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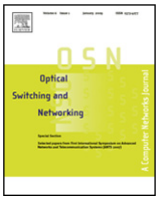

A new predictive dynamic priority scheduling in Ethernet passive optical networks (EPONs)

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ABSTRACT

Efficient uplink scheduling in Ethernet passive optical networks (EPONs) is very important for maximizing the network capacity while maintaining the required quality of service (QoS). Several variants of dynamic bandwidth resource allocation have been proposed in recent research literature. However, the available techniques do not fully exploit the elastic properties of the user traffic. In this paper, we explore optimal predictive resource allocation strategies by exploiting the elasticity of QoS-constrained traffic and using the knowledge of traffic patterns of different service classes. We propose a predictive dynamic uplink bandwidth allocation scheme that offers lower access delay and packet loss rate, yet achieves a higher overall network throughput. We formulate a model for determining the traffic burstiness-dependent optimum prediction order that would enhance the quality of prediction with a minimum possible prediction-related processing overhead. We then demonstrate that, in a multi-class access scheduling, with respect to the conventional dynamic allocation strategies, our priority scheduling with judicious prediction of individual traffic classes can enhance the system performance significantly. Our analytic observations are supported by extensive simulation results.

1. Introduction and motivation

Access networks are cost-sensitive. Therefore, simple and easily upgradeable technologies are appealing from deployment and maintenance viewpoints. Passive optical network (PON) technology is an attractive contender for the last-mile communication or broadband access, as it offers a highly stable broadband communication channel and has the unique feature of easy upgradability that can be done by only changing the electronics at the extreme ends of the networks.

In PON-based access techniques, the uplink traffic from different end users is aggregated at the optical network unit (ONU), which is located at the customer site and is capable of buffering the aggregated data. The ONUs are connected to a passive optical combiner/splitter, which in turn connects to the optical line terminal (OLT) via a single optical fiber. In Ethernet PONs (EPONs), the data packets are encapsulated in Ethernet frames. Because of its compatibility with the ubiquitous IEEE 802.3 Ethernet standards, advantages of low cost, simplicity of maintenance, large coverage area, and multicast and broadcast capabilities, the EPON has emerged as a promising broadband access solution.

In EPONs, the downstream data transmission to multiple ONUs is simply broadcast based, wherein the data packets for all ONUs are sent in all downstream links from the passive optical splitter that acts as a hub. An ONU extracts its intended data and delivers it to its local users. In

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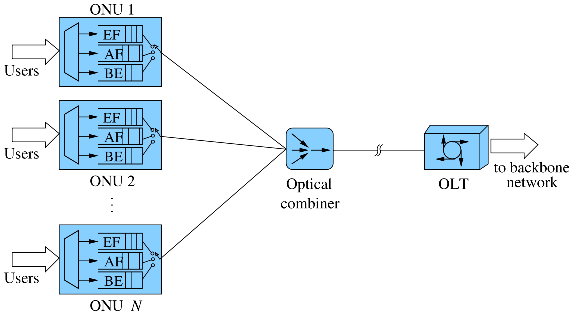

Fig. 1. The EPON architecture with differentiated service classes.

the upstream direction, an EPON acts as a multipoint-to-point network. From the optical combiner to the OLT link, the ONUs share a common upstream channel, and at most one ONU may transmit packets to the OLT in a particular time slot. Thus, in the upstream direction, using the shared channel fairly and efficiently is an important media access control issue. To this end, an EPON uses a time-division multiplexing (TDM) technique and also supports differentiated quality-of-service (QoS) traffic. In particular, according to the DiffServ model, the user traffic is classified into three types. The most delay-sensitive traffic with a certain degree of loss tolerance, which requires a guaranteed channel bandwidth, e.g., packetized voice traffic, is classified as expedited forwarding (EF) traffic. Traffic with a greater delay flexibility but requiring a minimum bandwidth guarantee, e.g., video, is categorized as assured forwarding (AF) traffic. Traffic with neither delay nor bandwidth guarantee constraints is classified as best effort (BE) traffic.

A multipoint-to-point EPON architecture with *differentiated class-based queues at the ONUs* is depicted in Fig. 1, where each ONU collates the class-based traffic information and sends it to the OLT for resource allocation. This classification at the ONUs helps the OLT assign the share of total available uplink resource proportionally to the ONUs per service class. In time-division multiplex-based upstream resource sharing in EPONs, the resource (i.e., number of time slots) to be assigned in a frame to different ONUs is done by an OLT that takes into account the upstream requests obtained in the previous frame. The efficiency of resource allocation in terms of guaranteeing user QoS and maximizing the system capacity (and hence the service provider's revenue) depends on the intelligence incorporated in generating bandwidth requests at the ONUs as well as the bandwidth allocation policy at the OLT subject to the ONU requests.

In recent years, several works have been reported on resource provisioning and differentiated QoS issues, for example, dynamic resource allocation [1–5], strict QoS support [6], and predictive resource allocation [7,8]. However, we argue that fine-tuning the ONU requests and the OLT's allocation strategies can significantly reduce over-provisioning of limited bandwidth resource, which is a key parameter in access networks in view of its cost-sensitivity. Additionally, although the Internet traffic prediction quality has previously been studied [9,10] and the concept has been applied in EPONs [8], studies on user-end traffic burstiness dependent predictive bandwidth allocation have not been reported in the literature.

In this paper, we address joint optimization of user QoS and system capacity by accounting for the class-based traffic burstiness characteristics. In our proposed predictive dynamic priority scheduling (PDPS), we first show that, even with a naive prediction mechanism at the ONUs, properly utilizing the excess bandwidth of QoS-constrained users improves all users' QoS and also enables achieving an overall higher system throughput. We then show that, by introducing traffic class-based prediction mechanisms at the ONUs, the system performance can be further improved in terms of increased total throughput and reduced access delay of different classes. As an example, our simulations show that, compared to a naive first-order prediction, with optimum predictors for different traffic classes, up to 14% delay reduction of video traffic can be observed at a 91% system load with an equal distribution of voice, video, and data traffic. Also, up to 20% reduction of data packet delay can be observed with optimum predictors, irrespective of the traffic ratio and system load.

The rest of the paper is organized as follows. Section 2 contains a brief survey of the research literature pertaining to our current work. In Section 3, the generic approach of our proposed predictive dynamic priority scheduling is presented. The analysis of our proposed traffic-aware predictions is provided in Section 4. In Section 5, first, numerical results on the impact of traffic burstiness-aware prediction on user QoS support and system capacity are discussed, and then the simulation results on multi-class traffic access performance are described. Section 6 concludes the paper.

2. Related work

Traffic classification and shared upstream resource provisioning issues in EPONs have been addressed independently as well as jointly in prior studies. In TDMA-based fixed (static) bandwidth allocation (FBA) [11], resource sharing was based on ONU demands – not based on traffic classes or their temporal dynamics, where the allocated bandwidth by the OLT to ONU$_i$ is $b_i^g = B_i$. B_i is a constant, which could be different for different ONUs. The inflexibility and hence bandwidth resource waste in static allocation policy was relaxed in several variants of dynamic allocation strategies (e.g., [12,1,6,2,7,3–5]). Interleaved polling with adaptive cycle time (IPACT) [12] considered ONU demand-based dynamic allocation, where the OLT adjusts the polling sequence of the ONUs depending on their respective queue lengths.

Traffic class-based priority scheduling was combined with IPACT in [1] to meet the delay and jitter guarantees. In the bandwidth-guaranteed polling approach [2], the ONUs are assumed of two priority classes, and the upstream polling sequence is adjusted by the OLT depending on the ratio of active ONUs of the two types. To achieve low access latency, queue length estimation-based bandwidth allocation was proposed in [7]. The common feature in [1] and [7] is limited bandwidth allocation (LBA) based on a service level agreement (SLA), where the OLT assigns the requested bandwidth to ONU$_i$ in the current frame if the request is less than the SLA$_i$, or else it grants only SLA$_i$.