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 an Automatic Switched Optical Network (ASON), dynamically allocating capacity between different nodes by 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 2 OPS families.

2. REVISITING SKOL

2.1 The Clos architecture

Figure 1 shows a 3-stage Clos architecture for a NxN switch (in this paper we only consider symmetrical switches). The N in- and output ports are grouped per n, and for each such group there is a switching fabric in both the 1st and 3rd stage. The 2nd stage comprises k switches of dimension N/nxN/n, connected to each of the 1st and 3rd stage switches (size nxk, resp. kxn). The required number of 2nd stage switches (k) depends on the blocking requirements [7], e.g. a strictly non-blocking switch needs k≥2n−1 [8].

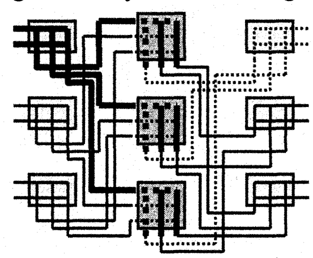

Figure 1. An example Clos architecture with N=6, n=2 and k=3.

The center stage switch size (N/nxN/n), is completely determined by the grouping factor n and the size N of the overall switching structure. Looking at the Clos structure as a modular switch, it has the disadvantage that all of the second stage fabrics have to be installed from the beginning: initial cost savings can only be made by suppressing blocks in the first and third stage. This seems to be not the most cost efficient upgrade facility.

2.2 From Clos to SKOL

To allow a more effective upgrade strategy, McDonald proposed to distribute the central fabrics' functionality over in- and output blocks [6]. For a crossbar switch, this means that an N/nxN/n switch in the second stage is split into two halves, indicated by the bold, resp. dotted lines in *Figure 1*.

This approach boils down to the following: an N/nxN/n switch in the central stage of *Figure 1* is split into 2 halves (each of size N/nxN/n), and each of those is split into N/n parts (of size 1xN/n or N/nx1). Of these halves, k are taken together (corresponding to the k original second stage fabrics), and integrated with a 1st stage switch to form a so-called SKOL building block of size N/n x (k.N/n). The other halves are joined with the 3rd stage switches to form output so-called SKOL blocks of size (k.N/n) x N/n. Note that these blocks can be exactly the same, given that the switch is reciprocal (i.e.the switch can be used in both directions, the in-and output functionality is interchangeable). This is a considerable advantage over the original Clos structure as of *Figure 1*, where at least 2 types of building blocks are required (cf. central stage fabrics have different sizes).

Yet, from an upgrade perspective, still not all of the provided building block's ports are used from the beginning. An expansion scenario is outlined in Figure 2. In Figure 2a, only 1 input and 1 output SKOL block are used, with a considerable amount of unused ports. But they are necessary to allow the switch to be expanded until its final size of NxN, as shown in Figure 2b and c. Note that the maximum possible dimension N is still limited from the beginning, as with a the original Clos switch.

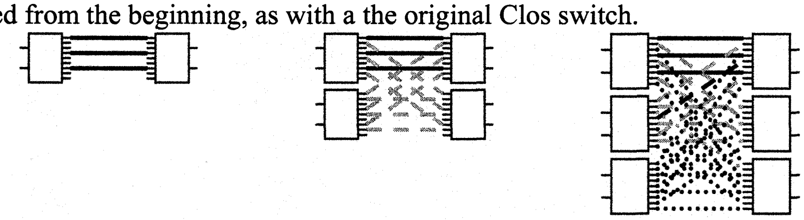

Figure 2. Upgrading using a SKOL architecture. First the full connections are present, then the grey dashed ones are added, and finally the dotted connections fully build the final node.

2.3 On the output block

As explained in 2.1, a SKOL output block has k switches of size k.N/nx1, integrated with the kxn 3rd stage switches of the original Clos design. To implement a strictly non-blocking switch, the condition $k \geq 2n-1$ needs to be fulfilled. The proof is analogue to that of the requirement of the number of 2nd stage switches in the original Clos design. Suppose that in *Figure 3* a connection from input port x in an input SKOL block A to output port y of an output SKOL block B needs to be made, while (i) all of the other $n-1$ inputs of block A are in already in use, and (ii) the $n-1$ remaining outputs of B are in use. (i) implies that $n-1$ of the output ports of the nxk sub-block in A are in use (and thus $n-1$ of the sub-blocks a). (ii) means that also $n-1$ inputs of the kxn sub-block in B, thus $n-1$ sub-blocks b. By design, each sub-block a is connected to only a single sub-block. The worst case occurs when the $n-1$ active blocks a in A are the ones connected to the $n-1$ non-active blocks b in B. To be able to connect x to y, it is required that $k \geq$ (# active a blocks) + (# active b blocks) + 1 = $2n-1$.

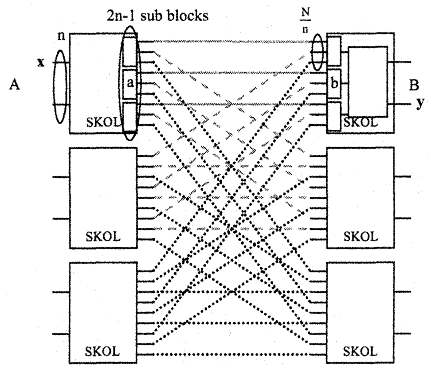

Figure 3. A SKOL node in a schematical representation

It is important to note that the sub-blocks b can be replaced by passive combiners, since they have only a single output and thus only 1 of their inputs should be active at any time. This means that the output SKOL block will be different from the input SKOL block. Yet, the potential decrease in cost advantage (due to economy of scale, which motivated McDonald to come up with symmetrical SKOL building blocks for in- and outputs, cf. section 0) should be easily compensated for by the now much simpler (thus cheaper) design of output SKOL blocks. We now apply the described SKOL design to 2 OPS node architectures, presented in more detail in [5].

3. SKOL AND AWG BASED OPS NODE

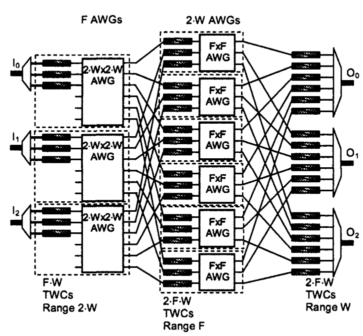

Figure 4. AWG Based Clos design

An AWG-based Clos building block (dashed box on *Figure 4*) has an AWG where input ports have Tuneable Wavelength Converters (TWC) installed, whose output wavelength determines the output port. The design isn't reciprocal: inputs and outputs can't be interchanged, so input and output SKOL blocks differ.

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 3rd 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.

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*.

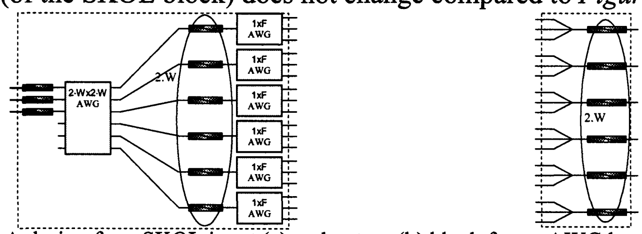

Figure 5. A design for a SKOL input (a) and output (b) block for an AWG based node

*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 set 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. In the Clos case we immediately install the full middle stage, in this case all 64 10x10 central AWGs. Then, as fibre count increases, outer blocks are added 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 twice the cost of an 1xF AWG [10], so the SKOL approach is not beneficial. The reason is that the switching elements in the AWG-based technology are governed by linear cost and not quadratic as with crosspoint switches. The Clos design of *Figure 4* can thus be quite good for upgrading with extra fibres, although some provisions must be made in the beginning, which also limit possible growth. A wavelength upgrade would be a lot more complex.

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

	With SKOL			Without SKOL		
F	*TWC*	*1xF AWG*	*2Wx2W AWG*	*TWC*	*FxF AWG*	*2Wx2W AWG*
2	320	128	2	320	64	2
3	480	192	3	480	64	3
4	640	256	4	640	64	4
5	800	320	5	800	64	5
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

4. SKOL AND SOA BASED B&S OPS NODE

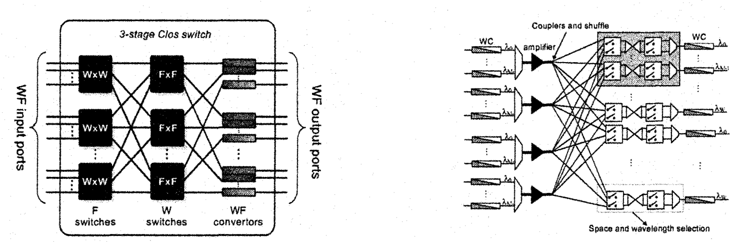

Figure 6.a) B&S SOA based Clos node design; b) Clos building block

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.

Again, we can use the SKOL mechanism to distribute the middle stage into the 1st stage, meaning we only have SOAs at the input stage. This means each input SKOL block would carry $2W^{3/2}+F_{max}W$ 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 is to 1. However increasing F_{max} this value grows larger. Again the origin of this discrepancy with [6] is due to the fact that a quadratic law (number of crosspoints) governs the node cost.

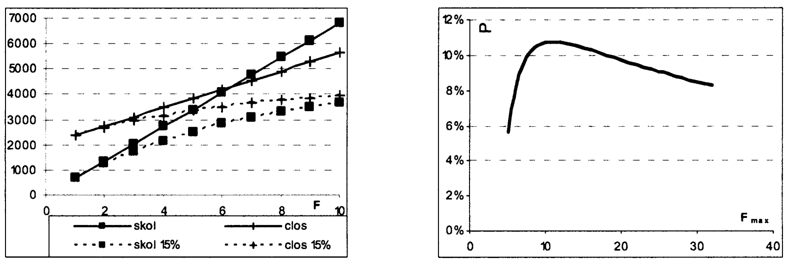

Figure 7. a) SOA count evolution for F_{max}=10 and W=32;b)Needed cost decrease

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

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}=10. For higher F_{max} the necessary reduction drops slowly. More importantly 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.

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