Title:

Bandwidth Efficient Inter ONU Communication Enabled Physical and MAC Layer Architecture for Next Generation PON

By

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ABSTRACT:

To meet the exponentially increasing and application-specific bandwidth demands of emerging technologies such as 5G backhaul, which may require data rates up to 20 Gbps in dense urban environments, cloud computing applications demanding 10 Gbps or higher, and time-sensitive industrial systems that need end-to-end delays below one millisecond, passive optical networks (PONs) have evolved from Gigabit PON (GPON) to high-capacity 50 Gigabit PON (50G-PON). However, in the conventional PON architectures, all communications are routed through the OLT, which introduces several limitations. First, the OLT is usually located at a distant location at the central office, resulting in higher latency. Secondly, the OLT experiences additional processing load as it handles all upstream and downstream traffic. Moreover, the unnecessary to-and-fro transmission of data introduces possible security risks and leads to inefficient use of upstream and downstream bandwidth. One effective way to overcome these issues is to enable inter-ONU communication (IOC) without involving the OLT.

This study presents IOC-enabled PON physical layer architectures that require minimal changes to the existing PON structure, as well as supporting media access control (MAC) layer. At the physical layer, two architectures are proposed that support simultaneous IOC and upstream communication at 25 Gbps and 30 Gbps data rates, respectively. In both architectures, each ONU uses a single transmitter along with a self-phase modulation (SPM)-based wavelength converter to enable either upstream or IOC communication. For IOC transmission, the ONU first generates a Return-to-Zero (RZ) optical signal at 1310 nm, which is then passed through the SPM to convert its wavelength to 1310.6 nm or 1310.7 nm, depending on the data rate. Meanwhile, another ONU can transmit an upstream signal at 1310 nm without passing through the wavelength conversion path, allowing both transmissions to occur simultaneously. These two signals are coupled at the remote node (RN), where a fiber Bragg grating (FBG) reflects the IOC signal while allowing the upstream signal to pass through it. Both proposed architectures support long-reach PON communication, achieving end-to-end reaches of 122 km and 93 km for 25 Gbps and 30 Gbps data rates, respectively, while meeting the maximum acceptable bit error rate of 10^{-12} as defined in the ITU-T G.987.1 recommendations. These proposed physical layer architectures also support IOC over a single wavelength among 32 users with a maximum ONU and RN separation of 5 km, fully compliant with standard requirements.

To further extend the number of users for IOC communication, another physical-layer architecture is also proposed that supports IOC at two different wavelengths, each serving 32 users, for a total of 64

simultaneous users at 30 Gbps. This is achieved by replacing the wavelength filter at the RN with two FBGs. The first FBG reflects the IOC signal at 1309.6 nm while passing other wavelengths, and the second FBG reflects the IOC signal at 1310.4 nm while passing the upstream signal. This configuration enables two simultaneous IOC transmissions with 32 users each, up to a maximum ONU and RN separation of 3 km, along with upstream communication at 1310 nm, achieving a maximum end-to-end reach of 112 km with BER performances for both IOC and upstream communication within acceptable ITU-T G.987.1 recommended limits. Moreover, replacing the wavelength filter with FBGs also helps reduce overall system cost.

A supporting MAC layer framework is also developed to provide compatibility with the standard XG-PON frame structure, enabling simultaneous IOC, upstream, and downstream communications. A new dynamic bandwidth allocation (DBA) scheme has also been proposed to provide effective scheduling of bandwidth for both IOC and upstream traffic simultaneously. Specifically, a slot conflict resolution algorithm is proposed along with the DBA scheme to ensure transmission of either an IOC or an upstream traffic at a time by each ONU. This algorithm ensures that an ONU is not scheduled for both types of transmissions in the same time slot, avoiding conflicts and ensuring efficient use of bandwidth. The proposed mechanism guarantees fair resource allocation, supports simultaneous communication scenarios, and maintains backward compatibility with XG-PON standards, making it suitable for deployment in existing networks with minimal modifications. Simulation results show that the proposed MAC layer and DBA scheme outperform conventional PON systems by reducing upstream delays and improving bandwidth availability per ONU under similar network load conditions. The proposed DBA approach is expected to serve as a foundation for future research on performance optimization in IOC-enabled PONs.