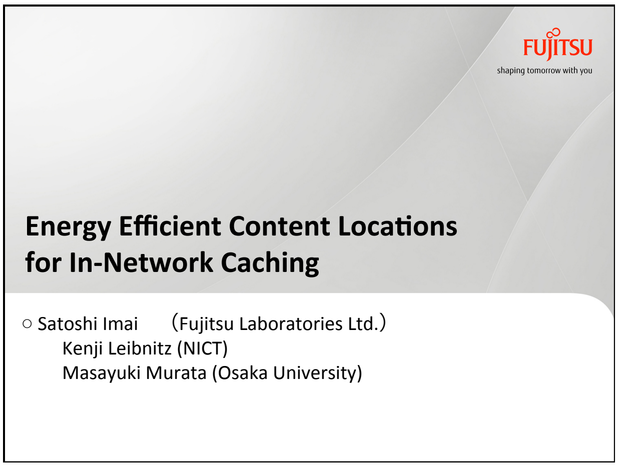

# Energy Efficient Content Locations for In-Network Caching

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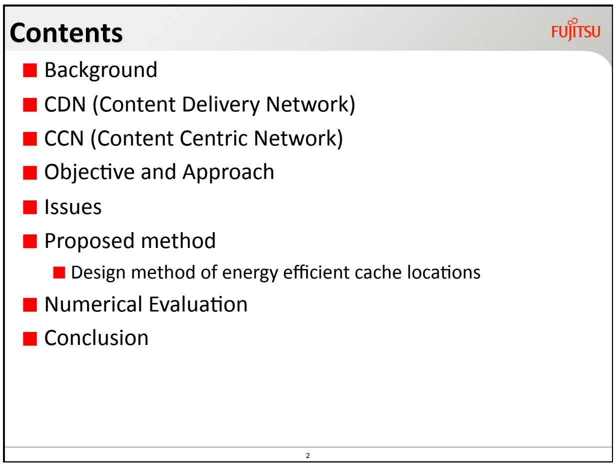
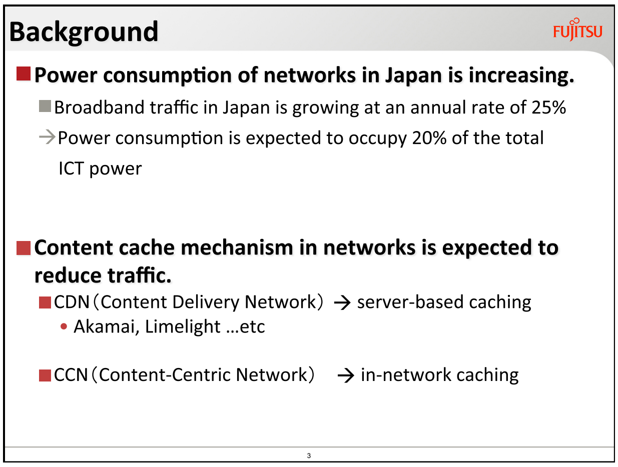
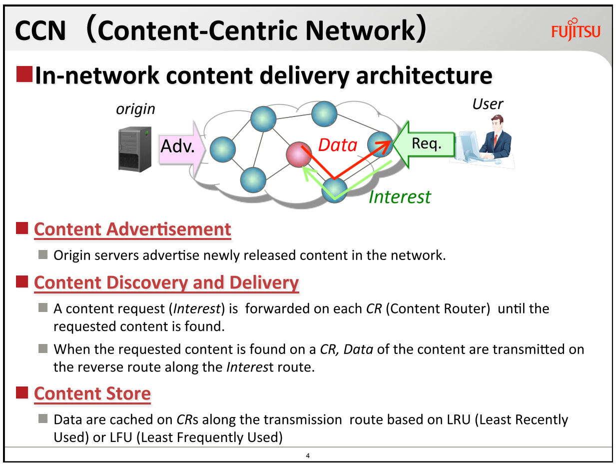


## Contents



## Background

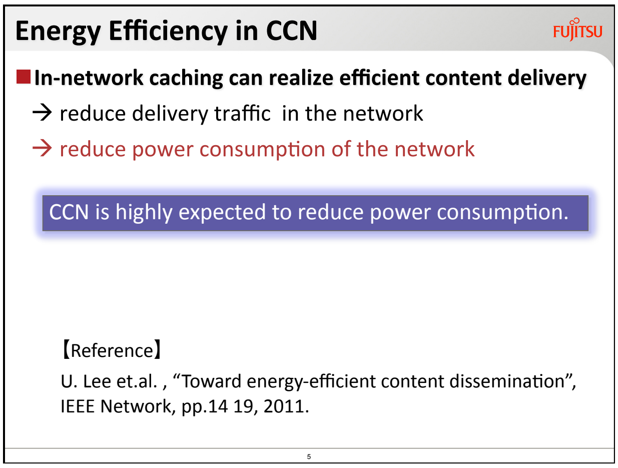
- **Power consumption of networks in Japan is increasing.**
  - Broadband traffic in Japan is growing at an annual rate of 25%
  - → Power consumption is expected to occupy 20% of the total ICT power
- **Content cache mechanism in networks is expected to reduce traffic.**
  - CDN（Content Delivery Network） → server-based caching
    - Akamai, Limelight …etc
  - CCN（Content-Centric Network） → in-network caching



## CCN （Content-Centric Network）

- **In-network content delivery architecture**

- Content Advertisement
  - Origin servers advertise newly released content in the network.
- Content Discovery and Delivery
  - A content request (*Interest*) is forwarded on each *CR* (Content Router) until the requested content is found.
  - When the requested content is found on a *CR, Data* of the content are transmitted on the reverse route along the *Interest* route.
- Content Store
  - Data are cached on *CRs* along the transmission route based on LRU (Least Recently Used) or LFU (Least Frequently Used)

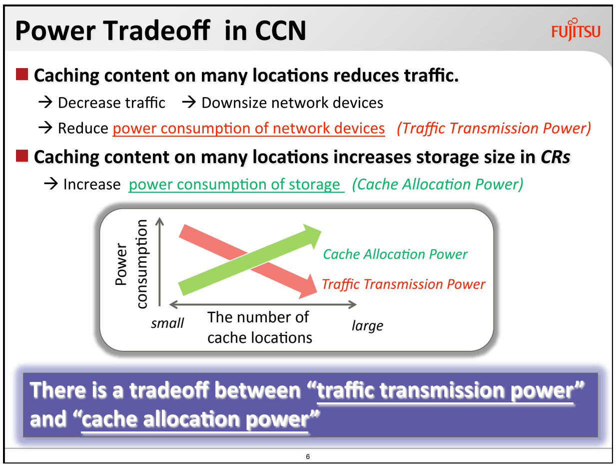


## Energy Efficiency in CCN

- **In-network caching can realize efficient content delivery**
  - → reduce delivery traffic in the network
  - → reduce power consumption of the network

CCN is highly expected to reduce power consumption.

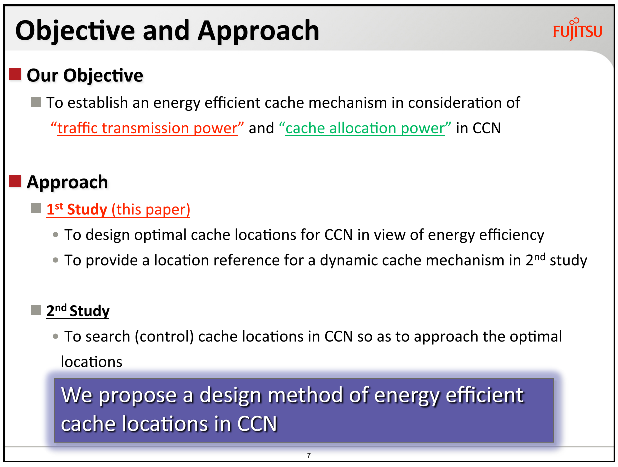
【Reference】
U. Lee et.al. , “Toward energy-efficient content dissemination”, IEEE Network, pp.14 19, 2011.



## Power Tradeoff in CCN

- **Caching content on many locations reduces traffic.**
  - → Decrease traffic → Downsize network devices
  - → Reduce power consumption of network devices *(Traffic Transmission Power)*
- **Caching content on many locations increases storage size in *CRs***
  - → Increase power consumption of storage *(Cache Allocation Power)*

**There is a tradeoff between “traffic transmission power” and “cache allocation power”**

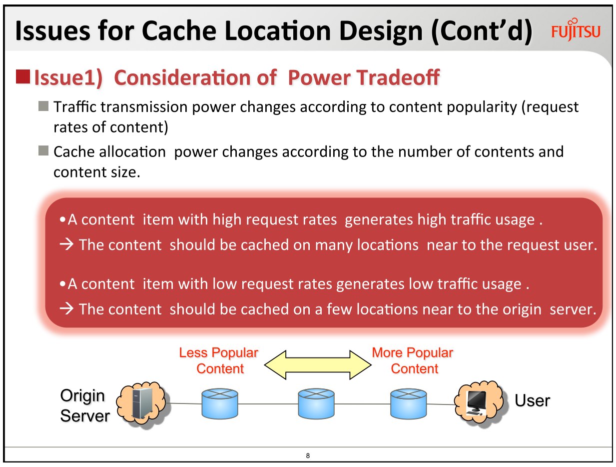


## Objective and Approach

- **Our Objective**
  - To establish an energy efficient cache mechanism in consideration of "traffic transmission power" and "cache allocation power" in CCN

- **Approach**
  - **1st Study (this paper)**
    - To design optimal cache locations for CCN in view of energy efficiency
    - To provide a location reference for a dynamic cache mechanism in 2nd study
  - **2nd Study**
    - To search (control) cache locations in CCN so as to approach the optimal locations

We propose a design method of energy efficient cache locations in CCN

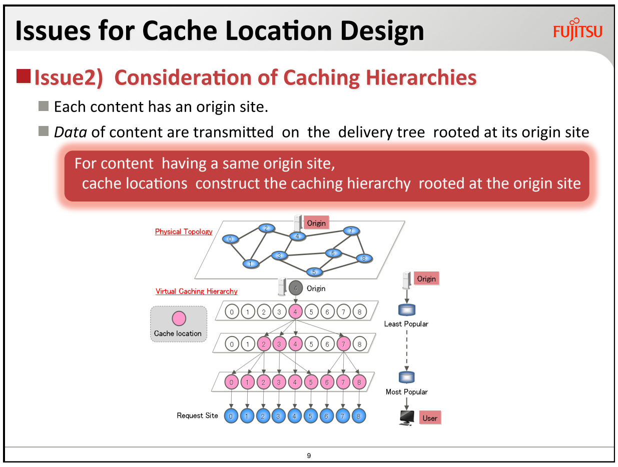


## Issues for Cache Location Design (Cont'd)

### Issue1) Consideration of Power Tradeoff

- Traffic transmission power changes according to content popularity (request rates of content)
- Cache allocation power changes according to the number of contents and content size.

- A content item with high request rates generates high traffic usage .
  → The content should be cached on many locations near to the request user.
- A content item with low request rates generates low traffic usage .
  → The content should be cached on a few locations near to the origin server.

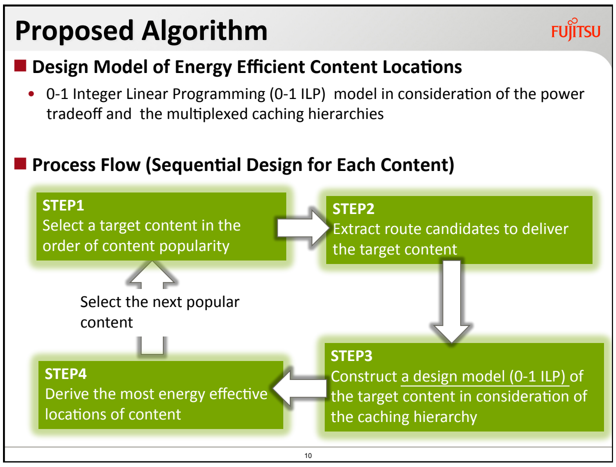


## Issues for Cache Location Design

### Issue2) Consideration of Caching Hierarchies

- Each content has an origin site.
- *Data* of content are transmitted on the delivery tree rooted at its origin site

For content having a same origin site,
cache locations construct the caching hierarchy rooted at the origin site



## Proposed Algorithm

- **Design Model of Energy Efficient Content Locations**
  - 0-1 Integer Linear Programming (0-1 ILP) model in consideration of the power tradeoff and the multiplexed caching hierarchies

- **Process Flow (Sequential Design for Each Content)**

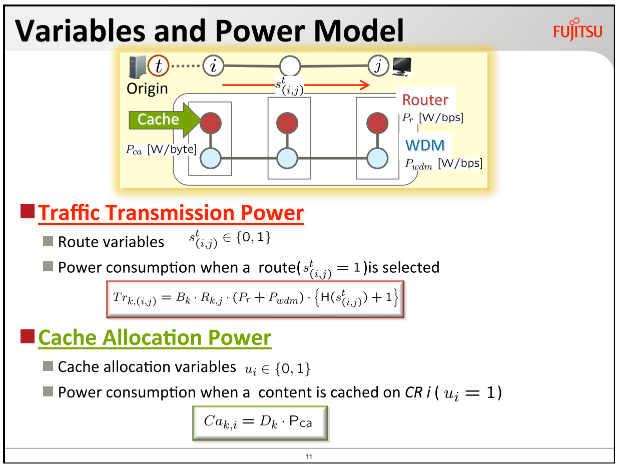
**STEP1**
Select a target content in the order of content popularity

**STEP2**
Extract route candidates to deliver the target content

**STEP3**
Construct a design model (0-1 ILP) of the target content in consideration of the caching hierarchy

**STEP4**
Derive the most energy effective locations of content

Select the next popular content



## Variables and Power Model

### Traffic Transmission Power

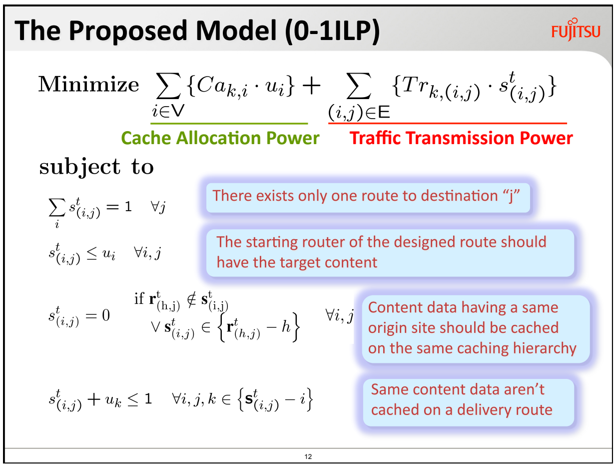
- Route variables $s^t_{(i,j)} \in \{0,1\}$
- Power consumption when a route($s^t_{(i,j)} = 1$)is selected

$$\boxed{Tr_{k,(i,j)} = B_k \cdot R_{k,j} \cdot (P_r + P_{wdm}) \cdot \left\{\mathrm{H}(s^t_{(i,j)}) + 1\right\}}$$

### Cache Allocation Power

- Cache allocation variables $u_i \in \{0,1\}$
- Power consumption when a content is cached on *CR i* ( $u_i = 1$)

$$\boxed{Ca_{k,i} = D_k \cdot \mathrm{Pca}}$$



## The Proposed Model (0-1ILP)

$$\text{Minimize} \quad \underbrace{\sum_{i \in \mathrm{V}} \{Ca_{k,i} \cdot u_i\}}_{\text{Cache Allocation Power}} + \underbrace{\sum_{(i,j) \in \mathrm{E}} \{Tr_{k,(i,j)} \cdot s^t_{(i,j)}\}}_{\text{Traffic Transmission Power}}$$

subject to

$$\sum_i s^t_{(i,j)} = 1 \quad \forall j$$

There exists only one route to destination "j"

$$s^t_{(i,j)} \le u_i \quad \forall i,j$$

The starting router of the designed route should have the target content

$$s^t_{(i,j)} = 0 \quad \begin{array}{l} \text{if } \mathbf{r}^{\mathrm{t}}_{(\mathrm{h,j})} \notin \mathbf{s}^{\mathrm{t}}_{(\mathrm{i,j})} \\ \vee\ \mathbf{s}^t_{(i,j)} \in \left\{\mathbf{r}^t_{(h,j)} - h\right\} \end{array} \quad \forall i,j$$

Content data having a same origin site should be cached on the same caching hierarchy

$$s^t_{(i,j)} + u_k \le 1 \quad \forall i,j,k \in \left\{\mathbf{s}^t_{(i,j)} - i\right\}$$

Same content data aren't cached on a delivery route

## Evaluation Conditions

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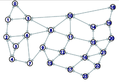
### Power Density

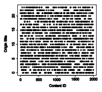
表 1　Power density parameters.

| Device | Product | Spec | Power | Power Density |
|---|---|---|---|---|
| DRAM | – | 4GB | 10W | $P_{ca} = 2.5 \times 10^{-9}$ W/byte |
| Core Router | CRS-1 | 320Gbps | 4185W | $P_r = 1.3 \times 10^{-8}$ W/bps |
| WDM | FLASHWAVE9500 | 480Gbps | 800W | $P_{wdm} = 1.67 \times 10^{-9}$ W/bps |

### Conditions



- Target network: 24 sites/ 84 links
- The number of contents:
  - 2000 [contents]
- The total number of requests from each site:
  - 1000 [requests]
- Request distribution (content popularity):
  - Zipf-distribution
    - Content ID: 0 (most popular) ~ 2000(least popular)
- Origin site of content: Uniform-distribution
- Content size 10 Mbytes
- Required rate of content 10 Mbps



High popular　Low popular

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## Power Tradeoff

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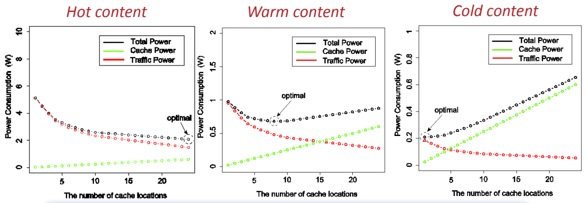
- **Power tradeoff for 3 contents with different popularity (Hot/Warm/Cold) having a same origin site**
  - "Total power" / "Traffic transmission power" / "Cache allocation power"
    when the number of cache locations is changed



According to differences of content popularity, the tradeoff characteristics are different.

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## Power Tradeoff

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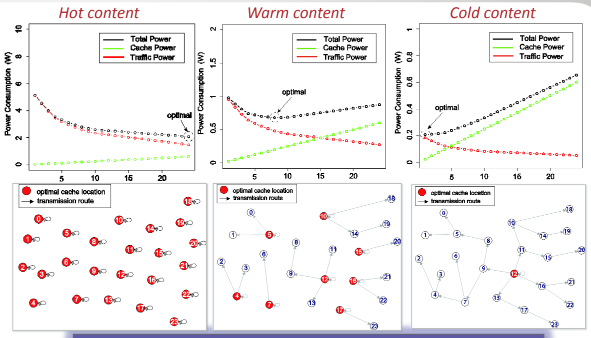

According to differences of content popularity, the optimal cache locations are different.

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## Energy Efficiency of The Proposed Method

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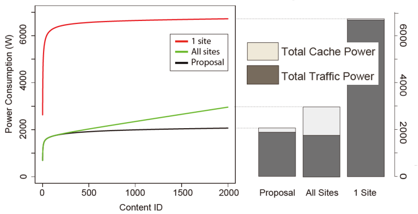
- **Comparison of 3 cache allocation policies**
  - "The proposed method"/ "Caching on 1 site (origin)"/ "Caching on all sites"

*Cumulative Power Consumption*



High popular　Low popular

The proposed method realizes more power-effective cache allocation than the other policies.

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## Analysis of Average Hop Length

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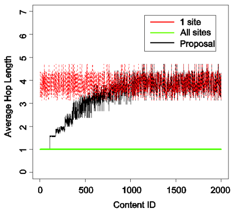
- **Average hop length from each site to the nearest target content**



High popular　Low popular

- In all caching, the average hop-length is shortest for all content Items at the sacrifice of power increasing
- In the proposed method, the average hop-length is increased as the content is less popular.

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## Conclusions

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### Summary

- Energy efficient design method to derive the optimal cache locations with considering
  - Tradeoff between cache allocation power and traffic transmission power
  - Multiplexed caching hierarchies

### Further Study

- 2nd Study
  - a distributed cache mechanism to search energy efficient locations using local information