A Universal Optical Network Unit for Hybrid TDM-PON and WDM-PON Transport Systems

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Abstract— Based on a vertical-cavity surface-emitting laser (VCSEL)-composed wavelength selector, a university optical network unit (ONU) is proposed for hybrid time and wavelength division multiplexing passive optical networks.

1. INTRODUCTION

Fiber to the Home (FTTH) transport systems have attracted plentiful attentions to provide triple-play multimedia services for residential and business clients due to their low loss and high capacity characteristics. By adapting this technique, the coverage range of an optical line termination (OLT) will be extended and the available bandwidth for the connected clients can be extended to Gbps range which is hundred times larger than the capacity of traditional ADSL or cable networks [1]. Time-division multiplexing (TDM)-passive optical networks (PONs) and TDM-access (TDMA) control protocols are therefore developed to share the extended bandwidth for clients. Basing on TDM-PON structure, a common type of optical network unit (ONU) installed in each client's premises can resourcefully diminish the deploying cost and more than 100 Mbps data rate is achievable for each client to enjoy convenient broadband services [2, 3]. Such economic TDM-PON architecture is popular in the beginning of deploying optical fiber in the last mile connection. Nevertheless, if the downstream bandwidth requirement is increased with the extended multimedia service environment, the network capacity of a ONU in such TDM-PON structure is difficult to be upgraded. Converting the TDM-PON structure to wavelength-division multiplexing (WDM)-PON structure will be a suitable solution to upgrade the ONUs' capacity. A WDM-PON with logical point-to-point connection for each ONU will be able to extend the available downstream bandwidth from 100 Mbps in TDM-PONs to 1 Gbps or larger bandwidth for a client [4]. There are two main methods to achieve this objective. One is to insert an optical wavelength selector, such as tunable optical bandpass filter (TOBPF) [5], in front of an TDM-ONU to select a dedicated optical wavelength and reject other inserted optical wavelengths, and another one is to replace the optical passive splitter deployed in the remote node of a TDM-PON by an optical wavelength de-multiplexer, such as arrayed waveguide grating (AWG) [6], to direct various downstream optical carriers into dedicated directions. Utilizing a TOBPF to select the inserted optical carriers in an ONU is convenient and the entire TDM-PON can be gradually migrated to WDM-PON according to consumers' requirements. However, the expensive TOBPF makes this solution inacceptable. On the other hand, the TDM-ONU is still able to be utilized in WDM-PON architecture if the optical splitter of a TDM-PON is replaced by an AWG. This can save a lot of cost but the entire network will need to be upgrade from TDM-PON to WDM-PON simultaneously. In addition, the type and amount of the employed optical wavelengths in such WDM-PON are fixed by the employed AWG. The internet service provider will not able to gradually achieve the migration according to consumers' requirements and the scale of the WDM-PON is fixed. It is clear from the discussion that utilizing a TOBPF to achieve the migration is much more flexible than employing AWG. If there is a method to provide economic wavelength selector for a TDM-ONU, a TDM-PON network will be able to migrate to WDM-PON network flexibly. To achieve this target, a novel wavelength selector is proposed and developed to compose a universal optical network unit (ONU) for both TDM- and WDM-PON architecture. Unlike the published TDM-PON to WDM-PON migration architectures which utilizing expensive tunable optical band-pass filter (TOBPF) or complicated optical routing schemes to select proper optical wavelengths, the proposed universal ONU can utilize an economic vertical-cavity surface-emitting laser (VCSEL) as a TOBPF to select a specific lightwave from multiple injected optical carriers. Besides, the VCSEL-composed wavelength selector with electrically adjustable characteristic will be able to assist the universal ONU with an ability to switch its receiver functionality for either economic TDM-PONs application or high-capacity WDM-PONs structure. Experimental results proof that by modifying the driving current of the VCSEL-based wavelength selector, both TDM-PON signal and WDM-PON signal can be received individually. This proposal provides an economic and flexible method for clients to migrate between TMD-PON and WDM-PON architecture.

2. EXPERIMENTAL SETUP

To evaluate the proposed universal ONU in a hybrid TDM- and WDM-PON transport system, a TDM and a WDM signals generated by mixing a 1.25 Gbps PRBS signal with a 10 GHz sinusoidal signal are individually phase modulated with two different downstream optical carriers and then transmitted to a tree-topology style PON network simultaneously. As shown in Fig. 1, both downstream lightwaves are combined by an optical combiner and amplified by an Erbium doped fiber amplifier (EDFA) before be communicated over a span of 12.5 km single mode fiber (SMF) and a $1*16$ optical splitter to ONUs which are composed by a wavelength selector, a photo-detector (PD) and frequency down-conversion circuit. In here, the wavelength selector in each ONU is the same and is composed by an optical circulator, a polarization controller (PC) and a commercial VCSEL. To perform both TDM-PON and WDM-PON performance, the ONU_1 is designed to receive the WDM signal (λ_1) and the $\mathrm{ONU}_{2\text{–}15}$ are designed to receive the TDM signal (λ_2). To select each dedicated downstream carrier and reject another one, the VCSEL in the ONU_1 is driving by i_1 (5.13 mA) current and the VCSEL in the $\mathrm{ONU}_{2\text{–}16}$ is driving by i_2 (3.5 mA) current. These two driving current values will make these VCSELs emit out two different lasing wavelengths which are aligned with the +1 sideband of the TDM and WDM signals, respectively. This process will resourcefully select and direct one of the two downstream signals into each ONU PD. In addition, the process will also convert the downstream phase modulated signals from double sideband (DSB) format to single sideband (SSB) format performing a phase modulation (PM) to intensity modulation (IM) conversion. The obtained TDM and WDM signals are then down-converted to baseband by mixing with another 10 GHz sinusoid signal and evaluated via an electrical spectrum analyzer (ESA) and eye diagrams.

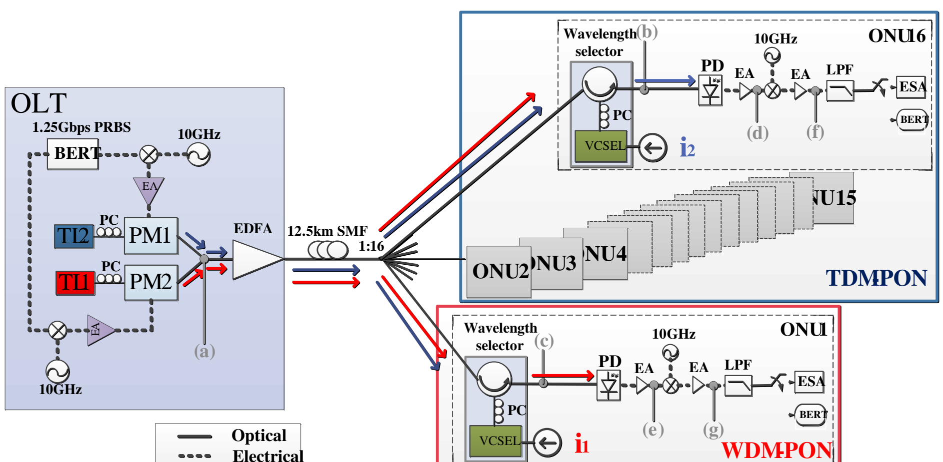
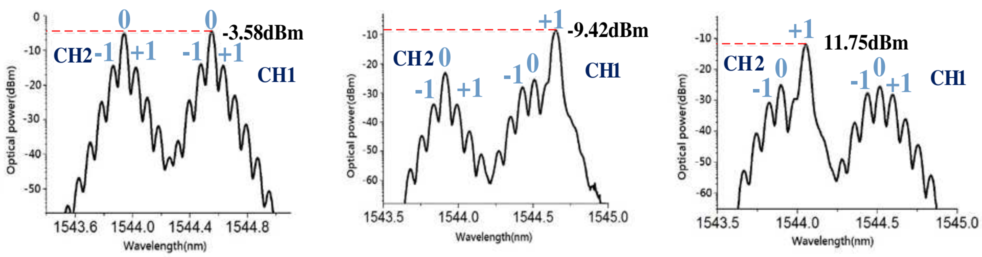


Figure 1: Experimental setup of the proposed universal ONU in a hybrid TDM- and WDM-PON transport system.

3. EXPERIMENTAL RESULT AND DISCUSSION

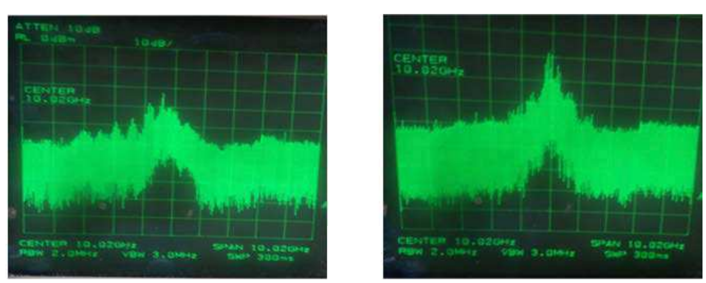
In this experiment, both of the downstream TDM and WDM signals will go through the VCSEL via an OC before be inserted into the PD. If the VCSEL in the TDM-ONU is driving with proper current, its lasing wavelength will align with the +1 sideband of the TDM signal, so that this sideband will go through the VCSEL quantum well and reflected back with roughly the same power. In parallel, roughly 15.28 dB attenuation will be added into the WDM signal as well as the central carrier and the −1 sideband of the TDM signal since these wavelengths are located outside the VCSEL free-running frequency. As shown in Fig. 2(a), both TDM and WDM signals originally have roughly the same optical spectra before been communicated though the downstream SMF, but both optical spectra observed before the PD of the TDM-ONU are not equal. As display in Fig. 2(b), more than 14.75 dB attenuation is added into the WDM signal (ch2) and the central carrier and −1 sideband of the TDM signal. This process will simultaneously perform wavelength selection and

PM-to-IM conversion for each TDM-ONU. Similarly, the +1 sideband of the WDM signal is also selected by the WDM-ONU, as presented in Fig. 2(c). In parallel with the optical spectra, clear electrical spectra diagrams of the obtained 1.25 Gbps/10 GHz TDM and WDM signals are presented in Figs. 3(a) and (b), respectively, and open eye diagrams for back to back and 12.5 km transmissions scenarios are presented in Figs. 4(a) and (b), respectively. These experimentally results proof that the VCSEL-composed wavelength selector can provide a $>$ 14.75 dB attenuation for the wavelengths located outside the target wavelength and its wavelength selection function can be electrically and continuously shifted by adjusting the VCSEL driving current. A roughly 3 nm shifting range is achievable for the proposed universal ONU to select the desired wavelength (signal) from the tree-topology hybrid TDM- and WDM-PON. It can be expected that by utilizing the universal ONU to deploy a passive optical access network, such as the Ethernet-PONs (EPONs) or Gigabit-capable PONs (GPONs), the clients will be able to enjoy a low capital expenditure (CAPEX) in the first beginning and any one of the client will be able to extend his/her network capacity form hundreds Mbps range (TDM-PONs) to thousands Mbps range (WDM-PONs) without replacing any deployed device or deployed network topology. The Internet service provides (ISPs) will be able to provide additional bandwidth for each specific client simply by electrically adjusting the working window of the VCSEL-composed wavelength selector inside each specific ONU and then adding a relative optical carrier to deliver the extra data in the presented network.



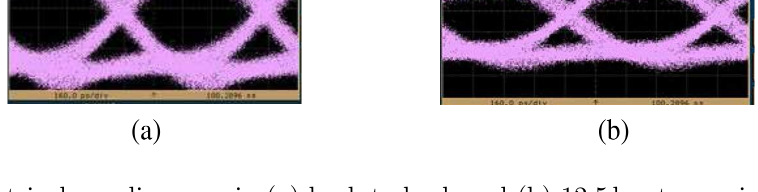
(a) (b) (c)

Figure 2: (a), (b) and (c) are the optical spectra diagrams obtained at the Fig. 1 observed points (a), (b) and (c) respectively.



(a) (b)

Figure 3: The electrical spectra diagram of the obtained 1.25 Gbps/10 GHz. (a) TDM signal and (b) WDM signal.



(a) (b)

Figure 4: Electrical eye diagrams in (a) back-to-back and (b) 12.5 km transmission scenarios.

4. CONCLUSION

To provide a resourceful TDM-PON to WDM-PON migration method for clients, a universal ONU is proposal for a hybrid TDM- and WDM-PON transport system. By adding a VCSEL-composed optical wavelength selector into a general ONU, the ONU can flexibly utilized to receive dedicated signals carried by different wavelengths. Proper optical spectra diagrams and eye diagrams proof that the proposed system can provide a proper TDM to WDM or WDM to TDM migration method for each client without changing the network structure and ONU circuit.

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