Multipath Routing as a Tool for Energy Saving in Transport Software Defined Network

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***Abstract*—The most important features of software defined networks are related to resource virtualization and centralized optimal control that is fully programmatically realized. In turn it gives rise to development of mathematical model which allows to find the optimal solution. On the other hand important role in optimization process belongs to criterion of optimality (objective function). Taking into account global world trends the paper offers mathematical model of SDN-driven transport packet optical network that allows to optimize network resources according to energy saving criterion. It will be shown that multipath routing over virtualized IP-links leads to saving 10% of power consumption per every additionally used path.**

Keywords*— *transport software defined network; multipath routing; mathematical model; energy saving

I. Introduction

Concept of Software Defined Network (SDN) is based on principle of decoupling the control pale from data forwarding plane. In turn it enables direct, explicit programmability of flows on packets according to control decisions which are results of global network optimization [1, 2]. It assumes centralized control engine which should be responsible for monitoring of global state of network and performing of its optimization. The engine should be based on some optimal control algorithm, developing of which is related to using of some mathematical models of the network. In order to achieve global optimal state the models cannot be heuristic; in order to program flows on packets the model should be flow-based; in order to realize adaptive network control the model should be dynamic. As analysis shows only one class of models can meet the requirements fully. It's models in space of states which underlie classic theory of optimal control.

Another very important feature of SDN is related to using of abstracted representation of lower layers of the network for higher level systems and applications. Such virtualization by hiding some detailed information allows to simplify and automate interoperations across multiple network layers. In transport SDN all main principles of SDN remain valid and were employed to transport optical network [2]. As a rule modern transport optical network is integrated packet-optical platform which combines packet services (IP, MPLS, Ethernet), Optical Transport Network *(*OTN) switching, Wavelength Division Multiplexing (WDM) optical transmission and switching by reconfigurable optical add-drop multiplexers (ROADMs). In order to realize virtualized control aimed at global optimization appropriate mathematical model of transport SDN is required. Note that obligatory component of any optimization is objective function. Taking into account global world trends one from most important criteria is related to minimization of power consumption. The paper offers mathematical model of transport packet optical network adapted to SDN concept that allows to optimize transport network resources according to energy saving criterion. It will be shown that multipath routing over virtualized IP-links leads to saving 10% of power consumption per every additionally used path.

II. Mathematical Model of Transport SDN

Transport packet optical network combines different technologies which can be divided into two levels, IP-level and optical level. The upper IP-level is associated with flows on IP-packets that must be delivered to router-destination. Mathematically dynamics of flows on IP-packets can be described by system of following equalities and inequalities [3]:

$$x_{i,j}(k+1) = x_{i,j}(k) - \sum_{\substack{l=1 \\ l\neq i}}^{N^r} b_{i,l}(k)\cdot\Delta t\cdot u_{i,l}^{j}(k) + \sum_{\substack{m=1 \\ m\neq i,j}}^{N^r} b_{m,i}(k)\cdot\Delta t\cdot u_{m,i}^{j}(k) + y_{i,j}(k), \quad (1)$$

$$0 \le x_{i,j}(k), \qquad \sum_{\substack{j=1, \\ j\neq i}}^{N^r} x_{i,j}(k) \le x_i^{\max}, \quad (2)$$

$$0 \le u_{i,l}^{j}(k) \le 1, \qquad \sum_{n=1}^{N^r} u_{i,l}^{n}(k) \le 1, \quad (3)$$

where $i,j = \overline{1,N^r}$, $i \neq j$; $\Delta t = t(k+1) - t(k)$; $b_{i,j}(k)$ is available at IP-level capacity of link (i,j) between routers R_i and R_j; $x_{i,j}(k)$ is state variable which shows the amount of data that are kept at the router R_i and are destined to router R_j in time moment t_k; $x_i^{\max}$ is maximal size of queue in router R_i; $u_{i,l}^{j}(k)$ is routing variable which defines share of (i,l) link' bandwidth allocated in time moment t_k to transmit the IP-flow with the destination address R_j; $y_{i,j}(k) = \zeta_{i,j}(k)\Delta t$ is load that arrives to router R_i at moment t_k and is addressed to R_j; $\zeta_{i,j}(k)$ is intensity of incoming load; N^r is number of routers in network.

System of differential equalities (1) corresponds to dynamic notation of conservation law for routers at IP-level. Inequalities (2) and (3) are related to physical meaning of defined state and control variables.

The principal distinction of model (1) in comparison with its known implementation is related to role of variables $b_{i,j}(k)$ which carry information about current network structure. In the context of transport packet optical network variables $b_{i,j}(k)$ are unknown variables. This is due to the fact that the links between IP-routers are lightpaths established between certain pairs of ROADMS at optical level. Since the transport SDN assumes optimal dynamic allocation of resources, the establishment of some lighpath must correspond to the serviced flow on packets. It means that the structure and bandwidths of lightpaths (formalized in (1) by variables $b_{i,j}(k)$) should be calculated. In other words, variables $b_{i,j}(k)$ define the virtual topology at IP-level, but physically the topology is provided by switching of appropriate lightwaves at WDM-level.

So variable $b_{i,j}(k)$ in (1) is lightpath variable which is resulting solution of problem of routing and wavelength assignment at optical layer. Physically, the establishing of the lightpath is related to choosing of sequence of optical multiplexers and fibers and assignment of wavelengths on every of them. Due to the process variables $w_{i,j}^{l,m,n}(k)$ are used. The variable $w_{i,j}^{l,m,n}(k)$ has unit value if l-th wavelength in fiber (m,n) is used for establishing of lightpath $b_{i,j}(k)$. Otherwise $w_{i,j}^{l,m,n}(k)$ =0.

In compliance with conservation law at optical layer and with physical meaning the wavelength variables should satisfy to following constraints:

$$\sum_{\substack{n=1,\\ n\neq m}}^{N}\sum_{l=1}^{N_{m,n}^{w}} cw_{i,j}^{l,m,n}(k)-\sum_{\substack{r=1,\\ r\neq m}}^{N}\sum_{l=1}^{N_{r,m}^{w}} cw_{i,j}^{l,r,m}(k)= \tag{4}$$

$$=\begin{cases} f_{i,j}(k), & if\ \ m=i;\\ 0, & if\ \ m\neq i,j;\\ -f_{i,j}(k), & if\ \ m=j,\end{cases}$$

$$f_{i,j}(k)\geq b_{i,j}^{req}(k)\,, \tag{5}$$

$$\sum_{i=1}^{N^r}\sum_{\substack{j=1,\\ j\neq i}}^{N^r}\sum_{l=1}^{N_{m,n}^{w}} w_{i,j}^{l,m,n}(k)\leq N_{m,n}^{w}\,,\quad \sum_{i=1}^{N^r}\sum_{\substack{j=1,\\ j\neq i}}^{N^r} w_{i,j,h}^{l,m,n}(k)\leq 1\,, \tag{6}$$

where c is capacity of single wavelength in optical network; $N_{m,n}^{w}$ is total number of wavelength in fiber (m,n); N is number of ROADMs in optical infrastructure; $b_{i,j}^{req}(k)$ is required capacity of lightpath (i,j).

Furthermore, in order to avoid differences in the delays at the optical level caused by plurality of lightpaths let us require using the wavelengths belonging to the same optical fiber, i.e. if the optical fiber is engaged in the establishing of the lightpath

$$\sum_{l=1}^{N_{m,n}^{w}} w_{i,j}^{l,m,n}(k)=\sum_{\substack{q=1,\\ q\neq m}}^{N}\sum_{l=1}^{N_{m,q}^{w}} w_{i,j}^{l,m,q}(k)\,, \tag{7}$$

otherwise

$$\sum_{l=1}^{N_{m,n}^{w}} w_{i,j}^{l,m,n}(k)=0\,.$$

Thus the model (1) – (7) covers IP-layer and optical layer, which have common variables $b_{i,j}(k)$. The variables together with $u_{i,l}^{j}(k)$ and $w_{i,j}^{l,m,n}(k)$ can be calculated jointly within optimization problem

$$P_{\Sigma}(k)=P_{tr}(k)+P_{IP}(k)+P_{o}(k)+P_{am}(k)\rightarrow \min\,, \tag{8}$$

subject to (1) – (7),

where $P_{\Sigma}(k)$ is total power consumption for the operation of IP-over-DWDM network at k-th time interval; $P_{tr}(k)$, $P_{IP}(k)$, $P_{o}(k)$, $P_{am}(k)$ are power consumed by the transponders, IP-routers, optical network elements (ROADMs, OXCs) and linear amplifiers, respectively;

If to assume transparent architecture of optical network power consumed by its elements can be calculated as [3, 4]

$$P_{tr}(k)=2E_{tr}\sum_{i=1}^{N^r}\sum_{\substack{j,\\ j\neq i}}^{N^r} V_{i,j}(k)\,, \tag{9}$$

$$P_{IP}(k)=E_{IP}\sum_{j=1}^{N^r}\sum_{\substack{i=1\\ i\neq j}}^{N^r}\left[\sum_{\substack{l=1\\ l\neq i}}^{N^r} b_{i,l}(k)\cdot\Delta t\cdot u_{i,l}^{j}(k)+\sum_{\substack{m=1\\ m\neq i,j}}^{N^r} b_{m,i}(k)\cdot\Delta t\cdot u_{m,i}^{j}(k)+y_{i,j}(k)\right], \tag{10}$$

$$P_{o}(k)=E_{o}\sum_{i=1}^{N^r}\sum_{\substack{j,\\ j\neq i}}^{N^r}\left(V_{ij}+\sum_{m}^{N}\sum_{\substack{n,\\ n\neq m}}^{N}\sum_{l}^{N_{m,q}^{w}} w_{i,j}^{l,m,n}(k)\right), \tag{11}$$

$$P_{am}(k)=E_{am}\sum_{m}^{N}\sum_{\substack{n,\\ n\neq m}}^{N} A_{m,n}N_{m,n}^{F}\,, \tag{12}$$

where $V_{i,j}(k)$ is number of lightpaths established between routers R_i and R_j at time moment t_k; E_{tr},

E_{IP}, E_o, E_{am} are rated (average) power consumption of transponders, routers, OXCs and amplifiers respectively presented in [4, 5]; $N^F_{m,n}$ is number of optical fibers in link (m,n); $A_{m,n}$ is the number of amplifiers in the link (m,n) which has length $L_{m,n}$, $A_{m,n} = \lceil L_{m,n}/L - 1 \rceil + 2$; $\lceil \bullet \rceil$ is rounding up operation; L is nominal length of the amplifying section.

III. Demonstration of Offered Mathematical Model: Multipath Routing as a Tool for Energy Saving

In order to demonstrate operation of offered mathematical model (1) – (12) let us focus on simple segment of optical transport network shown in fig. 1. The segment contains four ROADMs at optical layer and three routers at IP-layer (R1, R2, R3). Assume three flows on packets should be serviced, where $y_{1,2}(k) = y_{2,3}(k) = 20$ Gb/s, but rate of flow from R1 to R3 will be varied. Network parameters are following: $c = 100$ Gb/s, $E_{tr} = 150$ W, $E_{IP} = 5$ W per every 1 Gb/s of flow, $E_o = 7.5$ W per every wavelength.

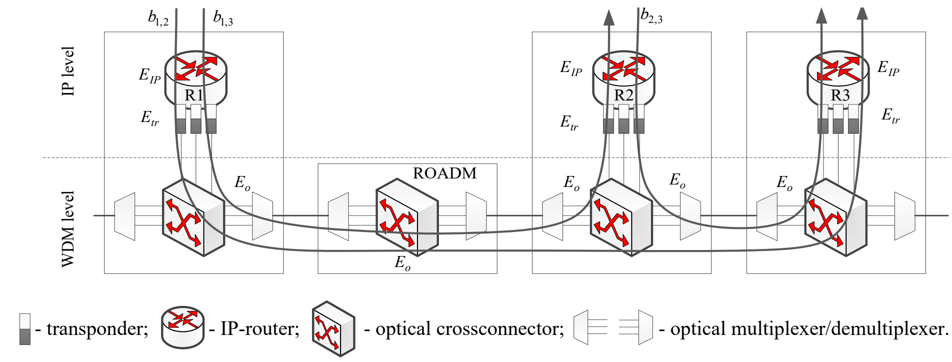

Fig. 1. Simulated segment of optical transport network.

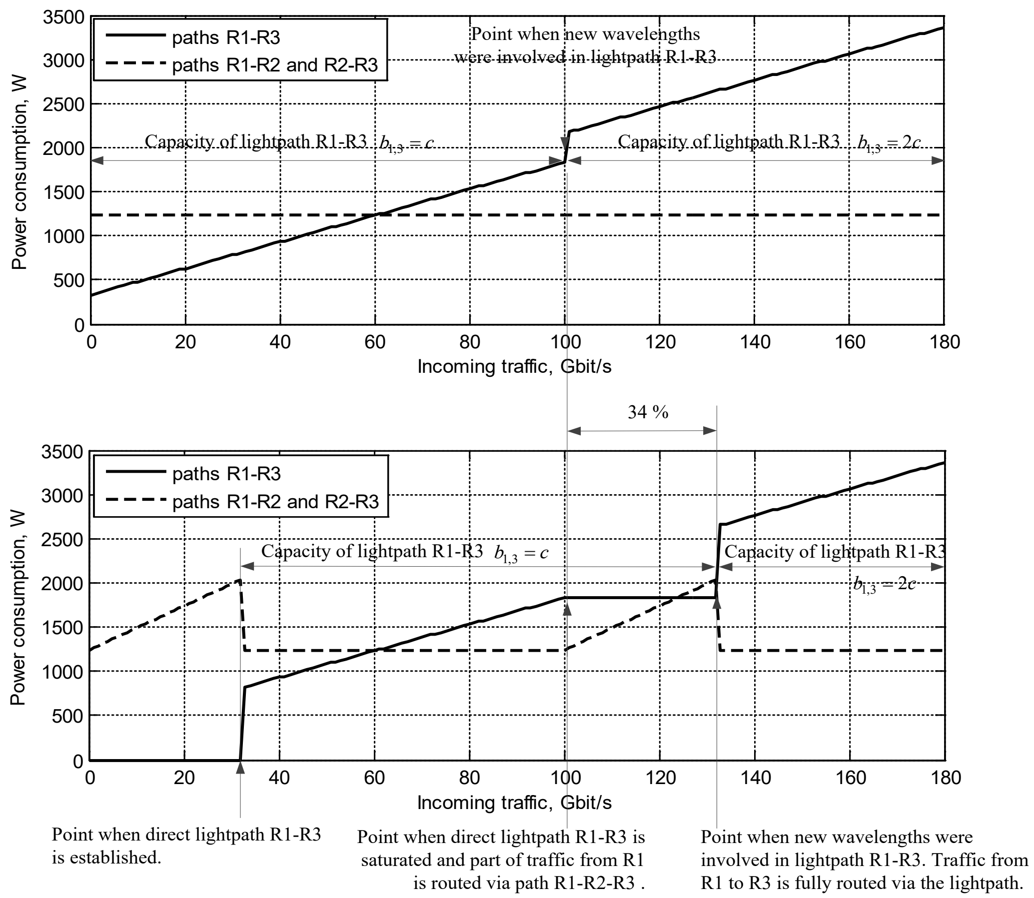

Fig. 2. Power consumption by established lightpaths under different routing strategies.

In order to deliver traffics $y_{1,2}(k)$ and $y_{2,3}(k)$ lightpaths R1-R2 and R2-R3 are established. When new traffic $y_{1,3}(k)$ is arriving into network, decision on route from R1 to R3 depends on ratio between the new flow and pre-existing flows $y_{1,2}(k)$ and $y_{2,3}(k)$. According to bypassing IP-over-WDM architecture for new flow new direct lightpath is preferable. Power consumption observed in the case is shown in top of fig. 2. Because traffic in paths R1-R2 and R2-R3 isn't varied power consumption in the paths is constant, but naturally power consumed by path R1-R3 is growing with growth of $y_{1,3}(k)$ (the traffic is shown along X-direction). Routing strategy obtained within offered mathematical model differs (bottom of fig. 2). When arrived traffic $y_{1,3}(k)$ becomes more than capacity of singe wavelength $y_{1,3}(k) > c$, model prefers to use pre-established lightpaths R1-R2 and R2-R3 to delivery difference $(y_{1,3}(k) - c)$. When the difference together with original flows $y_{1,2}(k)$ and $y_{2,3}(k)$ exceeds 50 % of wavelength capacity, direct path R1 – R3 is required. From viewpoint of network performance it allows to increase amount of delivered traffic by 34% under same power consumption (fig. 2). Or, from viewpoint of power consumption, to reduce it by 10 % (fig. 3). The reducing is observed when pre-established lightpaths from source to destination are exist. And every such path allows further decreasing in power consumption.

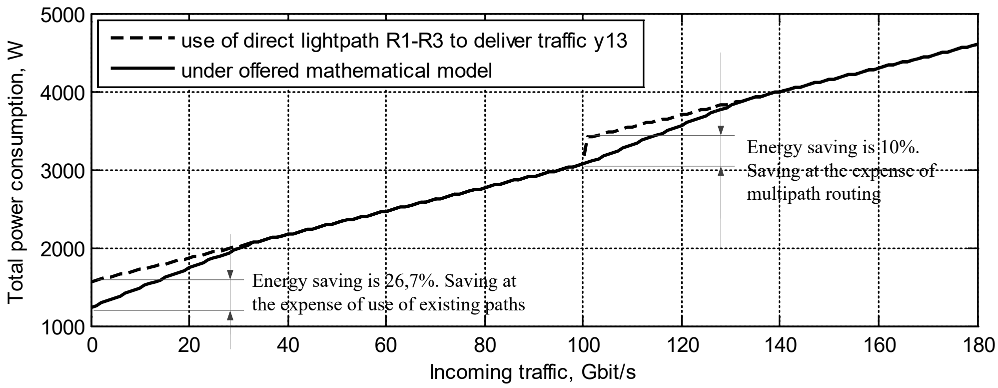

Fig. 3. Total power consumption under different routing strategies.

IV. Conclusion

Thus, offered mathematical model of optical packet transport network is adapted to SDN concept. It allows virtualization of optical resources and their abstracted representation at higher IP-layer. It is aimed at global optimization of network resources according to energy criterion.

Exanimated example points two important feature of offered mathematical model. In the first place, it's multipath dynamic nature of resource allocation at IP-layer. In the second place, it's energy saving achieved by use of pre-established non-direct active ligtpaths instead activation of new additional direct lightpath. It was shown that multipath routing over virtualized IP-links leads to saving 10% of power consumption per every additionally used path.

References

[1] Thomas D. Nadeau, and Ken Gray, SDN: Software Defined Networks. O'Reilly Media, 2013. 384 p.

[2] A. Sadasivarao, S. Syed, P. Pan, C. Liou, A. Lake, C. Guok, and I. Monga "Open transport switch: a software defined networking architecture for transport networks", Proceedings of the second ACM SIGCOMM workshop on Hot topics in software defined networking, HotSDN '13, pp. 115-120.

[3] O. Yevsyeyeva, and Y. Ilyashenko, "Cross-Layer Design for Optimal Energy Effective Resource Allocation in IP-over-DWDM Networks", Proceedings of XIIIth International IEEE conference CADSM'2015, pp. 414-418.

[4] F. Musumeci, M. Tornatore, and A.Pattavina, "A Power Consumption Analysis for IP-over-WDM Core Network Architectures", IEEE/OSA Journal of Optical Communications and Networking. vol. 4 (1), pp. 108-117, 2012.

[5] W. Van Heddeghem, F. Idzikowski, W. Vereecken, D. Colle, M. Pickavet, and P. Demeester, "Power consumption modeling in optical multilayer networks", Photonic Network Communications, DOI: 10.1007/s11107-011-0370-7, 2012.