Time Shared Optical Network (TSON): a novel metro architecture for flexible multi-granular services

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Abstract: This paper presents the Time Shared Optical Network (TSON) as metro mesh network architecture for guaranteed, statistically-multiplexed services. TSON proposes a flexible and tunable time-wavelength assignment along with one-way tree-based reservation and node architecture. It delivers guaranteed sub-wavelength and multi-granular network services without wavelength conversion, time-slice interchange and optical buffering. Simulation results demonstrate high network utilization, fast service delivery, and low end-to-end delay on a contention-free sub-wavelength optical transport network. In addition, implementation complexity in terms of Layer 2 aggregation, grooming and optical switching has been evaluated.

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1. Introduction

A broad range of emerging services and applications (wide-range of multi-media, distributed applications such as Cloud, etc.) are driving the growing trend of network traffic with increasing demand for high bandwidth and flexibility. In particular, service providers and network operators in future might realize a distributed Cloud environment where the IT resources are located at the metro region in order to reduce backbone traffic and meet the quality of experience (QoE) requirements (e.g. stringent latency requirements) of Virtual PC applications [1]. In addition, such applications require guaranteed multi-granular short-lived services i.e., from seconds to minutes with bandwidths from sub-wavelength to multi-wavelength. In order to provide these services, a new architecture is required that can support multiple end-to-end lightpaths (LPs) over single (or multiple) wavelength(s) and deliver dynamic access to transparent multi-granular flows as a guaranteed (no contention) network service.

Optical packet switching (OPS) and optical burst switching (OBS) have been proposed to support sub-wavelength services [2]. However, these techniques do not provide guaranteed bandwidth services. Recently, Time-Driven-Switched Optical Network [3] has proposed to deliver sub-wavelength switched synchronous virtual pipes. To guarantee such services, this approach uses a synchronous global common time reference from Galileo or GPS. Also, LOBS-H [4] is an alternative solution that allocates wavelength sharable home circuits for each source-destination pair. These circuits provide guaranteed bandwidth for conforming traffic that originates from the same source to different destinations and also allow for non-guaranteed statistically multiplexed non-conforming traffic from any source to any destination. Furthermore, there has been considerable effort on routing, wavelength and time assignment (RWTA) algorithms to calculate two-way reserved Time Division Multiplexed (TDM) wavelength services [5]. Work has been conducted on experiments and demonstration of integrated OPS and OCS node [6] and control mechanisms [7] under the same infrastructure platform to deliver relevant services. It is also worth noting that current approaches consider ring solutions [1,8] for metro. This introduces additional complexity on how to interconnect all nodes (e.g. interconnected rings) and deliver the bandwidth services over topologies such as the one portrayed in Fig. 1a that have an inherit mesh multi-degree connectivity. Considering these developments, there has also been effort on standardizing a framework for GMPLS and path computation to support sub-wavelength switched optical networks [9].

In this paper, a novel optical network solution is proposed – the Time Shared Optical Network (TSON) – to deliver both highly flexible statistically multiplexed optical network infrastructure and on-demand guaranteed contention-free time-shared multi-granular services. It supports traffic flows from any source to any destination in transparent optical networks for the metro region supporting the physical interconnection requirements. The architecture is based on user/application-driven bandwidth service requests, centralized RWTA calculation, and one-way tree-based provisioning that allows for flexible symmetric/asymmetric multi-granular bandwidth services with the use of either fixed or tunable transceivers. It delivers contention-free optical switching and transport of contiguous and non-contiguous time-slices across one or multiple wavelengths per service. It also doesn't require global synchronization, optical buffering and wavelength conversion, and time-slice interchange, thus, reducing implementation complexity.

2. Time-Shared Optical Network (TSON) network, node architecture and protocol design for metro region

The TSON architecture is shown in Fig. 1a. The architecture consists of a central server for RWTA and one-way tree-based provisioning initialization. As such, this is the only service blocking point, which simplifies provisioning. However, it is also a single point of failure and as such a redundant server on a different node is needed. The TSON node architecture (Fig. 1b) that is under development to construct a complete TSON testbed consists of two main functional entities. The FPGA-based TSON line card (based on Xilinx Virtex6-HXT) performs the Layer 2 functions for ingress traffic and the fast λ-modular OXC (based on bit-rate independent 10-ns PLZT 4x4 switch [10] and shown in Fig. 1b) switches time-slices transparently along the end-to-end multi-granular lightpath. The line card performs Ethernet frame parsing on incoming traffic. According to the allocated time-slices per wavelength for a particular connection the Ethernet frames are classified and aggregated in buffers to fill time-slices. The formed time-slice data sets are encapsulated/framed and fed to transmission queues (one per transceiver) to be transported on the allocated wavelength/time-slices within a frame. Transceivers can either be fixed or tunable. When deploying tunable transceivers, by using 70-ns tunable lasers and fixed receivers, different time-slices from the same transceiver can be carried over different wavelengths.
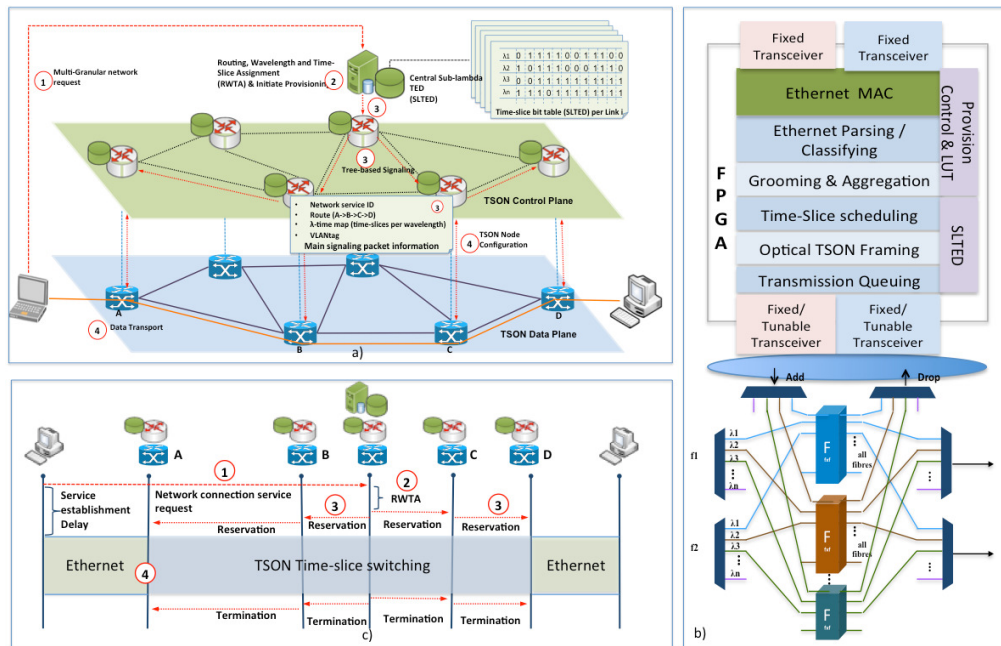

Fig. 1. a) TSON metro network architecture, b) TSON Node architecture, and c) end-to-end service provisioning flow.

The service provisioning mechanism across the network is shown in Fig. 1c. A client sends a network service request to the central TSON server (1). Then, the server performs RWTA by accessing the sub-lambda traffic-engineering database (SLTED) (2). The SLTED maintains updated link state information for the whole metro network and holds a λ-time bitmap resource representation (time-slices per lambda per frame and per port). One-bit represents a unique time-slice per wavelength. Such information is used by the RWTA to first compute the bandwidth availability of the candidate routes and then assign the finer contiguous or non-contiguous time-slices across one or multiple wavelengths on the selected path depending on algorithm used.
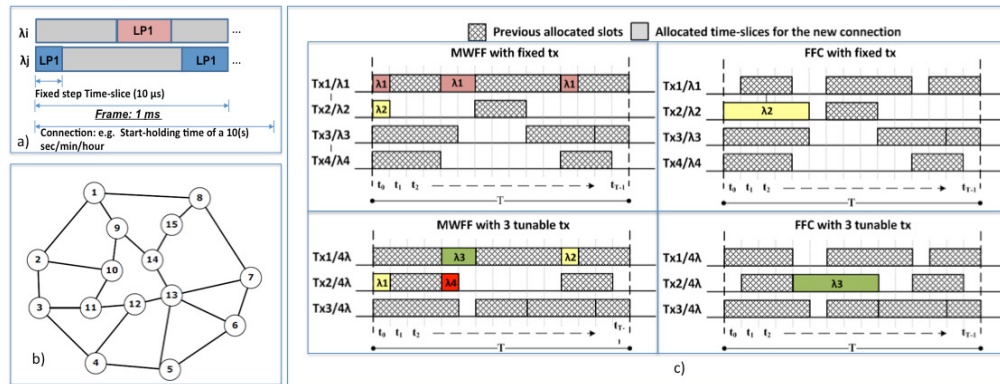
Fig. 2. a) Resource time-scales granularity b) proposed RWTA policies (MWFF and FFC) with fixed and tunable transmitters, c) Telefonica's Madrid Metro topology.

TSON architecture handles three time-scales for resource reservation as shown in Fig. 2a: a) time-slice, b) frame, c) connection. Time-slices have 10 μs duration and are the minimum resource unit per wavelength that can be transparently switched across the network. Multiple time-slices form a 1-ms frame. The actual number of time-slices in a frame depends on the inter-slice gap. For instance, if a worst-case scenario of 1-μs inter time-slice gap is considered to account for switching-time and clock recovery, the network can still achieve 90% efficiency. Finally, the connection represents the duration of the lightpath requested by the user. The minimum bandwidth and granularity is 100Mbps and the maximum depends on the total capacity of the network (e.g. 160Gbps on a 16 wavelength @ 10Gbps). A single LP might allocate sufficient number of contiguous/non-contiguous time-slices from one or more wavelengths to meet the bandwidth service demand.Such allocation considers the wavelength and the time-slice continuity constraint due to lack of wavelength conversion and time-slice interchange. After the calculation of RWTA, a provisioning control packet is constructed. It carries the following information: a) Network service ID, b) Route (A->B->C->D), c) time bitmap table, and d) VLANtag. The VLANtag is required to associate the provisioned multi-granular lightpath to the expected incoming flow. The control packet is signaled to all required nodes on a tree-based fashion (3). Since this originates from a central point of the metro network the service provisioning time is considerably reduced compared to standard two-way reservation systems (e.g. GMPLS). After a maximum provisioning time (based on processing and propagation times) the client can start transmitting data (4).

3. Simulation and results

The proposed architecture has been evaluated through simulations using Telefonica's Madrid metro reference network shown in Fig. 2b. The network comprises 15 nodes and 23 bidirectional links with 16 wavelengths per link and 10 Gb/s per wavelength. Each node operates as both core (with an OXC) and edge (with add&drop ports) according to the proposed node architecture. In such a scenario, there are 16 wavelength per link and 10 Gbps per channel. Wavelength conversion, optical buffering and time-slice interchange are not deployed in the network. Also, a fixed time-slice approach has been followed with a time-slice and frame size of 10 μs and 1 ms, respectively. With respect to the traffic characteristics, connection arrivals follow a Poisson process and exponential holding time with mean $1/\mu = 60$ s. A service connection request of 1 Gbps has been employed. Finally, the RWTA is implementing two different time-slice assignment policies namely, first-fit contiguous (FFC) and multi-wavelength first-fit (MWFF). FFC constraints the time-slice allocation per connection to be contiguous (no fragmentation) and on a single wavelength. However, MWFF is more flexible by allowing non-contiguous time-slice assignment on multiple wavelengths using one or multiple transceivers (Fig. 2c). Also, we have tested two ingress port

configurations: one with 16 fixed transceivers, and another with 12 tunable transceivers. The four proposed allocation scenarios are shown in Fig. 2c.

Figure 3a shows the connection blocking probability as a function of the offered load to the network. FFC allocation delivers similar results when ingress TSON nodes have either 12 tunable transceivers or 16 fixed transceivers, i.e. a 25% port-count reduction when tunable transceivers are used. Furthermore, by using the MWFF, same blocking probability (10E-3) can be achieved for an increased offered load (60% more) due to the greater time-slice allocation flexibility. Also, it is evident that MWFF can benefit more from higher number of fixed ports than transceiver tunability as shown in Fig. 3a, since the algorithm itself allocates time-slices per connection in both time and frequency domain (algorithm tunability). Figure 3b illustrates the connection blocking as a function of network load. In case of deploying 16 fixed transceivers, MWFF algorithm can deliver 55% network utilization with 10E-3 connection blocking, 49% higher than the FFC. It is again clear that due to inherent flexibility of allocating bandwidth resources (time-slices) across multiple wavelengths, MMFF provides better blocking performance when 16 fixed transceivers are used compared to 12 tunable. Additional results (Fig. 3c) show that MWFF provides up to 32% higher add-port utilization compared to FFC. Under maximum offered load the add port utilization for FFC reaches 68% with fixed and 63% with tunable transceivers, whereas for MWFF it reaches 82% with fixed and 72% with tunable transceivers.
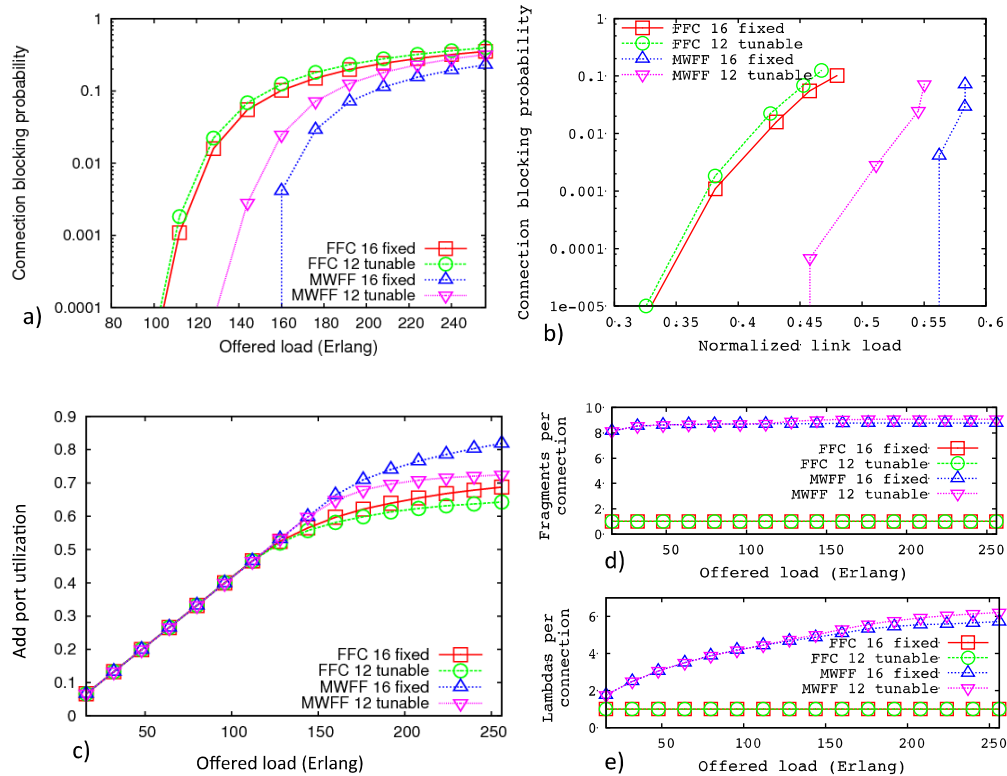

Fig. 3. Results of TSON on a metro network with 16 wavelengths: a) connection blocking probability vs. offered load, and b) connection blocking probability vs. network load, c) add port utilization, d) average number of non-contiguous time-slice fragments per connection and e) average number of lambdas per connection.
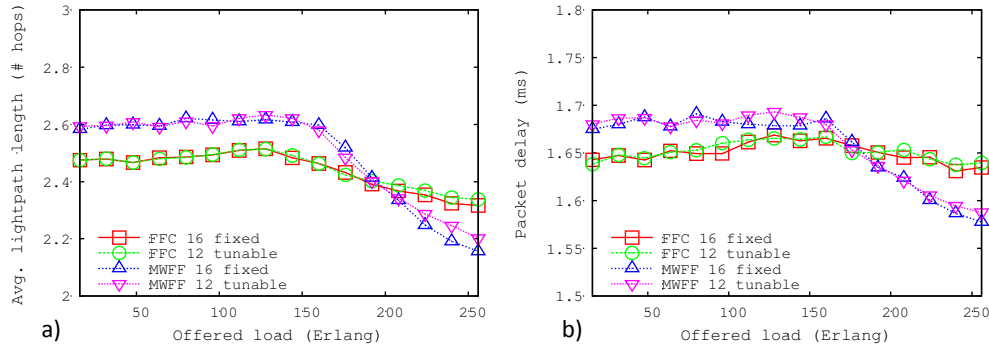
Fig. 4. Results of TSON on a metro network with 16 wavelengths: a) average lightpath length vs. offered load, and b) packet delay vs. offered load.

Apart from performance results, another critical factor evaluated was the implementation complexity in terms of Layer2 TSON aggregation/grooming and optical time-slice switching. Such complexity is directly associated with the number of fragments and number of wavelengths allocated per connection. The more fragments and wavelengths allocated per connection, the more complex the implementation becomes. As such, (Fig. 3d) shows that, as expected for the FFC case, the number of fragments per connection remains one, regardless of the offered load or transceiver type. In contrast, MWFF uses more than 8 fragments for all the levels of offered load considered.

Moreover, as shown in Fig. 3e, MWFF uses more wavelengths (up to 6) as the offered load increases to provide the required number of time-slices. As an outcome, MWFF guarantees lower blocking and increased throughput at the expense of heavily fragmenting the time-slice allocation across multiple wavelengths. Therefore, there is a tradeoff between blocking probability and implementation complexity that relates to electronic aggregation/grooming and optical time-slice switching. Finally, results shown in Figs. 4a and 4b demonstrate that both FFC and MWFF deliver similar results in terms of average lightpath length and end-to-end delay. The maximum average number of hops is 2.6 and the maximum end-to-end packet delay is 1.7 ms for all approaches.

4. Conclusions

This paper reports on a novel architecture, Time-Shared Optical Network (TSON) that enables guaranteed contention-free optical multi-granular services on metro mesh networks. Two routing, wavelength and time-slice assignment policies using both fixed and tunable ingress transceivers are proposed and evaluated. The MWFF algorithm delivers 60% increased network efficiency and 32% improved add-port utilization compared to FFC when fixed transceivers are considered. To deliver such performance a number of fragmented time-slices and multiple wavelengths have to be allocated for each connection. However, the deployment of tunable transceivers on TSON nodes can reduce the total number of transceivers by 25% in case of FFC time-slice policy for almost the same performance and reduce the implementation complexity due to non-fragmented allocation of time-slices on a single wavelength. Finally, the proposed overall architecture delivers less than 2 ms Ethernet-frame end-to-end delay.