Integrated Packet/Circuit Hybrid Network Field-Trial

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Abstract: We report the first field-trial of an integrated packet/circuit hybrid optical network. Bypassing routers with circuit quality of service and network throughput of 99\% is demonstrated on a shared packet/circuit layer lightpath.

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1. Introduction

A variety of applications and systems require support of timing-critical transport from the underlying transport layer. Low latency in the order of microseconds and latency variation in the order of nanoseconds, enabling synchronization support, are properties offered by legacy circuit technologies like SDH/SONET. Packet networks on the other hand, offer a higher throughput by using statistical multiplexing, but do not match legacy network timing-performance [1]. The transport of synchronization information is a key requirement for e.g. mobile backhaul networks. In the migration towards packet-based technologies there is a need for flexibility to carry different types of services over the same converged network; hence, to enable high network throughput efficiency while still supporting demanding services like e.g. synchronization [2]. Furthermore, because high capacity networks put high demands to routers capacity and performance, and may carry a large part of the traffic as transit-traffic through nodes, using circuits for bypass is an efficient method for offloading routers [3].

Integrated hybrid optical networks (IHON) [4], also known as Fusion, merge the circuit and packet network in a time-interleaved manner without using time-slots. A guaranteed service transport (GST) circuit stream offers a circuit-switched Quality of Service (QoS), i.e., absolute transfer guarantees up to full lightpath capacity with no packet loss, while packet delay and packet delay variation (PDV) have the characteristics of circuit switching. The GST offloads the packet layer’s switching resources and offers a transport for the most demanding services like real-time traffic, synchronization, and control information. Any capacity not utilized by the GST is identified in the packet stream as gaps between the GST packets. Figure 1a shows how packet switches increase the lightpath utilization by filling these gaps with packets from a statistical multiplexed (SM) class with best effort QoS.

A fixed delay \(\delta\) (fig. 1a) of 2.64 µs is applied electronically to the GST stream (packets) bypassing a node. This delay also enables the GST gap detector that detects the GST in the input to update the information on the free gaps before SM insertion. The round-robin gap-filling scheduler finds SM packets at the head of the input queues that fit in the gaps and schedules them. (b) The IHON field-trial setup in the carrier network of UNINETT with three prototype FUSION nodes from TransPacket (http://www.transpacket.com), two FreeBSD servers with Iperf traffic generators and Spirent SPT-2000 packet generator/tester. Xe0 and x1 are 10GE interfaces while ge0-ge9 are GE interfaces.

A fixed delay \(\delta\) (fig. 1a) of 2.64 µs is applied electronically to the GST stream (packets) bypassing a node. It corresponds to a maximum SM packet length of 3300B and prevents SM packets to be preempted by incoming GST packets. Hence, the effect of \(\delta\) on the overall GST packet delay is predictable through the network. In addition, this delay enables a GST gap detector that looks into the GST input stream of packets, to detect the length of gaps before SM insertion. When a gap is detected, a statistical multiplexing (SM) packet scheduler inspects the input queues of the SM interfaces for an SM packet of suitable size that fits the gap. If such a packet is found, it is inserted in the gap.
without affecting the timing of the packets in the GST stream. IHON nodes can use VLAN-tags to separate GST and SM packets and to switch SM packets towards their egress node.

2. Field-trial setup

The field-trial setup uses three prototype IHON nodes, FUSION Ethernet nodes from TransPacket, in the carrier network of UNINETT as illustrated in fig. 1b. The experiment has two main objectives: first, to demonstrate that IHON is able to transport GST traffic with circuit QoS, independent of the insertion of statistically multiplexed traffic; second, to show the efficient add/drop of SM traffic on the lightpath used for router bypass of circuit traffic.

Scenario 1. In order to accurately measure the GST traffic performance, we generated one Gigabit Ethernet (GE) GST stream from the packet generator. The traffic was added at node 1 (N1) and was forwarded towards node 2 (N2), bypassing it and received on node 3 (N3). The packet length was uniformly distributed between 64 and 1518 bytes. The average GST load on the GE interface \( L_{GST}^{GE} \) was set to 0.99 by fixing the inter-packet length. The GST performance was measured for different network loads by changing the load \( L_{SM}^{GE} \) of nine added SM streams up until network congestion. The measurements were conducted up to a total load \( L_{10GE}^{10GE} = 0.99 \) on the 10 Gigabit Ethernet (10GE) lightpath.

Scenario 2. The second goal of the field trial was to emulate router offload and the effective increase in the network throughput by adding/dropping SM traffic on top of an already provisioned lightpath with a traffic pattern emulating production traffic. Hence, the GST traffic was generated by the Iperf network generator on the xe1 interface at N1 and received on xe1 at N3, passing through all the three hybrid nodes as GST traffic (fig. 1b). The average load \( L_{10GE}^{10GE} \) of the GST stream was set to a high load of 0.535. Two SM GE streams were added on each of the nodes (N1 and N2) with destination N3. All streams had equal average load \( L_{SM}^{GE} \) which was varied by changing the inter-packet lengths.

3. Analysis and Discussion of Results

Figure 2 illustrates the results for the first scenario with a fixed average GST load \( L_{GST}^{GE} = 0.99 \). We observe that: 1) the experiment results confirm that the GST traffic is transported through the network with absolute priority and neither PLR nor delay is affected by the SM insertion, i.e. no GST packet losses and the average GST delay remains constant regardless of the network condition/congestion; 2) SM insertion increases the 10GE lightpath utilization up to 97% without any losses; 3) with SM PLR at 1e-02 for the total load \( L_{10GE}^{10GE} = 0.99 \), the network performs as a saturated statistical multiplexing packet network with high utilization while providing a service with circuit QoS properties.

The total propagation delay on the two fiber links connecting the nodes was measured to 266.11 µs. The nodal processing delay of the SM packets added on one GE interface, transmitted through the 10GE lightpath and dropped at the other ends’ GE interface was measured to a reference value of 2.37 µs. The GST average end-to-end delay was 311.66 µs through all the measurements. Hence, the added delay by the nodes on the GST path is 45.55 µs. The PDV peak value is 130 ns and on average 30 ns. The experiment demonstrated for the first time 1GE to 10GE GST traffic insertion and the measured delay at the load of \( L_{10GE}^{10GE} = 0.99 \) was 26 µs. The results show that the hybrid network enables transmission of packet layer synchronization traffic in GST, while enabling lightpath utilization of 96.9 % without any packet losses using SM.
The results from the second scenario, with a high GST share of 5.35 Gb/s generated by Iperf, are illustrated in fig. 3. There are two cases considered for the SM streams added on N1: 1) not processed at the intermediate node N2 but bypass it like GST traffic, thus given higher priority than N2 streams; 2) dropped and re-added at N2 towards the destination N3 (drop/add). In the latter, the N1 SM streams, dropped and re-added at N2, are competing with the streams added at N2. The results show that the SM insertion on N1 increases the utilization by 16.75% (6.246 Gb/s), while the downstream node N2 increases it further by 16.52% more (7.13 Gb/s), close to doubling the total SM load in the lightpath. At the network level we deduct an interesting result: the lightpath utilization increases with the number of streams added by the downstream nodes. Consequently, the insertion of SM packets by the upstream nodes as priority traffic does not seriously affect the lower priority SM traffic added by the downstream nodes. The reason is that the probability of finding packets fitting in gaps increases with the number of nodes, e.g. when scheduling packets from both N1 and N2, compared to just N1. This is also visible while comparing it with the second case (drop/add) when all SM streams in the network have equal priority. The packet losses are 1e-05 at 0.713 for the bypass and 0.7142 for drop/add. Thus, the total increase in throughput is 33.27/33.49% respectively. The difference is a loss of only 0.23% utilization for the bypass, but with the benefit of lower processing overhead since the SM traffic added by the upstream node (N1) is bypassing the downstream node (N2).

4. Conclusions

We have demonstrated the feasibility of integrated hybrid networking through a network field-trial of IHON Ethernet-based prototype nodes from TransPacket. The results demonstrate circuit quality of service performance for the circuit transport: zero packet loss, a node-delay much lower than the fiber transmission delay and with a packet delay variation in the nanosecond range. The circuit transport, with its low processing overhead, enables efficient transparent router bypass. Its quality is higher than for routers, enabling transport of time-sensitive traffic and packet layer synchronization information. High throughput efficiency was demonstrated by adding packet-switched statistical multiplexed traffic on the common circuit/packet lightpath. Circuit traffic was then not affected even at maximum lightpath utilization of 99% with 10% circuit traffic. For a high share of circuit bypass traffic, 5.35 Gb/s, additional packet switched traffic was added in two nodes increasing the load to 7.14 Gb/s and demonstrating that lightpath utilization is rising with an added number of nodes. This is due to the increased probability of finding a packet of suitable size when selecting from several nodes to fit in the available packet-gaps. The conducted field-trial demonstrates the maturity of the IHON technology as well as its compatibility with existing Ethernet based networks.

5. References


