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アトラクター選択を用いた仮想網制御手法の実機検証

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あらまし　波長分割多重 (WDM) ネットワークにおいて、波長レベルの仮想パスで構成される仮想網 (VNT) を構築し、その上に IP トラヒックを収容する IP over WDM ネットワークが広く検討されている。我々の研究グループでは、環境変動に対して仮想網を再構築する仮想網制御手法として、アトラクター選択を用いた仮想網制御手法を提案し計算機シミュレーションにより有効性を示している。本稿では、実機実験により提案手法の実現可能性を検証する。7 ルーター規模の実験ネットワークにおいて実機実験を行った結果、環境変動による通信品質の悪化に対して、提案手法を用いることで通信品質が回復することがわかった。

キーワード　波長分割多重、仮想網制御、アトラクター選択

Experimental Study of Large-scaled Virtual Network Topology Control Method Based on Attractor Selection

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Abstract　One approach for accommodating large amount of traffic and achieving adaptive control of the network is to construct a Virtual Network Topology (VNT) on Wavelength Division Multiplexing (WDM) network and reconstruct VNTs according to network environment changes. We propose the VNT control method based on attractor selection. In this paper, we verify the feasibility of our method through experiment with seven-router network. The results of the experiments show that our method recovers the network condition after deterioration caused by environmental changes.

Key words　Wavelength Division Multiplexing, VNT Control, Attractor Selection

1. Introduction

Now that the Internet plays an important role as an infrastructure, adaptive control of communication network to environmental changes such as traffic changes or node failures and providing planned network quality is desired. Simultaneously, since the amount of traffic transferred in the network is increasing drastically, the network is responsible for accommodating huge amount of traffic.

WDM (Wavelength Division Multiplexing) network is an expected substrate network accommodating huge amount of traffic by using wavelength division multiplexing, which multiplexes several optical signals operating on different wavelengths into a fiber. One approach for accommodating traffic on Internet Protocol over WDM (IP over WDM) network is to construct a VNT (Virtual Network Topology) that consists of optical signals called lightpaths. Figure 1 shows IP over WDM network. IP over WDM network has two layers composed of WDM network and IP network. WDM network consists of OXCs (Optical Cross Connects) that switch optical signals and fibers. In IP network, VNT control constructs a VNT that consists of lightpaths connected between IP routers via OXCs in WDM network. There is traffic demand between IP routers and traffic is transferred through transmitters and receivers on IP routers and lightpaths. Since traffic demand is changed from time to time, it is necessary to construct a suitable VNT for current environment with limited transmitters and receivers. VNT control methods that establish or tear down lightpaths dynamically and reconstruct VNTs according to environmental changes and moves to a preferable VNT for current environment are considered [1–4].

We propose a VNT control method based on attractor selection for adapting to a wider variety of changes in traffic and achieving effective transport of traffic [5]. Attractor selection is a model of behavior of organisms during adaptation to unknown changes in their surrounding environment and recovery of their state. The proposed method, which is an extension of our previous method in [6], relaxes computational overhead of our previous method. With computer simulation, we showed the proposed method maintains the previous method's adaptability to environmental changes [5]. In this paper, we verify the proposed method through experiments.

The remainder of this paper is organized as follows. Section 2. describes the proposed VNT control method based on attractor selection. We give the experimental verification in Section 3. We conclude the paper in Section 4.

2. VNT Control Method Based on Attractor Selection

Here we introduce the proposed VNT control method based on attractor selection. First, we explain the attractor selection model, which is a key mechanism for VNT control. Second, we explain how to apply attractor selection to VNT control.

2.1 Attractor Selection Model

Attractor selection is a model of behavior of organisms during adaptation to unknown changes in their surrounding environment and recovery of their state. A system driven by attractor selection can be described as

$$\frac{d\boldsymbol{x}}{dt} = \alpha \cdot f(\boldsymbol{x}) + \eta, \tag{1}$$

where $\boldsymbol{x} = (x_1, ...x_i, ..., x_n)$($n$ is the number of variables) are variables that represent the state of the system, α is called the activity and represents feedback of the system state, $f(\boldsymbol{x})$ represents the deterministic term, and η represents the stochastic term. The state of the system is thus determined by α, $f(\boldsymbol{x})$, and η. When the system condition is suitable for current environment, α is set to a large value, and the deterministic term, $f(\boldsymbol{x})$, controls the system and drives the system toward an attractor. When α is small, the stochastic term, η, controls the system and the system state fluctuates randomly as the system searches for a new attractor. A system driven by attractor selection thus flexibly and adaptively responds to environmental changes by selecting between deterministic and stochastic behavior depending on the activity.

2.2 VNT Control Method Based on Attractor Selection

To apply attractor selection model to VNT control, we map the variables in Eq. (1) by associating x_i with the state of a possible lightpath l_i, $\boldsymbol{x}$ with the state of a VNT, and α with the condition of the IP network. This gives the following equation for x_i,

$$\frac{dx_i}{dt} = \alpha \cdot \left(\zeta \left(\sum_j W_{ij} x_j \right) - x_i \right) + \eta, \tag{2}$$

where $\zeta(\sum_j W_{ij}x_j) - x_i$ represents the deterministic term η represents the stochastic term which is set to white Gaussian noise, and $\zeta(z) = tanh((\mu/2)z)$($\mu$ is a parameter) is the sigmoidal regulation function. Just like attractor selection found in biological systems, our method constructs a suitable VNT for current environment by selecting between deterministic and stochastic behavior according to feedback from the IP network.

Whether a lightpath l_i is established depends on the value of x_i, which takes values of between -1.0 and 1.0, with l_i established if and only if x_i is greater than or equal to 0.0. An established lightpath l_i is torn down if x_i is less than 0.0.

2.2.1 Activity

We use the maximum link utilization on the IP network as a metric indicating the state of the IP network and convert maximum link utilization into activity as follows

$$\alpha = \frac{1}{1 + \exp(\delta \cdot (u_{max} - \zeta))}, \tag{3}$$

where δ represents the gradient of this function and the constant ζ is the threshold for α. If the maximum link utilization, u_{max}, is greater than ζ, α rapidly approaches 0 due to the poor state of the IP network. When the maximum link utilization is less than ζ, α increases rapidly due to the good state of the IP network.

2.2.2 Attractor Structure

The regulatory matrix $\boldsymbol{W}$ contains elements W_{ij} in Eq. (2) and is an important parameter since it determines the locations of attractors in phase space. Since our method selects one attractor and constructs the VNT corresponding to the selected attractor, the definition of $\boldsymbol{W}$ is a challenge. To define arbitrary attractors in phase space, we use knowledge of the Hopfield neural network [7], and $\boldsymbol{W}$ is defined as

$$\boldsymbol{W} = \boldsymbol{X}^{+}\boldsymbol{X}, \tag{4}$$

where $\boldsymbol{X}$ represents a matrix in which the s th row is the s th attractor. $\boldsymbol{X}^{+}$ represents the pseudo inverse matrix of $\boldsymbol{X}$.

If Eq. (4) is used to define the attractor structure, $\boldsymbol{x}$ tries to converge to any of the stored attractors. However, it does not always converge to an attractor due to the stochastic term. The system might find a suitable VNT for current environment, but that VNT might not be an attractor. If the VNT is one of the attractors, the system converges to the VNT and achieves good condition. Thus, when the constructed VNT is preferable for current environment, we reconfigure the attractor structure so that the constructed VNT can be one of the attractors. Since there is the memory capacity limitations of attractors pointed out in [7], we simply use a first-in

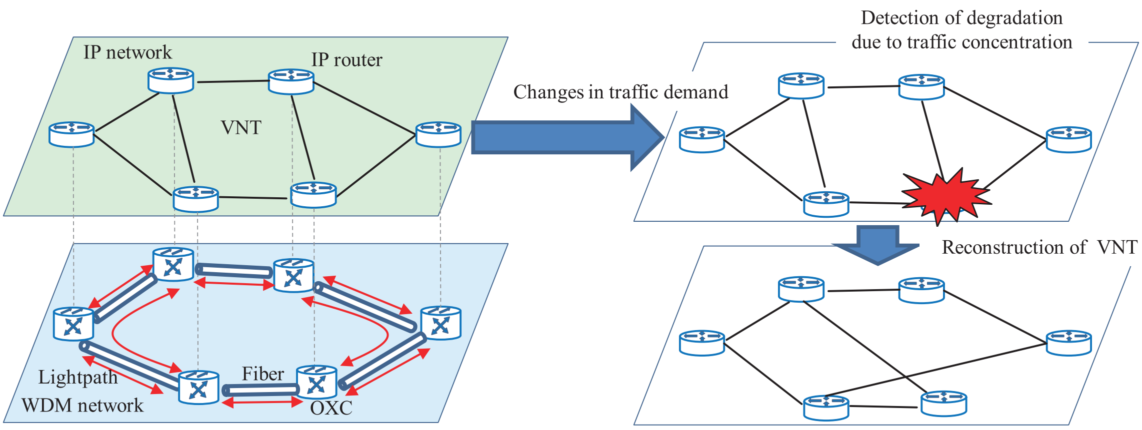

Figure 1 Reconstruction of a VNT in IP over WDM Network

first-out (FIFO) policy for managing attractors. That is, when we add a new VNT to attractors, we remove the oldest attractor from the set of attractors.

3. Experimental Verification

We verified feasibility of the proposed method with experiment. First, we explain a network used for the experiments and experimental scenarios. After that, we show our experimental results.

3.1 Experimental Setup

Our experimental environment consists of physical topology and a control server. We explain the physical topology and the control server in following sections.

3.1.1 Physical Topology of Experiments

Figure 2 shows equipment used for our experiments. There are seven IP routers and one OXC and they are connected via fibers. We use Juniper MX5 and MX10 for the routers and Glimmerglass System 100 for the OXC. Figure 3 illustrates the physical topology of our experiments. The OXC is logically divided into 10 OXCs. Single line between routers and OXCs in Figure 3 represents a fiber supporting full duplex transmission. In our experiment, each router establishes lightpaths with other routers by using multiple fibers where a fiber accommodates only one lightpath instead of multiplexing multiple lightpaths. We give a static route of each lightpath established between routers. The line speed of router interfaces is 1 Gbps, so the bandwidth of a lightpath is 1 Gbps. We use OSPF (Open Shortest Path First) protocol for routing protocol.

3.1.2 Control Server

Figure 4 shows the overview of VNT control with the control server based on attractor selection. The control server repeatedly performs the following three steps,

(1) Retrieves link utilization information from IP routers by using SNMP (Simple Network Management Protocol),

(2) Converts the maximum link utilization to the activity. Our VNT control method then calculates a VNT.

(3) Sends a request to establish or tear down lightpaths that correspond to the calculated VNT.

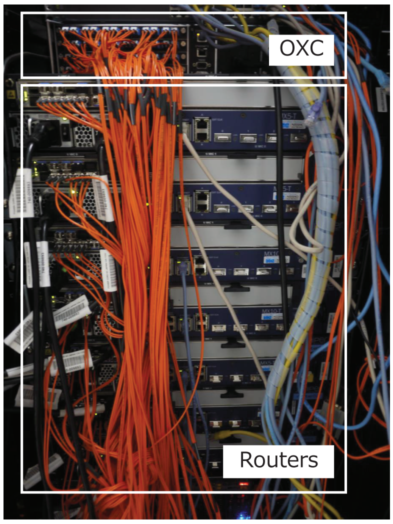

Figure 2 Experimental environment

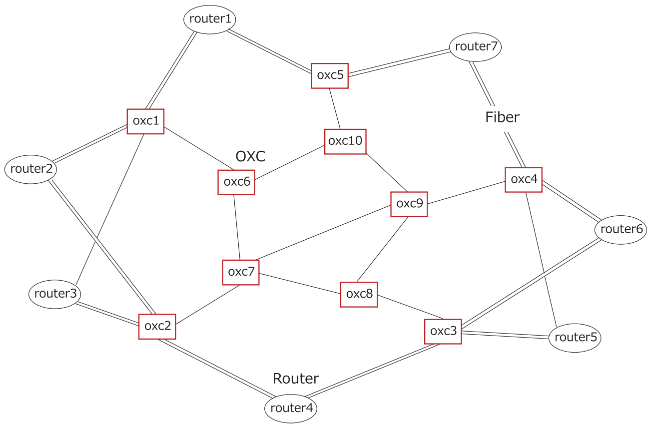

Figure 3 Physical topology of experiments

We calculate link utilization by dividing amount of traffic during a certain period of time by the time. In following experiments, we set 15 seconds for the time. When VNT is actually reconfigured, routing table of IP network is re-constructed by OSPF protocol. In our experimental environment, it requires around 11 seconds for the reconstruction. Since the traffic is not transferred during the reconstruction, we ignore the reconstruction time for calculating the link

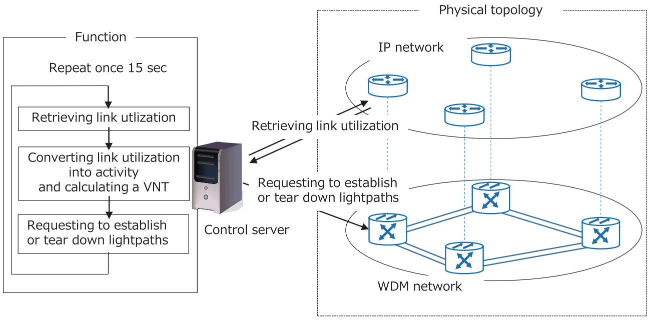

Figure 4 Overview of VNT control based on attractor selection

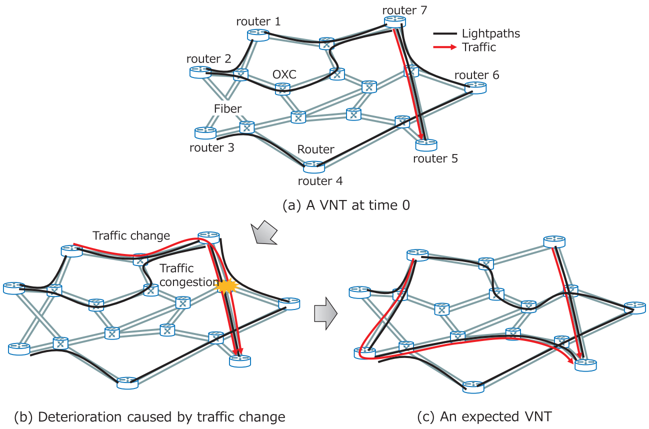

Figure 5 Scenario A: Traffic change

utilization. The request of establishing a lightpath will be rejected when the resources of the physical network are insufficient.

3.2 Experimental Scenario

We verify the feasibility of the proposed method with the scenario that the propose method recovers the condition after getting the feedback of poor condition, which is caused by environmental changes such as traffic changes or node failures (OXC failures). We explain three scenarios with different environmental changes, 1) traffic change, 2) single node failure, 3) multiple node failures.

3.2.1 Scenario A: Traffic Change

A first scenario involves traffic increase as the environmental changes (Figure 5). Detailed description of Scenario A is,

(1) at time 5, a 400 Mbps UDP flow starts to be transferred from router 7 to router 5,
(2) at time 10, a 400 Mbps UDP flow starts to be transferred from router 1 to router 5,
(3) after (1) and (2), link utilization of the lightpath between router 7 and router 5 becomes 0.8,
(4) the maximum link utilization is fed back as activity to the proposed method,
(5) then, the proposed method searches for a VNT which accommodates changed traffic.

We expect that the proposed method converges to the VNT that accommodates two UDP flows. An expected VNT is depicted in Figure 5(c).

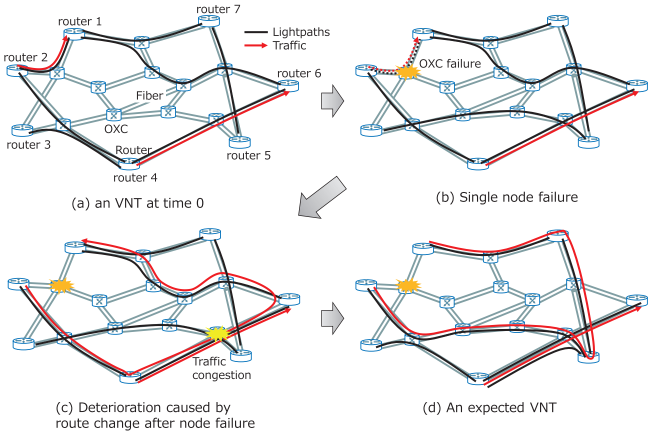

Figure 6 Scenario B: Single OXC failure

3.2.2 Scenario B: Single OXC Failure

A second scenario involves single OXC failure as the environmental changes (Figure 6). We make OXCs be failed by shutting down ports of OXCs through operation console. Detailed description of Scenario B is,

(1) at time 5, two 400 Mbps UDP flows start to be transferred. The first flow is transferred from router 2 to router 1 and the second flow is transferred from router 4 to router 6,
(2) at time 10, OXC 1 breaks down,
(3) the route of the flow from router 2 to router 1 is changed by OSPF protocol,
(4) after that, link utilization of the lightpath between router 4 and router 6 becomes 0.8,
(5) the maximum link utilization is fed back as activity to the proposed method,
(6) then, the proposed method searches for a VNT which accommodates changed traffic.

We expect that the proposed method converges to the VNT which that accommodates two UDP flows. An expected VNT is depicted in Figure 6(d).

3.2.3 Scenario C: Multiple OXC Failures

A third scenario involves multiple OXC failures as the environmental changes (Figure 7). Detailed description of Scenario C is,

(1) at time 5, two 400 Mbps UDP flows start to be transferred. The first flow is transferred from router 6 to router 2 and the second flow is transferred from router 7 to router 2,
(2) at time 10, OXC 6 and OXC 7 break down,
(3) the route of the two flows from router 6 to router 2 and from router 7 to router 2 is changed by OSPF protocol,
(4) after that, link utilization of the lightpath between router 1 and router 2, and router 7 and router 1 becomes 0.8,
(5) the maximum link utilization is fed back as activity to the proposed method,
(6) then, the proposed method searches for a VNT which accommodates changed traffic,

We expect that the proposed method converges to the VNT that ac-

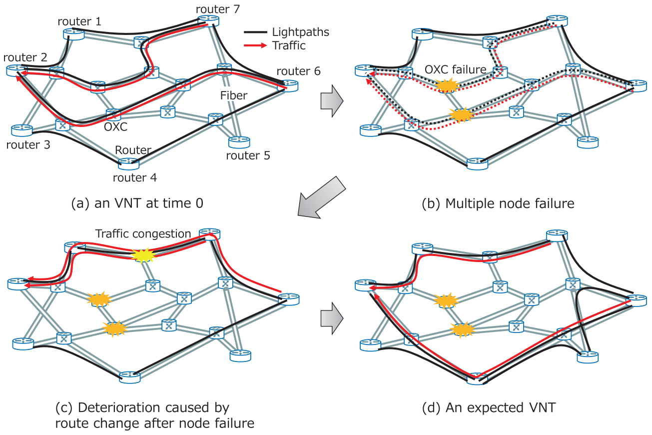

Figure 7 Scenario C: Multiple OXC failures

commodates two UDP flows. An expected VNT is depicted in Figure 7(d).

3.3 Experimental Results

Figure 8 shows the result of Scenario A. In the figure, horizontal axis represents the elapsed time after starting the experiment. The figure has two vertical axes: "Maximum Link Utilization" and "Discarded Packets [Mbps]". "Maximum Link Utilization" represents the maximum link utilization and "Discarded Packets [Mbps]" represents the rate of discarded packets in routers. We plot the rate of discarded packets since packets will be discarded if a router do not know the forwarding address of the packets on constructed VNT. Note here that although information of discarded packets is easily and quickly retrieved by SNMP in general, in our experiments, we calculate amount of discarded packets by subtracting the amount of packets arriving at a router from the amount of packets departing packets from the router during the measurement interval, which were retrieved by SNMP, since the routers, Juniper MX5 and MX10, do not support SNMP statistic of discarded packets and it takes more time to retrieve the statistic from the router's original management information. As shown in Figure 8, maximum link utilization increases to around 0.4 at time 5, when the proposed method do not search VNTs since less than 0.5 of maximum link utilization is interpreted as good condition of IP network. When traffic change occurs at time 10, the maximum link utilization becomes about 0.8 and the proposed method receives feedback of poor condition of IP network. Then, our method starts to search a suitable VNT for current environment. At time 12, maximum link utilization becomes low and the condition gets recovered. The proposed method converges to the VNT after time 12 as we see that the maximum link utilization is stable after time 12.

When we conducted experiments with Scenario B, we found that a router sometimes lost connectivity with other routers. A router may lose connectivity with other routers when failures occur since we assume that failures are not to be detected. Note here that if we assume that failures can be detected, the topology after the failures can be fed into our method. With this case, the packets arriving at

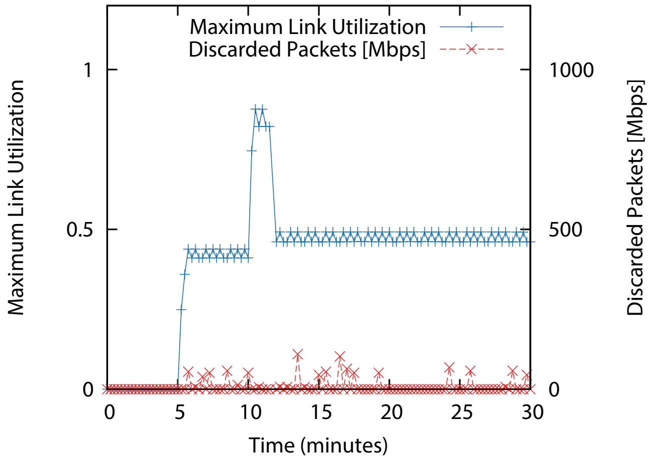

Figure 8 Maximum Link Utilization

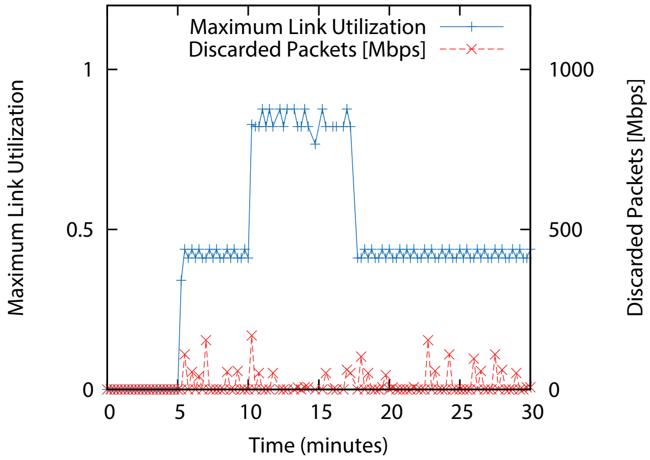

Figure 9 Maximum Link Utilization

the router were discarded, and thereby the maximum link utilization becomes low. Our method may converge to the VNT even though the packets are discarded. To prevent this problem, we additionally use information of the rate of discarded packets to calculate the activity. That is, when the rate of discarded packets exceeds a threshold (100 Mbps) we regard that connectivity between routers is lost in the VNT and set the value of activity to zero.

Figure 9 shows the result of experiment with Scenario B. As shown in Figure 9, maximum link utilization increases to around 0.4 at time 5. When single node failure occurs at time 10, the maximum link utilization becomes about 0.8 and the proposed method receives feedback of poor condition of IP network. Then, our method starts to search a suitable VNT for current environment. At time 18, maximum link utilization becomes low and the condition gets recovered. The proposed method converges to the VNT after time 12 as we see that the maximum link utilization is stable after time 18.

Figure 10 shows another result of the experiment with Scenario B. In this experiment, we give a different VNT at time 0. As shown in Figure 10, traffic change occurs at time 5 and maximum link utilization increases to about 0.4. When node failure occurs at time 10, maximum link utilization becomes about 0.8 and the proposed

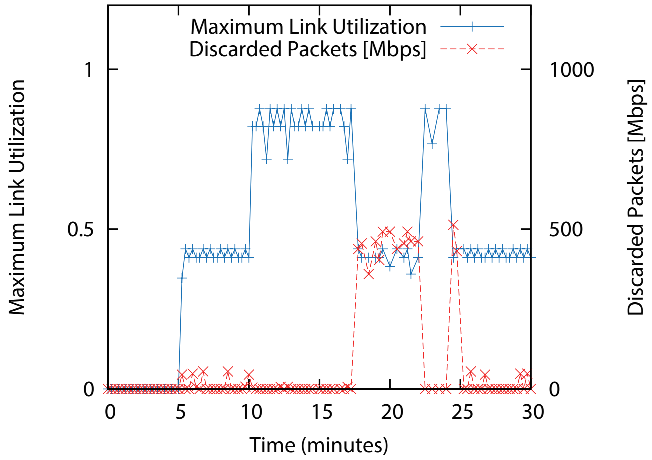

Figure 10 Maximum Link Utilization

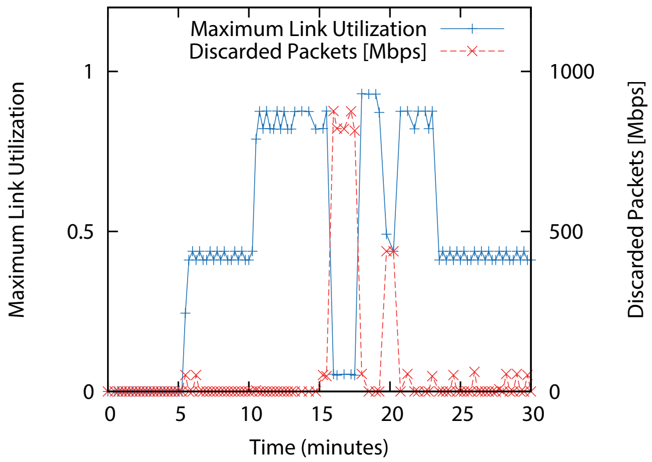

Figure 11 Maximum Link Utilization

method starts to search a suitable VNT for current environment. At time around 17, the maximum link utilization gets low while the rate of discarded packets increased. The increase of the rate of discarded packets is fed back, activity is set to zero and the proposed method search a suitable VNT for current environment. Though the maximum link utilization increases again at time around 22 as the result of searching, the rate of discarded packets decreases and the maximum link utilization becomes around 0.4 at time around 24.

Figure 11 shows the result of experiment with Scenario C. The result is similar to Figure 10. After deterioration of network condition at time 10, the proposed method searches a suitable VNT for current environment and finally finds the VNT at time around 23 and converges to the VNT.

4. Conclusion

We verified the feasibility of the VNT control method based on attractor selection through experiment. When we conducted experiments with OXC failures, we found that a router sometimes lost connectivity with other routers. With this case, the packets arriving at the router were discarded, and thereby the maximum link utilization became low, i.e., activity became high. To prevent this, when the rate of discarded packets exceeds a threshold, we regard that connectivity between routers is lost in the VNT and set the value of activity to zero. The results of the experiments show that the proposed method recovers the network condition after deterioration caused by environmental changes such as traffic changes or node failures.

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