COST EFFICIENT UPGRADING OF OPS NODES

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Abstract: We come back on a technique to build modular switch nodes. This approach allows for a more cost effective expansion of OPS nodes. We give two example designs, showing that the method is useful only for Broadcast & Select OPS nodes when taking price decrease in function of time into account.

Key words: Optical Packet Switching, upgrade

1. INTRODUCTION

At the end of the 20th century, (D)WDM and optical amplifiers unlocked vast bandwidth, making static optical networks the carrier of growing bandwidth demands. Next step is Automatic Switched Optical Networks (ASONs), which dynamically allocate capacity between different nodes by means of wavelength paths forming logical links [1]. Still, ASONs are unable to cope with the bursty traffic of the current Internet, due to their coarse granularity, leading to inefficient bandwidth usage. Therefore, Optical Packet Switching (OPS) [2] and Optical Burst Switching (OBS) [3], where data is switched per packet/burst, receive much interest. They allow finer granularity and statistical multiplexing gains, leading to efficient bandwidth usage. Both technologies need fast optical switching matrices, of which 2 major families are Semiconductor Optical Amplifier (SOA) based Broadcast & Select (B&S) architectures and Arrayed Waveguide Grating (AWG) based designs [4]. We discussed Clos architectures for OPS nodes in [5], however, upgradeability of OPS nodes is also of key importance. Starting from SKOL, a more upgradeable modification of the

Clos design [6], we evaluate applicability of the existing modular designs for the two OPS families.

2. REVISITING SKOL

2.1 The Clos architecture

Figure 1 shows a Clos architecture with the switching nodes drawn explicitly as crosspoint switches. In an NxN switch the N input ports are grouped per n, and both the 1st and 3rd stage have a switching fabric for each such group of n ports. The 2nd stage contains k switches, which each in turn are connected to each of the N/n 1st and 3rd stage switches. Thus the 1st stage has nxk switches, the 2nd N/nxN/n, and the 3rd kxn. For a strictly non-blocking architecture k≥2n-1 is sufficient [7]. [8] gives a detailed classification of different blocking natures and their conditions.

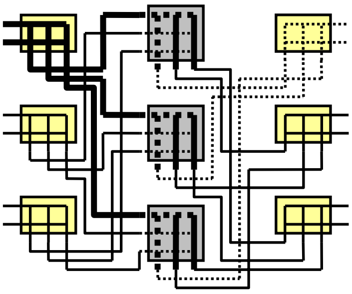

Figure 1. An example Clos architecture with N=6, n=2 and k=3.

The size of the centre stage blocks (N/nxN/n) is fully determined by the number of outer stages. In normal Clos switches upgrades can only be done by adding extra outer blocks, the centre stage must be built completely form the start. Upgrades are possible by adding extra outer blocks. This means that all k inner stages need to be present from the start even if only 1 outer stage is installed. The SKOL design is an improved way to build upgradeable switches.

2.2 From Clos to SKOL

Mc Donald distributes the centre stage over the outer stages to achieve a switch design that is more cost effective when upgraded [6]. *Figure 1* shows how: starting from the input side the bold lines form a single switch module. The same can be done with an output block, indicated in dotted lines. This makes the input and output blocks exactly the same, giving the important condition that the switch is reciprocal. This is a great advantage as it means that higher volume production of identical blocks can be reached. We will continue to use the terminology introduced by Mc Donald: SKOL architecture, an anagram of Clos's name. The volume advantage should translate into a cost decrease. We see that the SKOL blocks now have N/n input ports and kN/n output ports. Figure 2 shows an upgrading scenario. Indeed, in the initial blocks not all outputs (inputs) are used, and as the switch grows, more of these pins are used. When at its full size, all interconnections are present. Note that the maximum possible dimension is still limited from the beginning, as was the case with a Clos switch.

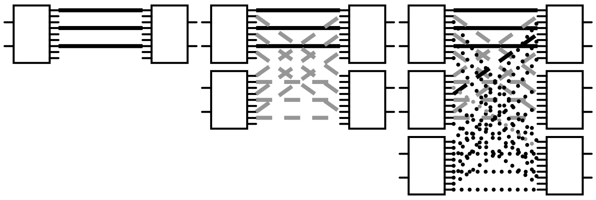

Figure 2. Upgrading using a SKOL architecture. First the full connections are present, then the grey dashed ones are added, and finally the dotted connections fully build the final node.

2.3 On the output block

We now discuss the output block some more than in the original paper. We focus on the top output block of *Figure 3*. We indicated the part of the distributed centre stage by the small block denoted with the small letter b. Such a small block can be replaced with a passive combiner. The proof is very much alike the proof for the strictly non-blocking condition for the Clos design itself: consider the worst condition under which we want to add an extra connection. We consider the distributed middle stages in node B, and a connection coming from node A. The worst case:

1. n-1 (output) ports of node A are already in use.
2. Suppose there are already n-1 connections to node B. Note that although the Output block has N(2n-1)/n input ports, they can not all be used simultaneously, as these blocks have only n output ports.

If we want the b-blocks to be simple passive combiners (which are cheap), only one input (of these b-blocks) can be used simultaneously. Condition 2 means that for this to hold, n-1 of these blocks are necessary (as each input block has a connection to each b-block). Condition (1) means n-1 of it's a-blocks are in use. As only one of the N/n output ports of the a-blocks can be active, the worst case corresponds with the case where the n-1 active ones are the one's corresponding to the non active b-blocks in the considered B node, i.e. n-1. So 1 more is needed: (n-1)+(n-1)+1=2n-1. This condition holds, so the b-blocks can be passive optical combiners. The output block can be made simpler than the input block; however it does make the block different, decreasing the volume advantages mentioned in section 2.2. We will now apply the described SKOL technique to two OPS Clos node architectures, described in more detail in [5].

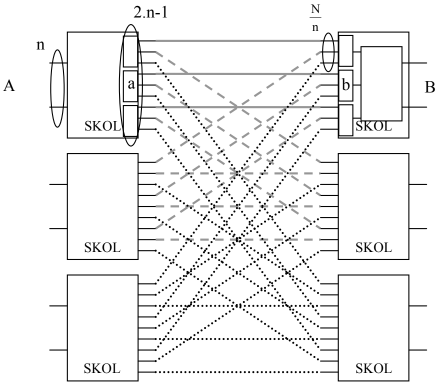

Figure 3. A SKOL node in a schematical representation

3. SKOL AND AWG BASED OPS NODE

An AWG based Clos building block (e.g. dashed box on *Figure 4*) consists of an AWG where input ports have Tuneable Wavelength Converters (TWC), whose output wavelength determine the output port. An important feature of this design is that it is not reciprocal: inputs and outputs can not be interchanged, thus input and output SKOL blocks differ.

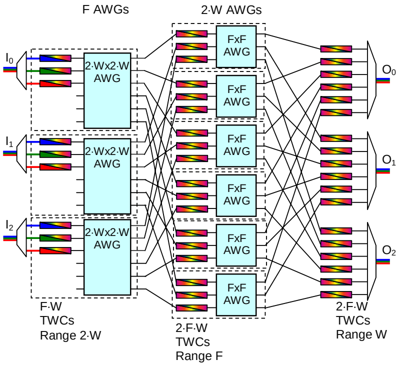

Figure 4. AWG Based Clos design

In *Figure 4* we chose the number of input blocks N/n=F (the number of fibres) and thus the number of ports per block n=W (the number of wavelengths on a fibre). This made the AWG at the third stage unnecessary, since that AWG only switched between wavelengths on the same fibre. However, the design is dedicated (fixed) to a certain value of W. Note that we chose to have 2W inner stages instead of the minimum required 2W-1.

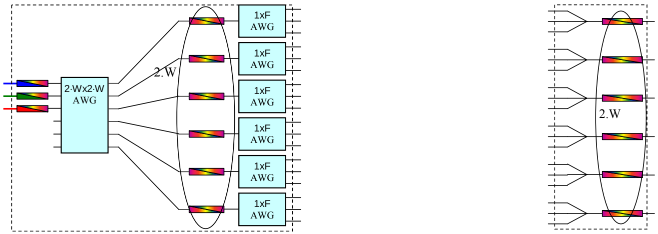

Figure 5. A design for a SKOL input (a) and output (b) block for an AWG based node

A possible implementation of a SKOL input block for this design is shown in *Figure 5*a. When all input blocks (F of them) would be designed like this, we need 2FW 1xF AWGs and 2FW TWCs of range F for the 'distributed' inner stage. The original Clos (*Figure 4*) has the same TWC count, but needs only 2W AWGs of size FxF. Component count for the first stage (of the SKOL block) does not change compared to *Figure 4*.

Table 1. Component count evolution for an AWG based node with F_{max}=10 and W=32.

	With SKOL			**Without SKOL**		
F	*TWC's*	*1xF AWG*	*2.Wx2.W AWG*	*TWC's*	*FxF AWG*	*2.Wx2.W AWG*
2	320	128	2	320	64	2
3	480	192	3	480	64	3
4	640	256	4	640	64	4
6	960	384	6	960	64	6
7	1120	448	7	1120	64	7
8	1280	512	8	1280	64	8
9	1440	576	9	1440	64	9
10	1600	640	10	1600	64	10

*Figure 5*b shows an output SKOL block in AWG based technology, including the considerations in section 2.3 on the passive first block in the output block, so that we can realise it by a passive combiner. We have 2n (=2W) outputs here, and not n as expected. This has the same cause as in the Clos design of *Figure 4*: we remove the AWG from the 3rd stage, as it would only switch packets from one wavelength to another within the same fibre. This way, only having the converters suffices in order to have the (at most) W packets on W different wavelengths. Using these building blocks we create an upgradeable node with respect to adding a fibre. Per fibre we

need one of the above blocks, where a maximum number of fibres is chosen in advance to F_{max}. The switch can then grow (cfr. *Figure 2*) until F_{max} is reached. *Table 1* shows the evolution of a node for F_{max}=10, W=32.

Unfortunately, the SKOL method is not beneficial in the AWG-based case, as we look at the number of central (1xF in the SKOL case, FxF case without) AWGs. The Clos case is one where we immediately install the full middle stage, in this case all 64 10x10 central AWGs. We can then, as fibre count increases, add the outer blocks as needed. Also the TWCs of the centre stage can be gradually added. So the only difference is the AWG count and their nature, i.e. 1xF vs. FxF. Roughly speaking an FxF AWG will be 2 times the cost of an 1xF AWG. This means that using the SKOL approach is not beneficial. The crucial reason is that the switching elements in the STOLAS technology (AWG) are governed by linear growth and not quadratic as with crosspoint switches. However, the Clos design of *Figure 4* can be quite good already for upgrading with extra fibre(s), although some provisions must be made in the beginning, which also limit possible growth. A wavelength upgrade would be a lot more complex.

4. SKOL AND SOA BASED B&S OPS NODE

In the B&S node architecture of *Figure 6* [9], all inputs are broadcast to all possible outputs, where a choice is made using SOA based space and wavelength selection. [9] shows that an optimised (in number of SOAs) building block with N ports has $2N^{3/2}$ SOAs, in the case of a 2-stage architecture of *Figure 6*a. We consider a slotted approach and thus W FxF stages suffices, as we can suffice with a rearrangeable node.

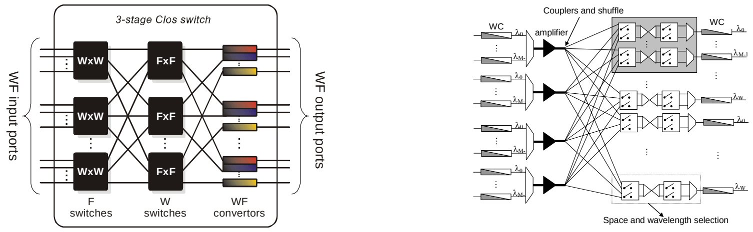

Figure 6.a) B&S SOA based Clos node design; b) Clos building block

Again, we can use the SKOL mechanism to distribute the middle stage into the first stage, meaning we only have SOAs at the input stage. This means each input SKOL block would carry $2.W^{3/2}+F_{max}W$ SOAs. In *Figure 7*a, the full lines show the evolution of cumulative cost as a SKOL SOA-based switch would grow, for W=32 and F_{max}=10. We compare this with a Clos solution, where we immediately overbuild the central stage with

$F_{max}xF_{max}$ nodes. The initial number of SOAs of the node is lower, but as the node grows, the number of SOAs rises and becomes higher than the eventual total cost for the Clos design. Analytically:

$$\frac{\text{SKOL(final)}}{\text{Clos(final)}} = \frac{2\sqrt{W}+F_{max}}{2(\sqrt{F_{max}}+\sqrt{W})},$$

The larger W, the closer this value goes to 1. However with increasing F_{max}, this value grows larger. Again the origin of this discrepancy with the original paper [6], is due to the fact that a quadratic law (i.e. the number of crosspoints) governs the cost of a node.

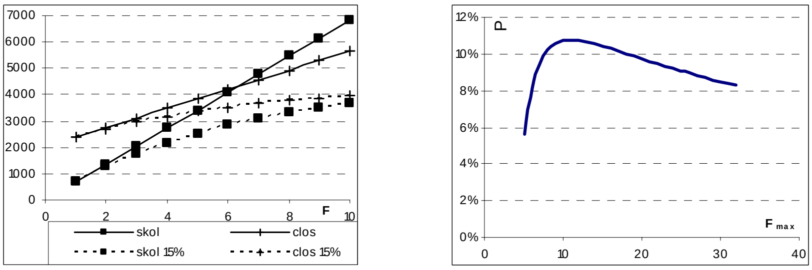

Figure 7. a) SOA count evolution for F_{max}=10 and W=32;b)Needed cost decrease

Still SKOL may be useful for this kind of node, if the cost of the building blocks (i.e. the number of SOAs) would show a steep enough decrease in time. Look at the test case of a switch with F_{max}= 10, where every step a fibre is added. In *Figure 7*a the dashed curves show the same cumulative cost, where every upgrade, the cost is 15% lower than the previous upgrade. *Table 2* formulates the cumulative cost for the final design, so as the node has reached F_{max}, p denotes the constant cost drop at every upgrade.

Table 2. Number of SOAs for both the Clos and SKOL final design

Clos	**SKOL**
$2.W.(F_{max}.\sqrt{F_{max}}+\frac{\sqrt{W}.(1-(1-p)^{F_{max}})}{p})$	$\frac{W.(2.\sqrt{W}+F_{max}).(1-(1-p)^{F_{max}})}{p})$

The final cost of SKOL and Clos is equal if

$$\frac{1-(1-p)^{F_{max}}}{p} = 2.\sqrt{F_{max}}$$

The condition is independent of the number of wavelengths per fibre, W. The equation's result is shown in *Figure 7*b. We see an initial increase in the needed value of cost reduction, with a maximum of 10.8% at F_{max}=11. After this the necessary reduction drops slowly. More important is that the needed value is not extremely high, so quite realistic, certainly for components like SOA's which still have a large margin to mature. A needed value of 10% reduction at every upgrade is a good rule of thumb.

CONCLUSION

We extended the SKOL mechanism to OPS switching nodes. A crucial difference is the non–reciprocal character of an AWG based switching node. For AWG based OPS nodes, the SKOL method doesn't result in any improvement. SOA based B&S architectures can reach a cost benefit if the price of building blocks drops sufficiently over time: 10% between every upgrade is a good rule of thumb.

ACKNOWLEDGEMENTS

This work was partly funded by the European Commission through IST- STOLAS, IST-NOBEL and the Flemish Government through IWT-GBOU ONNA. J. Cheyns is Research Assistant of the Fund for Scientific Research–Flanders (Belgium) (FWO–Vlaanderen). E. Van Breusegem and D. Colle thank IWT for support through their (post-)doctoral grants.

REFERENCES

[1] S. De Maesschalck, et al., "Intelligent Optical Networking for Multilayer Survivability", IEEE Comm. Mag., Vol. 40, 1, pp 42-49, Jan. 2002.

[2] P. Gambini, et al., "Transparent optical packet switching: network architecture and demonstrators in the KEOPS project," IEEE J. on Sel. Areas in Comm., Vol. 16, 7, pp. 1245–1259, Sept. 1998.

[3] C. Qiao, et al., "Optical burst switching (OBS) - A new paradigm for an optical internet", J. High Speed Netw., Vol. 8, 1, pp. 69–84, Jan. 1999.

[4] C. Develder, et al., "Architectures for optical packet and burst switches ", ECOC 2003, Rimini (Italy), Sept. 2003.

[5] J. Cheyns, et al., "Clos lives on in optical packet switching", IEEE Comm. Mag., Vol. 42, 2, pp. 114-121, Feb. 2004.

[6] R. I. MacDonald, "Large Modular Expandable Switching Matrices", Phot. Techn. Lett., Vol. 11, 6, pp. 668-670, 1999.

[7] C. Clos, "A study of non-blocking switching networks", Bell System Technical Journal, Vol. 32, pp. 406-424, 1953.

[8] A. Jajszczyk, "50 Years of Clos Networks a Survey of Research Issues", HPSR, http://www.tlc-networks.polito.it/HPSR2003/talks/Clos_HPSR_AJ.pdf, June 2003.

[9] C. Develder, et al., "Multistage architectures for optical packet switching using SOA-based broadcast-and-select switches", OFC, Atlanta (GA, USA), Mar. 2003.