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Hybrid scheduling mechanisms for Next-generation Passive Optical Networks based on network coding

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ABSTRACT

Network coding (NC) integrated into Passive Optical Networks (PONs) is regarded as a promising solution to achieve higher throughput and energy efficiency. To efficiently support multimedia traffic under this new transmission mode, novel NC-based hybrid scheduling mechanisms for Next-generation PONs (NG-PONs) including energy management, time slot management, resource allocation, and Quality-of-Service (QoS) scheduling are proposed in this paper. First, we design an energy-saving scheme that is based on Bidirectional Centric Scheduling (BCS) to reduce the energy consumption of both the Optical Line Terminal (OLT) and Optical Network Units (ONUs). Next, we propose an intra-ONU scheduling and an inter-ONU scheduling scheme, which takes NC into account to support service differentiation and QoS assurance. The presented simulation results show that BCS achieves higher energy efficiency under low traffic loads, clearly outperforming the alternative NC-based Upstream Centric Scheduling (UCS) scheme. Furthermore, BCS is shown to provide better QoS assurance.

1. Introduction

With the deterioration of environment and climate, the increase of greenhouse gas emissions has become an important problem. Green networks that can reduce CO_2 emissions are becoming increasingly important due to the exponential growth of the Information and Communications Technology (ICT) industry in the future. As the energy consumption of broadband access networks is responsible for nearly 70% of the whole telecommunications network sector and is expected to further grow in the future [1], energy saving has become a key issue with the development of Passive Optical Networks (PONs).

A variety of technologies and countermeasures have been proposed for improving the energy efficiency of PONs. Enabling Optical Network Units (ONUs) to enter sleep mode for energy saving is considered one of the most effective methods. Kubo et al. proposed a sleep and adaptive link rate control mechanism in [2] and extended their work to a mechanism with a variable sleep period for power saving in [3]. This mechanism uses Sleep and Periodic Wake-up (SPW) principles, which are widely applied in wireless sensor networks. The Optical Line Terminal (OLT) performs the sleep control without requiring a report message for dynamic bandwidth allocation (DBA) and also takes different levels of service into consideration. However, the lack of a message exchange between the OLT and ONUs may misjudge the actual traffic load in burst mode. In [4,5], Yan et al. introduced an energy management mechanism and demonstrated the importance of a well designed scheduling mechanism for energy saving and enhanced sleep mode control. Two scheduling mechanisms, Upstream Centric Scheduling (UCS) and Downstream Centric Scheduling (DCS), were compared. It was shown that UCS improves the energy saving gains while DCS provides better Quality-of-Service (QoS) guarantees. Zhang and Ansari proposed a Medium Access Control (MAC) scheduling mechanism with two different ONU sleep modes, which allows one sleep period to be longer than the DBA period, while the other sleep period to be shorter than the DBA period [6]. ONU sleeping within a DBA period achieves high energy efficiency, but has the disadvantage of waking ONUs up early. To alleviate this disadvantage, precision time synchronization is needed. In [7], the so-called Energy Saving scheme based on downstream Packet Scheduling (ESPS) was proposed for an Ethernet Passive Optical Network (EPON). The authors designed a hybrid sleep mode that contains an ONU deep-sleep mode and independent sleep modes for the transmitter and receiver. The hybrid sleep mode leads to lower energy consumption of ONUs.

The aforementioned mechanisms were designed and evaluated by considering the energy consumed by ONUs, while possible energy saving methods for the OLT were ignored. It is important

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to note, however, that it is imperative to reduce the energy consumption of the OLT since the OLT consumes more than half of the total energy of a PON [8]. On the other hand, typical PONs have multicast features due to the power-splitting coupler at the remote node. The aforementioned mechanisms considered only unicast traffic and didn't involve any multicast traffic and thus will lead to a waste of energy under multicast traffic due to the fact that they require multiple unicast transmissions, one for each destination. Therefore, an energy saving mechanism that takes the energy efficiency of the OLT as well as multicast features of PONs into consideration is needed.

Given the wide use of the peer-to-peer (P2P) file sharing, intra-area voice and video communications, and community network service, a network localization trend is becoming increasingly obvious. Enhancements to support intra-area network communications have become one of the main network development tendencies. A key technology to improve the transmission performance of internal traffic has become a pressing need. As an important breakthrough in information theory, network coding (NC) is able to improve the performance of the network significantly. The application of NC in PONs is anticipated to create new technological innovations [9]. In fact, in [9] and [10], it was shown that NC can be realized in PONs without requiring any hardware modification. The basic idea of the proposed NC implementation is illustrated in Fig. 1. In the considered scenario, ONU_1 and ONU_2 are assumed to have NC functionality while ONU_3 and ONU_4 are conventional ONUs. Packets A, B, C, and D are internal PON packets that are exchanged between the ONUs. Note that without NC, the transmission of Packets C and D between ONU_3 and ONU_4 requires twice the bandwidth and transmitter power in the OLT than in the NC enabled case. The network performance can be improved by using NC. For illustration, consider the communication between ONU_1 and ONU_2 as an example, where Packet A is still stored in the buffer of ONU_1 after its uplink transmission. A new encoded packet is generated through bitwise exclusive-OR (XOR) operation between A and B at the OLT. The new encoded packet is broadcast to the ONUs and each ONU receives the A⊕B packet. By performing the XOR operation for Packets A⊕B and A, whereby the latter one is stored in the buffer of ONU_1, ONU_1 is able to decode Packet B. A similar procedure is implemented at ONU_2, leading to the successful reception of Packet A. Note that during the whole transmission process 50% of the energy consumption has been saved at the OLT by reducing the number of time slots required for transmission in the downstream direction. Also note that this method also leads to the store of the packet in the buffer of ONUs. However, since the energy consumption of ONUs is mainly caused by the high-speed circuitry rather than the memory itself, whereby the low-speed circuitry has a minimum impact on the total energy consumption [11], and the store of the packet in the buffer of ONUs will not cause any dropping of packets as long as the buffer size of ONUs is set properly, the negative effects of buffering packets at the ONU side can be ignored.

Recently, we have proved the feasibility and advantage of NC-enabled NG-PONs by means of experimental emulation in an actual network environment [12]. The NC-based Energy Management Mechanism (EMM) and our proposed improved UCS scheme were shown to achieve excellent performance in NG-PONs. However, the support of QoS was not supported in EMM. As the traditional DBA is designed for the unicast applications, an effective DBA for the multicast applications (MSDBA) was proposed in [13] for the NG-PON with NC. Further, Ref. [14] proposed an energy-efficient P2P communication architecture include NC techniques over a wavelength division multiplexing/time division multiplexing PON (WDM/TDM-PON). Note that the application of NC in PONs is still in its infancy. Previous studies have focused on the realization of NC in PONs with taking hardly any QoS assurance into account. To further improve the efficiency of NC while at the same time also supporting QoS, the design of a new energy-saving scheduling scheme with service differentiation and QoS assurance is necessary in NC-based PONs.

In this paper, based on our previous study [12], the standard energy saving modes, novel scheduling, and QoS assurance are taken into account. We propose an NC-based hybrid scheduling mechanisms with service differentiation and QoS assurance in order to improve both network performance and energy efficiency. An IEEE 802.3ah EPON network with two sleep modes, (Transmit Receive Unit) TRx mode and (Transmit Unit) Tx mode, is proposed. First, we discuss the energy-saving mechanism and then present

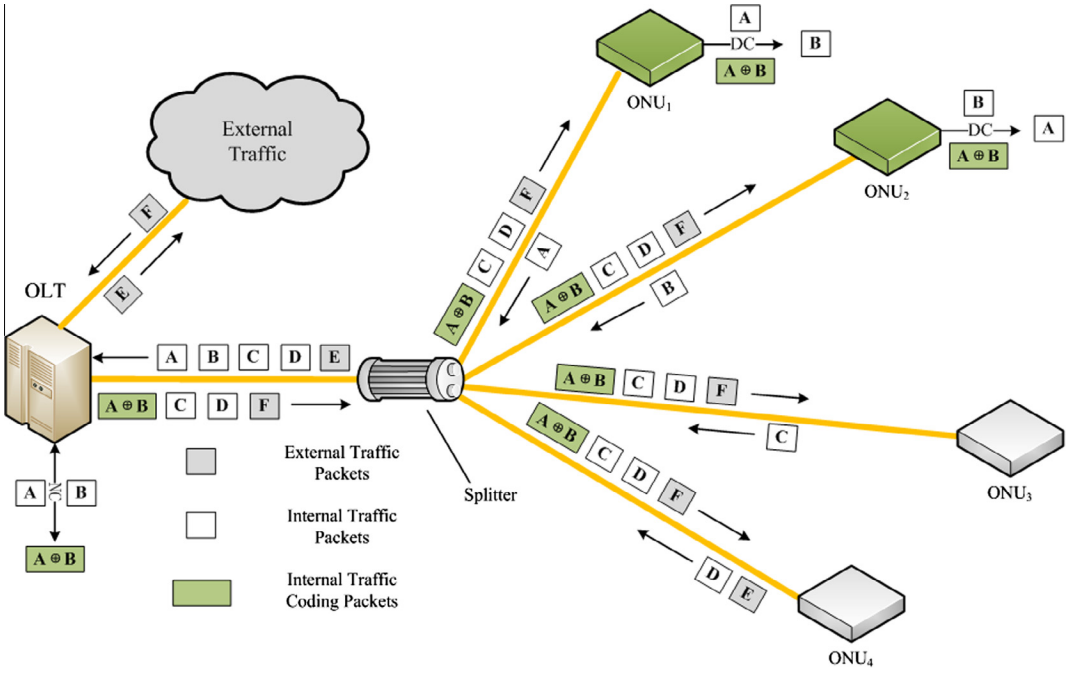

Fig. 1. Implementation of NC in a PON.