

Lecture Series, TU Munich
October 22, 29 & November 5, 2013

Glocal Control for Hierarchical Dynamical Systems

**Theoretical Foundations with
Applications in Energy Networks**

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The University of Tokyo, Japan

OUTLINE

1. Glocal Control & Energy Networks
2. A Unified Framework for Networked Dynamical Systems with Stability Analysis
3. From Homogeneous to Heterogeneous
4. From Flat to Hierarchical
5. Decentralized Hierarchical Control Synthesis
6. Applications in Energy Networks

OUTLINE : Part 6

6. Applications in Energy Networks

with Fujitsu

with Azbil

with Tokyo-Gas



Different Target Systems

Different Shift Elements

Different Focuses

Smart Water Surrounding System

Features of Energy & Water NWs

★ Energy & Water

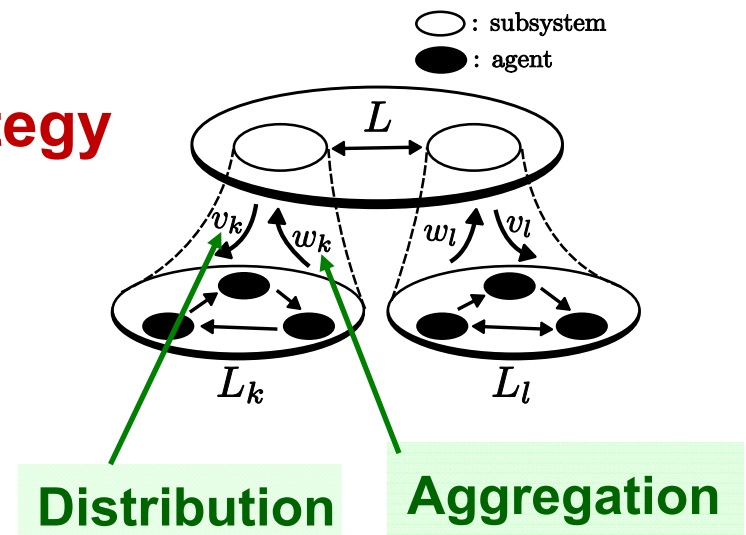
- not uniformly distributed in time/space
- unbalance between demand & supply
 - **Control = balancing energy/water in time/space**
- but, transfer is very costly
 - **only local actions with exchanges in neighbors are available**
 - **shifting elements in time/space are important**

★ To reduce total energy

→ **Utilizing Nature & Control Strategy**

★ Key Points

- Hierarchical with Multi-resolution
- Aggregation & Distribution
- **Passivity**



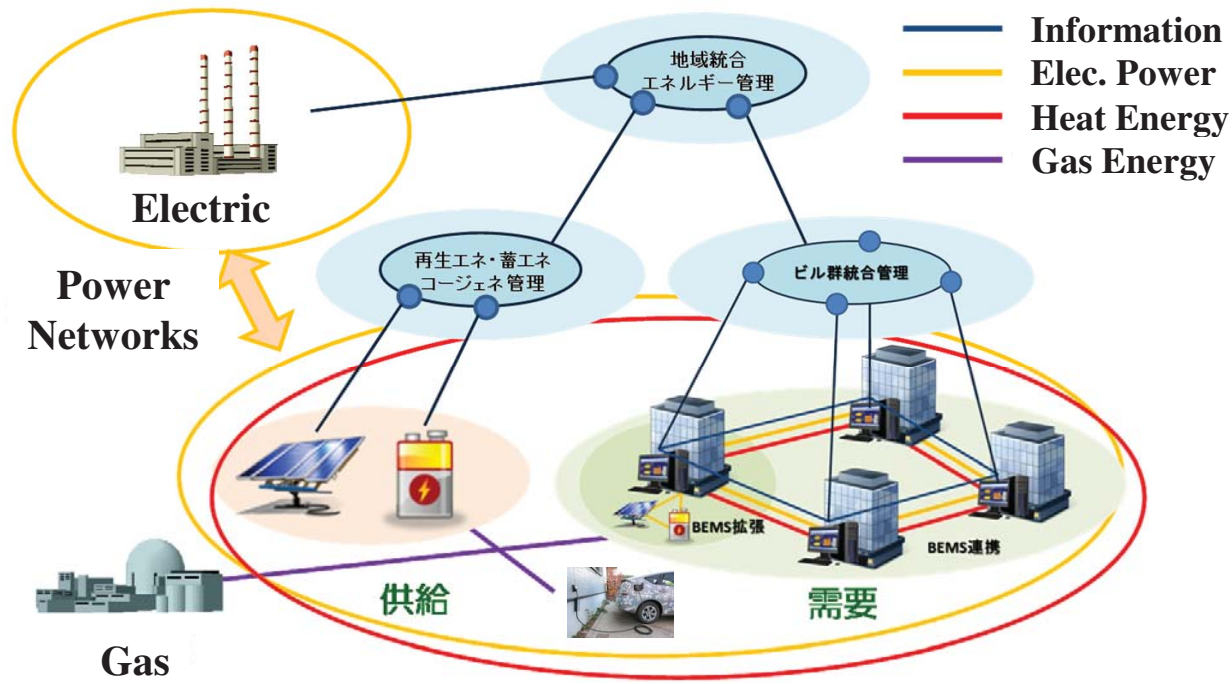
Integrated Energy Networks

Integrated Energy Network

Electric power network
+ Gas energy network
+ Heat energy network

Multi-resolved Hierarchical

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alized



Regional Energy Network System

yo
Gas
u

OUTLINE : Part 6

6. Applications in Energy Networks

with Fujitsu

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Electric NWs

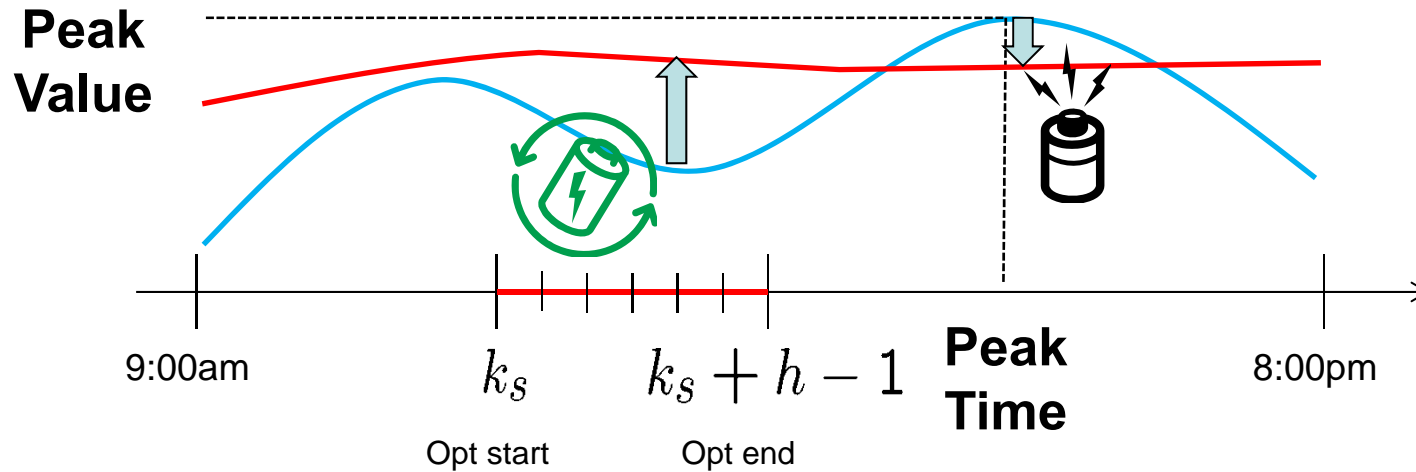
Static Storages

Aggregation

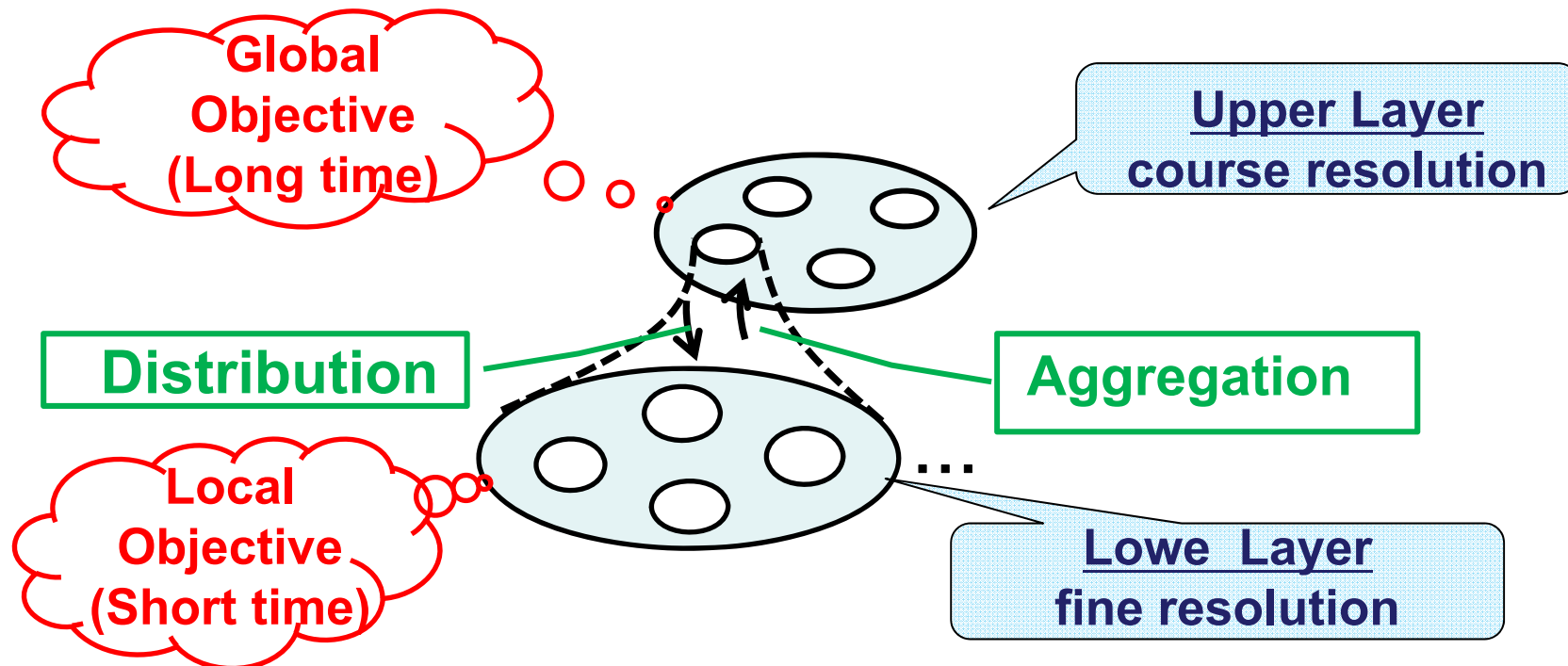
Smart Water Surrounding System

Laptop PC Battery System

(with Fujitsu)

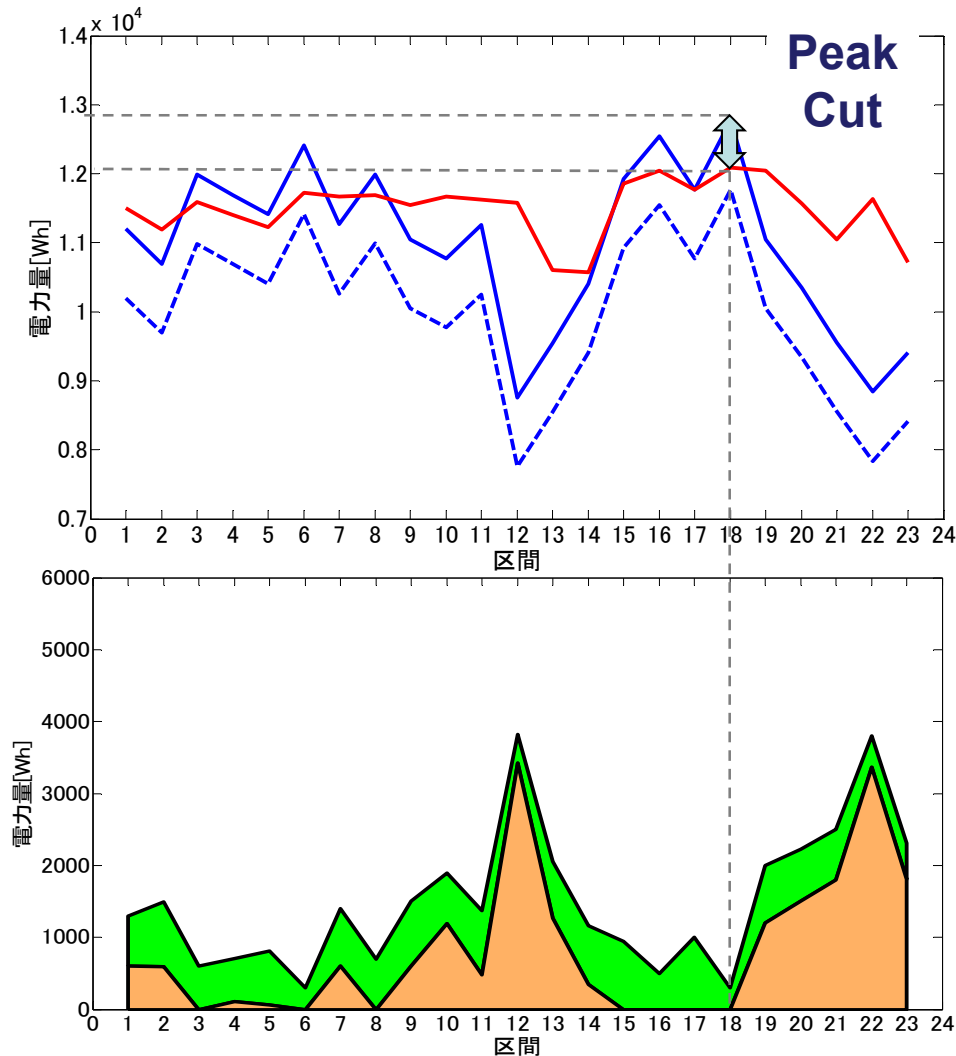


Three modes:
AC driven
B. driven
B. charge



Hierarchical Model Predictive Control for Laptop PC Battery Systems

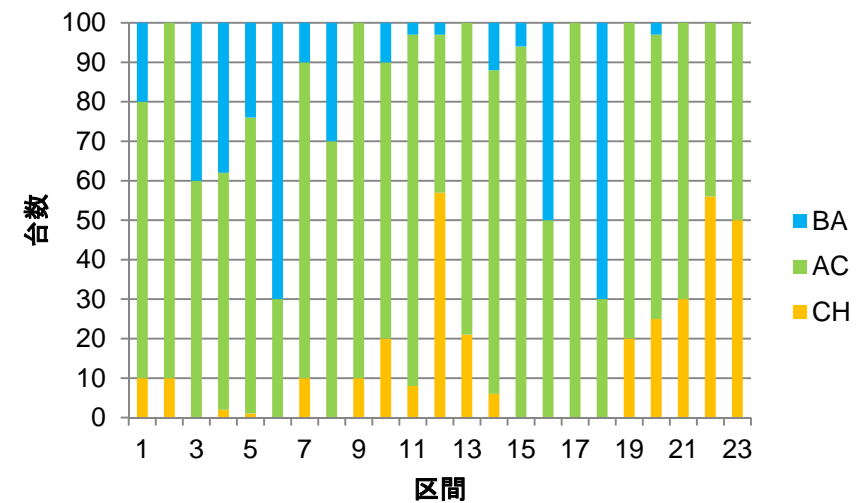
(with Fujitsu)



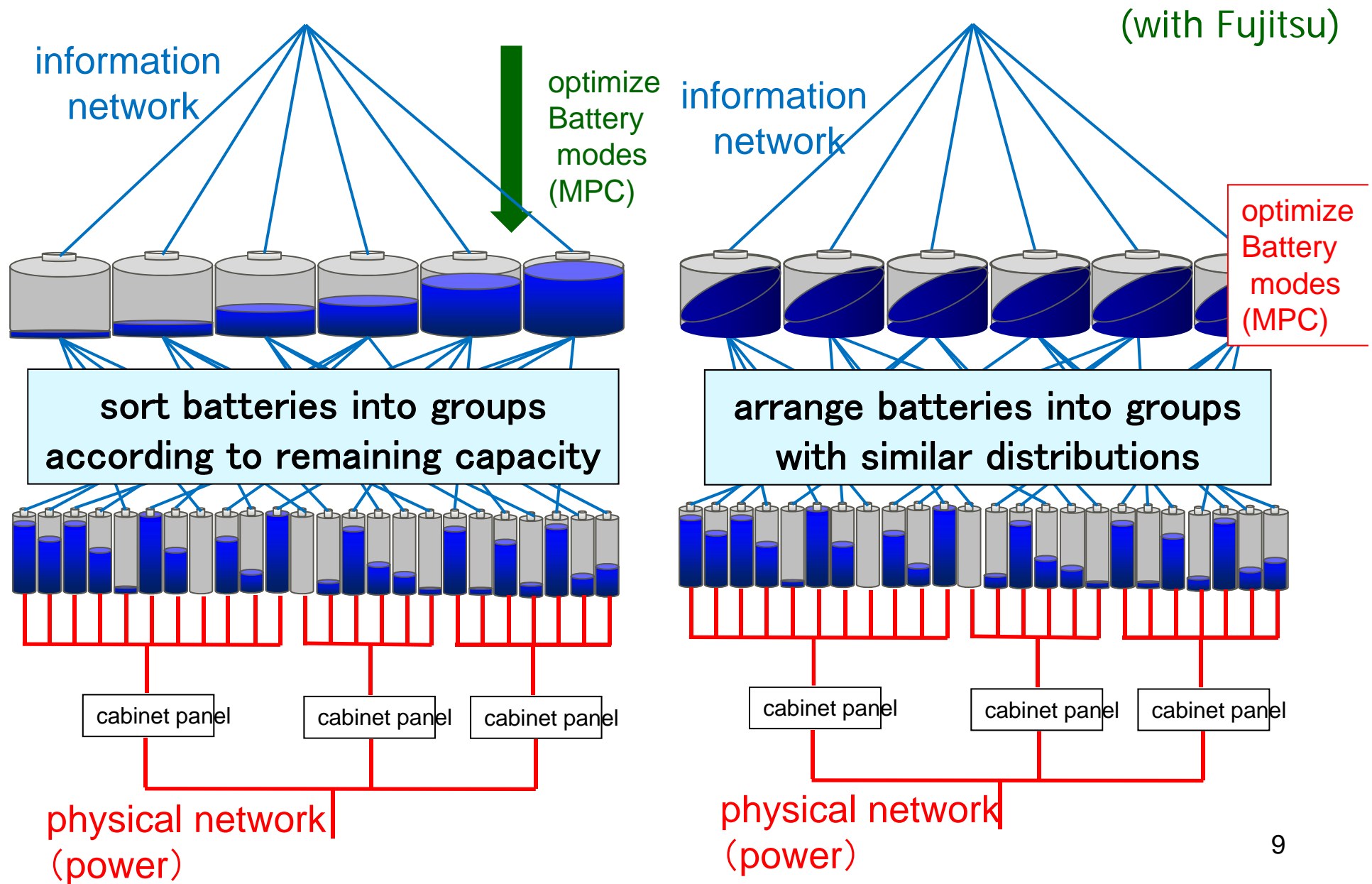
100 PCs \rightarrow 10 PCs x 10 G

Upper Layer Horizon: 8

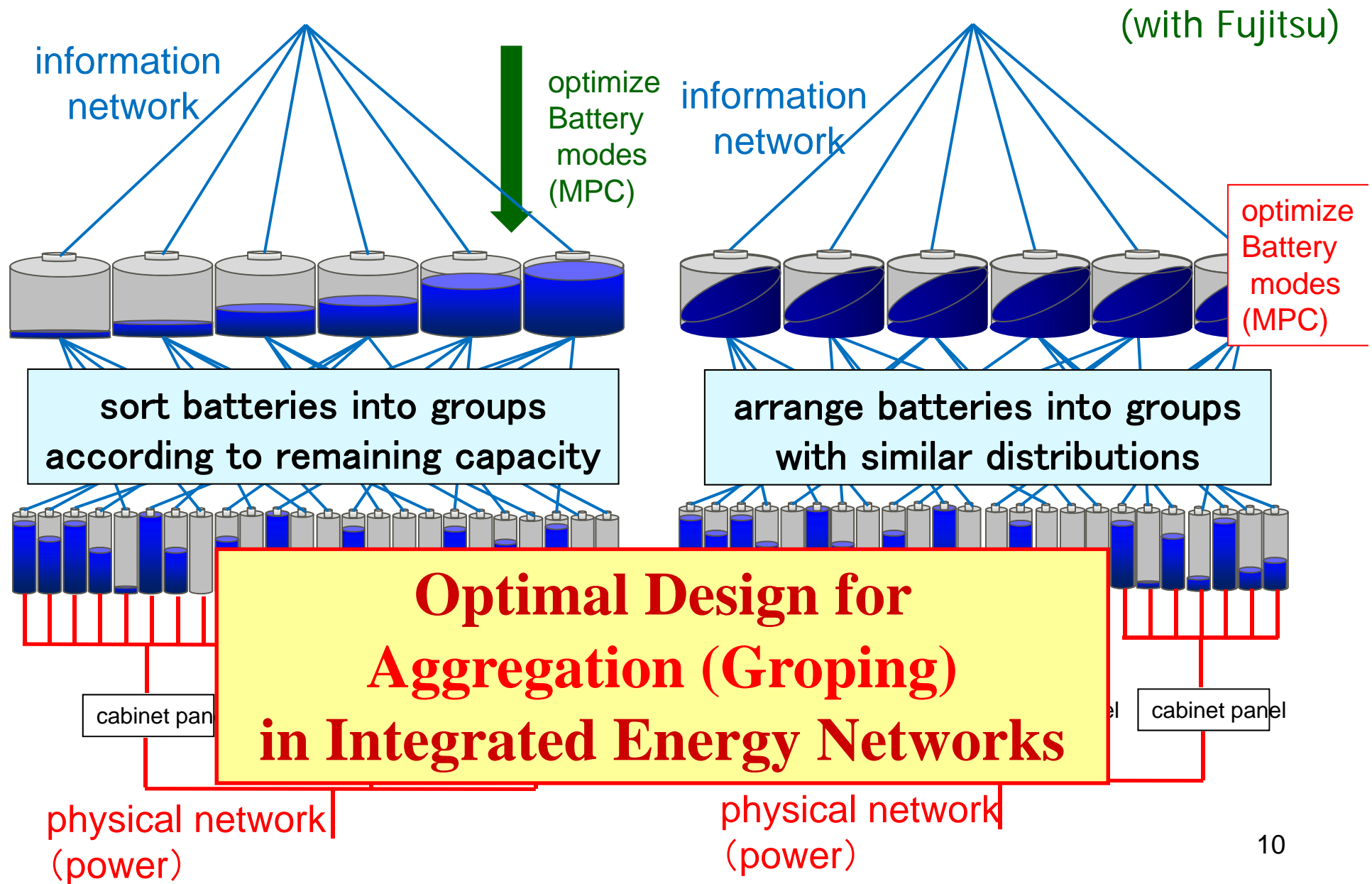
Lower Layer Horizon: 3



Two Types of Aggregation



Two Types of Aggregation



OUTLINE : Part 6

6. Applications in Energy Networks

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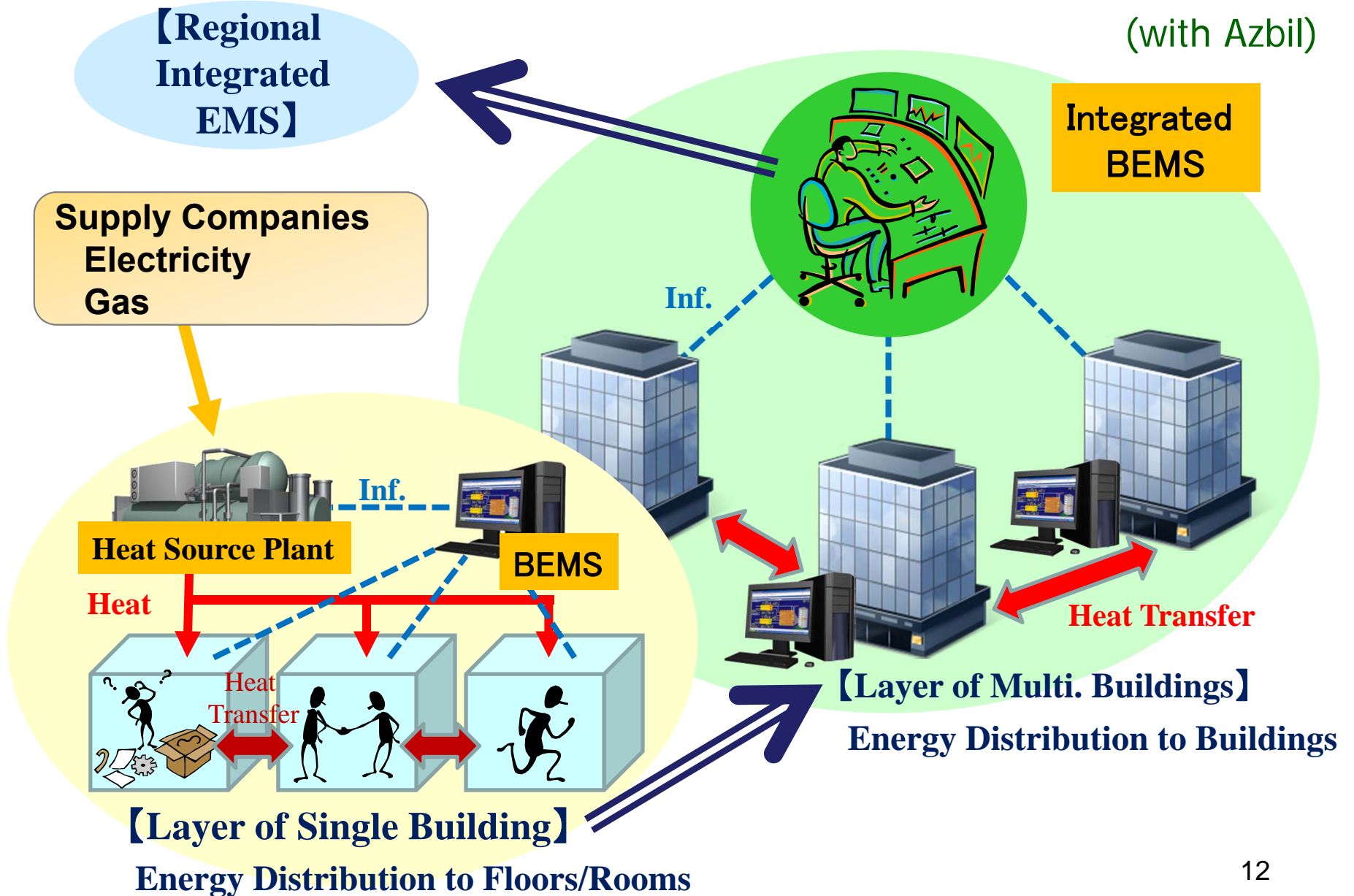
**Air Conditioning
Systems**

**Thermal Energy
Transfer/Storage**

**Decentralized
Control**

Smart Water Surrounding System

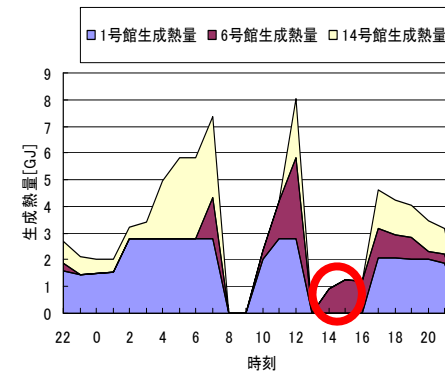
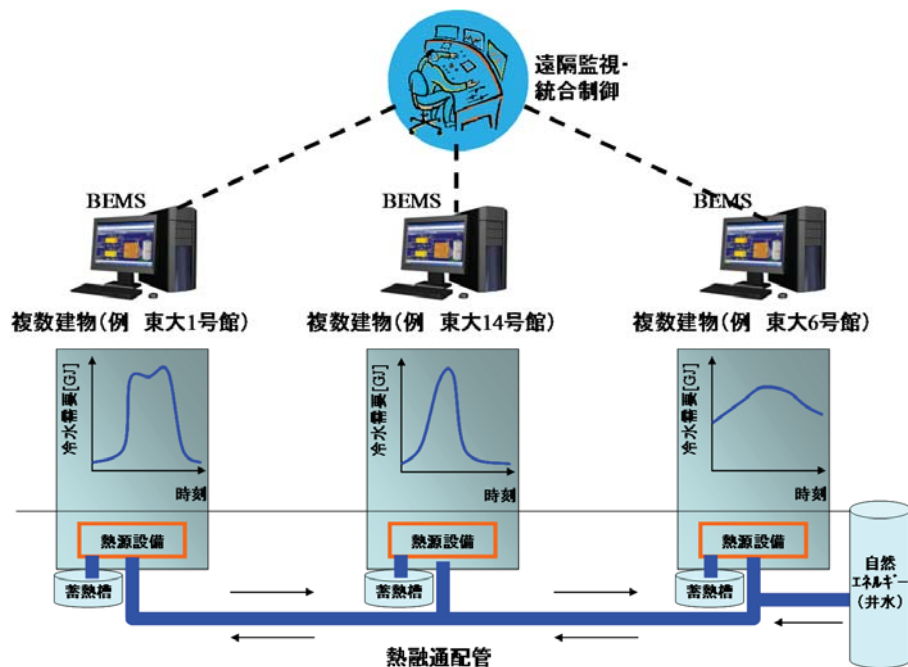
Towards Regional Integrated EMS



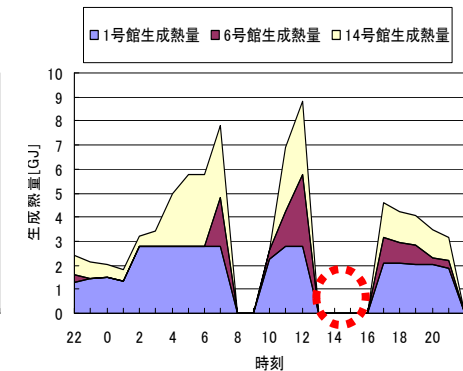
Integrated BEMS by Heat Transfer

(with Azbil)

Purpose
Energy Management Control
by Heat Transfer
with Thermal Energy Storages



Without Heat Transfer



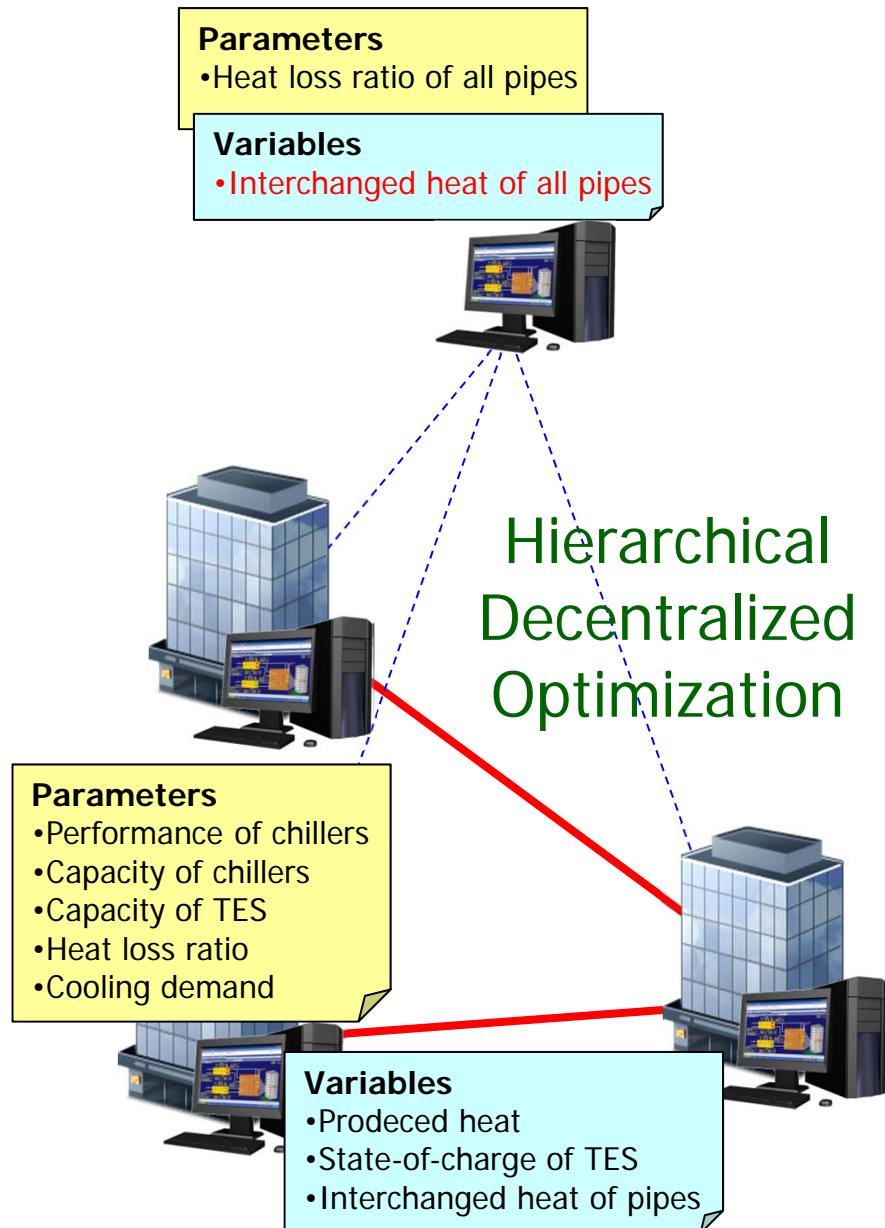
With Heat Transfer

On Going Work

- 1) Hierarchical Modeling & Decentralized Control
- 2) Design Guideline for NWS (TESs, GEs)

Features of Decentralized Control

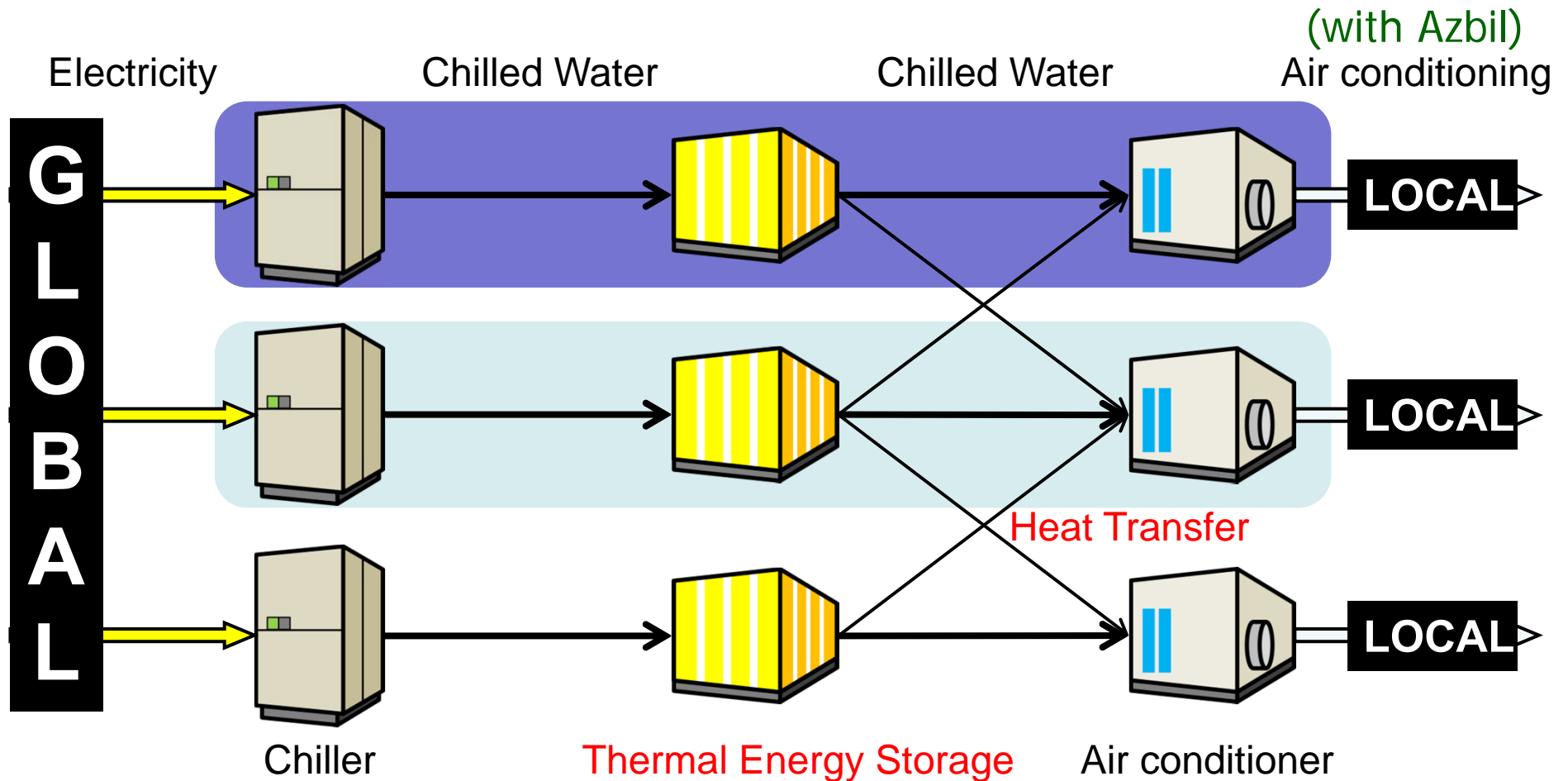
(with Azbil)



Advantages

- *Reduction of computation load* in each control device
- *Localization of confidential information* (e.g. facility information, energy consumption)
- *Adaptation capability* for facility replacement and performance degradation with updating of subsystems

Decentralized Control for Int. BEMS



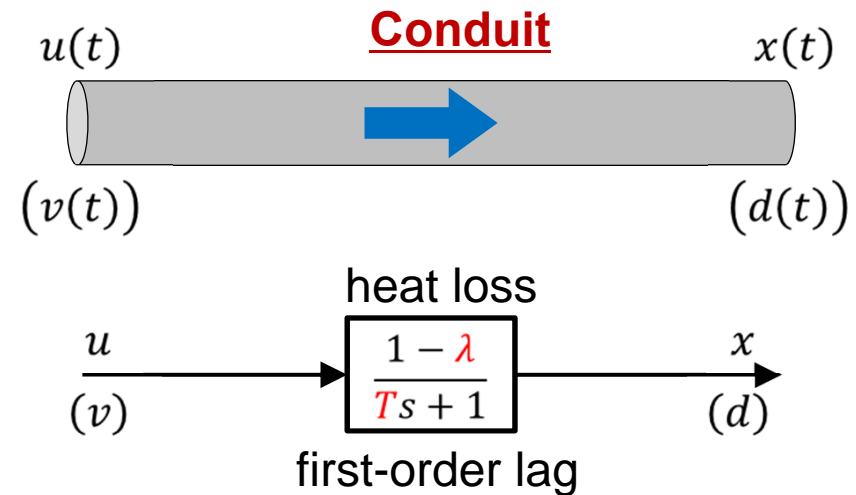
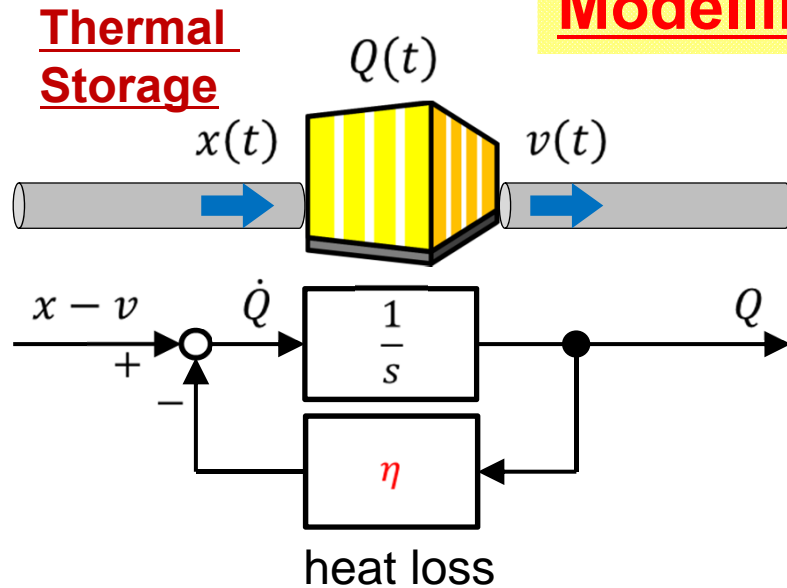
Minimizing
Total Energy

Maximizing
Each Utility

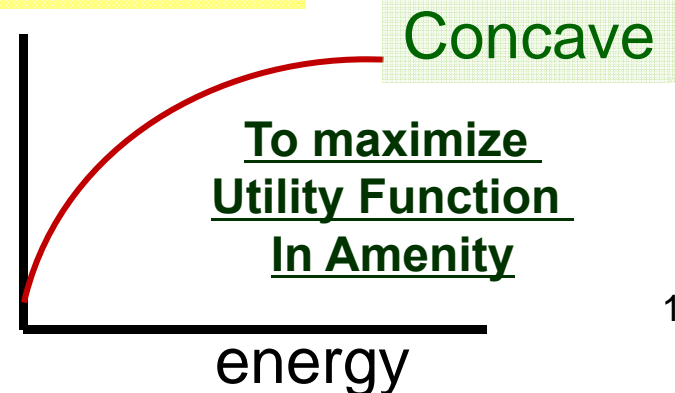
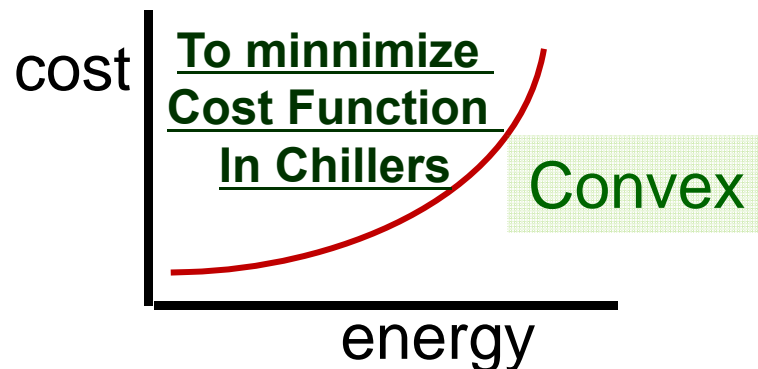
Modeling of Elements and Setting of Objective Functions

(with Azbil)

Modelling of Elements



Setting of Objective Functions



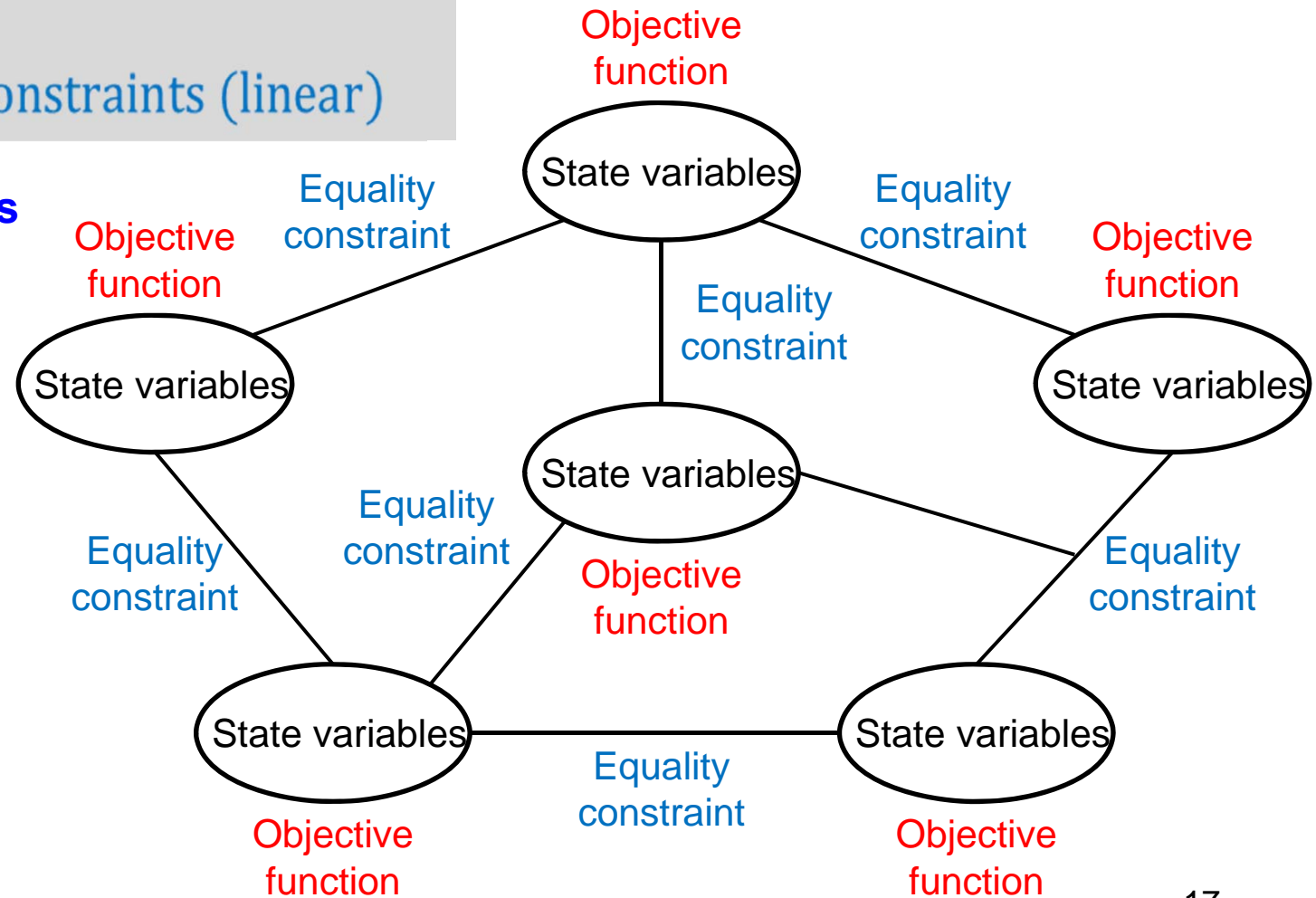
Decentralized Control : Optimization

(with Azbil)

$$\max_{\text{State variables}} \sum \text{Objective function}$$

s. t. Equality constraints (linear)

**Conservative Laws
Dynamics**



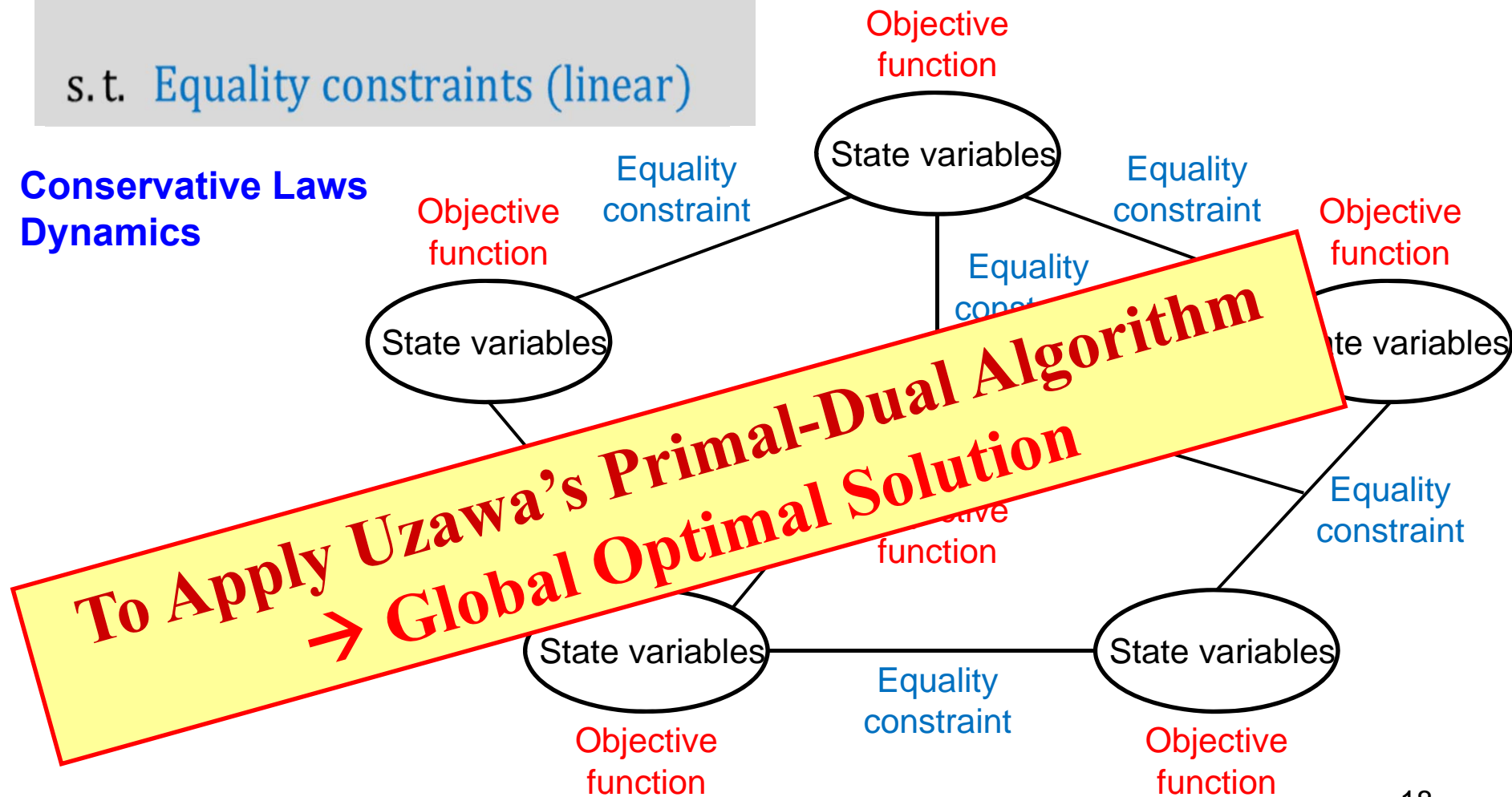
Decentralized Control : Optimization

(with Azbil)

$$\max_{\text{State variables}} \sum \text{Objective function}$$

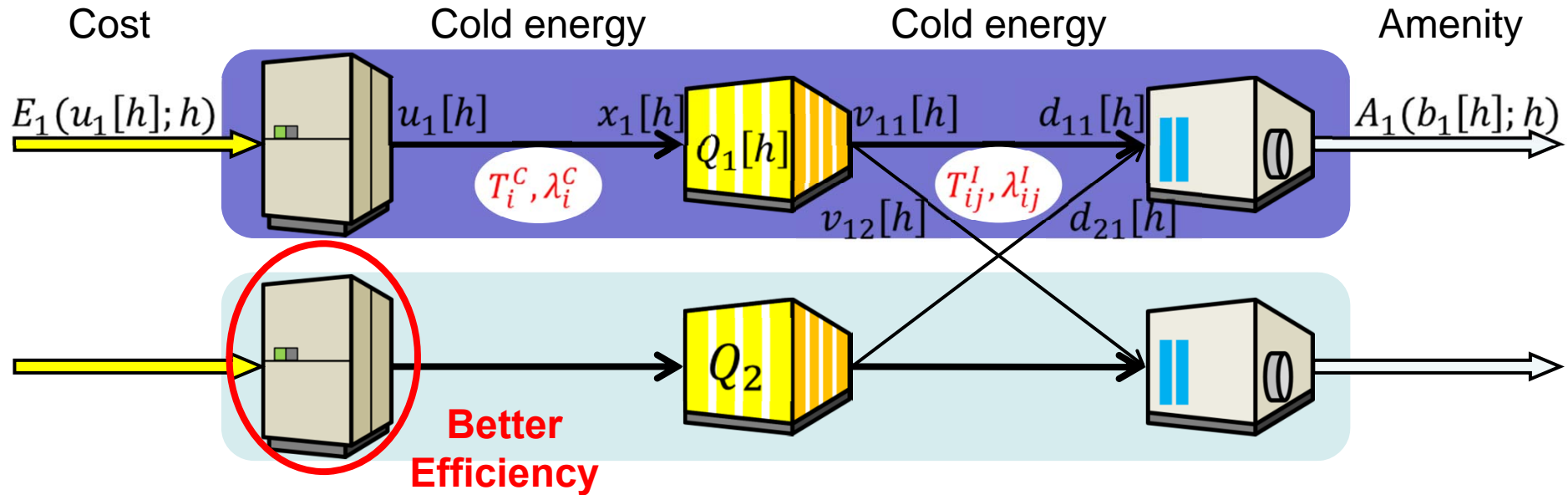
s. t. Equality constraints (linear)

Conservative Laws
Dynamics



An Example : two buildings

(with Azbil)



$$\max \sum_h \sum_i (A_i(b_i[h]; h) - E_i(u_i[h]; h))$$

$$H = 24 \quad \Delta t = 1.0$$

$$\begin{bmatrix} 0.13 \\ 0.30 \end{bmatrix} \leq u[h] \leq \begin{bmatrix} 1.30 \\ 3.00 \end{bmatrix}$$

$$\begin{bmatrix} 0 & 0 \\ 0 & 0 \end{bmatrix} \leq v[h]$$

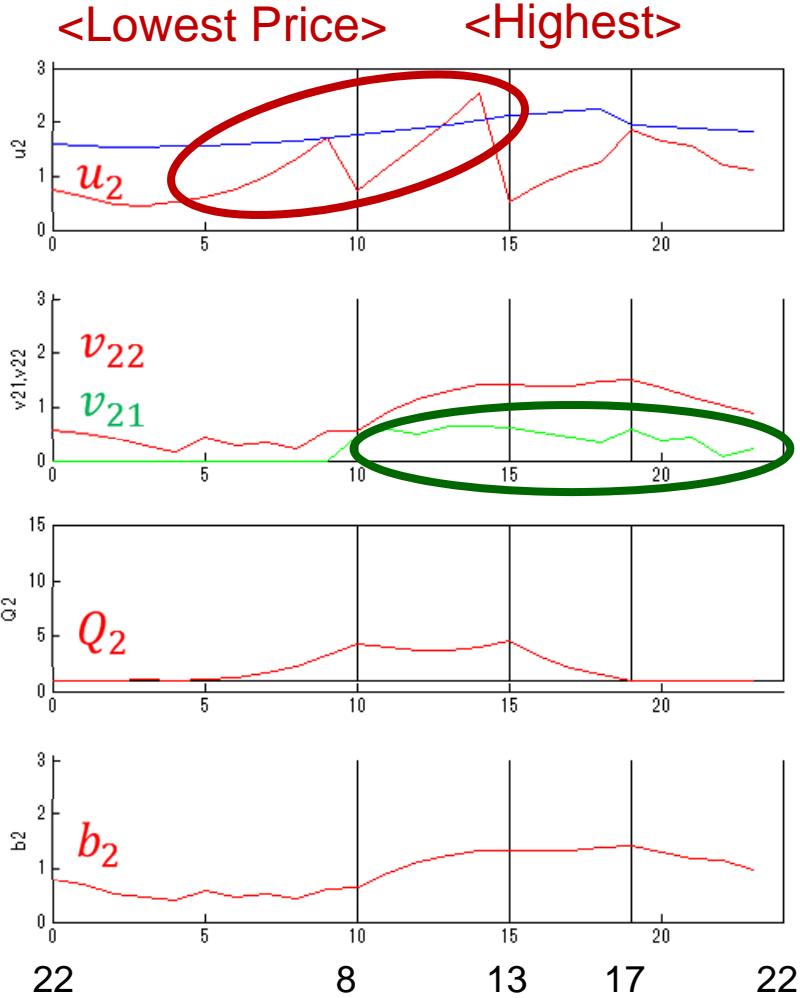
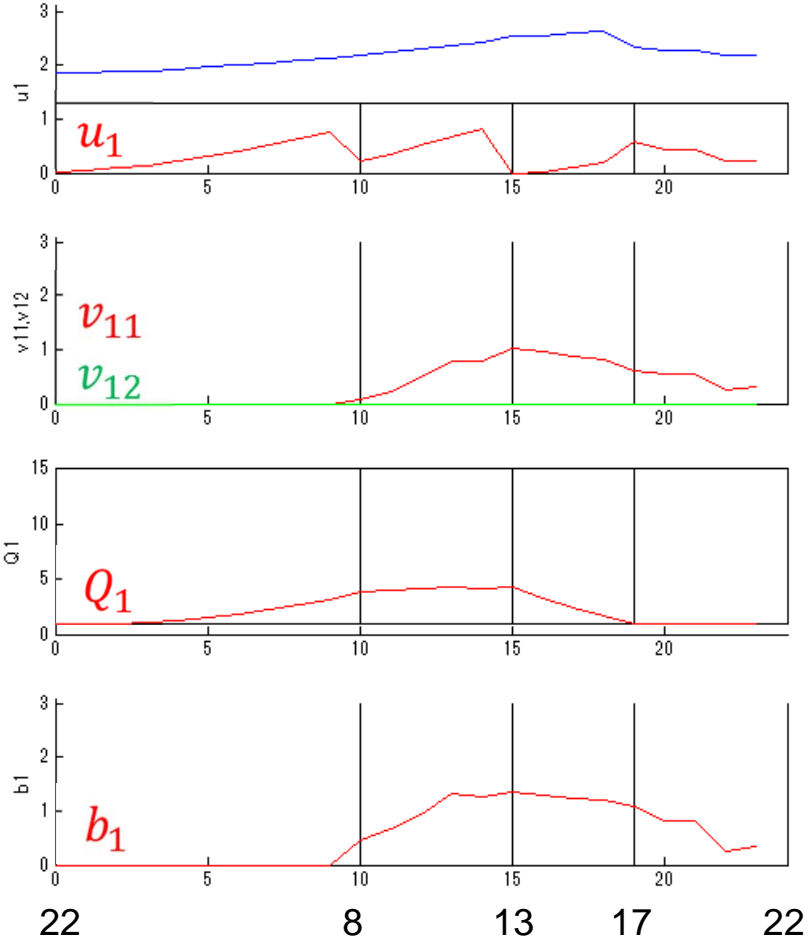
$$\begin{bmatrix} 1.0 \\ 1.0 \end{bmatrix} \leq Q[h] \leq \begin{bmatrix} 15.0 \\ 15.0 \end{bmatrix}$$

$$Q[0] = \begin{bmatrix} 1.0 \\ 1.0 \end{bmatrix}$$

$$A(b[h]; h) = -100(b - demand)^2$$

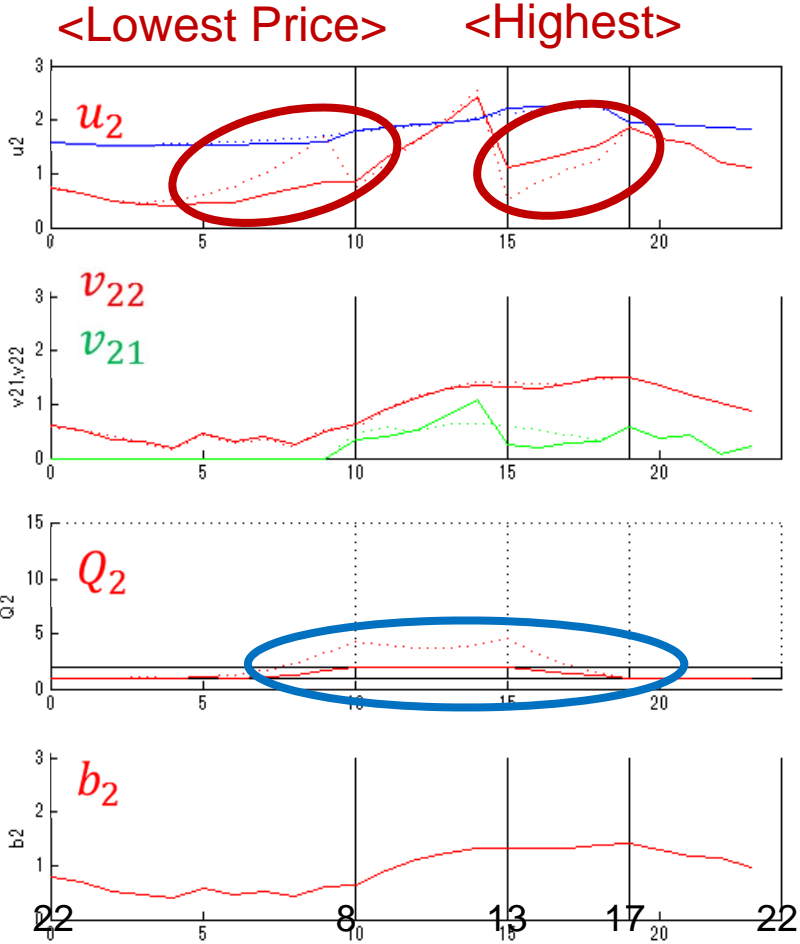
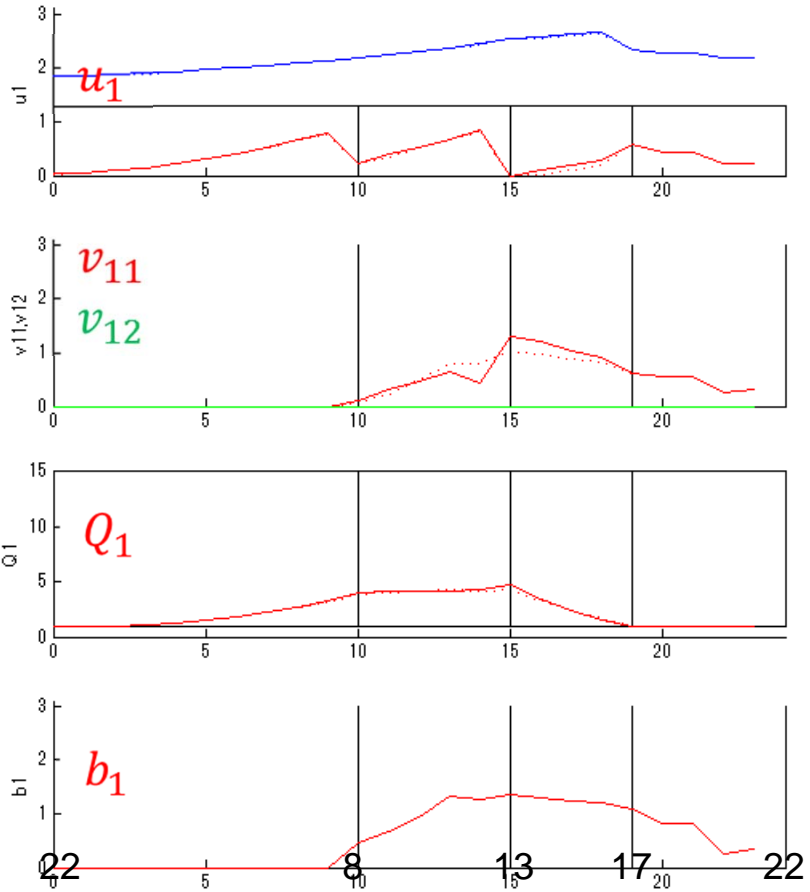
$$1 \leq Q_2 \leq 5$$

Enough Capacity



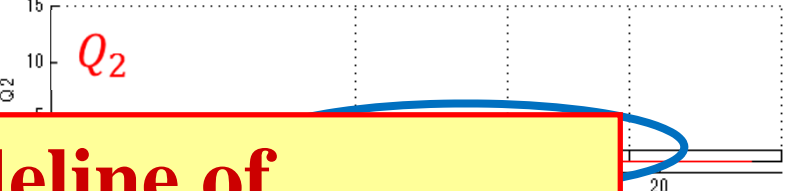
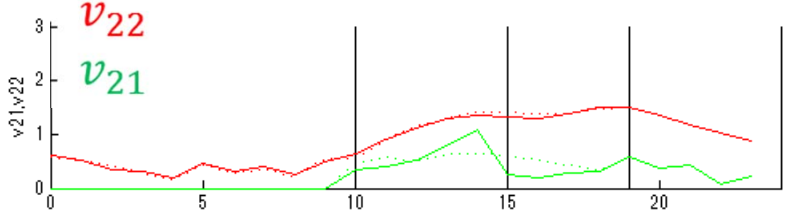
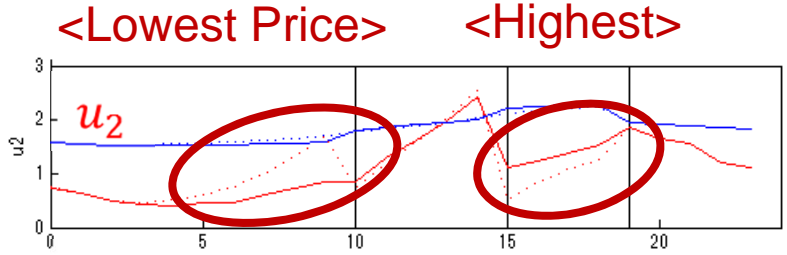
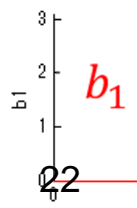
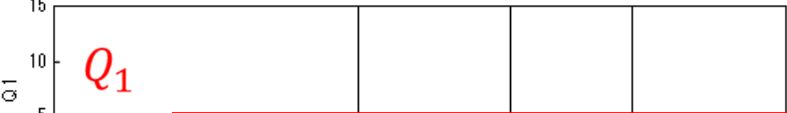
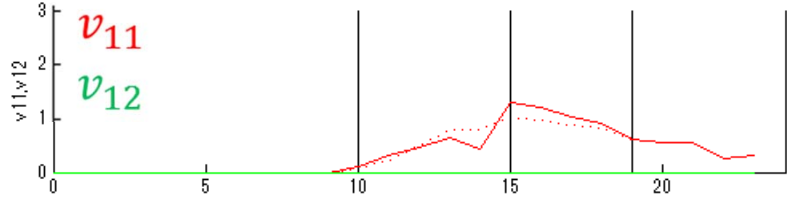
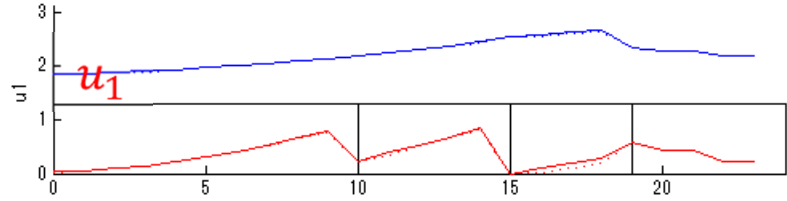
$$1 \leq Q_2 \leq 2$$

Limited Capacity



$$1 \leq Q_2 \leq 2$$

Limited Capacity



**Design Guideline of
Integrated Energy Networks from the View Point of
Hierarchical Decentralized Control**

OUTLINE : Part 6

6. Applications in Energy Networks

with Fujitsu

with Azbil

with Tokyo-Gas

Electric NWs with
PV by Gas Engines

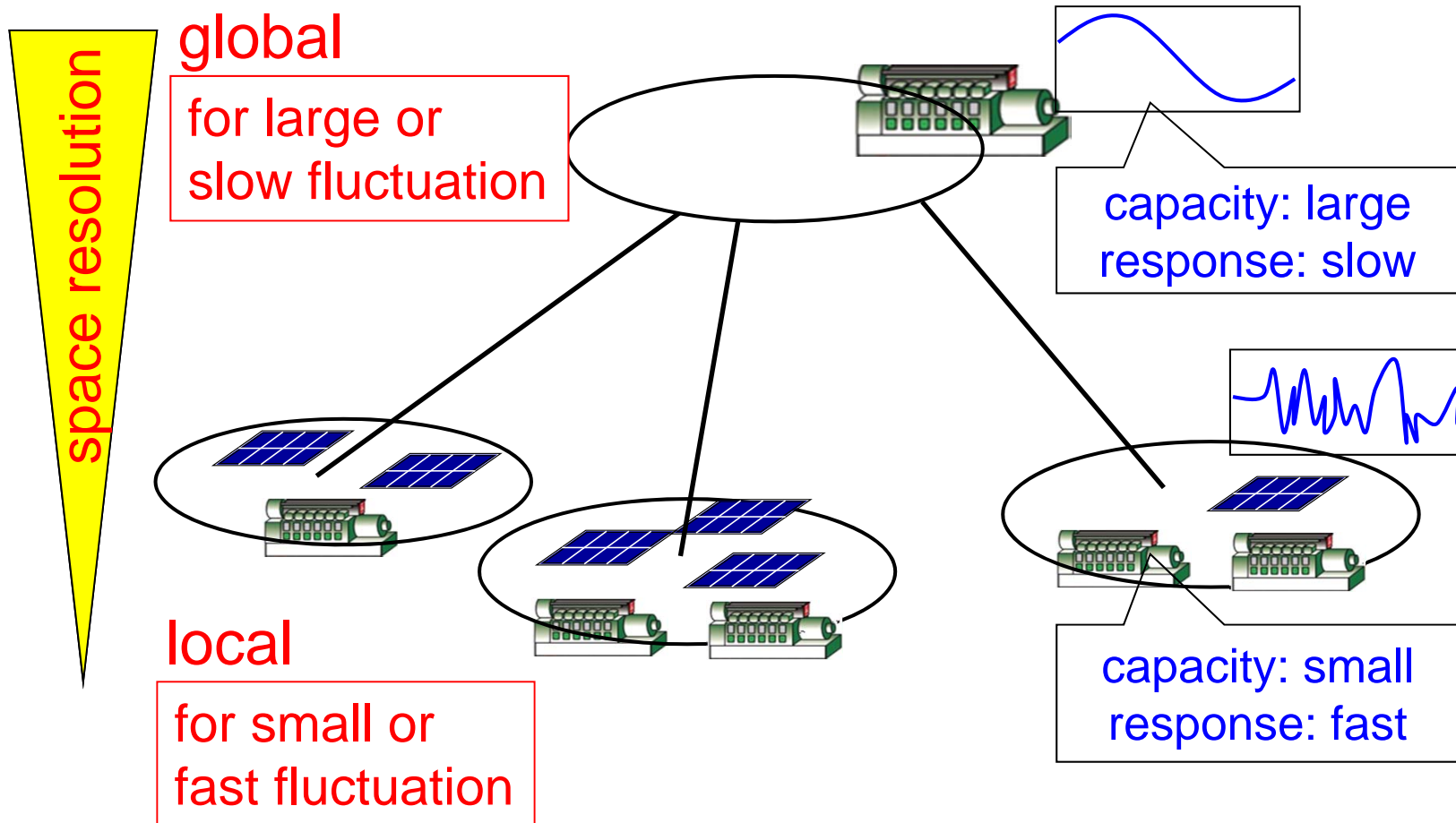
Dynamic Energy
Storages

Objective in
Each Layer

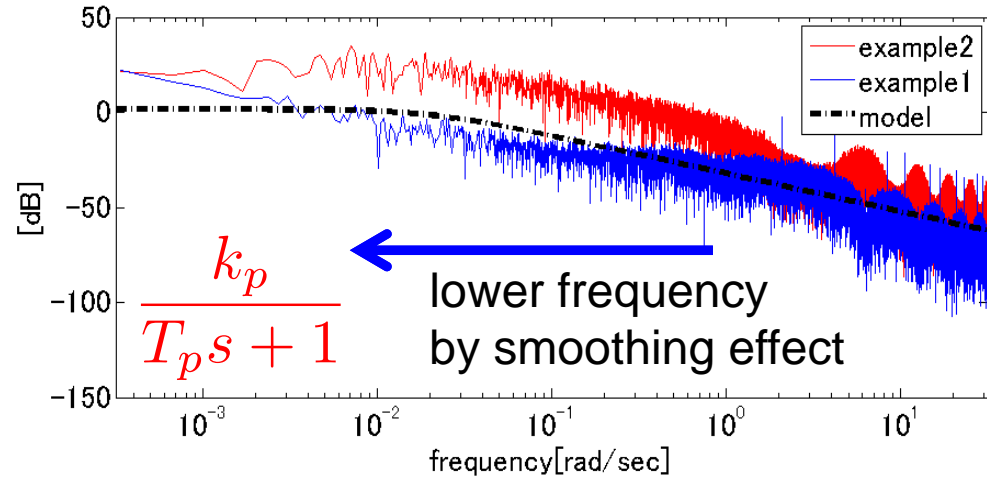
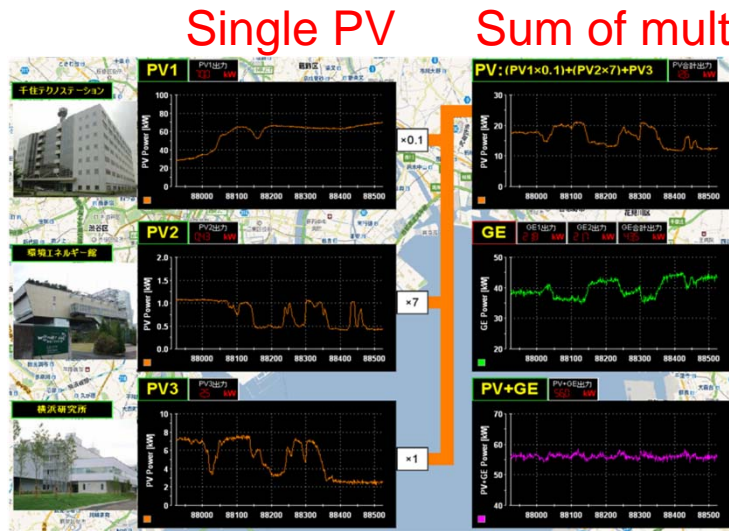
Smart Water Surrounding System

Multi-time/space Resolution Approach

(with Tokyo Gas)



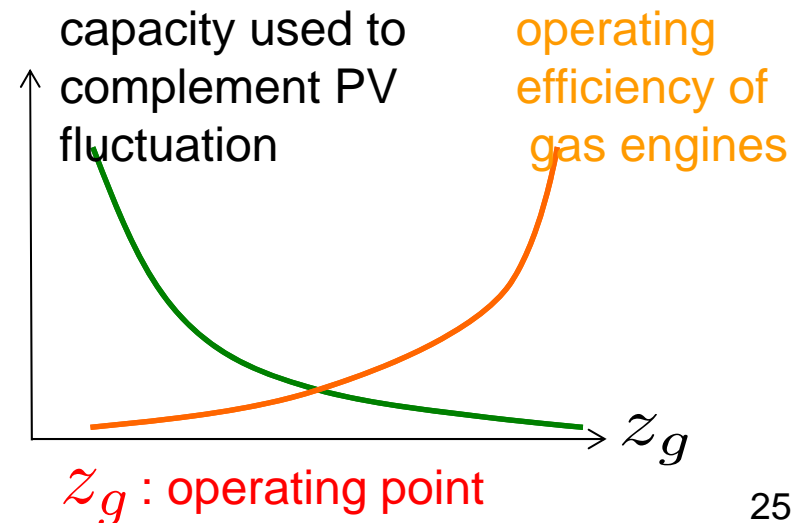
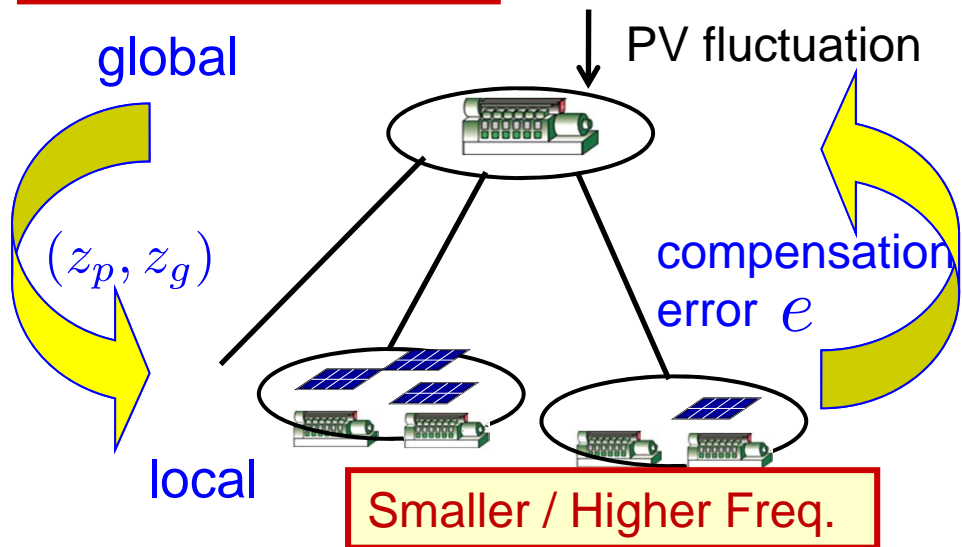
Hierarchical Control with Multiple Gas Turbines



Bigger / Lower Freq.

To decide optimal z_g for maximizing the efficiency

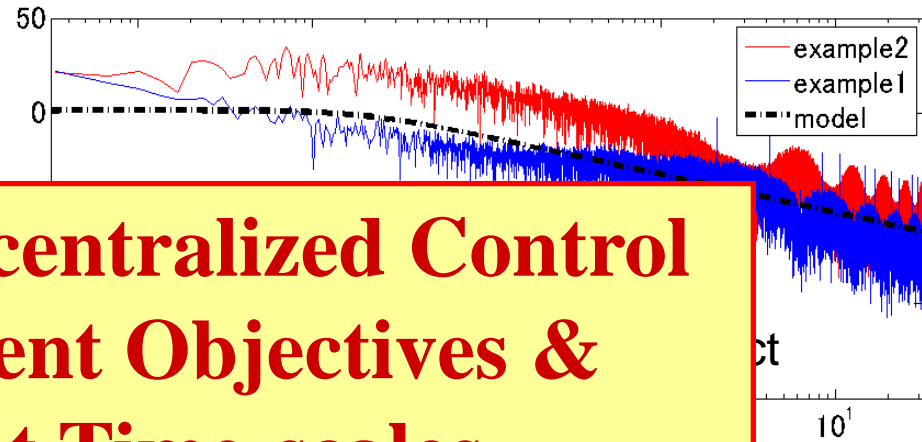
Trade-off



Hierarchical Control with Multiple Gas Turbines

Single PV

Sum of multiple PV

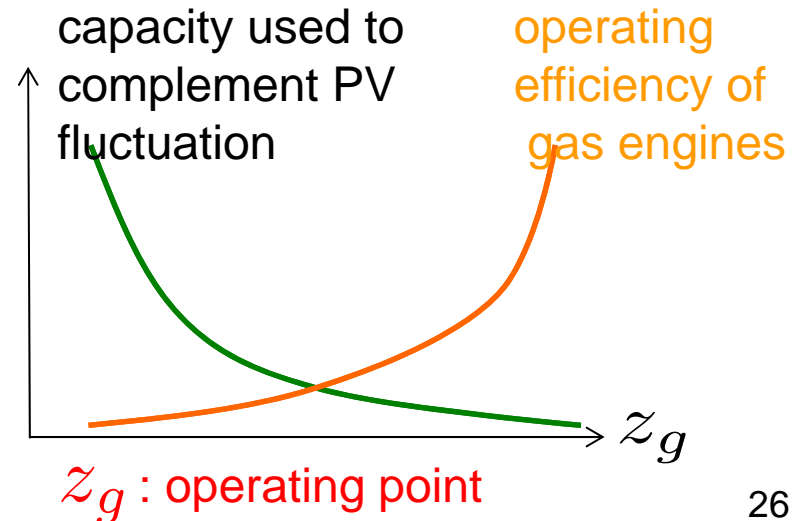
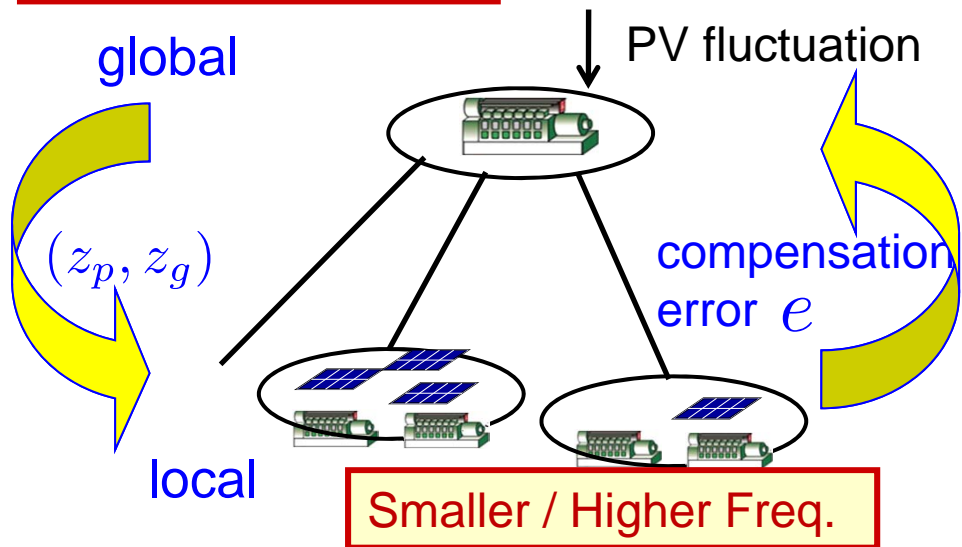


**Hierarchical Decentralized Control
with Different Objectives &
Different Time-scales
in Integrated Energy Networks**

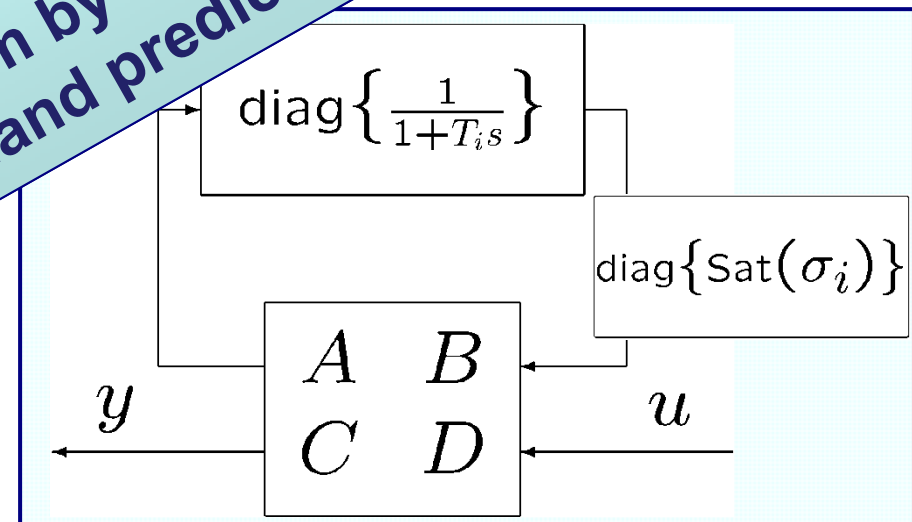
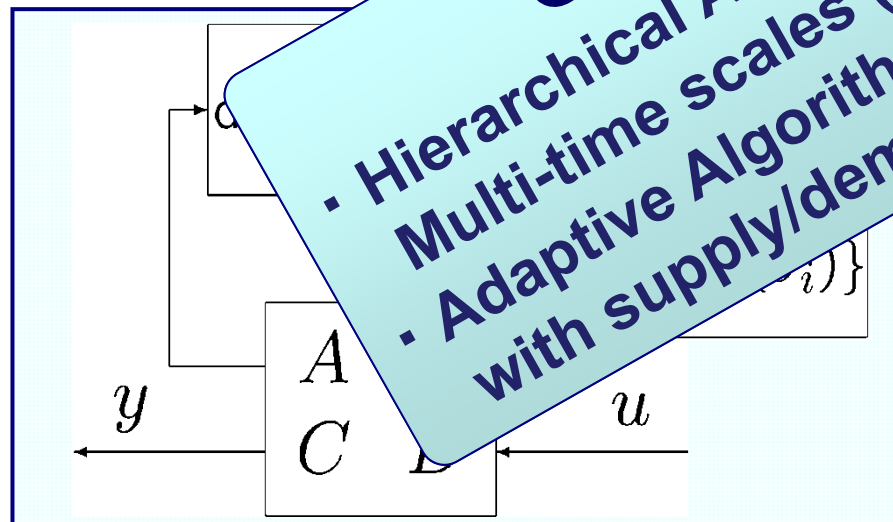
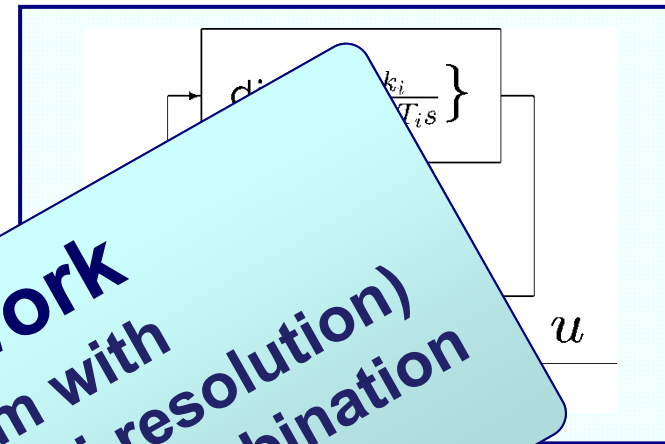
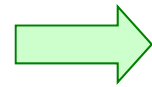
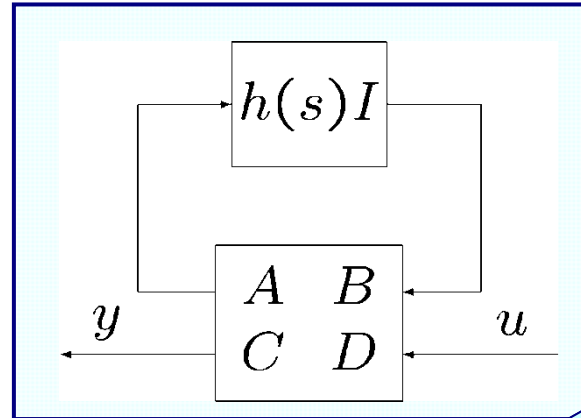
Bigger / Lower Freq.

Maximizing the efficiency

Trade-off



A Unified Model for Energy NWs



Ongoing Work

- Hierarchical Algorithm with Multi-time scales (multi-resolution)
- Adaptive Algorithm by Combination with supply/demand prediction

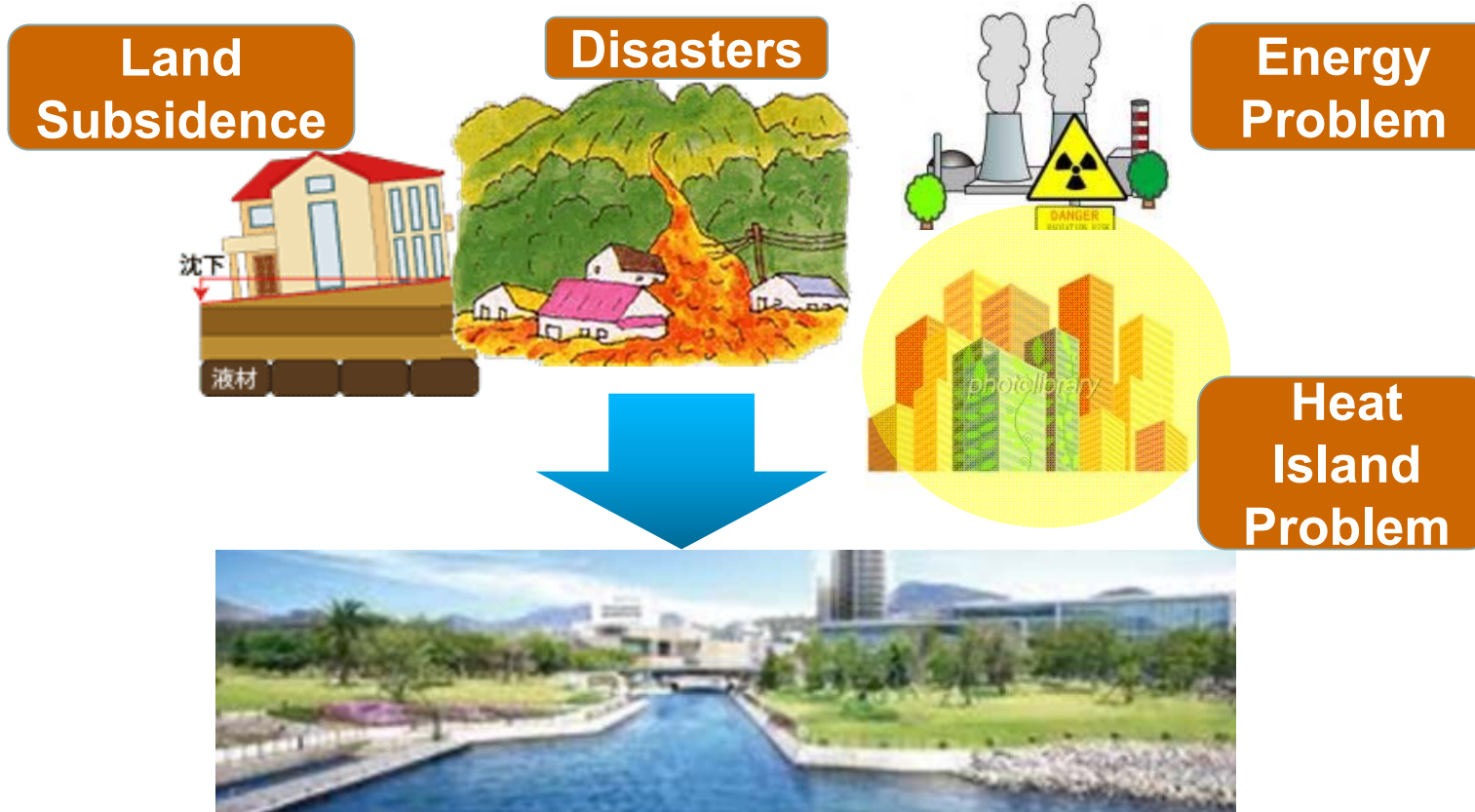
OUTLINE : Part 6

6. Applications in Energy Networks
with Fujitsu
with Azbil
with Tokyo-Gas

Smart Water Surrounding System

Design of New Water Space

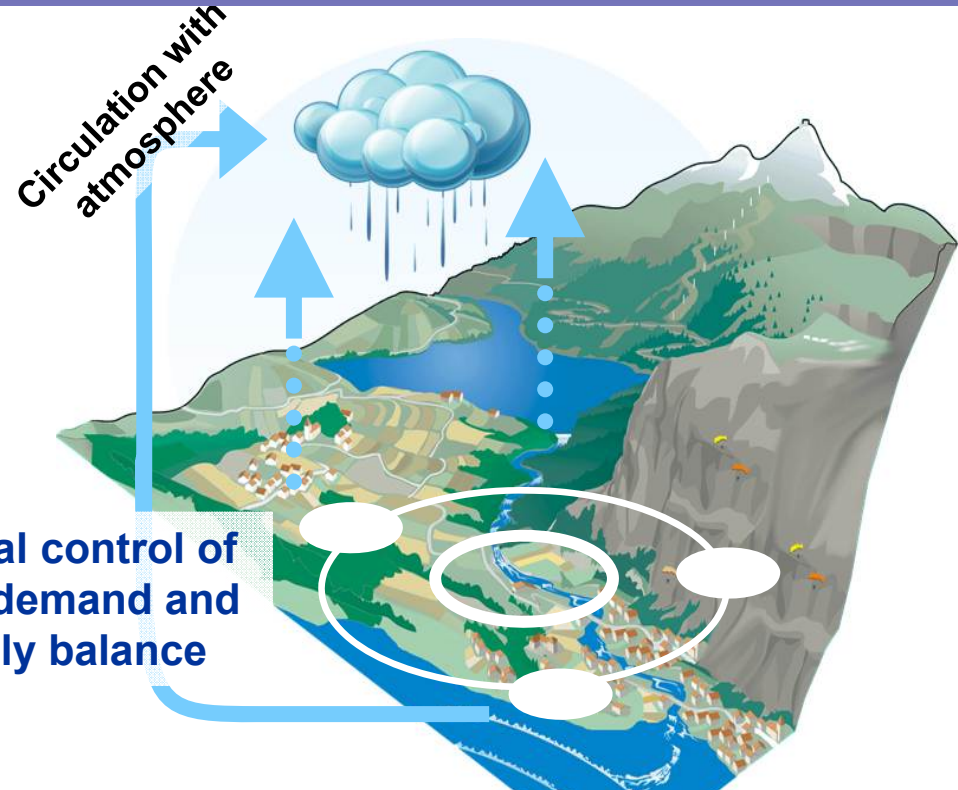
- Diversity and Multiple Properties of Water
- Self Circulation in Nature



Design of New Water Space “Smart Water City”

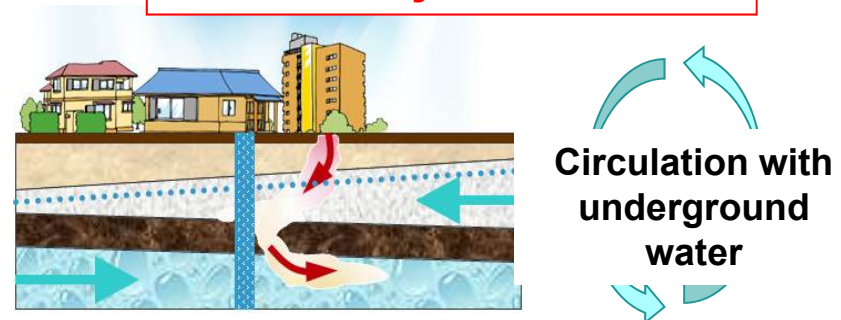
Smart Water City (Proposed by SICE)

I **New Cities of Water: Utilization of various functions of water**

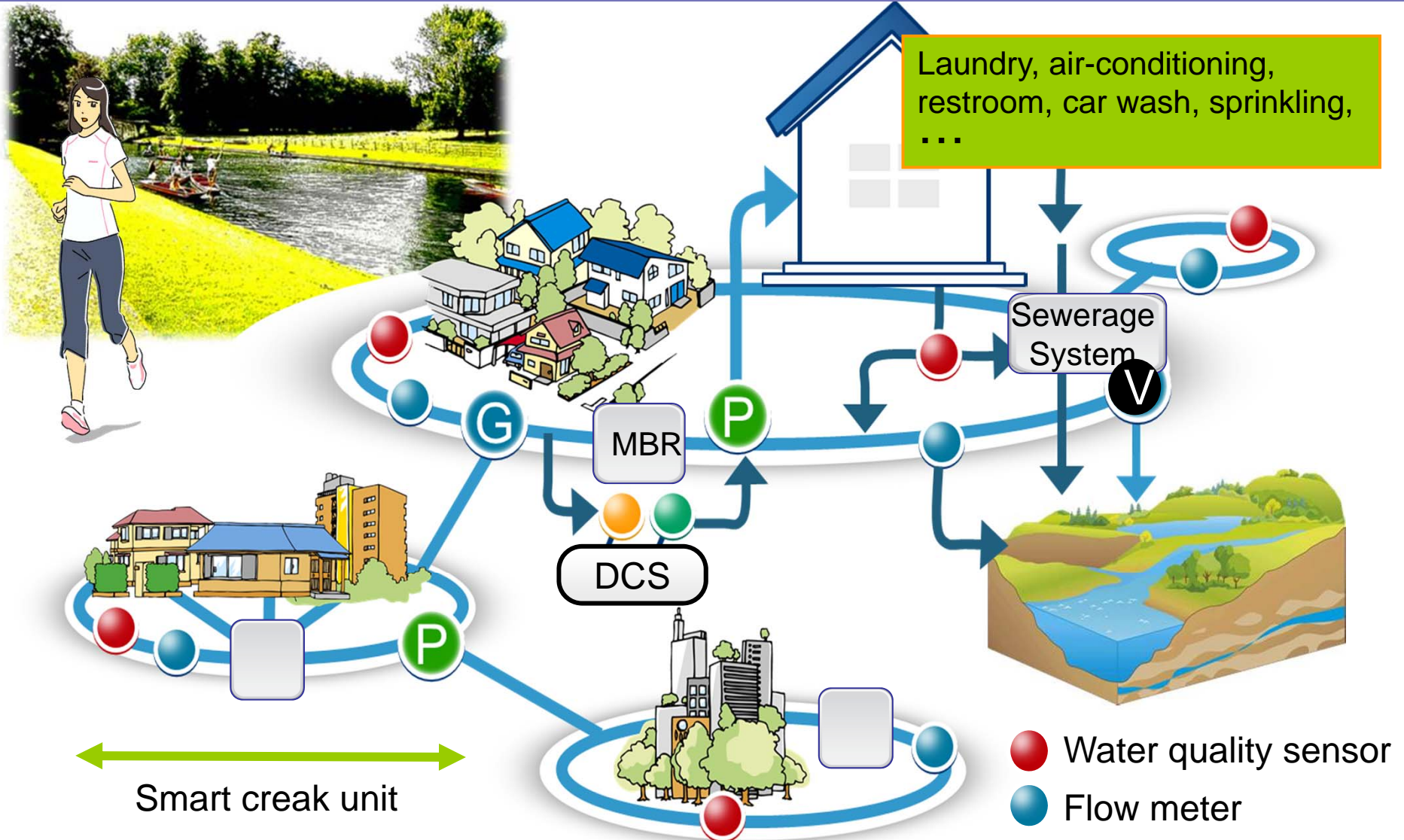


III **Smart Creeks: Distributed water treatment & circulation system**

II **3D Water System: In harmony with nature:**



Smart Creek: Decentralized Wastewater Treatment & Circulation System



“Natural Water Cycle” Social System

Future

To Solve Social Problems Simultaneously

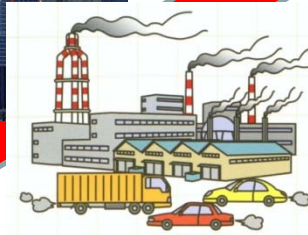
Innovative Social System coexisting with “Water Cycle”

The present

Pre-modern times

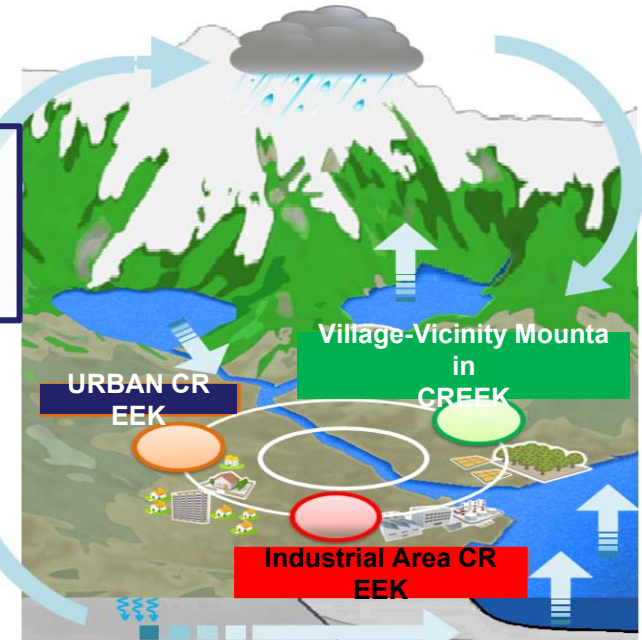


**Fight against Natural Threat
Society according to the Nature**



Explosion of Human Activities

- Lack or Absence of Balanced Activities with the Nature (Global Warming etc)
- Many Natural Disasters → High Cost

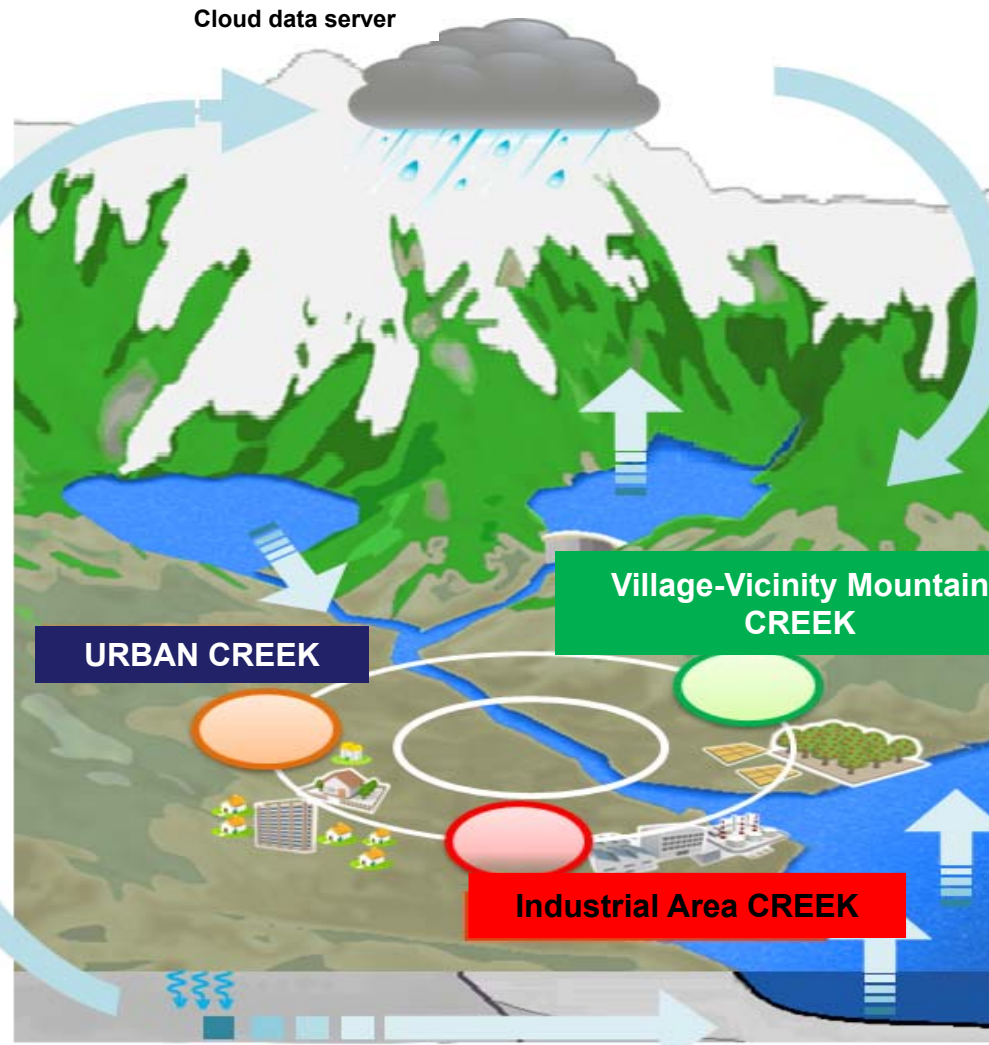


**The “Basin”
City Coexisting
with the Nature**

From Smart Water City Toward Smart Water Surrounding System

The "Basin"
City Coexisting
with the Nature

Global Prediction
Development of
Three Dimensional
"Water" General
Circulation Model

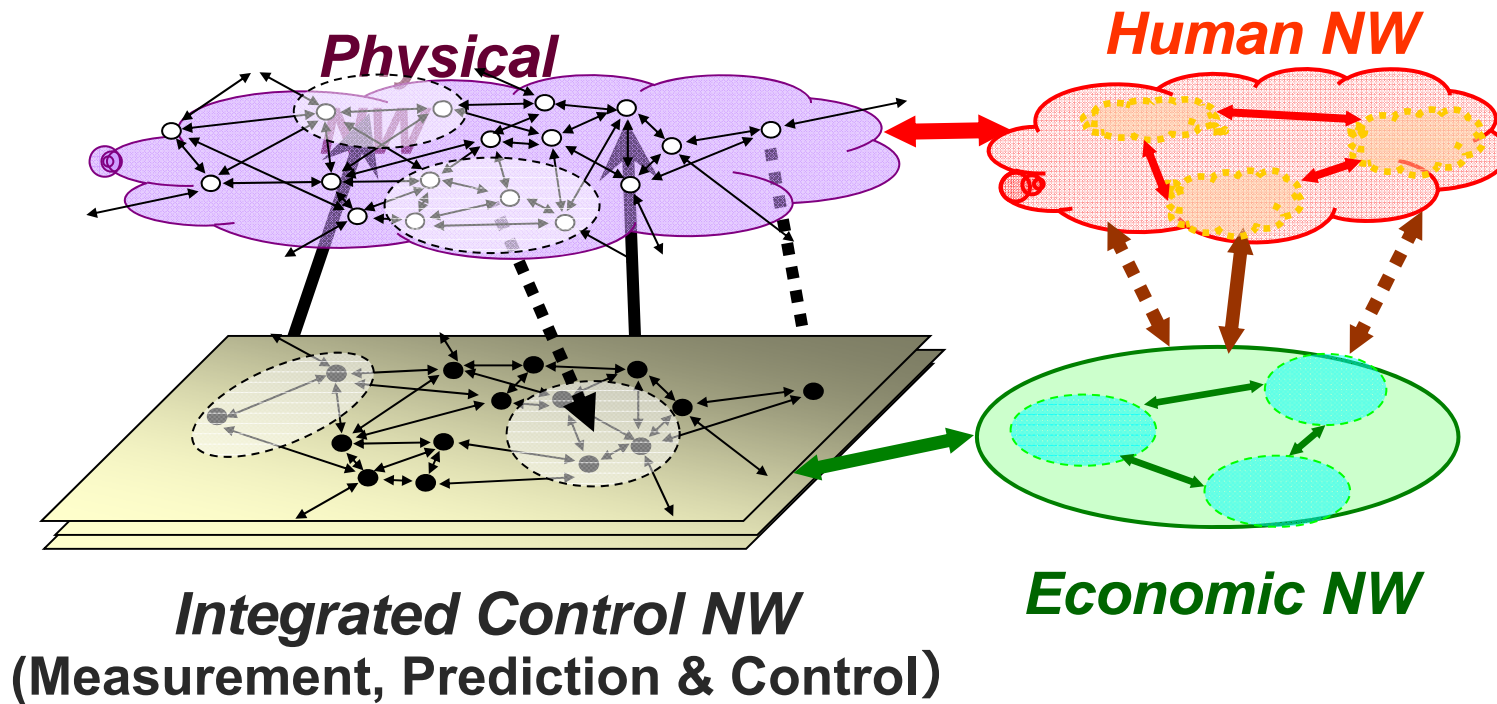


Glocal Control
Social System
Design for the
Implementation

Local Unit Design : Creek NWs

Key Notion for “Future”

Harmony with Nature and Social Systems



Thank you very much !