Performance Improvement of Colored Optical Packet Switching Thanks to Time Slot Sharing

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***Abstract*—N-GREEN is a cost attractive optical network which uses coloured optical packets. Its basic component is a ring of novel overdimensioned switch/router nodes, which promises low latency, making it interesting for applications with strict latency requirements like 5G. Nevertheless, it suffers from a low efficiency of resources usage, especially when it is used in the Unicast mode popular in the metro aggregation. Here, we try to ensure a better use of network resources by proposing an alternate packet management and transmission method referred to as Ssh-time which could be used in both the Unicast mode and the Broadcast-and-Select (B&S) one. We show by simulation that the proposed method improves not only the resources efficiency in case of a metro-aggregation network, but also decreases the mean access delay.**

Keywords–optical networks; coloured optical packets; N-GREEN; Time Slot Sharing; slotted ring.

I. INTRODUCTION

The optical packet switching technology has been identified as substantial for an improvement of data rate, transparency of a modulation format, fine switching granularity and efficient bandwidth utilization [1]. On the other hand, such optical interfaces are very expensive and power-hungry which limits their applications; this is why the N-GREEN [2] architecture is proposed. It provides streamlined, cost-optimised interfaces [3][4] which use 10 fixed wavelengths yet without the expensive add-ones like accordable lasers, a possibility of an independent assignment or routing of the wavelengths. In applications like the X-haul networks or 5G where the majority of traffic is real-time [5]; N-GREEN is typically overdimensioned. It can be even more simplified by removing any substantial buffer management as well as processing and thus guarantee a very low latency. This is possible, for example, if there are up to 10 Ethernet cards of 10 Gbit each connected to a single N-GREEN ring whenever the network operates in B&S mode.

Nonetheless, due to its reduced cost in terms of price and energy, N-GREEN seems to be attractive also in a number of other segments of network that are less demanding in latency where resource efficiency is important namely in metro aggregation network [6]. Some existing proposals of enhancements of N-GREEN node use input buffers which would improve its performance. Among them we find Ssh-wavelength [7] which proposes to take advantage of the network overdimensioning in order to reduce the latency and increase the network efficiency. The limit condition of this method is that it is restricted to the B&S mode. However, in some cases, we need to use the Unicast mode in order to not flood a whole ring by a local traffic (e.g., two neighbouring nodes in a machine-to-machine traffic). On the other hand, within this mode, different queues should be considered for each destination, which imply that grooming at the source node is not allowed and thus not only low efficiency of resources but also high latency is resulted [7].

For all these reasons and for a further improvement of the network, we propose a method of slot filling referred to as Ssh-time which could be used for both the Unicast and the B&S mode.

The article is organized as follows. Section II discusses basic traits of an N-GREEN ring. In Section III, Ssh-time is elaborated and our simulation setup is presented. Section IV and Section V show performance improvements thanks to Ssh-time in terms of container filling and insertion delay.

II. ARCHITECTURE

In the metro and aggregation networks [8] and also small sized data centres, physical ring topology is often used. A single network consists of two parallel rings, one for each direction. It could be used both for data transmissions or which could be used both for data transmission or one ring for transmission and the other for protection. Let us assume that both rings are used for data transmissions. In each ring we dispose of x fixed size slot of size S = 12500 bytes each, 1250 bytes per a wavelength. A slot passes a node in 1 μs which gives a transfer rate of 100 Gbps. There is no arbitrariness in the choice of a carrier wavelength in a single node since we dispose of fixed lasers. A typically 10 Gbps Ethernet card emits or receives traffic which is converted to/from an optical form by a fixed shift register. Each 10 μs of packets in the electronic form can fit into 1μs of an optical signal of all 10 wavelengths, as illustrated in Figure 1. An additional wavelength is reserved for network control as data and control information are sent separately. This control channel is regenerated at each intermediate node to guarantee in particular a self synchronization of the network. A specificity of N-GREEN is that there is only a single semiconductor optical gate/amplifier (SOA) [9] for all wavelengths (see Figure 1), which stays in contrast to a separate SOA for every wavelength in the much more

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expensive POADM technology [10]. This means that a slot can only be cleared in its totality, when all the wavelengths are either transferred or suppressed.

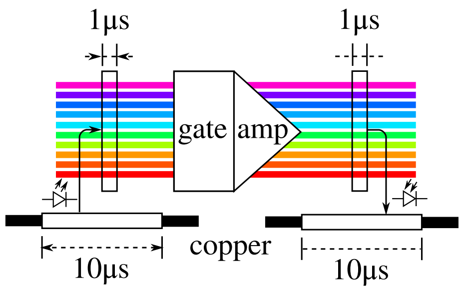

Figure 1: A symbolic presentation of an NGREEN node connected to a 10Gbps Ethernet.

An N-GREEN network includes two types of nodes: those on the ring termed *bridge nodes* and the node that closes the ring by an electrical bridge termed *optical switch node*. Transit traffic bypasses intermediate nodes in a transparent way, i.e., it does not need to be demodulated inside the nodes' electronic structures. Indeed an *optical switch node* connects the ring to other rings where Optical Electrical Optical(OEO) conversions occur at the level of this node. The architecture in question is shown in Figure2 We investigate the performance within the two distribution modes: Unicast, where slots are used by data packets sent to a single other node, and B&S where slots can be used by packets sent to a set of other nodes. In the former mode, a slot has a single destination and that receiver node extracts its corresponding packets and releases the slot. In the B&S mode, a slot may have parts with multiple destinations and as it can only be cleared in its entirety; it may carry an information which is no longer needed. Note that the traffic exchanged between two nodes uses the direction which does not pass by the switch node to avoid OEO conversions and reduce the energy consumption. As packets crossing the switch will be dropped, a special routing is needed where node I sends a packet to node J clockwise if $J \leq I$, or counter-clockwise if $J \geq I$ as shown in Figure 2.

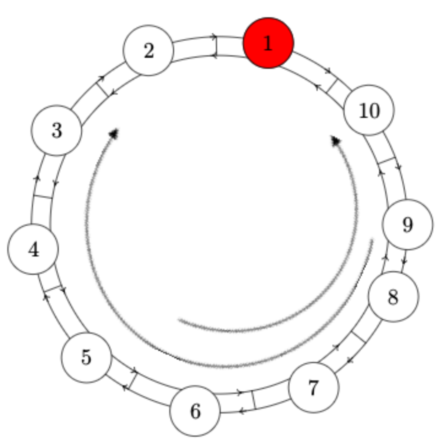

Figure 2: Optical ring topology.

III. SSH-TIME AND CONSIDERED SCENARIOS

In Ssh-time, each node always sends its packets in a sub slot over all the 10 wavelengths. A partially filled slot can be reused by another node which will place its packets over the 10 wavelengths but after the used part of the slot, yet a guard time must be added in between. This margin or gap is required for lasers and other electronic components to be re-adjusted, and to avoid collisions with the fragment already in the fiber. Technically, the guard time consists of zero bits of a minimal duration of 32.8 ns per sub slot. In our simulation, the slot is divided into 4 sub slots in order not to lose more than 18% of its capacity. Figure 3 presents an example of a shared slot encoding according to the two different methods: without and with Ssh-time. The traffic is assumed to be uniformly distributed: packets destinations are randomly chosen with the same probability. Packet size is fixed at 125 bytes which represents an average Ethernet packet size. Packets arrival to nodes are assumed to follow a Poisson process. Note that the packet Loss Rate (PLR) criterion is not considered since no packet loss is allowed in the overdimensioned network. We simulated time division multiplexing (TDM) [11] in which containers are sent upon a regular interval of time (e.g., 10μs) regardless of current network state and container filling level. As for the based-timer mechanism [12], container sending is delayed until the expiration of a previously fixed delay (timer value in T20=20μs, T30=30μs or T40=40μs), unless it is completely filled before timer expiration. In the following we set timer values between T20 and T40. These values were chosen for two reasons: firstly, to avoid an excessive latency since obviously increasing this very value increases subsequently the latency latency, and secondly, whenever a node has enough packets to fill the slot, Ssh-time has almost no interest. Adding to that, in our case timer values have been chosen according to the applied transmission mode respectively 20μs, 40μs for the Unicast mode and 10μs, 20μs for the B&S mode. Contrary to the B&S mode, the Unicast one requires more packets to fully fill the slot hence, we attribute it bigger timer value.

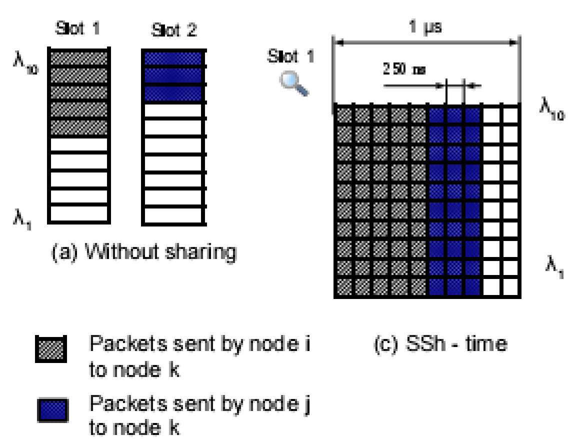

Figure 3: Packet insertion methods.

IV. RESULTS WITHIN UNICAST MODE

The results for Unicast are presented hereafter where Figure 4 and Figure 5 show network load as a function respectively of a mean access delay and the container filling for all scenarios. Note that SSh T20 and SSh T40 stand respectively for 20 and 40 μs timer based mechanism when applying Ssh-time. We pinpoint that the container filling ratio has a value between 0 (entirely empty) and 1 (entirely full) and it is equal to the ratio between the useful data (inserted packets) size and the container size which is in our study equal to 12500 bytes (10 μs at 10 Gbps). While the mean access delay represents the average waiting time of a packet before being inserted into the ring.

The access delay of the first inserted packet in the container is equal to 10 μs. Within TDM insertion method, the mean access delay has to be independent from the system load. When $\rho = 0.9$, the access delay of the inserted packets follows an arithmetic progression with common difference on packets' duration (100 ns). The sum of an arithmetic sequence is:

$$Sn = (n+1) \times \frac{(U_0 + U_n)}{2} \quad (1)$$

where n is the number of terms and U_0 and U_n are respectively the first and the last terms. Let $\overline{A}$ define the mean access delay at $\rho = 0.9$:

$$\overline{A} = \frac{101}{100} \times \frac{(100\,\mathrm{ns} + 10\mu s)}{2} = 5.2\mu s. \quad (2)$$

As expected, the mean access delay is almost constant for TDM insertion method, and has a value between 5.2 and 5.8 μs. Obviously, the TDM mode and one-aside timer 40 (i.e, T40) present respectively the biggest and lowest access delay. However, the slot filling rate remains too low mostly within the TDM mode. It is due to the fact that the packets generated during 10 μs will be put and transported in 9 different slots. Therefore, in order to increase the resources use efficiency by avoiding sending containers with very low occupancy rate; different values of timer has been considered (i.e, T20 and T40). As expected, increasing the timer value significantly improves the container filling yet at the expense of the access delay. This is due to packets clustering that engenders their waiting until the timer is elapsed. Therefore the timer duration should be carefully chosen to achieve a good trade-off between latency and container filling. As seen in Figures 4 and 5, the latency and container filling problems arise mostly when the system is not overloaded within the scenarios without Ssh-time. This is caused by the fact that the timer expires before the slot is fully filled even in the case of the high load.

Thanks to Ssh-time, each node sends its packets to one of the other 9 nodes (division by $(n_{nodes} - 1)$), but in addition to the primary node to which the slot corresponds, three other nodes can share the slot, so during a slot time, we may have up to three emitters (multiplication by $(n_{subslot} - 1)$ where $n_{subslot}$ represents the number of sub slots considered as represented in Figure3). Thus, as pointed out in Figure 4 and Figure 5, Ssh-time improves significantly the container filling and therefore the mean access delay, more particularly, for lower and medium load cases by 20% compared to scenarios without sharing.

It is also important to note that for Ssh-time , in the case of a low load, we does not improve too much the latency however we consider it a beneficial method since it improves the resources use efficiency by 30% as demonstrated in Figure 5. Applying Ssh-time using larger timer values, can improve the latency and slot filling rate for small load values but degrades its performance when the load is big compared with scenarios without Ssh-time. This is due to the guard time that causes a loss of resources.

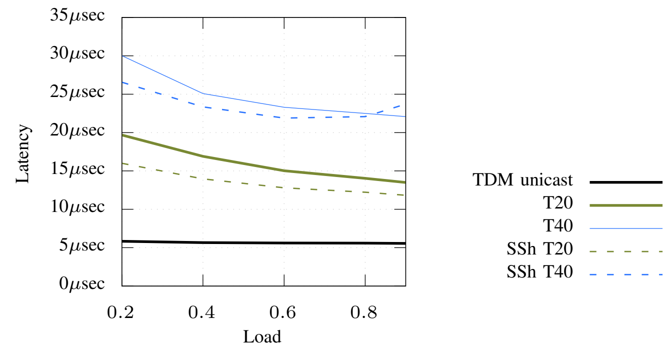

Figure 4: Mean Access delay within Unicast transmission mode for scenarios with and without Ssh-time

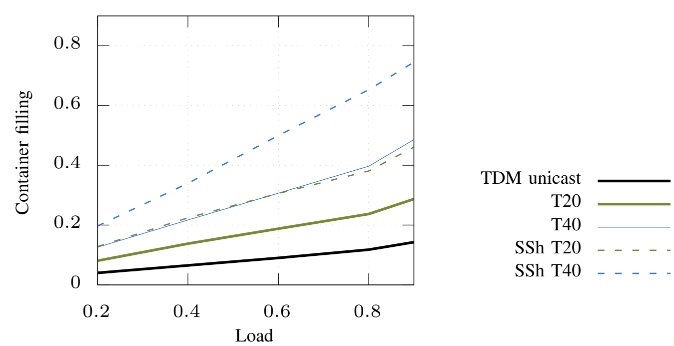

Figure 5: Container filling within Unicast transmission mode for scenarios with and without Ssh-time

V. RESULTS WITHIN B&S MODE

The results of the BS mode are presented below in Figure 6 and Figure 7 where SSh TDM and SSh T20 stands respectively for TDM and 20 μs timer based mechanism applying for both Ssh-time. Within TDM B&S, the packets gathered during $10\mu s$ will be put in the worst case into two different slots which makes the slot filling rate less than the system load, ρ. As for the Unicast mode, an increase in the timer value increases the slot filling ratio and does the same for the latency as shown in Figure 6. To increase this filling without affecting latency, we apply Ssh-time to the B&S mode, which causes the said bandwidth loss because of the guard time and thus the slot is considered fully filled at 0,8. At $\rho = 0.9$, we have almost not only the same filling rate as in the case without Ssh-time but also the same latency: the principal emitter node to which corresponds the slot has sufficient packets to entirely fill the container and the slot sharing does not occur. As ρ decreases, the filling rate increases. Indeed, the principal emitter node does not entirely fill the container, as such other nodes will be able to share the slot. A next sharing node will begin by sending its first buffered packets till filling the container. Since those packets were buffered at the same time or before, their access delay is the same compared to the mean delay of the principal emitter packets. As a result, the mean access delay of all the sent packets during a shared slot is a little less.

Regarding the slot filling rate, as seen in Figure 7, Ssh-time improves the slot filling rate but not as expected since we will have at most three nodes ($n_{subslot} - 1$) that can add their packets in the slot.

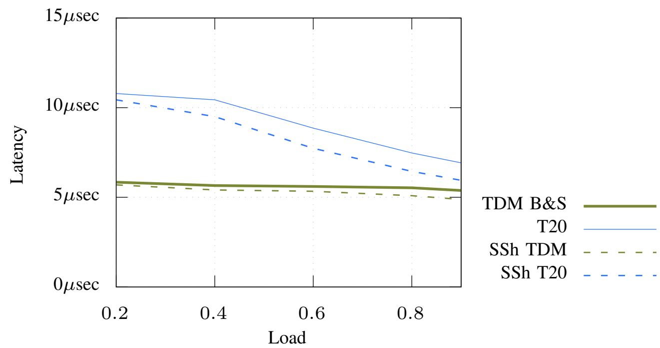

Figure 6: Mean Access delay within B&S mode for scenarios with and without Ssh-time.

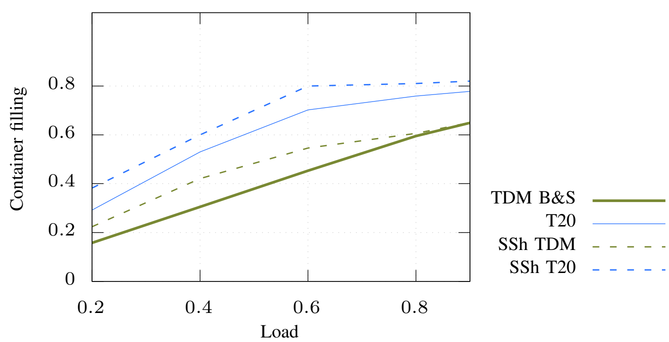

Figure 7: Container filling within B&S mode for scenarios with and without Ssh-time.

VI. Conclusions

In this paper, we have presented the specifities of the N-GREEN architecture compared to legacy existing solutions. We were interested in performance analysis of the metro part of the network. Within a slotted ring architecture, we have proposed and simulated Ssh-time approach for Unicast and B&S distribution modes. In conclusion, our approach Ssh-time improves the performance in terms of latency and the utilisation of resources especially for low and medium network loads reinforcing as such N-GREEN advantages in terms of cost and energy consumption reductions.

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