Comparison of Reservation Protocols for SOA and MEMS Technology

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Abstract. *The data transmission by high-speed optical networks has an upward trend. The most effective data transmission can be achieved by powerful reservation protocols, which are together with optical switches very important parts of high–speed optical networks. This paper deals with new reservation protocol called Search & Compare, which is designed according to the well–known Segment-based Robust Fast Optical Reservation Protocol. In this paper, we present time analyses of both reservation protocols. We focused mainly on intra–segment time analyses. During the reservation of network resources, we used the optical cross-connect as the core node, which is based on microelectromechanical system and semiconductor optical amplifier. These two technologies are becoming the dominant technologies in optical switching.*

Keywords

Microelectromechanical systems, optical switches, reservation protocols, semiconductor optical amplifiers.

1. Introduction

Network service providers have to design their core networks to satisfy increasing user claims in the future. To make this possible, they have to use the multiplex methods. Time-division multiplexing (TDM) and wavelength-division multiplexing (WDM) belong among the most popular multiplex methods [1]. WDM allows more efficient data transmission via multiple wavelengths transmitting in single optical fiber. The advantage of WDM is the ability to transmit the data with different transmission speed and modulation format in every single wavelength [2].

With growing demands of IP services for transmission capacity and speed, the optical burst switching (OBS) presents the solution for future high-speed WDM optical networks. OBS networks need high-performance nodes, which can handle the growing flexibility and efficiency. Important parts of high-performance nodes are the reservation protocols and optical switches.

The major role of the reservation protocols is a discovery of the most suitable path (or the wavelength) followed by the reservation of the node resources. The best-known reservation protocols are Segment-based Robust Fast Optical Reservation Protocol (S-RFORP), Robust Fast Optical Reservation Protocol (RFORP), Resource Reservation Protocol-Traffic Engineering (RSVP-TE) and Intermediate-node Initiated Reservation (IIR). The S-RFORP protocol has the best features in comparison to the mentioned reservation protocols [3].

The optical switching plays an major role in resources reservation. Optical switches provide the optical path and improve the optical network reliability. Currently, several switching technologies are available, e.g. optomechanical switches, microelectromechanical system (MEMS) based switches, electrooptical switches, thermooptical switches, liquid-crystal switches, bubble switches, acoustooptical switches, switches based on semiconductor optical amplifier (SOA), switches based on fiber Bragg grating (FBG). From abovementioned switching technologies the MEMS and SOA are the most widely used. These technologies allow us to build the cost-effective and high-capacity optical cross-connects [4] and [5].

The paper is organized as follows. Section 2. describes the usage of MEMS technology in optical networks such as optical switches. Optical switches based on SOA technology are mentioned in Section 3. Section 4. describes time analysis of S-RFORP protocol and suggested reservation protocol. The performance comparison of the reservation protocols is reported in Section 5. The conclusion is drawn in Section 6.

2. MEMS Technology

Optical MEMS switches can be categorized into three groups: MEMS switches using micromirror, MEMS switches using membranes, MEMS switches using plane moving waveguides. The first two groups represent free space switches because they use space as the transmission medium. The last group represents waveguide switches that require moving certain parts of the switch once functioning. Most of the optical MEMS switches use micromirrors which can be divided into two groups, namely, two-dimensional MEMS (2D MEMS) and three-dimensional MEMS (3D MEMS) [6] and [7].

2.1. 2D MEMS Optical Switches

In 2D MEMS optical switches the micromirrors are arranged in a crossbar configuration. Micromirrors work in a digital mode, it means that each micromirror has only two positions, so their position is bistable (ON/OFF). The bistable position of micromirrors greatly simplifies the control mechanism. Typically, the control mechanism consists of simple transistor-transistor-logic (TTL) gates and appropriate amplifiers to apply an adequate voltage to actuate micromirrors [8], [9] and [10].

Micromirrors are placed on an electrostatic actuator that is suspended on a torsion spring. When the switch voltage (only a few microwatts) is applied, the actuator rotates around the axis of the torsion spring so that the micromirror moves downward into the optical beam. The 2D MEMS switch consists of two or more collimator arrays that are actively aligned with the micromirrors (a collimator is an optical element that transforms the optical mode of a single mode fiber into a light beam) [8], [9] and [10].

2D MEMS technology can deliver a range of applications including medium-sized and large optical cross-connects, wavelength selective optical cross- connects, wavelength add-drop multiplexing, optical service monitoring, and optical protection switching. MEMS technology is an important key to ensuring reliability and flexibility of a network [11] and [12].

3. SOA Technology

An SOA gate array is an array of devices monolithically integrated on the same substrate. By changing the electric current, the SOA array can act as "ON/OFF" switch. If electric current falls near zero, the input signals are absorbed ("OFF" position). In another case, if the current grows, SOA will amplify the input signals ("ON" position). The combination of amplification in "ON" position and absorption in "OFF" position make SOA capable of achieving very high extinction ratio [13], [14] and [15]. Due to the nonlinear characteristics, the SOAs are versatile devices used in optical networks. SOA technology is used not only to optical switching but also for all-optical wavelength conversion, regeneration, wavelength selection, booster and in-line amplification, in-node optical preamplification and mid-span spectral inversion in optical networks [13], [14] and [15].

4. Reservation Protocols

The reservation protocols are the important part of high-speed optical networks. The main role of reservation protocols in nodes is to reserve its resources for some time period. Currently, several reservation protocols are designed, which are trying to use the resources of nodes most efficiently with the lowest blocking probability of wavelength assignment. Good reservation protocols can save a big amount of data losses.

4.1. Reservation Protocol S-RFORP

The reservation protocol S-RFORP consists of two phases. During the first phase, the phase of wavelength discovery, all available wavelengths for each segment are discovered and then one of them is chosen for the reservation. During the second phase, the phase of wavelength reservation, the chosen wavelength is reserved. S-RFORP uses the parallel inter-segment discovery and reservation to minimize the wavelength assignment delay and the serial intra-segment discovery and reservation [16] and [17].

The time of the intra-segment discovery of S-RFORP is given by the sum of time that is necessary for wavelength discovery in a given node and time that is necessary for wavelengths comparison, as seen from equation Eq. (1).

$$D_t = D_{t_{S1}} + (D_{t_{S2}} + D_{t_{C2}}) + (D_{t_{S3}} + D_{t_{C3}}) + ... \\ +(D_{t_{Sn}} + D_{t_{Cn}}), \tag{1}$$

where D_t is the discovery time, $D_{t_{S1}}$ is the discovery time necessary for the discovery of wavelength in the segment, $D_{t_{cC}}$ is the discovery time necessary for comparison of two wavelengths [16] and [17].

From Eq. (1) it is seen that the first node in a segment only needs time for available wavelengths discovery since it has nothing to compare with the discovered wavelengths. If we separate from equation Eq. (1) the time that is needed for wavelength discovery and time that is necessary for wavelengths comparison we can write equations Eq. (2) and Eq. (3):

$$D_{t_{S1}} + D_{t_{S2}} + D_{t_{S3}} + ... + D_{t_{Sn}} = \sum_{i=1}^{n} D_{t_{Si}}, \quad (2)$$

$$D_{t_{C2}} + D_{t_{C3}} + D_{t_{C4}} + ... + D_{t_{Cn}} = \sum_{j=2}^{n} D_{t_{Cj}}. \quad (3)$$

If we substitute Eq. (2) and Eq. (3) to Eq. (1), we will have Eq. (4), which describes the total time needed for intra-segment discovery.

$$D_{t_{S-RFORP}} = \sum_{i=1}^{n} D_{t_{Si}} + \sum_{j=2}^{n} D_{t_{Cj}}, \quad (4)$$

where $D_{t_{S-RFORP}}$ is the total time of the intra-segment discovery of S-RFORP, n is the number of active nodes in the segment [16] and [17].

When equally powerful nodes are presented in the given segment, we can write Eq. (5) and Eq. (6). Equation (7) describes the total time, which is necessary for intra-segment discovery in the reservation protocol S-RFORP, but only on condition that all the nodes in a segment are equally powerful.

$$D_{t_{S1}} = D_{t_{S2}} = D_{t_{S3}} = D_{t_{S4}} \rightarrow \sum_{i=1}^{n} D_{t_{Si}} \rightarrow nD_{t_{Si}}, \quad (5)$$

$$D_{t_{C2}} = D_{t_{C3}} = D_{t_{Cn}} \rightarrow \sum_{j=2}^{n} D_{t_{Cj}} \rightarrow (n-1)D_{t_{Cj}}, \quad (6)$$

$$\begin{aligned} D_{t_{S-RFORP}} &= nD_{t_{S1}} + (n-1)D_{t_{Cj}} = \\ &= nD_{t_{S1}} + nD_{t_{Cj}} - D_{t_{Cj}} = \\ &= n(D_{t_{S1}} + D_{t_{Cj}}) - D_{t_{Cj}}. \end{aligned} \quad (7)$$

The time of the intra-segment reservation of S-RFORP is given as a sum of time intervals which are necessary for resource reservation in each node that is involved in the transfer, as seen from Eq. (8). If all nodes in the segment are equally powerful, the total time needed for intra-segment reservation is given by Eq. (9):

$$R_{t_{S-RFORP}} = R_{t_1} + R_{t_2} + R_{t_3} + ... + R_{t_n}, \quad (8)$$

$$R_{t_1} = R_{t_2} = R_{t_3} = R_{t_i} \rightarrow R_{t_{S-RFORP}} = nR_{t_n}, \quad (9)$$

where $R_{t_{S-RFORP}}$ is the reservation time of S-RFORP protocol, R_{t_1} is the reservation time in the first node in the segment, R_{t_n} is the reservation time in the last node in the segment, n is the number of active nodes in the segment [16] and [17].

4.2. Reservation Protocol S&C

The suggested reservation protocol S&C is based on S-RFORP. Inter-segment discovery and reservation of S&C protocol are identical with S-RFORP protocol. S&C uses parallel segment-based discovery and parallel link-based reservation within the segment. It is possible to achieve a shorter time of intra-segment discovery and reservation [16] and [17].

The total time of intra-segment discovery of S&C is given as the sum of time for wavelengths discovery in the table of the main reservation node and the time for comparison of discovered wavelengths, as seen from the Eq. (10):

$$D_{t_{S\&C}} = t_s + t_c, \quad (10)$$

where $D_{t_{S\&C}}$ is the discovery time of S&C protocol, t_s is the discovery time, t_c is the comparison time [16] and [17].

The total time necessary for intra-segment reservation of S&C is given by the sum of time, which is necessary for verification (if the discovered wavelengths are still available) and the reservation time of the slowest node in the segment, which is participated in the transfer, as seen from Eq. (11). In case that all the nodes in a segment are equally powerful, the time $R_{t_{S\&C}}$ is populated from any node in the given segment.

$$R_{t_{S\&C}} = t_v + R_{t_S}, \quad (11)$$

where $R_{t_{S\&C}}$ is the reservation time of S&C protocol, t_v is the verification time, R_{t_S} is the time for reservation of the slowest node [16] and [17].

5. Performance Results

The performance evaluation of S&C reservation protocol is based on the intra-segment discovery time and on the following intra-segment wavelength reservation. The performance S&C is compared with S-RFORP. The numerical computer network model was executed in MATLAB development environment.

The network model was based on the topology of the Pan-European network [18], which was divided into the three segments. Each segment is different in the number of active nodes Fig. 1.

The optical cross-connects are used as OBS core nodes with different switching technologies: MEMS-based switching nodes and SOA-based switching nodes. The switching time of each 2D MEMS switch was 10 ms and SOA switch was 3 ns for following calculations [6] and [19].

In the network model it was required to set the main reservation node in each segment the distances between

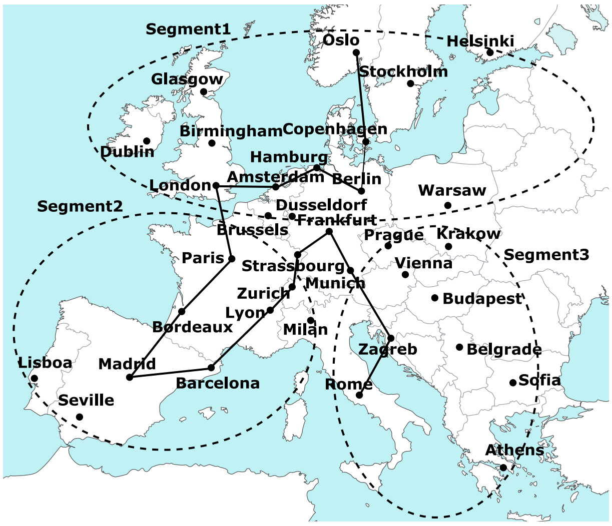

Fig. 1: The proposed node topology.

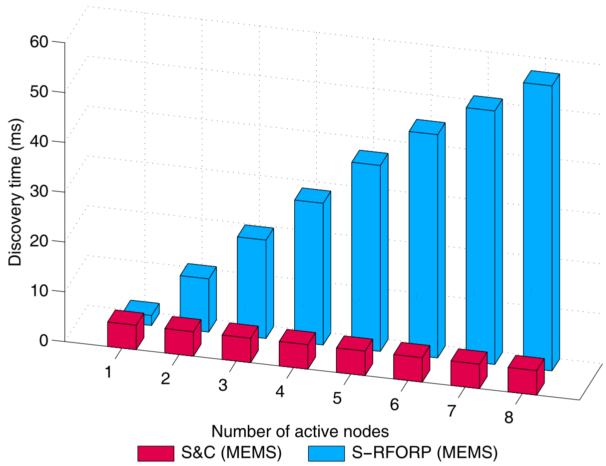

Fig. 2: Discovery time in Segment 2 with MEMS-based optical switch.

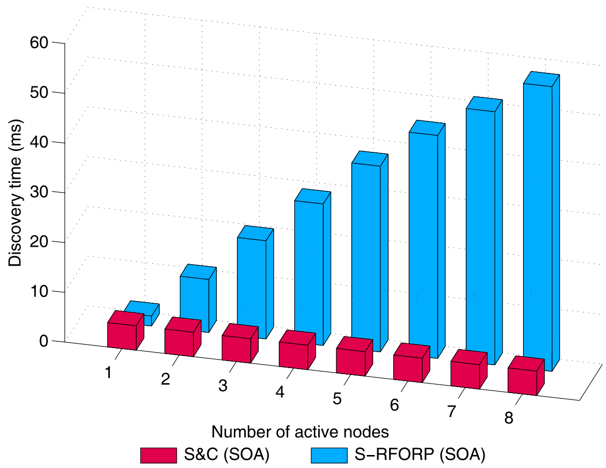

Fig. 3: Discovery time in Segment 2 with SOA-based optical switch.

the network nodes (the distances are listed in [18]), the type of optical fiber (G.652), bitrate (40 Gbit$\cdot$s^{-1}), and wavelength (1550 nm). It was crucial to set the time for discovery of wavelength (2 ms), the time for comparison of wavelengths (3 ms), the reservation time of the node (2D MEMS switch 10 ms, SOA switch 3 ns). It was also needed to set the time for discovery of wavelengths in the table of the main reservation node (2 ms), the time for comparison of discovered wavelengths (2.9 ms), the verification time (0.1 ns), the time for reservation of the slowest node (2D MEMS switch 10 ms, SOA switch 3 ns).

5.1. Intra-Segment Discovery Time

As can be seen in Fig. 2 and Fig. 3, the time necessary to intra-segment discovery in S-RFORP protocol is longer than the time necessary for intra-segment discovery in S&C protocol. It is caused by the fact that the time which is necessary for wavelength discovery in the given segment, is markedly dependent on the number of active nodes in the given segment. The greater amount of nodes in the given segment, the longer discovery time.

The time needed for wavelength discovery in both compared reservation protocols is independent of the chosen switching technology Fig. 4.

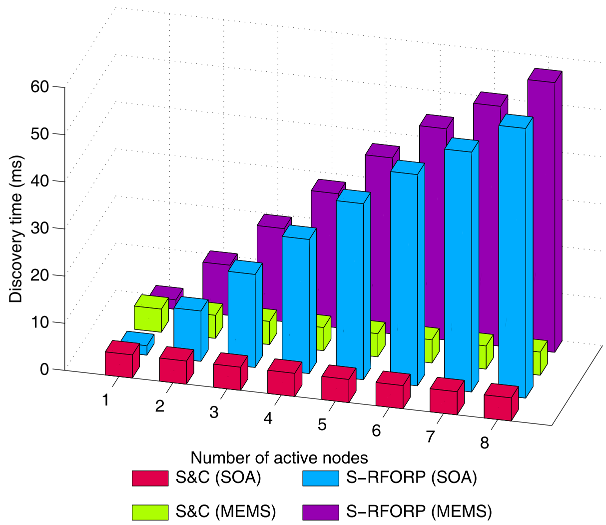

Fig. 4: Total time of discovery for Segment 2 with MEMS and SOA-based optical switch.

5.2. Intra-Segment Reservation Time

As can be seen in Fig. 5 and Fig. 6, the time necessary for intra-segment reservation in S-RFORP protocol is again longer than the time necessary for intra-segment reservation in S&C protocol. The reservation time of

S-RFORP protocol is dependent on the number of active nodes in the given segment.

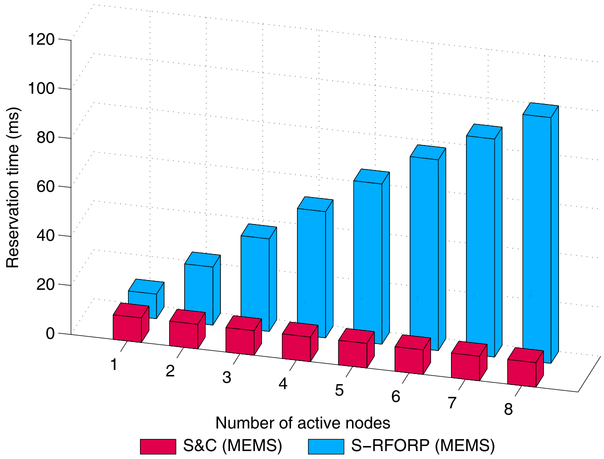

Fig. 5: Reservation time in Segment 2 with MEMS-based optical switch.

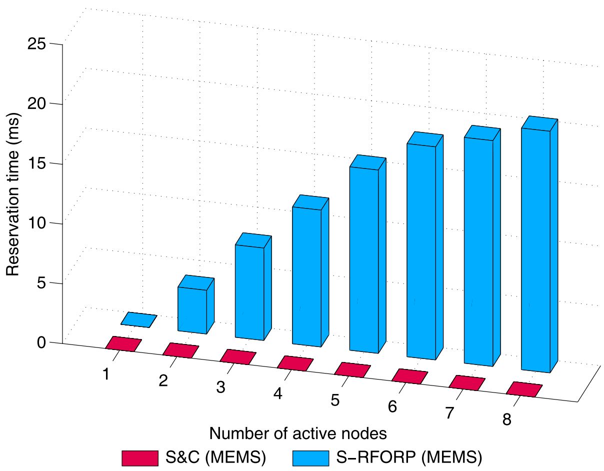

Fig. 6: Reservation time in Segment 2 with SOA-based optical switch.

On the switching technology is dependent only the time necessary for wavelength reservation Fig. 7. From the results could be seen, that the optical bursts can be handled with the SOA-based optical switches in the range of a few ns. That means that the optical switches based on SOA technology are well suited for optical switching due to their switching time.

The results show that the intra-segment discovery and reservation time of S-RFORP is dependent on the number of active nodes in the given segment. The time necessary for discovery and reservation in protocol S&C is independent of the number of active nodes in the segment, but is dependent on the speed of the main reservation node and from the slowest node in the given segment. The reservation time of both protocols depends on the chosen switching technology.

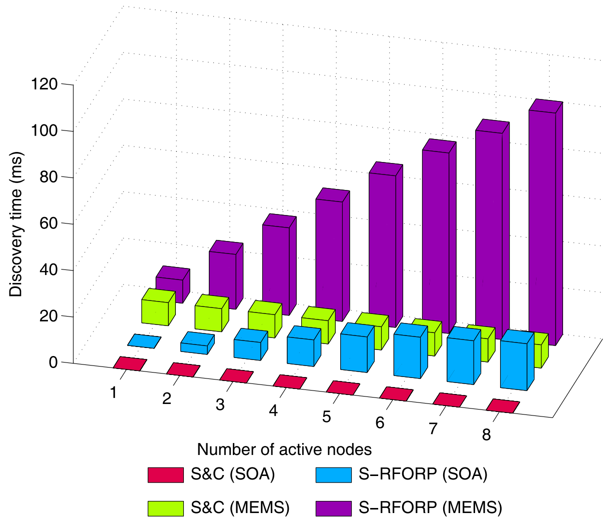

Fig. 7: Total time of reservation for Segment 2 with MEMS and SOA-based optical switch.

6. Conclusion

In this paper, we present the performance comparison of the currently known and proposed reservation protocol. From the analytical and numerical models could be seen, that proposed reservation protocol needs much shorter time, which is necessary to wavelength discovery and reservation in the given segment. Therefore proposed reservation protocol S&C is more powerful than the reservation protocol S-RFORP. From the results could be also seen that the optical switching plays an important role in the resource reservation. SOA belongs to the most attractive candidates to realize high-speed optical switching.

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