Experimental Evaluation of Delay-Sensitive Traffic Routing in Multi-Layer (Packet-Optical) Aggregation Networks for Fixed Mobile Convergence

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Abstract *An experimental evaluation of delay-sensitive traffic routing within GMPLS multi-layer (MPLS-TP/WSON) aggregation networks for fixed mobile convergence is presented. We compare the performance of two novel routing algorithms designed to fulfill both the delay and bandwidth service requirements while exploiting the multi-layer (grooming) objectives.*

Introduction

In the coming years, a tremendous data traffic growth is expected, both in fixed (e.g., ADSL, FTTH) and mobile (e.g., LTE) access networks, supporting high-bandwidth multimedia services / applications[1] (e.g., IPTV, online gaming, etc.). In the past, fixed and mobile networks have been optimized and have evolved independently. However, the necessity of coping with such huge demand of data traffic as well as reducing both OPEX and CAPEX is pushing operators to deploy convergent networks to seamlessly handle both services. This is referred to as Fixed Mobile Convergence (FMC)[2].

In FMC, both mobile and fixed access segments may be connected to the aggregation edge nodes (EN) via point-to-point fiber links and/or optical access (PON trees). Aggregation networks are being deployed over Carrier Ethernet / packet transport technologies (e.g., MPLS-TP[3]). This allows exploiting their inherent statistical multiplexing. These infrastructures can also be combined with data transport based on optical circuit switching (WSON) resulting in a multi-layer network (MLN) architecture leveraging the bandwidth flexibility provided by MPLS-TP and the coarse high transport capacity of WSON. The convergence of mobile and fixed packet services with different bandwidth requirements may be located at the aggregation ENs, where both services are transported over MPLS-TP packet connections (Label Switched Paths, LSPs) and multiplexed into high-capacity optical tunnels (see Fig. 1).

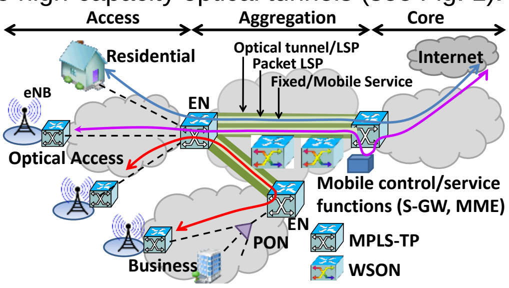

Fig. 1: FMC architecture: MLN aggregation

The cooperation between both electrical packet and optical circuit switching layers increases the efficiency of the network resource utilization through applying MLN traffic engineering (TE) strategies (e.g., grooming). To this end, a GMPLS unified control plane is adopted enabling the automatic and dynamic provisioning and restoration of packet / optical LSPs within the MLN infrastructure[4].

A QoS parameter critical for the path selection is the maximum delay / latency (e.g., typically 20 ms in LTE) required by some applications such as online gaming, etc. To deal with this, it is essential to rely on delay-sensitive traffic routing strategies. Herein, these strategies are deployed within the MLN aggregation segment of FMC. The aim is that for each LSP both bandwidth and maximum delay restrictions are fulfilled whilst exploiting MLN TE path decisions. Two on-line delay-sensitive routing algorithms are proposed and experimentally compared within the ADRENALINE. To this end, GMPLS routing protocol is extended to flood the link delay metric. The comparison is done in terms of connection blocking assuming different service types (with respect to the required bandwidth and latency) and traffic characteristics/scenarios for those services.

MLN provisioning and TE link delay metric

In a MLN, an LSP initiates and terminates at the same layer, and may traverse one or more lower-layers. In this regard, the establishment of a packet LSP may trigger the creation of lower-layer (optical) LSPs between pairs of MPLS-TP nodes (Label Switched Routers, LSRs) along the multi-layer route. Such optical tunnels are then viewed as logical data links in the upper (packet) layer and are referred to as Forwarding Adjacency (FA) TE links[4,5]. Once a FA is created and induced, multiple higher-layer (packet) LSPs can be routed (groomed) through such a FA (optical LSP) to globally enhance the use of network resources. As regular (physical) TE links, an FA has a set of TE attributes (e.g., bandwidth, metric, etc.) which are flooded by the GMPLS routing protocol (e.g., OSPF-TE) and used to compute MLN routes. Most of these attributes are inherited from the associated optical tunnel, e.g., the available bandwidth of the FA link is set to the data rate supported by the allocated wavelength of the optical LSP. Other attributes (e.g., link metric) are, however, administratively set to favor specific policies or strategies (i.e., MLN decisions). In this context, as in[4], the FA link metric is set to *max (1, cost Optical Tunnel - 3*), where the *cost Optical Tunnel* is the sum of the TE metrics (set to 1) of all the traversed physical TE links. Thereby, subsequent packet LSP requests may reuse the remaining available bandwidth of created FA in preference to occupy unused resources (wavelengths). To deal with the latency constraint, routing algorithms require information about network delay performance. This is accomplished through extending GMPLS routing protocols to flood measured/estimated link latency[6]. Fig. 2 shows the wireshark capture of the OSPF-TE link Metric Delay attribute (expressed in µs). Thus, the FA delay is the sum of the delays of each physical link forming the optical tunnel. In Fig. 2, the delay for the FA between LSR12-11 is 400 µs resulting from the accumulated delay through LSR12-13-6-7-11.

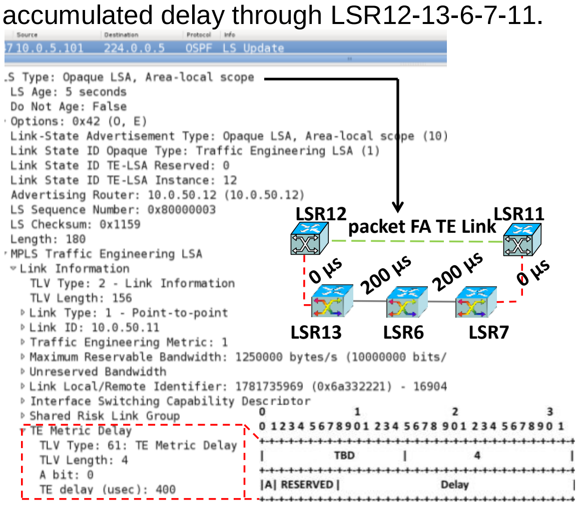

Fig. 2: OSPF-TE link delay extension and use in MLN

Delay-Sensitive Routing Algorithms

A LSP request (*req*) specifies the ingress (*i*) and egress (*e*) endpoints along with two constraints (R1 and R2) to be fulfilled: bandwidth (*bw_req*) and maximum end-to-end service delay (*d_req*). Upon receiving a *req*, an on-line routing algorithm is triggered using as input the MLN topology (i.e., physical and FA TE links) and TE link attributes flooded by the routing protocol. Such an algorithm is based on a Constrained Shortest Path First (CSPF) mechanism. Conceiving CSPF algorithms that minimize two or more additive constraints (e.g., cost, latency, hops, etc.) was proved to be NP-complete[7]. Here, CSPF algorithms exclusively minimize a single metric (e.g., cost or latency). The rest of restrictions are only verified with respect to the restrictions imposed by *req*. For example, if a CSPF algorithm computes the shortest path cost, the path is feasible as long as the available path bandwidth is above *bw_req* (R1), and the end-to-end path latency is below *d_req* (R2).

The two adopted CSPF algorithms are based on modifying well-known Widest Shortest Path (WSP[8]) applying MLN TE objectives and satisfying R1 and R2 restrictions:

- *WSP_Latency_Restr* computes the shortest path cost with available bandwidth larger than *bw_req* (R1) and whose path latency is below *d_req* (R2). If two paths have the same cost, the selected path has the lowest latency. If the tie persists, the path with larger available bandwidth on the most congested link is chosen.
- *WSP_Min_Latency* computes the path with the minimum latency satisfying both R1 and R2. If two routes have the same path latency, the one with the lowest path cost is selected. If the tie persists, the path with larger available bandwidth on the most congested link is chosen.

The CSPF output is a path combining packet links (physical or FAs) and optical segments where the layer adaptation is ensured. Optical segments are subject to the wavelength continuity constraint (WCC). The induced FAs have a cost set to the previously detailed value to favor grooming. However, computing paths through many FAs entails traversing multiple intermediate MPLS-TP LSRs. This may increase the overall latency due to potential buffering and queuing delays suffered by data packets at those nodes. Hence, a trade-off between efficient network resource utilization and latency must bear in mind when considering FAs during path computation. Hence, for each traversed intermediate MPLS-TP node, the latency is arbitrarily penalized by an offset of 1000 µs.

Experimental performance evaluation

The GMPLS control plane platform of the ADRENALINE is used for the experimental performance evaluation. Fig. 4 depicts the MLN topology (5 MPLS-TP, 9 WSON LSRs). Each link reflects its associated distance (km). The link propagation delay is set assuming 5 µs/km. For the packet-optical (port) links their distance / propagation delay are neglected. Each MPLS-TP LSR is connected to a WSON node by 4 bidirectional ports.

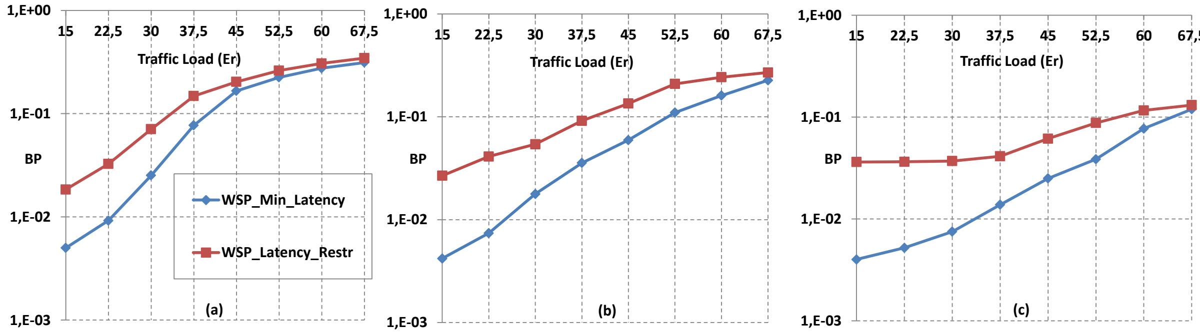

Fig. 3: Blocking vs. traffic load for delay-sensitive CSPF algorithms in scenario: a) S1; b) S2; c) S3

The bidirectional optical links support 8 WDM channels operating at 10Gbps. We consider a dynamic stochastic model for requesting two packet services (T1 and T2) with particular QoS (bandwidth and latency) requirements: 1 Gbps and latency of 3000 µs for T1; 3 Gbps and latency of 10000 µs for T2. For both services, LSP-arrival process is Poisson (avg. 5 s) and holding time follows a negative exponential distribution. All packet LSPs are uniformly distributed among MPLS-TP LSRs. Three different traffic scenarios (S1, S2 and S3) are used: in S1, T1 and T2 services represent 30% and 70% respectively of the total requested traffic; in S2, T1 and T2 LSPs are equally generated; finally, in S3, T1 and T2 LSPs are 70% and 30% respectively.

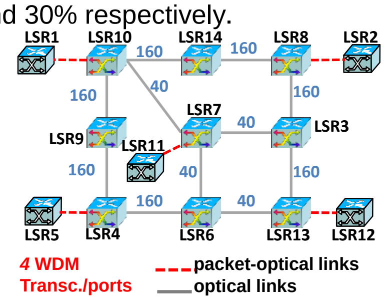

Fig. 4: MLN infrastructure (link distance in km)

Fig. 3 a), b) and c) plots the LSP blocking versus traffic load for dynamically setting up T1 and T2 packet LSPs for S1, S2 and S3 applying the CSPF algorithms. Each data point is obtained requesting 5000 LSPs. A LSP is blocked if the path computation fails to find a feasible route satisfying both R1 and R2 or due to a signaling failure: WCC is not satisfied on a specific optical segment or a considered FA TE link in the route does not longer exist.

We observe that in all the scenarios (S1, S2 and S3), at both low and intermediate load (15-37.5 Er), *WSP_Min_Latency* does lower the blocking compared to *WSP_Latency_Restr*. Such improvement ranges from 48-72% in S1, 61-84% in S2, and 66-89% in S3. The reason behind this is that in the considered network latency (R2) is the hardest restriction to be satisfied, especially for T1. Thereby, the larger T1 LSPs to be set up with respect T2 services, the higher blocking improvement is achieved by *WSP_Min_Latency*. In this algorithm, the computed routes are the shortest latency paths. That is, for an established LSP, the new created FAs between pairs of MPLS-TP LSRs have also the shortest latency. Consequently, this will favor the reusing of these FAs by the next incoming packet LSPs with stringent latency restrictions. In other words, having FAs with the shortest latency allows the MLN routing to better fulfill the end-to-end latency constraint when trying to reuse these FAs for a particular service. It is noteworthy that as the traffic load is increased both WSP algorithms, for all the traffic scenarios, perform similarly. Indeed, at such traffic loads, the lack of resources (i.e., ports, bandwidth, wavelengths) become the main constraint, and thus, the performance difference between both algorithms is practically negligible.

Conclusions

Two on-line delay-sensitive traffic routing algorithms for GMPLS MLN aggregation segment within FMC are experimentally evaluated. Moreover, a GMPLS routing extension to flood link delay metric is presented. Both algorithms are compared by connection blocking adopting services with different QoS requirements: (latency and bandwidth) and different traffic scenarios. The results show that the algorithm minimizing the overall latency performs the best. Indeed, besides addressing better the latency restriction, it tends to compute short (latency) optical tunnels (FAs) favoring their reuse for next packet LSPs.

Acknowledgements

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