Osaka University

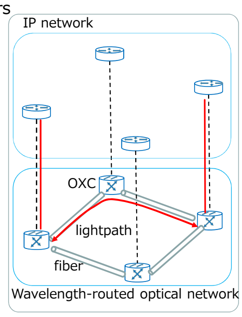
A Distributed Control of Virtual Network Topologies by Using Attractor Selection Model

Koji Mizumoto* Shin'ichi Arakawa* Yuki Koizumi* Daisaku Shimazaki** Takashi Miyamura** Shohei Kamamura** Kohei Shiomoto** Atsushi Hiramatsu** Masayuki Murata*

*Graduate School of Information Science and Technology, Osaka University
**NTT Network Service System Laboratories, NTT Corporation

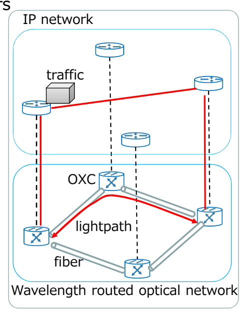
VNT (Virtual Network Topology) Control

- **Wavelength-routed optical network**
  - Establish lightpaths between IP routers via OXCs (optical cross connects)



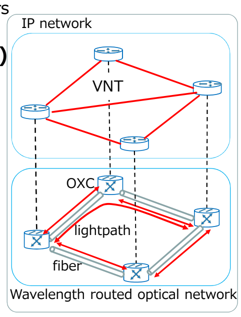
VNT (Virtual Network Topology) Control

- **Wavelength-routed optical network**
  - Establish lightpaths between IP routers via OXCs (optical cross connects)



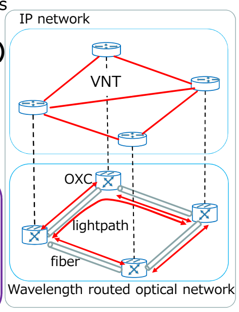
VNT (Virtual Network Topology) Control

- **Wavelength-routed optical network**
  - Establish lightpaths between IP routers via OXCs (optical cross connects)
- **VNT (Virtual Network Topology)**
  - Is a virtual network that consists of a set of lightpaths and IP routers
  - IP network uses the VNT as its network infrastructure and transports traffic on the VNT



VNT (Virtual Network Topology) Control

- **Wavelength-routed optical network**
  - Establish lightpaths between IP routers via OXCs (optical cross connects)
- **VNT (Virtual Network Topology)**
  - Is a virtual network that consists of a set of lightpaths and IP routers
  - IP network uses the VNT as its network infrastructure and transports traffic on the VNT
- **VNT control**
  - Constructs VNTs by configuring lightpaths according to its control objective
    - To avoid congestion
    - To transport IP traffic efficiently



Research Background and Objective

- **Problems of existing VNT control methods**
  - Not adaptive
    - They have to collect traffic demand matrix information
      - To retrieve traffic demand matrix information generally takes long time
    - They assume that no big traffic changes happen
- **VNT control based on attractor selection[5]**
  - More adaptive to traffic changes than existing methods
    - Utilize adaptability of biological systems (attractor selection)
    - Use only a small amount of information (link utilization information)

link utilization: the amount of traffic on a lightpath

But, high computational complexity

⇩

We extend our previous method and reduce its computational complexity

[5] Y.Koizumi, T. Miyamura, S.Arakawa, E.Oki, K.Shiomoto, and M. Murata, "Adaptive virtual network topology control based on attractor selection," *IEEE/OSA Journal of Lightwave Technology*, vol. 28, pp. 1720–1731,June 2010.

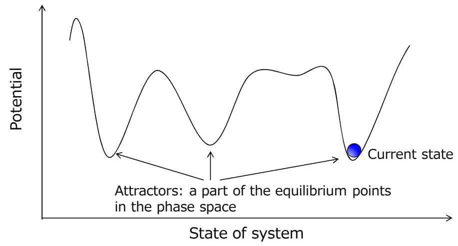
Osaka University 7

Attractor Selection

Dynamics of system

$$\frac{dx_i}{dt} = \alpha \cdot f(x_1, x_2, \dots, x_k) + \eta$$

activity, deterministic term, noise



Osaka University 8

Attractor Selection

Dynamics of system

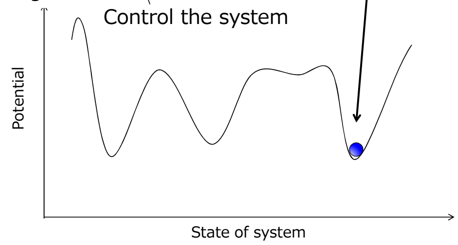
$$\frac{dx_i}{dt} = \alpha \cdot f(x_1, x_2, \dots, x_k) + \eta$$

activity, deterministic term, noise

High

Control the system

Converge to an attractor



Osaka University 9

Attractor Selection

Dynamics of system

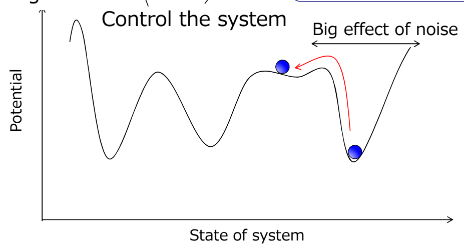
$$\frac{dx_i}{dt} = \alpha \cdot f(x_1, x_2, \dots, x_k) + \eta$$

activity, deterministic term, noise

High

Control the system

Degrade due to traffic change



Osaka University 10

Attractor Selection

Dynamics of system

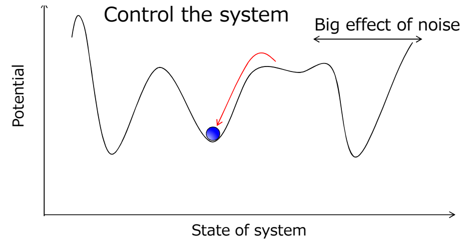
$$\frac{dx_i}{dt} = \alpha \cdot f(x_1, x_2, \dots, x_k) + \eta$$

activity, deterministic term, noise

Low

Control the system

Search for a suitable attractor



Osaka University 11

Attractor Selection

Dynamics of system

$$\frac{dx_i}{dt} = \alpha \cdot f(x_1, x_2, \dots, x_k) + \eta$$

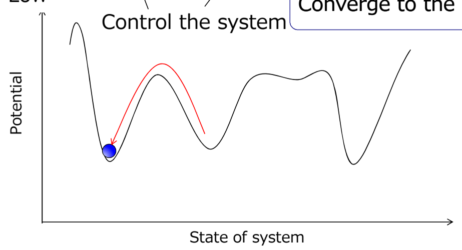
activity, deterministic term, noise

Low

Control the system

Find a suitable attractor

Converge to the attractor



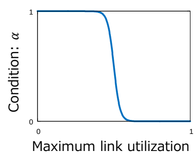
Osaka University 12

VNT Control Based on Attractor Selection

- **Dynamics of candidates of lightpaths**

$$\frac{dx_i}{dt} = \alpha \cdot \left(\zeta\left(\sum_{j=1}^{n-1} W_{ij} x_j\right) - x_i\right) + \eta$$

activity, deterministic term, noise



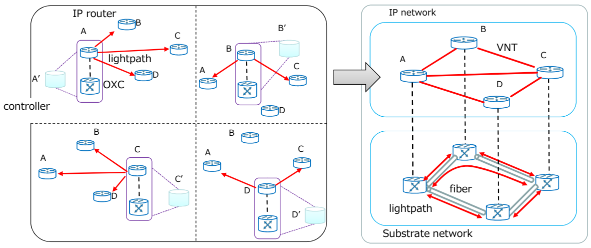
- x_i : State of candidate of i-th lightpath (l_i)
  - $0 \le x_i < 0.5$: tear down l_i
  - $0.5 \le x_i \le 1$: establish l_i
- α: Condition of IP network determined by the maximum link utilization
- η: Noise (Gaussian noise)
- $\zeta(\sum_{j=1}^{n-1} W_{ij} x_j) - x_i$: Deterministic term
  - Define W_{ij} by embedding attractors by using knowledge about Hopfield network[10]
  - Size of W_{ij}: $n^2 * n^2 (= n^4)$
    - The number of candidates of lightpaths: n^2

⇨ **The computational complexity: $O(n^4)$**

[10] Y. Baram, "Orthogonal patterns in binary neural networks," tech.rep., NASA, Mar. 1988.

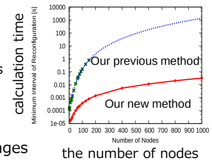
Decentralizing Our Previous Method

- **Each node constructs sub-VNT**
  - Each node has VNT controller
  - Sub-VNT consists of lightpaths that originate from the node
  - Set of sub-VNTs forms a VNT



Reduction of Computational Complexity

- **Reduce computational complexity $O(n^4)$ to $O(n^2)$**
  - New method
    - Each controller manages $(n-1)$ lightpaths
  - Previous method
    - A central controller manages $n(n-1)$ lightpaths



- **Adaptability to changes in traffic**
  - New method must inherit adaptability to changes in traffic from our previous method
  - However, decentralization may cause selfish behavior of each controller
    - New method may configure unsuitable VNTs for traffic demands

We validate the adaptability of our method by simulation

In 1000-node network, our new method requires only 0.032 sec while our previous method requires about 1000 sec

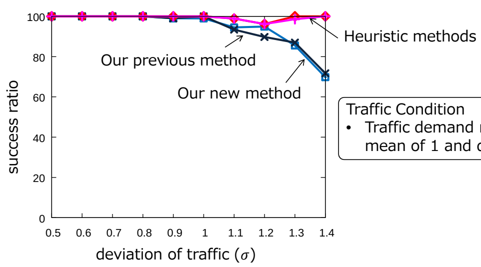
Simulation Conditions (1)

- **Physical network**
  - 50 nodes and 200 optical fibers
  - Each node has 16 transmitters and 16 receivers
- **Traffic demand matrices**
  - Generate randomly
    - Elements follow a log-normal distribution with a mean of β and with a deviation of σ
- **Initial attractors**
  - Randomly generated

Simulation Conditions (2)

- **Control objective**
  - Construct a VNT with a maximum link utilization of less than the target link utilization (0.5)
- **Metrics: Success ratio**
  - Ratio of the simulation trials where a method successfully achieves the control objective to total number of simulation trials
- **Comparison methods**
  - Our previous method
  - Heuristic methods (MLDA and I-MLTDA)
    - Assume that heuristic methods can use traffic demand matrices and then these methods configure sub-optimal VNT
    - Use the heuristic methods as benchmarks

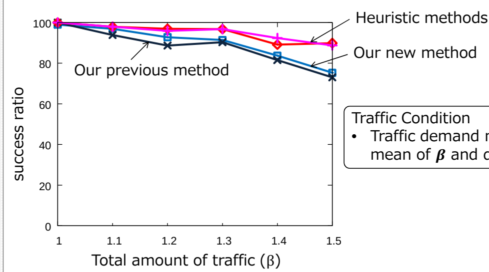
Success Ratio vs. Deviation of Traffic



Traffic Condition
- Traffic demand matrices with mean of 1 and deviation of σ

Our new method achieves the same adaptability as the previous method

Success Ratio vs. Total Amount of Traffic



Traffic Condition
- Traffic demand matrices with mean of β and deviation of 1

Our new method achieves the same adaptability as the previous method

Conclusion and Future Work

- **Conclusion**
  - We propose a distributed VNT control method based on attractor selection
  - Our method reduces computational complexity compared to our previous method
  - Our method achieves the same adaptability to traffic changes as our previous method while reducing computational complexity
- **Future work**
  - Evaluate our method in large networks (1000-node network)