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# **TANGO: Traffic-Aware Network Planning and Green Operation**

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## ❖ 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

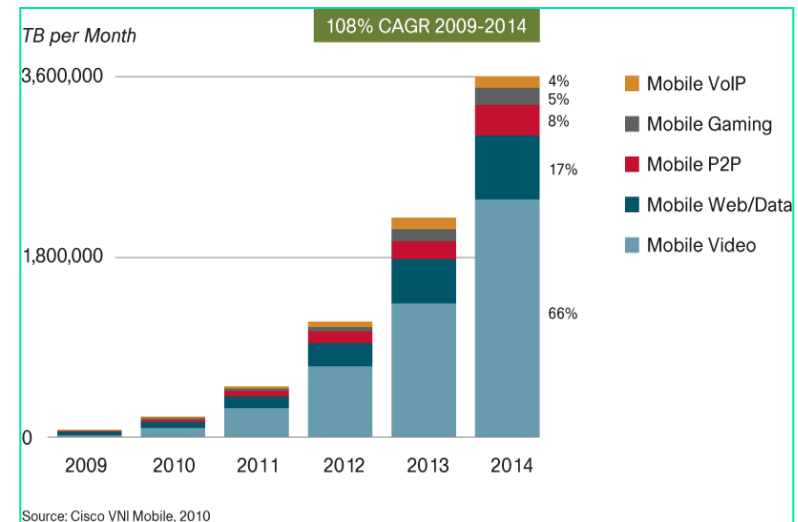
- Mobile Internet booms
- Smart phones with DTV reception

## ❖ Personalized services

- 1G (80s) → 2G (90s) → 3G (00s) → 4G (10s) → **mG?** (20s)
- mG = **MY** (*personalized*) services?

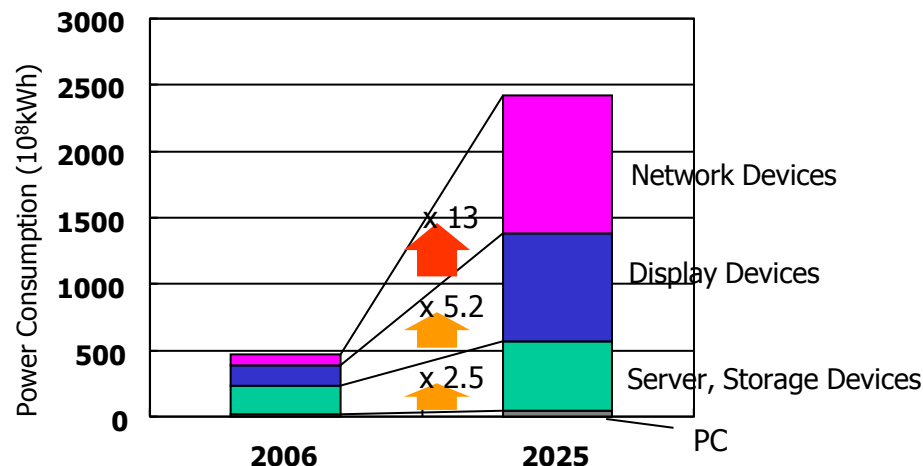


Trillion's Wireless devices



# 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

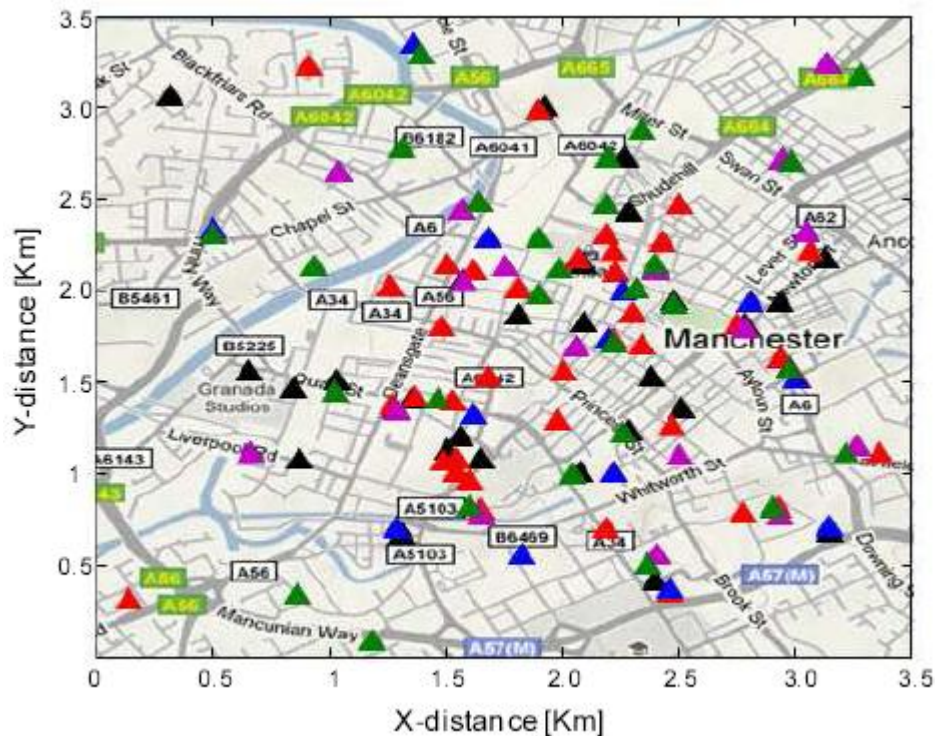
## ❖ Key challenge

- 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**?

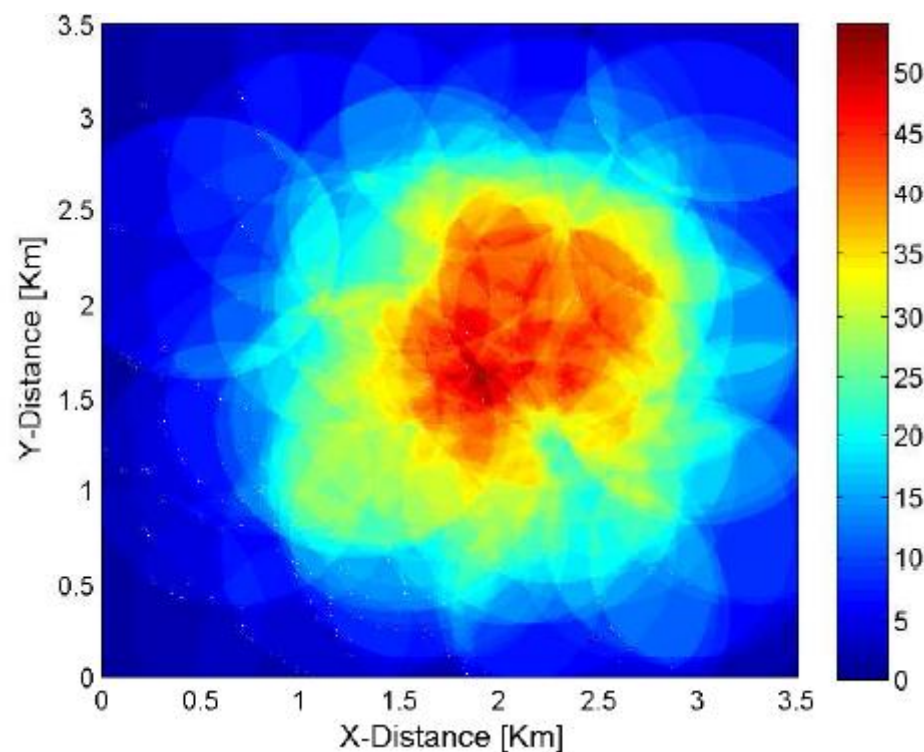
## ❖ Hence, **Green** is not just low (transmitting) power, or high energy-efficiency (EE), but a **holistic** approach with **paradigm shift**

- **GREEN: Globally Resource-optimized & Energy-Efficient Networks**

# Redundant Overlap in Coverage



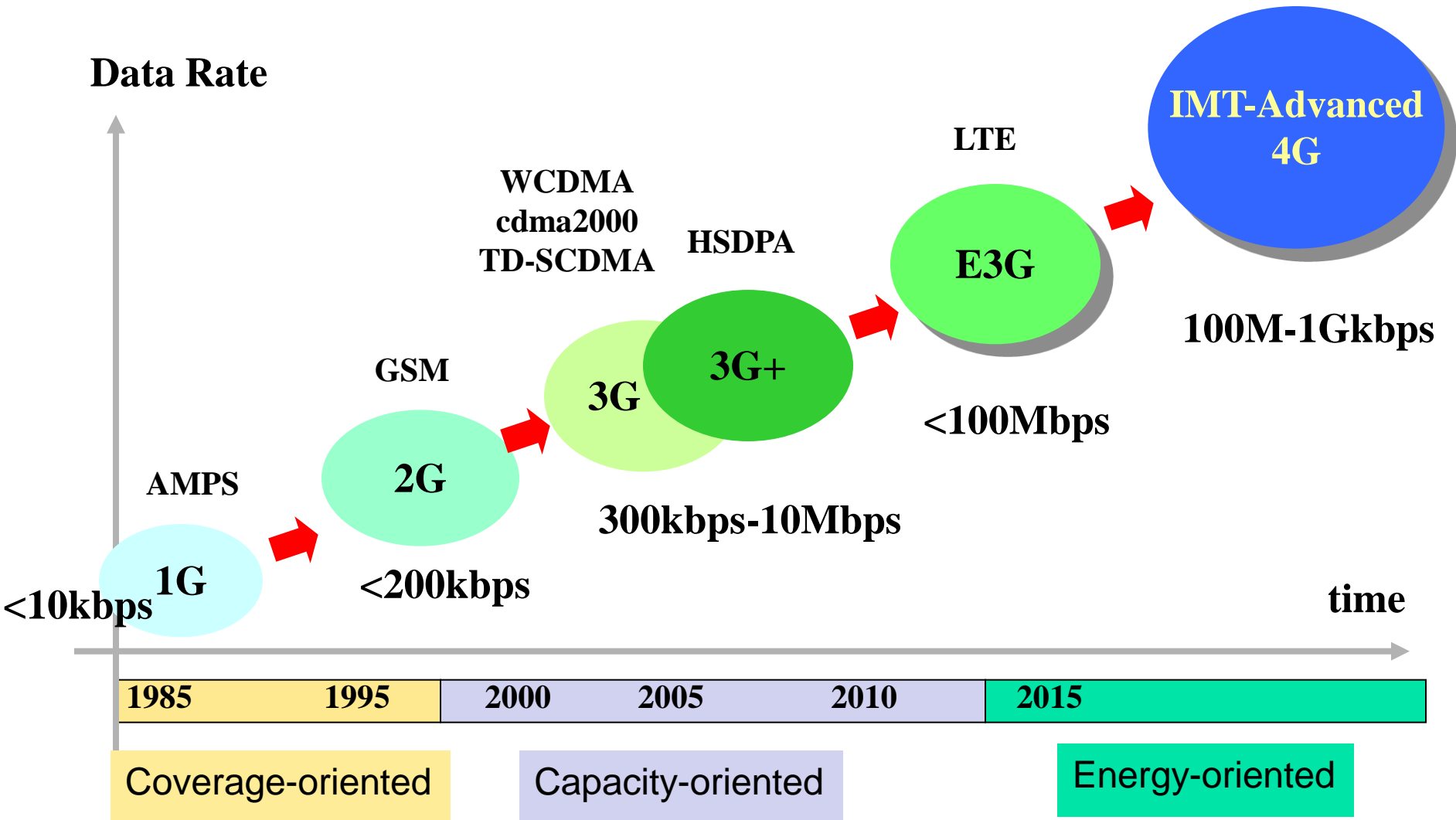
BS location data from a part of Manchester, UK. (Some base stations are collocated, in which case just one triangle is shown on the map.)



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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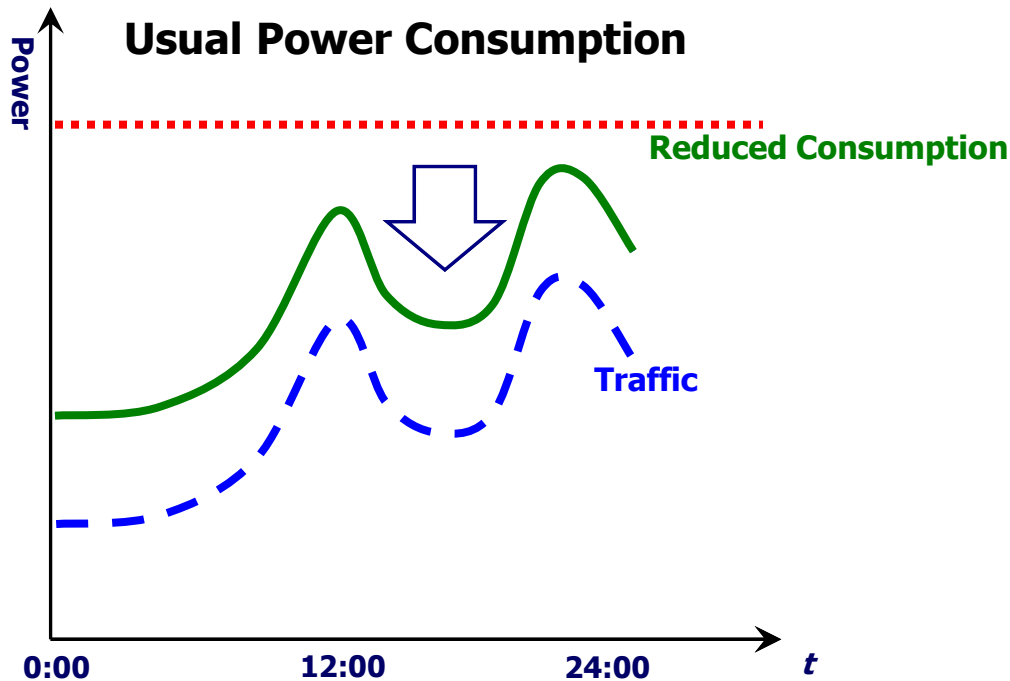
## ❖ Conclusion



# Paradigm Shift to GREEN (2)

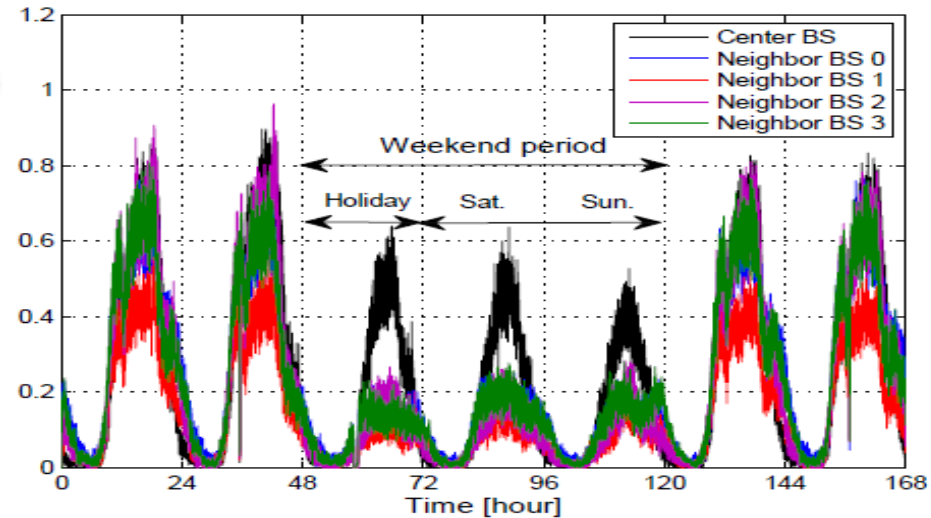
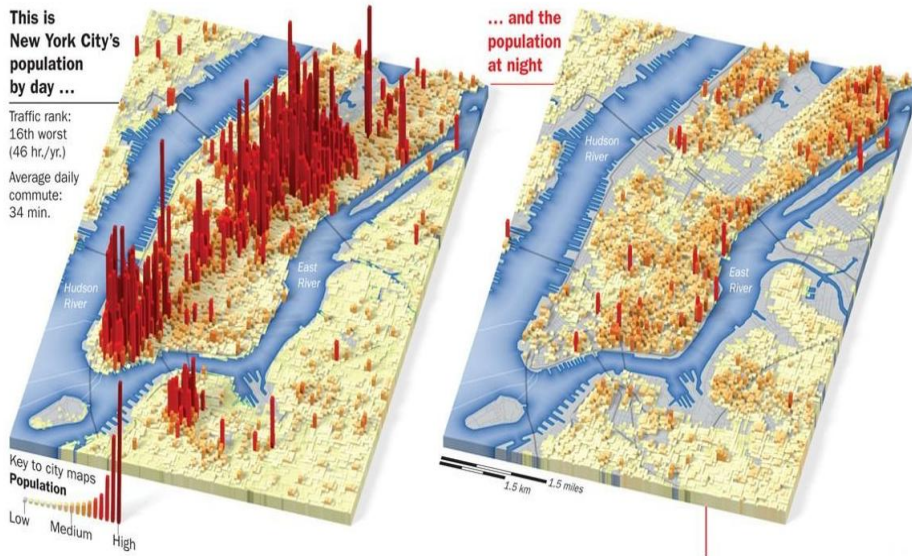
## ◆ **Tango**: Traffic-aware network planning & green operation

- Adapted to traffic volume (*daily and weekly*)
- Adapted to traffic characteristics (*unicast, multicast, broadcast*)
- Adapted to QoS requirements (*realtime, nonrealtime*)



# Understanding the Traffic

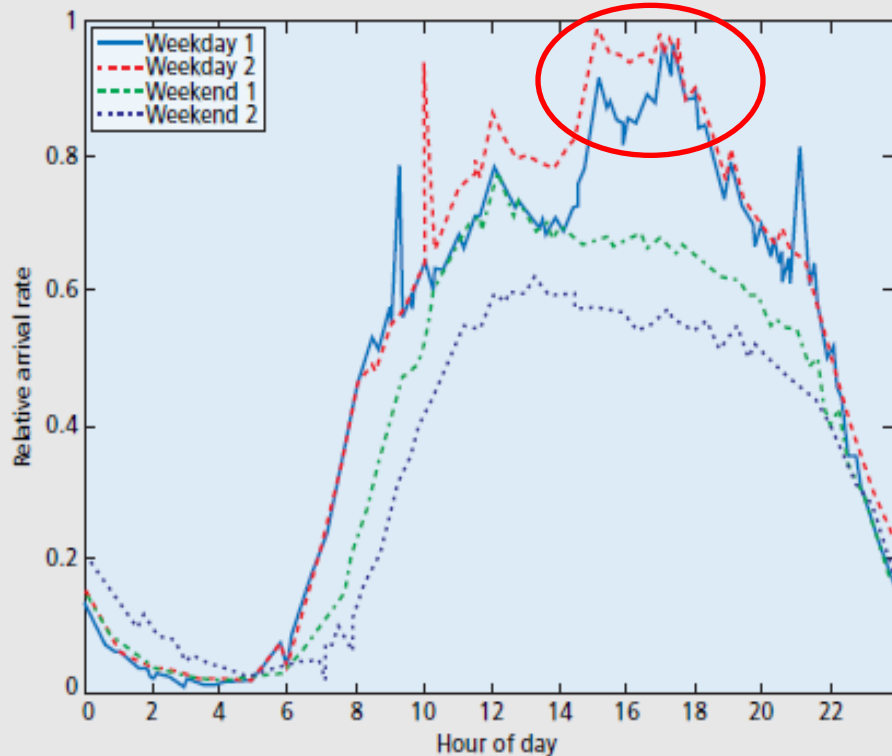
- ❖ **Dynamics in time-domain (*large- and small-scale*)**
  - day and night, weekday and weekend
- ❖ **Dynamics in spatial domain (*getting worse as cells are getting smaller*)**
  - hot cells and cool cells



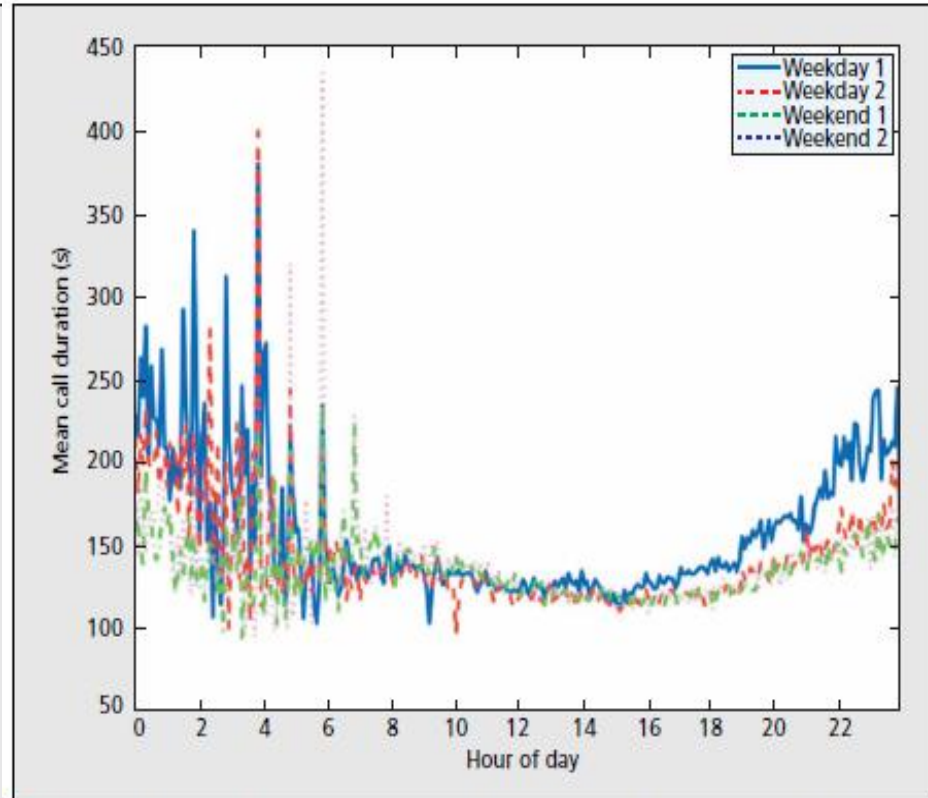
E. Oh, B. Krishnamachari, X. Liu, and Z. Niu, "Towards Dynamic Energy-Efficient Operation of Cellular Network Infrastructure", to appear in *IEEE Commun. Mag.*, June 2011

# 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.

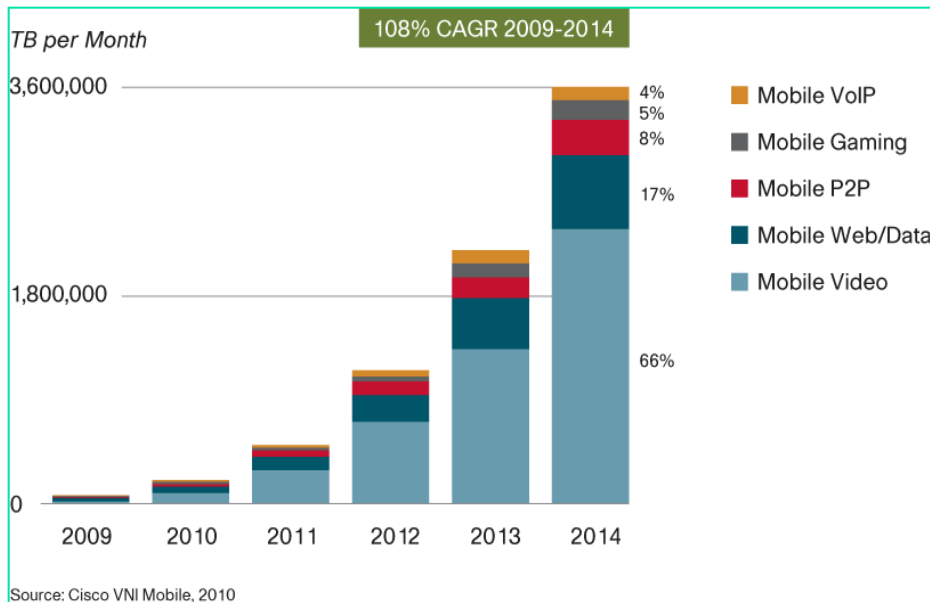


■ Figure 3. Distribution of average call duration over 5-min periods during four different days. The large spikes during the mornings are due to small gaps in collection.

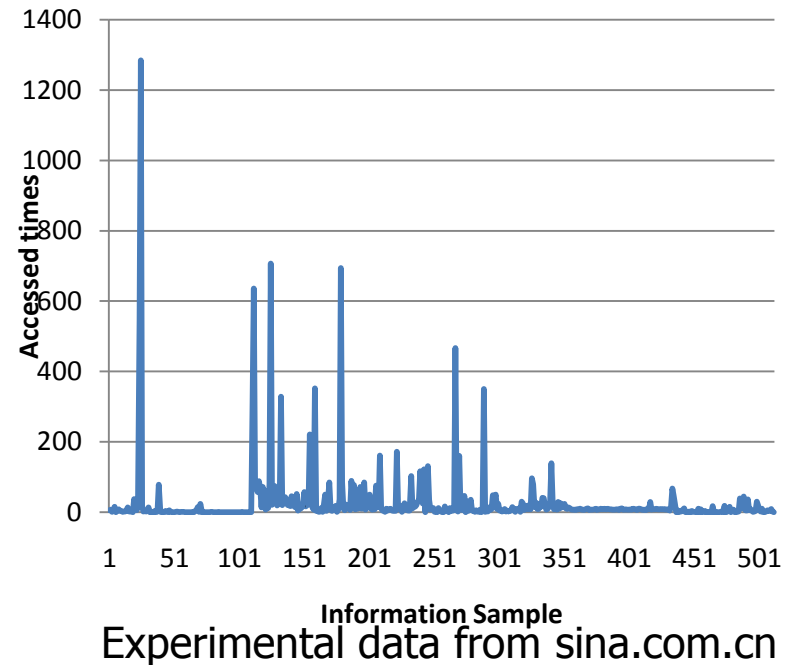
D. Willkomm, S. Machiraju and J. Bolot, Adam Wolisz, "Primary User Behavior in Cellular Networks and Implications for Dynamic Spectrum Access", *IEEE Com. Mag.*, March 2009

# 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



# 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**

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

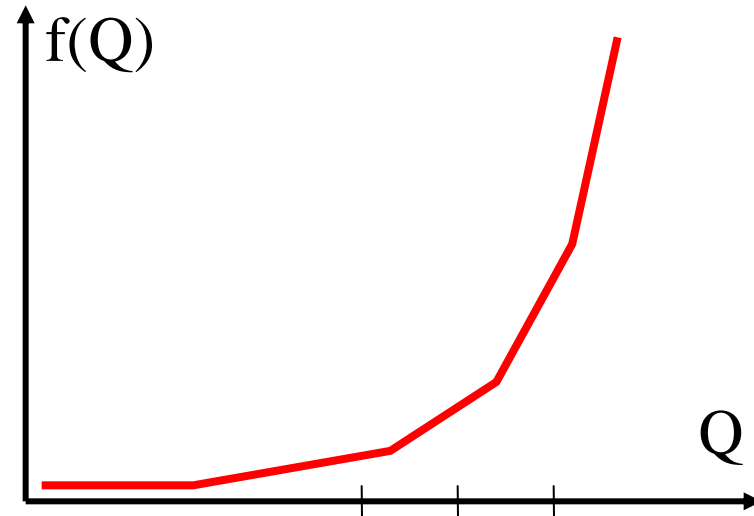
Where  $N_{\text{user}}$  = number of users;

$B_{\text{user}}$  = bandwidth/user;

$\rho$  = bandwidth utilization ratio

$A_{\text{service}}$  = service area (**coverage**);

$f(Q)$  = QoS guarantee level

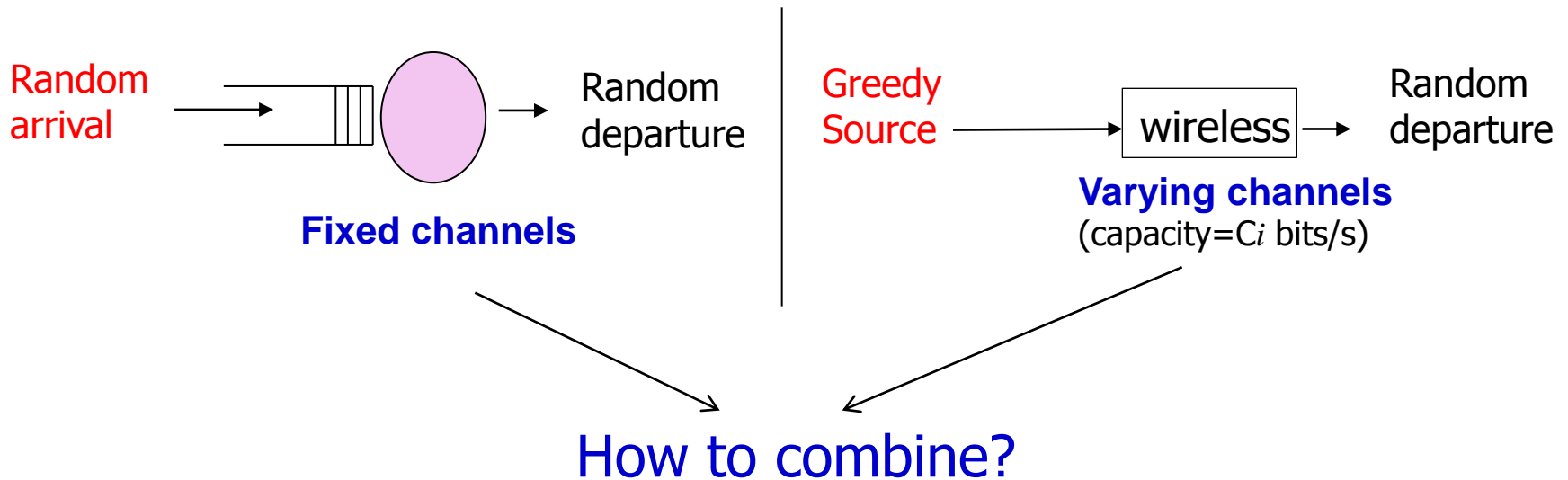
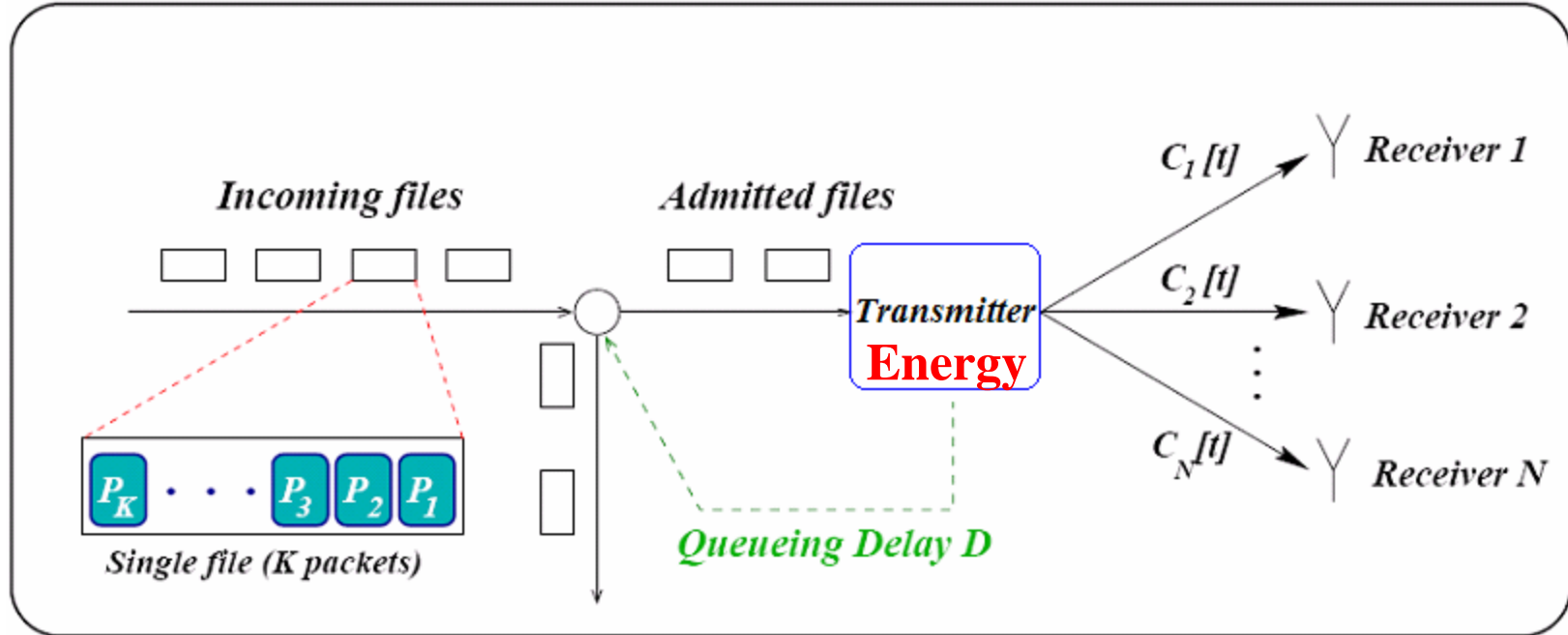


# Performance Metrics of Typical Applications

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 lost 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.

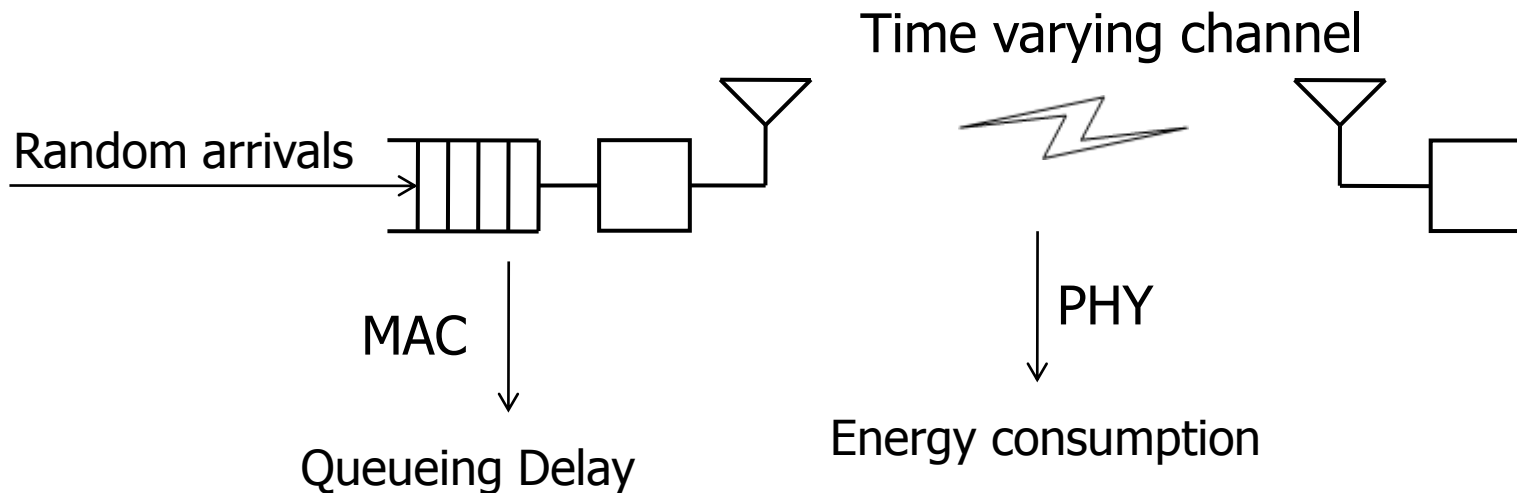
# Information Theory and Queueing Theory





# Tradeoff between EE and Delay

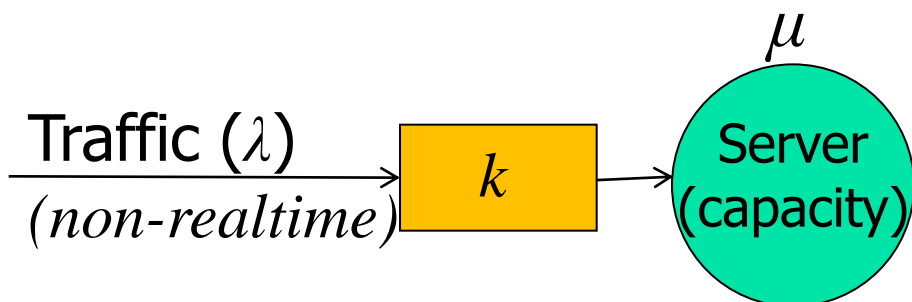
- ❖ From queueing theory: *Constant rate minimizes the delay*
  - $W_{M/D/1} = 1/2 \times W_{M/M/1}$
- ❖ From information theory: *Variable rate minimizes the energy*
  - *Water-filling maximizes the capacity*



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

Variation of channels

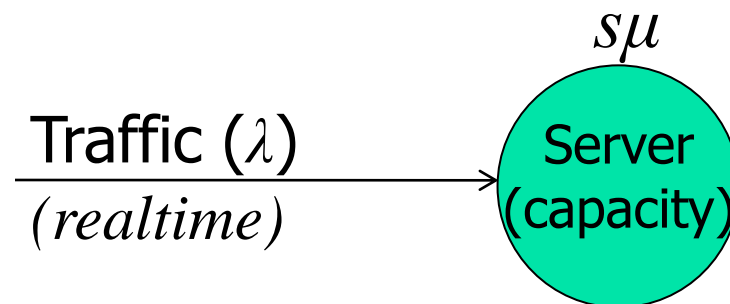
# Use delay to trade for energy?



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  $\rho_1 = \lambda/s\mu$

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



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

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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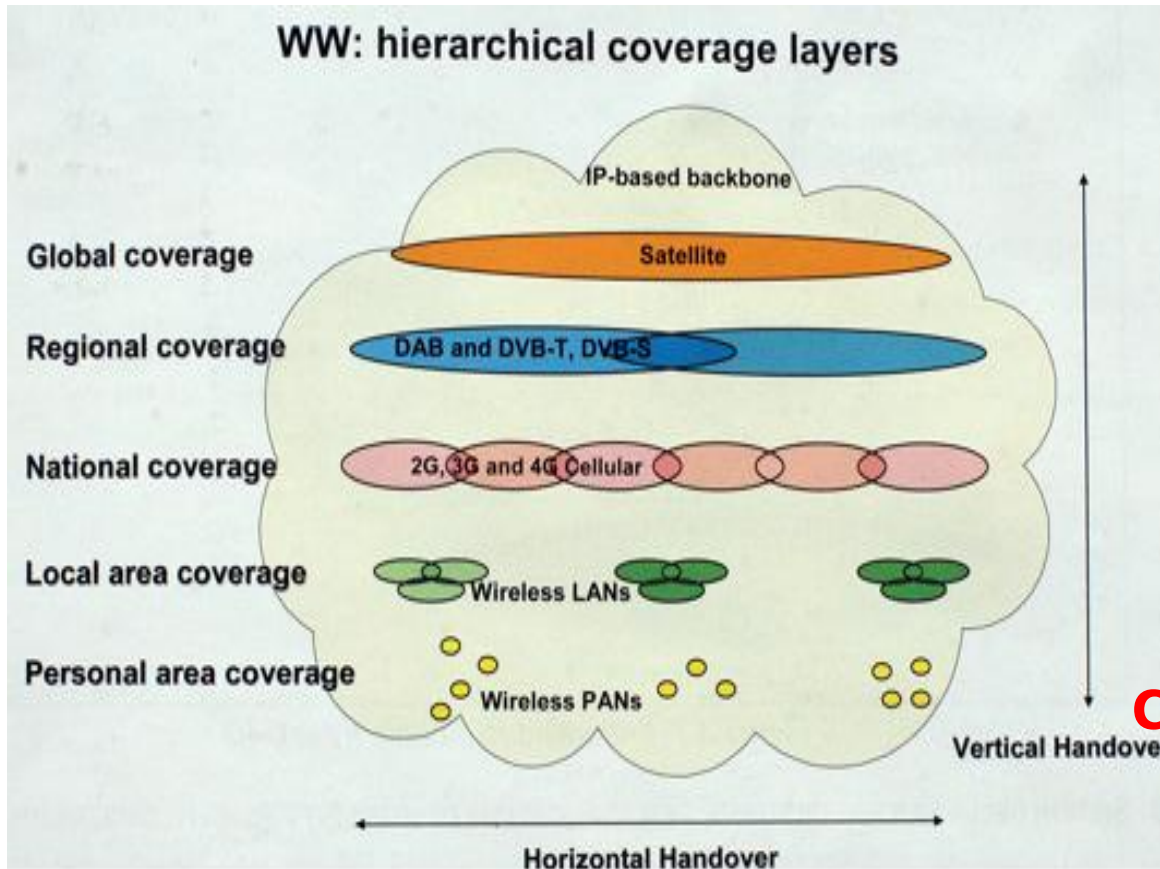
## ❖ Self-Organization for GREEN

- **Cell Zooming and Dynamic BS Sleeping Control**

## ❖ Conclusion

# 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**

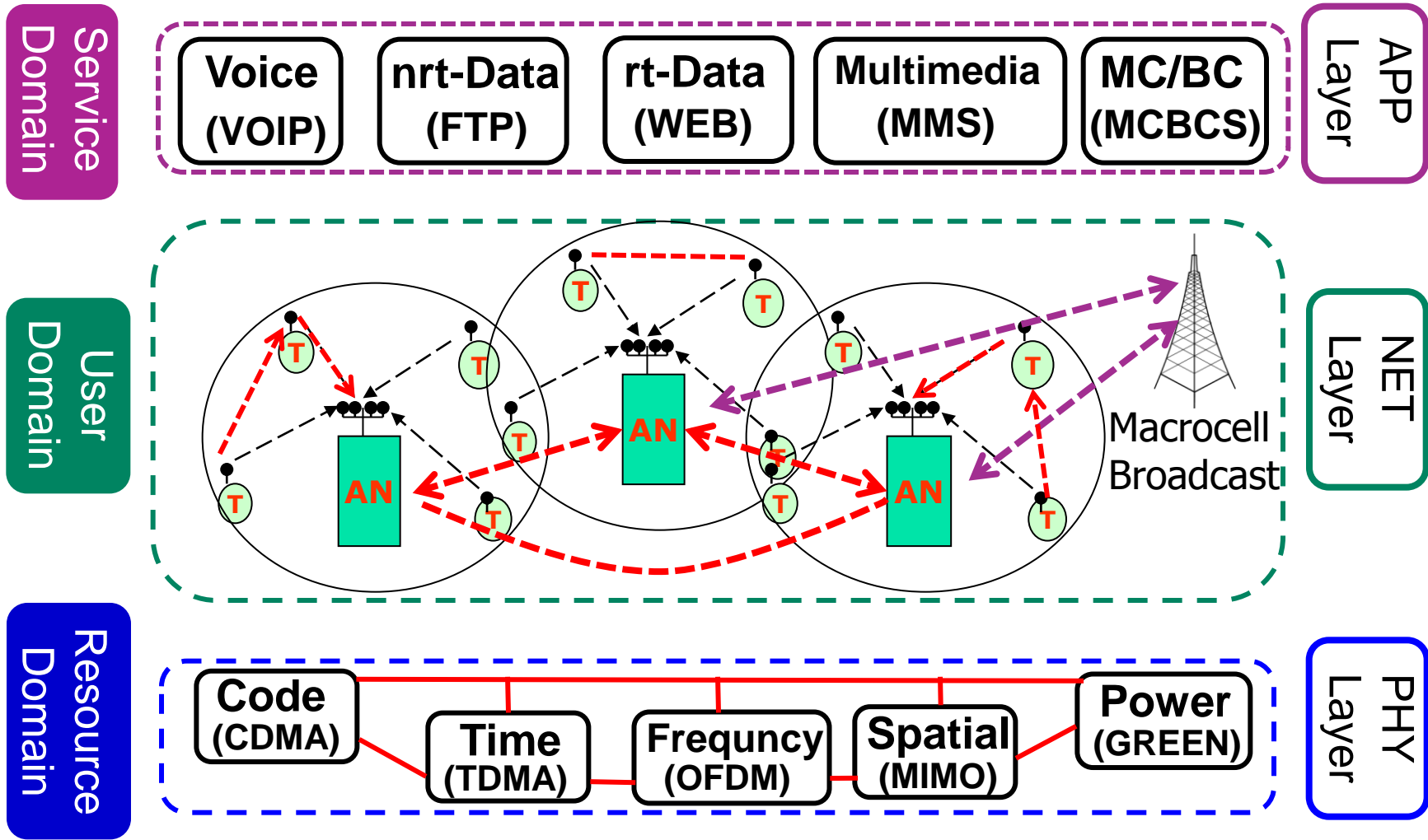


*cross-network* design

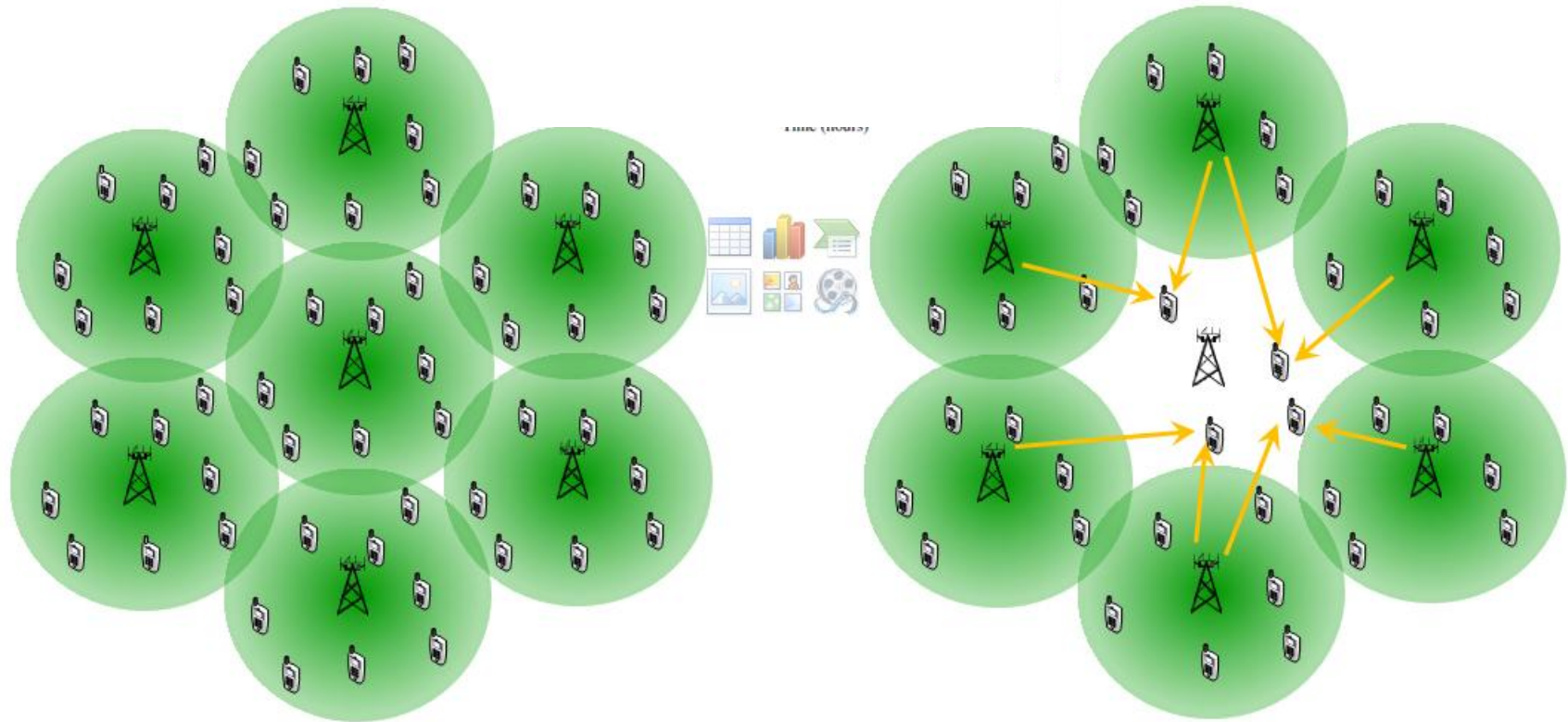
**Cooperation**

*cross-layer* design

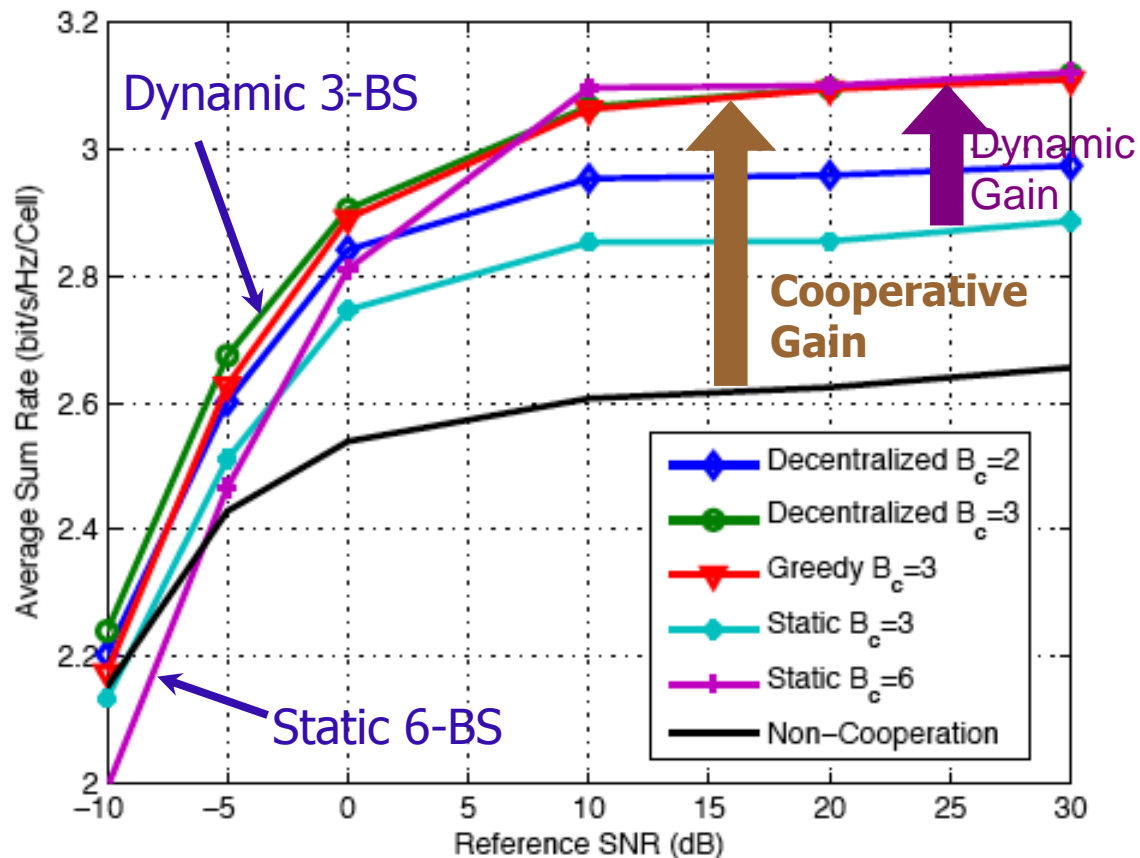
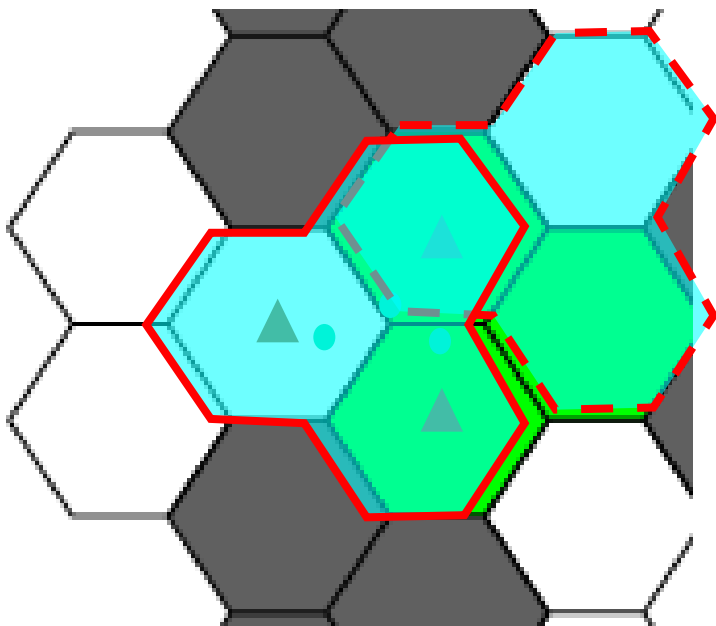
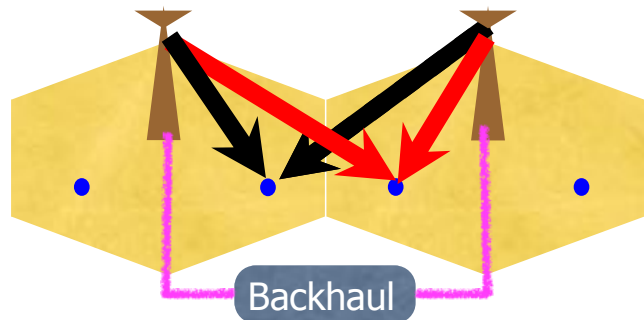
# Collaboration should be in Multi-domains



# Energy Saving by BS Cooperation



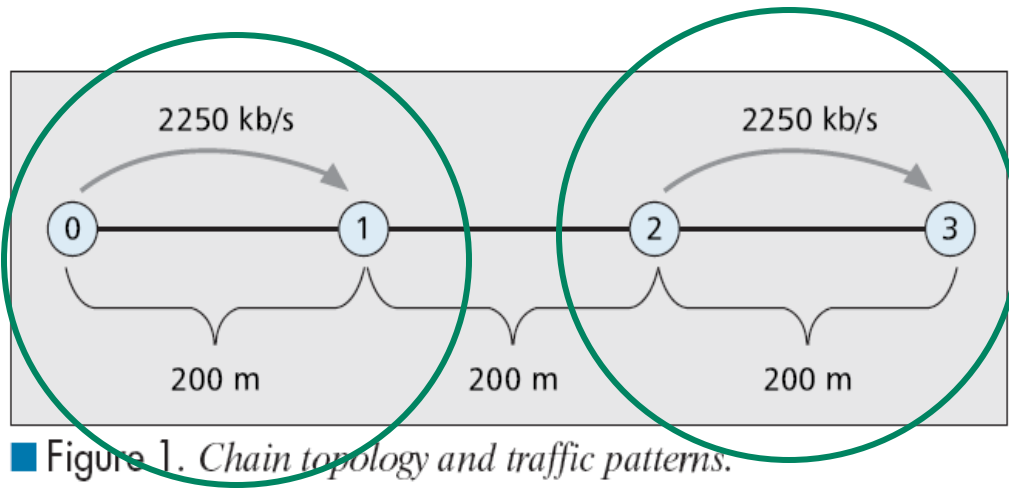
# Dynamic Clustering with Limited Feedback



[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.

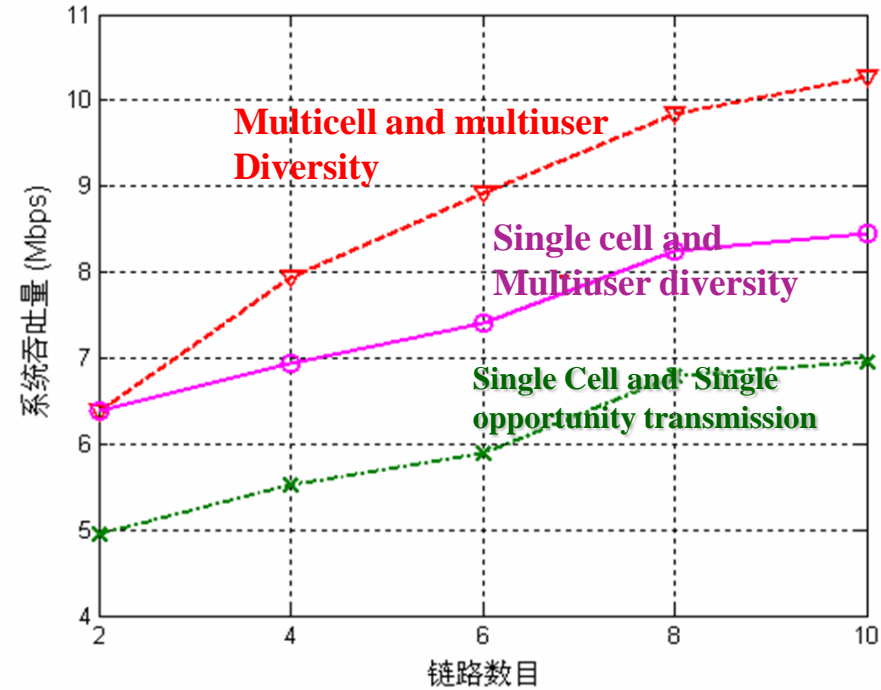
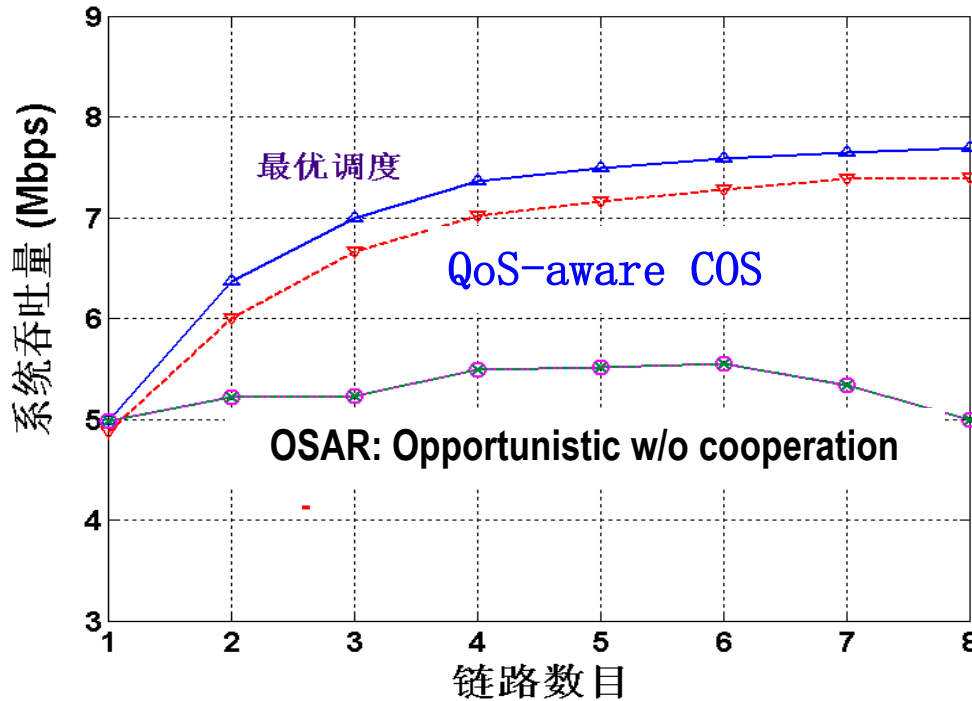
	PHY rate on (0, 1)	PHY rate on (2, 3)	Total power consumption (mW)
Non-cooperative solution	48 Mb/s	9 Mb/s	6.704
<u>Optimal solution with node cooperation</u>	18 Mb/s	18 Mb/s	2.352

■ 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. Veh. 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.

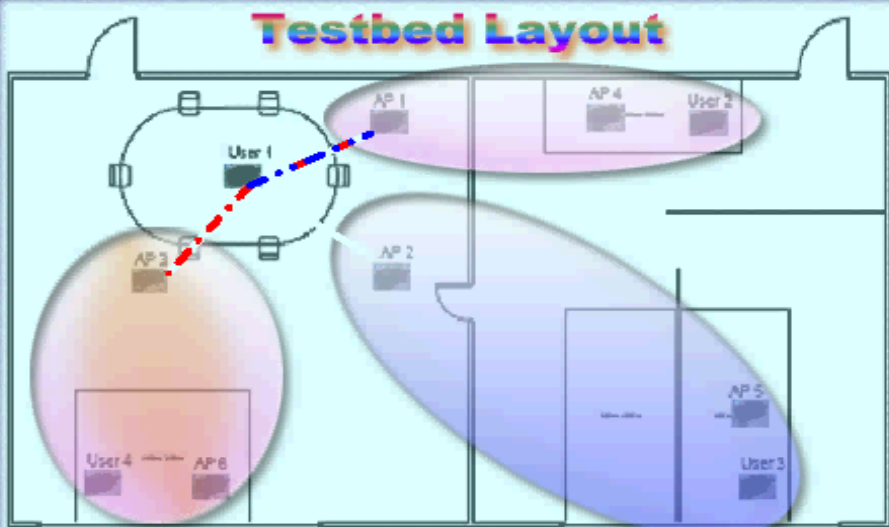
# Multi-AP Association & Collaboration



## High-Density WLAN Multi-AP Research Platform



### Testbed Layout



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

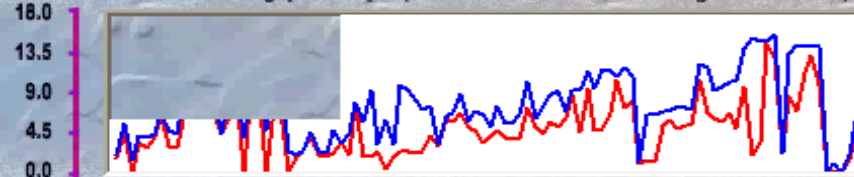
### Received Frames

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

Uplink PLR Gain ( relative:  $(P - P_0) / P_0$  )



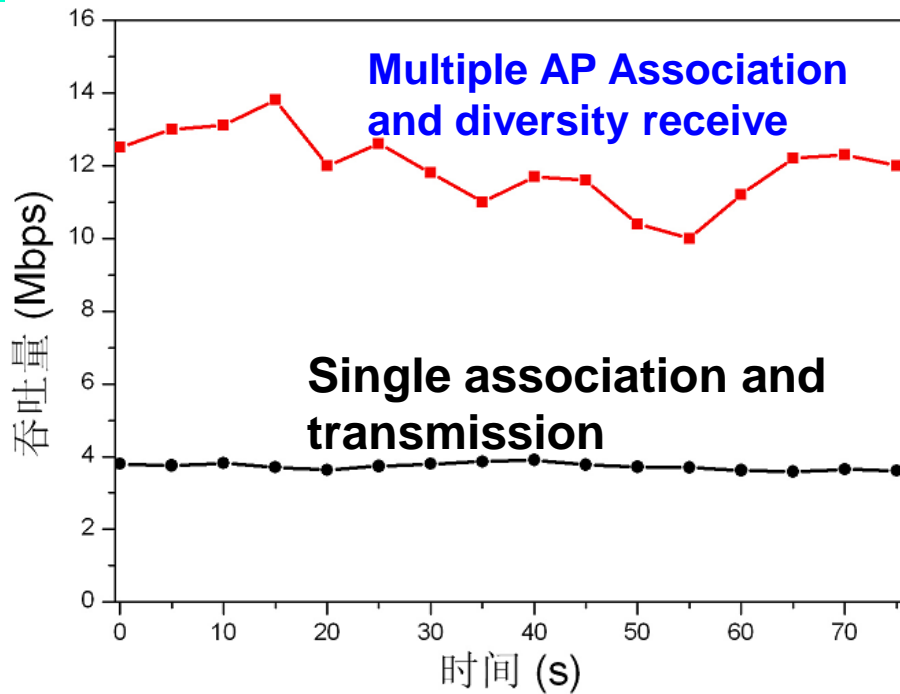
Downlink Throughput / Mbps ( RSSI-based: Red Band-usage-based: Blue)



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

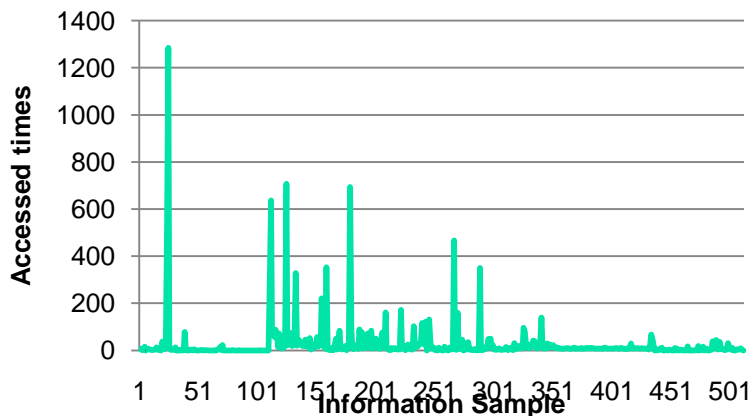


## Related Publications:

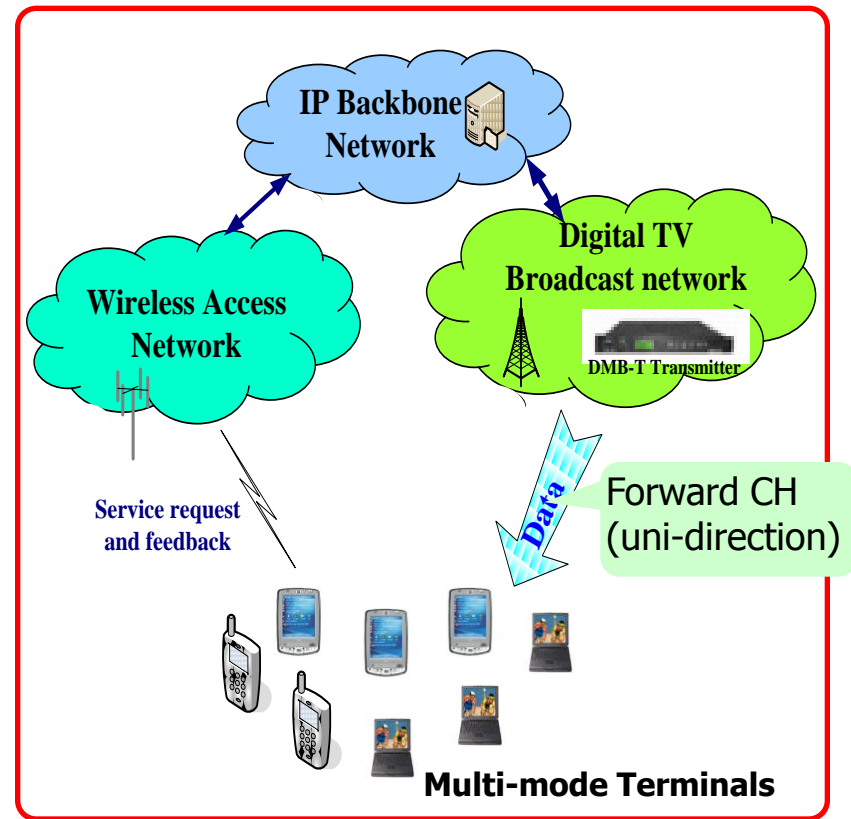
- [1] Y. Zhu, Q. Zhang, Z. Niu, and J. Zhu: "On Optimal QoS-aware Physical Carrier Sensing: Theoretical Analysis and Protocol Design", *IEEE Transactions on Wireless Communications*, pp. 1369-1378, April 2008.
- [2] Y. Zhu, Q. Zhang, Z. Niu, and J. Zhu, "Leveraging Multi-AP Diversity for Transmission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

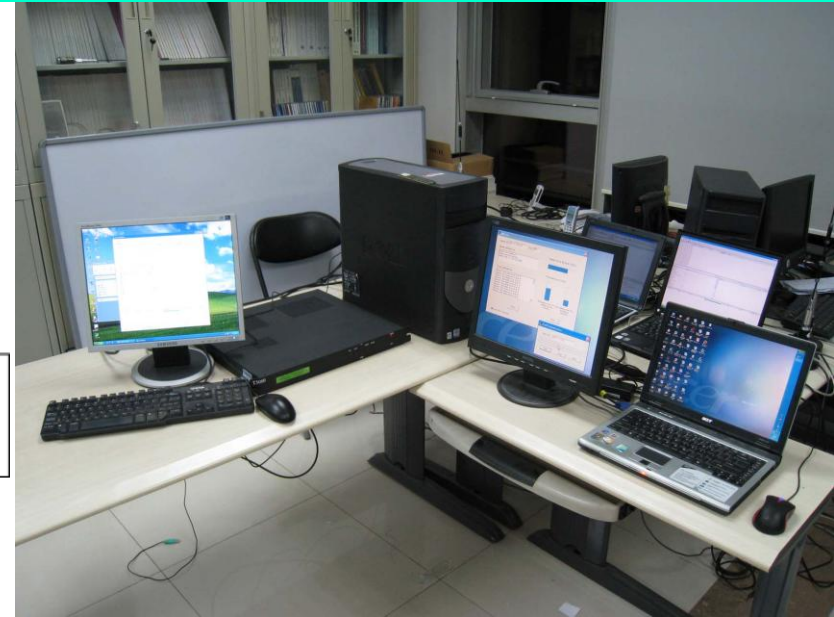
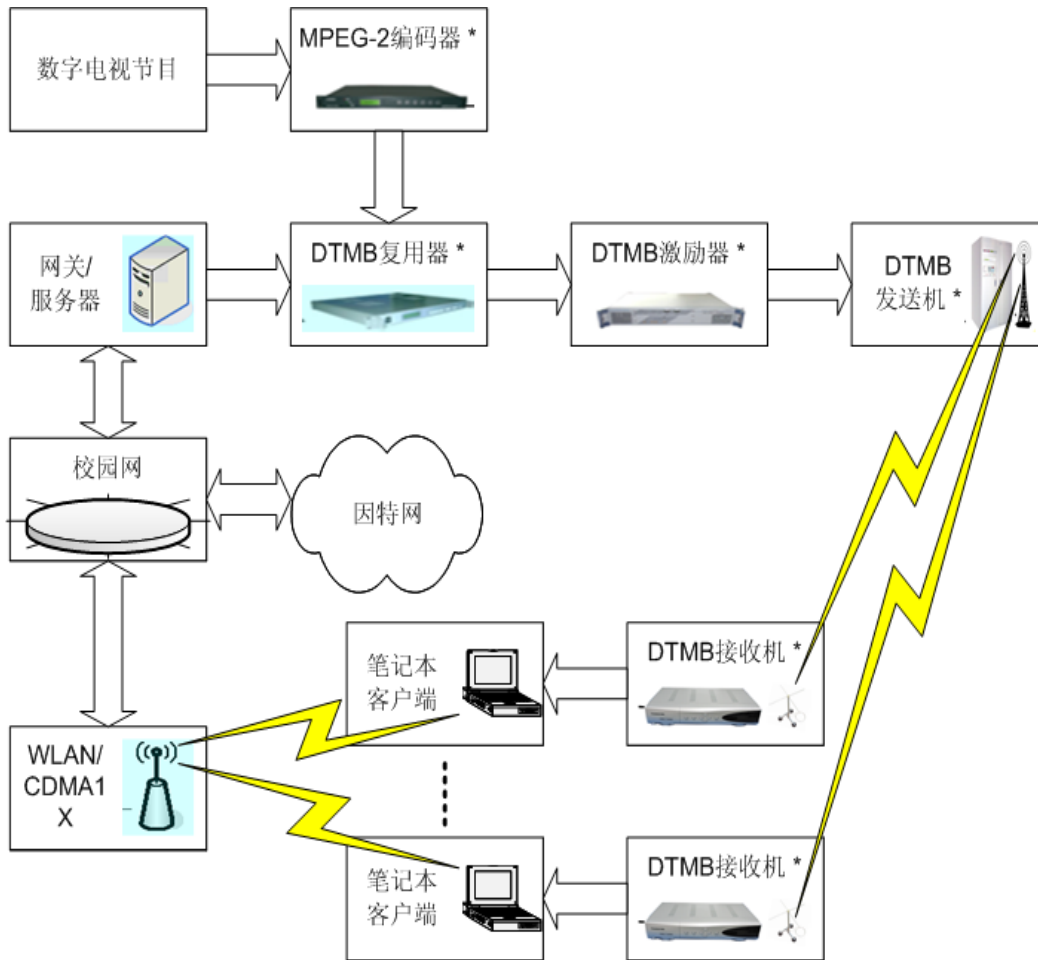
- ❖ Use DTV or MBMS/BCMCS channels to deliver commonly interested contents to mass users **on demand**
- ❖ Use mobile NWs as interactive channels (*requests and retransmissions*) to realize VoD and **data broadcast**
- ❖ **Multi-modal** terminals make it possible and promising



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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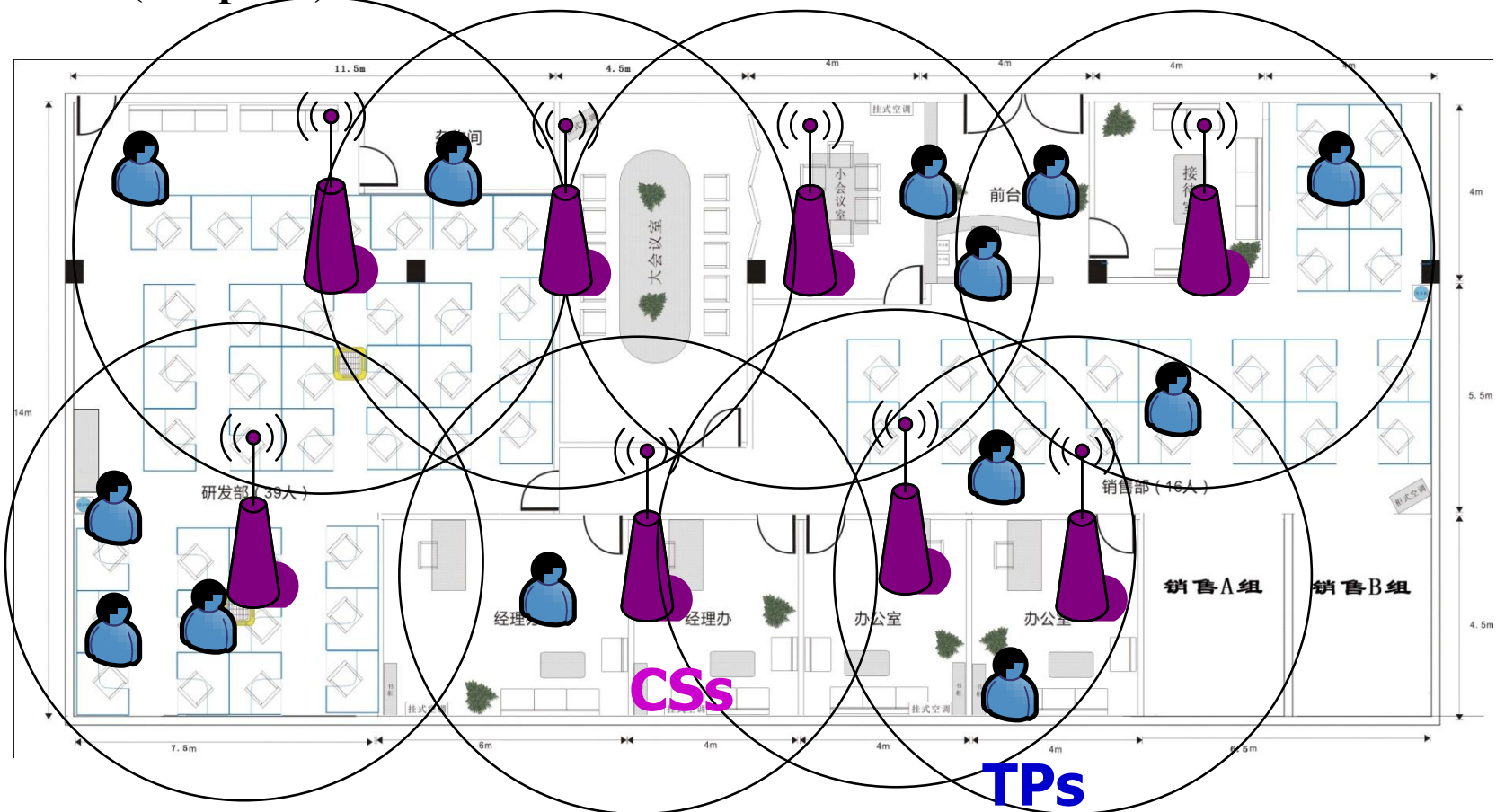
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- **Cell Zooming and Dynamic BS Sleeping Control**

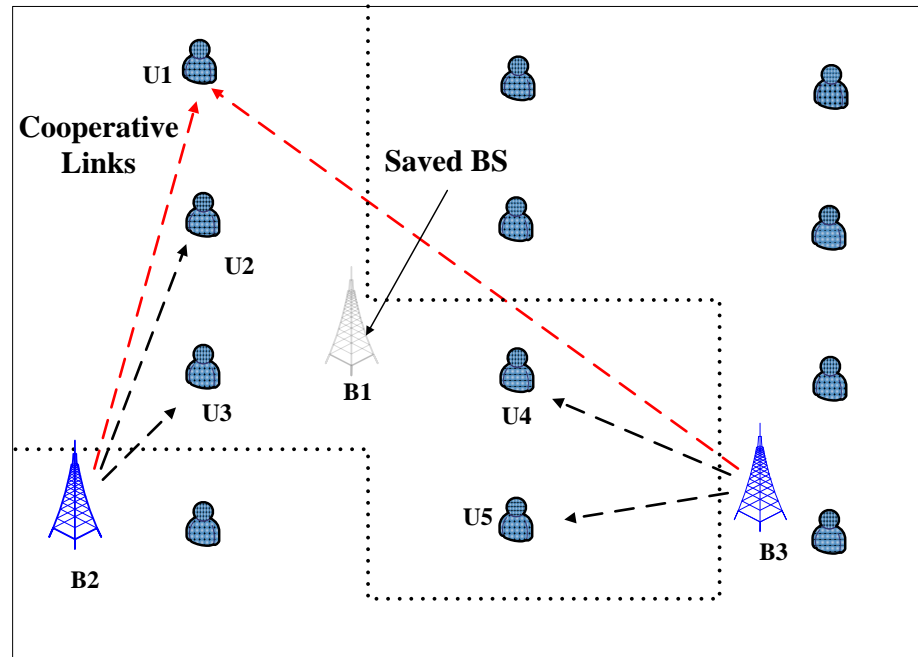
## ❖ **Conclusion**

# 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

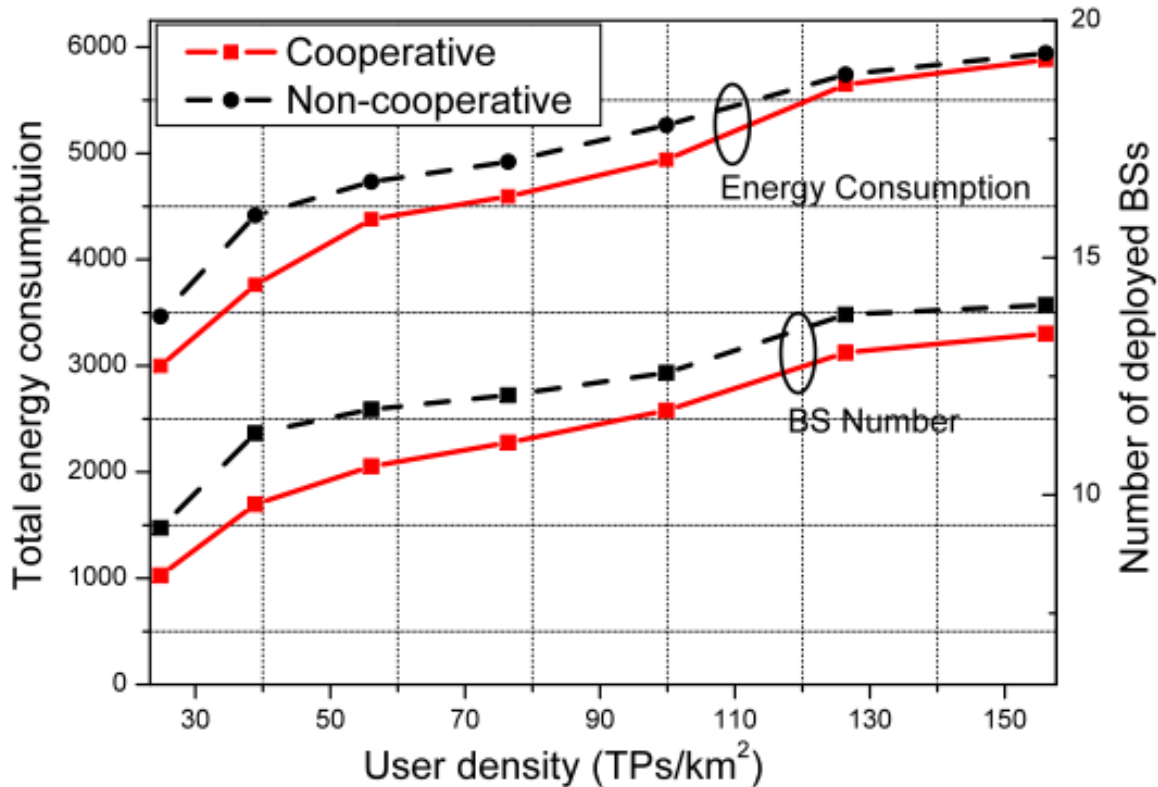


Link SINR (dB)	B1	B2	B3	B2/B3
U1	21.8096	2.8722	1.7872	5.3738
U2	37.1323	18.6598	11.6098	19.4416
U3	52.5756	35.3629	15.6645	35.4092
U4	50.4949	14.8198	28.5362	28.7169
U5	16.0759	13.7267	36.7377	36.7594



# User density vs energy efficiency

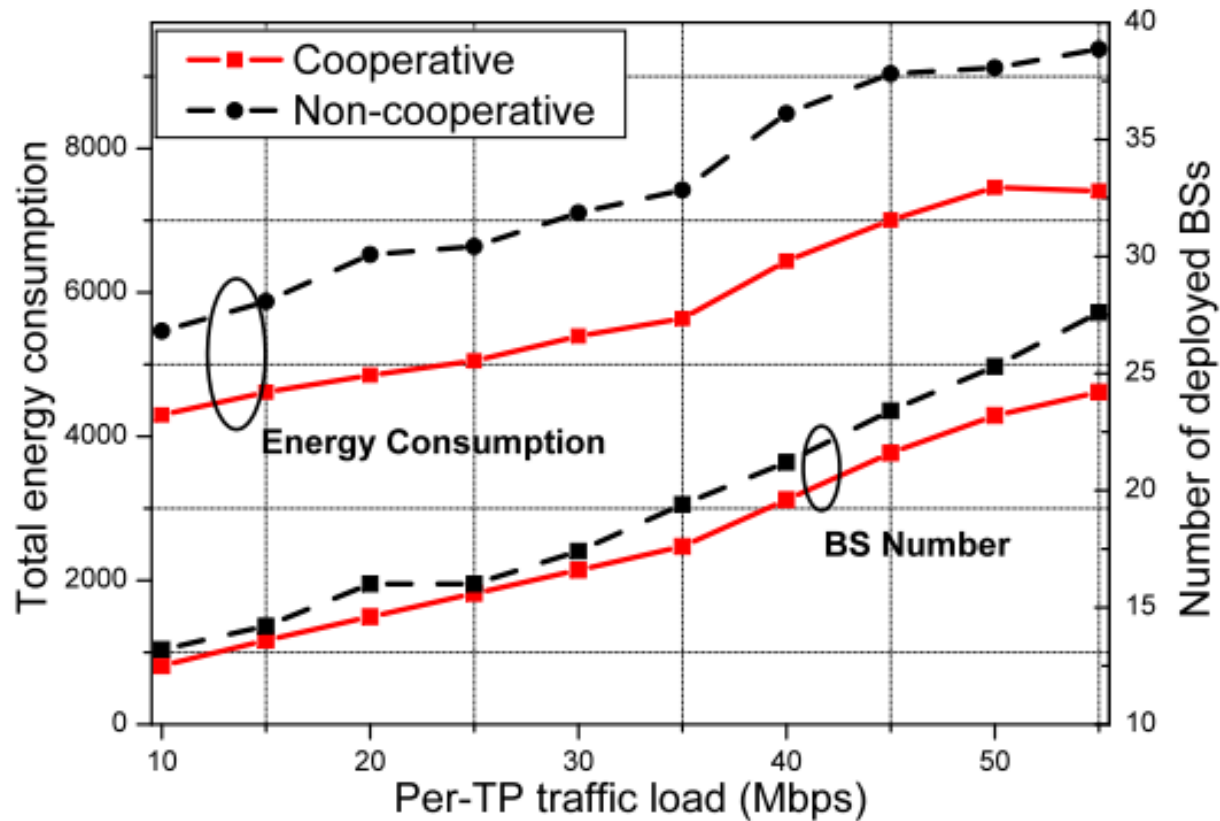
- ❖ 25 CSs, 36 TPs, with varying user density



Cooperative gain increases as user density decreases

# Traffic intensity v.s. energy efficiency

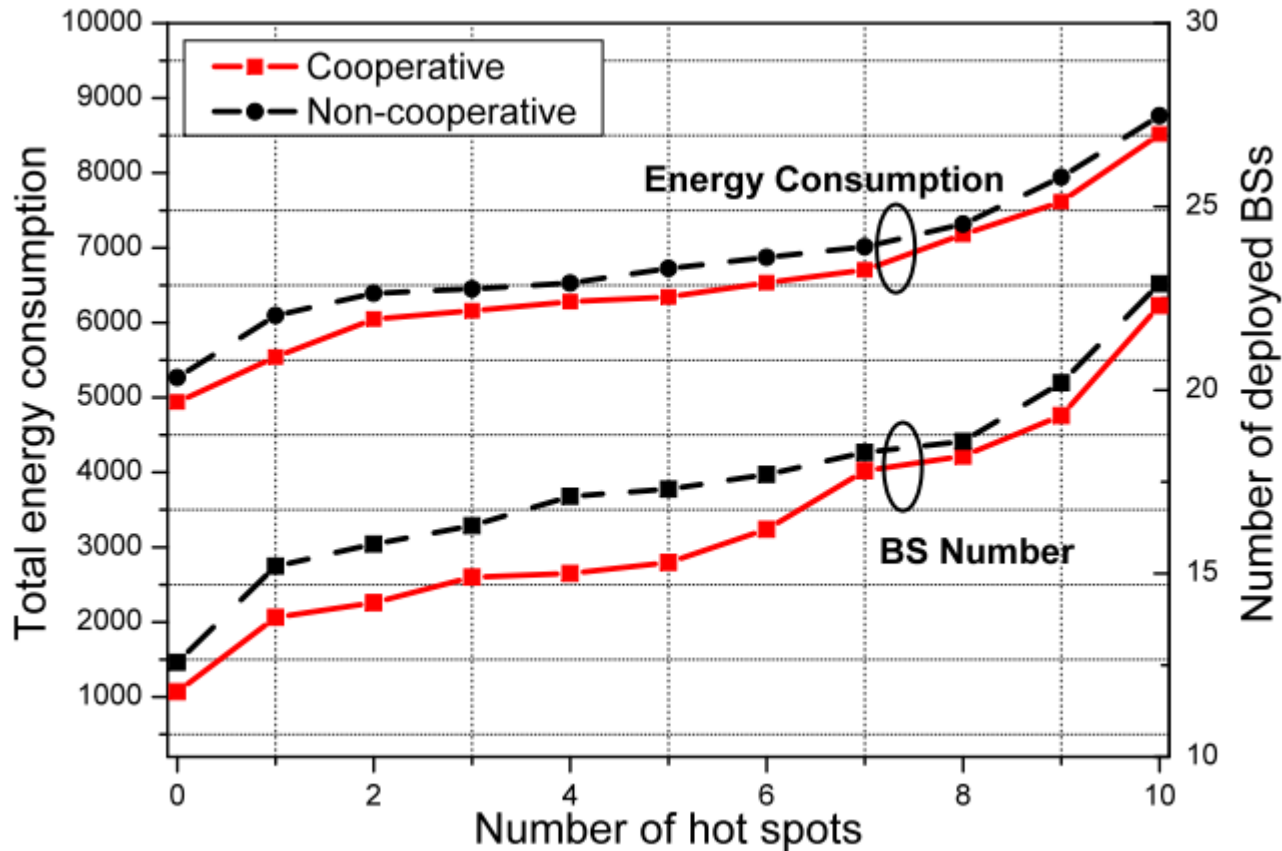
❖ 40 CSs, 36 TPs



Cooperative gain increases as the traffic load increases

# Traffic Non-uniformity vs energy efficiency

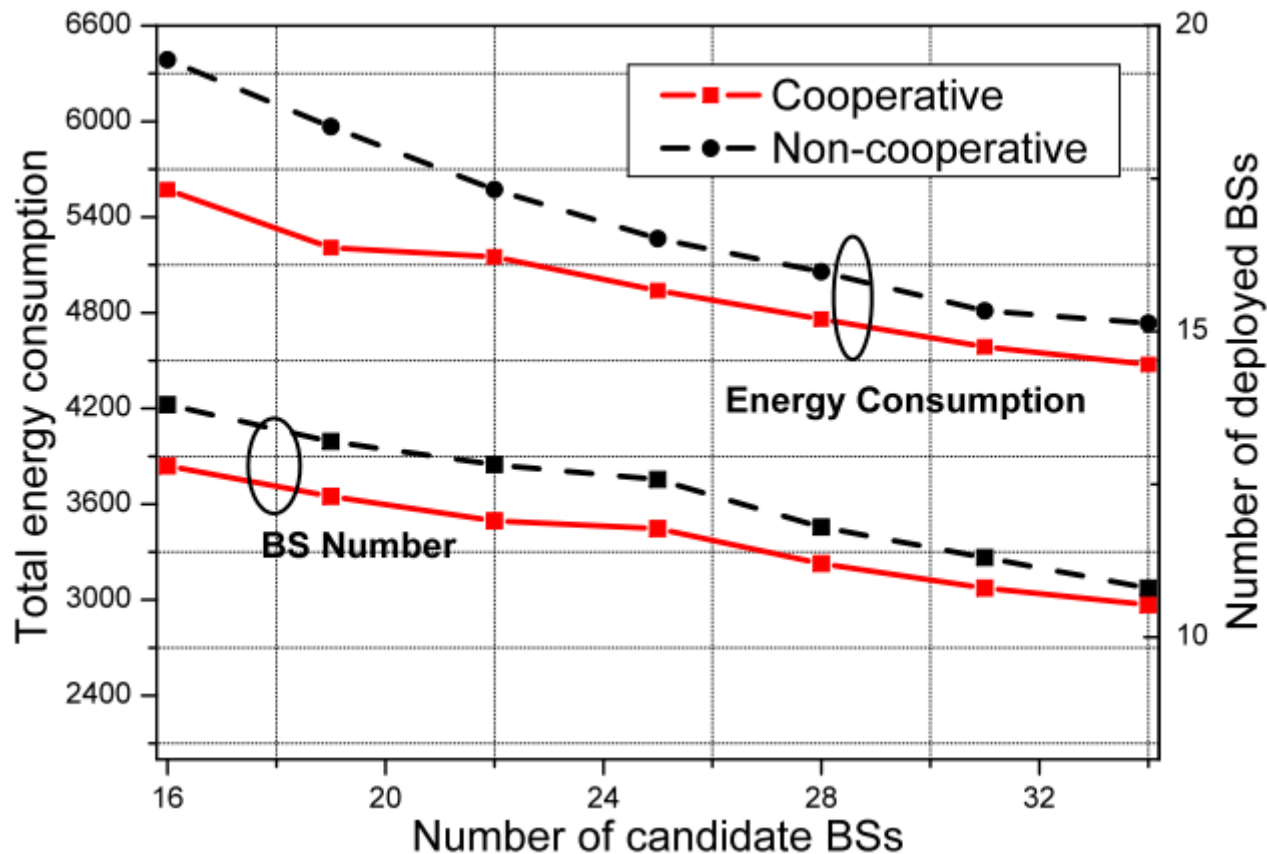
- ❖ 25 CSs, 36 TPs, with varying # of hot spots



Cooperative gain decreases as # of hot spots increases

# Traffic intensity vs energy efficiency

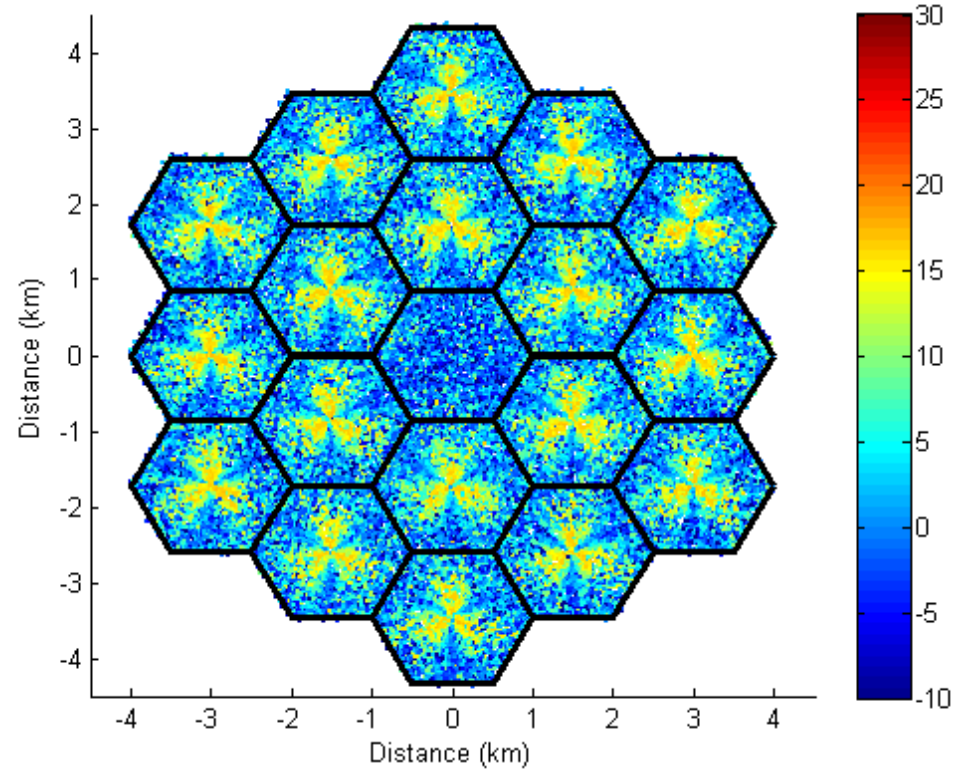
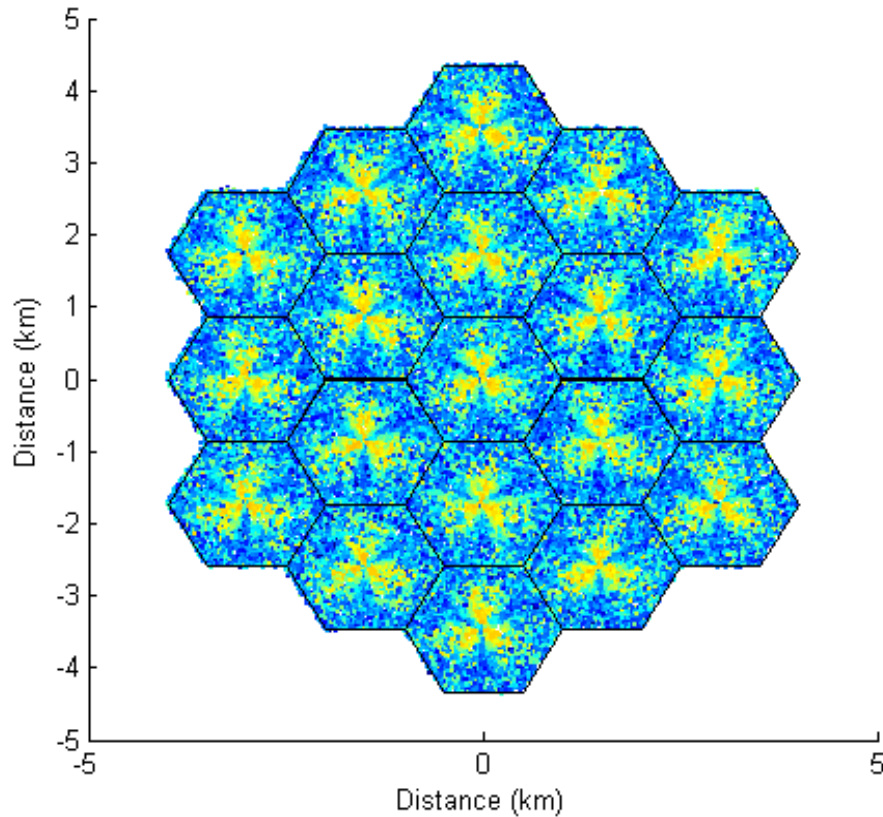
## ❖ 36 TPs with varying # of CSs



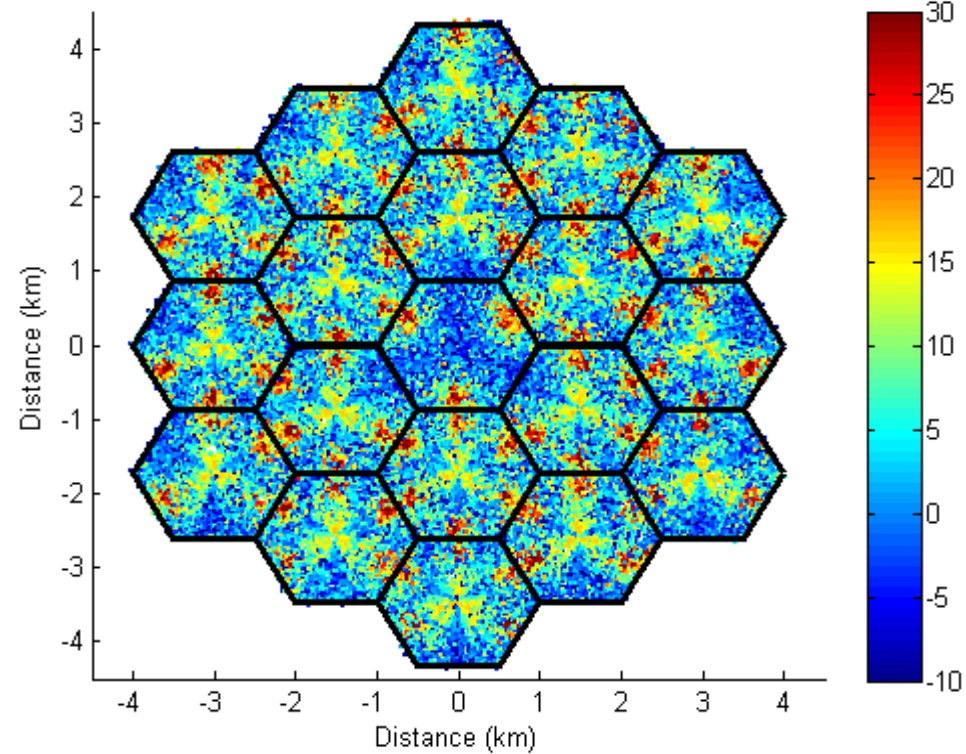
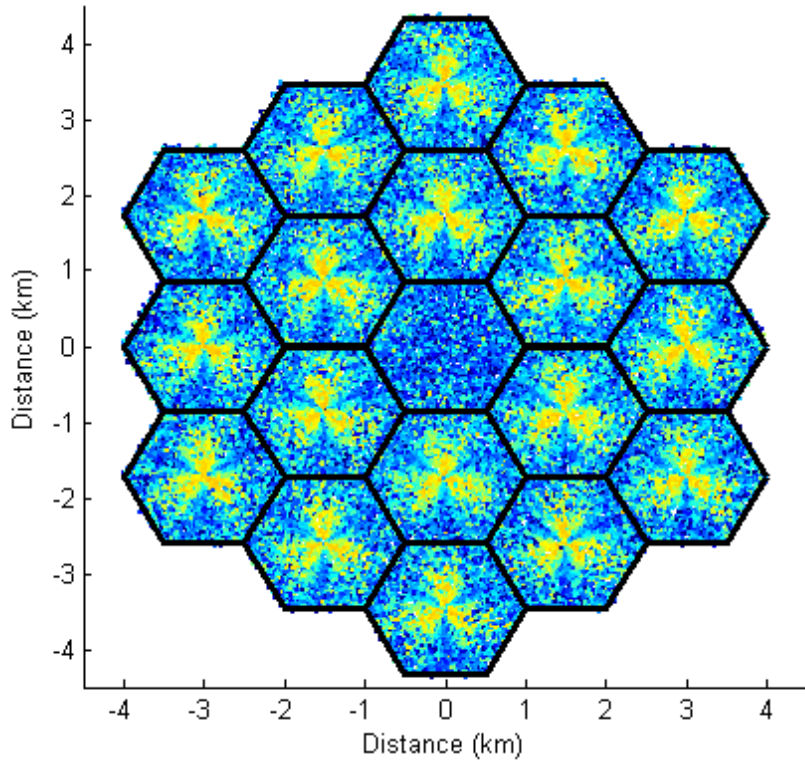
Cooperative gain increases as # of CS increases

# Switch Off Cell 0

## ❖ Geometry



# Solution (1) – Relay Station

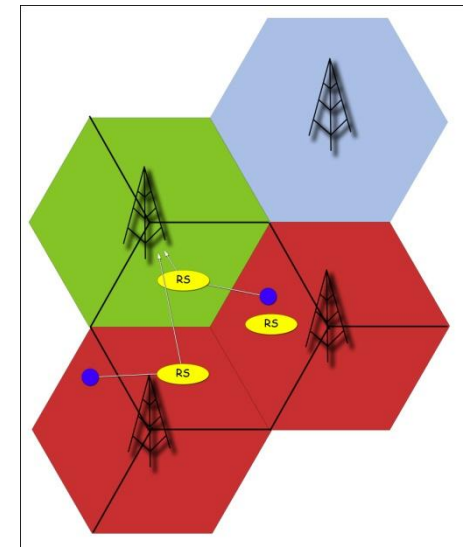
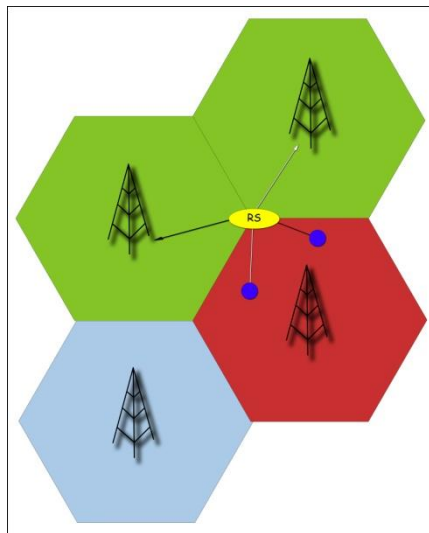
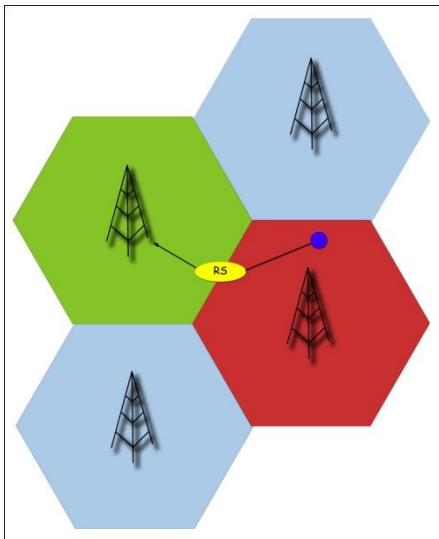


# If we further consider relaying, ...

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

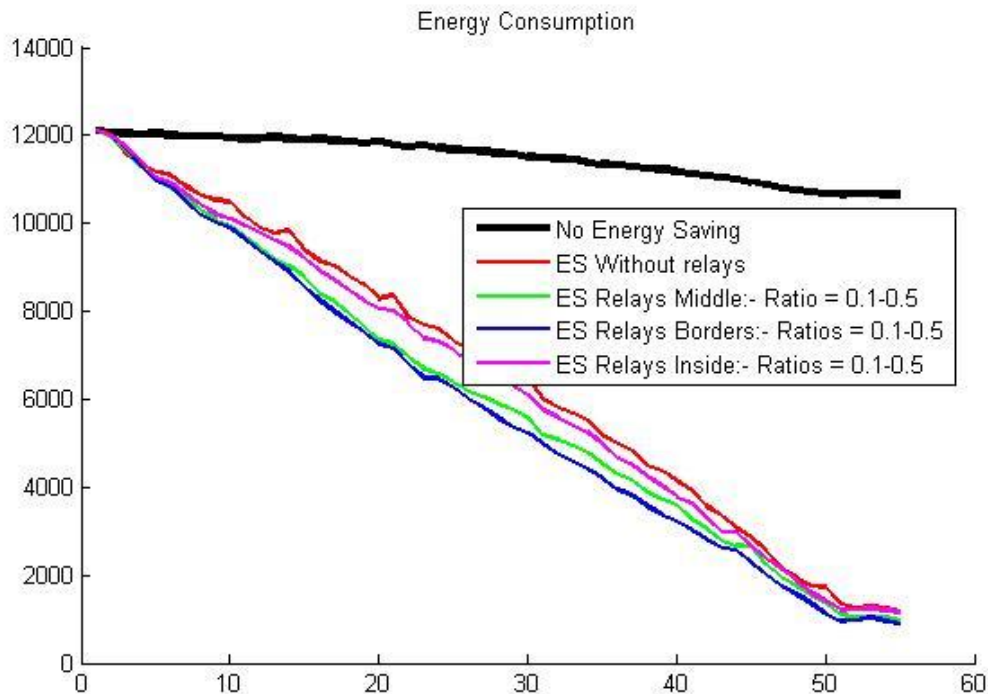
## Question: how to deploy relays?

- (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:

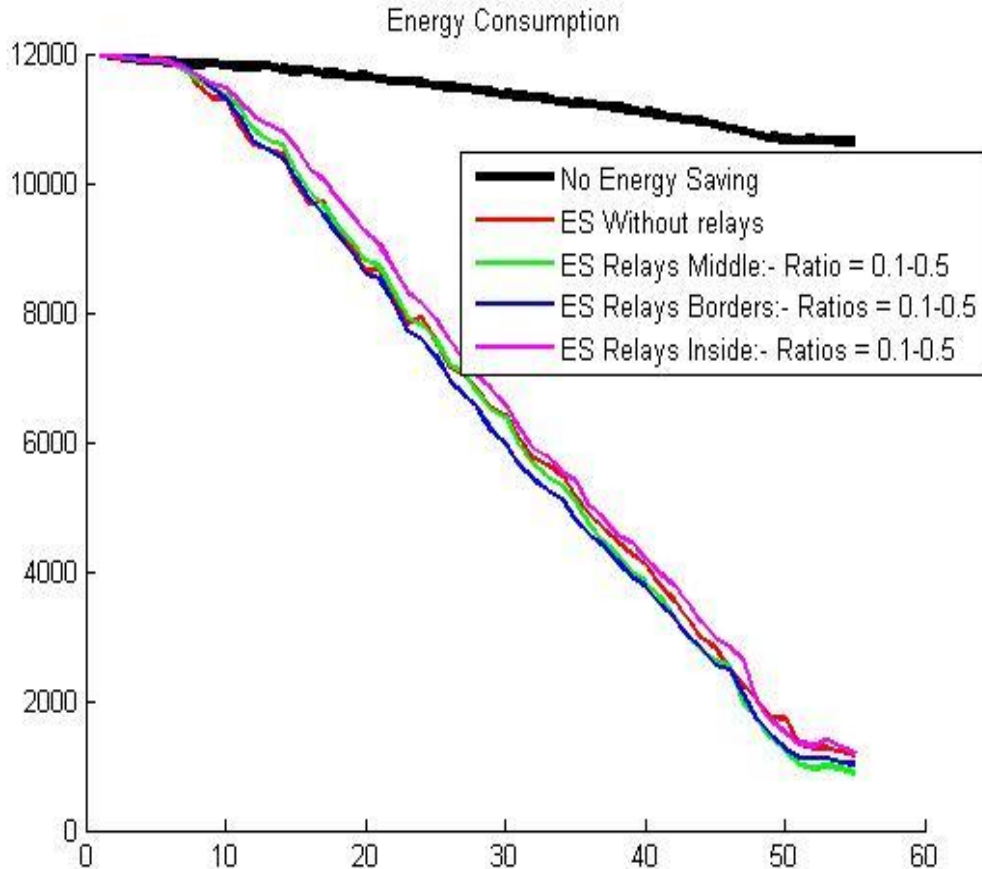
- No Relays = 43.8%
- Relays Middle = 48.6%
- Relays Corner = 50.2%
- Relays Inside = 45.7%

## Compared with no relaying case:

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



## 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

## ❖ 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

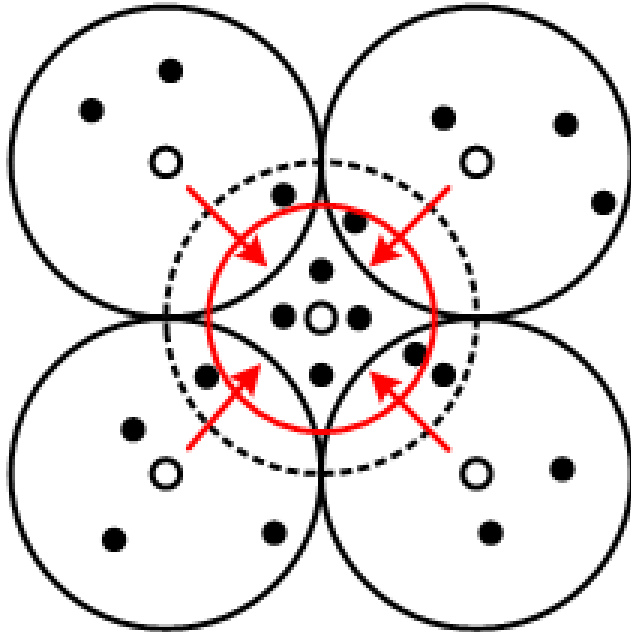
## ❖ Self-Organization for GREEN

- Cell Zooming and Dynamic BS Sleeping Control

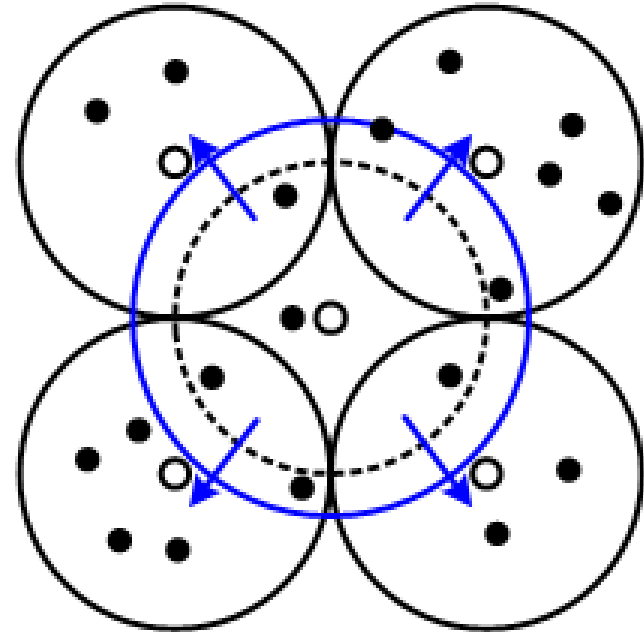
## ❖ Conclusion

# A New SoN Scheme: Cell Zooming

## ❖ Cell zooming for load balancing

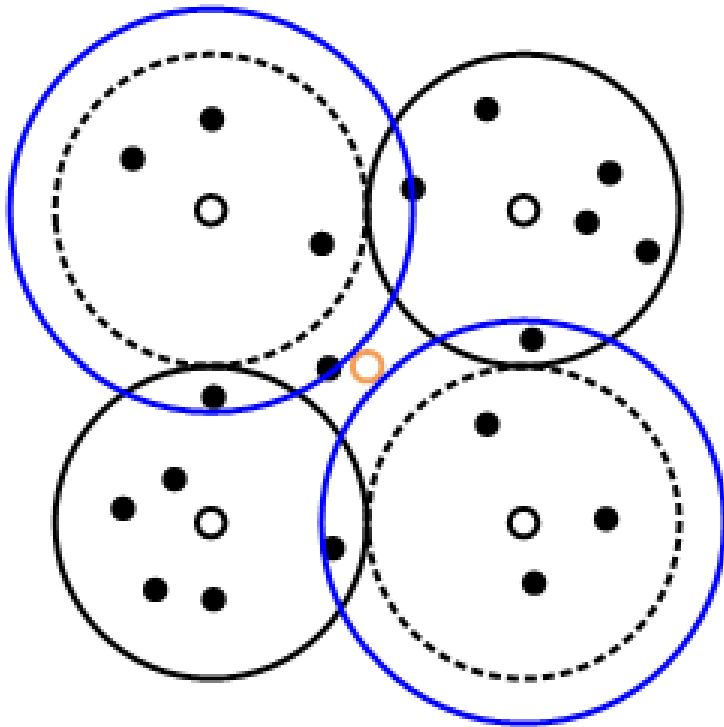


**Central cell zooms in as traffic load increases**

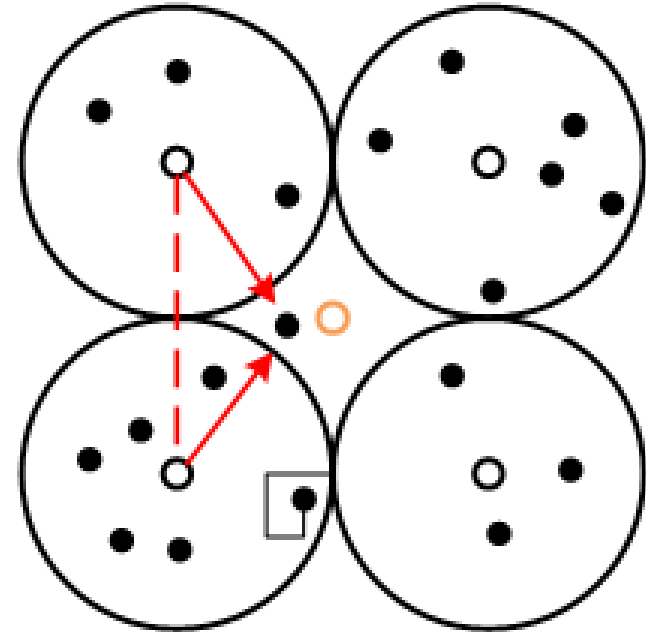


**Central cell zooms out as traffic load decreases**

## ❖ Cell zooming for energy saving



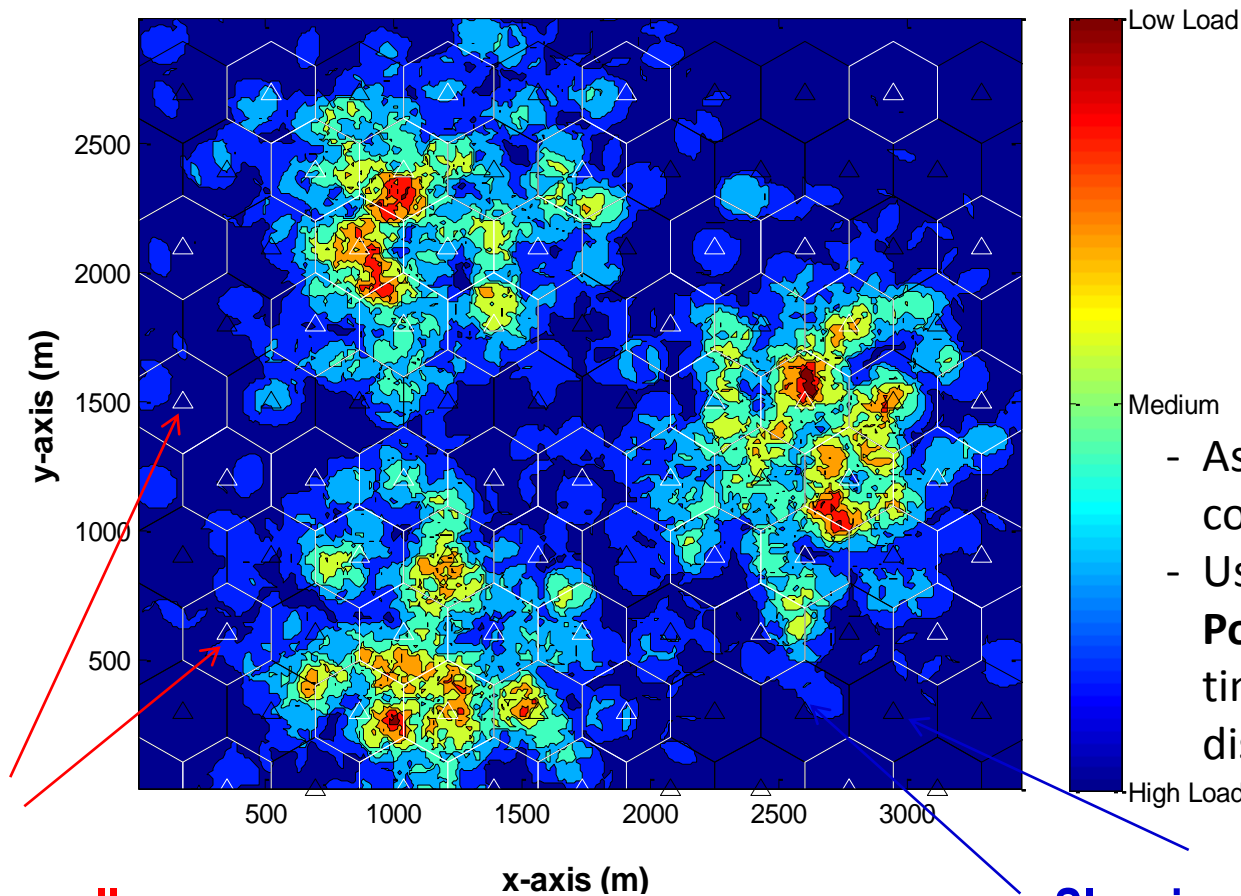
**Central cell sleeps, and other cells zoom out**



**Central cell sleeps, and other cell cooperate to transmit**

# Cell Zooming for Energy Saving

## ❖ A snapshot of BS sleeping pattern



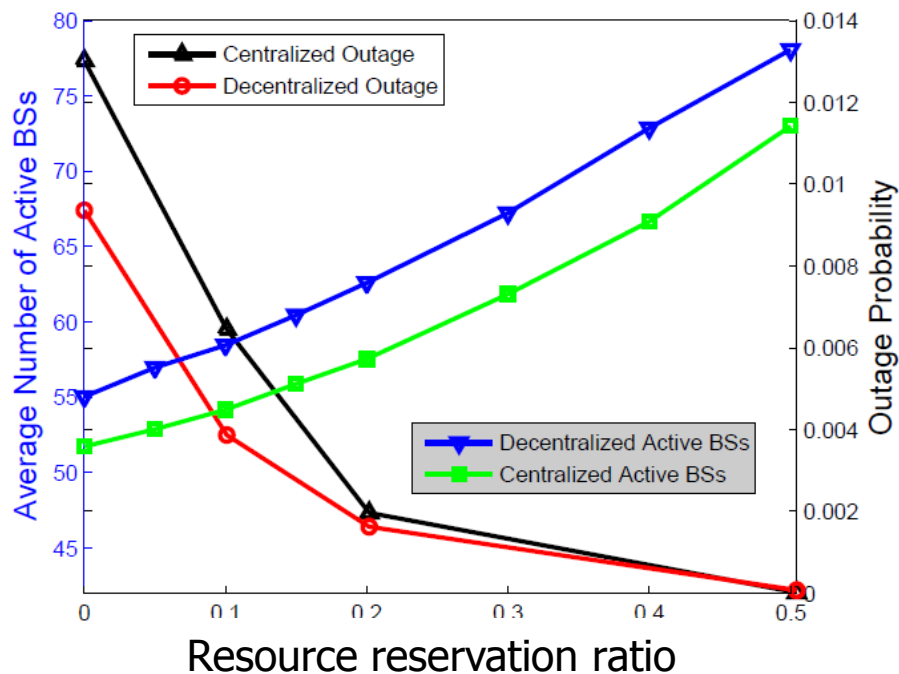
- Assuming BSs can extend coverage from **200m** to **400m**
- Users arrive according to **Poisson** Process and service time is **exponentially** distributed

Active cells

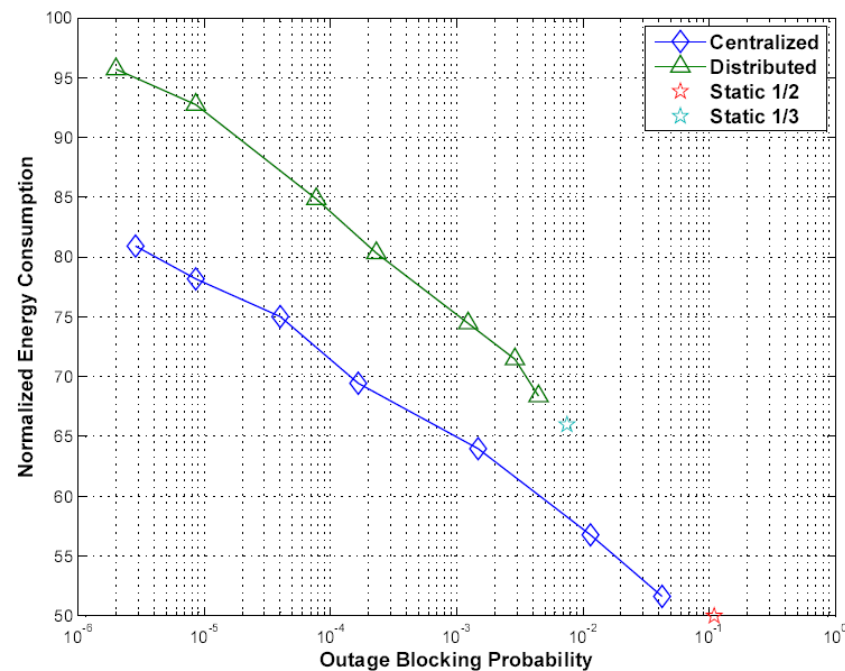
Sleeping cells

# Tradeoff between Energy and QoS

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





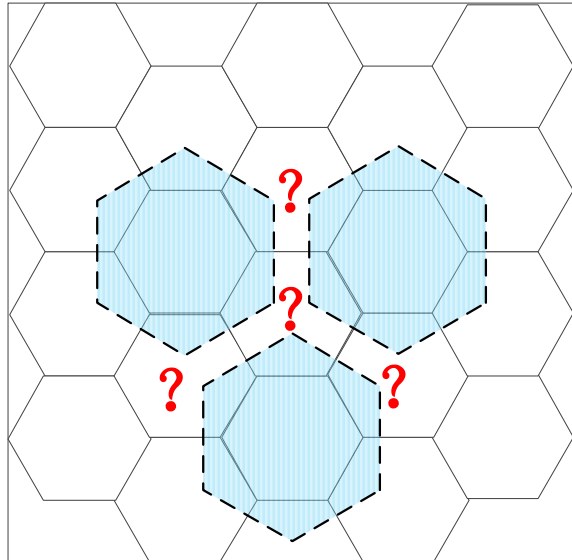
Tradeoff between ES and QoS



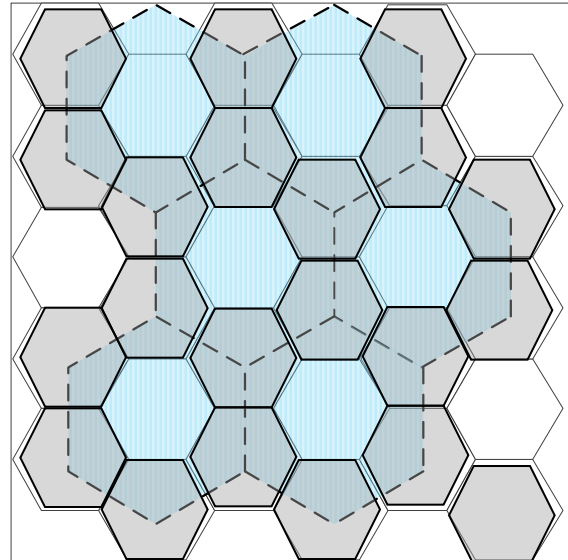
Zhisheng Niu, Yiqun Wu, Jie Gong and Zexi Yang: “Cell Zooming for Cost-Efficient Green Cellular Networks”, *IEEE Com. Mag.*, Nov. 2010

# Dynamic Cell Planning under Insufficient Zooming

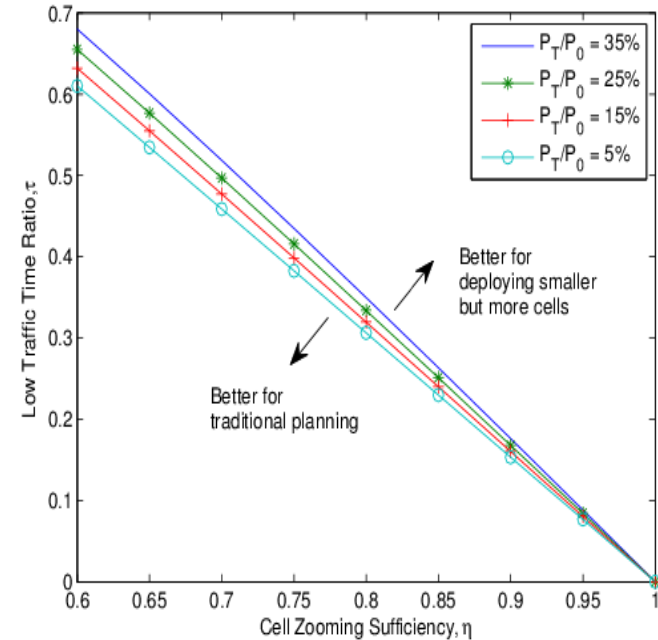
 Coverage in high traffic time  
 Maximum coverage by cell zooming



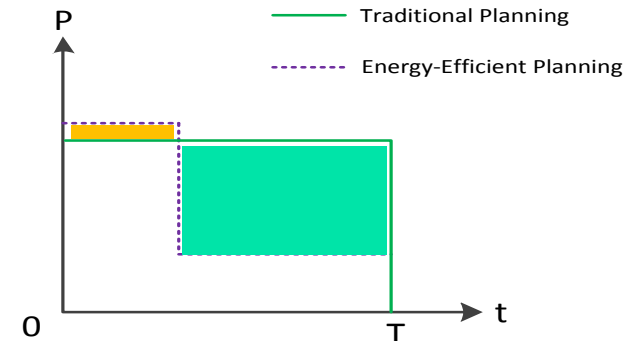
Traditional planning



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.





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## ❖ Conclusion

## ❖ What's Green?

- **GREEN:** *Globally Resource-optimized and Energy-Efficient Networks*

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- **CHORUS:** *Collaborative & Harmonized Open Radio Ubiquitous System*
- **TANGO:** *Traffic Aware Network planning and Green Operation*

## ❖ Key Approaches to TANGO

- Coverage on-demand
- Resource on-demand
- Service on-demand

