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Invited Papers

Energy-efficient technologies for point-to-point fiber access

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ABSTRACT

This article discusses the fundamental issues and the technologies to achieve an energy-efficient Gigabit-Ethernet point-to-point (PtP) fiber access network. To minimize the power consumption of PtP fiber access for long-term development, it is essential to optimize each of the network components such as optical transceiver, user network interface, Ethernet aggregator and also their modes of operation. Our analysis shows that the energy consumption of a PtP fiber access network using our proposed technologies can be up to 7.5 times lower than that of the 2010 technologies when a combination of appropriate technologies is applied.

1. Introduction

Fiber-to-the-Premises (FTTP) is widely seen as the next generation fixed access system due to the sustainable bandwidth that can be provided by the fiber. There are two network architectures for FTTP: point-to-multi-point (PtMP) and point-to-point (PtP) fiber access. Nowadays, majority of broadband subscribers are connecting to the Internet using the PtMP FTTP network architecture such as the Gigabit enabled passive optical network (GPON) and the Ethernet passive optical network (EPON). The advantages of PtMP-FTTP system include high energy-efficiency and low capital expenditure due to the reason that multiple subscribers share a single fiber connection to the central office. An alternative fiber access architecture is the Gigabit Ethernet (GbE) PtP system, which connects the subscriber to the central office via a dedicated fiber connection. Practically, as compared to PtMP, an increased optical line terminal (OLT) footprint and an increase in the number of fiber cables in the field are the physical limitation of the PtP access network. These issues directly affect the capital expenditure. With the technological advancements in the multicore fiber and the laser diode and photodiode array, we envision that a reduction in the footprint of the PtP system will be achievable in the near future. Since PtP offers a physically separate data link not shared by other users, it provides higher data security and a lower data latency compared to the PtMP-FTTP. Also, PtP fiber access provides a symmetric upstream and downstream traffic with extra bandwidth headroom for the subscribers who are demanding higher data-rate with good traffic latency. Therefore, a portion of residential households and most business subscribers, including fiber to the premise, fiber to the node and mobile backhaul, are considering PtP fiber access as their broadband access solution.

Recently, there is increased awareness of energy-efficiency requirements of the broadband network equipment and design guidelines for equipment power consumption have been published by various global organizations [1,2]. Second to the wireless network, the wireline access network is one of the main contributors to the power consumption in telecommunication networks [3]. Since optical access network is considered to be the most energy-efficient broadband access technology compared to copper-based wireline access and the wireless access systems [3,4], deploying FTTP is recommended from an energy efficiency perspective. To further reduce the energy consumption of optical access networks, the access technologies working group of GreenTouch (GT) consortium initiated the mission to deliver the architecture, specifications and roadmap to increase network energy efficiency compared to 2010 technology as a baseline. The baseline power consumption per-subscriber of GPON and GbE PtP fiber access networks are 5.7 W and 5.3 W, respectively [1]. Reducing the power consumption of the OLT and the ONUs of FTTP will directly reduce the overall energy consumption of the entire telecommunications networks. In addition, power reduction at the OLT translates to lower operation expenditure (OPEX) for the access network provider due to the relaxed cooling. Whereas, a lower power ONU at remote nodes opens up the opportunity in using energy-harvester and a smaller back-up battery, which also helps reducing the OPEX.

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Existing research has shown that, with the right technology mix, the energy consumption of the PtMP fiber access can be further improved [4–6]. We therefore dedicated our research efforts on developing low-power access technologies for energy-efficient PtP-FTTP fiber access at both the OLT and the ONU [7–9]. Our research outcomes in access networks have been contributing to the development of energy efficient PtP fiber access network for the businesses.

In this paper, we review our previous published activities on the simulation of sleep mode operation in PtP access network and the investigation of power consumption of PtP optical transceiver [7–9]. In addition, we also discuss our latest experimental studies on the low-power optical transceiver prototype and its applications in both the PtP fiber access link and the user network interface. Further, we also present our recent analysis of the power consumption of the Ethernet aggregation switch and provide some guidelines to improve the energy-efficiency. In Section 2, we will first discuss the power distribution of each network component. In Section 3, the technologies for the mid- and long-term evolution of PtP access will be discussed in terms of energy-efficiency. Finally, we conclude the paper by summarizing the individual contribution of different technologies on the overall power consumption of the PtP fiber access.

2. Architecture and power consumption of PtP fiber access

Fig. 1 shows the network architecture of the PtP access network where the optical line termination (OLT) located at the central office consists of multiple optical access interfaces (AIs), each connected to one optical network unit (ONU). In the upstream direction, multiple stages of Ethernet aggregators (EAs) connect between the OLT AIs and the service provider's network. The ONU mainly consists of an AI, a digital processing unit which is normally a System on Chip (SoC), and the user network interface (UNI).

The AIs at both the OLT and the ONU are electro-optics transceivers that enable the transport of the upstream and the downstream traffic over the fiber using non-return-to-zero modulation format. When downstream packets arrive at the OLT, the EA will process the Ethernet packets and distribute them to the corresponding OLT-AI according to the medium-access-control (MAC) addresses of the packets. At the ONU, the AI receives the downstream Ethernet packets which are then forwarded to the ONU-SoC for packet processing. The extracted data will further be distributed to the subscriber end-terminals via the UNI. For upstream Ethernet packets from the subscriber end-terminals, they are transmitted to the OLT via the UNI, the ONU-SoC and the AIs following the reverse process. The upstream packets from different subscribers will be processed and aggregated by the EA for uplink transmissions. Conventionally, in a GbE PtP fiber access, a 1000Base GbE MAC processor is used in the SoC and the GbE PHY is used as the UNI.

The power consumption of a GbE PtP fiber access link is estimated to be 5.3 W per subscriber [1]. The power consumption includes key components in the OLT and ONU such as the optical access interfaces, the UNI, the ONU-SoC and the EAs. The corresponding power contributions of the ONU and the OLT are estimated to be 60% and 40%, respectively [1]. To understand the power distribution of each component in the ONU and the OLT, the power consumption has been further broken down for each functional block as shown in Fig. 2. The power distribution is estimated based on an OLT equipped with more than 500 ports (see Section 3.3). Unlike PtMP fiber access in which the power consumption per subscriber is dominated by the ONU [3], the power consumption of a GbE PtP access link is evenly distributed among different components. As shown in Fig. 2, the power consumption of the access interfaces for the OLT and ONU are different. It is because the access interfaces used at the OLT are with a more compact design resulting in relatively lower power consumption than the ONU access interface. In order to improve the energy efficiency of the PtP fiber access, each component needs to be investigated from the physical hardware perspective to their operation mechanisms.

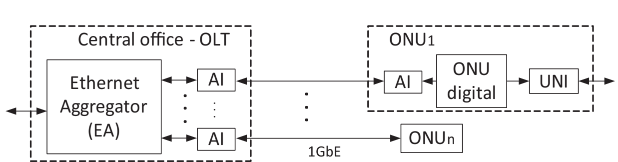

Fig. 1. The network architecture of a Gigabit Ethernet PtP access network. OLT: optical line terminal, AI: optical access interface, ONU: optical network unit, ONU digital (System-on-chip), UNI: user network interface.

3. Technologies for energy-efficient PtP access

In this section, various low-power technologies for the energy-efficient PtP fiber access will be discussed. A key characteristic of a PtP access system is that each individual subscriber is connected to an OLT port through a dedicated fiber as shown in Fig. 1. Therefore, all downstream and upstream packets arriving at an OLT port are destined or originated from a unique ONU, respectively. Conceptually, this characteristic enables a simple traffic management between the OLT and the ONU.

However, the conventional GbE PtP fiber access system is often designed based on legacy components (including EA, optical transceiver, UNI, etc.) that are not energy optimized for simple PtP fiber access networks. Therefore, there is room for redesign of the components using more energy-efficient hardware technologies complemented with smart power-saving operation algorithms. In the following sub-sections, power-saving technologies for some of the components shown in Fig. 2 will be discussed.

3.1. Low power optical transceiver

From the power distribution discussed in Section 2, more than 33% (19% from ONU AI + 14% from OLT AI) of the overall power is consumed by the access interfaces (i.e. the optical transceivers) located at the OLT and the ONU. The conventional PtP optical transceivers are designed with limited consideration on the power consumption. As a result, the optical transceiver is always operated at

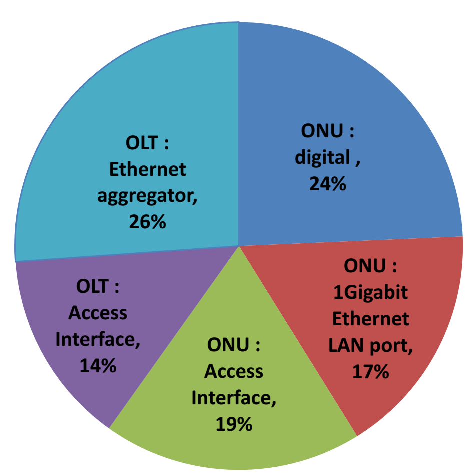

Fig. 2. Power distribution of a Gigabit PtP access link.