Availability Aspects of Self-healing Optical Nodes Designed by Architecture on Demand

Branko Mikac[1], Matija Dzanko[1], Marija Furdek[1, 2], Emilio Hugues-Salas[3], Georgios Zervas[3], Dimitra Simeonidou[3]
[1]*University of Zagreb, Faculty of Electrical Engineering and Computing (FER), Zagreb, Croatia,*
[2]*Royal Institute of Technology (KTH), ICT School, Kista, Sweden*
[3]*University of Bristol, High-performance Networks Group, Bristol, United Kingdom.*
Tel: +385 1 6129752, *Fax:* +385 1 6129832, *e-mail: branko.mikac@fer.hr*

ABSTRACT
The paper demonstrates the concept of optical networks with nodes implemented by the architecture on demand (AoD) and proposes a procedure for finding out possible benefits of AoD application, related to node and network availability. AoD node structure enables efficient failure management by creating a set of redundant components, which can be used for self-healing of optical nodes after failure. Availability evaluation procedure is based on Monte Carlo simulation of times to failure/repair of network components. A case study network with AoD nodes is compared to the network with hard-wired nodes in regard to availability performance, and results are presented.
Keywords: optical nodes, architecture on demand, failures, availability, self-healing, Monte Carlo simulation.

1. INTRODUCTION

Hard-wired (HW) optical node architectures can be characterized by a low level of architectural flexibility and scalability [1]. These characteristics imply lower availability and survivability due to the fact that all lightpaths (abbr. paths) passing HW nodes traverse the same set of component types, even though they are not needed for specific function. As a consequence, unnecessary component usage can inherently degrade path availability. In the case of a path breakdown caused by a node component failure, unless the nodes incorporate a high degree of redundancy, the only possible recovery action includes path rerouting at the network level, requiring a number of protocol steps and consuming switchover time in range of seconds.

By introducing architecture on demand (AoD) paradigm in the design, optical node functionalities can be dynamically adapted according to different traffic patterns, switching and processing requirements [2]. AoD can be implemented by using additional switching elements (e.g. mirrors in 3D MEMS or collimator arrays in piezo electric switch) that interconnect optical components necessary for implementation of specific functions or for achieving different switching granularities, from fibre to sub-wavelength switching.

By using internal rerouting in AoD nodes, self-healing can be achieved after node component failures. Self-healing action is based on the possibility to switch over the connections, affected by failures, to the node redundancy that can be i) deliberately added for survivability purposes, or ii) created by releasing all unused components. In the letter scenario if no extra components dedicated for survivability are present in the node, there are, at least, two ways of creating node redundancy: 1) By decreasing traffic load in a node, the need for using of deployed components decreases. Surplus components are treated as redundant. 2) By grouping of wavelength or waveband paths into fibre-switched paths, if possible. Unnecessary node components are set free and they are treated as redundant.

All redundant components can be used on-the-fly for self-healing, providing backup resources for the paths on the optical node level and eliminating the necessity of path rerouting on the network level. Note, switchover time at node level can be estimated to 10 ms range (when 3D MEMS is applied), yielding faster path recovery compared to switchover time at network level. A lower number of components traversed by a path, as well as the usage of backup connections inside a node, increase the path and overall network availability.

In order to improve optical network availability one should take into account self-healing at node level, protection & restoration scenarios at network level, as well as network traffic load. When comparing HW to AoD availability structures three trade-offs are considered: 1) Can the introduction of the AoD with self-healing capability enhance availability sufficiently to compensate for the loss of availability, stemming from the usage of additional switching elements? 2) Can the increase of the cost of AoD due to the use of additional switches, compared to HW, be compensated by a decrease of operator's revenue loss, which is highly correlated to end-to-end availability? 3) Can the increase in power consumption of AoD due to the additional switching device, compared to HW, be compensated by a decrease in consumption caused by changing the state of unnecessary components from active to low-power sleep mode?

A study of benefits of AoD *reconfigurable optical add-drop multiplexers* (ROADMs) to the overall network availability, compared to HW node structures, was presented in [3]. Simulation results showed that the deployment of AoD nodes, combined with lightpath routing approach which increases the portion of connections undergoing fibre switching (FS), produces higher availability and lower restoration switching time due to releasing idle components and reusing them for self-healing.

Two novel redundant optical self-healing node configurations, based on HW and AoD ROADMs, were experimentally verified in [4]. Simulation results showed that AoD improves availability and shortens recovery time due to node-level restoration, leading to as decrease of operator revenue losses.

An approach for improving optical network availability and energy efficiency through flexible optical amplification of signals within ROADMs based on AoD was presented in [5], comparing availability performances of AoD nodes using 3D MEMS and piezoelectric optical switch as optical backplane. Simulation results indicated that, by avoiding unnecessary amplifications inside the nodes and reusing idle optical amplifiers as redundant components, path availabilities can be improved at an additional decrease of power consumption.

2. AVAILABILITY OF SELF-HEALING OPTICAL NODES

In order to compare availability performance of optical networks implemented by hard-wired nodes (*HWnet*) and networks, which consist of AoD self-healing optical nodes (*AoDnet*), a set of assumptions is defined. Network topology and protection scheme 1+1 are predefined. The traffic load in the network is assumed to be static. It is generated for the German topology with 11 nodes and 34 links [6] based on populations & distance traffic calculus for each node pair. Data on populations and distances were taken from [7] and [8], respectively. Total traffic load was normalised to different values, keeping the same ratio between end-to-end traffic loads. A set of paths between pairs of nodes is established using as many 10 Gbit/s paths as needed to serve the offered traffic. Each optical end-to-end connection consists of a pair of paths: the first shortest path (1st SP) is assigned to the working path, while the second shortest path (2nd SP), (independent of the working path) is assigned to the backup path. HW node architecture comprises splitters (*SPLs*) and wavelength selective switches (*WSSs*) in a broadcast & select configuration. AoD nodes deploy additional switching elements in order to interconnect *SPLs* and *WSSs*, and to enable self-healing after failures, as shown in Fig. 1. The additional switching elements are assumed to be mirrors of 3D MEMS.

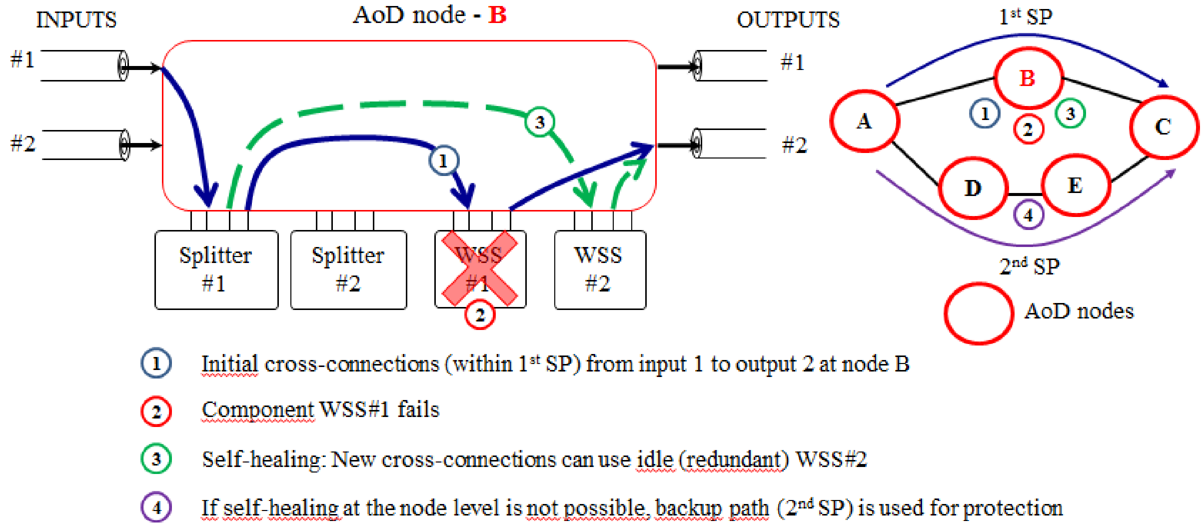

Figure 1- *Self-healing procedure in an example network with AoD nodes*

Additional mirrors along each path bring higher path failure rate and lower path availability. An assumption is that the total number of *SPLs*, as well as *WSSs*, in a node is equal to node degree. All unused node components, treated as idle, are placed in the *spare bank* of components. The number of idle components is equal to the difference between their total number and the number of used components (*SPLs* and *WSSs*). The letter number depends on the traffic load in the node, i.e., increased traffic decreases the number of idle components.

In order to increase the number of idle components in the spare bank, a search is applied over all paths, in order to find if they fulfil the requirement to be fibre-switched, i.e. all paths from a single input fibre have to be cross-connected to the same output fibre, traversing only the switching matrix (e.g. one pair of mirrors in 3D MEMS). Each fibre-switched cross-connection found within an optical node sets a pair of *SPL* and *WSS* to idle state. Idle components are placed in the spare bank and they can be used further on as redundant, aiming to replace any future faulty component in the node. The sequence of components along a path which does not undergo FS, cross-connecting an input (*IN_F*) and an output fibre (*OUT_F*), is as follows: *IN_F* // *SPL* // *WSS* // *OUT_F* (symbol / replaces a mirror). If *FS* is applied, the number of components on each path is reduced (*IN_F* // *OUT_F*) and a *SPL-WSS* pair is rendered redundant. The achieved redundancy enhances the availability of all cross-connected paths in the node. On the other hand, any reduction of the number of components along a fibre-switched single path improves related end-to-end availability.

Three availability measures are evaluated in order to compare *HWnet* and *AoDnet*: 1) *s,t-availability* $A_{s,t}$ is the minimal value of all *i,j-availabilities* ($A_{i,j}$) among all node pairs, where $A_{i,j}$ is equal to the probability that at least one path between nodes *i* and *j* is in working state. $A_{s,t}$ is a non-linear measure reflecting the availability of the worst end-to-end connection in a network. If any requirement related to the minimal end-to-end connection availability denoted as $A_{i,j}$(min) exists, then $A_{s,t}$ should not be lower than $A_{i,j}$(min): $A_{s,t} \geq A_{i,j}$(min). 2) *av-availability* (A_{av}) is the average value of all end-to-end connection availabilities $A_{i,j}$ among all node pairs. A_{av} is a linear measure reflecting the availability level of all end-to-end connections in a network. 3) *g-availability* (A_g) is the probability that all end-to-end connections are in working state. The measure we used instead of A_g is *mean down time* (MDT_g), denoted as the number of minutes per year when at least one end-to-end connection is broken due to concurrent failures of the working and the backup path: $MDT_g=(1-A_g)\times 525{,}600$ minutes/year.

3. AVAILABILITY EVALUATION

Based on the assumptions from Section 2 the following steps lead to availability figures for *HWnet* and *AoDnet*:

(1) Using *Fixed shortest path* (FSP) algorithm, two paths are found for each source and destination node pair of connection requests: 1st SP as the working path and independent 2nd SP as the backup path.

(2) In *AoDnet* all paths which fulfil the requirements for fibre switching are found at each node.

(3) If *FS* exists in an AoD node, one *SPL* and one *WSS* are released and placed in the node spare bank.

(4) Monte Carlo failure simulation is executed, based on component failure rates λ and repair rates μ, assuming that time to failure and time to repair have exponential probability density functions. Each simulation run is accomplished for different total traffic loads. In the simulation, when an AoD node component fails, the node spare bank is checked if there exists any idle component identical to the failed type. If an idle component exists, it is used as a backup for all paths traversing the failed component, and the number of idle components in the spare bank is decreased by one. If there is no idle component in the spare bank, the recovery procedure is switched to the network level, using 1+1 protection. The time period in which an end-to-end connection is up is recorded as *time to failure* (*TTF*). In opposite, when a repair of a failed node component occurs, the paths are restored back to those which use the previously repaired component, releasing the redundant component at the node level and incrementing the number of idle components in the spare bank by one. If recovery was done on the network level, transmission is switched from the backup path back to the working path. If both the working and the backup paths fail at the same time, the breakdown of end-to-end connection occurs. The time period when the end-to-end connection was down is recorded as *time to repair* (*TTR*).

(5) *i,j-availabilities* ($A_{i,j}$) are calculated from *MTTF*/(*MTTF*+*MTTR*) where *MTTF* is the mean of all *TTF*s and *MTTR* is the mean of all *TTR*s. Consequently *s,t-availability* ($A_{s,t}$) and *av-availability* (A_{av}) are calculated from all $A_{i,j}$. MDT_g is calculated from A_g.

The av-availability, s,t-availability and MDT_g are calculated using the procedure (steps 1 to 5) on the German topology, deploying i) HW and ii) AoD nodes as shown in Fig. 2 a), b), and c). At low traffic loads, logical topologies are not fully connected, i.e. connections are not established between all pairs of nodes. Therefore, AoDnet shows higher values for all availability measures because some components are idle and they can be used as redundant for recovery when active components fail. For higher traffic loads (no. of lightpaths ≥ 144), logical topology becomes fully connected and all deployed components in AoD nodes have to be used. If there is no FS, then there are no idle components and self-healing is not possible. Paths in AoDnet traverse more components compared to the HWnet architecture because of additional mirrors in 3D MEMS switch. As a consequence, availability figures for AoDnet degrade, compared to the HWnet architecture.

Fig. 2 d) shows the number of idle components in *AoDnet* under different traffic loads. The results are in line with the availability performance analysed before. Under lower traffic loads, the number of redundant components is high and the self-healing capability of nodes is significant. For higher loads, there are no idle components in the network, causing a drop of the availability performance.

Fig. 2 e) shows the number of node failures, which cannot be restored neither by self-healing in the node nor by 1+1 protection at network level. The benefits of using AoD diminish as the traffic load increases.

4. CONCLUSION

The paper presents a procedure for evaluation of optical network availability performance when using AoD nodes with self-healing capability. The benefit of using AoD nodes, compared to HW nodes, is evident at lower traffic loads. In our future work the benefits of AoD deployment will be extended to higher traffic loads by using tailored routing algorithm, which can change the initial shortest path layout, in order to increase number of fibre-switched paths, and consequently, the number of redundant components on the node level which can be used for self-healing. Availability improvement occurs if the availability decrease of prolonged rerouted paths in a network is overcompensated by the increase of availability caused by a higher number of fibre-switched paths. Further on, AoD self-healing capability can be improved by investing in additional spare parts dedicated for failure recovery in optical nodes.

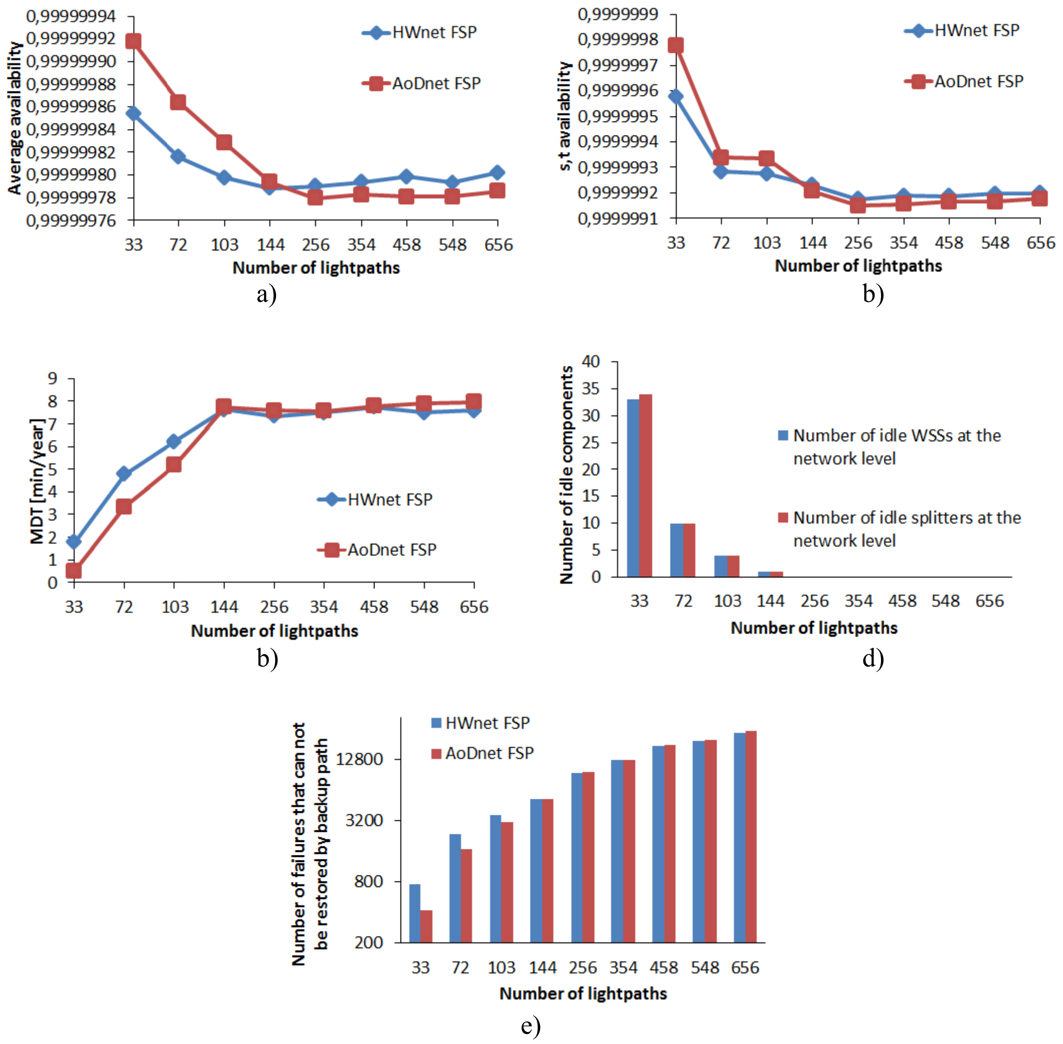

Fig. 2 Availability figures and statistics when comparing HWnet and AoDnet with FSP routing algorithm

ACKNOWLEDGEMENTS

This work is supported by: the EPSRC grant EP/I01196X, The Photonics Hyperhighway; the EC FP7 grants No. 317999, IDEALIST and No. 318137, DISCUS; and grant No. 036-0362027-1640, MZOS of the R. of Croatia.

REFERENCES

[1] N. Amaya, G. Zervas, and D. Simeonidou, Introducing Node Architecture Flexibility for Elastic Optical Networks, *Journal of Optical Communications and Networking*, vol. 5, no. 6, pp. 593-608, 2013.

[2] N. Amaya, G. Zervas, D. Simeonidou, Architecture on Demand for Transparent Optical Networks, *in Proceedings of the International Conference on Transparent Optical Networks* (*ICTON 2011*), Stockholm, Sweden, 2011, pp. Th.A1.5.1-4.

[3] M. Dzanko; M. Furdek, N. Amaya, G. Zervas, B. Mikac, D. Simeonidou, Self-Healing Optical Networks with Architecture on Demand Nodes, *in Proceedings of the 39th European Conference and Exhibition on Optical Communication* (*ECOC 2013*),. London, 2013. P.5.18.1-P.5.18.3.

[4] M. Dzanko; M. Furdek, N. Amaya, G. Zervas, B. Mikac, D. Simeonidou, Experimental Demonstration and Benefits of Self- Healing Hard-Wired and Synthetic ROADMs, in *Proceedings of the Optical Fiber Communication Conference* (*OFC 2014*), San Francisco, USA, 2014. 1-3.

[5] M. Furdek, M. Dzanko, P. Glavica, L. Wosinska, B. Mikac, N. Amaya, G. Zervas, D. Simeonidou, Efficient optical amplification in self-healing synthetic ROADMs, *in Proceedings of Optical Network Design and Modeling conference* (*ONDM 2014*), Stockholm, 2014, pp. 1-6.

[6] S. Orlowski, M. Pioro, A. Tomaszewski, and R. Wess, Survivable Network Design Library [Online]. Available: www.sndlib.zib.de/home.action

[7] T. Brinkoff, City population. [Online]. Available: www.citypopulation.de

[8] Geobytes, City distance tool. [Online]. Available: www.geobytes.com/citydistancetool.htm