Cost Evolution of Packet Switching Nodes

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Abstract

This paper addresses the cost of packet switching nodes in terms of component cost. It investigates the node cost difference between four different packet switching nodes: an optical packet switching node with electronic header processing, an electronic IP packet switching router and two all-optical packet switching nodes.

The cost of these nodes is calculated as a function of the traffic load in the network. The study shows that although originally, all-optical packet switching nodes are far more expensive than the other technologies, the cost difference decreases with increasing traffic.

Introduction

The transport of IP packets through an optical network is possible in different ways. The first packet switching networks put IP packets directly on the optical wavelength. Every intermediate node on the packet's path converts the packet back to the electronic domain to make the routing decisions. Because these Optical Electronic Optical (OEO) conversions at high bit rates are very costly one decided to only convert the packet's header in intermediate nodes. The payload of those packet remains in the optical domain during the packet's itinerary. Recently, the concept of all-optical packet switching is proposed. A packet traverses through the optical network in an all-optical way, [1]. No costly OEO conversions are necessary in intermediate nodes because the header (label) of the packet is examined all-optically and intermediate nodes decide all-optically where to forward the packet. A drawback of this approach is that the all-optical node requires an enormous amount of hardware to perform the necessary label reading/replacing actions on the packet's label, [1]. This also influences the nodes cost. This paper focuses on the cost of the four proposed packet switching node architectures. It compares them and maps how they relate to each other when the traffic load increases.

The packet switching node architectures

Although all the packet switching nodes that are addressed in this paper use different switching technologies, they all belong to an optical network architecture. Optical networks are built out of fibers. These fibers interconnect the different network nodes. By virtue of Wavelength Division Multiplexing (WDM) several wavelengths are multiplexed into one fiber, increasing de bandwidth capacity of that fiber.

The first packet switching node is an electronic IP router. Thanks to WDM, IP packets are wavelength-multiplexed into one fiber for transportation. At the nodes, the wavelengths are demultiplexed and the IP packets are converted on a packet-by-packet basis to the electronic domain. The electronic IP router then decides to which output port to switch the packet. The packet is then again re-converted to the optical domain and wavelength-mutliplexed into the fiber which leads to the next node on the packet's path.

The second node is the Electronic Header processing node. In contrast to the first packet switching node, this node only converts the packet's header to the electronic domain. It is also called an optical packet switch because the payload of the packet is switched optically. Moreover, it remains optically during the whole packet's journey through the optical network. Because the header of the optical packet is relatively short compared to the payload (in number of bits) it can be modulated at a lower bit rate. Thus, although OE conversions still need be made, they are at lower bit rate, so less costly. The example node that is used in this study is the node proposed by the WASPNET project, [3]

The third and fourth packet switching approaches are all-optical approaches. They form a logic next step in the evolution of packet switching nodes. Although logic, the development of all-optical components to perform the necessary routing functionality still is mature. Moreover, the design of all-optical node architectures encounters new problems (e.g., the lack of optical memory causes the nodes to be hardly scalable [1]). The LASAGNE project, [1], proposes two different all-optical nodes. The first's routing principle is based on the Multi Protocol Label Switching (MPLS) protocol. It sets up Label Switched Paths (LSP). A LSP is a route followed by all packets sent from a particular source to a particular destination node. Packets belonging to a particular LSP are distinguished by a label. This label has a local meaning on a link of the packet's path and it is 'swapped' (changed into another label) in each intermediate node of the packet's path. The first all-optical node possesses the necessary all-optical components to perform the label swapping functionality and thus route the packet all-optically.

The fourth packet switching node, the second all-optical node, makes use of the label stripping principle to route the packets through the network. Here also, packets carry a label. Now, the label is a concatenation of different smaller local labels. Each of these local labels is responsible for the correct routing in a particular intermediate node of the packet's path. It refers to the output port in that node the packet has to be routed to. When used, this local label is removed.

The Cost Functions

The total cost function of a node possesses an optical cost part and an electronic cost part. The optical cost is defined by the number of Fiber-to-Chip Couplings (FCCs) for each of the optical components in the node architectures. This choice is based on the assumption that packaging and more specifically the number of interconnections to the outer world dominate the cost of optical components. The cost functions are calculated by the method proposed in [4]. To address the electronic cost of a node we counted the number of OEO conversions. We assume that the reference cost of 1 can be set to the cost of one OEO conversion at a bit rate of 155 Mb/s. For higher bit rates the cost is defined according to the following relation:

$$\text{Bit Rate x 4} \rightarrow \text{Cost x 2.5} \quad (1)$$

Table 1 shows the parameters that define the cost functions. Before summing the optical and electronic cost we multiply the electronic cost by P. In the following, we will plot the cost in function of the parameter P.

Name	Description
F	The number of fibers
W	The number of wavelengths in one fiber
P	The ratio between the optical cost for an FCC and the electronic cost for an OEO at 155 Mbps
B	The number of bits in a label
Head. BR	Header bit rate

Table 1 The parameters used in the cost functions

The individual cost functions

This section discusses the cost functions of the four proposed packet switching node architectures. The cost functions are collected in Table 2. We do not go into detail in the building of these cost functions because this would bring us outside the scope of this article. For the first node architecture, the fully electronic packet switching approach – IP over WDM – there exists only an electronic cost: the cost increases linearly with F, W, the cost of an OEO conversion (defined by (1)) and P, whereas the cost is independent of B. The second approach is that of an optical packet switching node with electronic header processing. Headers are often modulated at a lower bit rate than the payload to avoid costly high bit rate OEO conversions. The cost function has an optical and electronic part. Although the cost functions for a node with electronic header processing and IP over WDM node are equal, the cost function of the node with electrical header processing is calculated at a lower bit rate, which causes a decrease in the final result. The optical cost is only dependent on F and W. The cost functions of these first two nodes are parallel when they have the same parameter values. The third and fourth approaches are all-optical. Both the label swapping and label stripping approaches are considered. These last approaches only have an optical cost, which is exponentially dependent on B (2B). Header and payload are modulated at the same bit rate, although it is possible to modulate the header at a faster bit rate than the payload. When the traffic increases, this allows the all-optical nodes to easily increase their capacity by adapting the payload bit rate to the maximum wavelength speed, without the need for installing new and additional hardware.

The cost of all-optical nodes is only dependent on the number of FCC of the components to build the node. It would thus be advantageous for the all-optical node cost if the level of integration could be increased. Due to integration, the number of individual components that need be installed would decrease, which would certainly decrease the cost of the all-optical nodes.

Node	Cost Function (in number of FCC)
IP over WDM	$P \cdot F \cdot W \cdot C_{BR}$
Elect. Header	$2 \cdot F + 15 \cdot F \cdot W + W \cdot F^2 + P \cdot F \cdot W \cdot C_{BR}$
Label swapping	$F \cdot (2 + 48 \cdot W + 21 \cdot W \cdot 2^{(B-1)} \cdot B + 27 \cdot W \cdot 2^{(B-1)} + 4 \cdot W \cdot B)$
Label stripping	$F \cdot (2 + 42 \cdot W + 15 \cdot W \cdot B \cdot 2^{(B-1)} + 9 \cdot W \cdot 2^{B} + 4 \cdot W \cdot B)$

Table 2 The total cost functions for the different nodes

Initial Case Study

To make cost comparisons we start form an initial situation in which the node has a traffic load of 80 Gbps (today this is a common router capacity). This corresponds with 4 fibers of each 8 wavelengths at data bit rate of 2.5 Gbps (4*8*2.5 Gbps). The details of the case study are summarized in Table 3. We assume data can be modulated at a maximum of 40 Gbps per wavelength.

The IP over WDM node and the Electronic header processing node handle packets at a lower speed than the maximum data rate. With a traffic load of 80 Gbps it is not needed to modulate the data faster, which maintains the OEO conversion cost.

The header bit rate for the packets of the all-optical networks is higher than the payload bit rate. The reason is that the all-optical components to do the label recognition/swapping are developed for a particular bit rate. If the header bit rate would have been chosen to be less than the wavelength data rate, it wouldn't be possible to increase it when the traffic load increases. Indeed, when traffic load increases, one will try to increase the bit rate in order to modulate more bits in a smaller time period. There is a difference in the number of bits that is assumed for label stripping labels and label swapping labels. The difference comes from the study in [1]. Indeed, the local label for label stripping can be much shorter than for label swapping because it only has to distinguish between the output ports of a node and not between all possible LSPs on a link in the network.

Fig 1 depicts the cost functions of the different node architectures with the parameter values of Table 3 in function of the parameter P. The figure shows that the optical cost of the Electronic Header processing node is very small compared to the electronic part (both curves of IP over WDM and Electronic Header processing almost overlap). It is also visible that the all-optical approaches (in special the label swapping) are far more costly than the IP over WDM and the Electronic Header processing nodes. The intersection points of the all-optical node cost functions and the IP over WDM node or the Electronic Header processing node are at high P values. These intersection points give the cost from which all-optical approaches are cheaper than the other packet switching approaches. The high P value reflects the huge difference between the FCC cost and the OEO cost.

	Swapp.	Stripp.	IP over WDM	Electr. Head.
B	8	3	-	-
Payl. BR	2,5 Gbps	2,5 Gbps	2,5 Gbps	2,5 Gbps
Head. BR	40 Gbps	40 Gbps	2,5 Gbps	2,5 Gbps
F	4	4	4	4
W	8	8	8	8

Table 3 Parameter values for the initial case study.

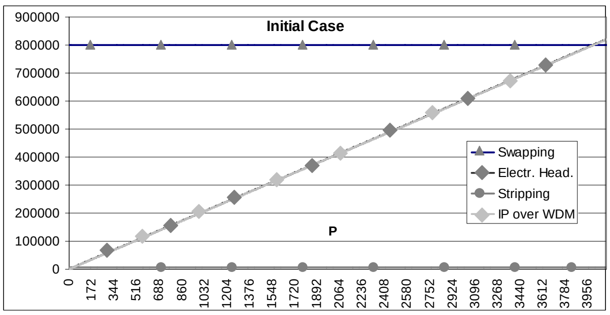

Fig 1 The cost functions for the initial case study

Cost Comparisons

To compare how these cost functions relate to one another, the traffic load is assumed to increase with a factor 100 (a time space of about 10 years for a traffic growth of 65% per years). In the following case studies a traffic load of 8000 Gbps is assumed. To carry the traffic bigger nodes are needed. The parameters for different situations are summarized in Table 4. The wavelength data rate is still 40 Gbps. For label stripping and label swapping packets are modulated at the maximum bit rate. Due to this, a smaller number of wavelengths is needed to transport the 8000 Gbps.

For the Electronic Header processing node and the IP over WDM node header bit rates are assumed to be 2.5 Gbps or 10 Gbps. The IP over WDM node handles packets of which header and payload have the same bit rate because the whole packet needs conversion to the electronic domain. For the Electronic Header processing node, the header bit rate is lower than the payload bit rate. The reason is that at higher bit rates more data is modulated in the same time slot, but to maintain the OEO conversion cost, low bit rates are preferred. Because only the header is converted to the electronic domain, the payload may have a high bit rate. The difference between the header bit rate and the payload bit rate can not be more than four times because the header would become too long compared to the payload length (i.e. to have a lower header bit rate, the header bits are alternated with stuffing (meaningless) bits).

Fig 2 shows how the cost functions relate to one another when traffic increases. The cost for the label stripping/swapping approaches does not increase as much as the cost for the IP over WDM and Electronic Header processing nodes. This is because, the all-optical approaches allow higher payload and header bit rates and thus fewer wavelengths and fibres need be installed to accommodate the same traffic load. It makes the cost difference between the all-optical approaches and the others less explicit because it was the need for hardware that caused all-optical nodes to be very expensive.

We foresee that for further traffic increase the all-optical approaches will have even more advantage and beat the other nodes, even for P-values only slightly bigger than 0.

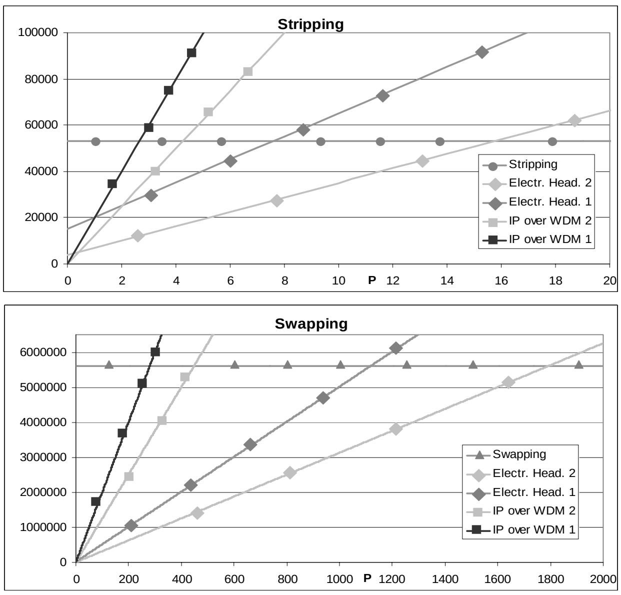

Fig 2 Cost Functions for the case studies from Table 3

	Swapping	Stripping	Electronic Header processing 1	IP over WDM 1	Electronic Header processing 2	IP over WDM 2
B	8	3	-	-	-	-
Payload BR (Gbps)	40	40	10	2,5	40	10
Header BR (Gbps)	40	40	2,5	2,5	10	10
F	4	4	4	4	4	4
W	50	50	200	800	50	200

Table 4 Parameter values for the cost comparisons

The slope of the cost curves for IP over WDM and Electronic Header processing nodes is defined by the cost of an OEO conversion (which is defined by (1)) multiplied by the number of wavelengths and the number of fibers. Due to this, none of the 4 curves have the same slope. If high-bit-rate OEO conversions (10 Gbps) are possible, the Electronic Header processing node can modulate payloads at wavelength data rate and so reduce the number of wavelengths that need be installed. This reflects in a smaller optical cost. It also reduces the electronic cost but not as much, because if also the OEO conversion speed increases, these OEO become more costly (e.g., Electronic Header processing 1 needs 4 times more wavelengths than Electronic Header processing 2, though the slope of Electronic Header processing 2 is only 1.6 times different of Electronic Header processing 1 (i.e. 4*200*6.25 (one OEO costs 6.25 at 2.5 Gbps) divided by 4*50*15.6.25 (one OEO costs 15.625 at 10 Gbps), thus 5000/3125 = 1.6)).

Conclusions

The extra cost of all-optical nodes with respect to other packet switching nodes decreases with increasing traffic load and possibilities of integration. This is because the electronic cost is mainly defined by the cost of OEO conversions and the fact that all-optical nodes can increase easily their capacity by using the maximum wavelength speed without additional cost.

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References

1. “IST-LASAGNE: Towards All-Optical Label Swapping Employing Optical Logic Gates and Optical Flip-flops”, F. Ramos, E. Kehayas, J. M. Martinez, R. Clavero, J. Marti, L. Stampoulidis, D. Tsiokos, H. Avramopoulos, J. Zhang, P. V. Holm-Nielsen, N. Chi, P. Jeppesen, N. Yan, I. Tafur Monroy, A. M. J. Koonen, M. T. Hill, Y. Liu, H. J. S. Dorren, R. Van Caenegem, D. Colle, M. Pickavet, and B. Riposati, accepted for Journal of Lightwave Technology, Nov 2005
2. “All Optical Label Swapping: a challenge for node dimensioning”, R. Van Caenegem, D. Colle, M. Pickavet, P. Demeester, Invited Paper, ICTON 2005, Barcelona 3-7 july
3. “WASPNET: A wavelength switched packet network”, D. K. Hunter, M. H. M. Nizam, M. C. Chia, I. Andonovic, K. M. Guild, A. Tzanakaki, M. J. O’Mahony, J. D. Bainbridge, M. F. C. Stephens, R. V. Penty, and I. H. White, IEEE Communications Magazine, 37, no. 3, pp. 120-129 (1999)
4. “Evaluating Cost Functions for OPS node architectures: A packaging driven approach”, Jan Cheyns, Erik Van Breusegem, Chris Develder, Didier Colle, Mario Pickavet, Piet Demeester, ONDM 2004