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On the Benefits of Virtual Network Topology Control based on Attractor Selection Model in Changing Environments

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Abstract Virtual Network Topology (VNT) is one efficient way to transfer IP packets over wavelength-routed optical networks. In recent years various new services have emerged, and IP traffic has been highly fluctuated. Therefore, adaptability against changes of traffic is one of the most important characteristics to accommodate the IP traffic efficiently. To achieve the adaptability, we have proposed a VNT control method using an attractor selection model. In this paper, we investigate the effect of number of transmitters/receivers that restrict the number of lightpaths between node pairs of our method via computer simulations. Simulation results indicate that to achieve an adaptive VNT controls to the changes of network environments, enough number of transmitters/receivers is crucial. With this case, our VNT control based on attractor selection achieves good adaptability to the traffic change and lower control durations.

Key words WDM (Wavelength Division Multiplexing), IP (Internet Protocol), virtual topology configuration, virtual topology control, self-organization

1. Introduction

The rapid growth in the number of users and in the number of multimedia services is dramatically increasing traffic volume on the Internet. Wavelength division multiplexing (WDM) offers high-capacity data transmission by multiplexing optical signals into a fiber. With the optical cross-connects (OXCs) that switches the optical signals in all-optical domain offers the wavelength-routing. That is, sets of optical transport channels, called lightpaths, are established between nodes. Since the Internet protocol (IP) is emerging as a dominant technology, the ability to carry the IP traffic efficiently is an important issue to enjoy the WDM-based optical networks. One approach to accommodate IP traffic on WDM networks is to configure a virtual network topology (VNT), which consists of lightpaths and IP routers, through the wavelength-routing.

Many approaches to accommodate traffic demand by configuring VNTs have been investigated. One of the approaches is that VNTs are statically constructed to efficiently accommodate traffic demand matrices [1] [2] [3] [4], [5]. These 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, the approaches cannot efficiently handle unexpected changes in traffic demand matrices since VNTs are configured for a certain set of traffic demand matrices. For example, the emergence of new services, such as peer-to-peer networks, voice over IP, and video on demand causes large fluctuations on traffic demand in networks [6], which makes the existing VNT control mechanisms insufficient to accommodate the traffic demand. Koizumi et. al [7] points out that, when 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. Therefore, VNT control methods that are adaptive to the traffic changes become important to avoid traffic congestions and to use network resources efficiently.

Recently, the dynamic VNT control methods that dynamically reconfigures VNTs based on their detection of degraded performance or periodic measurements of the network status without a priori knowledge of future traffic demand has been proposed [8], [9]. In Ref. [9], the authors consider an hour-order traffic change and propose a VNT control method to adapt to the change. The methods measures the traffic volume on each lightpath for short period and reconfigures

VNT by using traffic demand matrices estimated from the measurement. The VNT control method again relies on the traffic demand matrices and the authors therefore try to estimate the traffic demand matrices more accurately. However, it requires several traffic measurements to estimate the traffic demand matrix. Thus the method cannot estimate traffic demand matrices correctly with a short period of time, and cannot be applied when the traffic demand is highly fluctuated.

We therefore developed a VNT control method that is adaptive against changes in network environment without using traffic demand matrices [10]. Our method uses an attractor selection that models behavior where living organisms adapt to unknown changes in their surrounding environments and recover their conditions. We describe the method briefly in Sec. 2..

In this paper, we evaluate the method to see the effect of number of transmitters/receivers that restrict the number of lightpaths between node pairs. We conduct a set of simulations by changing the number of transmitters and receivers and evaluate the success rate.

2. VNT Control Based on Attractor Selection

In this section, we briefly explain VNT control methods based on attractor selection. Please refer to Ref. [10]. Attractors are a part of the equilibrium points in the solution space in which the current condition is preferable. In our VNT control method, we regard the attractor as VNT, and then select it based on the attractor selection model.

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 is consists of regulatory behaviors having attractor which is determined by activation and inhibition between each genes, growth rate as feedback of the current condition of the network, and noise, which is stochastic behavior [11].

Attractors are a part of the equilibrium points in the solution space in which the current condition is preferable. The basic mechanism of an attractor selection consists of two behaviors: deterministic and stochastic behaviors. When the current condition is 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. When the current condition is 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 current condition has 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 current condition 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 behavior 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 VNT 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.

Outline of our VNT control method is as follows:

- Step. 1 Measure the link utilization via SNMP (Simple Network Management Protocol).
- Step. 2 Determine growth rate from the link utilization. Growth rate express if IP network is in good condition or not. We describe detail of how to determine growth rate in Section II-C. Note that the degree of influence of deterministic behaviors and stochastic behaviors is determined by the growth rate.
- Step. 3 The number of lightpaths is determined based on the expression level of each gene. Then, the VNT is reconfigured. We describe how to decide the number of lightpaths in Section II-C.
- Step. 4 Transfer the IP traffic over the newly constructed VNT. Consequently the link utilization changes again, so we repeat these steps again.

2. 3 Interaction in VNT Control

This section describes our VNT control method in detail. 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,

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

where η represents Gaussian white 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 control value than a node pair that has a low control value. $\theta_{p_{ij}}$ 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}. Please refer to Ref. [12] for the dateils of motivations for defining the regulatory matrix in WDM networks.

The growth rate indicates the current condition 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 current condition of the IP network. To retrieve the maximum link utilization, we collect the traffic volume on all links and select their maximum value. 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*. Please refer to Ref. [12] for the details of the function.

The number of lightpaths between node pair p_{ij} is calculated from $x_{p_{ij}}$ that is the expression level of gene placed for p_{ij}. To simplify the model of our VNT control method, we assume that the number of wavelengths on optical fibers will be sufficient and the number of transmitters and receivers of optical signals will restrict the number of lightpaths between node pairs. Please refer to Ref. [12] for the details.

3. Performance Evaluation

3.1 Simulation Conditions

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 variance of logarithm of d_{ij} to be σ^2 and with the mean to be 1. 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 and is set to 10 or 15 in a unit of bandwidth of lightpaths.

In the simulation, our VNT control method collects information about the link utilization every 5 minutes by SNMP.

Tab 1 Three traffic scenarios in the EON topology

	Total traffic volume	σ^2
Scenario 1	10	2.0
Scenario 2	15	1.0
Scenario 3	15	2.0

The parameter settings used in Eq. 1 are the same in Ref. [12].

For comparison purpose, we introduce an existing heuristic method and then present some simulation results. Ref. [8] proposed a heuristic VNT control method, which we will refer to "ADAPTATION". ADAPTATION aims at achieving adaptability against changes in traffic demand. This method reconfigures VNTs according to the link utilization and the traffic demand matrix. For the details and settings in the simulation, please refer to Ref. [8] and [12], respectively.

MLDA (Minimum-delay Logical topology Design Algorithm) [3] which is a heuristic and centralized VNT control method on the basis of a given traffic demand matrix. MLDA simply places lightpaths between nodes in descending order of traffic demand. We show the results of MLDA with the actual traffic demand matrix to see how transmitters and receivers are effectively used in VNT control methods. From the table, we observe that each VNT control method have significantly low success rate with the small number of transmitters/receivers. This means that enough number of transmitters/receivers is crucial for VNT controls in changing network environments.

3.2 Simulation Results

To see the effect of number of transmitters/receivers, we conduct a set of simulations for the European Optical Network (EON) topology [12] by changing the number of transmitters and receivers and evaluate the success rate for each VNT control method. We prepare three traffic scenarios shown in Table 1 by changing traffic volume and σ^2. In scenario 1, we set the traffic volume to 10 and σ^2 to 1.0. In scenario 2, we set the traffic volume to 15, but use the same value for σ^2. For scenario 3, we set the traffic volume 15 and σ^2 to 2.0. We generate a traffic demand matrix based on the parameters for each traffic scenario and then evaluate whether VNT control methods successfully adapt to the traffic demand. In this simulation, the parameter settings used in Eq. 1 are the same in Ref. [12]. We set traffic demand at time 500 by setting the different value of random seed for d_{ij}. 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 conducting the simulation 100 times.

Table 2 summarizes the success rate of VNT reconfigurations. The benefit of heuristic VNT control methods appears

Tab 2 Success rate (in percentage)

	Number of transmitters/receivers								
	1	2	3	4	5	6	7	8	9
scenario 1 ATTRACTOR	0	0	0	0	6	12	52	89	96
scenario 1 ADAPTATION	0	0	0	0	7	23	30	37	51
scenario 1 MLDA	0	0	0	0	7	17	52	85	92
scenario 2 ATTRACTOR	0	0	0	0	0	0	17	82	100
scenario 2 ADAPTATION	0	0	0	0	0	2	8	18	32
scenario 2 MLDA	0	0	0	0	0	0	23	79	97
scenario 3 ATTRACTOR	0	0	0	0	0	0	5	44	96
scenario 3 ADAPTATION	0	0	0	0	0	0	0	2	7
scenario 3 MLDA	0	0	0	0	0	0	4	20	42

with the small number of transmitters/receivers; ADAPTATION and MLDA have a higher success rate than ATTRACTOR when the number of transmitters/receivers is 5 or 6 for traffic scenario 1, but the differences are marginal. More importantly, the benefit of MLDA disappears as the number of transmitters/receivers increases; the success rate of ATTRACTOR and MLDA is mostly the same for traffic scenarios 1 and 2. Looking at the case of traffic scenario 3, we observe a disadvantage of MLDA. That is, the results of MLDA show poor success rate comparing with the results of ATTRACTOR. The reason is that when the variance of traffic demand matrix increases, the heuristic behind MLDA fails. ADAPTATION has a much lower success rate than the other VNT control methods due to the estimation error in obtaining the traffic demand matrix from the information of link utilization.

In summary, heuristic VNT control methods based on the traffic demand matrices have a capability to obtain good VNTs with the small number of transmitters/receivers. Therefore, the heuristic VNT control methods are useful for the network with gradual change in traffic demand matrices. However, for the network having large fluctuations on traffic demand, enough number of transmitters/receivers is crucial. With this case, our VNT control based on attractor selection achieves good adaptability to the traffic change and lower control durations.

4. Conclusion

Adaptability against changes of traffic demand is one of the important characteristics. In this paper, we evaluate the effect of number of transmitters/receivers that restrict the number of lightpaths between node pairs of our method. We then evaluated the success rate with different number of transmitters/receivers for three traffic scenarios, and compared our VNT control methods with existing two heuristic VNT control methods. Simulation results indicate that existing methods have a higher success rate than our VNT control method when the number of transmitters/receivers is small, but its differences are marginal. To achieve an adaptive VNT controls to the changes of network environments, enough number of transmitters/receivers is crucial. With this case, our VNT control based on attractor selection achieves good adaptability to the traffic change and lower control durations.

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