

Scalability of Ethernet Passive Optical Networks

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Abstract—We investigate the impact of overheads in Ethernet passive optical networks to the scalability of such networks and propose solutions to reduce the overheads.

Keywords—component; EPON, DBA, FTTP

I. INTRODUCTION

An Ethernet passive optical network (EPON) is an IEEE standard [1] for the deployment of fibre-to-the-premises (FTTP) technology in order to provide very fast data rates to the user's premises.

EPON's have been deployed in a number of countries where there are high population densities and therefore fibre deployment in the last mile becomes economic. In these deployments, however, the number of Optical Network Units (ONUs) per Optical Line Terminal (OLT) is either 16 or 32.

Figure 1 shows a typical architecture of an EPON system and the one that is considered in this paper. The EPON architecture consists of an OLT at the central office that is connected to a 1:N passive splitter with a feeder fibre of up to 20km in length and with a 1Gbps bandwidth. The splitter is then connected to a number of ONUs at the customers premises that can each serve one or more users.

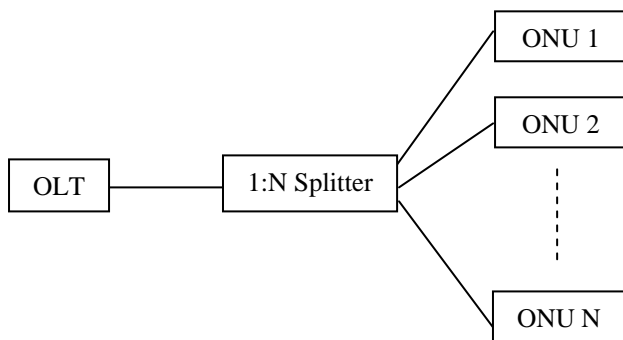


Figure 1. Architecture of an EPON system.

There is now more effort into looking at larger splitting ratios so that one OLT can serve more ONUs and therefore more customers. This will reduce the total cost per customer of deploying an EPON system.

This paper looks at the higher layer scalability of the current EPON IEEE standard to large numbers of ONUs. We are not looking at any physical layer constraints, but the overheads generated in the protocol layers in servicing the desired number of ONUs from one OLT. We discuss the issues in using large numbers of ONUs and what factors we can use in order to maximise the efficiency of an EPON. Also, we compare the results of the current 1Gbps IEEE standard EPON with a 10Gbps EPON in order to better understand the dominant issues.

II. EPON OVERHEADS

The overhead in an EPON system will reduce the efficiency and therefore will reduce the maximum throughput of data between the OLT and the ONU.

There are several factors that have been considered to contribute to the overhead in an EPON system [2]. They are the Ethernet encapsulation overhead, multi-point control protocol overhead (MPCP), guard band overhead and the frame delineation overhead. Other potential overheads such as inefficiencies in the OLT due to the dynamic bandwidth allocation (DBA) algorithm and scheduling algorithms have been ignored as they are implementation dependent.

The Ethernet encapsulation overhead is generic in all Ethernet systems and is not specific to EPON. It represents the overheads due to the packet framing and the inter-frame gap that are specified in the Ethernet standard.

The MPCP is used to control the flow of information from the ONU's to the OLT in order to prevent collisions because CSMA/CD cannot be used in an EPON system due to the nature of the architecture. MPCP REPORT messages are used by the ONU's to tell the OLT the amount of packets in its buffer to be sent to the OLT and the MPCP GATE message is used by the OLT to grant a time slot for the ONU to transmit a message. The sending of MPCP REPORT and GATE messages represents an overhead that cannot be used to send data.

In addition the MPCP discovery messages are used by the OLT to register new ONU's in the system. The MPCP discovery messages are periodically sent by the OLT and new ONU's are given some fixed time in which to respond and register themselves. This discovery process presents an addition MPCP overhead on the system.

The guard band is a time between Ethernet frames that is specified in the EPON standard to allow for the turn on and off times of the lasers, settling time, code data recovery lock time, code group alignment time and an allowance for clock drift. This represents an overhead where no data is sent.

All the above discussed overhead factors lead to increasing inefficiency as the number of ONU's per OLT increases. To determine the level of inefficiency, the overhead factors were calculated.

Several assumptions and parameters have been used to base our calculations. To calculate the upstream overhead the following values have been used:

- Ethernet frame encapsulation overhead due to the 8 byte preamble, 14 byte header, 4 byte FCS and 12 byte inter-frame gap.
- Control message overhead due to GATE and REPORT messages based on a GATE/REPORT cycle time of 2ms.
- Guard band overhead based on a laser ON/OFF time of 512ms, AGC and CDR times of 96ns and a dead zone of 384ns for a 1G EPON and 38.4ns for a 10G EPON.
- Discovery overhead assuming that a 300us discovery window will be made available every 1 second.
- Frame delineation overhead based on the fact that the Ethernet frames will not completely occupy the GRANT window.

To calculate the downstream overhead only the following values have been used:

- Ethernet frame encapsulation overhead due to the 8 byte preamble, 14 byte header, 4 byte FCS and 12 byte inter-frame gap.
- Control message overhead due to GATE and REPORT messages based on a GATE/REPORT cycle time of 2ms.

Using the above values the total overhead for a 1G and 10G EPON system was calculated. Figure 2 shows the resultant total overhead for 1G and a 10G EPON system as a function of the number of ONU's serviced by one OLT.

As can be seen in the figure, the total EPON system overhead is directly proportional to the number of ONU's being serviced by an OLT. In the 1G EPON case the overhead grows rapidly as the number of ONU's is increased to very high overhead levels. In the 10G EPON case the upstream overhead is approximately one half that of the 1G EPON but the downstream overhead remains low.

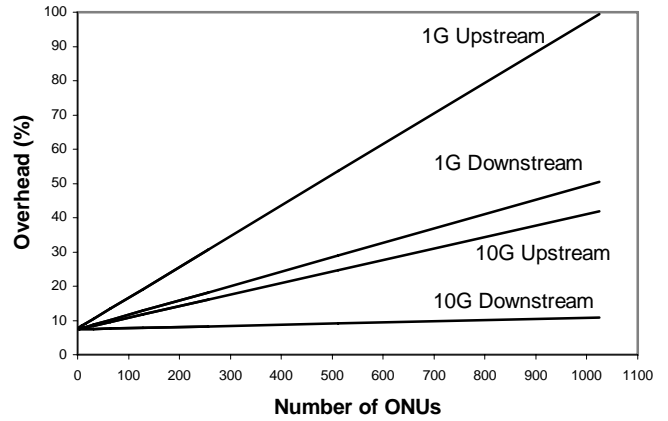


Figure 2. Total overhead in an EPON system as a function of the number of ONUs.

Figure 2 shows that the EPON standard using the typical parameters presented in this paper is not scalable to large numbers of ONU's without significant impact on the data throughput of the system.

III. DISCUSSION

In order to obtain a better understanding of the major contributors to the total EPON overhead a breakdown of the overhead components is required. This is shown in Figure 3 for a 1G EPON and in Figure 4 for a 10G EPON system.

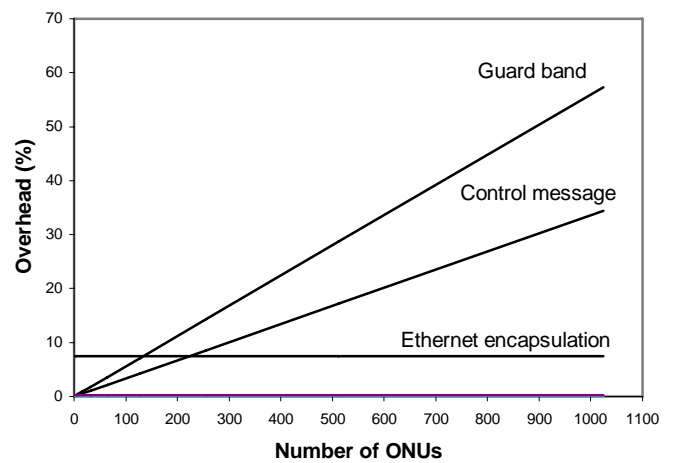


Figure 3. Breakdown of the major overheads in a 1G EPON system.

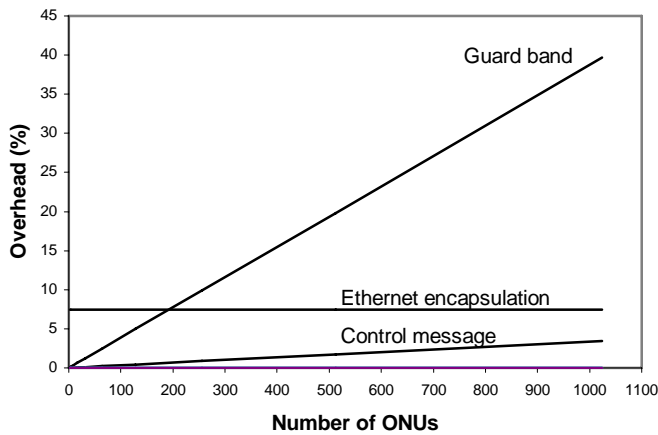


Figure 4. Breakdown of the major overheads in a 10G EPON system.

As can be seen, at low numbers of ONUs the EPON overhead is dominated by the Ethernet frame encapsulation. This is the Ethernet standard requirement for frame encapsulation and is not due to any EPON requirement. Therefore, the Ethernet frame encapsulation overhead cannot be altered.

As the number of ONUs in the EPON is increased other factors become significant. In 1G EPON the overhead due to the REPORT/GATE control messages and the overhead due to the guard bands are significant.

In 10G EPON the overhead due to the REPORT/GATE control messages remain very low with only the guard band overhead becomes significant at high numbers of ONU's. One must take into account that the 10G EPON standard is currently being formulated and the guard band parameters used in this calculation may not accurately represent the final 10G EPON standard.

IV. PROPOSED SOLUTIONS

There are a number of ways in which to reduce the overheads and therefore increase the effective scalability of an EPON system. Broadly one can look at the physical layer and manipulate the EPON architecture to more effectively use the control protocol and one can look at the higher layers in order to be more efficient in how the protocols are used. Thirdly one can make use of both the physical layer and higher layer protocols in order to realize an optimum EPON system.

On the physical layer one can implement a local area network (LAN) [3] thereby grouping a set of ONU's into one network area and therefore using only one logical link ID (LLID). This would reduce the amount of ONU's required and therefore reduce the overheads associated with the MPCP control protocol. Such architecture is shown in Figure 5.

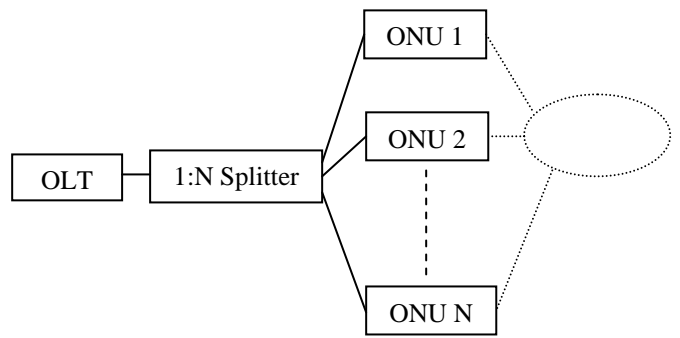


Figure 5. Architecture of an EPON with an emulated LAN.

Another physical layer solution is to provide more wavelengths [4] thereby grouping a set of ONU's, or a single ONU, to particular wavelengths. This solution also reduces the MPCP control protocol overheads as the REPORT/GRANT messages only need to be sent on a per wavelength basis as there is no potential for frame collisions between wavelengths.

Finally, an upstream repeater [5] can be employed near the ONU's which can serve as an intelligent control point aggregating the ONU messages for upstream transmission. This will reduce the amount of MPCP control messages required and therefore reduce the total overhead of the EPON system.

The improvement in the total upstream overhead by grouping a set of ONU's is shown in Figure 6 for a 1G EPON system and in Figure 7 for a 10G EPON system.

As can be seen, there is a dramatic improvement in the upstream overhead when users are grouped so that they only used one LLID. Note that there is not a large different if there are groups of 16 users or groups of 32 users per LLID.

There is a trade off in the improvement in the upstream overhead. That is the reduced ability to guarantee a quality of service to each individual user. However, this may be a reasonable tradeoff in a residential setting.

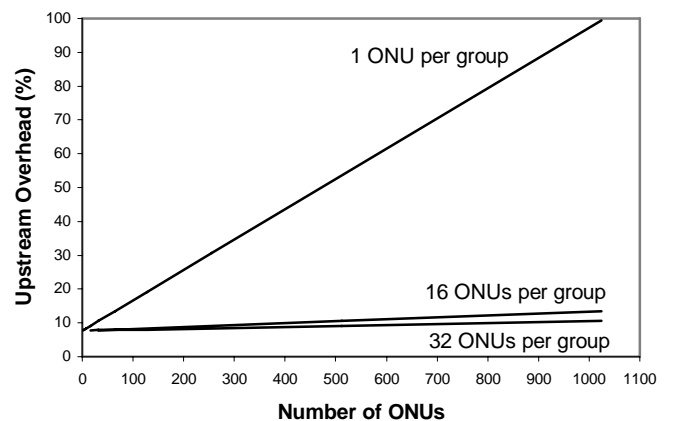


Figure 6. Total overhead as a function of the number of ONUs for a 1G classical EPON and a 1G EPON system that has grouped ONUs.

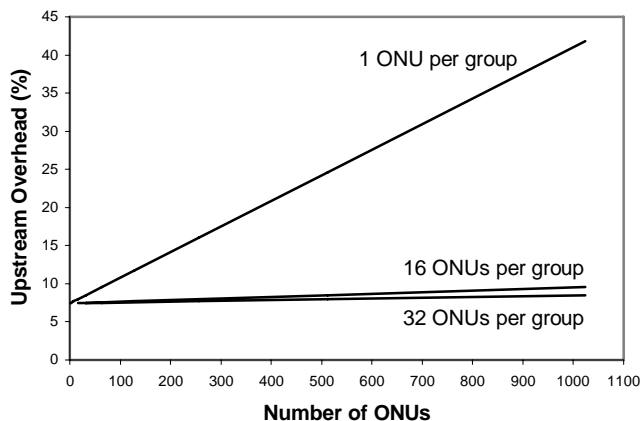


Figure 7. Total upstream overhead as a function of the number of ONUs for a 10G classical EPON and a 10G EPON system that has grouped ONUs.

Higher layer solutions requires a more intelligent mechanism to be employed with the MPCP control messaging than simply generating messages every 2ms in order to significantly reduce this overhead. We suggest that smart and efficient DBA and scheduling schemes must be implemented in an EPON system in order to reduce the requirement to send the control messages. We believe that such smart algorithms have the potential of reducing the MPCP overhead by reducing the amount of control messages that need to be sent. Also, a smart priority scheduling scheme in conjunction with the DBA is required in order to maintain quality of service to be maintained to the ONU's.

Smart DBA and scheduling algorithms are currently being developed in order to facilitate large numbers of ONU's to be serviced by an OLT while reducing the total overhead of the system.

V. CONCLUSION

The current 1G EPON standard is not scalable to large ONU's due to the significant overhead associated with the

MPCP control messages and the guard band requirement. Other overhead factors are relatively insignificant.

A projection was made for a 10G EPON system to obtain an idea of the types of overheads that may be dominant in such a system. In the 10G EPON case the MPCP control message overhead is significantly reduced from that in the 1G EPON case, but this will only drive the requirement for even larger ONU's in the future.

Several solutions to reduce the overhead in an EPON system were proposed. Two of which used novel physical layer architectures which have been shown to reduce the overhead significantly.

In addition to physical layer advances fast and efficient dynamical bandwidth allocation coupled with an efficient priority scheduler are required in order to reduce the MPCP control message overhead if large ONU's numbers are to be realised.

ACKNOWLEDGMENT

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