Defragmentation in the W-S-W Elastic Optical Network

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***Abstract*—In most cases defragmentation for elastic optical networks is done in links between network's nodes. In this article defragmentation for elastic optical network's node is investigated. As a node it was used the W-S-W switching architecture. A short description of a special prepared simulator was introduced. Few methods of defragmentation which are implemented in this simulator were described as well.**

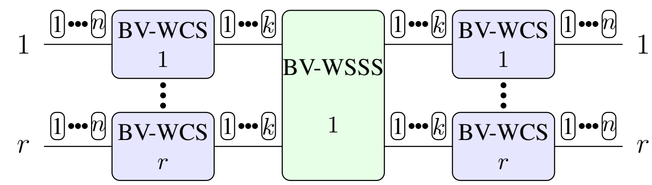

Fig. 1. WSW1 elastic optical network

I. Introduction

A typical optical WDM network offers nowadays enough bandwidth, however, it is high probable that in the nearest future it will be not enough to handle a fast-growing Internet's traffic. Of course, to solve this problem a higher speed of the transmission could be used. Nevertheless, optical path with speed 100 Gbps, 400 Gbps, or even 1 Tbps is not needed by all users. Such a speed will be used mostly by network operators inside a core network therefore some cost-effective and scalable solution to transport such a diversity of traffic will be needed. Therefore it was proposed to use Elastic Optical Networks (EONs) [1] which allows for flexible assignment of optical bandwidth. General optical bandwidth is divided into a lot of frequency slots where one such a frequency slot constitutes the smallest amount of optical bandwidth which can be assigned to an optical path. Therefore, any connection could demand a different number of such slots. In general one connection demands m such a slots. Currently the slot width granularity has 12.5 GHz and it is called a frequency slots unit (FSU) [2].

EONs makes bandwidth management easier, however, it brings also a new challenges like for example a spectrum fragmentation. A sequence of connections and disconnections operations causes by a dynamic network operations sooner or later brings to existing of non-aligned, isolated, and small-sized blocks of spectrum segments. These segments can only sometimes be used for future connections. In most cases it caused low spectrum utilization and high blocking probability.

There are know several architectures of elastic optical switching nodes [3]–[5]. Recently a new architectures of EONs called W-S-W (wavelength-space-wavelength) [6] and S-W-S (space-wavelength-space) [7] were proposed. In this paper only a special case of the W-S-W architecture, called the WSW1 [8] which architecture's is presented in Fig. 1, is considered.

The WSW1 switching fabric consists of r bandwidth-variable wavelength converting switches (BV-WCSs) of capacity 1×1 in the first and third stages, and one bandwidth-variable wavelength selective space switch (BV-WSSS) of capacity $r \times r$ in the center stage. Each BV-WCS contains one bandwidth-variable wavelength selective switch (BV-WSS), one passive coupler (PC), and c tunable waveband bandwidth converters (TWBCs). The role of BV-WSS is to direct connections from the input fiber to different TWBCs, one connection to one TWBC. In the TWBC, the connection is moved from one set of FSUs (one frequency slot) to another set of FSUs (another frequency slot). After conversion all connections are combined to the output fiber by the PC. One BV-WSSS has r BV-WSSs and r PCs. For detailed description of the WSW1 structure see [8].

Each input and each output fiber in the W-S-W switching fabric has n FSUs and each interstage fiber has k FSUs (see Fig. 1). As mentioned before, a new connection could require m frequency slots, where m is typically limited by m_{max}, i.e. $1 \leqslant m \leqslant m_{max} \leqslant n$.

Rest of the paper is organized as follows. In Section II problem statement and four defragmentation methods are described. Section III introduces a simulator which allows to simulate W-S-W elastic optical network. The last Section consists conclusions and the future work.

II. Defragmentation

Defragmentation for EONs is very often done in a network level [9]–[11]. It means that input and output node's FSUs are defragmented according to the network state and for such a defragmention it is not important what structure of the network node is used. However, from node's point of view defragmentation could be done also inside a node. Defragmentation in EON's node is done only inside interstage links. It means that order of FSUs at each input as well as at each output link of the W-S-W switching fabric wont be changed. The only place where order of FSUs can be changed is at inputs ond outputs of the BV-WSSS switch.

Frequency slot units defragmentation algorithm needs to address the following questions: *When to defragment?*, *What for defragment?*, and *How to defragment?*.

When to defragment? – defragmentation in the WSW1 node could be done in a different moments. The fist moment of defragmentation is done when some m-slot connection was just disconnected and m free FSUs appeared in a switching node for a new future connection(s). The second moment of defragmentation is done when a new m-slot connection appears in a node and there are enough FSUs to establish this connection, however, these FSUs are not adjacent.

What for defragment? – defragmentation allows to establish a new connection when in a switching node there are enough FSUs, however, there are not adjacent. After defregmentation process there will be enough adjacent FSUs to establish a new connection.

How to defragment? – it could be distinguished a few methods of defragmentation of FSUs: re-optimization [12], make-before-break [13], push-and-pull [14], and hop-tuning [15]. All of them are commonly used for defragmentation of an available spectrum used in links between EON's nodes. In a prepared simulator these methods are used to defragment an optical bandwidth inside an EON's node.

There are more methods of defragmentation, however, they are not yet implemented in the prepared simulator. Simulator is described in the next Section, nevertheless, it is still under the development process.

A. *Re-optimization*

In the re-optimization method all existing connections have to be disconnected and set up once again. Advantage of this method is that no additional transmitters are required. Disadvantage is a time of defragmentation. Sometimes this time is a very long. A simple example of this method is shown in Fig. 2.

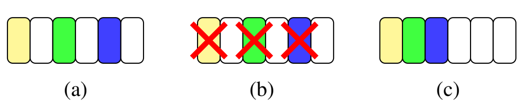

Fig. 2. Re-optimization defragmentation method: (a) Step 0 – state before defragmentation, (b) Step 1 – disconnecting all existing connections, (c) Step 2 – seting up all connections once again (state after defragmentation)

B. *Make-before-break*

In the make-before-break method a copy of some existing connection is created in a free FSUs and during some time exist two identical connections. To handle this an additional transmitter is needed. What is more, during the defragmentation process a new connection could not be established due to fact that more FSUs are occupied compared to "before defragmentation state" in EON's node. It is obvious that to do defragmentation using this method an additional number of free slots are required and not always it will be possible to defragment optical bandwidth inside EON's node. A simple example of this method is shown in Fig. 3.

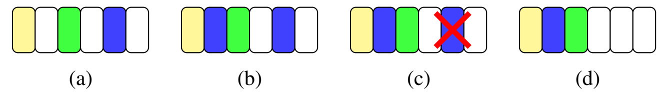

Fig. 3. Make-before-break defragmentation method: (a) Step 0 – state before defragmentation, (b) Step 1 – creating a copy of the existing (blue) connection, (c) Step 2 – disconnecting original connection, (d) Step 3 – state after defragmentation

C. *Push-and-pull*

In the push-and-pull method existing connections are moved in optical bandwidth. Any connection could be moved inside a free adjacent FSUs till considered connection became adjacent to other connection. In case when there are no free adjacent FSUs to considered connection this connection cannot be moved into other FSUs. A simple example of this method is shown in Fig. 4.

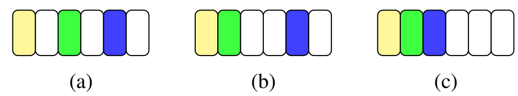

Fig. 4. Push-and-pull defragmentation method: (a) Step 0 – state before defragmentation, (b) Step 1 – moving second (green) connection to the left side, (c) Step 2 – moving third (blue) connection to the left side (state after defragmentation)

D. *Hop-tuning*

In the hop-tuning method existing connection is moved into any free FSUs not necessary adjacent to the considered connection. Unlike the make-before-break and push-and-pull methods this method ensures to move few connections in the same time. This is a big advantage – time needed for such a defragmentation is less then 1μs. A simple example of this method is shown in Fig. 5.

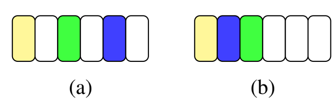

Fig. 5. Hop-tuning defragmentation method: (a) Step 0 – state before defragmentation, (b) Step 1 – moving (blue) connection (state after defragmentation)

III. Simulator

To simulate the WSW1 architecture of EON it was prepared a special simulator. As an environment it was used the OMNeT++ discrete event simulator in version 5.0 [16]. All functionality (like behavior of all elements) and algorithms were prepared in the C++ language. In turn, all graphical representation of each elements were prepared in the NED (network elements description) language – a special language used in the OMNeT++ environment. The OMNeT++ ensures also a variety of generators which can be used as a traffic generators. Such a traffic simulates very well all connections appearing in the investigated elastic optical node.

First version of this simulator was used to simulate a strict-sense nonblocking conditions for the WSW1 switching fabric. Obtained results were published in paper [8]. Then simulator in version 2 was extended to simulate also a rearrangeable nonblocking conditions for the WSW1 architecture. Obtained results were presented in paper [17]. However, in both mentioned simulator versions' a graphical representation of the WSW1 switching fabric was not possible. Therefore

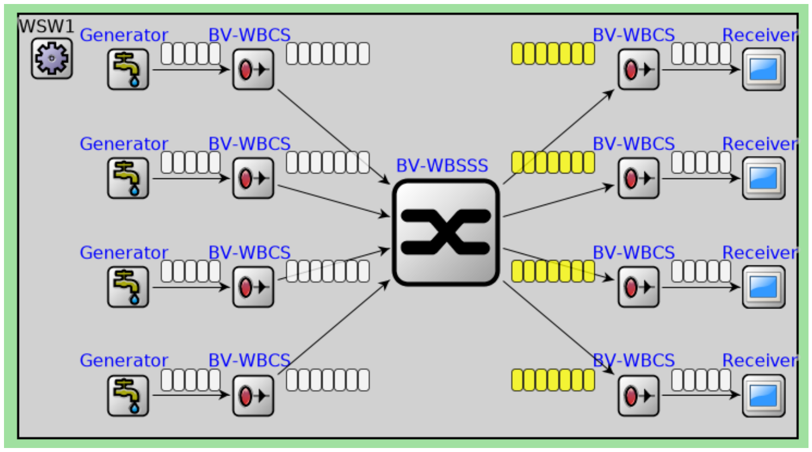

Fig. 6. The WSW1 node with $n = 5$, $r = 4$, and $k = 7$ implemented in the OMNeT++ environment

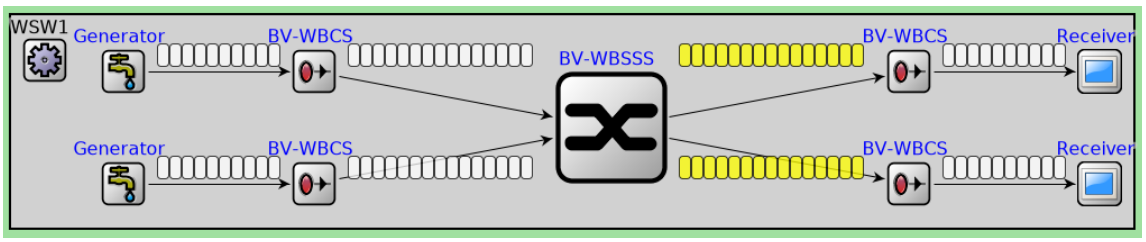

Fig. 7. The WSW1 node with $n = 10$, $r = 2$, and $k = 15$ implemented in the OMNeT++ environment

it was prepared version 3 of the simulator where a graphical representation of the WSW1 EON is now possible (see Fig. 6). There were added also four defragmentation algorithms. In the future more defragmentation algorithms will be added as well as more different EON structures will be supported (like for example the WSW2 structure or S-W-S-type switching fabrics).

The prepared simulator of the WSW1 switching node is asking user just after start what parameters (like n, r, and k) should be used in simulation. Giving different values of n, r, and k different structure of the WSW1 will be obtained. For example, when $n = 5$, $r = 4$, and $k = 7$ the WSW1 EON looks as it is shown in Fig. 6. In turn, giving $n = 10$, $r = 2$, and $k = 15$ the WSW1 structure looks as it is shown in Fig. 7.

In the prepared simulator each BV-WBCS as well as BV-WBSSS are represented by a proper module which consists from smaller peaces like PCs, BV-WSSs, and TWBCs. For example, for $n = 5$ BV-WBCS can looks as it is shown in Fig. 8. For $r = 7$ BV-WBSSS switch looks as it is show in Fig. 9 and for $r = 7$ it looks at is shown in Fig. 10.

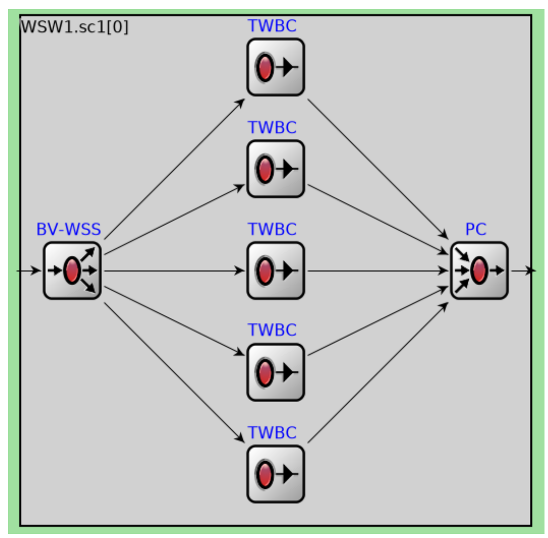

Fig. 8. The BV-WBCS switch implemented in the OMNeT++ environment

IV. Conclusions

In this paper four defragmentation methods for the WSW1 architecture were described. All of these methods were already implemented in a special prepared simulator. This version of simulator ensures right now a graphical interface, however, it is still under a development process. The future step is to represent inside this simulator also the WSW2 switching structure – an another example of the W-S-W elastic optical network. Then S-W-S architectures will be implemented as well. It allows in future to compare both kinds of structures to each other.

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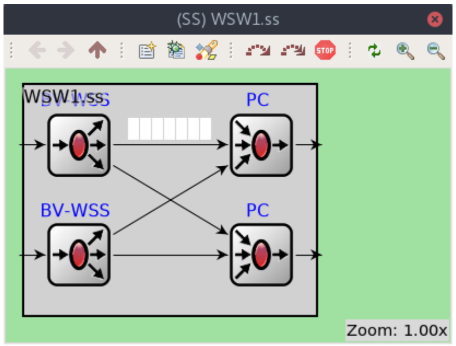

Fig. 9. The BV-WSSS switch for $r = 2$

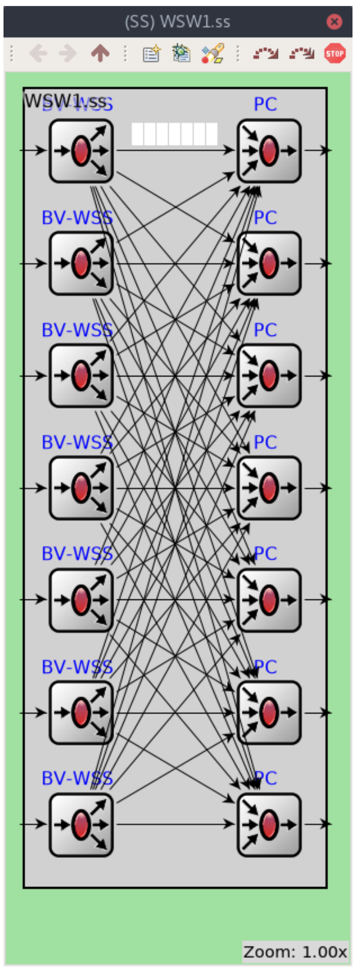

Fig. 10. The BV-WSSS switch for $r = 7$

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