Dynamic Multi-Wavelength GPON (DMW-GPON) Protocol

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Abstract: A Gigabit Passive Optical Network (GPON) upstream map frame format enhancement has been developed to support dynamic multi wavelength (DMW) operation over splitter-based GPONs, together with an algorithm to manage the bandwidth allocation among the supported wavelengths. OPNET modelling of the performance characteristics of the DMW-GPON Fibre-to-the-Home (FTTH) topology has demonstrated a minimum 100 Mb/s bandwidth provision for each of 32 Optical Network Units (ONUs) with a maximum 0.09 s packet delay for the lower service level agreement (SLA) ONUs.

1. Introduction.

Scalability of standard GPON [1] topologies to larger split ratios would result in increased polling waiting-time in the upstream that could be intolerable for real-time services. The application of wavelength division multiplexing (WDM) to assign each ONU a unique point-to-point (P2P) logical connection with the optical line termination (OLT) provides a solution for reducing the polling waiting time and relaxing the bandwidth requirements on optical and electrical components. At present coarse WDM operation over the currently deployed splitter-based PONs has been proposed by means of the GPON band enhancement defined by the international telecommunication union (ITU-T) [2]. The application of extended band overlay has been demonstated over a standard GPON topology and has been provide an ideal interim solution for smooth, dynamic and on-demand capacity upgrade [3].

This was achieved by reviewing the upstream and downstream frame format maps and consequently developing a new protocol based on the dynamic bandwidth allocation (DBA) algorithms previously developed for single-wavelength GPONs as explained in [3]. To adapt and extend these algorithms for coarse WDM operation, extra fields were incorporated into the GPON frame format [4]. Both the grant and the report packets used to establish communication between the OLT and ONUs were reconfigured to support dynamic multi-wavelength operation. Out of the twelve bits, in the Flags-field of the GPON upstream map frame format, the six unused reserved bits were utilised by assigning four bits to express the ONU's operating wavelength for proceeding cycles and two bits to specify the packet type, e.g. whether it is a control packet or data packet as shown in Fig. 1.

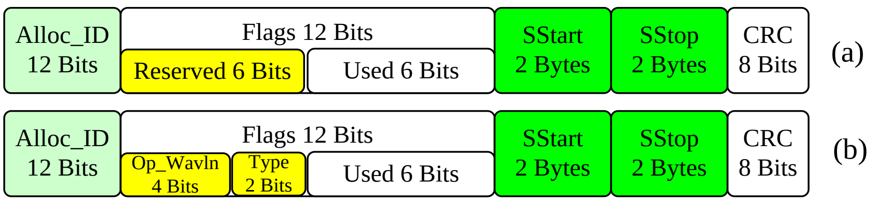

Fig.1: GPON upstream map frame format, (a) Single-wavelength, (b) DMW.

The wavelengths utilised by each ONU for data transfer can be defined during the ONU's registration stage by means of each ONU reporting its supported wavelengths to the OLT [3]. To demonstrate the maximum transmission time-slot utilisation for each operating wavelength and consequently provide reduced packet delay, a scheduling algorithm was developed that prioritises user transmission according to traffic status.

2. The Dynamic Multi-Wavelength Protocol.

The aim of the DMW protocol is to increase the upstream bit-rate by introducing dynamic allocation of bandwidth concurrently in the wavelength and time domains. This has been initially achieved by developing the DMB algorithm [5] and modifying the GPON frame format to support multi-wavelength operation. The DMB algorithm facilitates three SLAs to assign each ONU with a guaranteed minimum bandwidth, to satisfy their basic service requirements, plus an additional allocation of extra bandwidth on demand, based on the assigned SLA. In the DMW algorithm presented here, a fourth service level is introduced to comply with modern service level provisioning [6] and to provide greater user experience and network flexibility. In addition, an extra upstream wavelength, bringing the total to five, is introduced with respect to previous DMW developments [3] to scale-up wavelength assignment in view of the ITU-T G.984.5 standard [2].

During ONU registration, the OLT puts a request for each ONU to confirm the supported wavelengths. This is crucial to distinguish between different network sectors and bandwidth provision status among ONUs. Consequentlly the OLT assings the upstream bandwidth available in every polling-cycle in three stages. In the first stage, and after having received the requested bandwidth from each ONU, the OLT calculates a safety margin to refine the maximum cycle time for bandwidth allocation independently for each wavelength, allowing for more accurate population of the polling cycles with considerable decrease in idle time slots. The safety marging is determined by considering the overall ONU minimum bandwidth requirement and the ONU SLA contracts. In that manner the OLT allocates ONU bandwidth by means of the individual total network capacity depending on the time and wavelength measures ($BW_{\text{total available}}$), minus the safety margin as seen in equation (1).

$$BW_{\text{total available}}(\text{multi - wavelength}) = BW_{\text{total network}}(\text{multi - wavelength}) - \text{safety margin} \qquad (1)$$

The maximum allocated bandwidth for ONU_i ($ONU_{\text{Allocated\_BW}}$) is then assigned according to the DMB algorithm [5] as seen in equation (2).

$$ONU_{\text{Allocated\_BW}} = \begin{cases} BW_{\text{ONU\_Reqested}} & \text{if } BW_{\text{total reqested}} \langle \; BW_{\text{total available}} \\ BW_{\text{ONU\_Max.allowed}} & \text{if } BW_{\text{total reqested}} \rangle \; BW_{\text{total available}} \end{cases} \qquad (2)$$

After the first stage is completed, the second stage is introduced to manage the network bandwidth allocation process in an more efficient manner by excluding random distribution of ONU traffic among the different wavelengths that in cases could result in exceeding the maximum available cycle-time, as shown in Fig. 2. To that extent the OLT specifies the highest ONU allocated bandwidth, positions it at the end of the cycle, expecting to increase the network throughput, and distributes the remaning ONU allocated bandwidths in order from high to low. In the third and last stage, the OLT commences assignment of the ONU time-slots to different wavelengths in sequence, starting by λ_{up0} to reach λ_{up2}. This process allows the OLT to gurantee that the last ONU time-slot in λ_{up2} can fit within the safety margin as shown in Fig. 2. Only three wavelengths and 16 ONUs are shown in Fig.2 for algorithm demonstration purposes. This approach potentially produces a shorter polling cycle length, a reduction in the ONU upstream packet waiting-time in proceeding cycles, and hence increased network utilization.

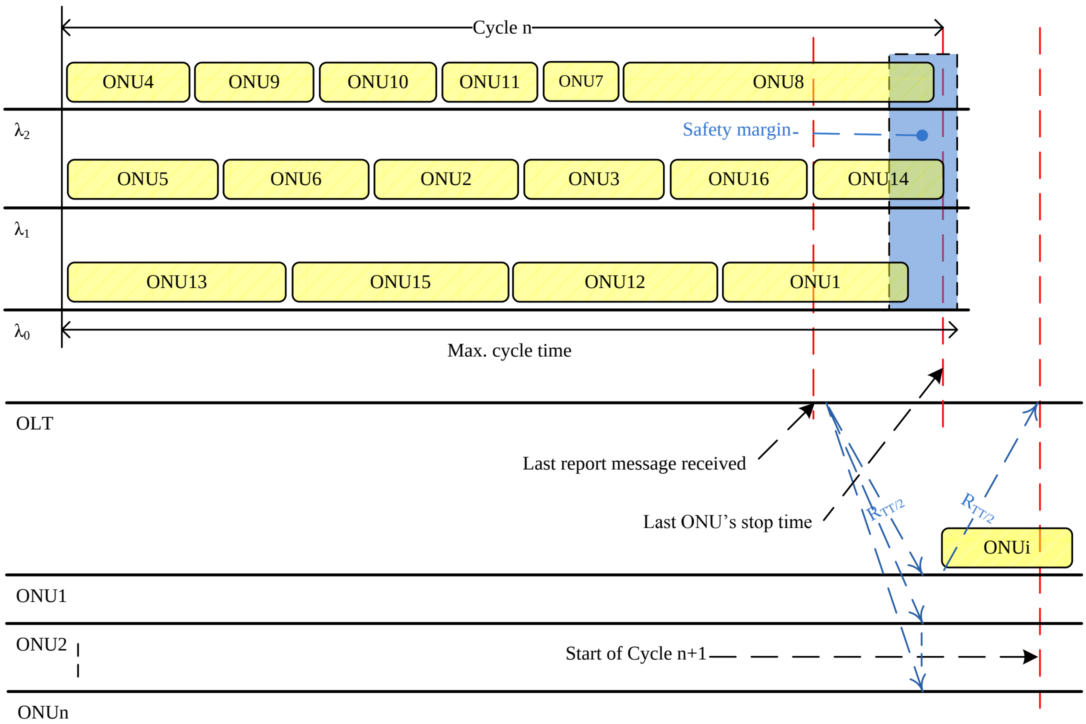

Fig. 2: Principles of the DMW-GPON bandwidth assignment

3. OPNET Performance Analysis.

To investigate the performance of the DMW protocol a FTTH oriented GPON network was modelled using the OPNET v.14.5 platform with pareto self-similar traffic with typical Hurst parameter of 0.8, 1.24416 Gbit/s upstream data-rate, 2.488 Gbit/s downstream data-rate, and 32 ONUs. The latter were organised to implement service level agreement diversity with 4 ONUs assigned at SLA_0, 4 ONUs at SLA_1, 8 ONUs at SLA_2, and 16 ONUs at SLA_3, simulating progressive network usage. ONUs were connected to the splitter via fibre cables, with a 196 bits GPON guard-time between ONU traffic, a 1.5 ms maximum cycle time, and as explained in the previous section a 3% of the maximun cycle time safety margin.

Comparing the DMW network performance with that of the DMB-GPON protocol, as shown in Fig. 3, it can be concluded that the overall network capacity has been increased by a factor equal to the number of wavelengths employed. Although expected, this has been achieved at 100 Mb/s minimum data rate per ONU for 32 ONUs, as oposed to 30 Mbit/s basic bandwidth per ONU for the same number of ONUs in the DMB-GPON. In additon the use of the 3%, safety margin has not limited each wavelength's channel throughput, again compared to the single wavelength capacity in DMB, due to the more effective utilisation of available time slots.

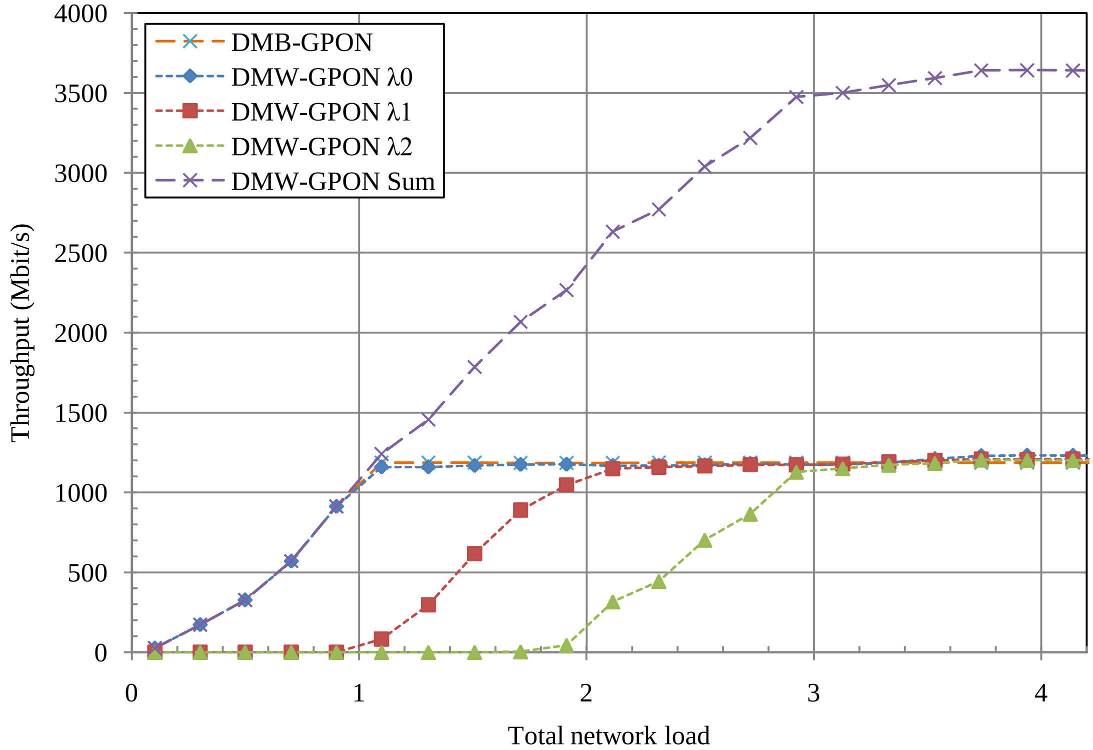

Fig.3: Throughput against total network load for single-wavelength and DMW-GPON

In another performance evaluation measure, while the mean packet delay of all SLAs utilising a single-wavelength overcome 0.1 s when the total network load achieves one wavelength capacity at 1.24 Gbit/s, the DMW protocol provides notably decreased packet delay with 0.003 s achieved up until the total network load reaches three wavelengths capacity as seen in Fig.4. This figure allows for the non obstructive transmission of interactive applications since it satisfies the recommended one-way delay requirement for these applications as defined by the ITU-T recommendation G.1010 [7]. Thus the DMW protocol allows for real time service provisioning at the stringiest requirements of service provisioning such as conversational voice and videophone, at increased 100 Mbit/s basic bandwidth and increased ONU volume.

Even at higher network load, reaching up to 3.72 Gbit/s, the lower service level ONUs displaying the greatest delay still maintains delay figures below 0.1 s which allows scope for further scalability to ONU provision and service advancements.

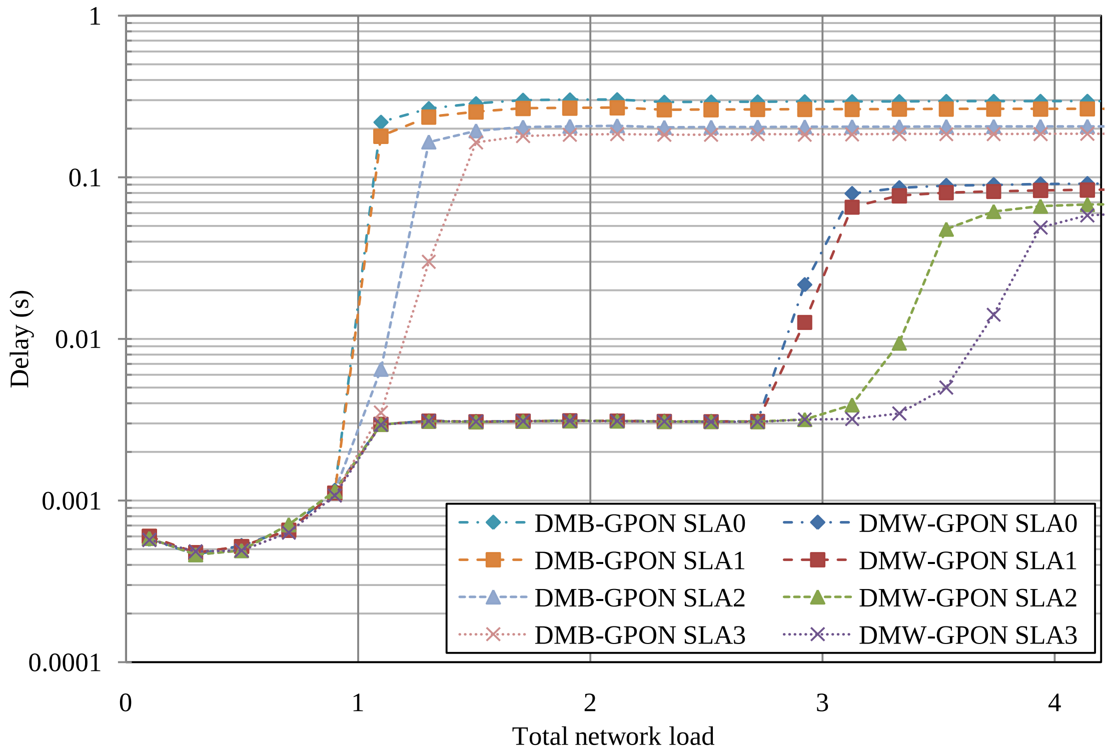

Fig. 4: Mean packet delay against total network load for single-wavelength and DMW –PON

4. Conclusions.

The DMW algorithm methodology and the corresponding protocol enhancements have been presented to accommodate multi-wavelength operation over splitter-based GPONs by means of smoothly upgrading the existing single-wavelength network infrastructure. This upgrade has been achieved by utilising additional bits in the frame fields of the GPON upstream format map to define the operating wavelength and packet type transfer for each ONU. The performance benefits of the multi-wavelength operation include agreegate trasmisstion bit-rate of 3.72 Gb/s in the presense of three wavelengths and 32 ONUs, 100 Mbit/s minimum bandwidth per ONU and a considerable reduction in mean packet delay in comparison with a resourceful single-wavelength GPON topology. The 0.003 s packet delay at typical network utilisation rates and the worst case 0.1 s equivalent at heavy loading allow for the continous communication of the stringest specification interactive services ans scope for further network upgrade in services, ONU penetration and reach capabilities.

References

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