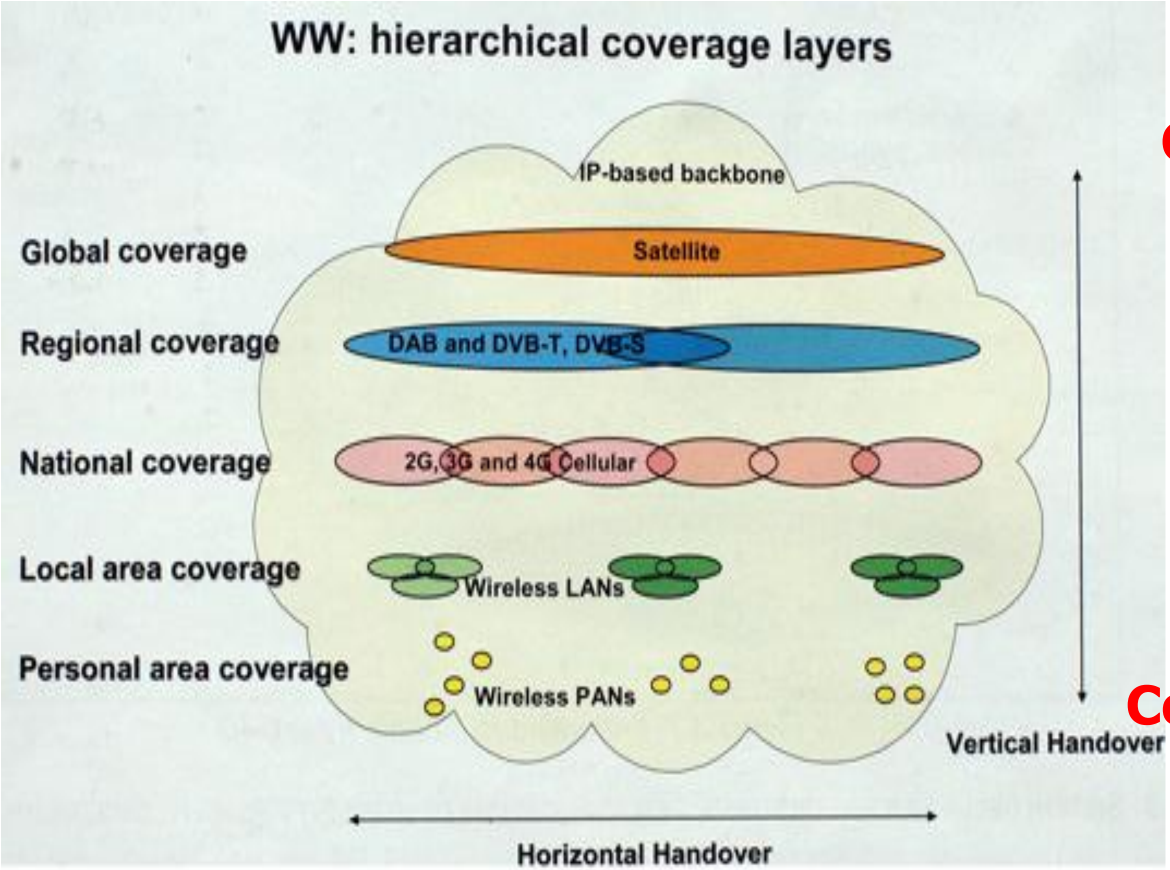
Paradigm Shift to GREEN (1)

- **CHORUS: Collaborative & Harmonized Open Radio Ubiquitous System**
  - ***under-utilized NWs could be switched off, whilst the neighboring NWs help to provide services by BS/AP cooperative transmission***



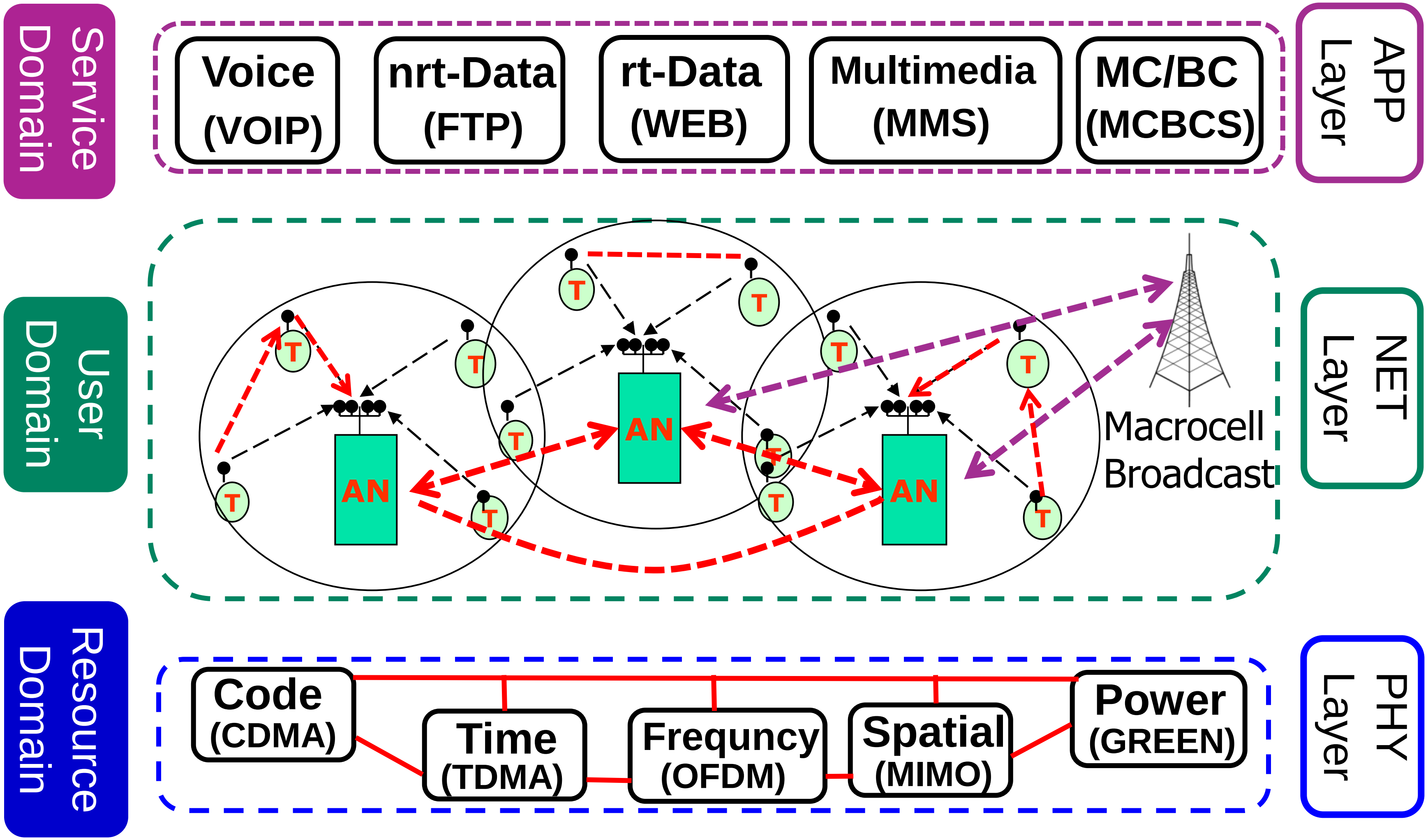
Cognition

cross-network design

Cooperation

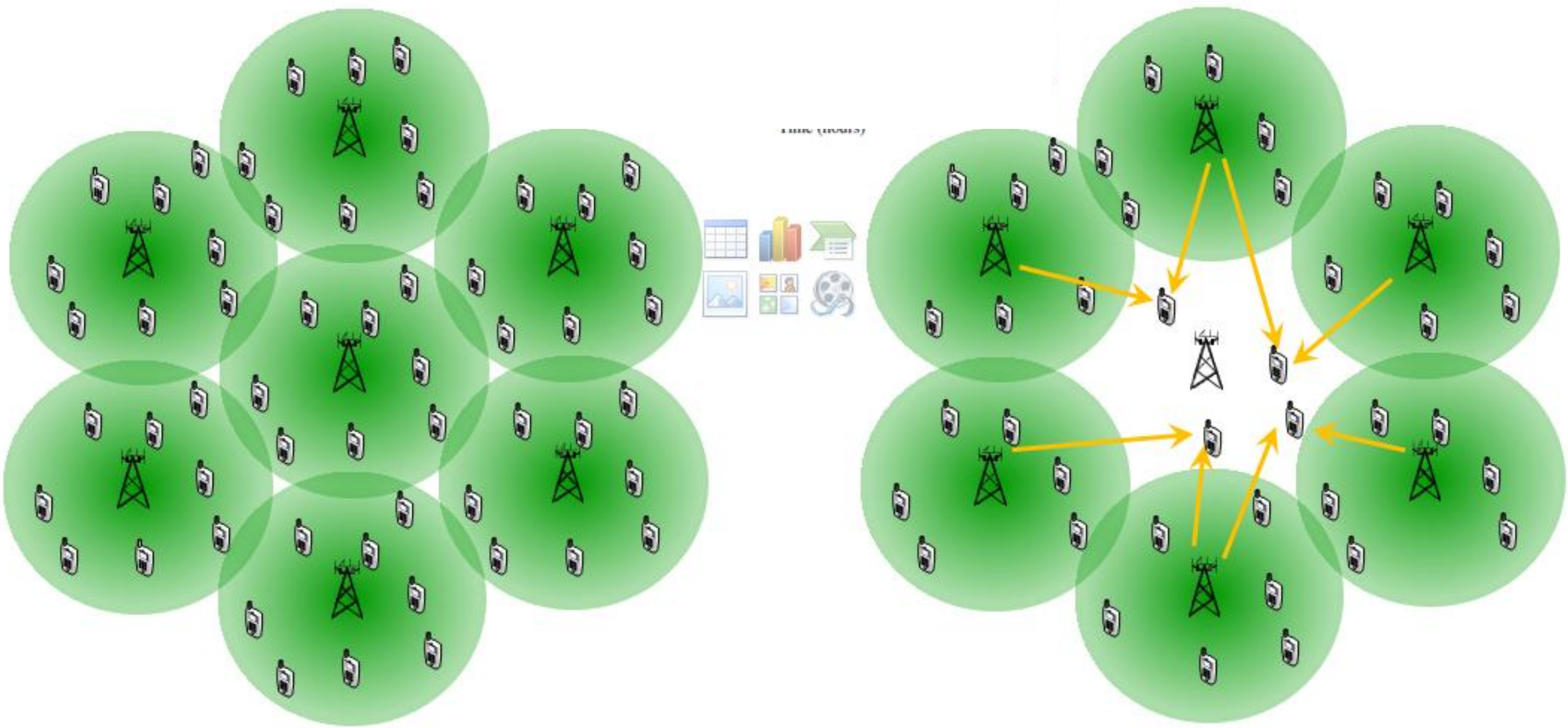
cross-layer design

Collaboration should be in Multi-domains

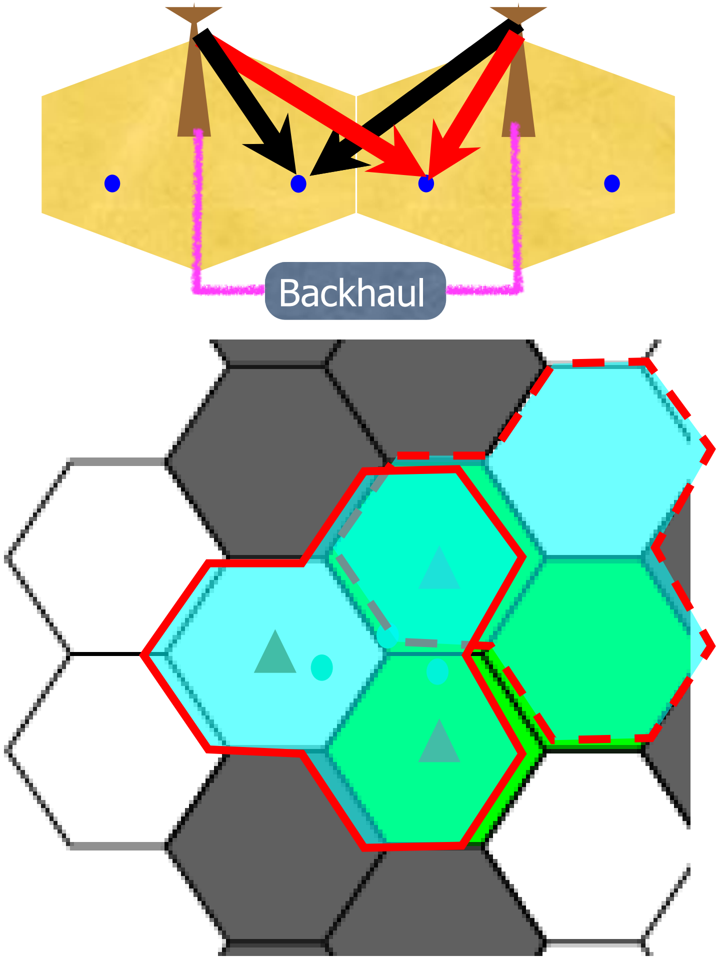


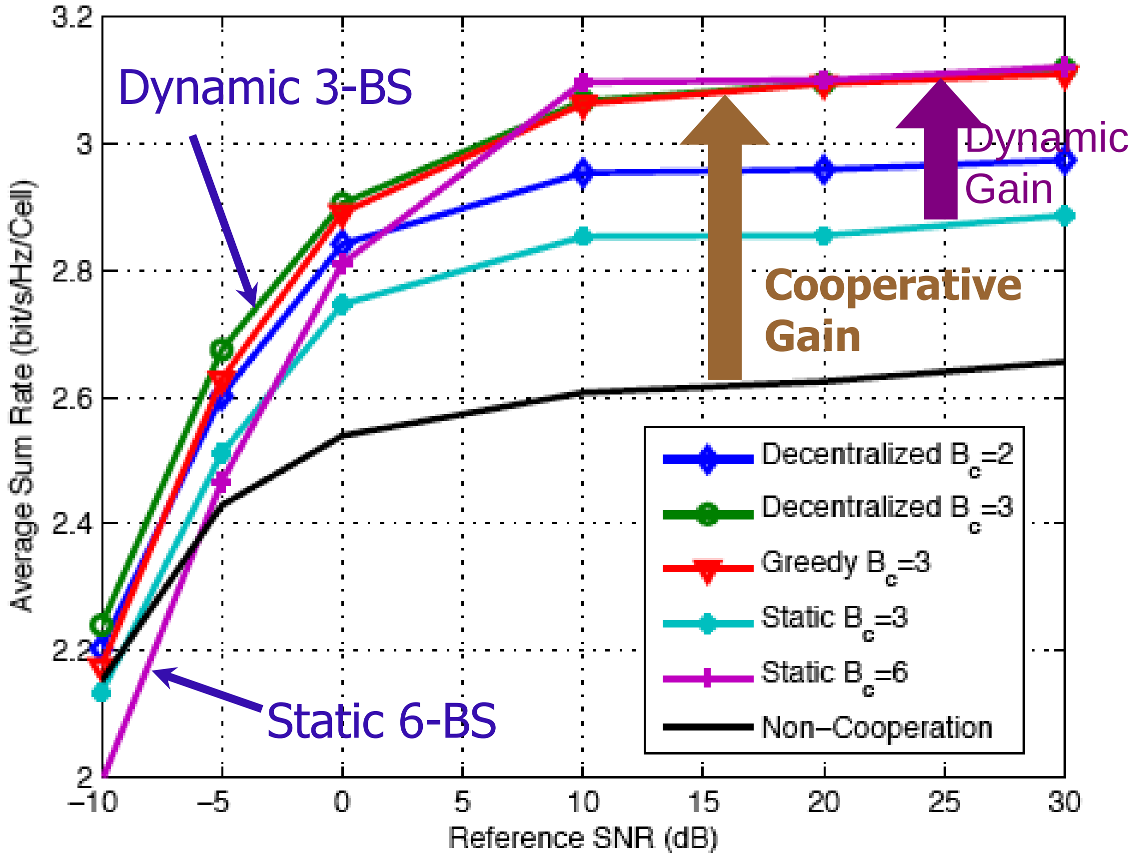
: Network integration for ubiquitous Linkage and broadband

Energy Saving by BS Cooperation



Dynamic Clustering with Limited Feedback





[1] Zhou S, Gong J, Niu Z, Jia Y. "A decentralized clustering scheme for dynamic downlink base station cooperation », ***IEICE Transactions on Communications***, 2011, E93-B(12):2656-2659.
[2] Zhou S, Gong J, Niu Z. "Distributed adaptation of quantized feedback for downlink network MIMO systems" ***IEEE Transactions on Wireless Communications***, 2011, 10(1):61-67.

Energy Saving by Multi-hop Cooperation

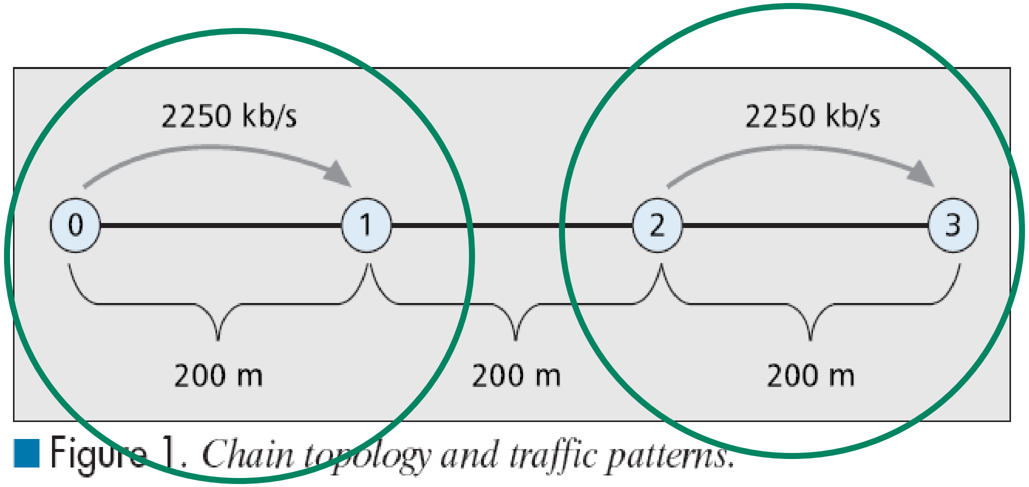


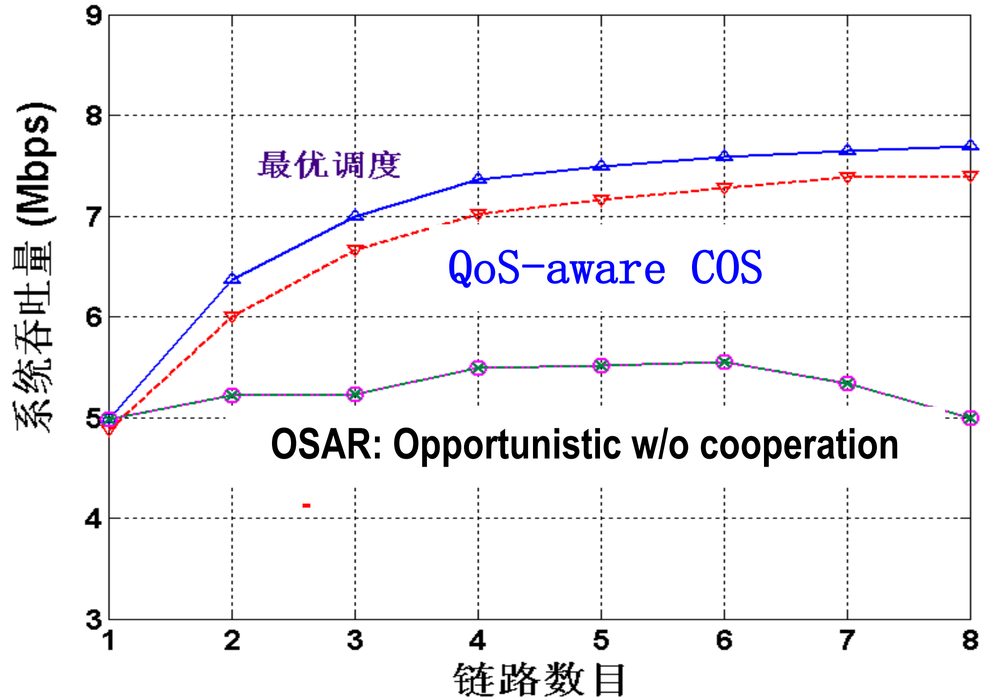
Figure 1. *Chain topology and traffic patterns.*

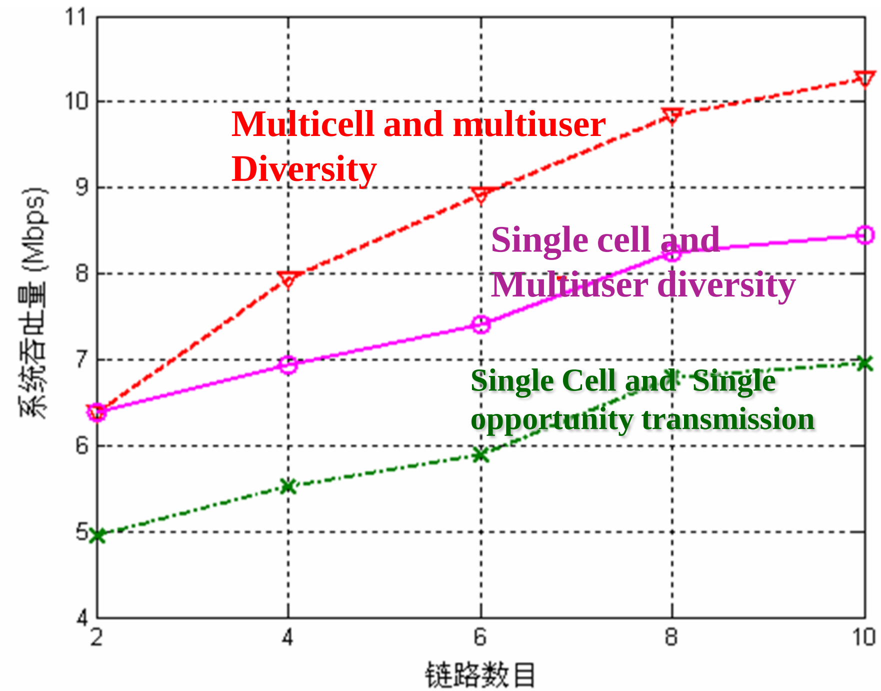
	PHY rate on (0, 1)	PHY rate on (2, 3)	Total power consumption (mW)
Non-cooperative solution	48 Mb/s	9 Mb/s	6.704
Optimal solution with node cooperation	18 Mb/s	18 Mb/s	2.352

Table 1. *PHY rates and energy consumption comparisons.*

Q. Zhang, Q. Chen, F. Yang, X. Shen, Z. Niu: "Cooperative and Opportunistic Transmission for Wireless Ad Hoc Networks", ***IEEE Network***, vol.21, No.1, pp.14-20, 2007

Performance of the QoS-aware COS





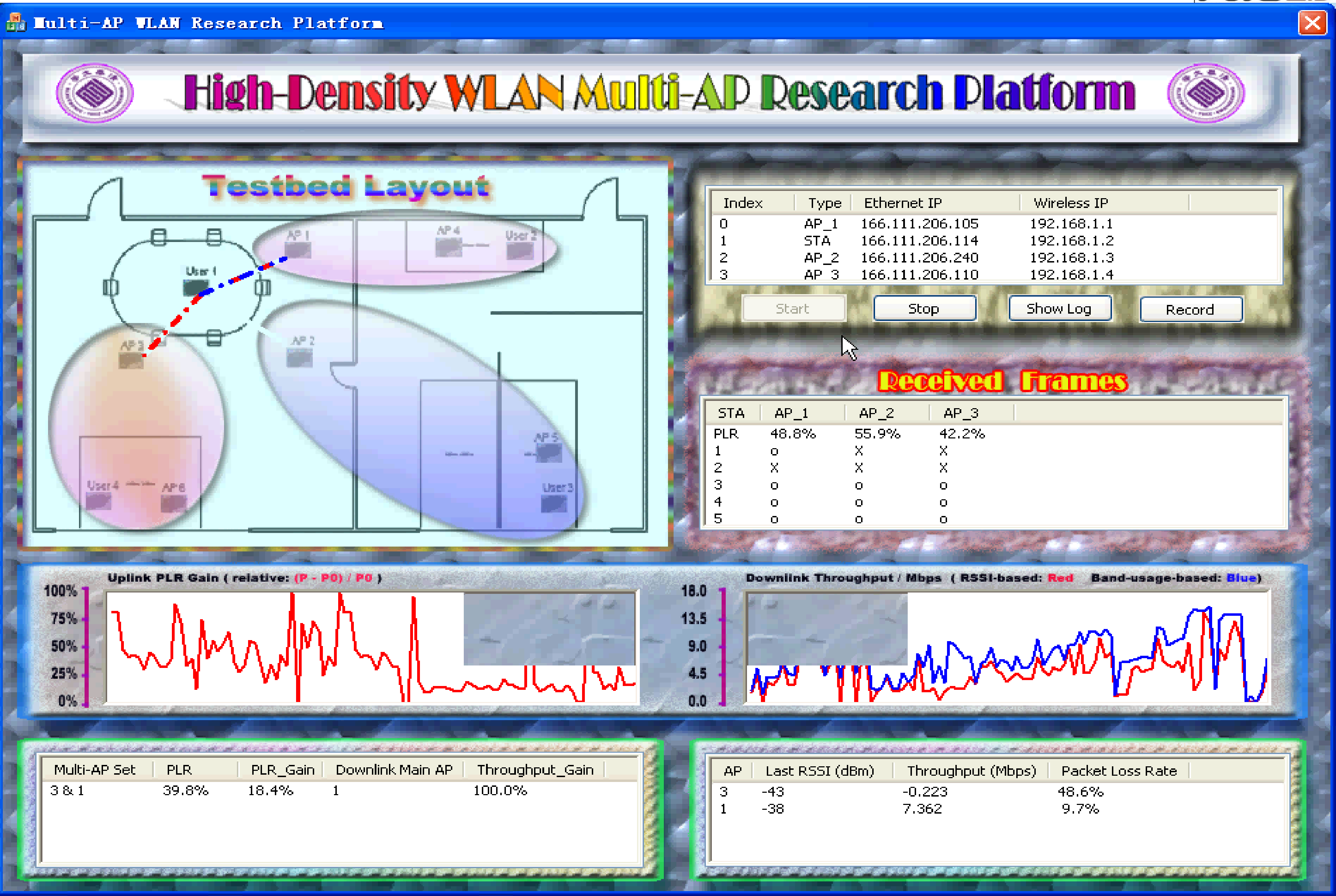
Related Publications:

[1] Q. Zhang, Q. Chen, F. Yang, X. Shen, Z. Niu, "Cooperative and Opportunistic Transmission for IEEE 802.11-based Ad Hoc Networks," ***IEEE Networks***, vol.21, No.1, pp.14-20, 2007.

[2] Q. Chen, Q. Zhang, Z. Niu, "QoS-aware Cooperative and Opportunistic Scheduling Exploiting Multi-user Diversity for Rate Adaptive Ad Hoc Networks," ***IEEE Trans. Vech. Tech***., vol.57, no.2, pp.1113-1125, April 2008.

[3] Q. Chen, Q. Zhang, Z. Niu, "A Graph Theory based Opportunistic Link Scheduling for Wireless Ad Hoc Networks", ***IEEE Trans. Wireless Comm***., Oct. 2009.

Multi-AP Association & Collaboration



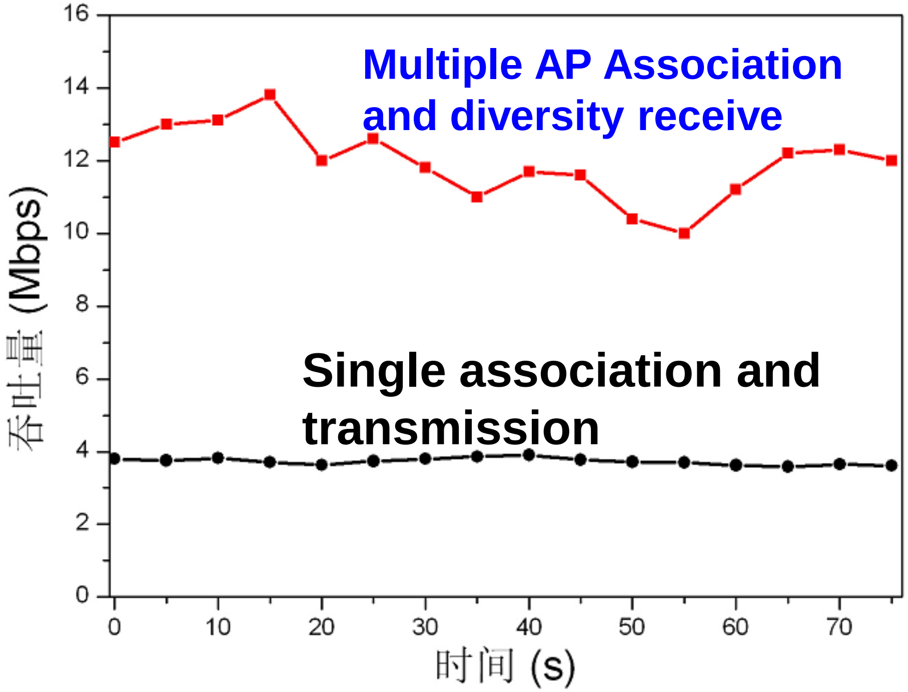
Index	Type	Ethernet IP	Wireless IP
0	AP_1	166.111.206.105	192.168.1.1
1	STA	166.111.206.114	192.168.1.2
2	AP_2	166.111.206.240	192.168.1.3
3	AP_3	166.111.206.110	192.168.1.4

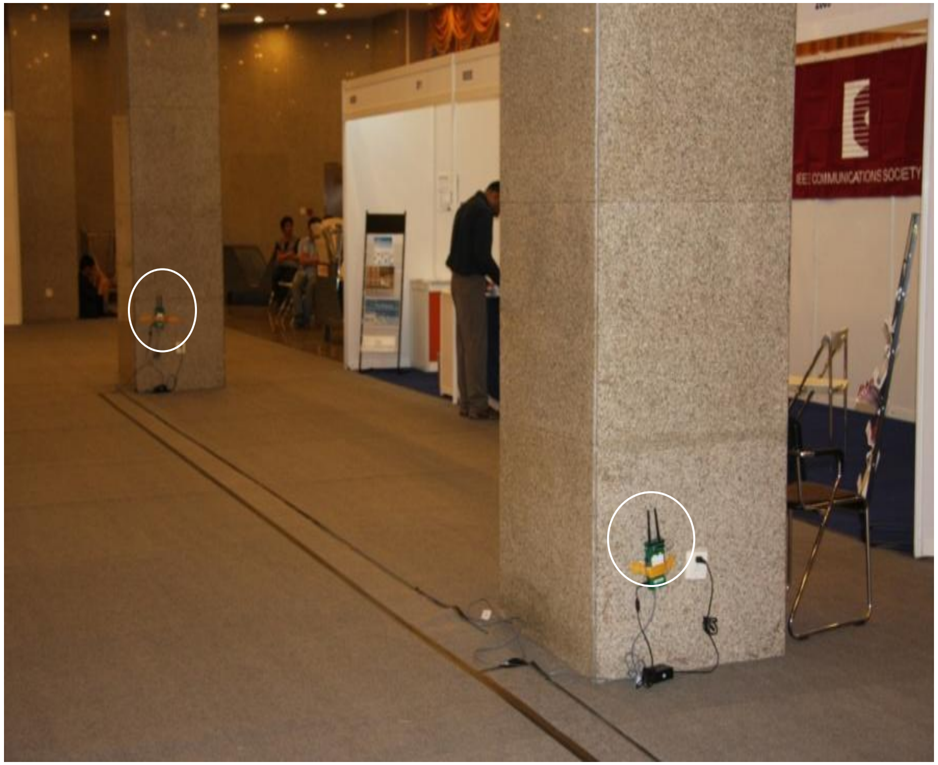
STA	AP_1	AP_2	AP_3
PLR	48.8%	55.9%	42.2%
1	o	X	X
2	X	X	X
3	o	o	o
4	o	o	o
5	o	o	o

Multi-AP Set	PLR	PLR_Gain	Downlink Main AP	Throughput_Gain
3 & 1	39.8%	18.4%	1	100.0%

AP	Last RSSI (dBm)	Throughput (Mbps)	Packet Loss Rate
3	-43	-0.223	48.6%
1	-38	7.362	9.7%

Performance of Multi-AP Diversity





Related Publications:

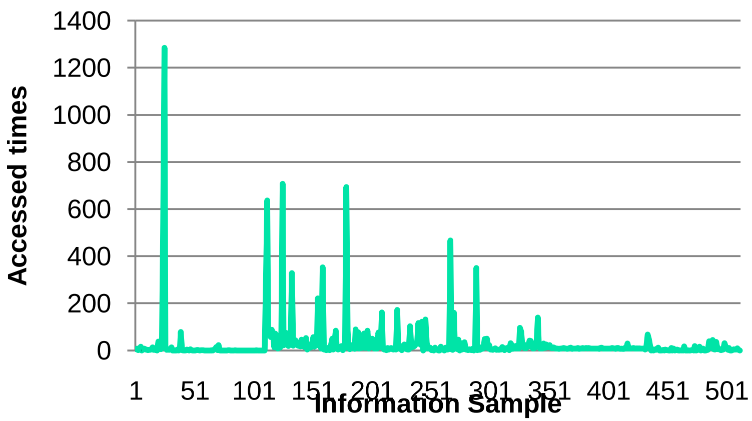
[1] Y. Zhu, Q. Zhang, Z. Niu, and J. Zhu: "On Optimal QoS-aware Physical Carrier Sensing: Theoretical Analysis and Protocol Design", ***IEEE Transactions on Wireless Communications***, pp. 1369-1378, April 2008.

[2] Y. Zhu, Q. Zhang, Z. Niu, and J. Zhu, "Leveraging Multi-AP Diversity for Transmission Resilience in Wireless Networks: Architecture and Performance Analysis", ***IEEE Trans. Wireless Commun.***, Oct. 2009.

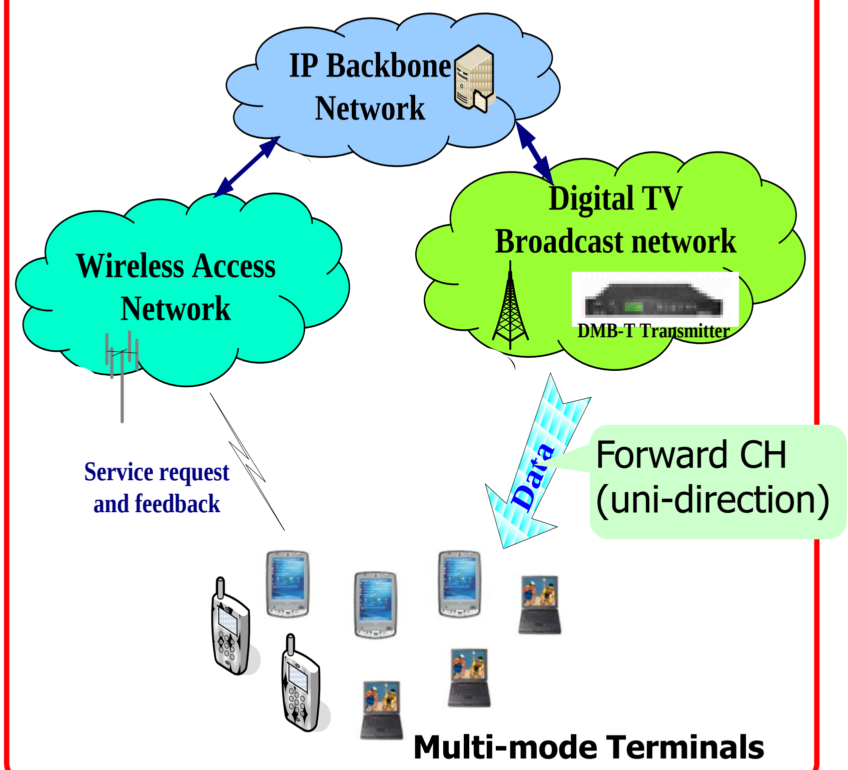
[3] Y. Hua, Q. Zhang, Z. Niu: "A Cooperative MAC Protocol with Virtual-antenna Array Support in Multi-AP WLAN System", ***IEEE Trans. Wireless Commun.***, March 2010.

A New Approach: ICBN

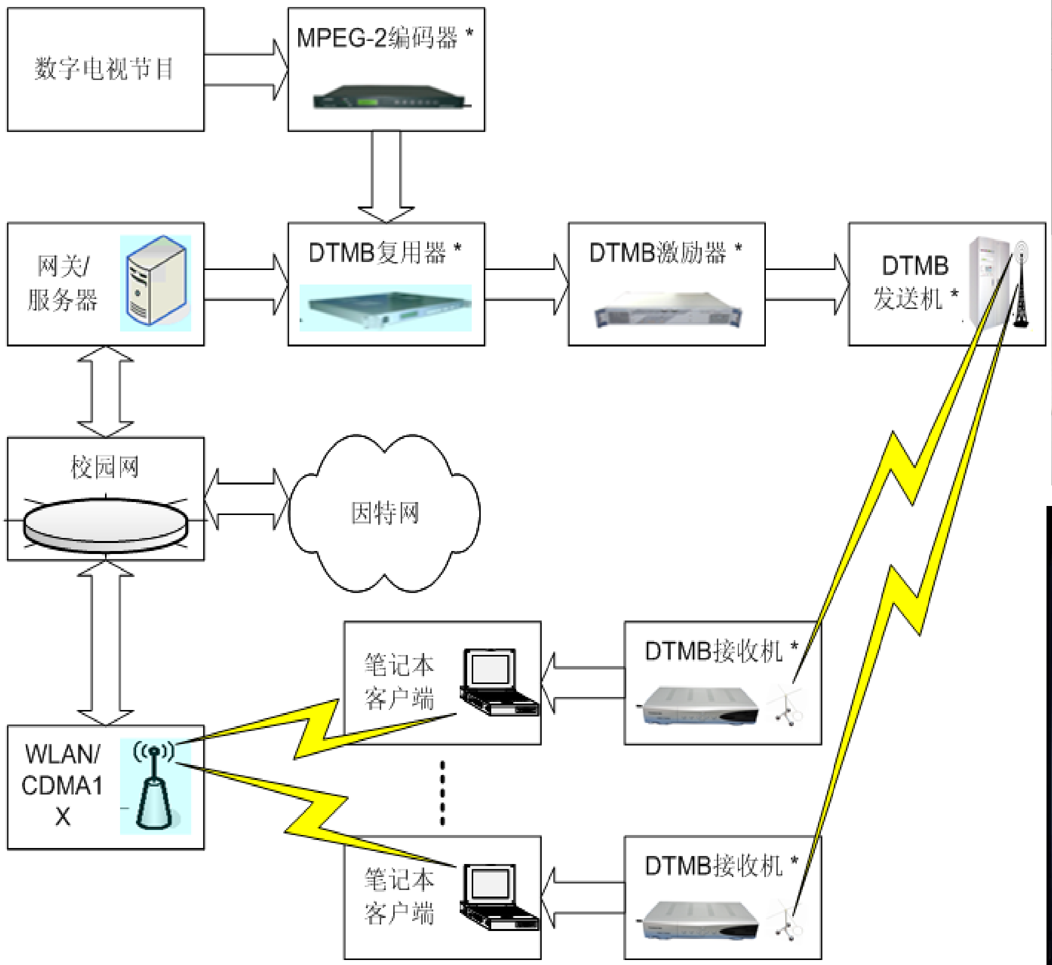
- **Use DTV or MBMS/BCMCS channels to deliver commonly interested contents to mass users on demand**
- **Use mobile NWs as interactive channels *(requests and retransmissions)* to realize VoD and data broadcast**
- **Multi-modal terminals make it possible and promising**

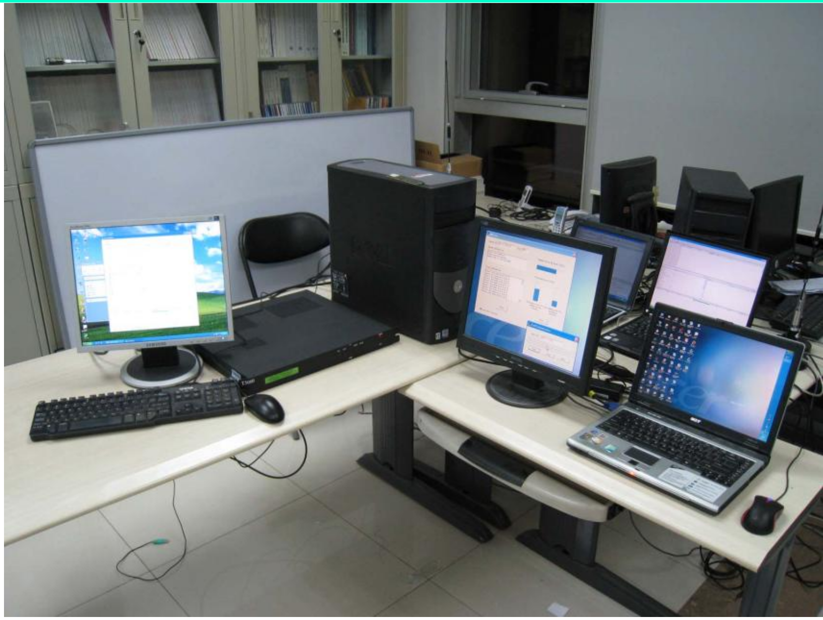


Z. Niu, L. Long, J. Song, C. Pan, *"A new paradigm for mobile multimedia broadcasting based on Integrated Communication and Broadcast Networks"*, *IEEE Communications Magazine*, *July 2008*



ICBN Testbed by DTMB and CDMA1X





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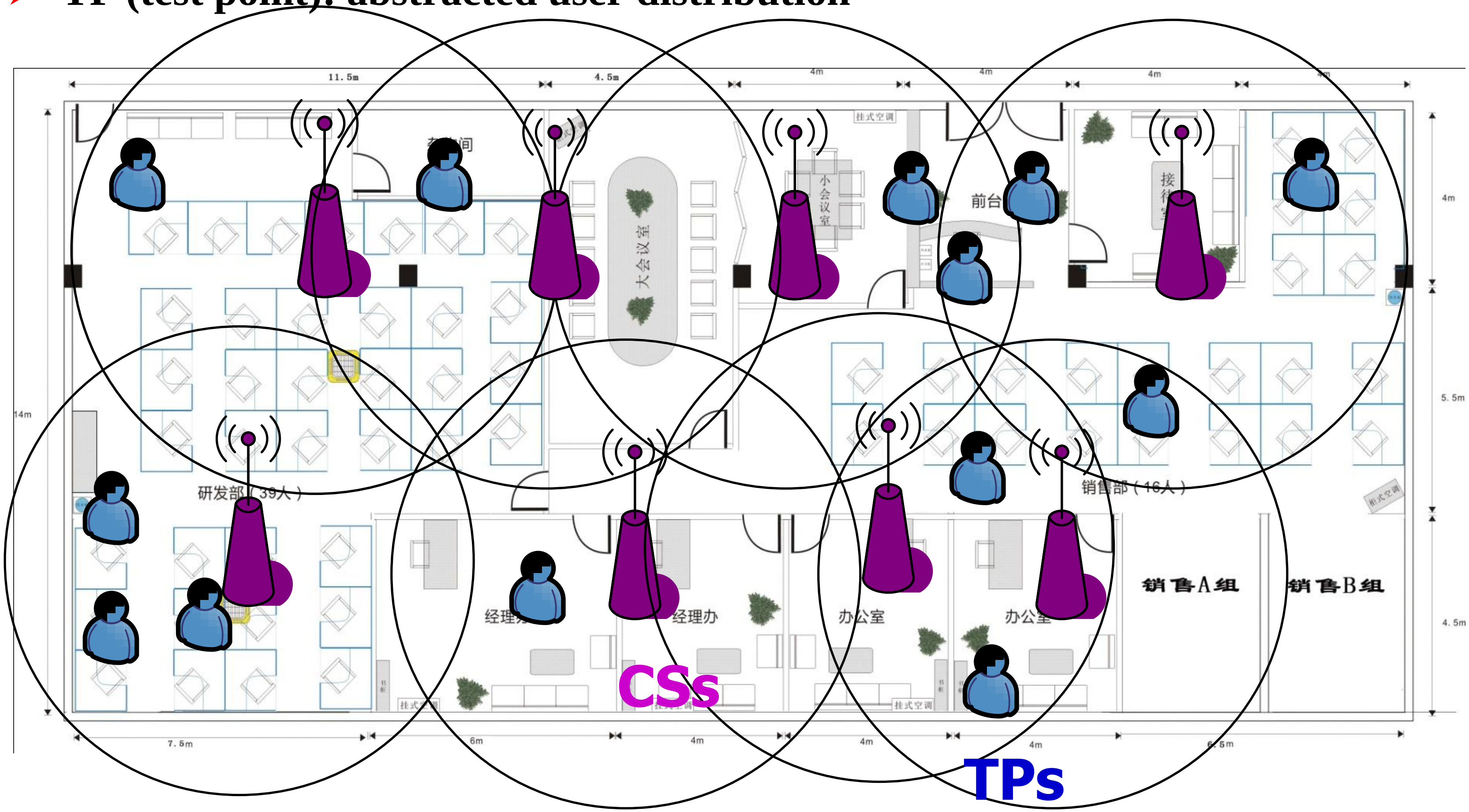
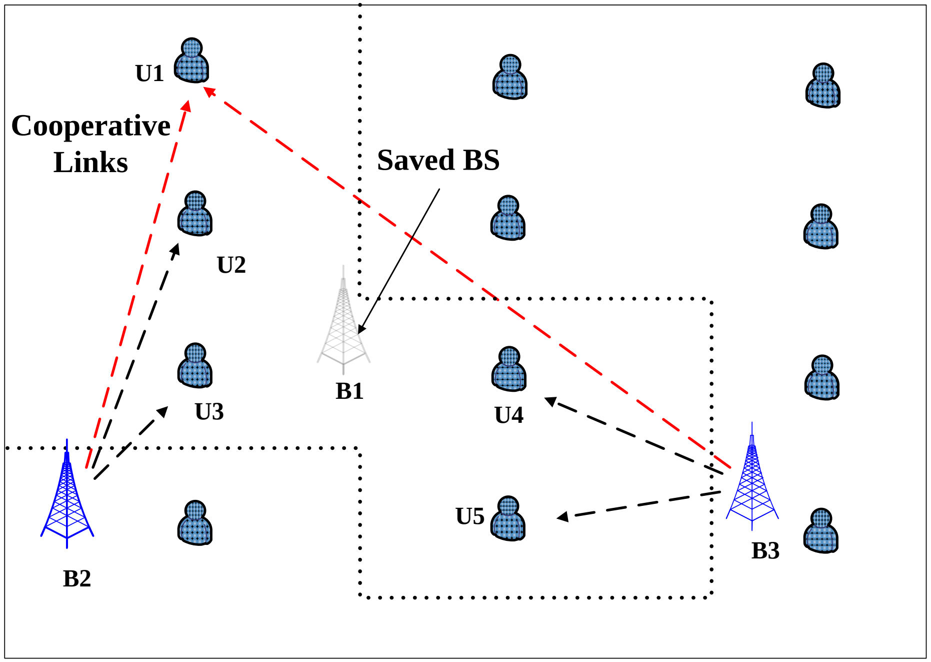
BS Placement

- Find an appropriate solution for the BS location from a given set of candidate sites
  - **CS (candidate sites): determined by buildings and geo info**
  - **TP (test point): abstracted user distribution**



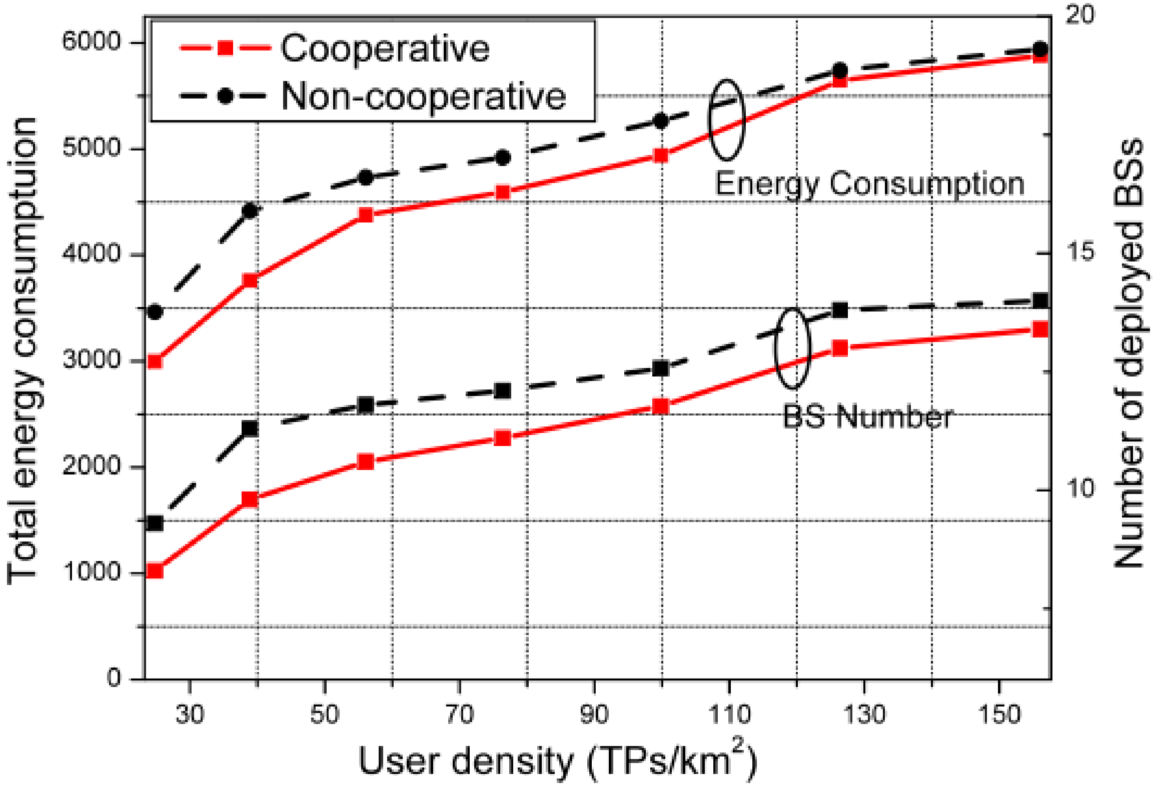
BS Placement with Inter-cell Cooperation



Link SINR (dB)	B1	B2	B3	B2/B3
U1	21.8096	2.8722	1.7872	5.3738
U2	37.1323	18.6598	11.6098	19.4416
U3	52.5756	35.3629	15.6645	35.4092
U4	50.4949	14.8198	28.5362	28.7169
U5	16.0759	13.7267	36.7377	36.7594

User density vs energy efficiency

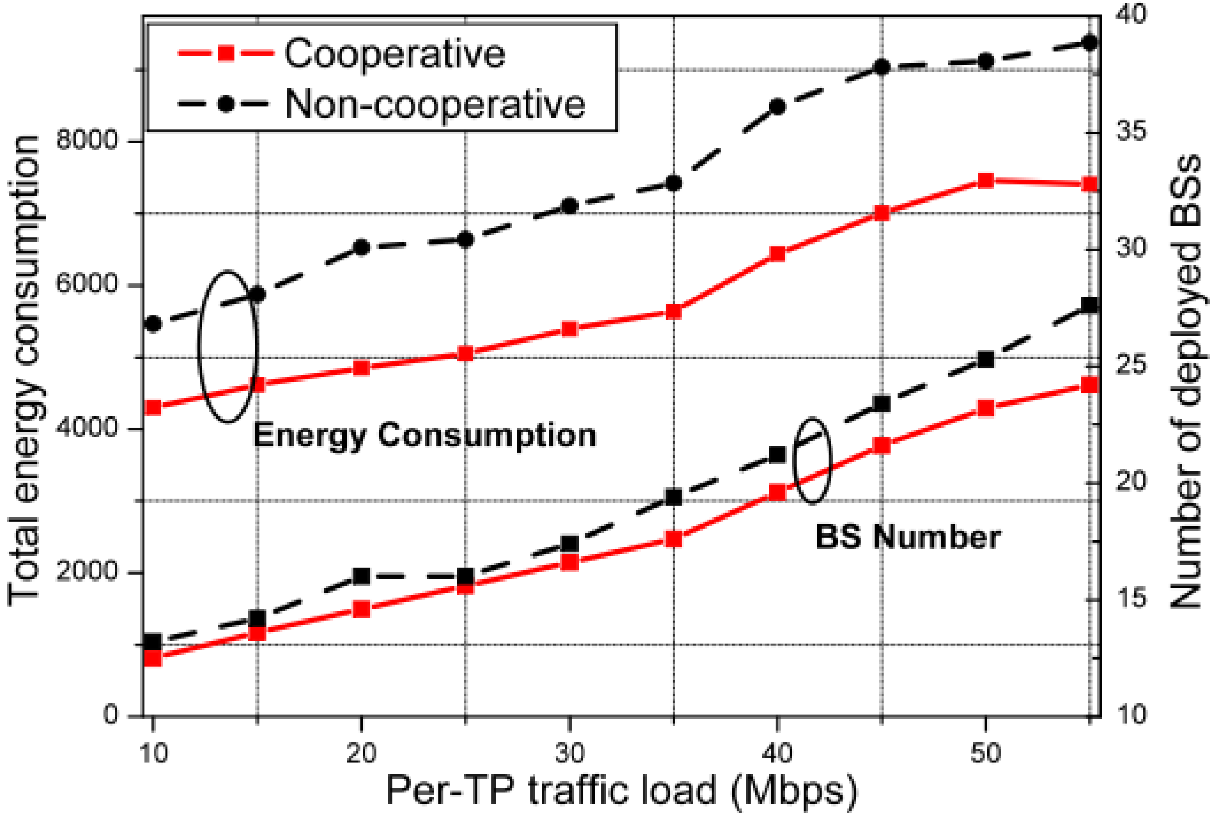
- **25 CSs, 36 TPs, with varying user density**



Cooperative gain increases as user density decreases

Traffic intensity v.s. energy efficiency

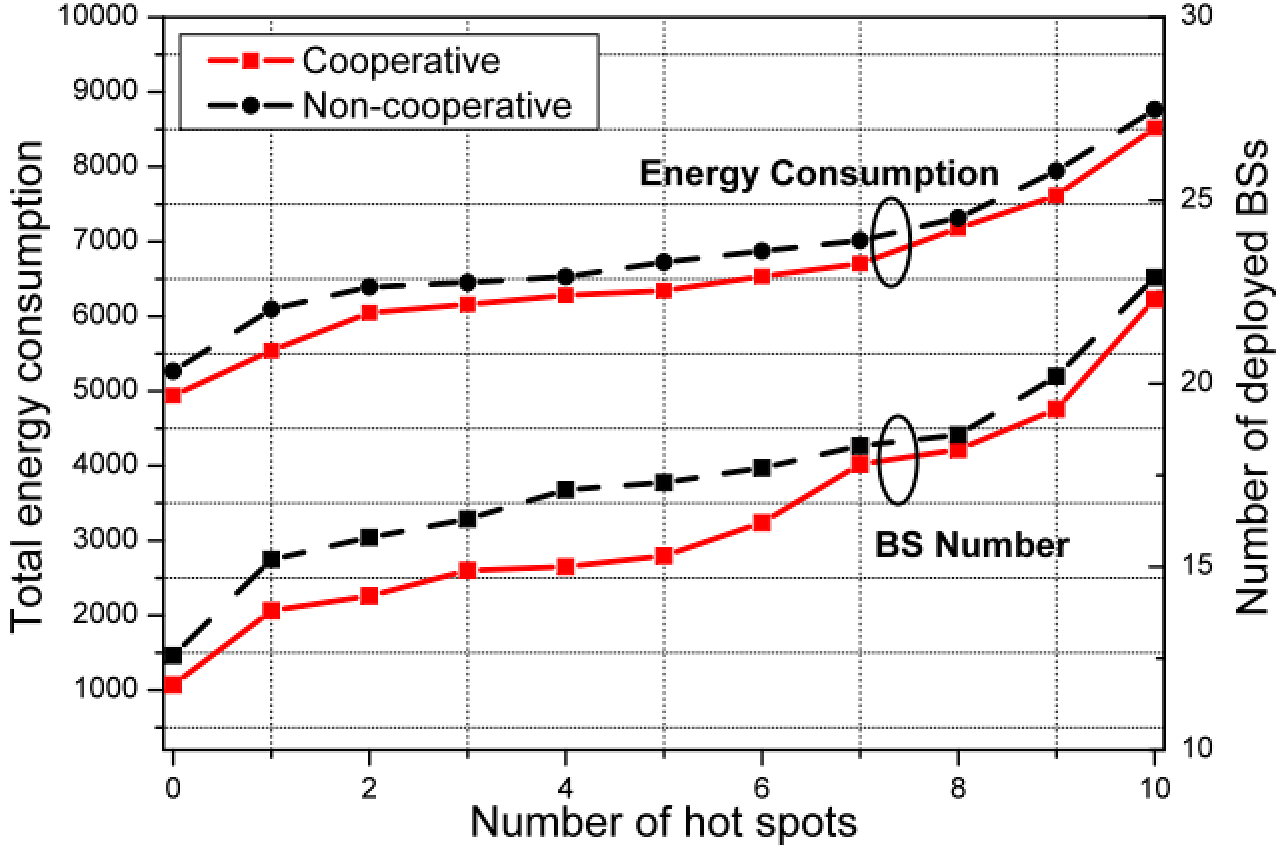
- **40 CSs, 36 TPs**



Cooperative gain increases as the traffic load increases

Traffic Non-uniformity vs energy efficiency

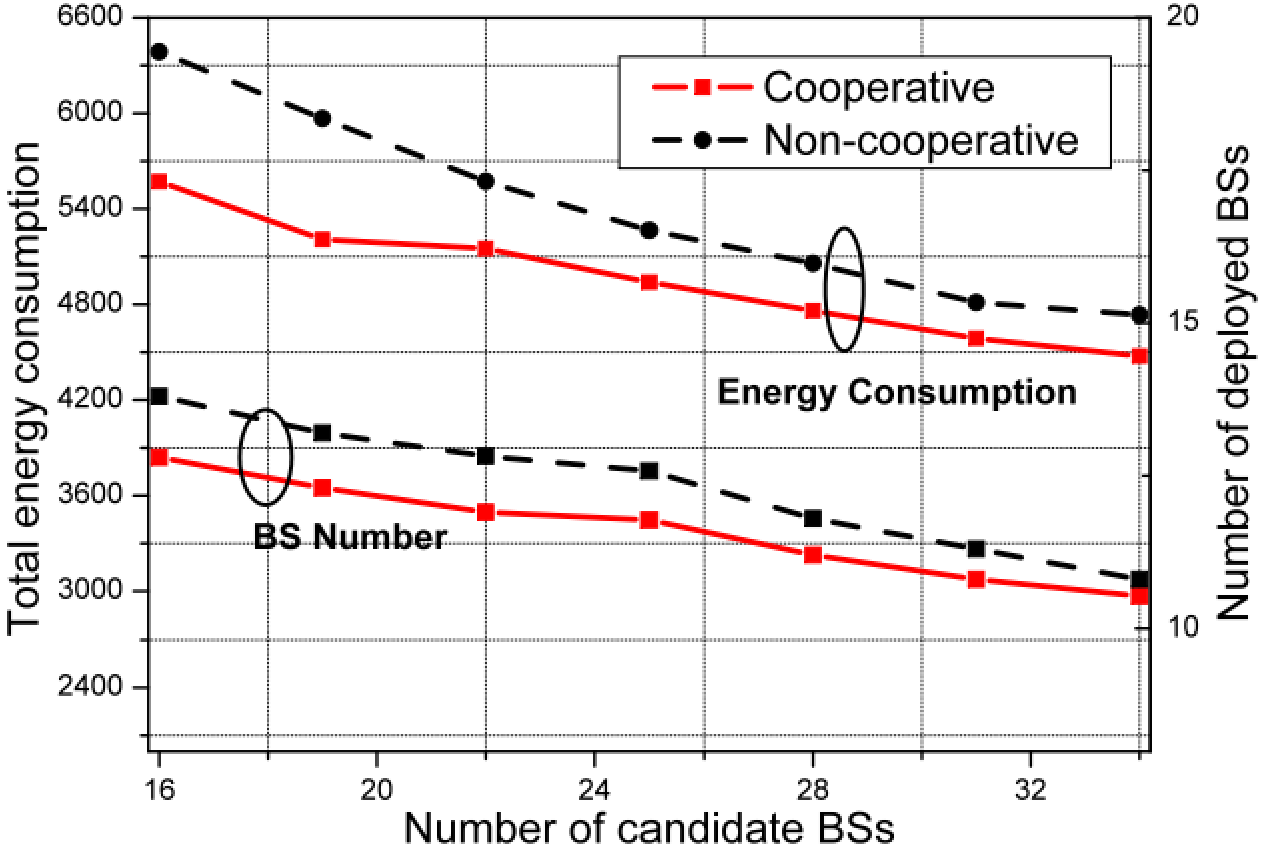
- **25 CSs, 36 TPs, with varying # of hot spots**



Cooperative gain decreases as # of hot spots increases

Traffic intensity vs energy efficiency

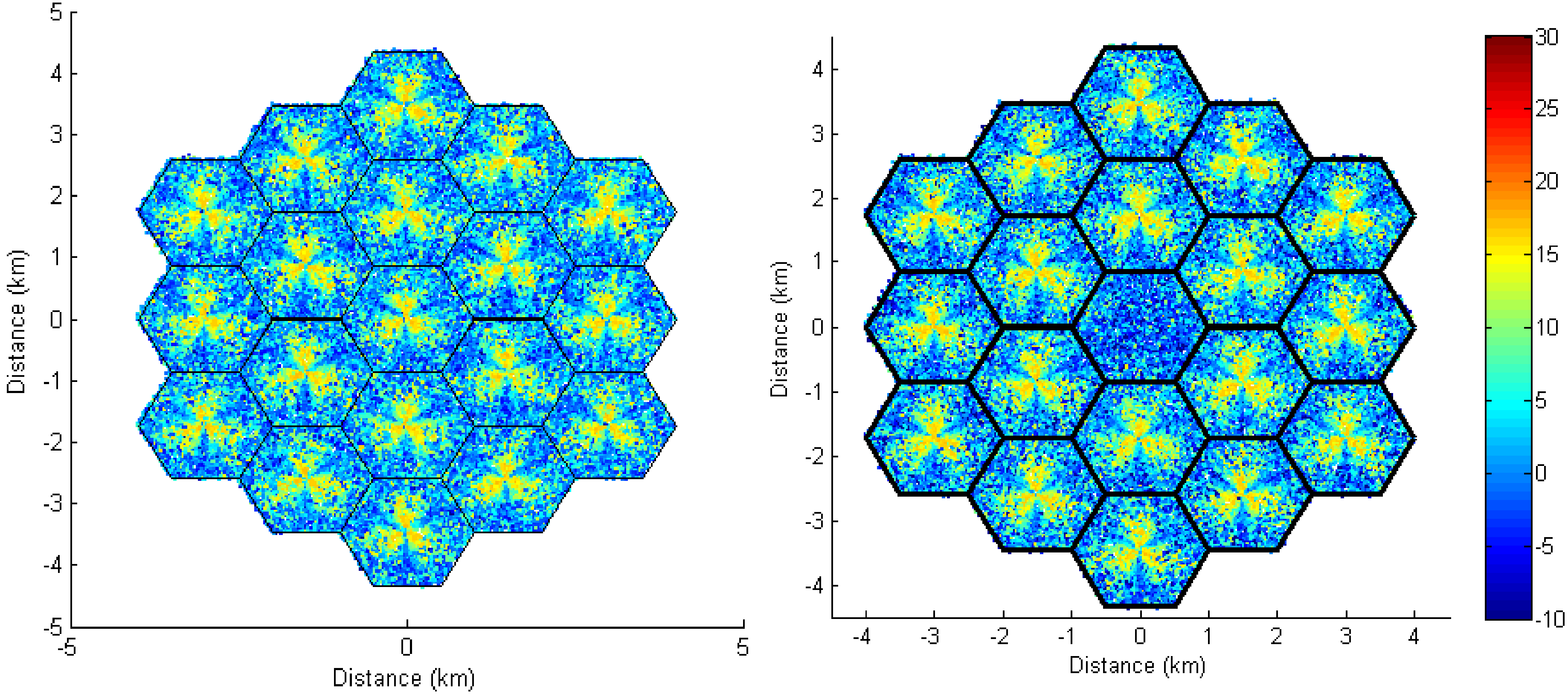
❖ 36 TPs with varying # of CSs



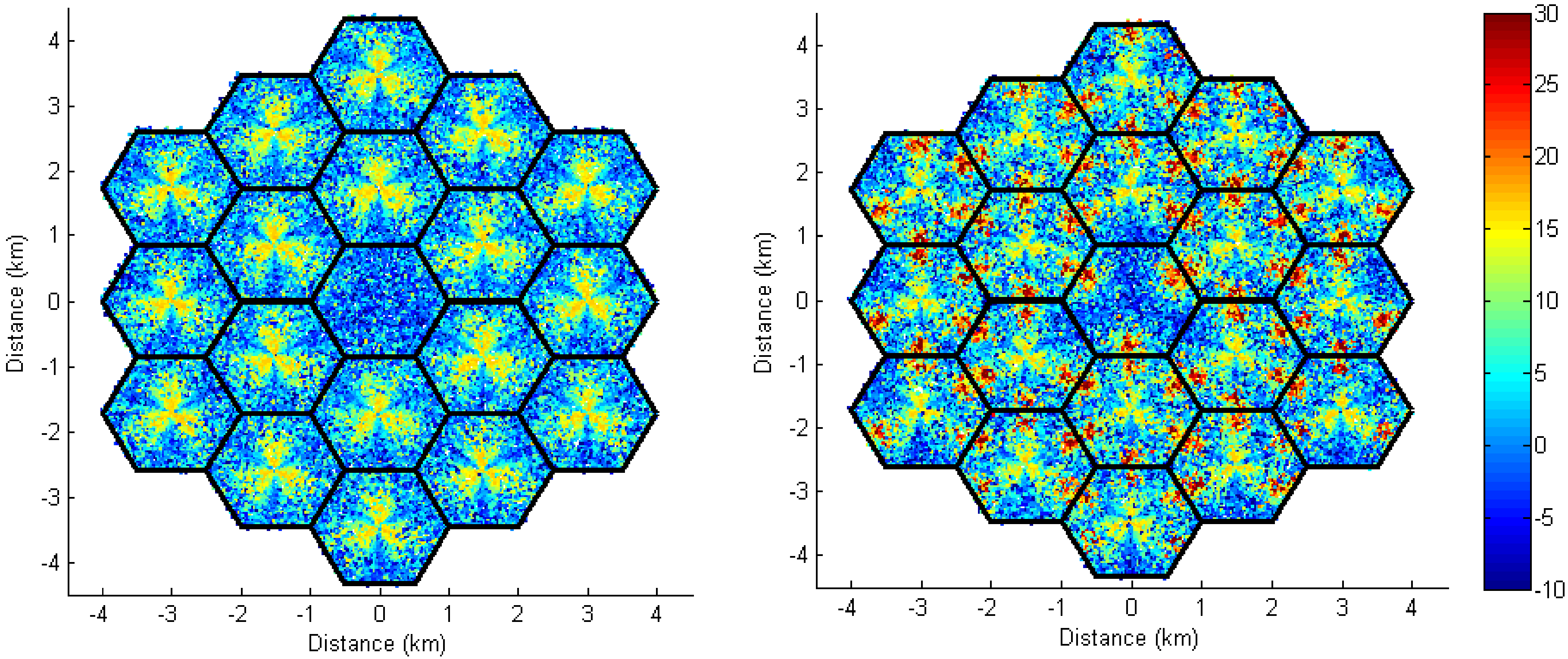
Cooperative gain increases as # of CS increases

Switch Off Cell 0

❖ Geometry



Solution (1) – Relay Station

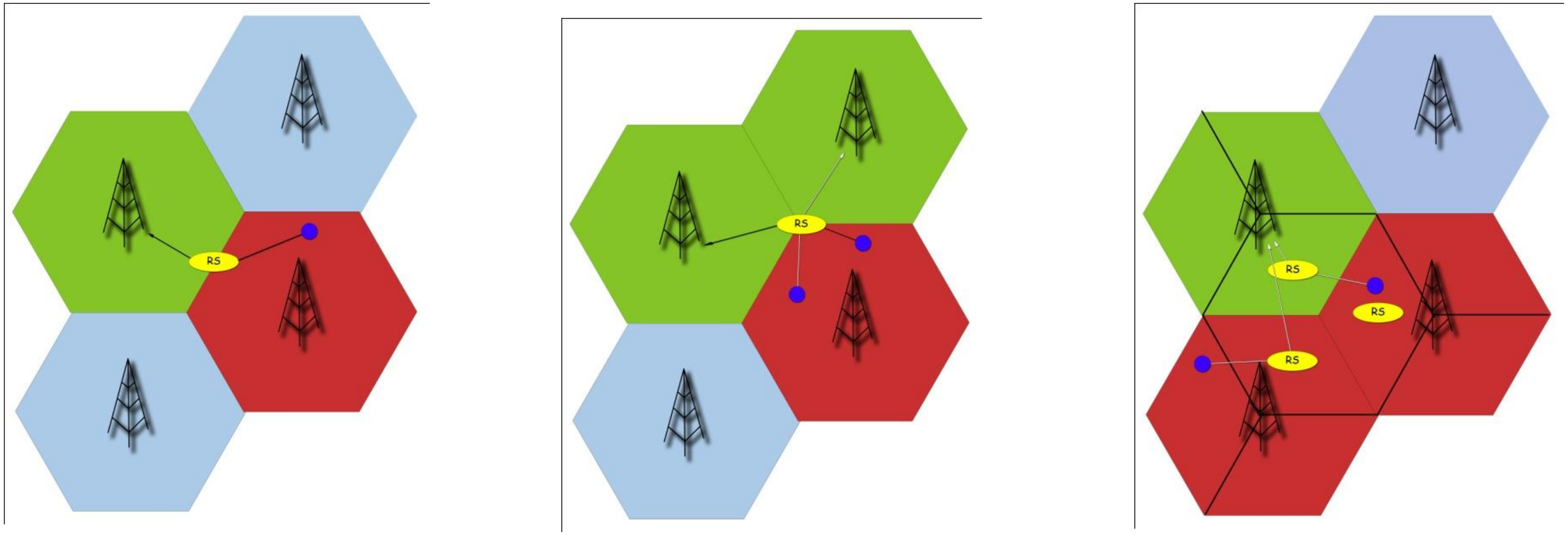


If we further consider relaying, ...

Relays for coverage extension ***(turned on only when one or more, but not all base stations it is associated with, are off)***

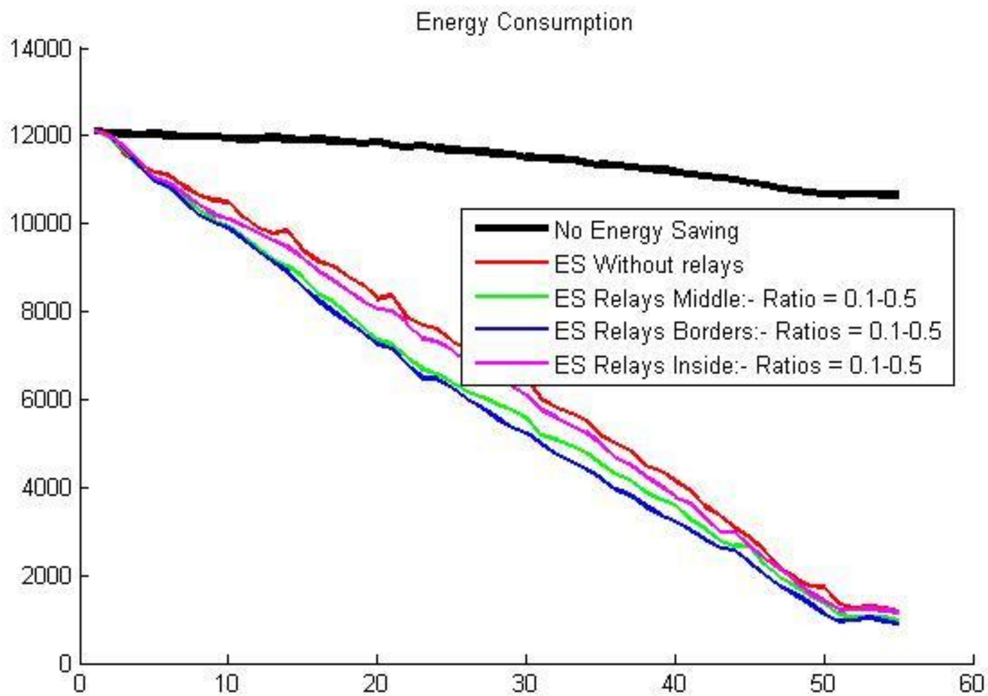
Question: how to deploy relays?

(1) in the middle of the cell border of 2 base stations
(2) in the corner of cell borders of 3 base stations
(3) inside the tri-sector cells



Energy Saving Performance

Uniformly Distributed Traffic Case:



Compared with no ES scheme:

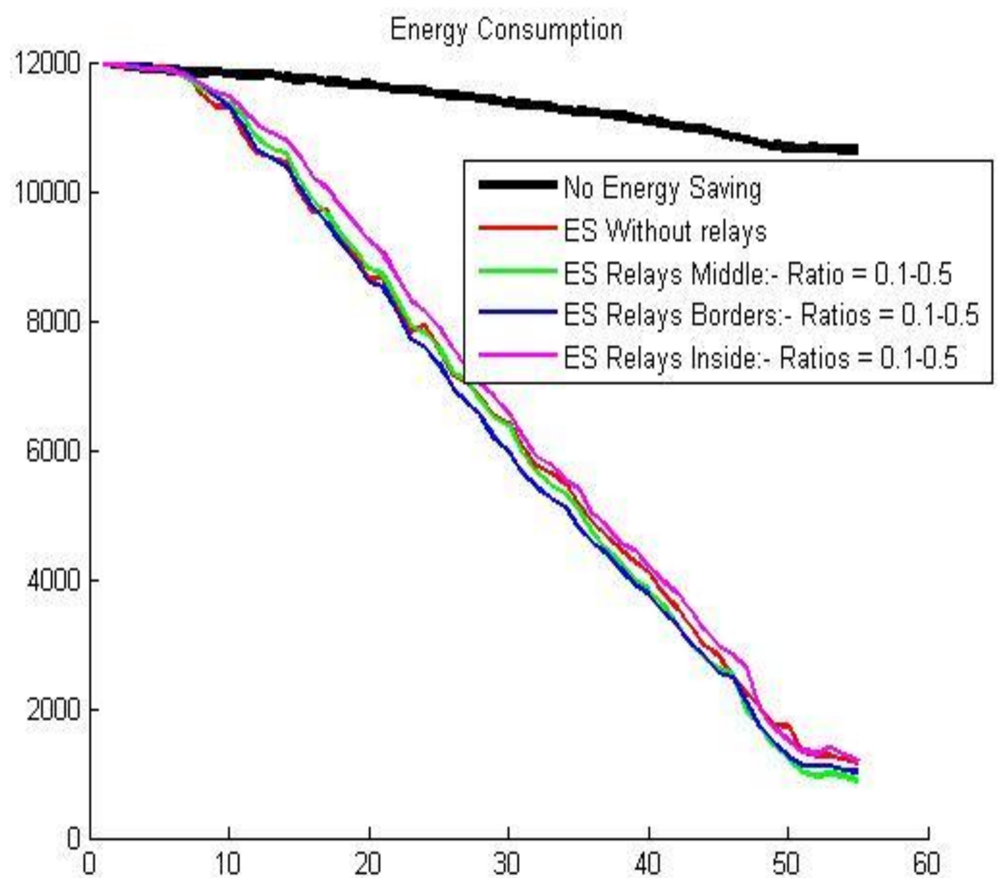
- No Relays = 43.8%
- Relays Middle = 48.6%
- Relays Corner = 50.2%
- Relays Inside = 45.7%

Compared with no relaying case:

- Relays Middle = 10.7%
- Relays Corner = 14.9%
- Relays Inside = 4.2%

Energy Saving Performance

Non-Uniformly Distributed Traffic Case (hot-spots):



Compared with no ES scheme:

- No Relays = 41.4%
- Relays Middle = 42%
- Relays Corner = 42%
- Relays Inside = 39.6%

Compared with no relaying case

- Relays Middle = 4.4%
- Relays Corner = 4.9%
- Relays Inside = -3.5%

Selected Published Papers

[1] **Zhisheng Niu, Sheng Zhou, Yao Hua, Qian Zhang, and Dongxu Cao, "Energy-aware Network Planning for Wireless Cellular System with Inter-cell Cooperation",** ***Submitted to IEEE Trans. Wireless Commun., 2010***

[2] S. Zhou, J. Gong, Z. Niu, Y. Jia, and P. Yang, "A decentralized framework for dynamic downlink base station cooperation," *IEEE Globecom'09*, Dec. 2009.

[3] S. Zhou, J. Gong, Z. Yang, Z. Niu, P. Yang, "Green Mobile Access Network with Dynamic Base Station Energy Saving", *ACM MobiCom2009 (Poster)*, Beijing, China, Sep. 2009

[4] F. Zhu, Z. Niu, "Delay Analysis for Sleep-Based Power Saving Mechanisms with Downlink and Uplink Traffic", *IEEE Commun. Letters*, 2009

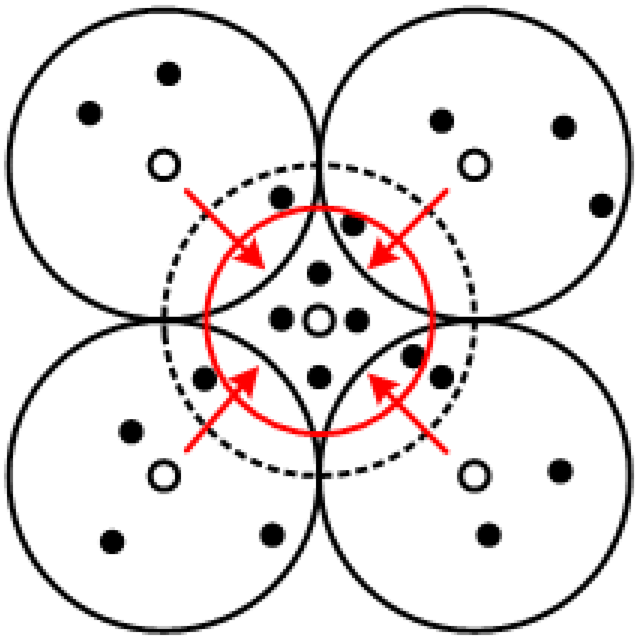
[10] E. Oh, B. Krishnamachari, X. Liu, and Z. Niu, "Towards Dynamic Energy-Efficient Operation of Cellular Network Infrastructure", to appear at *IEEE Commun. Mag.,* June 2011

Content

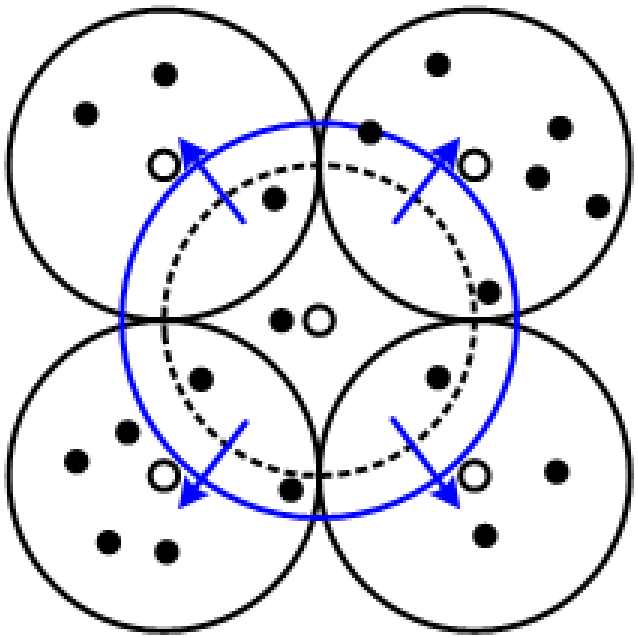
- Why and What's GREEN?
  - *Grand Challenge of Mobile Communication in 2020*
  - *GREEN: Globally Resource-optimized and Energy-Efficient Networks*
- Paradigm Shift to GREEN
  - *TANGO: Traffic Aware Network planning and Green Operation*
  - *CHORUS: Collaborative & Harmonized Open Radio Ubiquitous System*
- Dynamic Cell Planning for GREEN
  - Energy-aware network planning with inter-cell cooperation
- **Self-Organization for GREEN**
  - **Cell Zooming and Dynamic BS Sleeping Control**
- **Conclusion**

A New SoN Scheme: Cell Zooming

- **Cell zooming for load balancing**



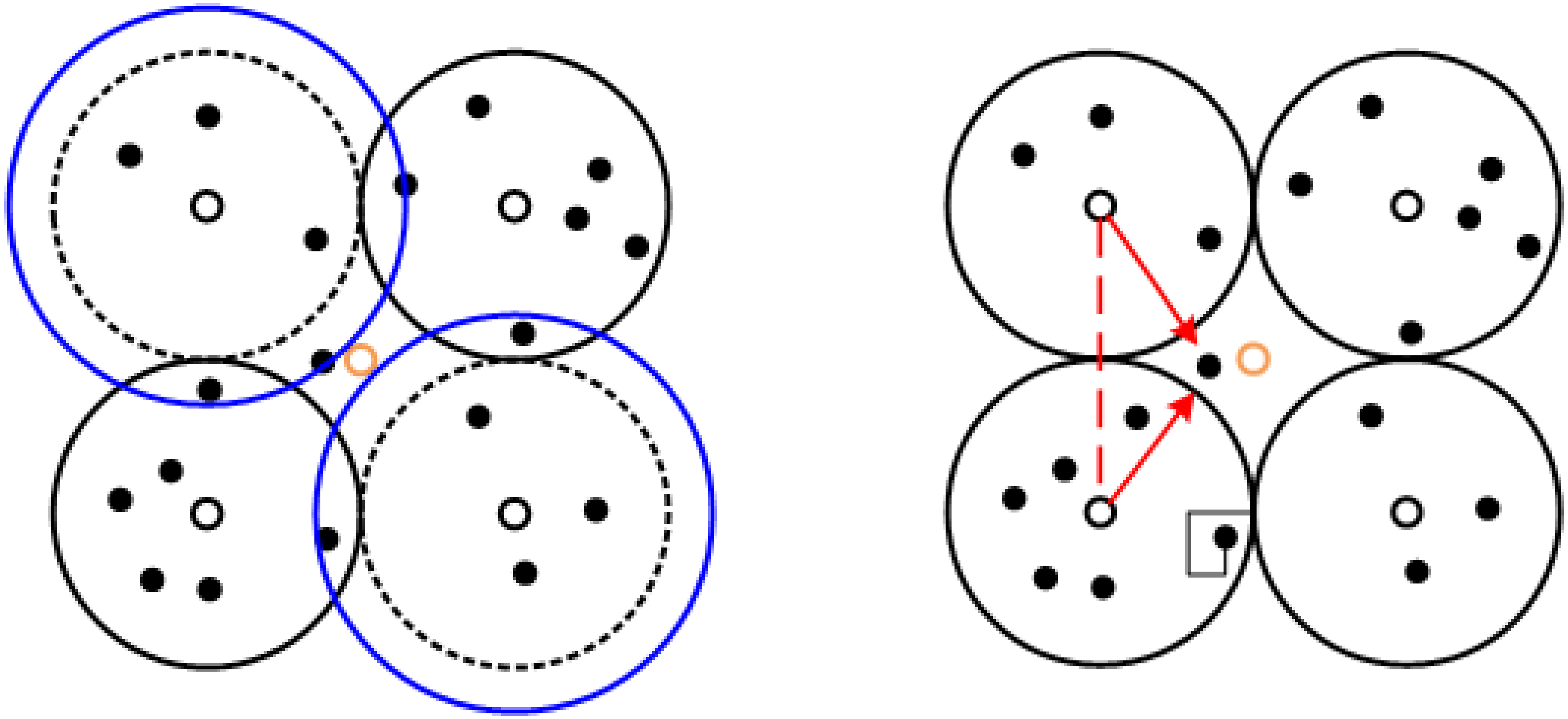
Central cell zooms in as traffic load increases



Central cell zooms out as traffic load decreases

Cell Zooming by Dynamic Association Control

- **Cell zooming for energy saving**

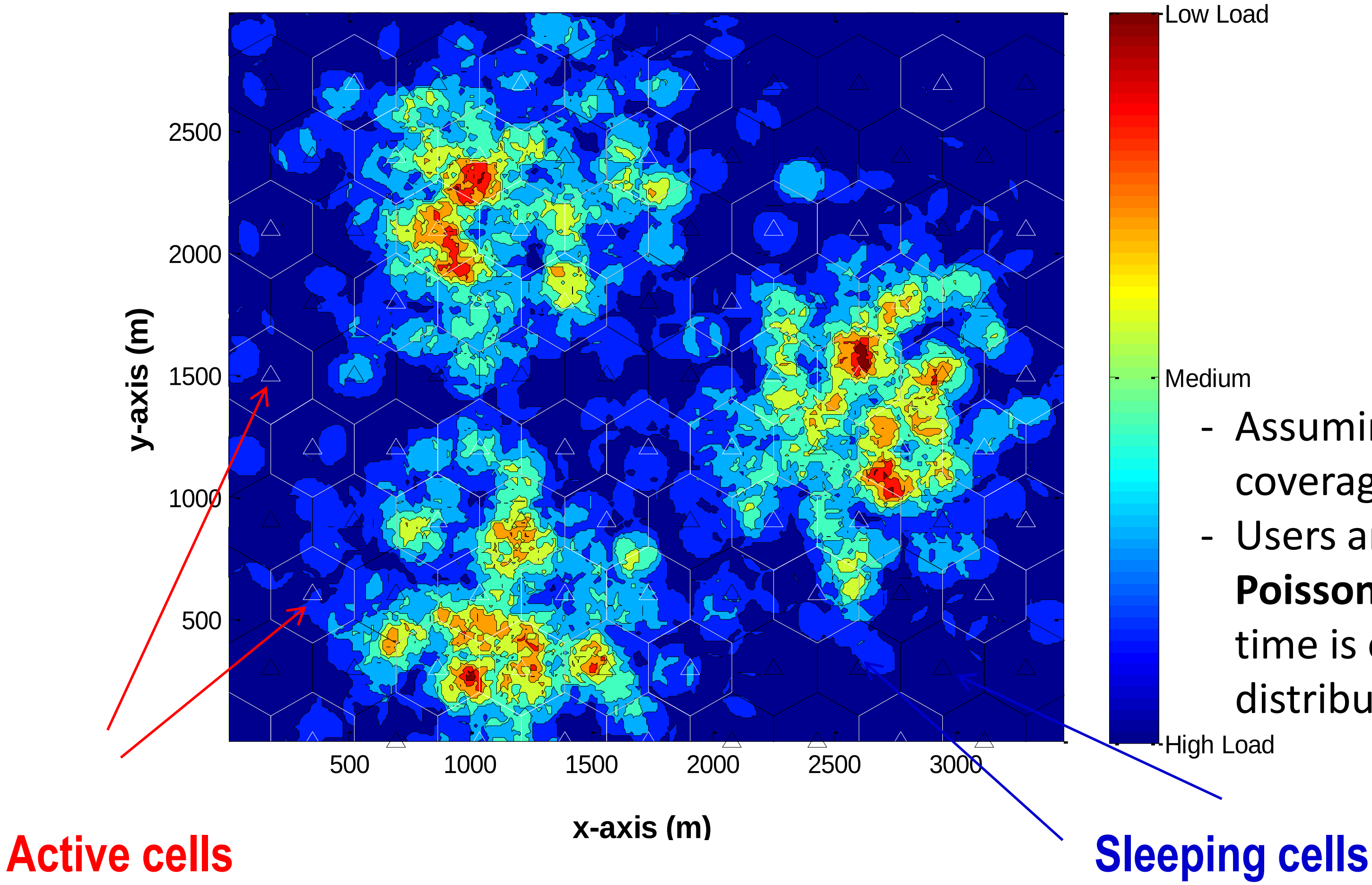


Central cell sleeps, and other cells zoom out

Central cell sleeps, and other cell cooperate to transmit

Cell Zooming for Energy Saving

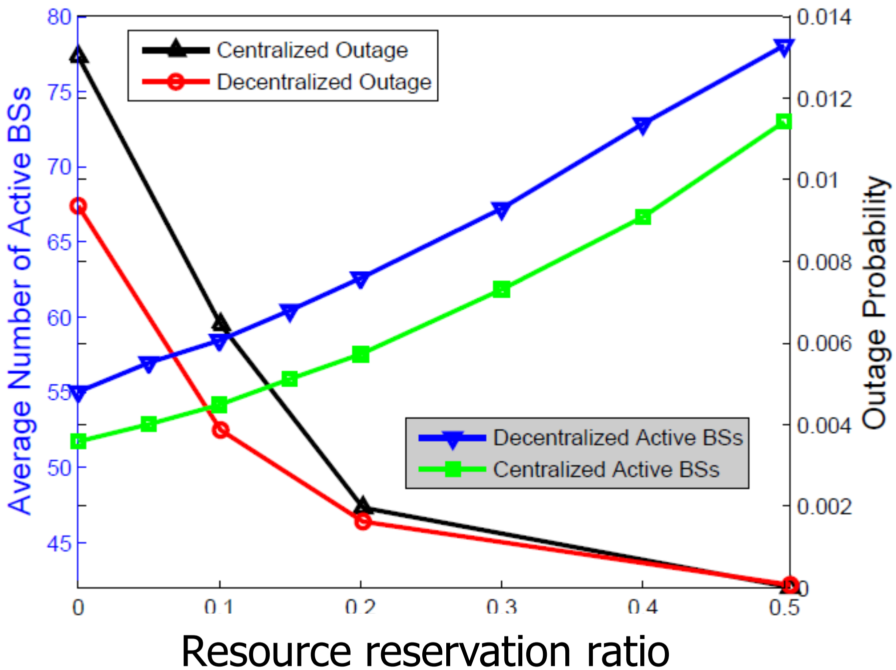
❖ A snapshot of BS sleeping pattern



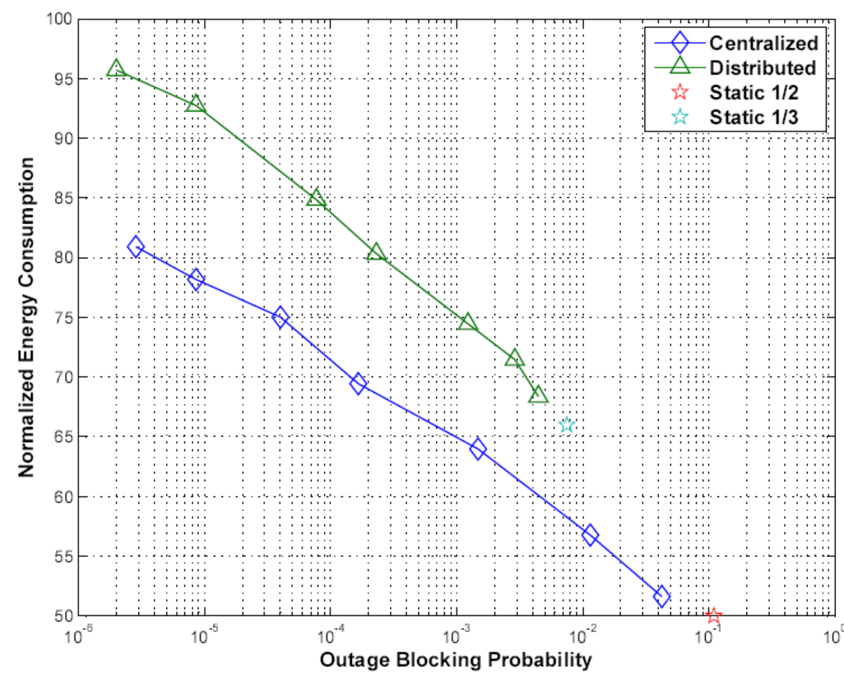
- Assuming BSs can extend coverage from **200m** to **400m**
- Users arrive according to **Poisson** Process and service time is **exponentially** distributed

Tradeoff between Energy and QoS

- Centralized and Decentralized algorithms
- Outage Probability vs. Number of active BSs in low traffic conditions

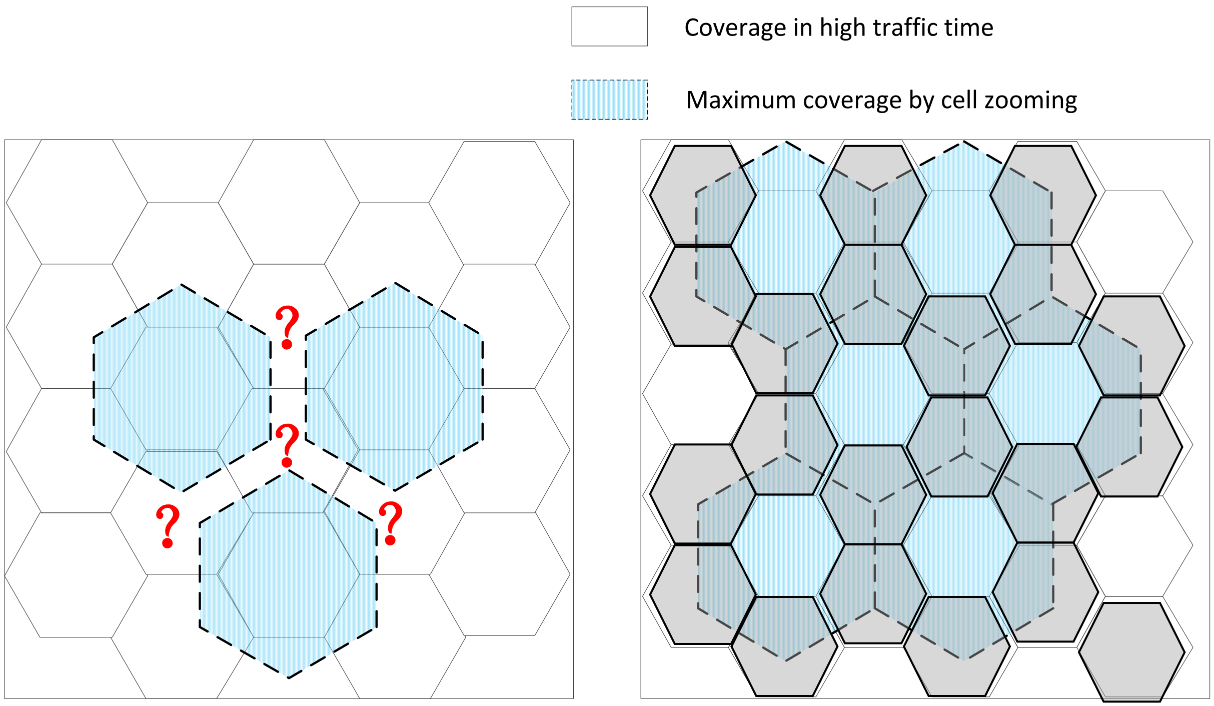


Tradeoff between ES and QoS



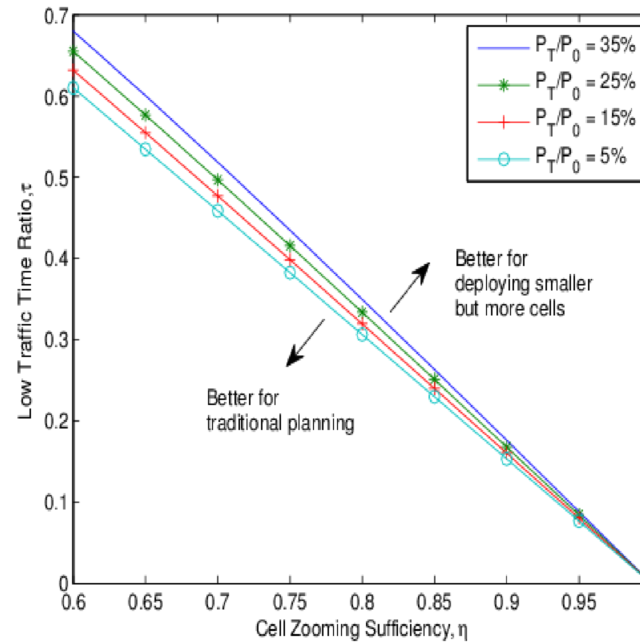
Zhisheng Niu, Yiqun Wu, Jie Gong and Zexi Yang: "Cell Zooming for Cost-Efficient Green Cellular Networks", IEEE Com. Mag., Nov. 2010

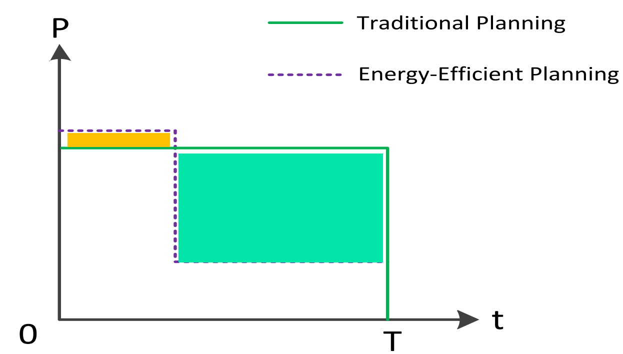
Dynamic Cell Planning under Insufficient Zooming



Traditional planning

Deploying smaller but more cells



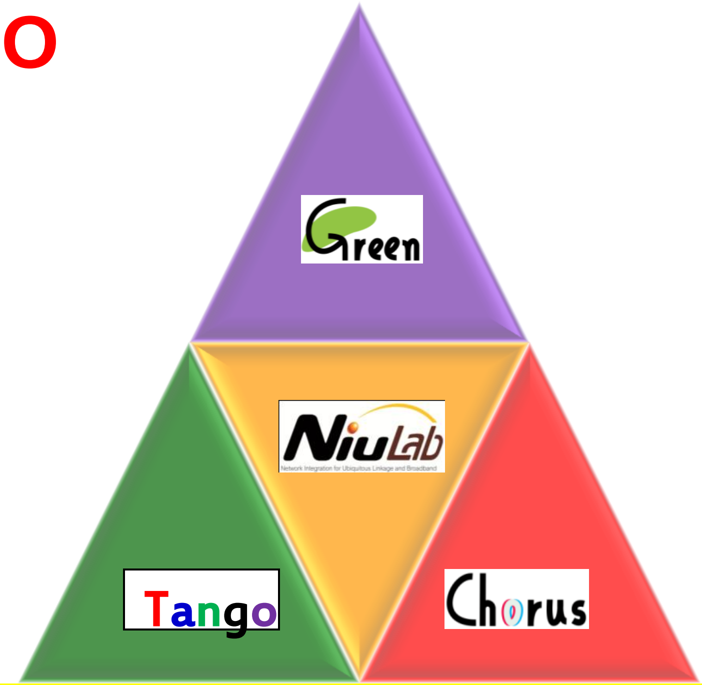


X. Weng, D. Cao, Z. Niu, **"Energy-Efficient Cellular Network Planning under Insufficient Cell Zooming"**, ***Greenet Workshop at IEEE VTC2011-spring***, Budapest, Hungary, May 2011.

Content

Summary

- **What's Green?**
  - **GREEN**: ***G**lobally **R**esource-optimized and **E**nergy-**E**fficient **N**etworks*
- **Paradigm Shift to GREEN**
  - **CHORUS**: ***C**ollaborative & **H**armonized **O**pen **R**adio **U**biquitous **S**ystem*
  - **TANGO**: ***T**raffic **A**ware **N**etwork planning and **G**reen **O**peration*
- **Key Approaches to TANGO**
  - **Coverage on-demand**
  - **Resource on-demand**
  - **Service on-demand**



http://network.ee.tsinghua.edu.cn