Application of Attractor Selection to Adaptive Virtual Network Topology Control

- Wavelength-routed network
  - Establish lightpaths
  - Optical transport channel
  - Virtual Network Topology (VNT)
  - Upper layer network (client network)
  - Transmit its traffic on the VNT

- Virtual Network Topology Control
  - Constructs an (sub-)optimal VNT by configuring lightpaths
  - To balance load or remove bottlenecks in the network
  - Efficient utilization of resources

Background: virtual network topology control
To achieve an adaptive VNT control to various environmental changes, we focus on attractor selection.

Achieve adaptability to environmental changes by control \( f(x) \) and \( \sigma \) depending on the activity

- Poor condition = low activity: \( \xi = f(x) \) dominates the system behavior
- Good condition = high activity: \( \xi = f(x) \) dominates the system behavior

To achieve an adaptive VNT control to various environmental changes, we focus on attractor selection.
Applying attractor selection to VNT control

- Achieve adaptability to environmental changes by using the noise and the feedback of the condition of the metabolic reaction network.

Condition of metabolic network is poor
- Search for other attractors where system condition is better by noise
- Condition of metabolic network is good
- Converge to the attractor

Condition of client network is poor
- Search for other VNTs that accommodate client network’s traffic better by noise
- Condition of client network is good
- Converge to the attractor

Fundamental behavior of attractor selection

- Since the system is driven by noise, attractor selection cannot guarantee the optimal performance.
- However, since the system is driven without any assumptions on changes in environments, it has the potential capability of adapting various changes.

Since the system is driven by noise, attractor selection cannot guarantee the optimal performance.

Attractor selection in a gene-metabolic network

- Layered structure
  - Metabolic reaction network
    - Generate vital substrates for cellular growth by metabolic reactions
    - Concentrations of the vital substrates are fed back to gene regulatory network as activity x
  - Gene regulatory network
    - Interactions of genes determine expression levels of proteins on each gene
    - x controls the corresponding metabolic reaction
- Three elements of attractor selection
  - Programmed operation
    - Activation / inhibition between genes
  - Noise
  - Activity
    - Concentrations of vital substrates

Converge to the attractor

- Since the system driven by noise, attractor selection cannot guarantee the optimal performance.
Applying attractor selection to VNT control

- The gene regulatory network controls the metabolic network adaptively to changes in environments
- The WDM network controls the client network adaptively to changes in environments

Behavior of VNT control based on attractor selection

- Behavior of our proposed method
  - Measure link load on the client network periodically
  - Convert link load to the activity
  - Determine the system state by the attractor selection model
  - Construct a VNT according to the system state

VNT control based on attractor selection

- Challenges
  - Differences between VNT control and biological systems
    - Cannot apply attractor selection to VNT control directly
  - To realize an useful VNT control
    - Need an appropriate interpretation of attractor selection to VNT control
- Features
  - Adaptive network control to environmental changes
    - Do not assume a specific type of environmental changes
  - Achieve adaptability to various environmental changes by utilizing the noise
  - Effective network control with limited information

Policies to design attractors

- Attractors are defined by
  - Activations and inhibitions between genes
    - Represented by \( f(p_i, p_j) \)
      - \( p_i \) activates \( p_j \) \( \Rightarrow \) increases the number of lightpaths on \( p_{ij} \)
      - \( p_j \) inhibits \( p_i \) \( \Rightarrow \) decreases \( p_{ij} \)
      - decreases the number of lightpaths on \( p_{ij} \)
  - Encode the motivations to set up or tear down lightpaths
    - Adding lightpaths for effective transport of traffic
    - Activation
    - Establishing lightpaths for detouring traffic
    - Decreasing lightpaths due to resources being shared with other node pairs
    - Inhibition

Activity

- Condition of the client network
  - The maximum link utilization (\( u_{\text{max}} \)) of the client network
    - The maximum link utilization (\( u_{\text{max}} \)) of the client network
      - The maximum link utilization (\( u_{\text{max}} \)) of the client network
      - Other metrics can be used
- Definition
  - \( u_{\text{max}} \) is higher than \( u \) \( \Rightarrow \) Poor condition
  - Decreases the activity drastically
  - Reconfigure VNT by noise
  - \( u_{\text{max}} \) is lower than \( u \) \( \Rightarrow \) Good condition
  - Increase the activity gradually
  - Converge to an attractor with retaining the incentive to improve the condition of the client network
Behaviors of VNT control based on attractor selection

VNT construction

- Determine number of lightpaths
- Assign resources in the WDM network according to $\frac{\mu_j}{\mu_j}$
- Number of transmitters $P_T$ and receivers $P_R$

Number of lightpaths $G_{ij}$ on the node pair $p_{ij}$

$G_{ij} = \min \left( \frac{P_T}{\mu_j}, \frac{P_R}{\mu_j} \right)$

- Convert to integers by the floor function
- Satisfy the constraints of both receivers and transmitters
- Other constraints can be considered by adding $x_{ij}$ normalized by total $x$ for node pairs that share the common resource

Simulation conditions

- Physical network
  - European Optical Network
    - 19 nodes, 39 links
- Physical constraints
  - Number of transmitters and receivers: 8 each
  - Number of wavelengths
  - Sufficient number on each fiber
- Environmental changes
  - Changes in traffic demand
    - Gradual and periodic changes
    - The cycle of changes: 24 hours
  - Sharp and sudden changes
  - Change traffic volume for every node pair randomly

Environmental changes

Number of lightpaths

- European Optical Network

Degradation of link utilization

- Degradation of activity

Change in traffic demand

VNT reconfiguration by noise

Degradation of activity
Conclusion and future work

- **Large changes in network environments**
  - Require an adaptive method of controlling VNTs
- **Attractor selection**
  - Is a model for explaining adaptability of biological systems
- **Adaptive VNT control**
  - Based on attractor selection in the gene and metabolic networks
  - Can adapt against
  - Various changes in traffic demand
- **Future work**
  - Determine the appropriate amplitude of the noise for VNT control