Adaptability of attractor selection in virtual network topology control method

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Abstract: *Telecommunication network topologies are dynamically changing nowadays. The core telecommunication networks are based on fiber optics infrastructure. WDM technology is used to transmit multiple flows of traffic over a single fiber. Virtual network topology (VNT) is used to route IP traffic over WDM networks. VNT control system must be adaptive to traffic changes and dynamically reconfigure VNT. This can be achieved by using attractor selection, which models biological system behavior. Biological systems are extremely adaptive to unknown changes in environmental conditions. This adaptability could be used as a model for VNT control system. Such VNT control method is based on a system of stochastic differential equations, which use load on links, retrieved by SNMP, and stochastic fluctuations – Gaussian noise – as input parameters to dynamically reconfigure VNT and optimize its performance. Network simulations show that this VNT control method is very quick and adaptable to traffic changes.*

Keywords: Virtual Network Topology, VNT, Adaptability, Attractor, Stochastic Differential Equation, SDE.

Introduction

Core telecommunication networks nowadays are based on Wavelength Division Multiplexing (WDM) technology. In such division multiplexing technology transmitting/receiving channels are divided by wave length. It allows transmitting multiple traffic channels over a single fiber. Traffic by fiber optics can be transmitted over long distances without any additional equipment. Because of that WDM networks are commonly used to carry Internet traffic at backbone level. The major protocol of Internet is IP protocol. One of possibilities to carry IP traffic over WDM network is to construct virtual network topology, which includes transmitting/receiving channels (lightpaths) and IP routers. There are many VNT control methods, which configure/reconfigure VNT according to traffic demand matrices. Traffic demand matrices show how traffic flows are distributed via lightpaths.

One of the most exciting Internet opportunities for end-users is to share their pictures, videos and so on with other users; to communicate with each other using online services such as Skype. These cause constant and rapid changes in traffic flows between IP routers in VNT. There is a need to reconfigure VNT over a period of time in order to provide high-level service with minimal delays. VNT needs to be adaptable to changes in traffic demand.

There are two modes of constructing traffic demand matrices – offline and online or dynamical mode. In offline approach traffic demand matrices are constructed using previous known information about changes in traffic demand (Agrawal et al., 2006; Chen et al., 2008; Ricciato et al., 2002). The major weakness of this approach – offline methods will not work correctly if traffic flow changes will be different from ones expected. Online approach allows reconfiguring VNT dynamically. In this case periodical measurement results are used. To evaluate VNT status, information about average or maximum link utilization, packet delays can be used. Based on this information new lightpaths are added to source-destination pair of nodes if, for example, link utilization between these nodes is more than threshold and deleted if lightpath is underutilized.

The majority of online VNT control methods are used when traffic demand is changing periodically and gradually (Lakhina et al., 2004). This approach will not work if changes of traffic demand are not predictable. There is a need to develop such VNT control method, which is adaptable to unknown changes in network environment.

One of the approaches is to use attractor selection, which represents mechanism of adaptation to unknown changes of biological systems (Koizumi et al., 2008). The main idea of attractor selection – the system is driven by two components – deterministic and stochastic. Attractors are a part of the equilibrium points in the solution space. Conditions of such system are controlled by very simple feedback. When conditions of a system are suitable (close to one of the attractors), it is driven almost only by deterministic behavior, stochastic influence is very limited. When conditions of the systems are poor, deterministic behavior influence is close to zero and in this case system is driven by stochastic behavior. It randomly fluctuates searching for a new attractor. When this attractor is found, deterministic behavior again dominates over stochastic.

In this paper a research of attractor selection method is presented, which is adopted from (Furusawa et al., 2008) and described in (Koizumi et al., 2008). The object of the paper - how adaptability of VNT, controlled by attractor selection, depends on variety of parameters. The paper is organized as follows. In the next section attractor selection mechanism is briefly described and the rest of the paper is devoted to network simulations and result analysis.

Attractor selection mechanism

Every pair of nodes, between which connection can be established, is represented by control unit u_{ij}, where i and j are indexes of nodes. Every control unit has its control value $x_{u_{ij}}$. Indexes s and d refers to source and destination nodes.

How control values change over time can be expressed by differential equation, also known as Langevin equation (Koizumi et al., 2008):

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

where v_g – indicates conditions of VNT ,
$W(u_{ij}, u_{sd})$ – regulatory matrix of VNT,
$\theta_{u_{ij}}$ – coefficient, which depends on minimum and maximum loads on links in VNT,
η – Gaussian noise.

As it was used in (Koizumi et al., 2008), Gaussian noise with mean value 0 and variance 0.1 is used. The first term in Equation (1) represents regulation function f(z):

$$f(z) = \frac{1}{1+e^{-z}}\ ; z = \sum_{u_{sd}} W(u_{ij}, u_{sd}) \cdot x_{u_{sd}} - \theta_{u_{ij}} \tag{2}$$

Dynamically adjusting $\theta_{u_{ij}}$, the number of lightpaths, assigned to node pair can be controlled. $\theta_{u_{ij}}$ is defined as follows (Koizumi et al., 2008):

$$\theta_{u_{ij}} = -\frac{y_{u_{ij}} - y_{min}}{y_{max} - y_{min}} \cdot 2\theta_c - \theta_c \tag{3}$$

where $y_{u_{ij}}$ – load on link between nodes i and j,
y_{max} - maximum load on link in the network,
y_{min} - minimum load on link in the network,
θ_c – coefficient, which scales y_{max} and y_{min}.

The amount of lightpaths, assigned to node pair u_{ij} is a function of unit control value $x_{u_{ij}}$. More lightpaths are assigned to node pair, which has higher control value.

Regulatory matrix $W(u_{ij}, u_{sd})$ is the most important parameter of Equation (1), since it shows the relationships between node pairs. Every element of this matrix can be -1, 0, or 1; it represents the influence of node pair u_{ij} on node pair u_{sd}. According to model, proposed in (Furusawa et al., 2008), -1 corresponds to inhibition of the node u_{ij} by u_{sd}, 0 corresponds to no relation and 1 to activation. These values are multiplied by corresponding control values u_{ij}. In such way node pairs affect each other – if u_{sd} is activated by u_{ij}, increasing in $x_{u_{ij}}$ will increase $x_{u_{sd}}$ and, as it was mentioned above, increase the amount of lightpaths between nodes *s* and *d*. In (Furusawa et al., 2008) has been shown that if node pairs can activate or inhibit each other with probability 0.03 and no relation with probability 0.94, such network will be extremely adaptable to changes in traffic demand. For example, if your network consists of 6 node pairs, one of possible regulatory matrix realizations can be found in Table 1. As it can be seen, node pair u_{12} is inhibited by node pairs u_{23} and u_{24}; u_{14} is activated by node pair u_{23}.

Table 1

Example of the regulatory matrix

Node pair	u_{12}	u_{13}	u_{14}	u_{23}	u_{24}	u_{34}
u_{12}	0	0	0	0	0	0
u_{13}	0	0	0	0	0	0
u_{14}	0	0	0	0	0	0
u_{23}	-1	0	1	0	0	0
u_{24}	-1	0	0	0	0	0
u_{34}	0	0	0	0	0	0

So for every node pair we construct regulation function, which is defined by Equation (2). Adjusting $\theta_{u_{ij}}$, we can move regulation function in the negative or positive direction, as it is shown in Fig. 1.

As it was mentioned above, v_g indicates conditions of VNT. As an input parameter for v_g maximum link utilization in the network is used. Maximum link utilization is selected as an input parameter because it can be easily retrieved using Simple Network Management Protocol (SNMP). But other parameters, such as average delay between node pair u_{ij} can also be used to indicate the conditions of VNT. It will be referred to v_g as *activity* or *goodness* of VNT after this. Activity of VNT is defined as follows (Koizumi et al., 2008):

$$v_g = \begin{cases} \frac{100}{1+e^{(\delta\cdot(u_{max}-\zeta))}}, & u_{max} \geq \zeta \\ \frac{100}{1+e^{(\frac{\delta}{5}\cdot(u_{max}-\zeta))}}, & u_{max} < \zeta \end{cases} \tag{4}$$

where δ - gradient of link utilization,
ζ – target link utilization.

From Equation (4) it can be seen that ζ is a threshold for VNT activity v_g. If maximum link utilization is more than ζ, activity of VNT dramatically degraded and stochastic behavior dominates over deterministic and the system is searching for a new attractor. Activity function can be seen in Fig. 2.

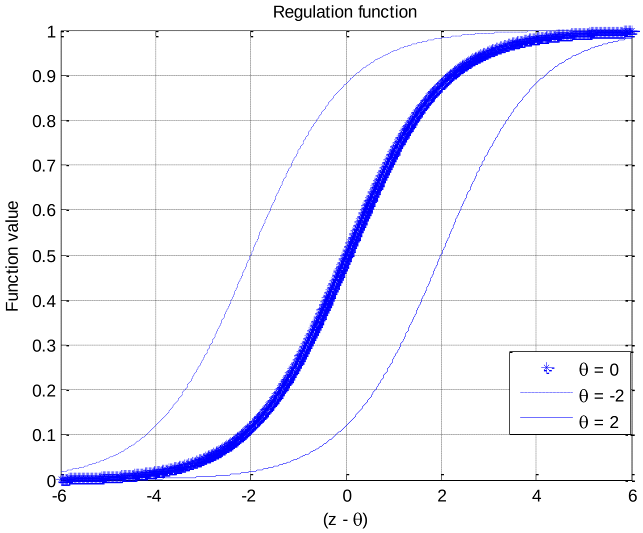

Fig. 1. **The regulation function's example.**

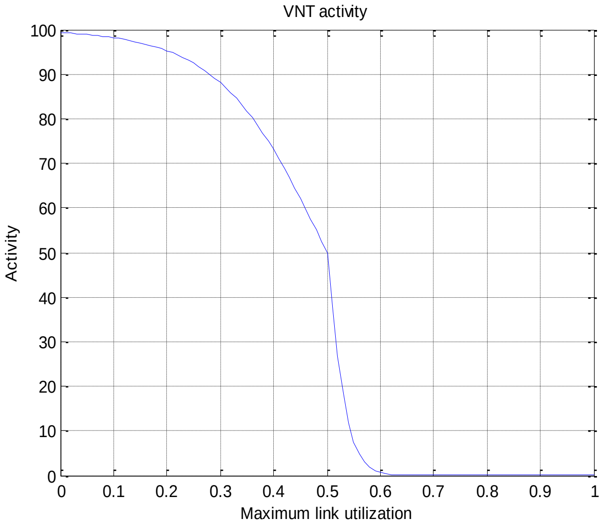

Fig. 2. **VNT activity function.**

As it was mentioned above, the number of lightpaths between node pairs depends on control unit value $x_{u_{ij}}$. More lightpaths are assigned to node pairs with a higher control unit value. It is supposed that every node has K_r receivers and K_t transmitters.

The amount of assigned transmitters and receivers is a function of $x_{u_{ij}}$ normalized by all control unit values of all node pairs, which use transmitters and receivers from node *i* to node *j*. The number of lightpaths between nodes *i* and *j* is defined as follows (Koizumi et al., 2008):

$$N_{u_{ij}} = \min\left(K_r \cdot \frac{x_{u_{ij}}}{\sum_s x_{u_{sj}}}\right), min\left(K_t \cdot \frac{x_{u_{ij}}}{\sum_d x_{u_{id}}}\right) \tag{5}$$

Network simulations

The network with 6 nodes and 15 bidirectional links will be simulated. Each node has 6 transmitters and 6 receivers. Traffic demand matrices are randomly generated in certain time moments *T*=10, 20, 40, 60, 90. The total time of simulation is 110. In these simulations two parameters – ζ and δ will be changed and it will be analyzed how it affect VNT activity and maximum link utilization.

In the first set of simulations δ is set to 50 and ζ to 0.5. The results of simulation – maximum link utilization and VNT activity – can be seen in Fig. 3 and Fig.4 respectively.

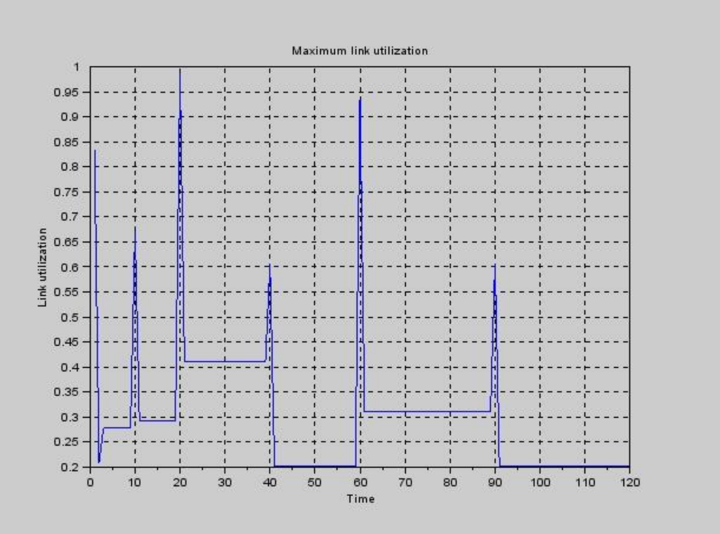

Fig. 3. **Maximum link utilization.**

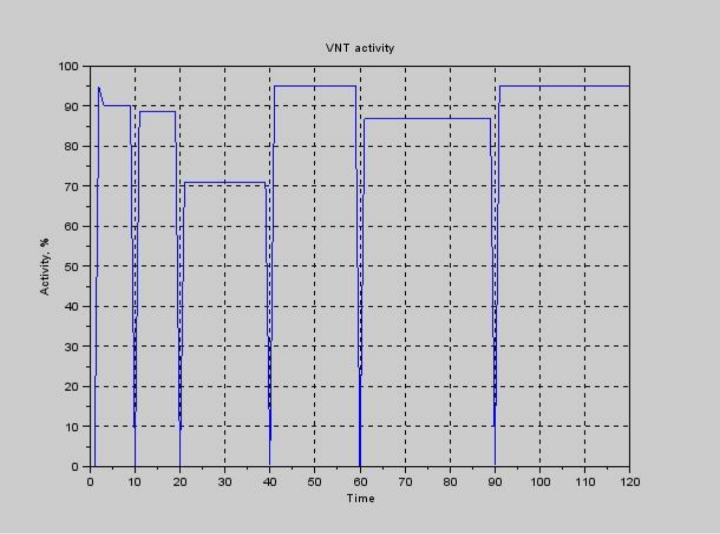

Fig. 4. **VNT activity.**

In time slots *T*=10, 20, 40, 60 and 90 VNT activity degrades due to changes in environment (maximum link utilization increases), in result stochastic behavior dominates system and the system state is driven by η. System randomly fluctuates searching for a new attractor. As soon as the system is close to an attractor VNT activity increases and deterministic behavior again dominates over stochastic one.

As it is seen, results are good, but in time period 20-40 VNT activity is only about 70%. Let us try to improve network activity by adjusting δ. By default δ value is 50. Let us see what happens if δ will be set to 30 and 80. The results can be seen in Fig. 5 and Fig.6. By increasing δ, we achieve quicker and more precise responses to changes in maximum link utilization.

In Fig. 5 and Fig.6 we can see a very interesting effect. In time period 0 – 10 and δ=30, the system conditions are good, but the maximum link utilization increases unexpectedly (Fig. 5), although there are no changes in traffic demand at this time moment. It happens because stochastic behavior always influences system conditions, even if VNT conditions are good. It causes VNT activity degradation. At this moment noise drives the system and a new attractor is being searched. After some time a new attractor has been found and system activity recovers. Because of noise random nature it cannot be predicted when it will happen.

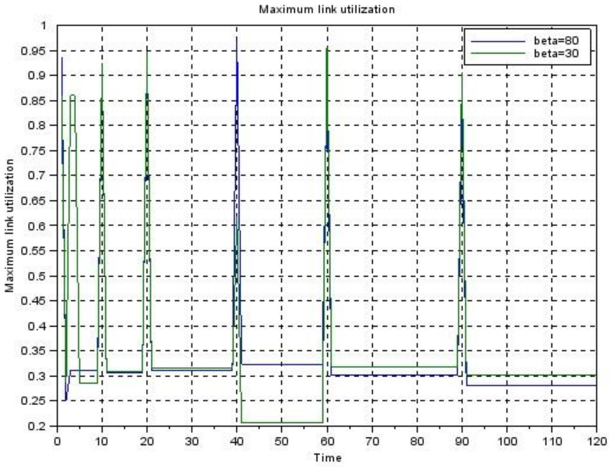

Fig. 5. **Maximum link utilization with respect to δ.**

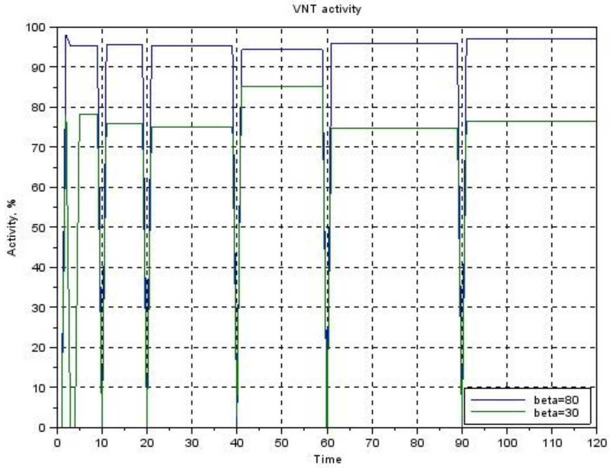

Fig. 6. **VNT activity with respect to δ.**

Now the target maximum link utilization ζ, which by default is 0.5, is changed. It is changed to 0.3 and 0.8. Results are presented in Fig. 7 and Fig. 8.

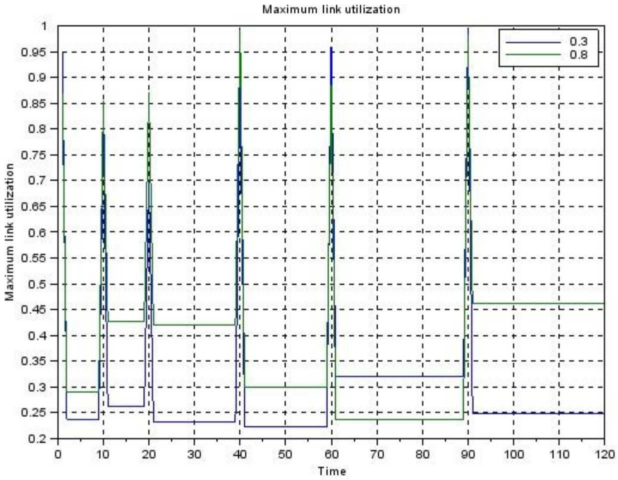

Fig. 7. **Maximum link utilization with respect to ζ.**

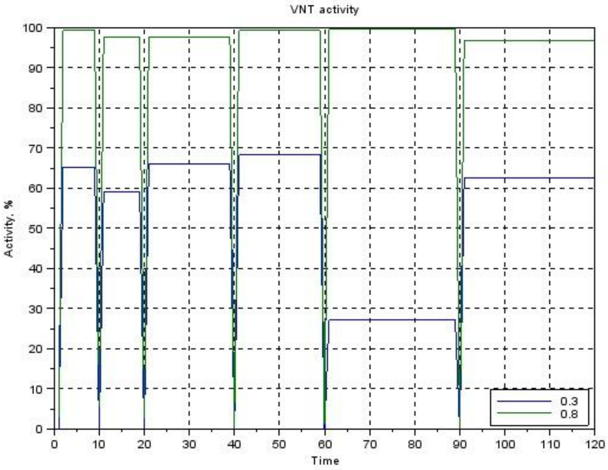

Fig. 8. **VNT activity with respect to ζ.**

In time slots T= 10, 20, 40, 60 and 90 due to changes in traffic demand and as a result changes in maximum link utilization VNT activity degrades. In these moments stochastic behavior dominates over deterministic as the first two terms in Equation (1) are zero or close to zero. Control unit values randomly fluctuate searching for a new attractor. As soon as a new attractor is found, VNT activity recovers and deterministic behavior again drives VNT.

As it can be seen from Fig. 7 and Fig. 8, if ζ is improperly selected, VNT goodness is poor even if maximum link utilization is not so high – please compare, in time interval $T\epsilon$ [90-120] maximum link utilization and VNT activity for threshold ζ. For ζ = 0.3 maximum link utilization is only about 0.25, but VNT goodness is 63%, but for ζ = 0.8 maximum link utilization is 0.47, but VNT goodness is close to 100%. It is obvious that in this case ζ is not appropriately chosen and this affects VNT activity and in the end VNT performance.

Conclusion

- Gaussian noise cause system randomly fluctuates searching for a new attractor. At this moment stochastic behavior dominates deterministic.
- Adjusting activity gradient δ can achieve quick responses to changes in VNT conditions.
- If activity threshold ζ is improperly selected, this can cause improper VNT conditions evaluation.
- As it has been shown in some cases Gaussian noise can cause system unexpectedly change its state. But on the other hand thanks to the same Gaussian noise the system quickly re-establishes its conditions.

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