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Wavelength Switched Hybrid TDMA/WDM (TWDM) PON: a Flexible Next-Generation Optical Access Solution [Invited]

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ABSTRACT

In this paper, we propose the system concepts of a next-generation wavelength switched hybrid time division multiple access and wavelength division multiplexing (TWDM) passive optical network (PON) architecture. In this architecture, wavelength selective switches (WSSs) are used at the remote node to improve flexibility, data security and power budget compared to other TWDM-PON variants. We map the proposed architecture to the requirements of next-generation optical access networks in a 2020 perspective. Finally, we benchmark the proposed architecture with other proposed TWDM-PON solutions.

Keywords: Flexibility, Passive Optical Networks, and Hybrid TDMA/WDM-PON.

1. INTRODUCTION

Many telecommunication operators have started deploying passive optical networks (PONs) to acknowledge the rapidly increasing demand for high bandwidth. So far, the time division multiple access (TDMA) based solutions like Ethernet PON (EPON) and gigabit-capable PON (GPON) have been used for mass rollout. However, to meet the increasing requirements of the end users, it is anticipated that the next-generation PON (NG-PON) - with a much higher bandwidth, a high customer fan out, long reach and flexibility in resource allocation - is a natural path forward. It is easy to comprehend the main motivation behind the design requirements of a NG-PON. It is clear that the bandwidth requirements will further increase the coming years and new applications will pop up to consume the available network bandwidth. A high customer fan out minimises the cost and power consumption of the network per user. Long reach is considered for a higher node consolidation, where a central access node (CAN) replaces many active central offices (CO). The reduction in active network sites minimizes operational expenditures for an operator. Flexible resource allocation provides several advantages like easy support of customer migration, improved system performance, support of network scalability, and use of minimal resources leading to increased energy efficiency [1]. Note that the European FP7 project OASE (optical access seamless evolution) investigates the most appropriate next-generation optical access (NGOA) solutions and has following key requirements for NGOA [2]:

- Support of 128 Gbit/s up to 500 Gbit/s aggregated capacity per feeder fibre
- Support of 256 up to 1024 ONUs (customers) per feeder fibre
- Support of 20 to 40 km extended passive reach option for the working path, depending on the degree of node consolidation

The wavelength division multiplexing PON (WDM-PON) offers the most straightforward way of capacity increase. It minimizes the complexities needed for TDMA and has a potentially high reach and security. However, WDM-PON suffers from some major issues like migration from presently deployed TDMA PONs, low customer fan out, and static resource allocation. Hybrid TDMA/WDM-PON (TWDM-PON) combines the flexibility of TDMA-PON with the increased overall capacity of WDM technology, and it is an important NG-PON candidate. The advantages of a TWDM-PON over a pure WDM-PON are its high fan out, easy migration capabilities and ability to provide higher peak data rates.

Different TWDM-PON flavours, with varying remote node architectures are proposed [3, 4]. Figure 1 gives the basic architecture of a TWDM-PON. Typically, they have a tree topology, with the optical line terminal (OLT) as the root of the tree and the optical network units (ONUs) at the leaves. In a node consolidation scenario, the OLT is located at the CAN which is connected to remote node 1 (RN1), typically at the local exchange (LE), by the feeder fibre (FF). Through the distribution fibre (DF), each output port of RN1 goes to a different remote node 2 (RN2) which includes a power splitter (PS), and then each output port of the PS is connected to a different ONU by the last mile fibre (LMF). According to the RN1 configuration, we have three variants of a TWDM-PON architecture: a) Wavelength Selected TWDM-PON with PSs at the RN1; b) Wavelength Split TWDM-PON with arrayed waveguide grating (AWG) at the RN1; and c) Wavelength Switched TWDM-PON with wavelength selective switches (WSSs) at the RN1. The wavelength selected TWDM-PON is a fully flexible solution as the PS at RN1 broadcasts all wavelengths to all users, but has a high insertion loss and poor security due to the use of only PSs. The wavelength split TWDM-PON has a fixed wavelength allocation and thus will not be able to serve flexibility advantages. However, paper [4] shows that the full flexibility is not always required and a partial flexible solution can already give several advantages of flexibility. Overcoming the drawbacks of both wavelength selected and wavelength split, paper [5] proposed such a partially flexible solution with a WSS in RN1, which we refer as the wavelength switched TWDM-PON.

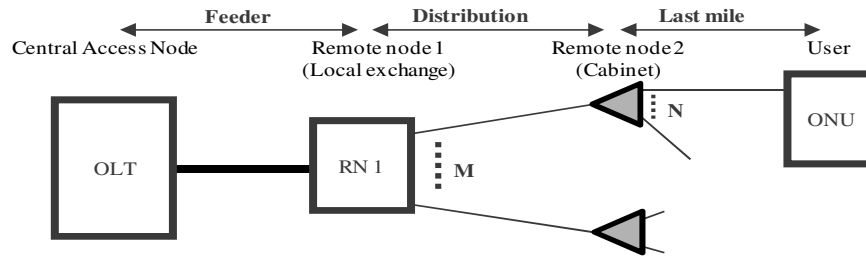


Figure 1. General hybrid TDMA/WDM-PON architecture

In this paper, we propose a new architecture of a wavelength switched TWDM-PON in which one WSS feeds wavelengths to multiple AWGs. In this way, it has a higher fan out and meets the OASE architectural requirements. We compare it with other important wavelength selected and split TWDM-PON variants. The rest of the paper is organised as follows. Section 2 outlines the detailed system aspects and advantages of a wavelength switched TWDM-PON. Section 3 presents the evaluation of the wavelength switched TWDM-PON and gives the cost, reach and power consumption comparison with the wavelength selected and wavelength split TWDM-PON. Finally, section 4 concludes the paper.

2. WAVELENGTH SWITCHED TWDM-PON

In this section, we discuss the system aspects and the advantages of the wavelength switched TWDM-PON.

2.1 System Aspects

In this paper, we outline the detailed system aspects of a wavelength switched TWDM-PON that uses WSS in combination with AWGs in RN1. Figure 2 shows the architecture of the wavelength switched TWDM-PON, with a detailed system design of the OLT for a 40 upstream (ONU to OLT) and downstream (OLT to ONU) channels configuration. We now outline the detailed system aspects.

OLT: The OLT makes use of the L (downstream) and C (upstream) band, and uses a series of L and C band diplexers to multiplex and demultiplex downstream and upstream channels, respectively. We consider TDMA at 50 GHz dense-WDM (DWDM) channels, each of which offers a symmetric 10 Gbps data rate. We use photonic integrated circuits (PIC) based transceiver arrays (TRXA) at the OLT, leading to a reduced power consumption and form factor in the OLT. The erbium doped fibre amplifiers (EDFAs) based pre-amplifier and booster are used to further increase the reach.

RN1: At RN1, we assume a cascaded configuration of WSSs and AWGs. To compensate for the insertion loss of a WSS, we use EDFAs based reach extenders (RE). Two 1:K WSSs are used, for downstream and upstream, respectively. The WSSs are used together with 1:M cyclic athermalized AWGs. The AWGs are of an M-skip-0 configuration. Both AWGs and WSSs are of a 50 GHz configuration. To keep the cost of WSS low, we have assumed no special functionality like broadcast etc; however more advanced WSSs with multicasting or broadcasting functionality can also be used. For a 40-channel configuration at the OLT, we use 1:4 WSS and 1:5 AWG. This allows us to have on average two wavelength channels at each output port of the AWG. However, on high traffic demand even each AWG can be fed with all 40 channels. Similarly, when the network demand is low, one of the two wavelengths can be switched off leading to energy efficiency. Note that in long reach PONs, we have different traffic scenarios at home and business premises. Normally, the peak traffic rate at home premises is in the night, whereas in the business premises it is more close to the morning hour. Thus, re-routing the traffic from some network parts to other parts leads to an improvement in the PON performance.

RN2: We consider a simple PS at RN2, which eases the migration of a wavelength switched TWDM-PON from the deployed GPON (or EPON) architectures.

ONU: At the ONU, we assume tunable transceivers. Another option is to use transceivers based on a reflective technology (i.e., reflective electro-absorption modulator-semiconductor optical amplifier [REAM-SOA] combinations). However, they lack long-distance capability because of Rayleigh crosstalk or require dedicated seed fibres, and thus we have not used them. Presently, the transceivers are tunable over 4 nm or so, but we expect cheap transceivers that will be tunable over the entire C/L band to be available in the next few years.

2.2 Advantages

The most important advantages of the wavelength switched TWDM-PON are as follows:

Network planning: An urban scenario will require a shorter reach and higher splitting ratio whereas a rural scenario will require a longer reach and smaller splitting ratio. Thus, a PS with a variable splitting ratio is required. Moreover, to support a different number of customers behind a PS, there has to be a different number of wavelengths fed at the input of a PS for the same bandwidth delivery per customer. We use a WSS to feed a different number of wavelengths at the input of RN2. In addition, the NGOA architecture should have the potential to provide narrowband services, and thus the ability of WSSs to support a different number of

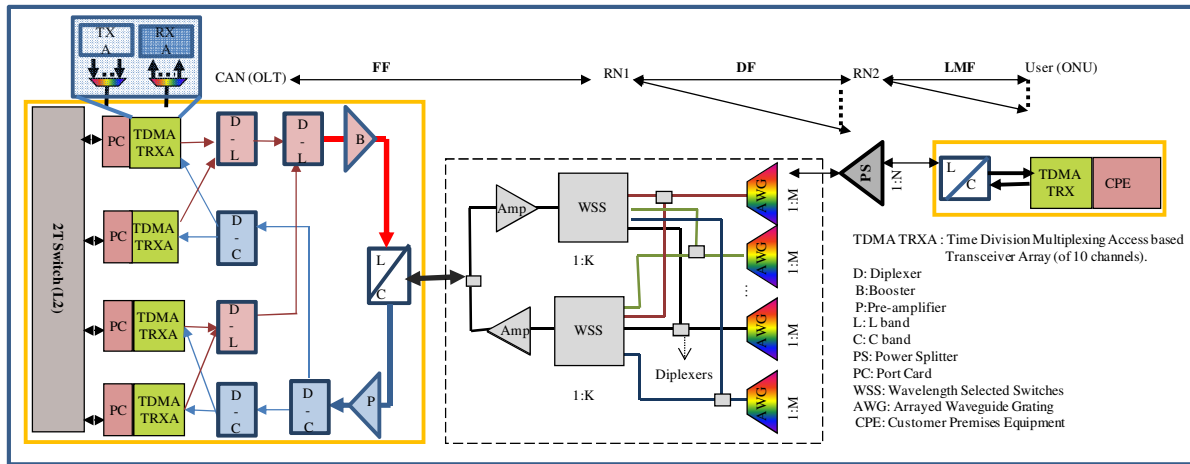


Figure 2. Wavelength Switched Hybrid TDMA/WDM-PON architecture

wavelengths at RN2 will ease the network planning according to the scenario and requirements.

Network migration: To support network migration, the network should have a dynamic capability to route 10 G and/or 1 G channels towards the PS as and when customers are willing to migrate. Also, note that at the input port of the PS, we can have different types of channels, and thus not all customers behind the PS need to migrate simultaneously.

Network extensibility: If the customer base is low during the network design phase, and gradually more users add up later on, we can accommodate all new users by assigning an additional wavelength to them. A WSS will help in easy wavelength routing.

Energy efficiency: WSSs can route the wavelengths from lightly loaded network parts to heavily loaded parts, leading to a minimal use of wavelengths, which saves energy and operational expenditures.

3. EVALUATION OF WAVELENGTH SWITCHED TWDM-PON

In this section, we evaluate the reach, cost and power consumption of the 40 and 80 channels wavelength switched TWDM-PON and compare it with the wavelength selected and wavelength split TWDM-PON. For page space efficiency, we denote numbers corresponding to 80 channels in [], wherever there is difference between parameters of 40 and 80 channels.

3.1 Reach, power consumption and cost calculations for a wavelength switched TWDM-PON

We show the calculations of reach, power consumption and cost for wavelength switched TWDM-PON. We use 1:4 WSS and 1:5 [1:10] AWG in RN1, and 1:32 PS in RN2.

Reach: The insertion Loss (IL) of the above configuration is the sum of the IL for OLT, RN1, RN2 and ONU. The IL for the OLT is due to a C/L band-splitter (1.5 dB) and two [three] diplexers (3 [4.5] dB). The 1:4 WSS (5.5 dB), 1:5 [1:10] AWG (4 dB), and two C/L band-splitters (3 dB) lead to the IL in RN1. The IL at RN2 is due to the use of 1:32 (17.5 dB) PS. At the ONU, the IL is due to a C/L band splitter. In addition, we assume an End-of-Life and connector IL of 5.7 dB. This leads to the total IL of 41.7 dB [43.2 dB]. The 10 G transmitter at the OLT is assumed with a power level of 6 dBm, and the 10 G avalanche photo-diode (APD) receiver with forward error correction (FEC) is assumed with a sensitivity of -30 dBm. Use of booster (4 [2.5] dB) and RE (20 dB) leads to a total fibre budget of 18.3 [15.3] dB, which gives a reach of 54 [45] km. Note that the booster gain is assumed such that the total power in the fibre does not exceed 21 dBm for the laser class 1 M safety considerations. This restricts the total power in one channel to be below 5.5 [2.5] dBm.

Power Consumption and Cost: Table 1 gives the cost and power consumption of the OLT, RN1, RN2 and ONU, and the floor space for the OLT. The cost and power consumption values for various components and the

Table 1. Cost and power consumption of system concepts of a 40[80] channel wavelength switched TWDM-PON

OLT		RN1		RN2	ONU
10x10 G TRX Array TDMA: Cost: 4[8] x26.26 Power: 4[8]x20 W MAC: Cost: 40[80]x2 Power: 40[80]x1W Diplexers: Cost: 7[15]x0.3 Shelf Space: 2[4] slots	Shelf Port Cards: Cost: 4[8]x10x10Gx0.1/G (port aggregator)+6[11]x0.8(mechanics for 12[22] slots) Power: 4[8]x10x10Gx0.5W/G (port aggregator)+6[11]x10 (base for 12[22] slots) Shelf space: 4[8]x2 slots Booster and Pre-Amp: Cost: 2x15 Power: 2x12 W Shelf space: 2 slot	Shelf Space: Cost: 12[22] slotsx5.56/slot Power: 12[22] slotsx5 W/slot L2 switching: 4[8]x10x10Gbpsx18 slots/12[22] slots=600[700] Shelf switch: 600[700] Gbps; Cards per shelf: 1.5[0.8] Cost=600[700]Gbpsx0.1/Gbps/1.5[0.8] Power=600[700] Gbpsx1W/Gbps/1.5[0.8]	AWG (1:5[10]): Cost: 0.3 (per trib port) WSS (1:4): Cost: 2x104 Power: 2x5.5 W	Diplexer: Cost: 5x0.3 Reach Extender: Cost: 2x20 Power: 2x50 W	Power Splitter 1:32: Cost: 6.6 CPE Mechanics: Cost: 0.6 Power: 3 W 10 G TDMA TRX (APD): Cost: 2.5 Power: 2.5 W

floor space are from [6]. The cost values are normalized with the cost of a GPON ONU. The OLT is assumed with a shelf capacity of 20 slots, where two slots are reserved for uplink. The shelf includes mechanics, backplane, power supply (redundant), management and a layer 2 switch (modular). The layer 2 switch capacity per shelf can be incremented in 100 Gbps steps.

3.2 Comparison of different TWDM-PON variants

Table 2 and Table 3 compare the cost and power consumption (PC) of various TWDM-PON configurations. The wavelength selected TWDM-PON has a PS and RE at RN1. It requires a RE to support high customer fan out and has a reach of 49 [30] km. The difference in the number of customers in wavelength selected TWDM-PON with the other configurations is because not all splitting ratios are possible for a PS. The wavelength split TWDM-PON has an AWG at RN1, and can support a pure passive reach of 27 [16] km. However, with a RE, it can have an additional reach of 59 km to meet the NGOA requirements. When comparing wavelength switched TWDM-PON with the other variants, first, we see that the additional cost and power consumption of using a WSS at RN1 is negligible as compared to the completely passive configuration and this is because many users (640 or 1280) share the cost and power consumption of RN1. Secondly, the use of amplifiers in RN1 compensates the insertion loss of WSSs and gives a long reach of 54 [45] km. Thirdly, in a NGOA PON, RN1 will be at the present location of a CO, which is already electrically powered, and thus there is no additional overhead in bringing the power to RN1. Besides, WSS leads to several other advantages as mentioned before, which will further bring down the operational expenditures. This helps us to conclude that the use of WSSs will accrue significant advantages while adding an insignificant component cost and power consumption per user.

Table 2. Cost comparison of various TWDM-PON configurations

Configuration	Channels	Power Split	Reach	Sustainable Data Rate	Number of Customers	Total Cost	OLT Cost	RN Cost	ONU Cost
Wavelength Selected+RE	40	1:16	49 km	780 Mbps	512	4.05	0.73	0.22	3.1
Wavelength Selected+RE	80	1:32	30 km	780 Mbps	1024	4.00	0.69	0.21	3.1
Wavelength Split	40	1:16	27 km	625 Mbps	640	3.92	0.58	0.24	3.1
Wavelength Split	80	1:16	16 km	625 Mbps	1280	3.88	0.55	0.24	3.1
Wavelength Switched	40	1:32	54 km	625 Mbps	640	4.28	0.58	0.6	3.1
Wavelength Switched	80	1:32	45 km	625 Mbps	1280	4.00	0.55	0.4	3.1

Table 3. Power consumption comparison of various TWDM-PON configurations

Configuration	Channels	Power Split	Reach	Sustainable Data Rate	Number of Customers	Total PC (W)	OLT PC (W)	RN PC (W)	ONU PC (W)
Wavelength Selected+RE	40	1:16	49 km	780 Mbps	512	7.2 W	1.67 W	0 W	5.5 W
Wavelength Selected+RE	80	1:16	30 km	780 Mbps	1024	7.2 W	1.67 W	0 W	5.5 W
Wavelength Split	40	1:16	27 km	625 Mbps	640	6.9 W	1.35 W	0 W	5.5 W
Wavelength Split	80	1:16	16 km	625 Mbps	1280	6.9 W	1.35 W	0 W	5.5 W
Wavelength Switched	40	1:32	54 km	625 Mbps	640	7.0 W	1.35 W	0.17 W	5.5 W
Wavelength Switched	80	1:32	45 km	625 Mbps	1280	6.9 W	1.35 W	0.09 W	5.5 W

4. CONCLUSION

In this paper, we have proposed a novel architecture for a hybrid and time division multiple access and wavelength division multiplexing (TWDM) passive optical network (PON) using wavelength selective switches (WSS) as the key component. Through a detailed reach and cost evaluation, we have shown that it provides the best combination of reach, flexibility, security and cost among all the existing TWDM-PON technologies.

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