Optical Switching and Networking 6 (2009) 151–162

Contents lists available at ScienceDirect

Optical Switching and Networking

journal homepage: www.elsevier.com/locate/osn

A survey of dynamic bandwidth allocation algorithms for Ethernet Passive Optical Networks

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ARTICLE INFO

Article history:
Received 1 October 2008
Received in revised form 20 February 2009
Accepted 17 March 2009
Available online 31 March 2009

Keywords:
Dynamic bandwidth allocation
Ethernet
Passive Optical Network

ABSTRACT

Ethernet Passive Optical Network (EPON) has been widely considered as a promising technology for implementing the FTTx solutions to the "last mile" bandwidth bottleneck problem. Bandwidth allocation is one of the critical issues in the design of EPON systems. In an EPON system, multiple optical network units (ONUs) share a common upstream channel for data transmission. To efficiently utilize the limited bandwidth of the upstream channel, an EPON system must dynamically allocate the upstream bandwidth among multiple ONUs based on the instantaneous bandwidth demands and quality of service requirements of end users. This paper introduces the fundamental concepts on EPONs, discusses the major issues related to bandwidth allocation in EPON systems, and presents a survey of the state-of-the-art dynamic bandwidth allocation (DBA) algorithms for EPONs.

1. Introduction

With the deployment of fiber optic technology over the past decade, the telecommunication infrastructure has experienced a tremendous growth in the bandwidth capacity of its backbone networks. This began with the wide area networks (WANs) that provide connectivity between cities through the metropolitan area networks (MANs) that connect service providers' central offices. However, subscriber access networks, which cover the "last mile" areas, and serve numerous residential and small business or organization users, have not been scaled up commensurately. The local subscriber lines for telephone and cable television are still using twisted pairs and coaxial cables. Many residential connections to the Internet are still through dial-up modems operating at a low speed on twisted pairs. With the ever-increasing users' demands for various broadband applications, such as Internet telephony, high-definition television (HDTV), interactive games, and video on demand, the "last mile" segment has become a bandwidth bottleneck in today's telecommunications infrastructure, which has largely limited the development of broadband services to subscriber users [1]. Although recent deployment of innovative xDSL and CaTV technologies has significantly upgraded this segment, they are still insufficient for meeting the ever-increasing bandwidth demand of subscriber users. To alleviate this bottleneck, fiber to the home/curb/building (FTTH/FTTC/FTTB) technologies have been long envisioned as a preferred solution, and passive optical networks (PONs) have been widely considered as a promising technology for implementing various FTTx solutions.

As one of the promising solutions, Ethernet Passive Optical Network (EPON) has received great attention from both industry and academia in recent years. EPON combines low-cost Ethernet equipment and low-cost passive optical components and thus has a number of advantages over traditional access networks, such as larger bandwidth capacity, longer operating distance, lower equipment and maintenance cost, and easier update to higher bit rates [2]. In an EPON system, all Optical Network

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doi:10.1016/j.osn.2009.03.003

Units (ONUs) share a common upstream transmission medium with limited bandwidth. To efficiently utilize the limited upstream bandwidth, an EPON system must employ a medium access control (MAC) mechanism to arbitrate the access to the shared medium in order to avoid data collisions in the upstream direction. For this purpose, bandwidth allocation becomes one of the critical issues in the design of an EPON system and a variety of bandwidth allocation algorithms have been proposed in the literature. The purpose of this paper is to give an introduction of the major issues in bandwidth allocation for EPON systems and present a survey of the state-of-the-art dynamic bandwidth allocation (DBA) algorithms proposed for EPONs.

The remainder of the paper is organized as follows. In Section 2, we introduce EPON architectures and discuss related issues. In Section 3, we discuss the major issues related to bandwidth allocation in EPON systems. In Section 4, we present a survey of the state-of-the-art dynamic bandwidth allocation (DBA) algorithms for EPON systems. In Section 5, we conclude this paper.

2. EPON architectures

In this section, we introduce EPON architectures, and discuss the channel separation and multiple access issues in EPON systems.

2.1. Network architectures

An EPON system is a point-to-multipoint fiber optical network with no active elements in the transmission path from its source, i.e., an optical line terminal (OLT), to a destination, i.e., an optical network unit (ONU). It can use different multipoint topologies, such as bus, ring, and tree [2], and different network architectures [2–5]. The most typical EPON architecture is based on a tree topology and consists of an OLT, a 1:*N* passive star coupler (or splitter/combiner), and multiple ONUs, as shown in Fig. 1. The OLT resides in a central office (CO) that connects the access network to a metropolitan area network (MAN) or a wide area network (WAN), and is connected to the passive star coupler through a singe optical fiber. Each ONU is located either at curbs or at subscriber premises, and is connected to the passive coupler through a dedicated short optical fiber. The distance between the OLT and each ONU typically ranges from 10 to 20 km. In an EPON system, all transmissions are performed between the OLT and the ONUs. In the downstream direction, an EPON is a point-to-multipoint network, in which the OLT broadcasts data to each ONU through the 1:*N* splitter, where *N* is typically between 4 and 64. Each ONU extracts the data destined for it based on its media access control (MAC) address. In the upstream direction, an EPON is a multipoint-to-point network, in which multiple ONUs transmit data to the OLT through the 1 : *N* passive combiner. The line data rate from an ONU to the OLT and the user access rate from a user to an ONU do not necessarily have to be equal and the line data rate is usually much higher than the user access rate. Since all ONUs share the same upstream transmission medium with limited bandwidth, an EPON system must employ a MAC mechanism to arbitrate the access to the shared medium in order to avoid data collisions in the upstream direction and thus efficiently share the upstream transmission bandwidth among all ONUs.

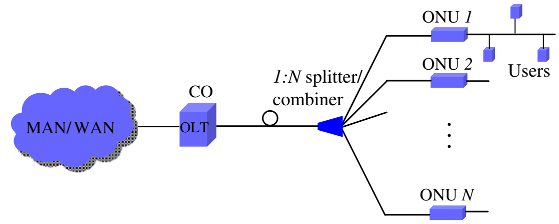

Fig. 1. EPON architecture.

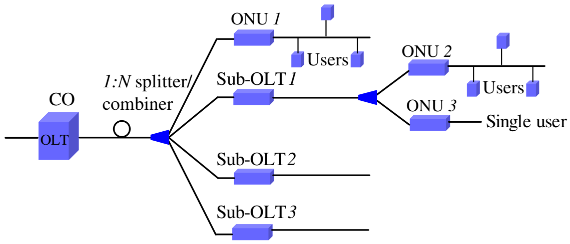

Fig. 2. Two-stage EPON architecture.

In [5], Shami et al. proposed a cascaded two-stage architecture for an EPON, which introduces an intermediate level of ONU nodes (called sub-OLT) to the network, as shown in Fig. 2. This architecture allows more end users to share the upstream OLT bandwidth without incurring extra overhead for switch-over between end users. It also enables longer access reach/distances than the usual 25 km because the intermediate sub-OLT nodes add another level of electrical generation. Moreover, the introduction of an intermediate stage can help reduce the OLT hardware complexity significantly.

2.2. Channel separation

In an EPON system, the upstream and downstream transmission channels should be appropriately separated in order to increase the transmission efficiency. A simple solution is to use space division multiplexing, where two separate optical fibers and passive couplers are used, one for upstream transmission and the other for downstream transmission. A more cost-effective solution is to use a single coupler and a single fiber for both directions with one wavelength for upstream transmission and another for downstream transmission. Typically, a 1550 nm wavelength is used for downstream transmission and a 1310 nm wavelength is used for upstream transmission [2].

2.3. Multiple access

In the upstream direction of an EPON system, multiple ONUs transmit data packets to the OLT through a common passive combiner and share the same optical fiber from the combiner to the OLT. Due to the directional property of a passive combiner, data packets from an ONU can only reach the OLT but not the other ONUs. For this reason,