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Adaptability of Virtual Network Topology Control based on Attractor Selection

Yuki Minami†, Yuki Koizumi†, Shin'ichi Arakawa†, and Masayuki Murata†

†Graduate School of Information Science and Technology, Osaka University
1-5 Yamadagaoka , Suita, Osaka, 565-0871 Japan
Email: {y-minami, ykoizumi, arakawa, murata} @ist.osaka-u.ac.jp

Abstract—In recent years, the Internet accommodates various kinds of traffic generated by new applications, such as P2P, VoIP, and video streaming services. Since traffic of these applications gives impacts on the performance in the network, an adaptability against changes of traffic becomes one of important characteristics. To achieve the adaptability, we have proposed a method for virtual topology controls using an attractor selection model. In this paper, we investigate the adaptability of our virtual topology control via computer simulations. Simulation results indicate that our virtual topology control can successfully adapt changes of traffic around twice higher variance comparing with conventional virtual topology controls. We also demonstrate that our virtual topology control achieves one-tenth of control duration.

1. Introduction

Wavelength Division Multiplexing (WDM) networks offer a flexible network infrastructure by using wavelength-routing capabilities. In such wavelength-routed WDM networks, a set of optical transport channels, called lightpaths, are established between nodes via optical cross-connects (OXCs). One approach to accommodating IP traffic on a wavelength-routed WDM network is to configure a virtual network topology (VNT), which consists of lightpaths and IP routers [1].

With the growth of the Internet, new application layer services, such as peer-to-peer networks, voice over IP, and video on demand have emerged and these applications cause large fluctuations on traffic demand in networks. For instance, Refs. [2] revealed that interactions between overlay networks and existing traffic engineering mechanisms causes the traffic flucutuation. Therefore, it is important to achieve a method of controlling VNT that is adaptive to changes in network environments.

The approaches to efficiently accommodating changing traffic demand on VNTs can be classified into two approaches: offline approaches and on-line approaches. In offline approaches, VNTs are statically constructed to efficiently accommodate one or multiple traffic demand matrices. The offline approaches inherently assume that the traffic demand matrices are available before the VNT is constructed or assume that changes in the traffic demand matrices are predictable. However, it is obvious that offline approaches cannot efficiently handle unexpected changes in traffic demand since VNTs are configured for a certain set of traffic demand matrices. In contrast with offline approaches, on-line approaches dynamically reconfigure VNTs based on their detection of degraded performance or periodic measurements of the network status without a priori knowledge of future traffic demand [3]. However, existing on-line VNT control methods assume that traffic demand is changing gradually and periodically. If there are overlay networks on top of the network controlled by the VNT control mechanism, traffic demand fluctuates greatly and changes in traffic demand are unpredictable as has been pointed out [2].

We therefore developed an on-line approach to achieve an adaptive VNT control method in [4, 5]. The method uses an attractor selection, which models behavior where living organisms adapt to unknown changes in their surrounding environments and recover their conditions [6]. The fundamental concept underlying attractor selection is that the system is driven by stochastic and deterministic behaviors, and these are controlled by simple feedback of current system conditions. This characteristic is one of the most important differences between attractor selection and other existing heuristic algorithms and optimization approaches.

Koizumi et. al [4, 5] demonstrated that the VNT control based on attractor selection can reconfigure VNT with fast reaction and adaptation against changes in traffic demand. In this paper, we evaluate the adaptability of our VNT control method against unknown and/or unexpected changes in surrounding environments. We conduct simulations with various changes of traffic demand, and quantatively show that our VNT control method can adapt to more various traffic changes than the existing heuristic method.

The rest of this paper is organized as follows. Section 2 briefly explains our VNT control based on attractor selection. Section 3 shows the evaluation results and the performance our VNT control method. Finally, we conclude this paper in Section 4.

2. VNT Control Based on Attractor Selection

In this section, we briefly explain VNT control method based on attractor selection. Please refer to Ref. [4] for the details.

2.1. Attractor Selection

In a cell, there are gene regulatory and metabolic reaction networks. Each gene in the gene regulatory network has an expression level of proteins and deterministic and stochastic behaviors in each gene control the expression level. An attractor selection model consists of regulatory behavior having attractor which is determined by activation and inhibition between each genes, growth rate as feedback of the conditions of the network, and noise, which is stochastic behavior [6].

Attractors are a part of the equilibrium points in the solution space in which the system conditions are preferable. The basic mechanism of an attractor selection consists of two behaviors: deterministic and stochastic behaviors. When the current system conditions are suitable for the current environment, i.e., the system state is close to one of the attractors, deterministic behavior drives the system to the attractor. Where the current system conditions are poor, stochastic behavior dominates over deterministic behavior. While stochastic behavior is dominant in controlling the system, the system state fluctuates randomly due to noise and the system searches for a new attractor.

When the system conditions have recovered and the system state comes close to an attractor, deterministic behavior again controls the system. These two behaviors are controlled by simple feedback of the conditions in the system. In this way, attractor selection adapts to environmental changes by selecting attractors using stochastic behavior, deterministic behavior, and simple feedback. In the following section, we introduce attractor selection that models the behaviors of gene regulatory and metabolic reaction networks in a cell.

2.2. VNT Control Method

In the cell, the gene regulatory network controls the metabolic reaction network, and the growth rate, which is the status of the metabolic reaction network, is recovered when the growth rate is degraded due to changes in the environment. In our VNT control method, the main objective is to recover the performance of the IP network by appropriately constructing VNTs when performance is degraded due to changes in traffic demand. Therefore, we interpret the gene regulatory network as a WDM network and the metabolic reaction network as an IP network.

Then, we consider the dynamical system that is driven by the attractor selection. We place genes on every source-destination pair (denote p_{ij} for nodes i and j) in the WDM network, and the expression level of the genes $x_{p_{ij}}$ determines the number of lightpaths on between nodes i and j. To avoid confusion, we refer to genes placed on the network as *control units* and expression levels as *control values*. The dynamics of $x_{p_{ij}}$ is defined by the following differential equation,

$$\frac{\mathrm{d}x_{p_{ij}}}{\mathrm{d}t} = v_g \cdot \mathrm{f}\left(\sum_{p_{sd}} W(p_{ij}, p_{sd}) \cdot x_{p_{sd}} - \theta_{p_{ij}}\right) - v_g \cdot x_{p_{ij}}, + \eta \quad (1)$$

where η represents white Gaussian noise, f is the sigmoidal regulation function, and v_g is the growth rate. v_g indicates the condition of the IP network.

The number of lightpaths between node pair p_{ij} is determined according to value $x_{p_{ij}}$. We assign more lightpaths to a node pair that has a high expression level of gene than a node pair that has a low expression level. $\theta_{p_{ij}}$ in the sigmoidal regulation function f is the threshold value to control the number of lightpaths.

The regulatory matrix W represents relations of the activation and inhibition between control units. Each element in the regulatory matrix, denoted as $W(p_{ij}, p_{sd})$, represents the relation between node pair p_{ij} and p_{sd}. The value of $W(p_{ij}, p_{sd})$ takes, a positive number α_A, zero, or a negative number α_I, each corresponding to activation, no relation, and inhibition of the control unit on p_{ij} by the control unit on p_{sd}. For example, if the lightpath on p_{ij} is activated by that on p_{sd}, increasing $x_{p_{sd}}$ leads to increasing x_{ij}. That is, node pair p_{sd} increases the number of lightpaths on p_{ij} in our VNT control method. In our method, we define α_A as $\alpha_A = 1.08N/N_A$, α_I as $\alpha_A = 1.08N/N_I$, where N is the number of control units, N_A is the number of control units that is activated, and N_I is the number of control units that is inhibited. There are three motivations for defining the regulatory matrix in WDM networks [4]. However, we do not present them in this paper due to space limitation.

The growth rate indicates the conditions of the IP network, and the WDM network seeks to optimize the growth rate. In our VNT control method, we use the maximum link utilization on the IP network as a metric that indicates the conditions of the IP network. To retrieve the maximum link utilization, we collect the traffic volume on all links and select their maximum values. This information is easily and directly retrieved by SNMP. Hereafter, we will refer to the growth rate defined in our VNT control method as *activity*. The activity must be an increasing function for the goodness of the conditions of networks. We therefore convert the maximum link utilization on the IP network, $u_{\max}$, into the activity, v_g, by the following equation.

$$v_g = \begin{cases} \frac{\gamma}{1+\exp(\delta \cdot (u_{\max} - \zeta))} & \text{if } u_{\max} \geq \zeta \\ \frac{\gamma}{1+\exp(\delta' \cdot (u_{\max} - \zeta))} & \text{if } u_{\max} < \zeta \end{cases} \quad (2)$$

where γ is the parameter that scales v_g and δ represents the gradient of this function. The constant number, ζ, is the threshold for the activity. If the maximum link utilization is more than threshold ζ, the activity approaches 0 due to the poor conditions of the IP network. Then, the dynamics of our VNT control method is governed by noise and search for a new attractor.

Table 1: Parameter settings of our VNT control method.

Name	Values
γ	100
δ	13
δ'	3
ζ	0.5
μ	1
$\theta^\star$	2.0

3. Performance Evaluation

We next evaluate the adaptability of our VNT control method against changes in traffic demand.

3.1. Existing Heuristic Method

Ref. [3] proposed an heuristic VNT control method, which we will refer as "ADAPTATION". ADAPTATION aims at achieving adaptability against changes in traffic demand. This method recon " ures VNTs according to the load on links and the traffic demand matrix. ADAPTATION measures the actual load on links every 5 minutes and adds a new lightpath to the current VNT when congestion occurs. This method places a new lightpath on the node pair with the highest traffic demand among all node pairs that use the congested link.

The ADAPTATION uses the information of traffic demand matrix to identify the node pair that has the largest traffic demand. However, collecting the information of traffic demand matrix is difficult in general because measurements of individual flows in a real-time manner are required. Therefore, we use the traffc demand matrix estimated with the method in [7] as the input parameter for ADAPTATION.

3.2. Simulation Conditions

We use the European Optical Network (EON) topology. The EON topology has 19 nodes and 39 bidirectional links [4]. Each node has eight transmitters and eight receivers. We focus on changes in traffic demand in the IP network as the environmental changes. For the evaluation, we prepare the traffic demand matrices where traffic demand from node i to j, d_{ij}, follows a lognormal distribution. We set the mean and variance of logrithm of d_{ij} to be 1 and σ^2. Then, we change the σ^2 to evaluate the adaptability against the changes of network environments. Each traffic demand matrix is normalized such that the total amount of traffic, $\sum_{p_{ij}} d_{p_{ij}}$, is the same.

The parameter settings of our VNT control method are summarized in Table. 1. The η used in Eq.1 is the ramdom number following normal distribution with variance of 0.2 and the mean of 0. For the parameter settings for the ADAPTATION method, we set the lower limit of the link utilization for deleting the lightpath to 0.1, and the upper limit of the link utilization for adding new lightpath to 0.5. In the simulation, we assume that our VNT control method and ADAPTATION collect the information of link utilization every five minutes via SNMP.

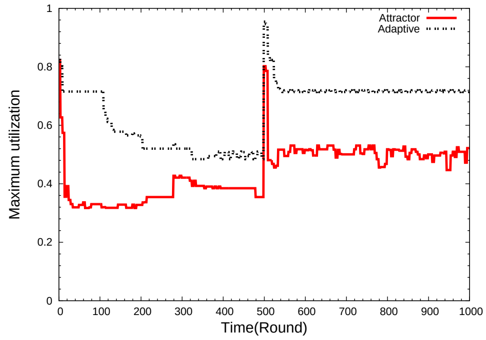

Figure 1: Changes of maximum link utilization

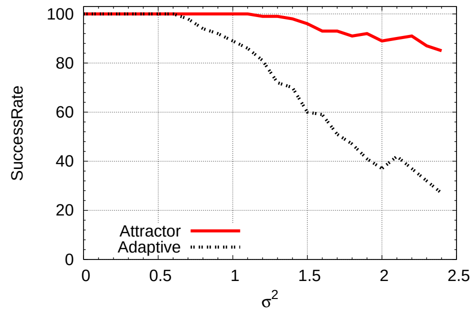

Figure 2: Success rate of VNT reconfigurations in EON topology

3.3. Simulation Results

We first show the maximum link utilization dependent on time in Fig. 1. In obtaining the figure, we set σ^2 to 2.0 and change the traffic demand at time 500 by setting the different value of random seed for d_{ij}. In both methods, the maximum link utilizations eventually decrease just after the change of traffic demand occurs. However, our VNT control method sharply reduces the maximum link utilization comparing to the ADAPTATION method. Our VNT control method successfuly decreases the maximum link utilization to be lower than 0.5, while the ADAPTATION cannot. Hereafter, we regard that the VNT control is successful when the maximum link utilization is decreased to less than 0.5. Otherwise the control is fail.

We evaluate the success rate of VNT reconfigurations by changing the parameter σ^2 from 0 to 2.4, and conducting the simulation 100 times for each value of σ^2. The results are shown in Fig.2 where the horizontal axis represents the value of σ^2 and the vertical axis represents the average of success rate. We observe that our method achieves 100% success of VNT reconfigurations when σ^2 is less than 1.1.

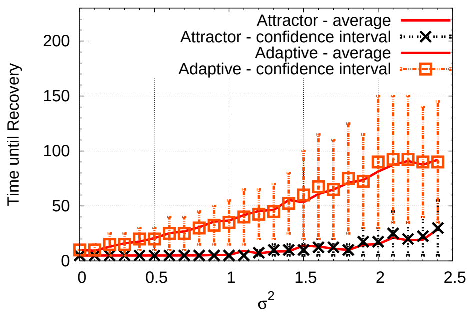

Figure 3: Average of the control duration in EON topology

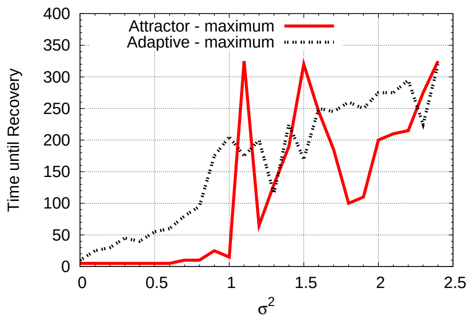

Figure 4: The maximum control duration in EON topology

Comparing with the results of the ADAPTATION method, our virtual topology control can successfully adapt changes in traffic demand around twice higher variance comparing with the ADAPTATION method. When σ^2 is 2.4, the success rate of our method is higher than 80%, while that of the ADAPTATION method decreases significantly.

We next discuss the control duration, defined as the time from when the traffic change occurs to when the maximum link utilization becomes less than 0.5. Figure 3 shows the average and 90 % confidence interval of the control duration dependent on σ^2. For calculating the control duration, we use only the cases when VNT reconfigurations are successful. Looking at the figure, we observe that our method achieves lower control duration comparing with the ADAPTATION method. When σ^2 is 2.4, the averaged control duration of the ADAPTATION method is 90 minutes, while the averaged control duration of our method is only 30 minutes.

Finally, we show the maximum value of control durations in Fig. 4. When σ^2 is 1.1 and 1.5, the control duration of our method is larger than that of the ADAPTATION method because of the stochastic behavior of our method. That is, the noise term in Eq. 1 does not work well in some cases. Note however that the success rate of our method is higher than that of the ADAPTATION method when σ^2 is 1.1 and 1.5. Thus, we can conclude that our method achieves a method of our virtual topology control can successfully adapt changes of traffic.

4. Concluding Remarks

In this paper, we evaluated the adaptability of VNT control method based on the attractor selection. Simulation results showed that our VNT control method can successfully adapt changes of traffic around twice higher variance comparing with existing heuristic method. We also demonstrated that our VNT control method achieves short control duration of VNT reconfiguration in most cases. However, in some cases, our VNT control method takes long time to finish the reconfiguration due to the stochastic behavior of attractor selection. One of future works is to investigate mechanisms to control the parameter settings according to, e.g., degree of traffic changes.

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