

Lanada

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

Yi, Yung (이웅)

KAIST, Electrical Engineering

<http://lanada.kaist.ac.kr>

yyung@kaist.edu

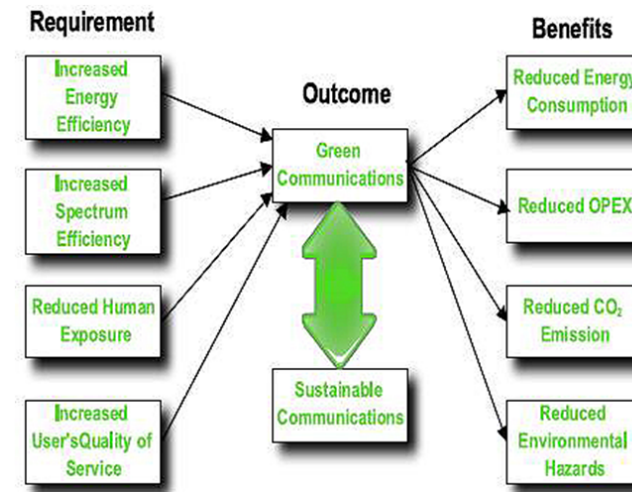
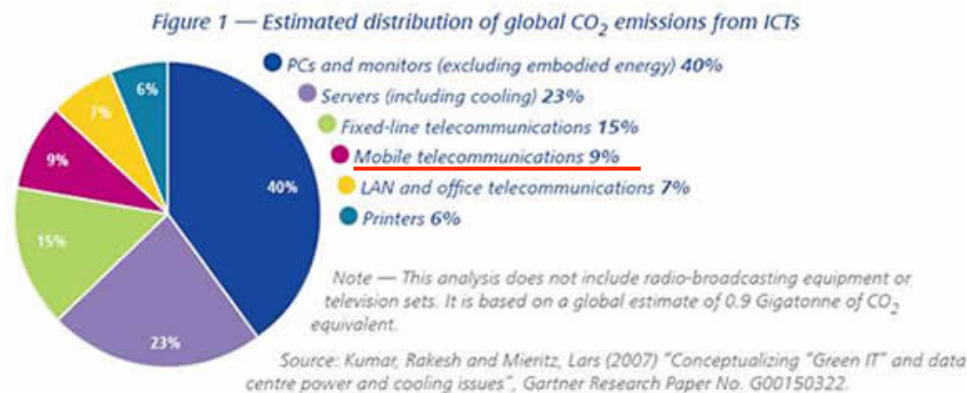
twitter.com/yiyung

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 for Future Cellular Networks", WWRF #25 WG4, Nov. 2010, London, United Kingdom

- 60-80% of energy consumed for maintaining and operating BS in cellular networks in mobile telecommunications

Greening Needs

- Environmental

- CO₂ emission
 - Greenhouse effect
 - Kyoto protocol
 - Government regulation



<CO₂ emission in power plants>

Source: www.veindirectory.org

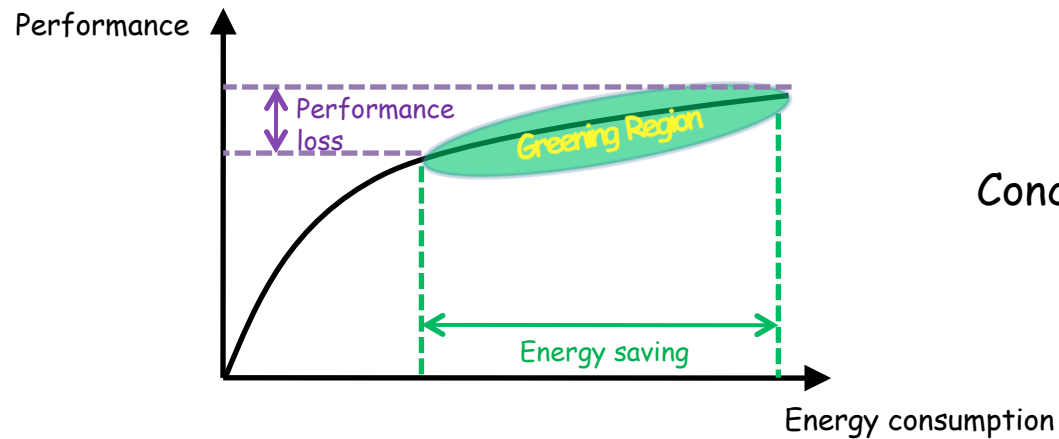
- Economic

- OPEX
 - Electric bill

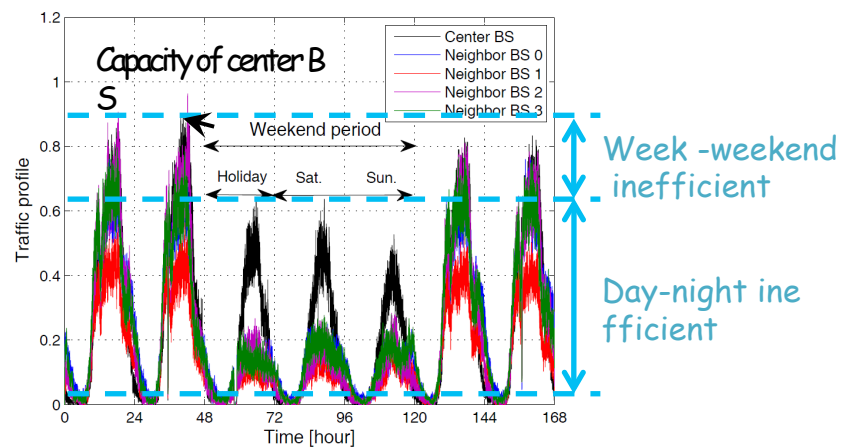


<Large amount of electric bill>

Spots for Greening



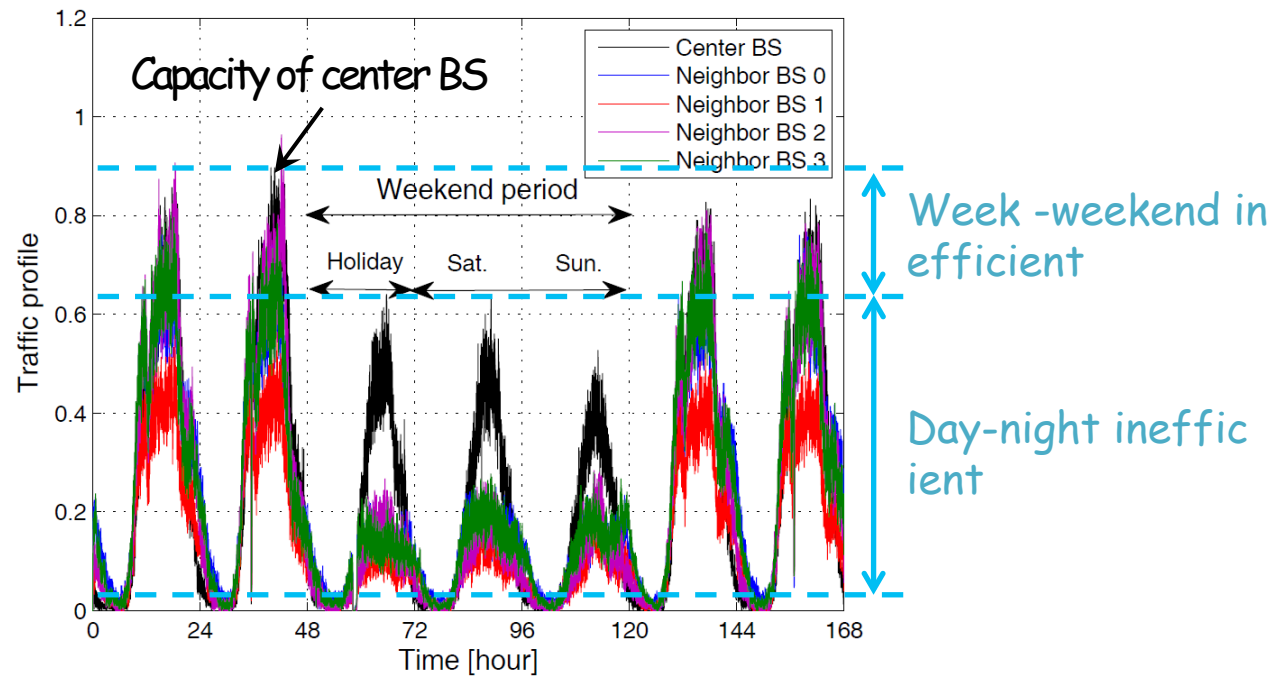
Concave performance-energy tradeoff



Resource consolidation

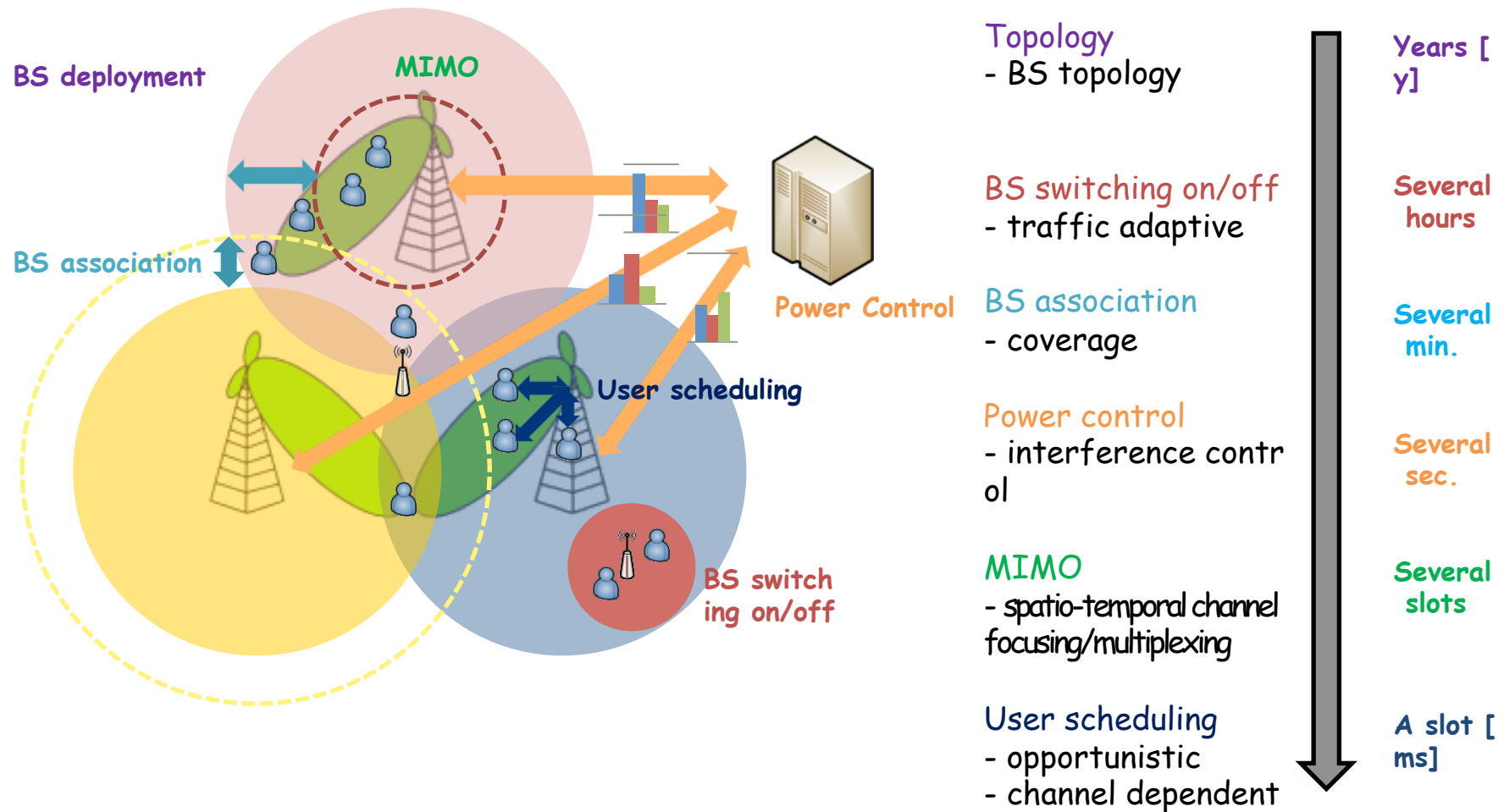
Traffic Adaptive Resource Consolidation

- Dynamic traffic pattern

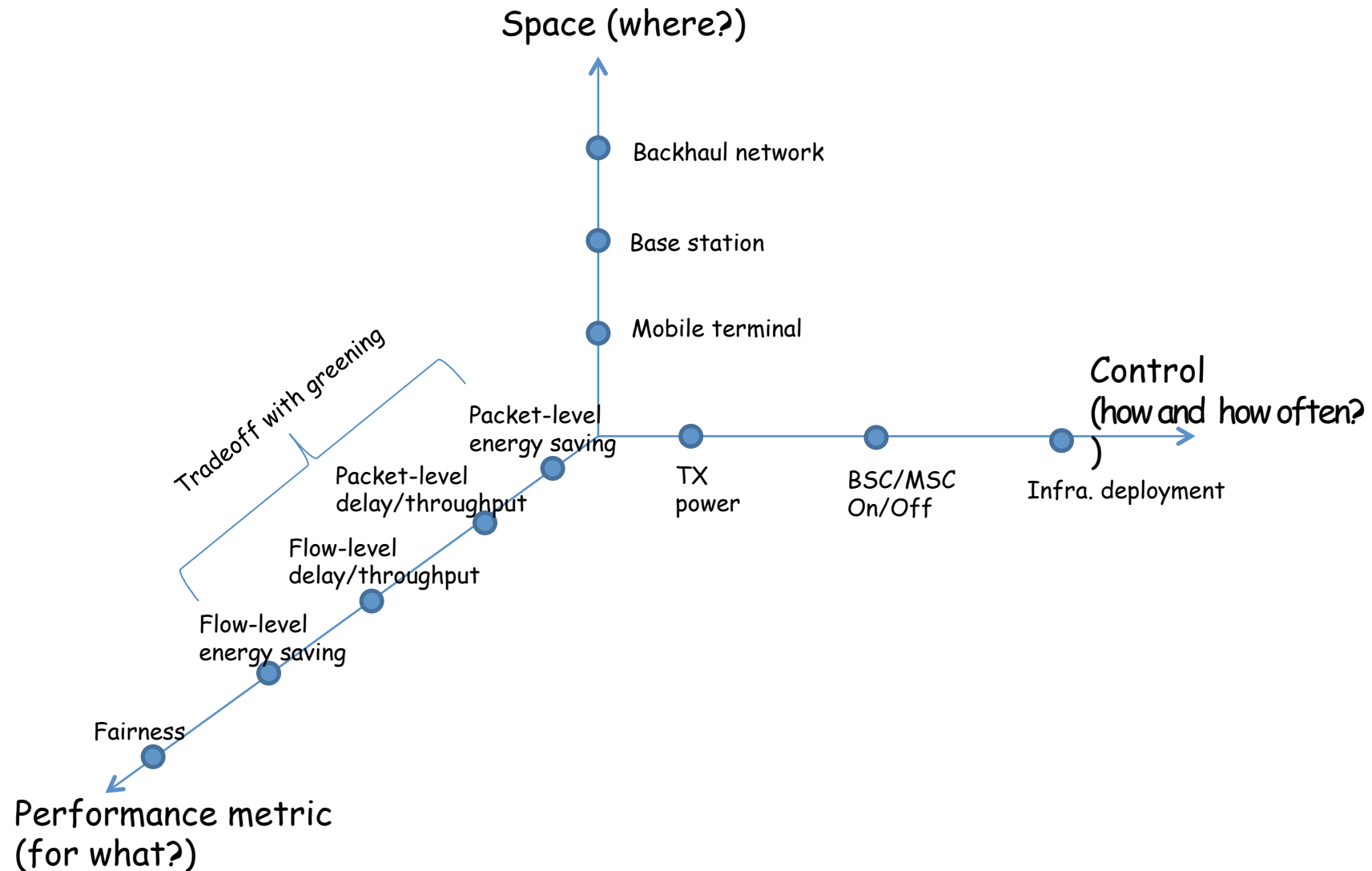


- Currently, all BSs deployed for serving peak data traffic
- Week-weekend, day-night inefficiency
- Traffic adaptive BS switching on/off for efficient network

Cellular Networks: Control Knobs



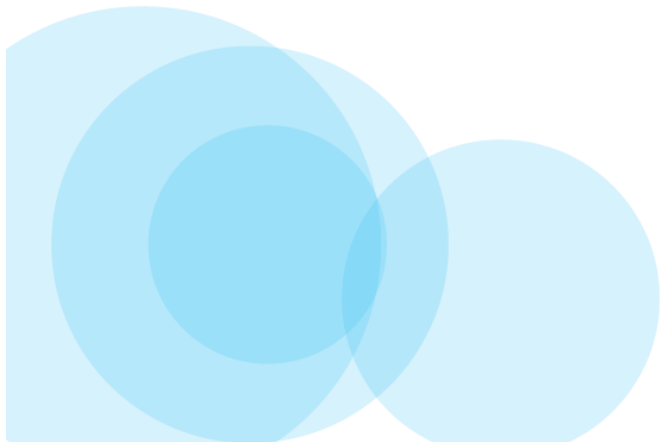
Cellular Greening: Problem Space



This Talk: Three Case Studies

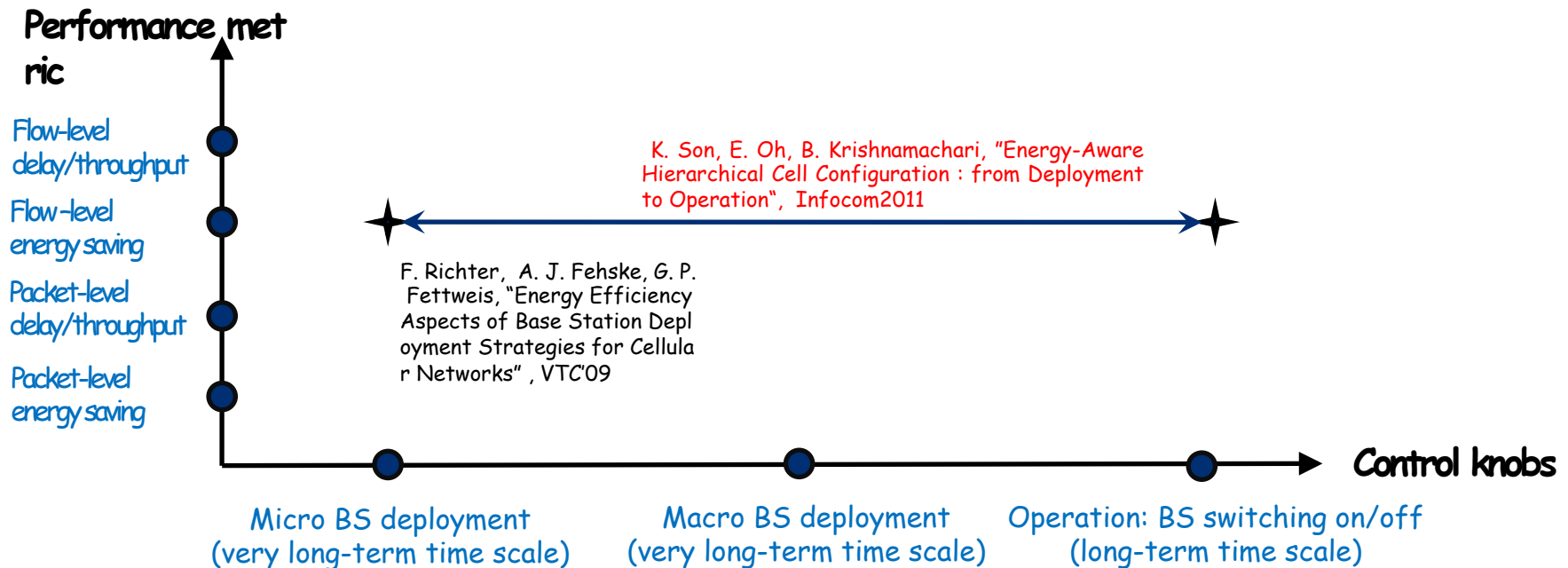
- 1. BS Topology Design
- 2. BS On-Off Mechanism
- 3. BS Transmit Power Control

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 consumption
 - 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

$$\min_{\{B^t\}} \int_{t_0}^{t_0+D} (P_M \cdot |B_M^t| + P_m \cdot |B_m^t|) dt$$
 : minimize energy consumption

$$\text{s.t. } S(A, B^t) \geq \zeta \cdot S_{th}^t \quad \forall t \in [t_0, t_0 + D),$$
 : Throughput enhancement

Active BS set sequence

Average flow level *throughput* on area A at time t [bit/s/Hz/m²] by active BSs (additional micro BS + deployed macroBS)

Average flow level *throughput* on area A at time t [bit/s/Hz/m²] by currently deployed macro BSs

Enhancement target constant > 1

Power consumption of a macro BS
 The # of active macro BS
 Power consumption of a micro BS
 The # of active micro BS
 A day

Approach: Time-scale Separation

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

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

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

*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

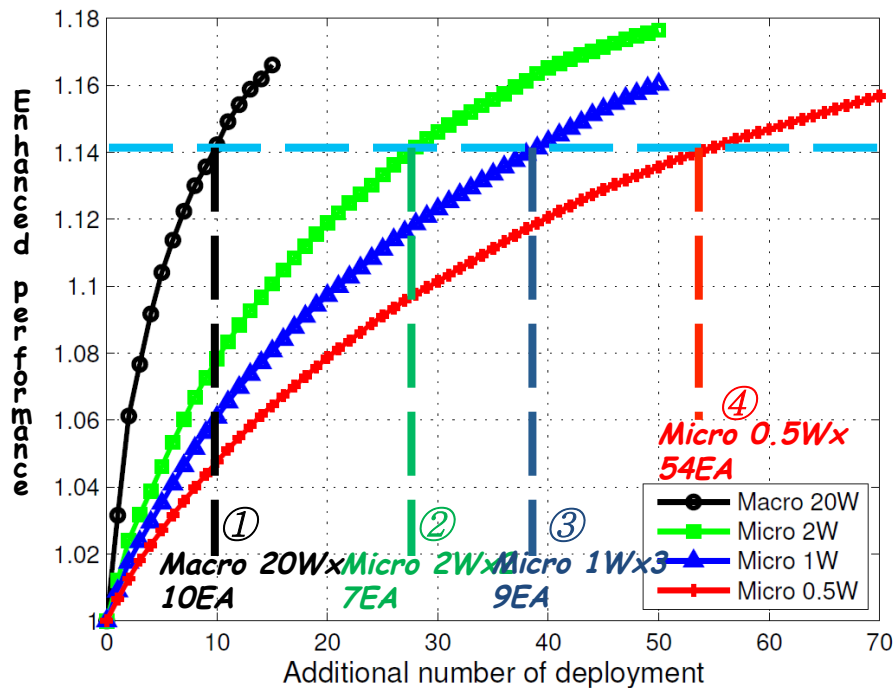
$$\min_{\mathcal{B}^t} P_M \cdot |\mathcal{B}_M^t| + P_m \cdot |\mathcal{B}_m^t| : \text{OPEX minimization at time } t$$

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

The set of active (turning on) BS

Simulation Results (I)

● BS deployment



Target performance

Energy consumption for target performance

①: 200 [W] Macro

②: 54 [W]

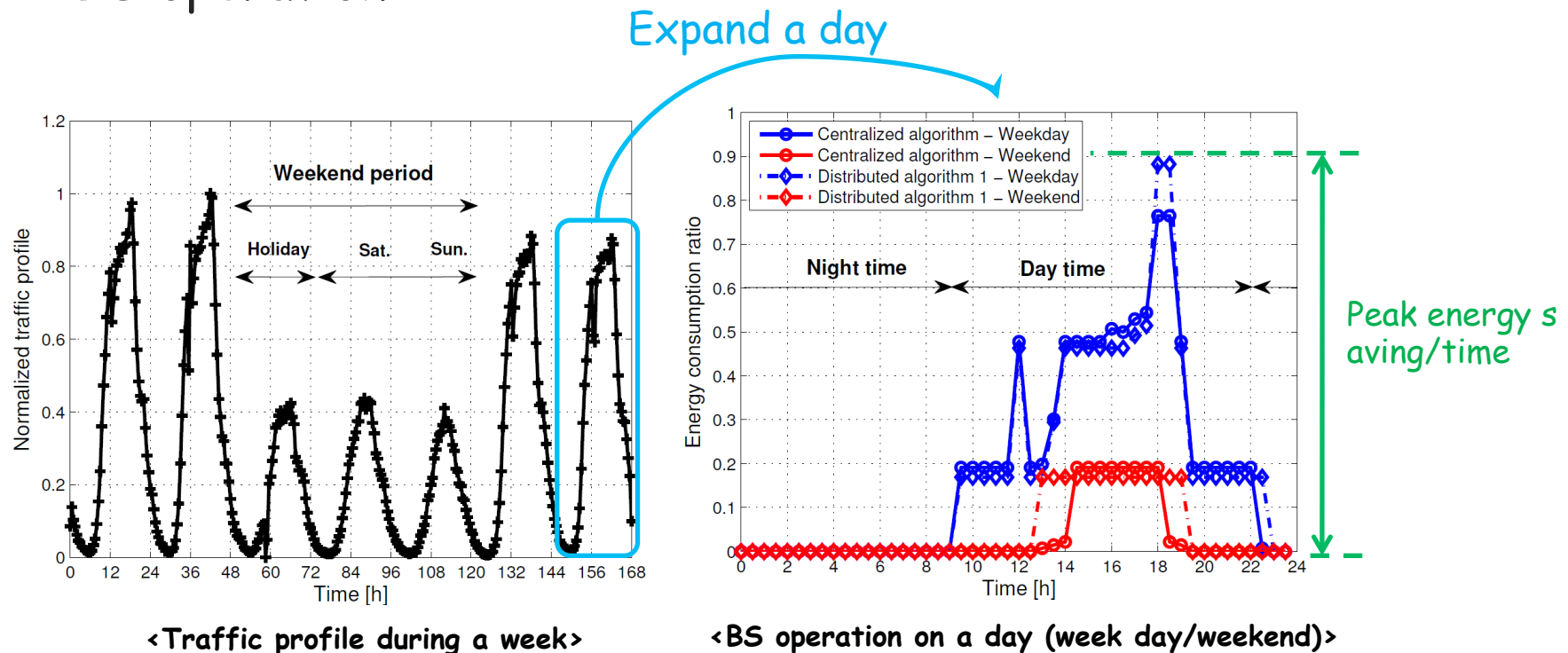
③: 39 [W]

④: 27 [W] Micro :energy saving

● Deploying smaller cell comes large energy saving

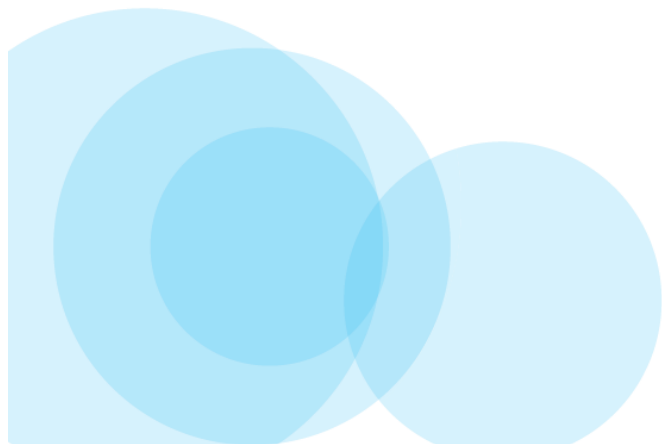
Simulation Results (II)

- BS operation

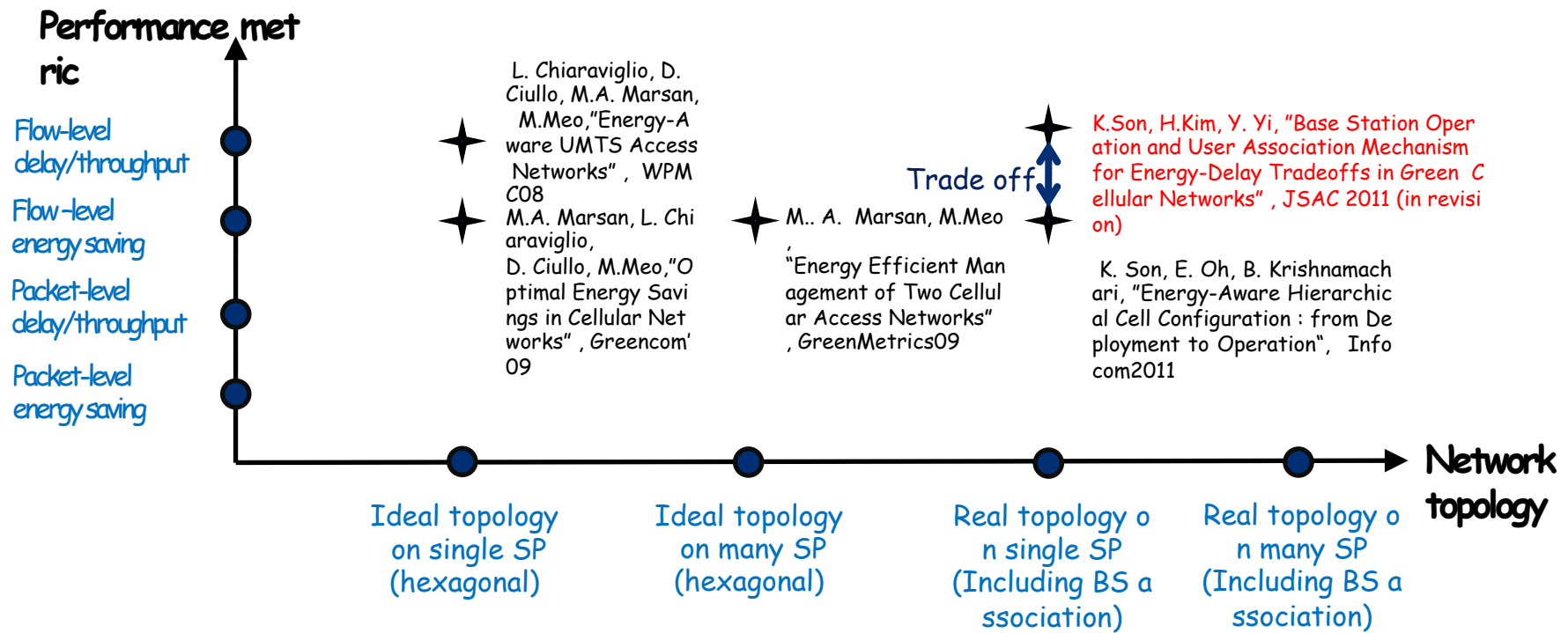


- Saving much energy during a day compared to always BS switching on
 - Energy saving = (Peak energy saving/time) × (turn-off duration)

Joint BS On-off/Association



BS On/Off



Model & Objective

- System model
 - Flow-level location dependent capacity
- Objective
 - Find optimal *active BS set* and *flow-level BS load* that minimize the total system cost function

$$\min_{\mathcal{B}_{\text{on}}, \rho} \left\{ \underbrace{\phi_{\alpha}(\rho, \mathcal{B}_{\text{on}})}_{\text{Cost of flow-level performance (delay)}} + \underbrace{\eta}_{\text{Balancing constant (performance \& energy)}} \underbrace{\psi(\rho, \mathcal{B}_{\text{on}})}_{\text{Energy consumption}} \mid \rho \in \mathcal{F}(\mathcal{B}_{\text{on}}), \mathcal{B}_{\text{on}} \subseteq \mathcal{B} \right\}$$

Cost of flow-level performance (delay)

Balancing constant (performance & energy)

Energy consumption

- \mathcal{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)

$$\min_{\mathcal{B}_{\text{on}} \subseteq \mathcal{B}} G(\mathcal{B}_{\text{on}}) + \eta \sum_{i \in \mathcal{B}_{\text{on}}} q_i P_i \quad \text{: minimize objective given } \rho^*$$

- User association (Load balancing)

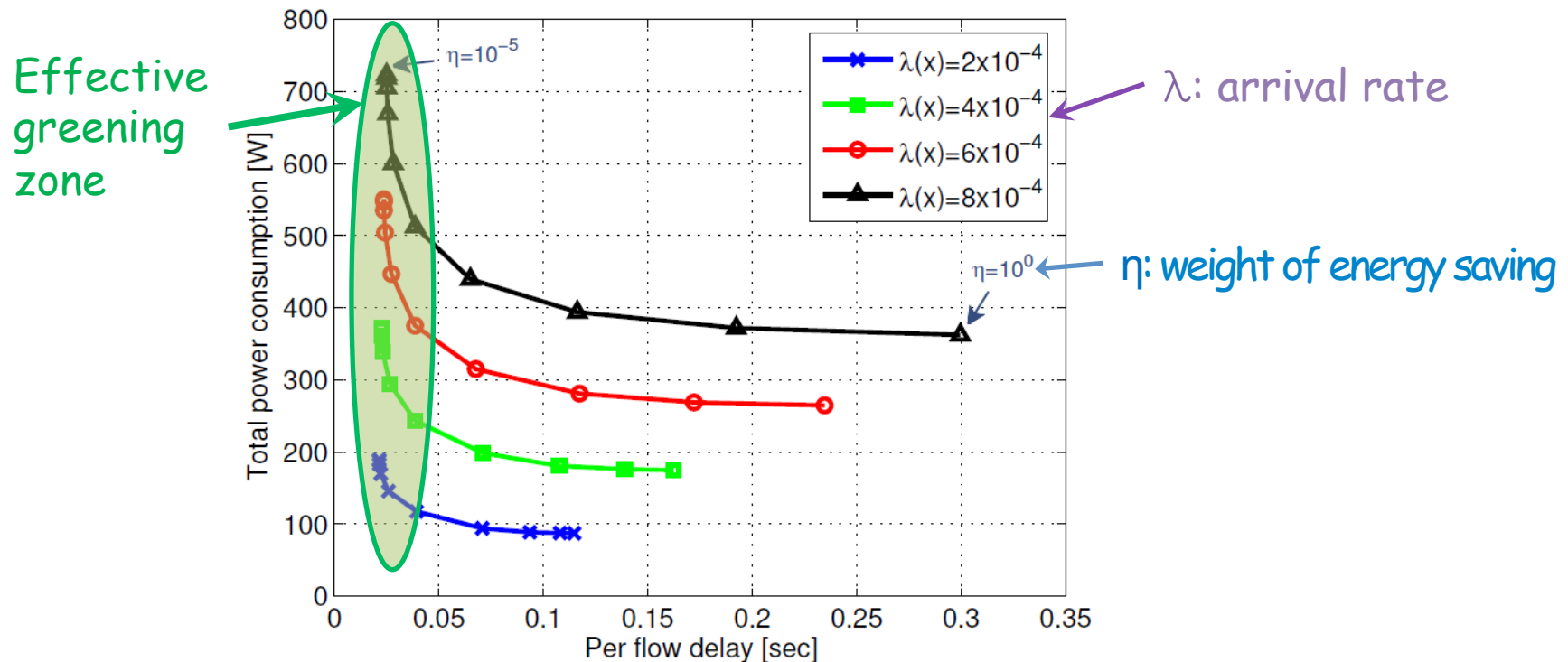
Given \mathcal{B}_{on}  $\min_{\rho \in \mathcal{F}(\mathcal{B}_{\text{on}})} \phi_{\alpha}(\rho, \mathcal{B}_{\text{on}}) + \eta \sum_{i \in \mathcal{B}_{\text{on}}} (1 - q_i) \rho_i P_i$: minimize objective given \mathcal{B}_{on}

Short-term operation

Long-term operation 

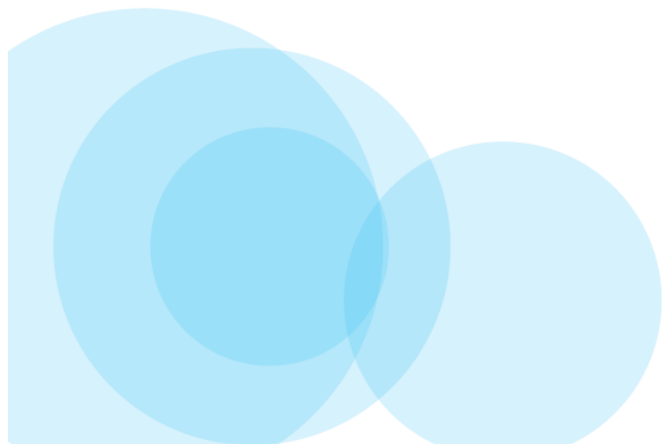
Performance Evaluation

- Energy saving-delay trade off



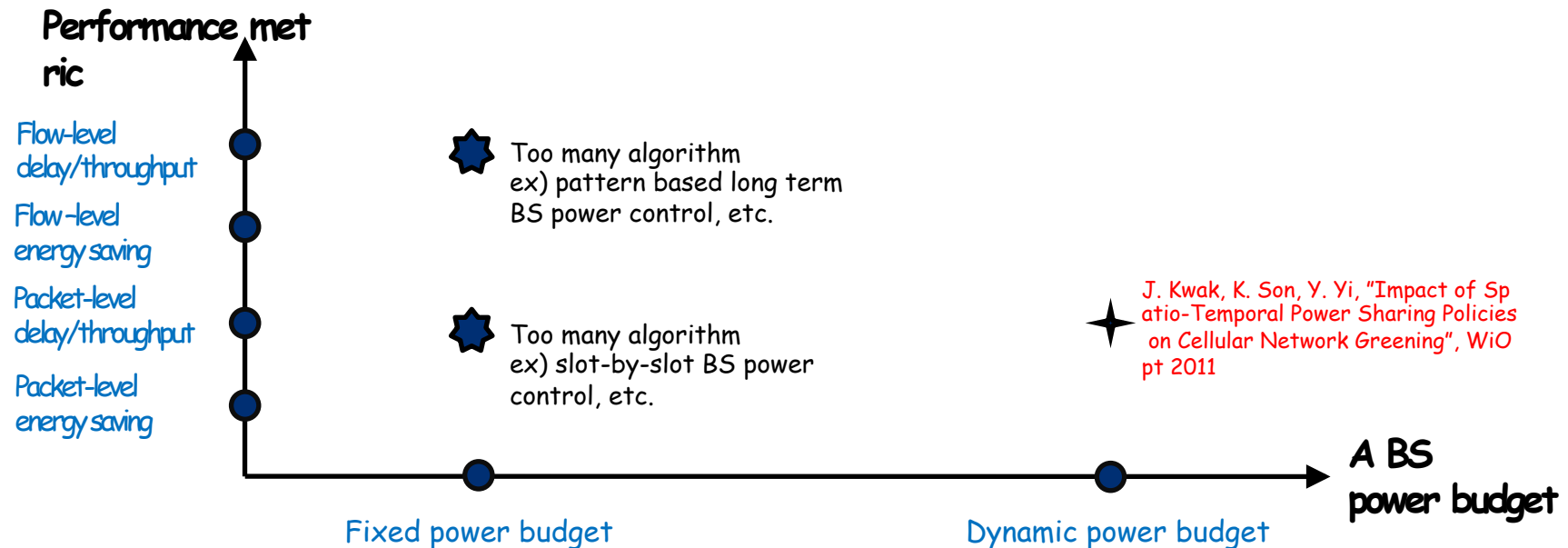
- Greening zone: large energy saving with small performance loss

BS Transmit Power Control



Transmit Power Control

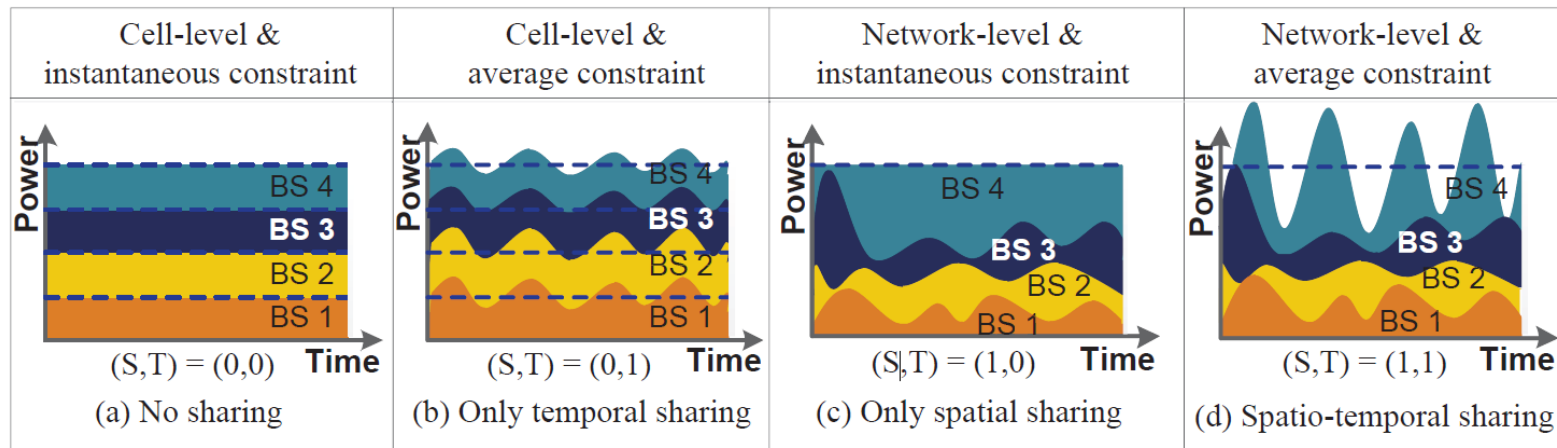
- Traffic adaptive dynamic network topology design



- 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?

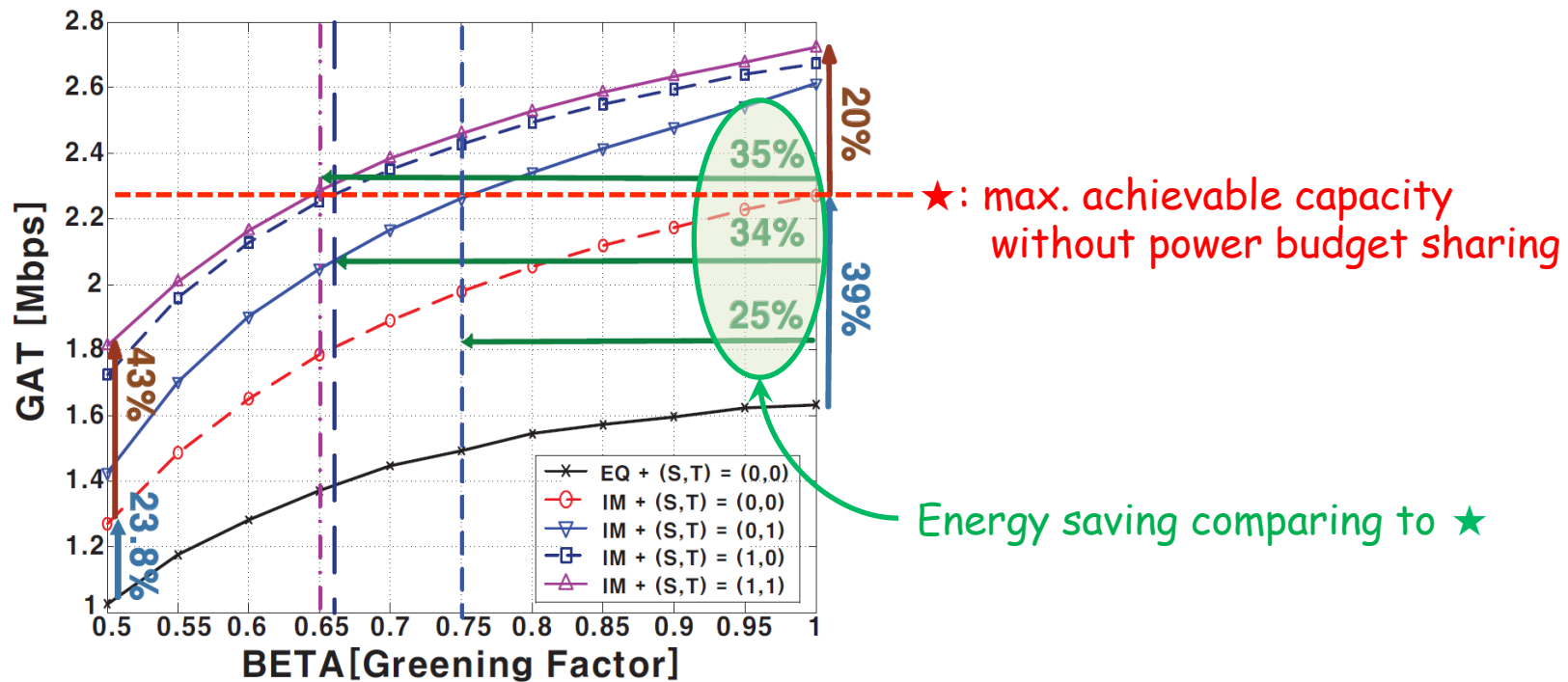


S: if 1, enable spatial power budget sharing

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

Lanada

Thank you

More comments and questions at
yyiung@kaist.edu