Cellular Greening via Efficient BS Control: Topology, On-off, and Transmission Power

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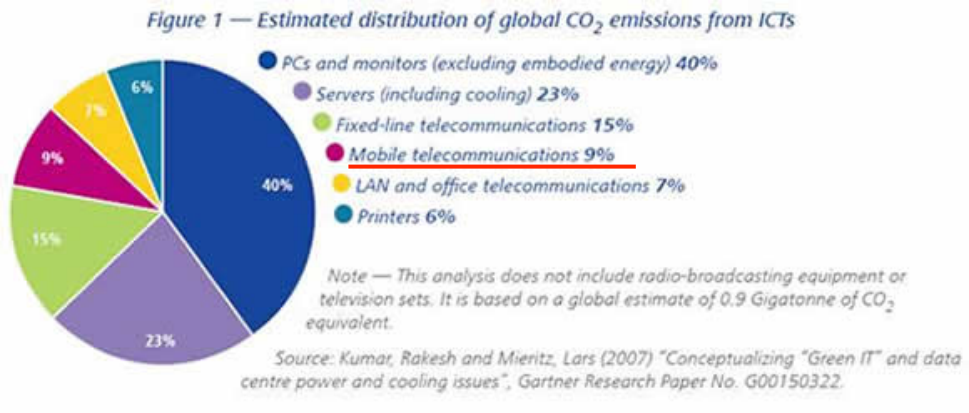
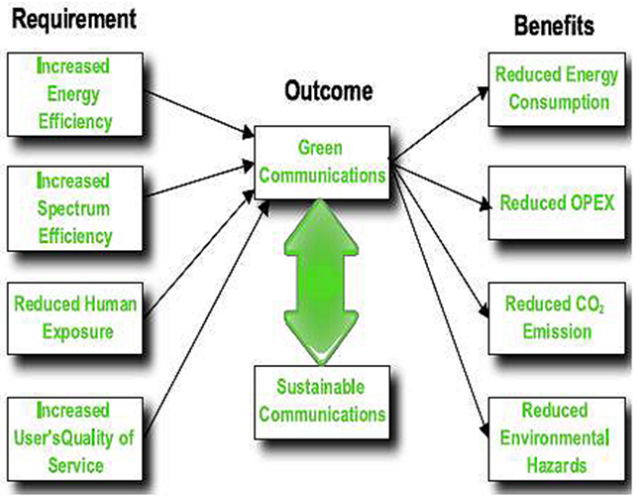
Outline

- BS control policies for Greening
  - Different Time-scales
- Biased on algorithmic solutions, not practical protocols
- Assumes general IT audience, not greening experts
- Academic bias
  - Based on my recent researches and colleagues'
  - Apology: for missing references
- Thanks
  - Kyuho Son (USC Post-doc, USA)
  - Dr. Bhaskar Krishnamachari (USC Prof., USA)
  - Hongseok Kim (Alcatel Bell Labs, USA)
  - Soohwan Lee (KAIST Student, Korea)

Energy Consumption

- Energy consumption in ICT
  - Currently, 2-10% of world's annual energy consumption
  - Rising 15-20% per every year





Source: O. Adigun and C. Politis, "Green Framework f or Future Cellular Networks", WWRF #25 WG4, Nov. 2010, London, United Kingdo m

- 60-80% of energy consumed for maintaining and oper ating BS in cellular networks in mobile telecommunica tions

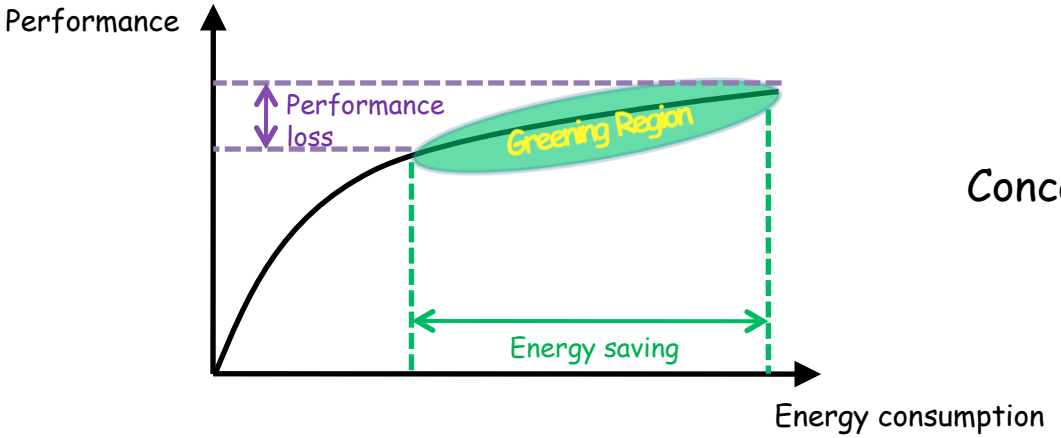
Greening Needs

- Environmental
  - CO2 emission
    - Greenhouse effect
    - Kyoto protocol
    - Government regulation
- Economic
  - OPEX
    - Electric bill

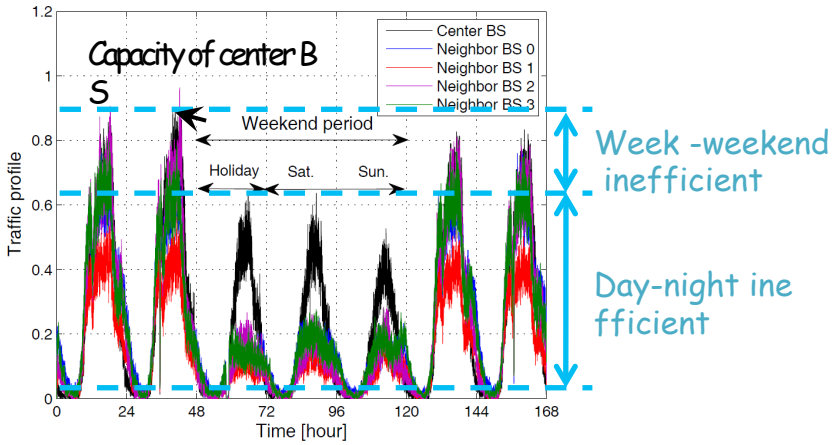
<CO_2 emission in power plants>
Source: www.veindirectory.org

<Large amount of electric bill>

Spots for Greening



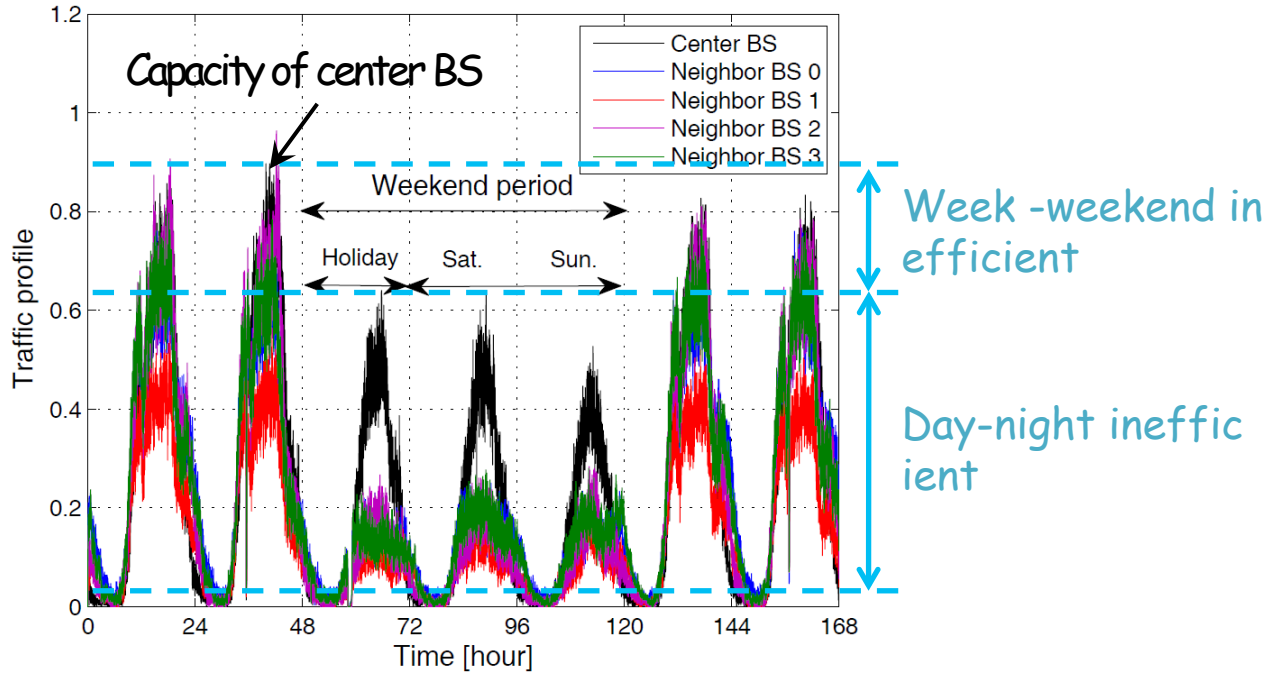
Concave performance-energy tradeoff



Resource consolidation

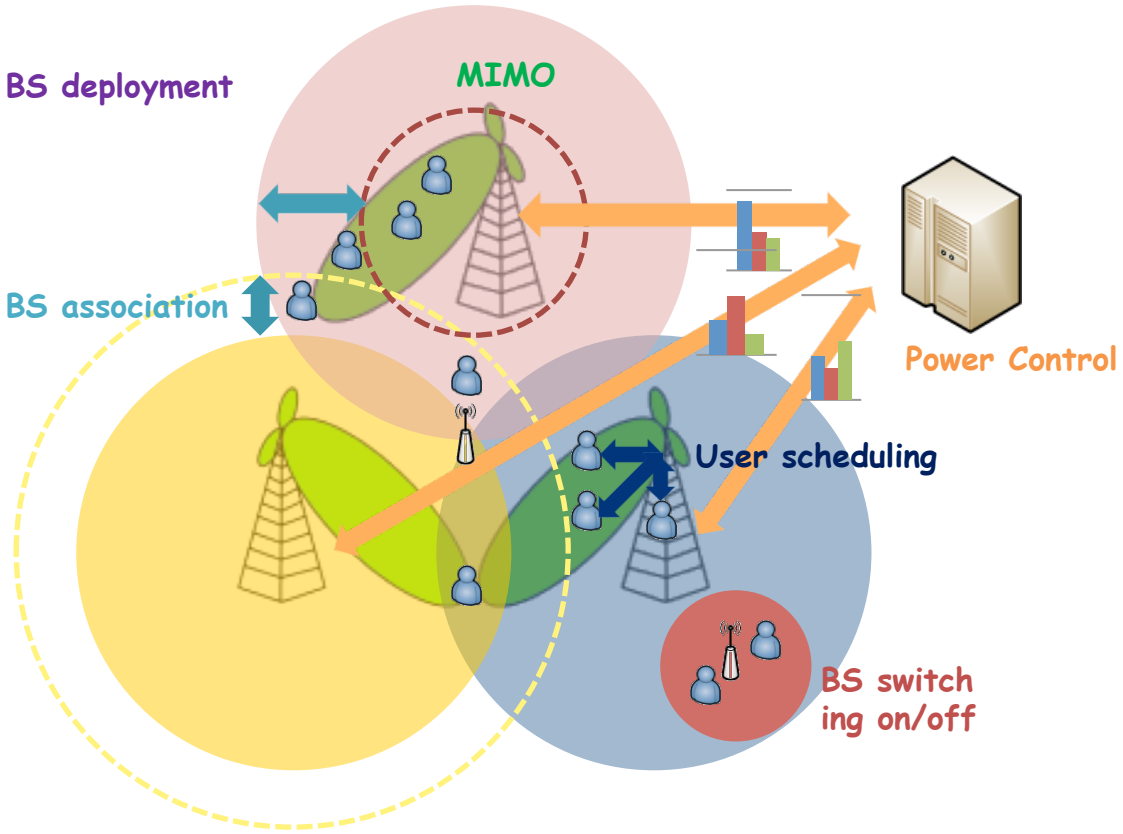
Traffic Adaptive Resource Consolidation

- Dynamic traffic pattern



- Currently, all BSs deployed for serving peak data traffic
- Week-weekend, day-night inefficiency
- Traffic adaptive BS switching on/off for efficient network

Cellular Networks: Control Knobs



Topology
- BS topology

Years [y]

BS switching on/off
- traffic adaptive

Several hours

BS association
- coverage

Several min.

Power control
- interference contr ol

Several sec.

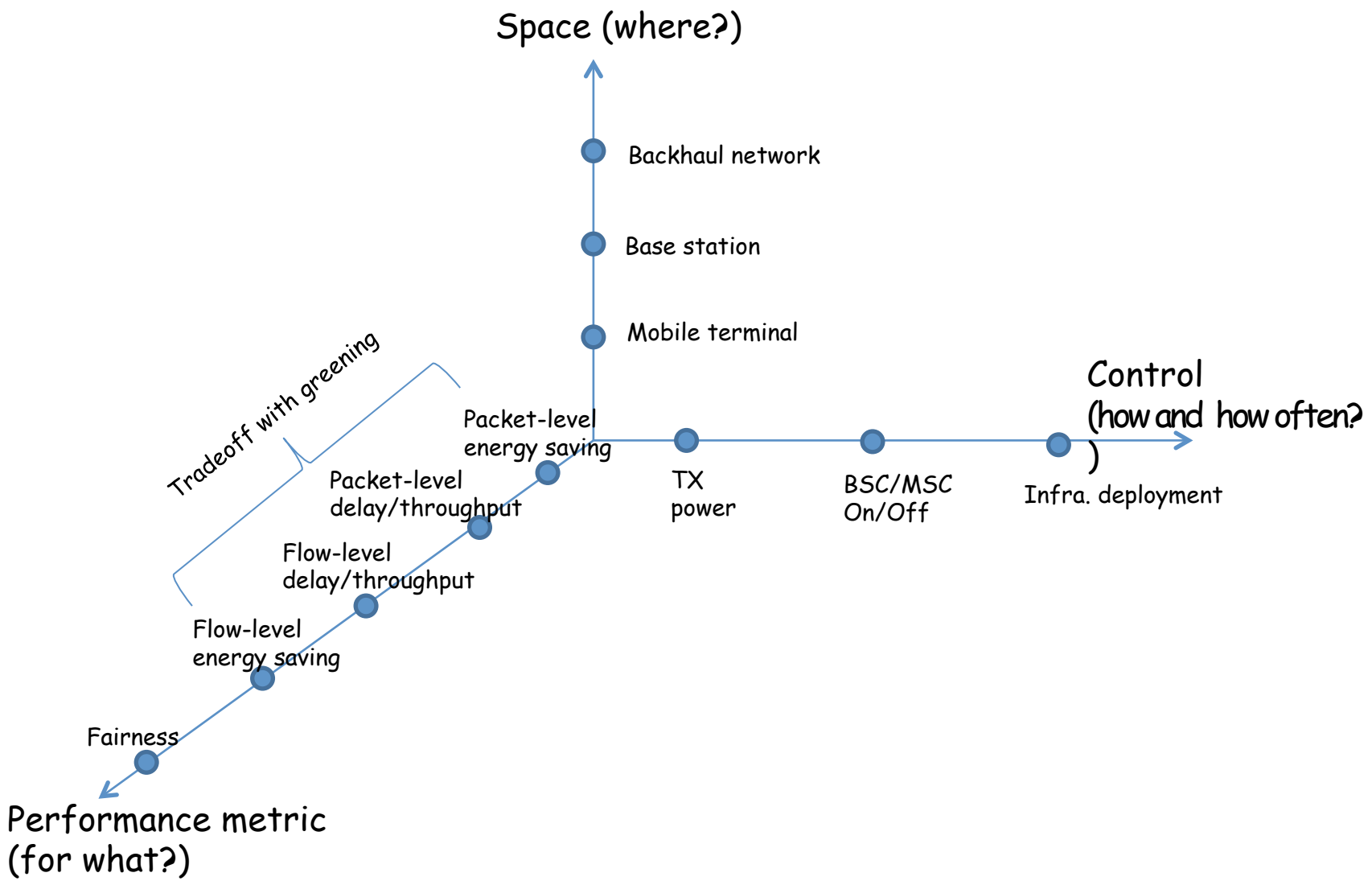
MIMO
- spatio-temporal channel focusing/multiplexing

Several slots

User scheduling
- opportunistic
- channel dependent

A slot [ms]

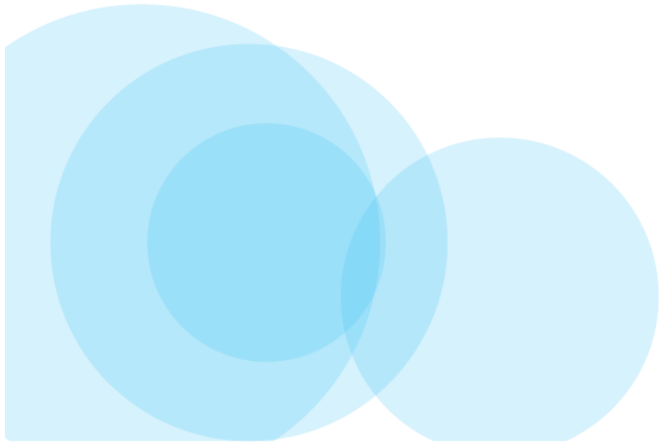
Cellular Greening: Problem Space



This Talk: Three Case Studies

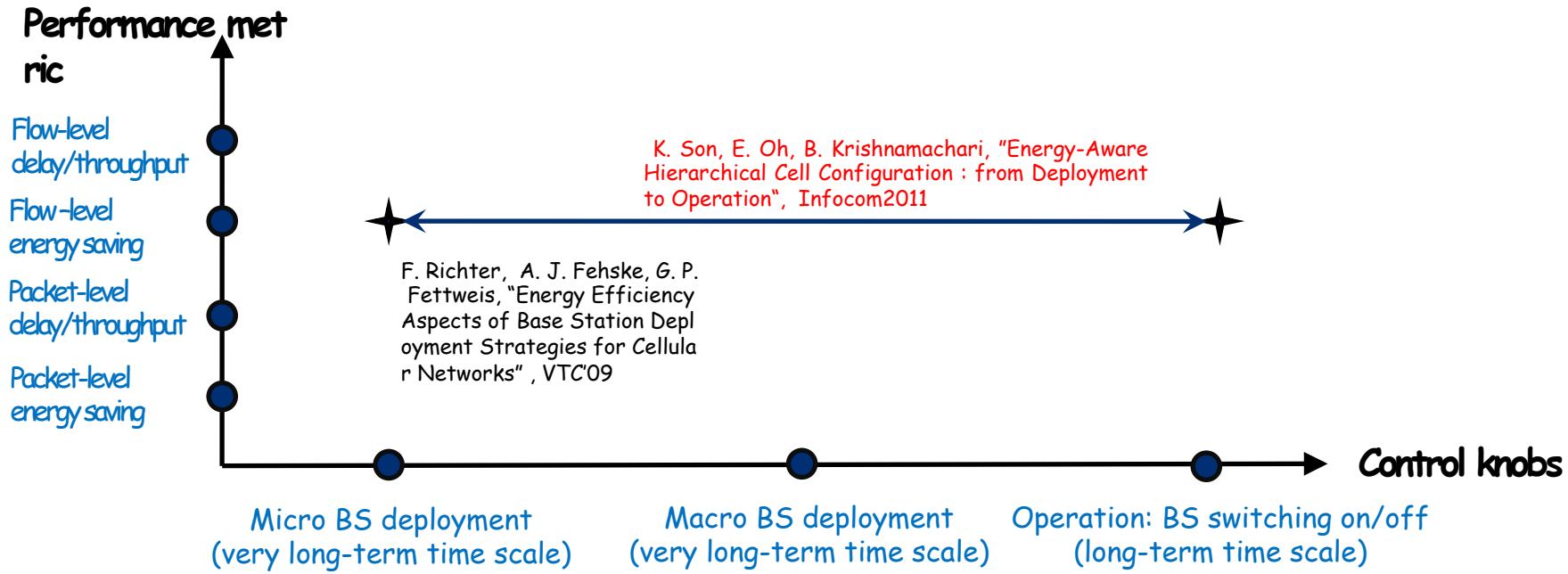
- 1. BS Topology Design
- 2. BS On-Off Mechanism
- 3. BS Transmit Power Control

Joint BS Topology/BS On-off



BS Topology Design

- Energy efficient network topology design



- Micro BS deployment on given macro BS deployment
- Time scale: several years

Problem

- Input
  - Macro BS deployment and performance enhancement factor
- Objective
  - Upgrade (flow level) throughput with the smallest energy con sumption
  - Smallest energy consumption → minimum number of micro BS deployment

Environment change during several year

↓

Macro BS suffers from congestion

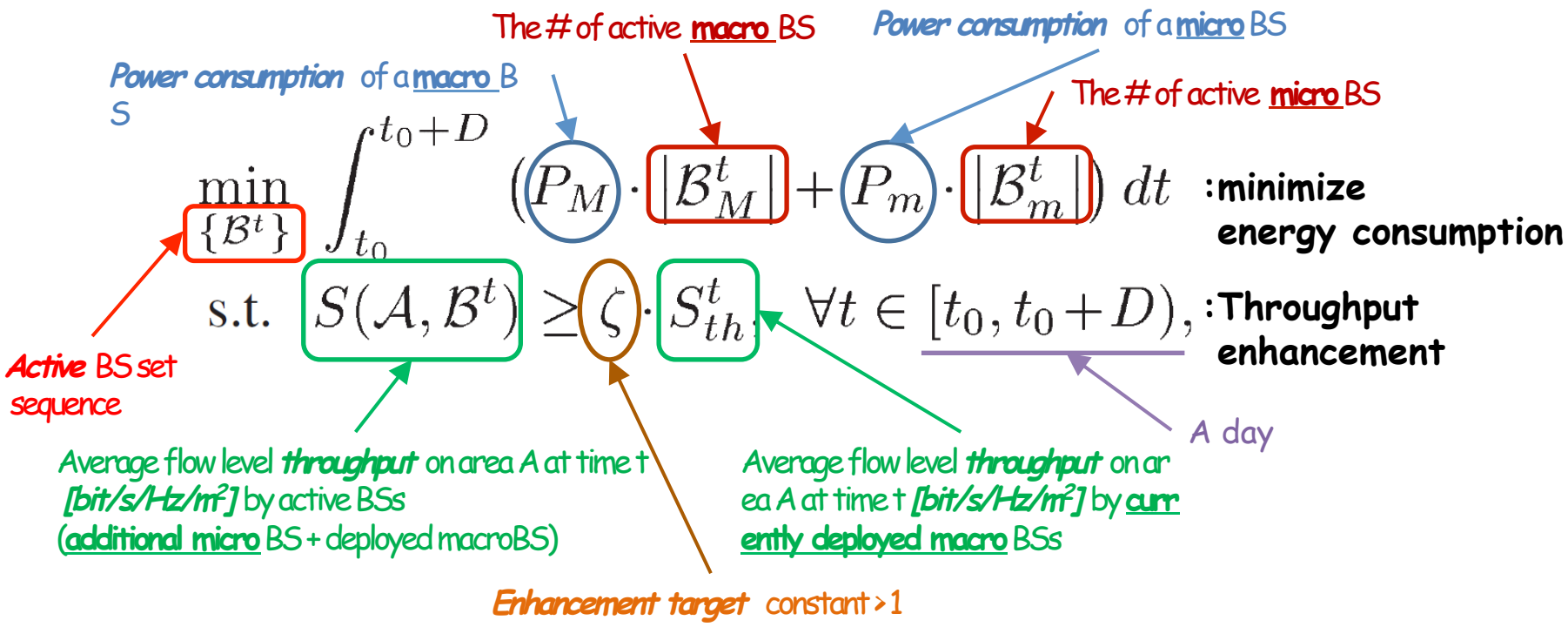
↓

By deploying min # of micro BS

Energy saving + performance enhancement

Objective

- General problem
  - ***Upgrade flow level throughput*** on some area with the ***smallest increment of energy consumption***



Approach: Time-scale Separation

- Micro BS deployment problem (topology design)
  - Minimize the # of micro BS that will be deployed for target enhancement

$$\min_{\mathcal{B}_m} \quad |\mathcal{B}_m| \text{ :CAPEX minimization}$$

$$\text{s.t.} \quad S(\mathcal{A}, \mathcal{B}_M \cup \mathcal{B}_m) \geq \zeta \cdot S_{th}^{t^*} \text{ :Enhancement of peak-time throughput}$$

t*: peak-time of daily traffic flow

Newly deploying micro BS set (location + the # of adding BS)

Capacity of current network

- BS operation problem (switching on/off)
  - Minimize total energy consumption for supporting dynamic traffic by BS switching on/off on given topology

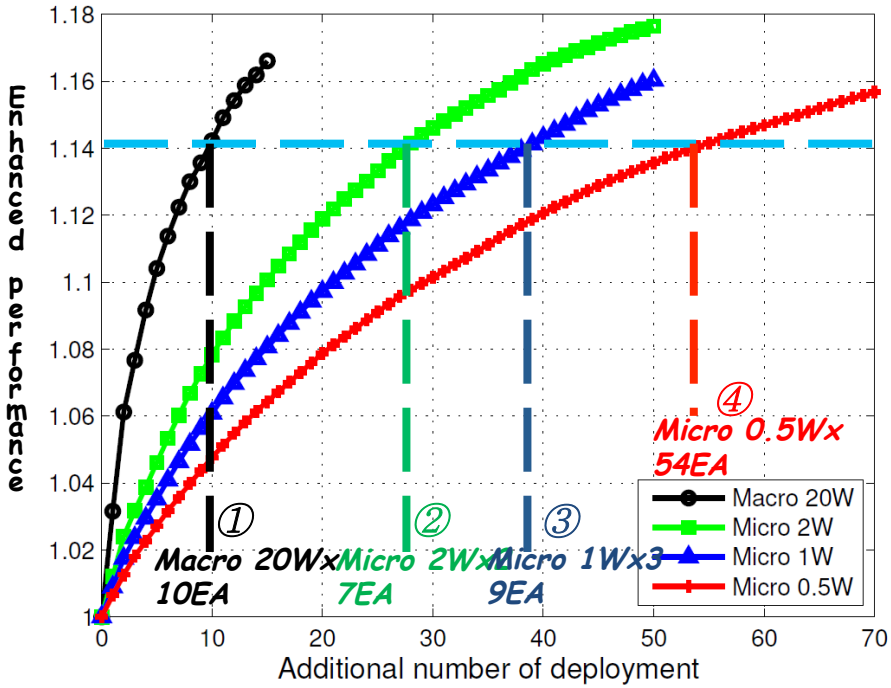
$$\min_{\mathcal{B}^t} \quad P_M \cdot |\mathcal{B}_M^t| + P_m \cdot |\mathcal{B}_m^t| \text{ :OPEX minimization at time t}$$

$$\text{s.t.} \quad S(\mathcal{A}, \mathcal{B}^t) \geq \zeta \cdot S_{th}^t \text{ :Enhancement dynamic traffic by time t}$$

The set of active (turning on) BS

Simulation Results (I)

- BS deployment



Target performance

Energy consumption for target performance

①: 200 [W]

②: 54 [W]

③: 39 [W]

④: 27 [W]

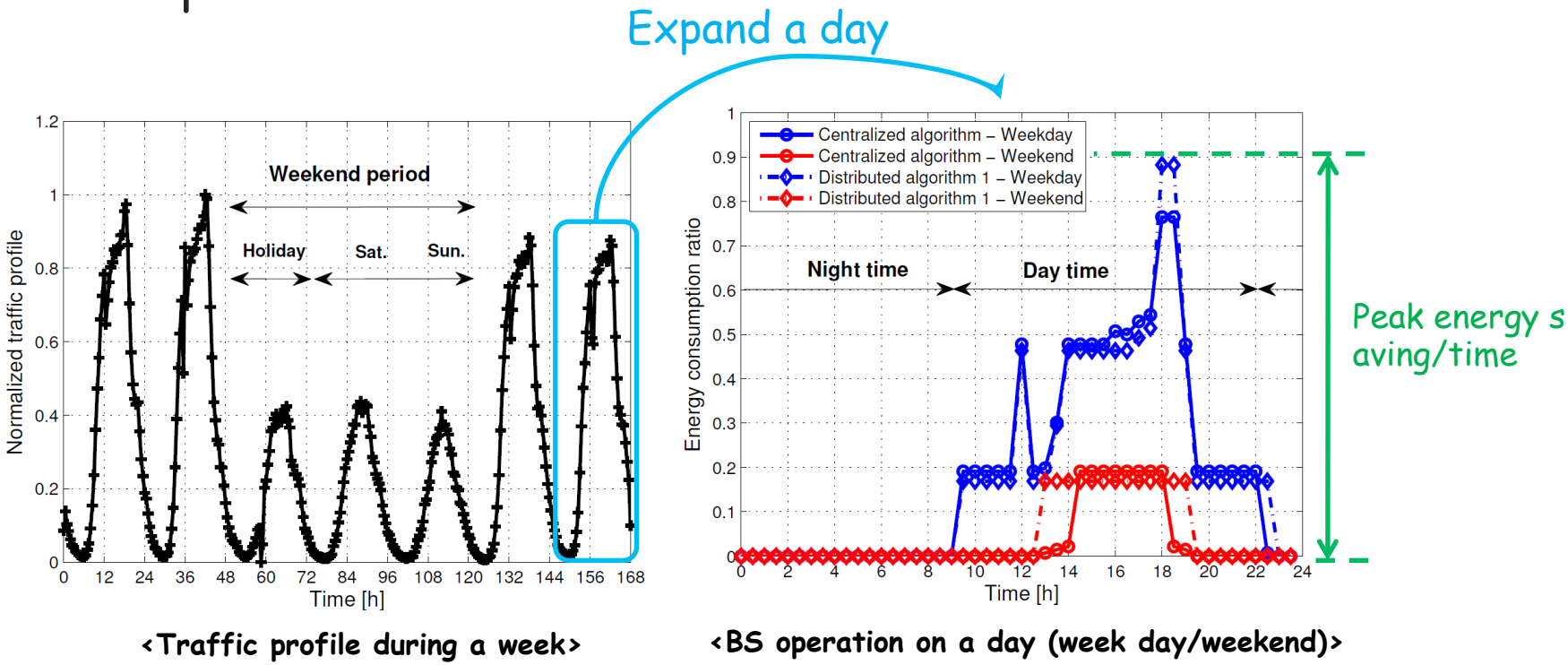
Macro

Micro
:energy saving

- Deploying smaller cell comes large energy saving

Simulation Results (II)

- BS operation



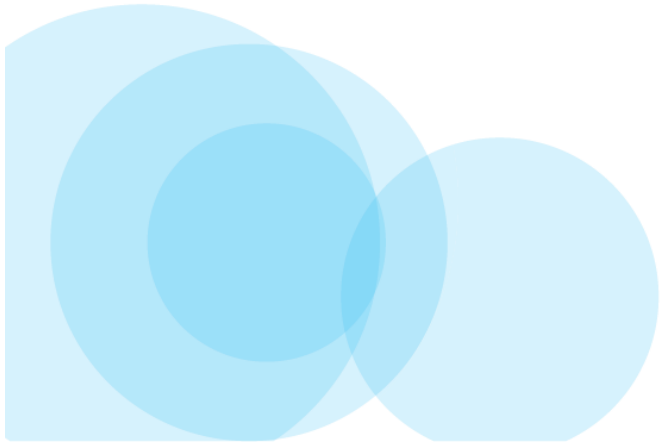
<Traffic profile during a week>

<BS operation on a day (week day/weekend)>

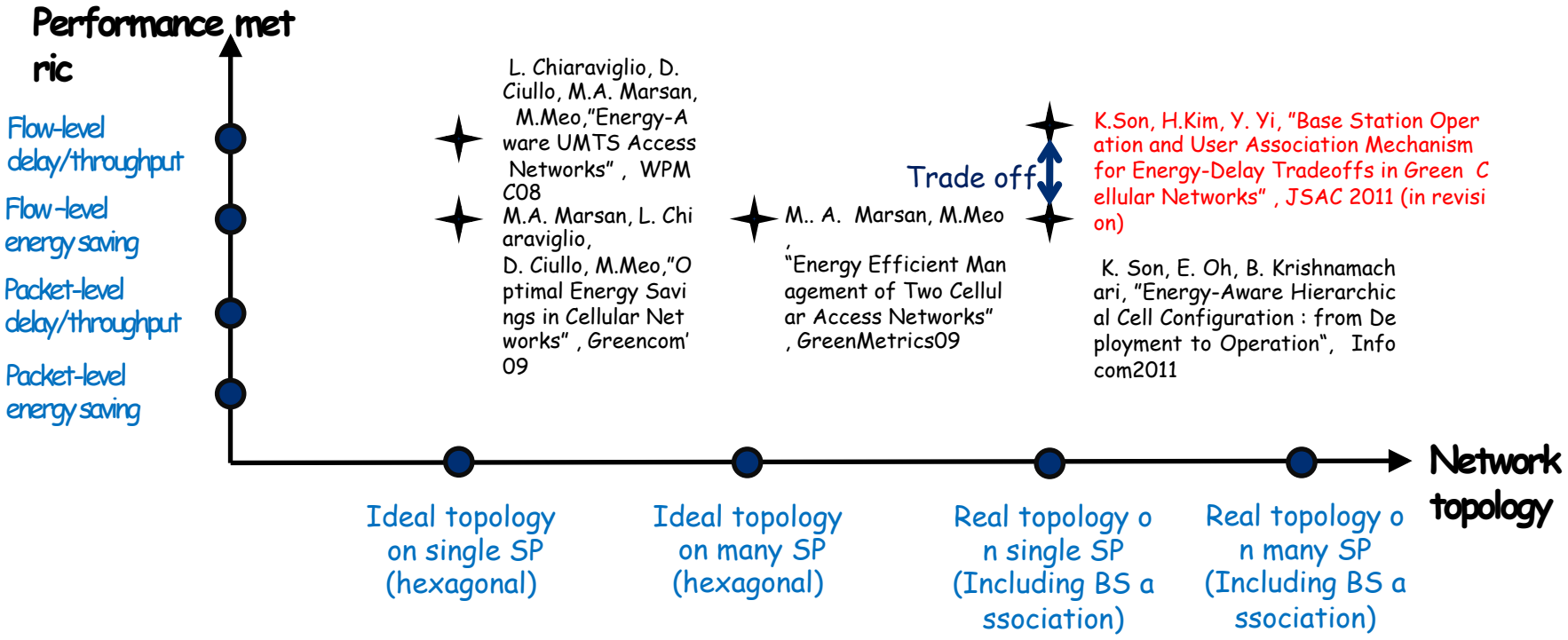
- Saving much energy during a day compared to always BS s witching on
  - Energy saving = (Peak energy saving/time) x (turn-off duration)

Joint BS On-off/Association

GreenTouch™



BS On/Off


Performance metric
Flow-level delay/throughput
Flow-level energy saving
Packet-level delay/throughput
Packet-level energy saving
L. Chiaraviglio, D. Ciullo, M.A. Marsan, M.Meo,"Energy-Aware UMTS Access Networks" , WPMC08
M.A. Marsan, L. Chiaraviglio, D. Ciullo, M.Meo,"Optimal Energy Savings in Cellular Networks" , Greencom'09
M.. A. Marsan, M.Meo , "Energy Efficient Management of Two Cellular Access Networks" , GreenMetrics09
Trade off
K.Son, H.Kim, Y. Yi, "Base Station Operation and User Association Mechanism for Energy-Delay Tradeoffs in Green Cellular Networks" , JSAC 2011 (in revision)
K. Son, E. Oh, B. Krishnamachari, "Energy-Aware Hierarchical Cell Configuration : from Deployment to Operation", Infocom2011
Ideal topology on single SP (hexagonal)
Ideal topology on many SP (hexagonal)
Real topology on single SP (Including BS association)
Real topology on many SP (Including BS association)
Network topology

Model & Objective

- System model
  - Flow-level location dependent capacity

- Objective
  - Find optimal ***active BS set*** and ***flow-level BS load*** that mini mize the total system cost function

$$\min_{\mathcal{B}_{\text{on}},\rho} \left\{ \phi_\alpha(\rho, \mathcal{B}_{\text{on}}) + \eta\psi(\rho, \mathcal{B}_{\text{on}}) \;\middle|\; \rho \in \mathcal{F}(\mathcal{B}_{\text{on}}), \mathcal{B}_{\text{on}} \subseteq \mathcal{B} \right\}$$

Cost of flow-level performance (delay)

Balancing constant (performance & energy)

Energy consumption

  - B_{on}: Set of Active BS (BS On/off)
  - ρ: BS load vector (BS Association)

Approach: Time-scale Separation

- Time scale separation
  - BS operation: Several hours
  - User association: Several minutes

given

- BS operation (Switching on/off)

$$\min_{\mathcal{B}_{\text{on}} \subseteq \mathcal{B}} \; G(\mathcal{B}_{\text{on}}) + \eta \sum_{i \in \mathcal{B}_{\text{on}}} q_i P_i$$

:minimize objective given ρ*

- User association (Load balancing)

Long-term operation

Given $\mathbf{B_{on}}$

$$\min_{\rho \in \mathcal{F}(\mathcal{B}_{\text{on}})} \; \phi_\alpha(\rho, \mathcal{B}_{\text{on}}) + \eta \sum_{i \in \mathcal{B}_{\text{on}}} (1 - q_i) \rho_i P_i$$

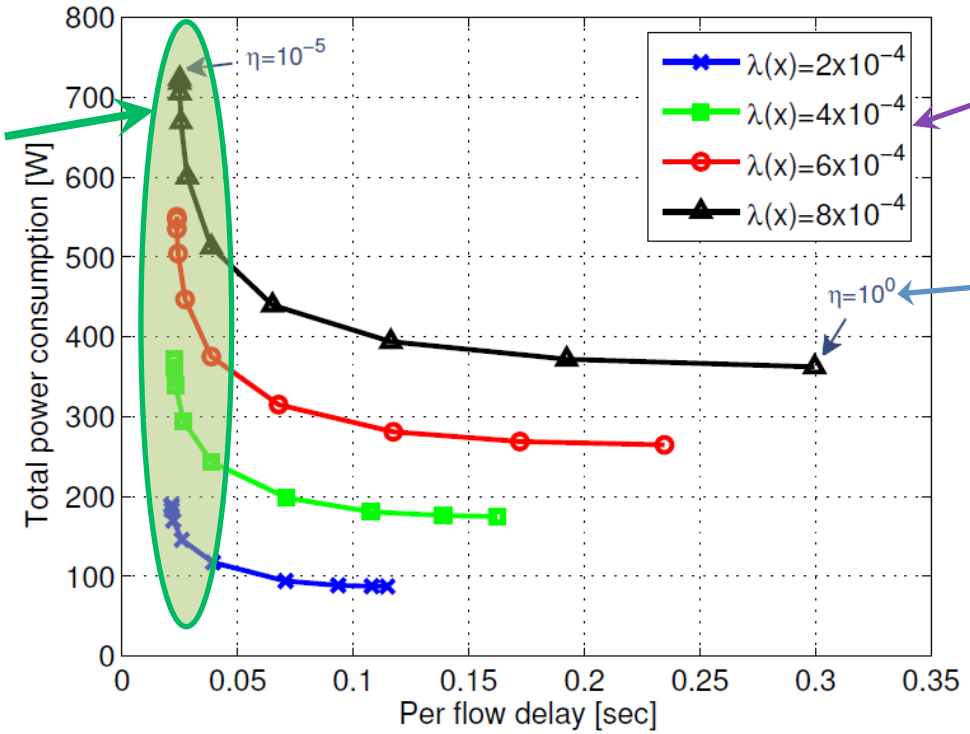
:minimize objective given $\mathbf{B_{on}}$

Short-term operation

Performance Evaluation

- Energy saving-delay trade off

Effective greening zone



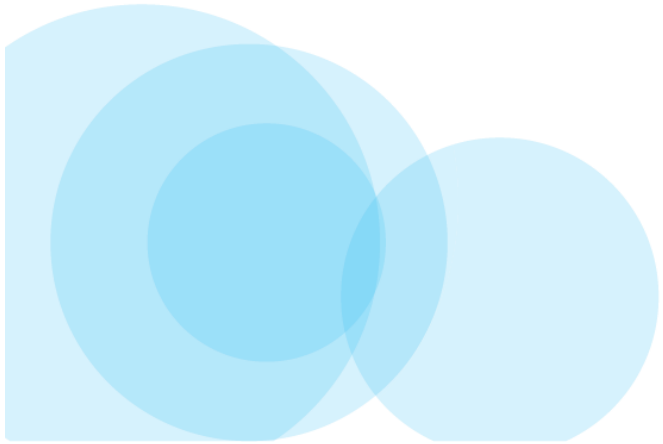
λ: arrival rate

η: weight of energy saving

- Greening zone: large energy saving with small perform ance loss

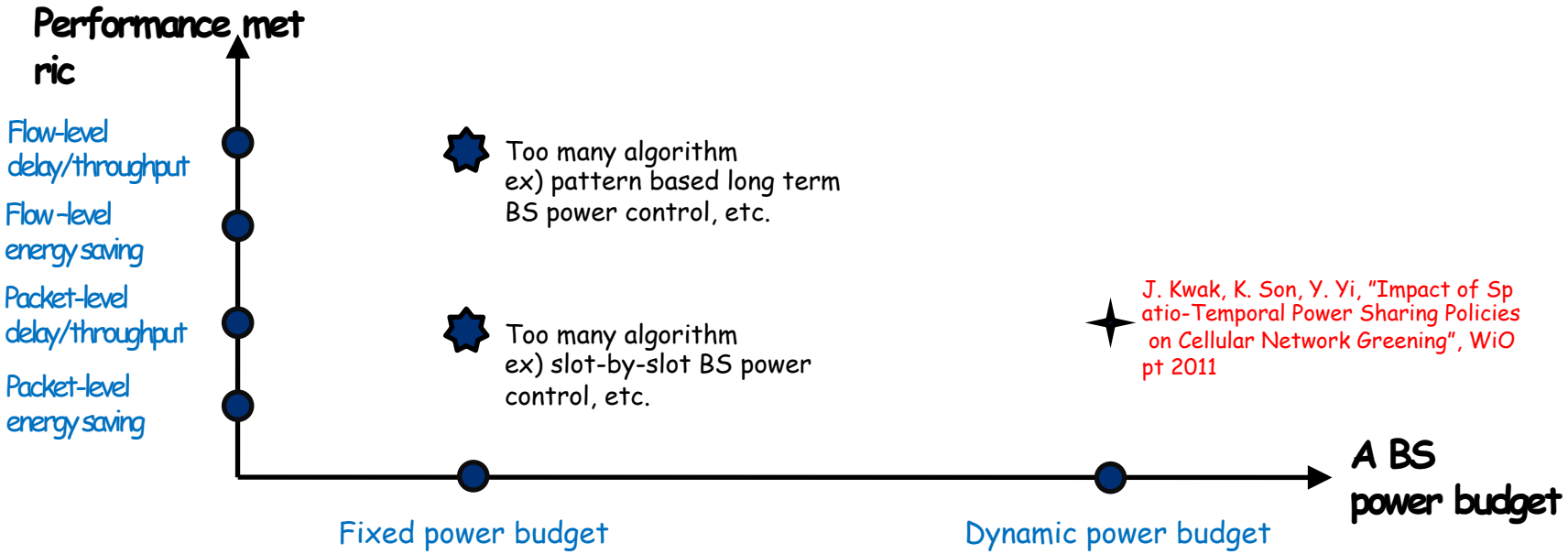
BS Transmit Power Control

GreenTouch™



Transmit Power Control

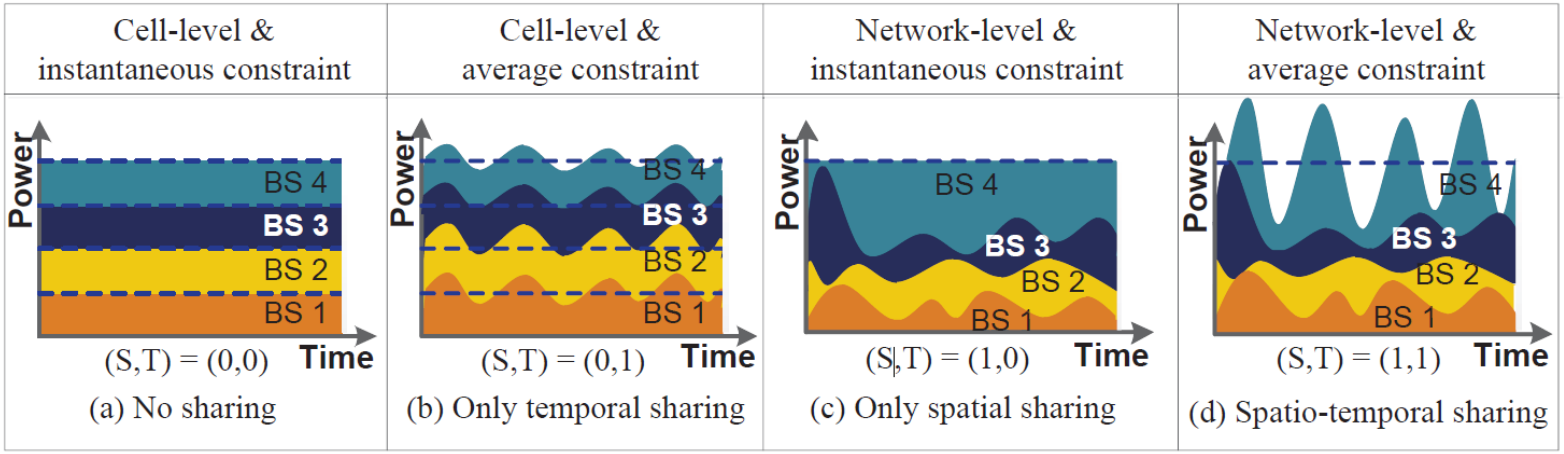
- Traffic adaptive dynamic network topology design



- Several slots [ms]~[sec] time scale

Motivation

- Cells: smaller and smaller
  - Interference management
  - Dynamic power control
- Kyoto protocol is expected to enforce the limit of annual energy consumption per country
- Impact of dynamic operation of the given power budget?

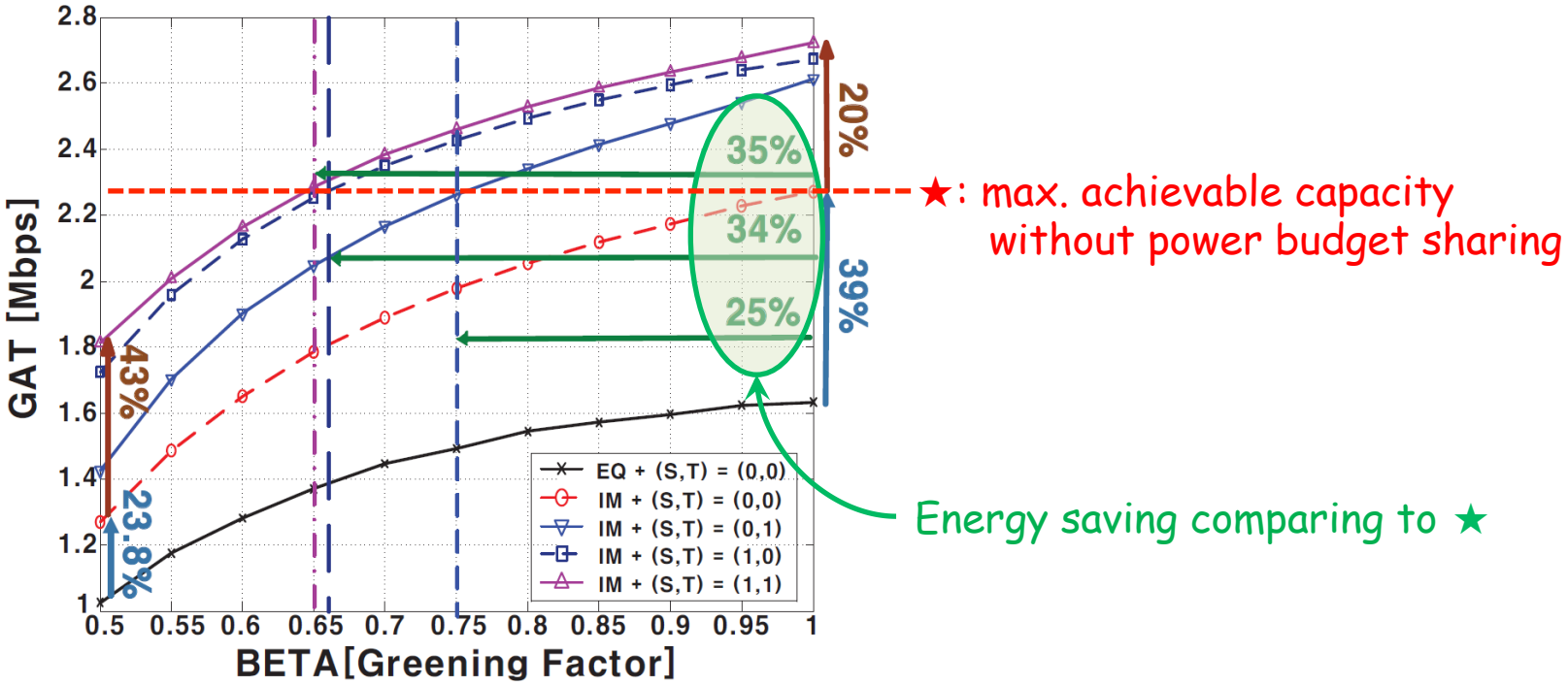


S: if 1, enable spatial power budget sharing

T: if 1, enable temporal power budget sharing

Performance Evaluation

- Effectiveness of spatio-temporal power budget sharing



- Power budget sharing reduce 25~35% energy consumption

Summary

- Greening policies in BS
  - Different time-scales
  - BS topology, on-off, power control
- Some Messages
  - Many spots for greening
  - Many open problems
    - Cooperative greening among multiple mobile network providers
    - Coupling with other greening policies
      - e.g., smart antennas, backhaul greening
    - Inter-play between greening and users' participation
- Greening has just started

Thank you

More comments and questions at
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