Hierarchical design of an attractor structure for VNT control based on attractor selection

Toshihiko Ohba Shin'ichi Arakawa
Yuki Koizumi Masayuki Murata

Graduate School of Information Science and Technology, Osaka University

Jan. 10, 2015

Research background

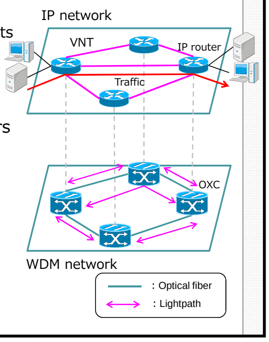
- **Emergence of new Internet services causes large fluctuations of traffic demands**
  - e.g., Video on demand, cloud computing services
- **A network should have flexibility to accommodate new and existing services**

⇩

- **Deploy a flexible infrastructure that can change a virtual network**
  - SDN (software-defined network)
  - WDM (wavelength division multiplexing)-based network

VNT (Virtual Network Topology) Control

- **SDN**
  - A controller reconfigure a VNT
    - to accept more virtual network requests
    - to fulfill QoS requirements
- **IP over WDM network**
  - Establish lightpaths between IP routers via OXCs (Optical Cross Connects)
  - Lightpaths and IP routers form a VNT
  - A VNT accommodates IP traffic
  - Reconfigure a VNT following traffic changes



Requirements of a VNT control method

- **Adaptability to traffic changes**
  - Reconfigure a VNT quickly following traffic changes
- **Scalability**
  - The amount of information and computational time do not increase explosively when the number of nodes in a network increase

⇩

- **<u>VNT control method based on attractor selection [8]</u>**
  - adaptive to traffic changes
    - Utilize adaptability of biological systems (attractor selection model)
    - Use only a small amount of information to reconfigure a VNT

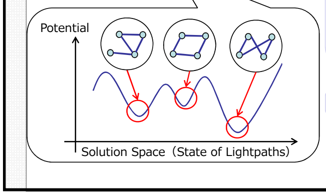
[8] Y.Koizumi, T. Miyamura, S.Arakawa, E.Oki, K.Shiomoto, and M. Murata, "Adaptive virtual network topology control based on attractor selection," *IEEE/OSA Journal of Lightwave Technology*, vol. 28, pp. 1720–1731,June 2010.

VNT control based on attractor selection

- **Control a state of lightpaths based on attractor selection model**
- **We prepare attractors (VNT candidates) in advance**

Dynamics of VNT control

$$\frac{d\boldsymbol{x}}{dt} = \underbrace{\boxed{\alpha}}_{\text{activity}} \cdot \overbrace{\boxed{f(\boldsymbol{x})}}^{\text{attractor structure}} + \underbrace{\boxed{\eta}}_{\text{noise}}$$



- $\boldsymbol{x} = (x_1, \ldots, x_{n^2})$: State of lightpaths
  - x_i : State of i-th lightpath（l_i）
    - $x_i \geq 0$: establish l_i
    - $x_i < 0$: tear down l_i
- α: Activity (Conditions of IP network)
  e.g., Maximum link utilization
- $f(\boldsymbol{x})$: Attractor structure
- η: Noise (White Gaussian noise)

○ : attractor（VNT candidate)

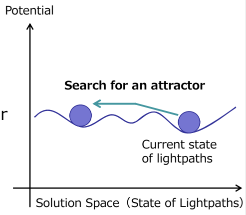
Use only α to reconfigure a VNT

Dynamics of our VNT control method (1/2)

- **Control the state of lightpaths using properly \`attractor structure' and \`noise' based on \`activity'**

Dynamics of VNT control

$$\frac{d\boldsymbol{x}}{dt} = \underbrace{\boxed{\alpha}}_{\text{activity}} \cdot \overbrace{\boxed{f(\boldsymbol{x})}}^{\text{attractor structure}} + \underbrace{\boxed{\eta}}_{\text{noise}}$$



- Conditions of IP network become poor
  - α takes a small value

⇩

- η is dominant in controlling a VNT

⇩

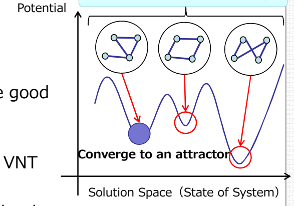
- Our VNT control method searches for a new attractor

Dynamics of our VNT control method (2/2)

- **Control the state of lightpaths using properly `attractor structure' and `noise' based on `activity'**

Dynamics of VNT control

$$\frac{dx}{dt} = \underbrace{\boxed{\alpha}}_{\text{activity}} \cdot \overset{\text{attractor structure}}{\boxed{f(x)}} + \underbrace{\boxed{\eta}}_{\text{noise}}$$



  - Conditions of IP network become good
    - α takes a large value

⇩

  - $f(x)$ is dominant in controlling a VNT

⇩

  - A VNT converges to a suitable attractor
    - Configure a VNT that can accommodate the current traffic demand

---

Research purpose

- **A main problem is how to design $f(x)$**
  - The number of VNT candidates that can be kept as attractors is limited to $0.1n^2$ [10]（n : the number of nodes）
  - We design $f(x)$ in a random manner in our previous work
  - If we do not design $f(x)$ properly, it takes a long time to configure a VNT that can accommodate the current traffic demand

⇩

We newly propose a method to decide VNT candidates

- **Requirements**
  - Since a VNT finally converges on one of attractors, any of VNT candidates should accommodate the current traffic demand

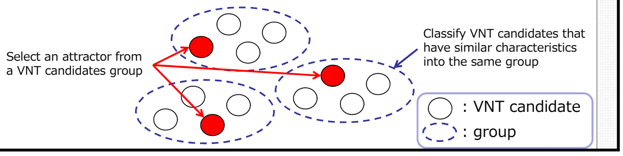
⇩

  - Prepare $0.1n^2$ VNT candidates with diverse characteristics

[10] Y. Baram, "Orthogonal patterns in binary neural networks," *NASA Technical Memorandum No.100060*, Mar. 1988.

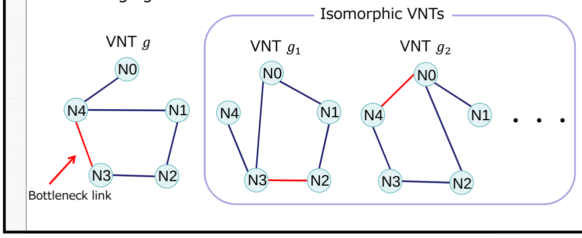
Approach to deciding VNT candidates

- **Classify VNT candidates into groups on the basis of their characteristics and select an attractor from each group**
  - Use Edge Betweenness Centrality (EBC) as characteristics of VNTs
    - EBC : the number of shortest paths that go through the link (lightpath)
  - Classify VNT candidates that have different bottleneck links each other into different groups
  - Pick up VNT candidates so that each has a different bottleneck link
    - It is expected that any of them accommodate various traffic demands



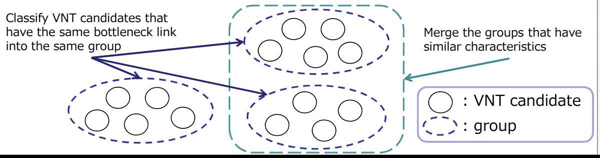
Design method of attractor structure (1/3)

1. **Enumerate isomorphic VNT candidates**
   - Enumerate $n!$ isomorphic VNTs of VNT g (n : the number of nodes)
     - g is given in advance, which is configured using a heuristic method
     - Isomorphic VNTs are generated by exchanging all the nodes of g
   - It is expected that any of isomorphic VNTs can accommodate changing traffic demands



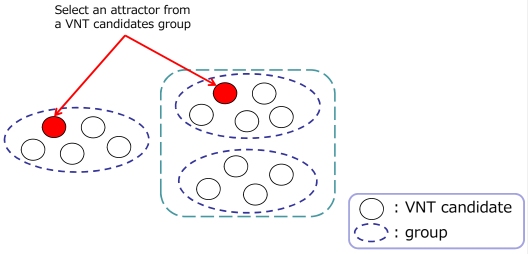
Design method of attractor structure (2/3)

2. **Classify the VNT candidates into groups on the basis of their characteristics**
   - Classify VNT candidates that have the same bottleneck link into the same group
     - The number of groups is n^2 at most
   - Merge the groups that have similar characteristics
     - VNT candidates groups whose bottleneck links are connected via a node whose degree is low have similar characteristics
     - Merge the groups until the number of them becomes $0.1n^2$



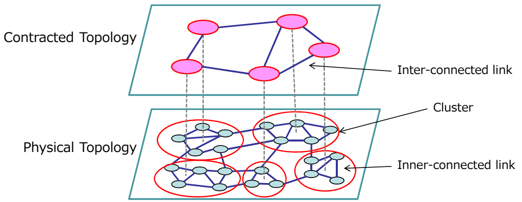
Design method of attractor structure (3/3)

3. **Select an attractor from each group**
   - Select a VNT candidate whose maximum value of EBC is lowest among the group



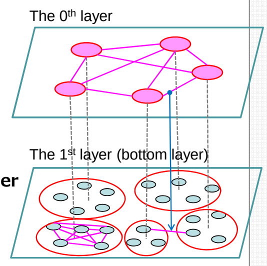
Applying the method to larger-scaled networks

- **Problem of our method**
  - It takes a heavy computational time for larger-scaled networks
    - We can apply the method for up to 10-nodes networks with a realistic calculation time
- **Approach**
  - Contract a physical network topology and apply our method to the contracted network topology

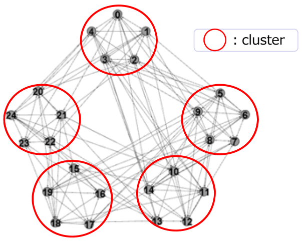


Hierarchical design method of attractor structure

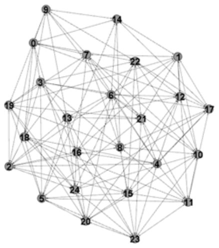
- **Step.1 Divide a physical network into c clusters**
  - Divide a network recursively so that the number of vertexes in a cluster $\leq c$
  - Decide a clustering structure
- **Step.2 Construct VNT candidates in clusters at the bottom layer**
  - Construct VNT candidates that have full-mesh topology
- **Step.3 Decide VNT candidates at upper layers**
  - Decide VNT candidates using EBC
- **Step.4 Connect lightpaths between clusters to nodes in the clusters**
  - Map lightpaths between clusters at upper layers to lightpaths between nodes inside the clusters at lower layers



Examples of VNT candidates



VNT candidate by our
hierarchical design method



VNT candidate used in our previous work
(constructed in a random manner)

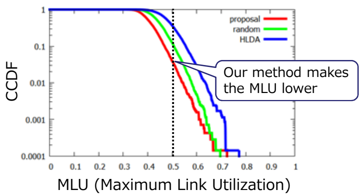
Performance Evaluation

- **Evaluation contents**
  1. Maximum link utilization that VNT candidates by our method show
     - Link utilization : the amount of traffic on a lightpath
  2. The number of steps of VNT control method based on attractor selection using VNT candidates by our method as attractors
- **Traffic demand matrices**
  - 1,000 patterns of traffic demands between each node pair according with a log-normal distribution
- **Methods for comparison**
  - Our previous method (construct VNT candidates by establishing lightpaths between randomly chosen node pairs)
  - HLDA[12] (construct VNT candidates on the basis of given traffic)

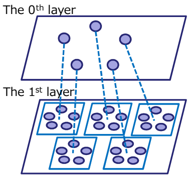
[12] D. Banerjee and B. Mukherjee, “Wavelength-routed optical networks: Linear formulation, resource budgeting tradeoffs, and a reconfiguration study,” IEEE/ACM Transactions on Networking (TON), vol. 8, no. 5,pp. 598–607, Oct. 2000.

Adaptability of VNT candidates

- **We decide 7 VNT candidates**
  - Physical network : 25 nodes, each node has 10 router ports
  - Clustering structure : 2 layers, each cluster has 5 nodes
- **Our method can decide better VNT candidates for larger-scaled networks**
  - Our method suppresses MLU to less than 0.5 against 97% of traffic demands
  - Random : 88%, HLDA : 64%



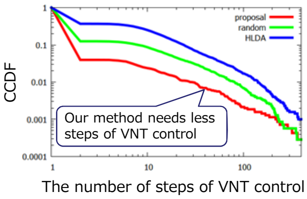
Our method makes the MLU lower



Clustering structure

Adaptability of our VNT control method

- **We use our VNT control method to accommodate traffic**
- **We evaluate the number of steps of our VNT control**
  - At each step, our VNT control method collects load information, calculate α and reconfigures a VNT
  - Control objective is to construct a VNT that can suppress maximum link utilization to less than 0.5
- **Our method achieves a shorter convergence time**



Our method needs less steps of VNT control

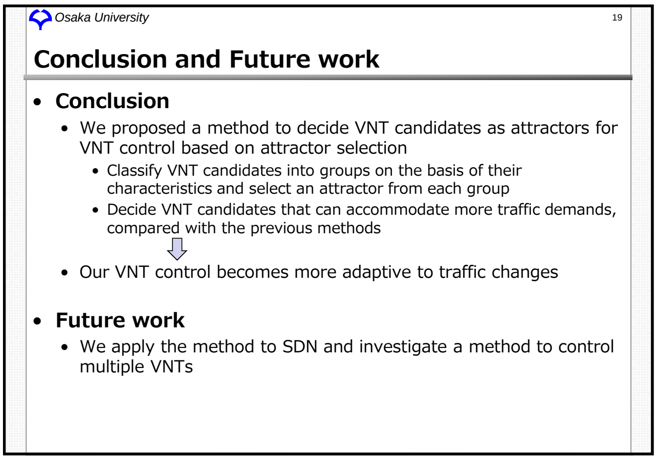
Dynamics of VNT control

$$\frac{dx}{dt}=\boxed{\alpha}\cdot\overset{\text{attractor structure}}{\boxed{f(x)}}+\boxed{\eta}$$

activity noise

Use decided VNT candidates as attractors

Physical network :
25 nodes, each node has 10 router ports



Conclusion and Future work

- **Conclusion**
  - We proposed a method to decide VNT candidates as attractors for VNT control based on attractor selection
    - Classify VNT candidates into groups on the basis of their characteristics and select an attractor from each group
    - Decide VNT candidates that can accommodate more traffic demands, compared with the previous methods

⇩

  - Our VNT control becomes more adaptive to traffic changes

- **Future work**
  - We apply the method to SDN and investigate a method to control multiple VNTs