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Network Power Saving based on Pareto Optimal Control with Evolutionary Approach

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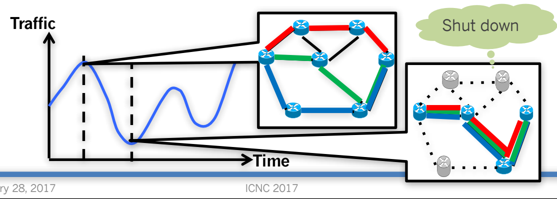
Research Background

- The power consumption of network has been increasing
  - The service over the Internet becomes popular
  - The power consumption has become a serious problem
- Method of power saving
  - Shut down unnecessary network devices following the changes in the traffic demands



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Research Background

[3] Amaldi, E. and Capone, A. and Gianoli, L. G., "Energy-aware IP traffic engineering with shortest path routing," Comput. Netw., vol. 57, pp. 1503–1517, Apr. 2013.

- The power consumption of network has been increasing
  - The service over the Internet becomes popular
  - The power consumption has become a serious problem
- Method of power saving
  - Shut down unnecessary network devices following the changes in the traffic demands
- These methods consider only **simple objective** [3]
  - The number of powered-on nodes and the maximum link utilization

delay, reliability and so on…

Multiple complex objectives should be also considered in the actual network

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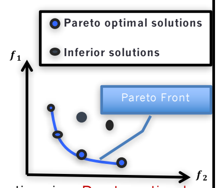
Our Objective and Approach

- Objective
  - Proposal of method to control a network
    - Save the energy consumption
    - Handle complex multiple objective functions
    - Follow the environmental changes
- Approach
  - A suitable solution considering multiple objectives is a Pareto optimal solution
  - Utilization of Pareto optimal control
    - Calculate Pareto front (the set of Pareto optimal solutions)
    - Select the network configuration from the Pareto front



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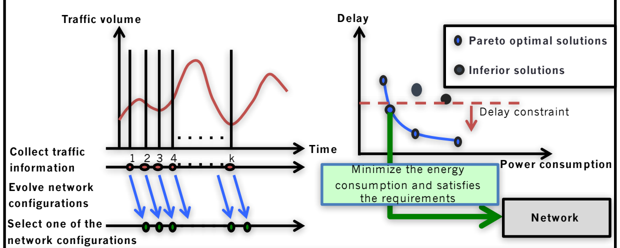
Power Saving Based on Pareto Optimal Control

- Our method performs following steps at each time
  1. Collect traffic information
  2. Evolve the candidate network configurations
  3. Select one of the network configurations



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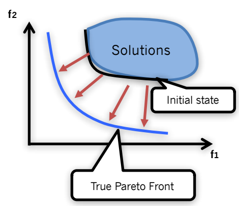
Application of Evolutionary Algorithm

- Multi-Objective Evolutionary Algorithms (MO-EA)
  - Calculate Pareto front
  - Evolve the solutions by using the mutation and crossover operators
    - Solutions : network configurations coded as gene

→ The solutions approach the true Pareto Front



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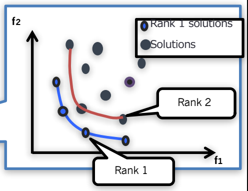
Calculation of Pareto Front by MO-EA

1. Initialization
   - Generate N solutions (P) randomly
2. Evaluation
   - Evaluate P based on each objective function
   - Non-dominated sort : Rank the solutions based on the number of dominating solutions
3. Generation of offspring
   - Generate N offspring (Q) by selection, crossover and mutation
4. Replacement of the old solutions
   - Update P to N solutions selected from P ∪ Q
     - Rank
     - Crowding distance
   - Save/update the solutions in rank 1 to Pareto archive



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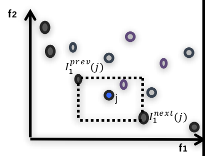
Crowding Distance

- Priorities between the solutions with the same rank
- Crowding distance c_x of solution x

$$c_x = \begin{cases} \infty \\ \sum_m \frac{f_m(I_m^{\text{next}}(x)) - f_m(I_m^{\text{prev}}(x))}{f_m^{max} - f_m^{min}} \end{cases}$$



- $f_m(i)$: mth objective function
- $I_m^{next}(x)$, $I_m^{prev}(x)$: the solution whose value of mth objective function is the largest/smallest among the solutions whose values are smaller/larger than the value of x
- f_m^{max} : the maximum value of the mth objective function
- f_m^{min} : the minimum value of the mth objective function

By selecting the solution with a large c_x,
we select the solutions that are different from the other solutions

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Objective Functions

- Energy consumption $E^{net}(x) = \sum_{(i,j)\in L} E^{Link} p_{i,j}(x) + \sum_{k\in V} E^{Node} p_k(x)$
  - The sum of the power consumption of the powered-on links and nodes
- Reliability $R(x) = min_{i,j} r_{i,j}(x) + \alpha \sum_{i,j} r_{i,j}(x)$
  - The number of distinct paths on the powered-on links
- Delay $P(x) = \max_{i,j} D_{i,j}(x)$
  - Maximum value of delays between devices

$$D_{i,j}(x) = \sum_{(s,d)\in q_{i,j}(x)} d_{(s,d)}(x)$$

$$d_{(s,d)}(x) = T_s \frac{\rho_{s,d}(x)}{1-\rho_{s,d}(x)}$$

E^{Link} : power consumption at each link
E^{Node} : power consumption at each node
$p_{i,j}(x)$: 1 or 0 (link between node i and j)
$p_k(x)$: 1 or 0 (node k)

$r_{i,j}(x)$: the number of distinct paths between node i and j
α : weighting coefficient

$D_{i,j}(x)$: a delay between node i and j
$q_{i,j}(x)$: the set of links on the path from node i to j
$d_{(s,d)}(x)$: the delay of link $s-d$
T_s : the average processing times of a packet in each link
$\rho_{s,d}(x)$: a utilization of link $s-d$

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Objective Functions

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Power consumption of links
Power consumption of nodes
The weighted sum of distinct paths
The minimum number of distinct paths
A delay between node i and j
The maximum delay of communication
M/M/1 model

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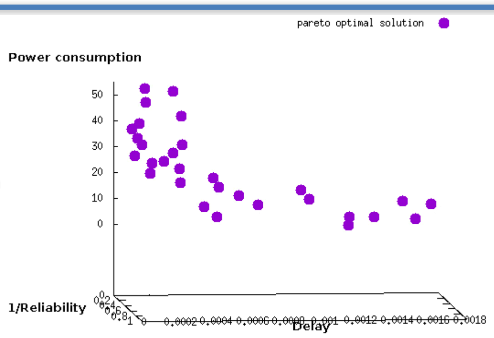
Pareto Front



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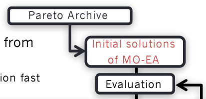
Calculation Following Environmental Fluctuation

- Pareto front becomes different from the previous one
  → Using previous Pareto front as the current solution is inexpedient
- It is necessary to calculate Pareto front fast at each time

Proposal of two methods which set initial solutions

1. **without Diverse Solutions (w/o DS)**
   - Evolve the network configurations only from the solutions in the **Pareto archive**
     - Obtain the suitable network configuration fast



Pareto front may become significantly different from the previous one if the significant environmental changes occur

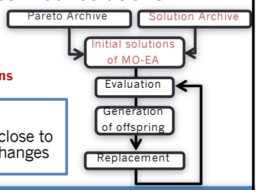
Calculation Following Environmental Fluctuation

- Pareto front becomes different from the previous one
  - → Using previous Pareto front as the current solution is inexpedient
- It is necessary to calculate Pareto front fast at each time

Proposal of two methods which set initial solutions

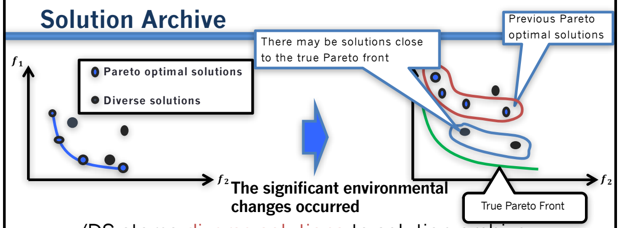
2. with Diverse Solutions (w/ DS)

- Evolve the network configuration from both of the **Pareto archive** and the archive storing the **diverse solutions**



Diverse solutions:
solutions that are possible to become close to Pareto front after the environmental changes

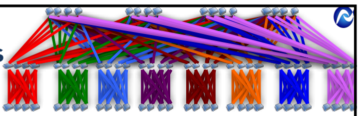
Solution Archive



- w/DS stores diverse solutions to solution archive
  - Diverse solutions are generated after completing the evolution based on the Pareto optimal
    - Evaluate all the candidate network configurations using the metric Ev(x)
    - $\mathrm{Ev}(x) = Distance(x) * Sim(x)$

$Distance(x)$: the distance from x to the closest solution in Pareto front
$Sim(x)$: the similarity between x and solutions in the set of the other stored solutions

Simulation Settings

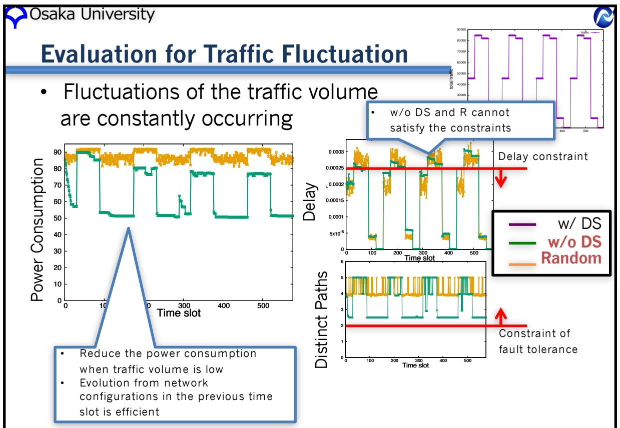


- Network topology
  - FatTree topology: 80 switches, 256 links
- Traffic
  - Traffic steadily fluctuates in the selected communication pair
    - within a predefined total traffic volume
- SLA requirements
  - Delay between any server pairs must be less than 250 [µs]
  - At least 2 distinct paths should be provided between any server pairs
- Parameter of MO-EA

Configurations in Pareto archive	Crossover ratio	Mutation ratio	Configurations in diverse archive
30	0.5	0.5	30

Evaluation for Traffic Fluctuation

- Fluctuations of the traffic volume are constantly occurring



Evaluation for Traffic Fluctuation

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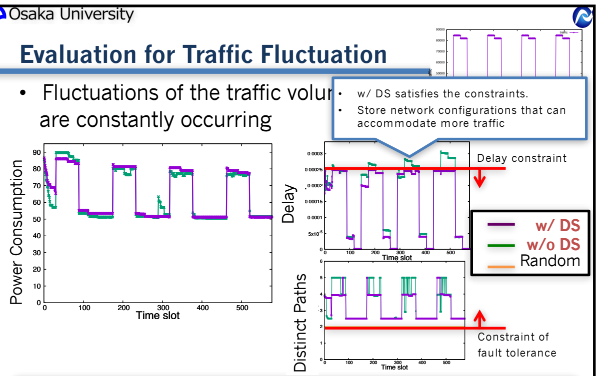
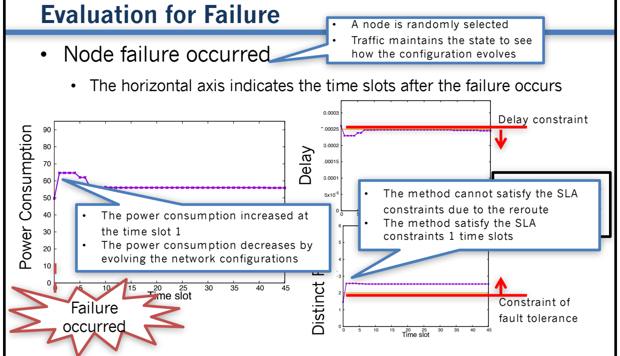


w/ DS reduced the power consumption of the network while satisfying SLA requirements, following the environmental fluctuation

Evaluation for Failure

- Node failure occurred
  - The horizontal axis indicates the time slots after the failure occurs



w/DS re-builds paths and gradually recovers the network configurations

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Summary and Future Work

- Summary
  - Proposal of power saving method
    - Handle multiple complex objectives, following the environmental changes
  - Evaluation
    - Our method reduces the power consumption of the network without violating the SLA constraints, following the traffic changes
    - Even when a failure occurs, our method re-builds paths and gradually recovers the network configurations so that the energy consumption is minimized under the SLA constraints
- Future Work
  - Evaluate our method in a more general network structure