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複数 VNT 制御のための自己組織化管理手法の提案と評価

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あらまし　IP を基盤とするネットワーク上で新たな通信サービスを展開するオーバーレイネットワーク技術が着目されている。しかし、新しい通信サービスが急速に発展すると、そのサービスのトラヒック増加により基盤ネットワークの帯域を圧迫し、他のサービスの通信品質が劣化する。本稿では、サービス毎に仮想ネットワークを構築し、サービスごとの通信品質を満たしつつ複数の仮想ネットワークを制御する手法を提案する。提案手法では、個々の仮想ネットワークを自己組織化制御により制御しつつ、一部の制御情報の交換によってネットワーク全体の通信品質を管理する。通信品質を仮想ネットワークの最大リンク利用率とした計算機シミュレーションにより、提案手法により各サービスの通信品質を満たすことを示す。

キーワード　波長分割多重、波長ルーティング、仮想網制御、アトラクター選択、自己組織化管理

A Managed Self-organization Method for Controlling Multiple Virtual Network Topologies

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Abstract　In this paper, we propose a framework to construct multiple VNTs in WDM-based optical network and then propose a control scheme, which we call a managed self-organization, to achieve adaptive and efficient VNT controls. Our basic idea is to introduce a system manager for managing and controlling the overall performance in multiple VNTs environments. The system manager collects the activities that represent the conditions of VNTs, calculate the overall condition of the network, and loosely controls each VNT through the feedback of the information about the overall condition. Simulation results show that the VNT control with system manager can adapt to the large traffic fluctuation within 47 minutes, while the VNT control without system manager takes more than 200 minutes.

Key words　Wavelength Routed Network, VNT Control, Attractor Selection, Managed self-organization

1. Introduction

Recently, overlay services on existing IP-based networks have expected to be a viable solution to deploy new services without violating underlying protocol standards. However, rapid increase of new overlay services may lead to the increase of traffic growth without control, which will result in a severe degradation of quality of service perceived by existing services. In Ref. [1], authors point out that the various services, such as peer-to-peer networks, voice over IP, and video on demand causes large fluctuations on traffic demand in networks. Koizumi et. al [2] 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. In more recent years, various new services such as SaaS and cloud services have emerged. However, because we do not know the traffic requirements of the new emerging services and we do not know its effect on the quality of existing services, we urgently need a framework for control and manage the current and future services in a flexible manner.

One of approach to overcome the performance degradation induced by multiple services is to prepare multiple VNTs over WDM-based optical networks, and then assign one or more VNTs to each service. We can take several approaches for managing multiple VNTs. For example, we can deploy centralized VNT control methods that control VNTs by collecting detailed information about the all of VNTs and by calculating VNT based on the information. However, it is easily imagined that the centralized VNT control methods have long control duration, and cannot adapt to rapid traffic changes induced by the overlay services.

In this paper, we develop a managed self-organization method of VNT controls to achieve adaptive and efficient VNT controls for multiple VNTs environments. Basis ideas of our framework is that each service deploys a VNT controller, and then configure the VNT by interactions between own condition and local information such that required quality of each service is satisfied. To realize this, we apply VNT control method based on attractor selection [3, 4] for each VNT control. We then introduce a system manager to control general situation of the all of VNTs. The system manager does not observe the details of the network and does not control all VNTs, but observes a condition of each VNT. The VNT controller prepared for each VNT collects conditions of its own VNT, and grasp whether each VNT control is acceptable or not. The conditions are collected by the system manager. Using the collected information, the system manager send a feedback which in turn used by the VNT controller of each VNT.

2. Network Model

Each node in the physical network has IP routers and OXCs and nodes are connected with optical fibers. Figure 1 shows an example of use of physical resources by multiple VNTs. Each IP router is connected with each OXC. Service0 uses IP router A', B', and C'. Service1 uses IP router A', B', C', and D'. VNT0 for service0 uses transmitters and receivers of OXC A, B, and C for setting up the lightpaths. VNT1 for service1 uses transmitters and receivers of OXC A, B, C, and D for setting up the lightpaths. Therefore VNT0 and VNT1 share the physical resources at OXC A, B, and C in the WDM network.

VNT controller configures VNT for the service. VNT controller observes own VNT performance and tries to reconfigure VNT properly based on the VNT control method. A VNT controller sends a request to physical resource manager to assign physical resources for the VNT configuring. Physical resource manager manages physical resources of the network. Physical resource manager receives the requests from each VNT controller and assigns physical resources to each VNT based on the requests from VNT controllers (Figure 2).

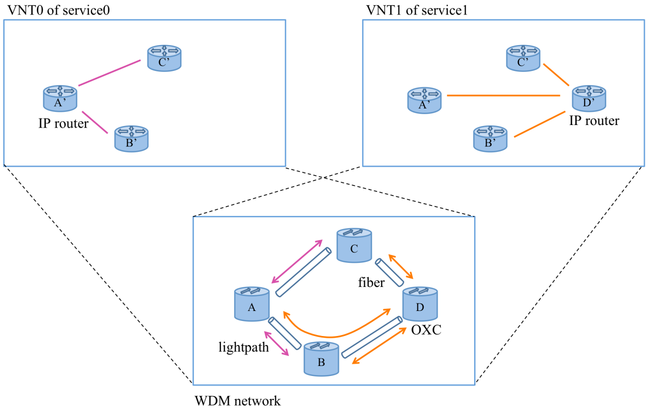

Figure 1 Multiple VNTs on top of a physical network

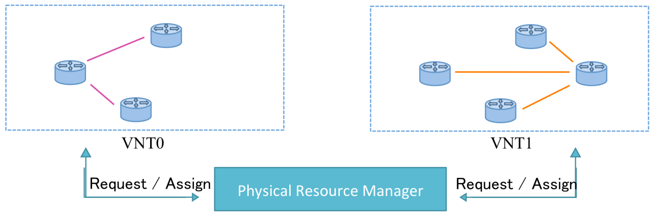

Figure 2 Physical resource manager

In our network model, when enough physical resources for the request remain, physical resource manager assigns physical resources and VNT controller configures the VNT. When enough physical resources do not remain, VNT controller keeps current VNT and sends a request to physical resource manager again at the next control period.

Therefore, if VNT0 use all transmitters and receivers of OXC A, then VNT1 cannot set up a new lightpath from or to IP router A'. In such case, we can avoid the competition by reconfiguring VNT0 such that VNT0 does not use all transmitters and receivers of OXC A. In another method, we can change allocation of physical resources by setting the physical resources as exclusive resources or shared resources. Exclusive resources are used only for one service. On the other hand, shared resources can be used for all services. In this way, services share physical resources of WDM network and configure VNTs.

We next explain the sequence of VNT control. Figure 3 shows the sequence when only one VNT exists. Figure 4 shows the sequence when multiple VNTs and system manager exist.

First, we explain the sequence of one VNT reconfiguration.

Step. 1 VNT controller observes performance of the VNT over which the service transfers IP traffic.

Step. 2 VNT controller calculates new VNT to improve the performance according to the VNT control method by using the observed information.

Step. 3 VNT controller sends a request to physical resource manager to assign physical resources for the new VNT. Physical resource manager assign physical resources if enough

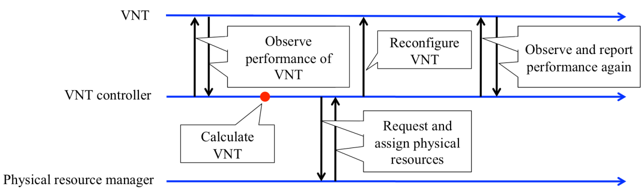

Figure 3 Information exchange for single VNT control

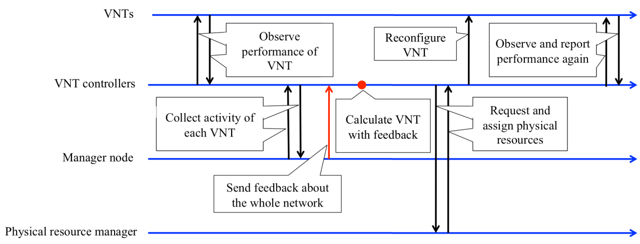

Figure 4 Information exchange for multiple VNTs control

resources remain. If not, physical resource manager reports it to VNT controller and does not assign physical resources.

Step. 4 VNT controller reconfigures VNT if physical resources were assigned. If not, VNT controller keeps current VNT.

Step. 5 Service transfers the IP traffic over the new VNT. Consequently the performance of the VNT changes again, so we repeat these steps again.

Next, we explain the sequence of multiple VNTs reconfiguration with system manager.

Step. 1 VNT controller observes performance of the VNT over which the service transfers IP traffic.

Step. 2 VNT controller calculates activity of the VNT. System manager collects activity of each VNT.

Step. 3 System manager calculates feedback from collected activities. The feedback indicates overall performance of all VNTs. System manager sends feedback to each VNT controller.

Step. 4 VNT controller calculates new VNT with the local information and feedback about the overall VNTs.

Step. 5 VNT controller sends a request to physical resource manager to assign physical resources for the new VNT. Physical resource manager assign physical resources if enough resources remain. If not, physical resource manager reports it to VNT controller and does not assign physical resources.

Step. 6 VNT controller reconfigures VNT if physical resources were assigned. If not, VNT controller keeps current VNT.

Step. 7 Transfer the IP traffic over the new VNT. Consequently the performance of the VNT changes again, so we repeat these steps again.

In this way, we configure one or multiple VNTs.

3. Managed Self-Organization of VNT Controls

In multiple VNT controls, we should reduce control overheads more strictly than one VNT control. The larger the number of VNTs becomes, the larger the information to control the all of VNTs become. Moreover, to adapt to various changes in the network quickly before influences of the change become big, control duration of each VNT control should be short. Therefore, the information to manage the all of VNTs should be simple and small.

In our method, we use self-organized VNT control method to control each VNT and then develop a managed self-organization of VNT controls to manage the all of VNTs. Our method can control multiple VNTs by the adaptability of self-organization. Moreover, our method can manage the all of VNTs by using the simple feedback from system manager.

3.1 Self-organized VNT control

Koizumi et al. developed self-organized VNT control method based on attractor selection [3] for single VNT control. The attractor selection model originally represents metabolic reactions controlled by gene regulatory networks in a cell. 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.

Koizumi et al. consider the dynamical system that is driven by the attractor selection. The authors 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. The dynamics of $x_{p_{ij}}$ is defined by the following differential equation,

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

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.

Attractors are a part of the equilibrium points in the solution space in which the current condition is preferable. In the current case, attractor represents a VNT. 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

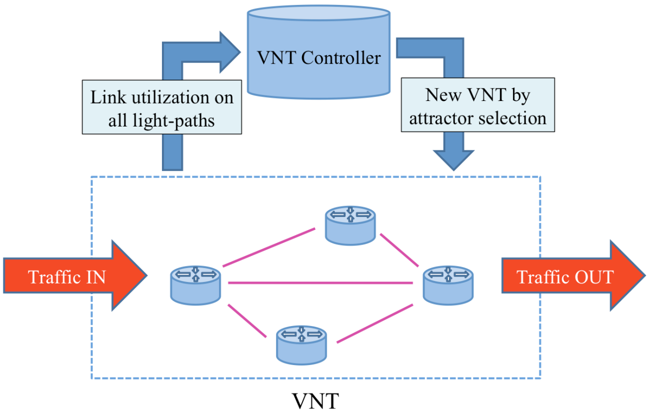

Figure 5　Self-organized VNT control method

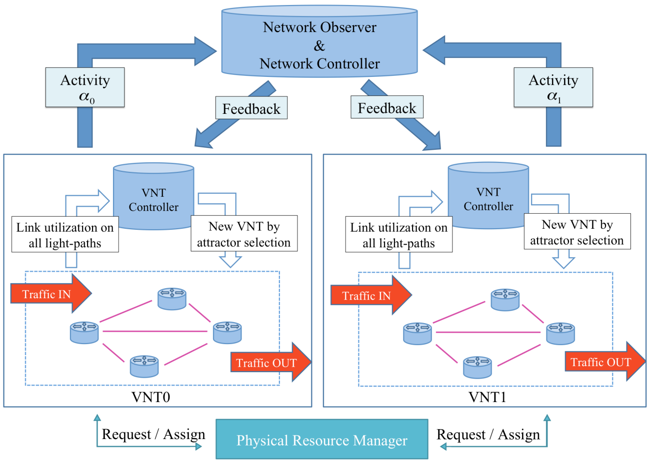

Figure 6　Concept of multiple VNTs control based on a managed self-organization

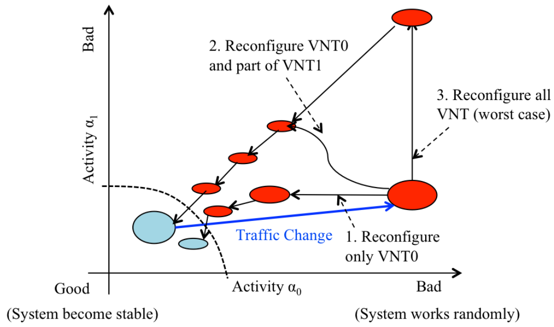

Figure 7　Interaction between the multiple VNTs

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.

3. 2　Outline of Managed Self-Organization

3. 2. 1　Functions of each control unit

Figure 5 shows the model of one VNT control based on self-organization, and Figure 6 shows the model of multiple VNT controls with system manager.

- VNT controller

VNT controller configures VNT for the service. The VNT control method is based on attractor selection (Section 3. 1). VNT controller observes own activity, and tries to reconfigure VNT properly to improve the activity. When system manager sends feedback to VNT controller, VNT controller reconfigures VNT by regarding the feedback as its own activity. Therefore, if the feedback indicates that the condition of the network is poor, VNT controller reconfigures its own VNT randomly by noise. After calculation of new VNT, the VNT controller sends a request to physical resource manager to assign physical resources for the new VNT configuring. VNT controller reconfigures VNT when physical resources are assigned. If physical resources are not assigned because of physical resource competition between other VNTs, VNT controller keeps current VNT.

- Physical resource manager

Physical resource manager manages physical resources of the network. Physical resource manager receives requests from each VNT controller, and assigns physical resources to each VNT following the situation. When enough physical resources for a request remain, physical resource manager assigns physical resources for the VNT. If enough physical resources for a request do not remain because of physical resource competition between other VNTs, physical resource manager sends message about it to the VNT controller.

- System manager

System manager consists of network observer and network controller. System manager collects activities of all VNTs. This is different from centralized network control method that collects much information from network. Activity is just a simple information; we do not need information of traffic demand matrix and/or link utilizations of all lightpaths that may be necessary for centralized VNT control. System manager calculates the activity of the whole network. We will refer to the activity as *network activity*. The network activity is based on the collected activities. System manager sends feedback to each VNT controller, and the network activity is used as the feedback. Again, the feedback is simple information. Each VNT controller reconfigures own VNT using the feedback. By this way, system manager controlls the degree of self-organization and manages the all of VNTs by sending feedback.

3. 2. 2　Management of interaction between the multiple VNTs

Figure 7 shows image of management of interaction between the multiple VNTs. In Figure 7, we assume that there are two VNT, called VNT0 and VNT1, in a physical network. Horizontal axis represents the value of α_0, which is the activity of the VNT0. Vertical axis represents the value of α_1, which is the activity of the VNT1. α_0 and α become high value when the condition of the system is good, and become low value when the condition of the system is bad. In the right of the figure, α_0 is low value. In the top of the figure, α_1 is low value. At first, both α_0 and α_1 are high value. When the change of traffic demand of VNT0 occurs, α_0 become low value (blue arrow in the figure). Here, when the change of traffic demand is low, it would be solved by reconfiguring of only VNT0. Therefore we reconfigure only VNT0 until a certain time pass (arrow #1). After a certain time passed, if α_0 do not become high value, we think that the change of traffic demand is high or physical resource competition between other VNTs occurs, and it cannot be solved by reconfiguring of only VNT0. Therefore we reconfigure VNT0 and part of VNT1 by sending feedback from system manager to VNT0 and VNT1 (arrow #2). After further time passed, we full reconfigure VNT0 and VNT1 (arrow #3). When the change of traffic demand is small, it would be more quick and efficient to reconfigure only the VNTs in poor condition rather than to reconfigure all of the VNTs in the network. Then we almost fix the VNTs in preferable condition and reconfigure the VNTs in the poor condition. When the change of traffic demand is large and VNTs in poor condition cannot recover the condition after a certain period of time, we consider the VNTs in poor conditions cannot adapt to the change by reconfiguring only its own VNTs. We then reconfigure all of VNTs in the network by the feedback from system manager. Then the physical resources in the network are reallocated to each VNT, and we can avoid physical resource competitions. In this way, our method can adapt to changes, and avoid physical resource competition.

3.3 Controlling activities for Managed Self-organization

In this section, we explain details of managed self-organization of VNT controls. When there are N VNTs in the network, each VNT has an activity, $\alpha_0, \alpha_1, ..., \alpha_N$. Each activity indicates the condition of the corresponding VNT. These activities are calculated by each VNT controller as explained in Section 3.1. We define α_{master} as the network activity. α_{master} is calculated from $\alpha_0, \alpha_1, ..., \alpha_N$.

Here, when the all activities in the network are high value, system manager does not update α_{master}. System manager send α_{own} as the feedback to each VNT. α_{own} is the same value as the value of α of each VNT.

Because then all VNTs are good condition, we do not need to change the VNTs. When some activities are low value, we update α_{master} and send α_{master} as the feedback to each VNT.

We update α_{master} by the following equation.

$$\alpha_{master} = \begin{cases} \alpha_{\min} * D(t) & \text{if } \alpha_{\min} < Th_\alpha \text{ and} \\ & \quad t > Th_{time} \\ \alpha_{own} & \text{if } \alpha_{\min} \geqq Th_\alpha \text{ or} \\ & \quad t \leqq Th_{time} \end{cases}$$

$\alpha_{\min}$ is the minimum value between $\alpha_0, \alpha_1, ..., \alpha_N$. Th_α is a threshold value about α. Th_{time} is a threshold value about time. t is the elapsed time from when $\alpha_{\min}$ become worse than Th_α. $D(t)$ is the rate decided by t, and it ranges from 0 to 1.

4. Simulation Results

We conduct computer simulation to evaluate our management model. Section 4.1 shows simulation conditions, and Section 4.2 shows simulation results.

4.1 Simulation Conditions

We use 19-node European Optical Network (EON) topology as the physical topology. Each node has transmitters and receivers that are used as exclusive physical resources of each service and that are used as shared physical resources between all services. In the simulation, we deploy two services in the network, and the two services configure VNT0 and VNT1. The number of transmitters/receivers of each node is $D_{node} * 2 + 8$. Here, D_{node} is the degree number of the node. Both services can use exclusive transmitters and receivers for base VNT that corresponds with physical topology. The lightpaths used for configuring the base VNT is set at all time irrespective of VNT control. Moreover, each service shares eight transmitters and receivers with other services per a node.

Each VNT controller configurse the VNT by self-organized VNT control (Section 3.1). The parameter settings used in Equation 1 are; γ =100, δ = 13, δ' = 3, $zeta$=0.5, and μ=1. We set N_{path} to 20. Each VNT controller collects information about the link utilization by SNMP and reconfigures VNT every minute. System manager collects activities from all VNTs and sends a feedback based on the activities to each VNT every one minute. The value of the feedback is used as the activity in each VNT, and the VNT controller reconfigure VNT based on the updated activity.

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. 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 6.5 in a unit of bandwidth of lightpaths. We change traffic demand of only VNT1 at 10 minutes by setting the different value of random seed for d_{ij}. We use the maximum link utilization on VNT as a metric that indicates the current condition of VNT. In the simulation, we set the target maximum link utilization to 0.5. Then the activity of the VNT is 50 in the parameter settings. Therefore, we set Th_α to 50. When the maximum link utilization of one VNT becomes less than 0.5, and the maximum link utilization of another VNT becomes higher than 0.5, system manager begins to count the time t, that is the time from when $\alpha_{\min}$ becomes worse than Th_α. When t becomes bigger than Th_{time}, that is threshold value about time, we consider that the situation cannot be solved by reconfiguration of VNT in a poor condition because of large change of the environment of the VNT and/or physical resource competition. Therefore, the system manager sends low value feedback to each VNT, and the VNTs in the network are reconfigured by noise. To adapt the all of VNTs to change of the environment quickly, we set Th_{time} to 4 minute, and set $D(t)$ as Equation 2.

$$D(t) = \begin{cases} 1 & \text{if 4minutes} < t \leqq \text{6minutes} \\ 0.5 & \text{if 6minutes} < t \leqq \text{8minutes} \\ 0.25 & \text{if 8minutes} < t \leqq \text{10minutes} \\ 0.125 & \text{if 10minutes} < t \leqq \text{12minutes} \\ 0.0625 & \text{if 12minutes} < t \leqq \text{14minutes} \\ 0 & \text{if 15minutes} < t \end{cases} \quad (2)$$

In this way, when poor condition of VNT cannot be solved by reconfiguration of the VNT because large change of environment or physical resource competition occurs, we reconfigure the all of VNTs by sending feedback.

4.2 Results

Figures 8 and 9 show maximum link utilization dependent on time with and without managed self-organization. In Figure 8, the change of traffic demand occurs in VNT1 at 10 minutes, and maximum link utilization of VNT1 becomes higher than 0.5 and the activity of VNT1 becomes low value. We can see that the VNT controller of VNT1 tries to reconfigure VNT1, but physical resource competition occurs and the maximum link utilization keeps high value. On the other hand, with a managed self-organization (Figure

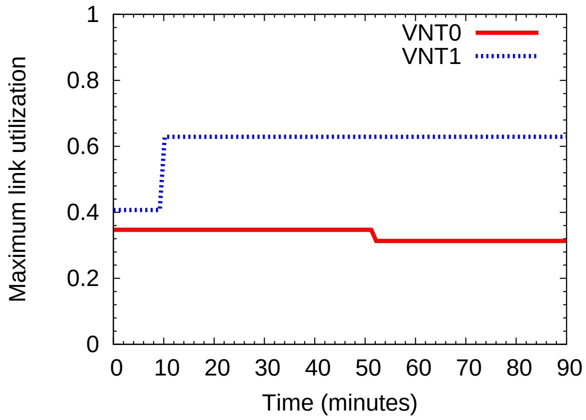

Figure 8 Changes of maximum link utilization without managed self-organization

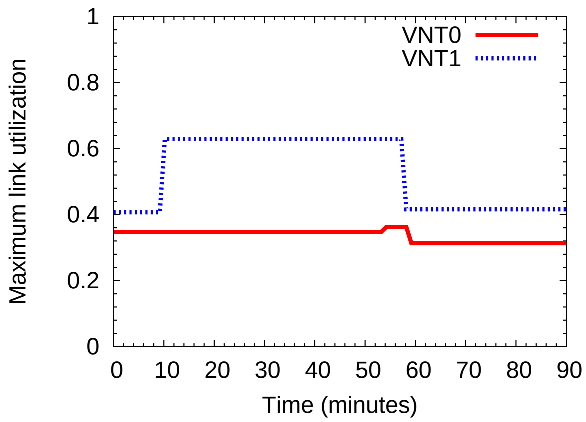

Figure 9 Changes of maximum link utilization with managed self-organization

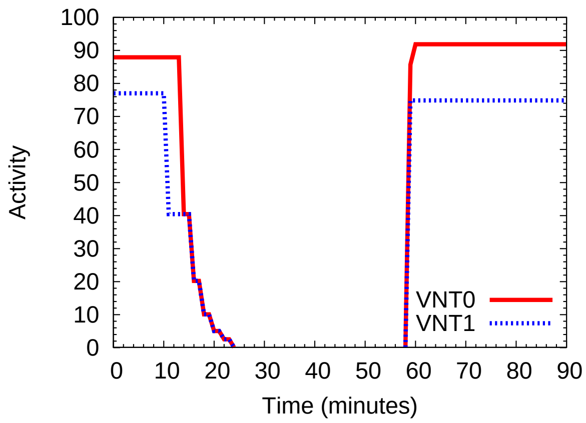

Figure 10 Changes of activity with managed self-organization

9), the change of traffic demand occurs in VNT1 at 10 minutes, and the maximum link utilization of VNT1 becomes higher than 0.5 and the activity of VNT1 becomes lower than 50. Then the maximum link utilization of VNT0 is under 0.5. Therefore system manager begins to count the time. VNT controller of VNT1 tries to reconfigure VNT1, but the maximum link utilization do not become lower than 0.5. At time 15, we regard that physical resource competition occurs and VNT1 cannot adapt to the change of traffic demand. Therefore system manager sends feedback to VNT0 and VNT1.

To see the behavior of our managed self-organization more clearly, we show the activities of VNT0 and VNT1 dependent on time in Figure 10. From 10 minutes, the activities are drop down gradually by $D(t)$. Activities of VNT0 and VNT1 become 0 at time 15. VNT0 and VNT1 work randomly by noise and the whole network is reconfigured. At time 47, VNT0 and VNT1 avoid physical resource competition and configure proper VNTs that can drop maximum link utilization to lower than 0.5. The maximum link utilizations of both VNTs become less than 0.5 by the reconfigurations. After that, the activities of both VNTs takes a higher value.

5. Concluding Remarks

Overlay services on existing IP-based networks have expected to be a viable solution to deploy new services without violating underlying protocol standards. However, rapid increase of new overlay services may lead to the increase of traffic growth without control, which will result in a severe degradation of quality of service perceived by existing services. One of approach to overcome this is to prepare multiple VNTs over WDM-based optical networks, and then assign one or more VNTs to each service. In this paper, we proposed a managed self-organization of VNT controls, that is a framework to construct multiple VNTs in WDM-based optical network and proposed a control scheme. The simulation results show that our managed self-organization of VNT control can avoid physical resource competition and adapt to change of traffic demand quickly by using feedback based on the network activity.

For the future work, we should exmaime various environmental changes to show the applicability of our method. More specifically, the frequency of physical resource competition depends on N_{path}. We should consider setting N_{path} dynamically by feedback to avoid physical resource competition more effectively.

Acknowledgement

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