
Long-reach Optical Access (LROA): A Cost-effective Promising Approach

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Abstract: To compensate the decrease in its revenue, most telecom operators have adopted similar strategy which is to provide faster Internet with low cost to its customers. Studies suggested that providing faster Internet with low cost can be achieved by reducing the cost of building next-generation access network. Among the various technologies introduced for next-generation access, long-reach optical access LROA is considered the largest candidate. This is due to the anticipated cost effectiveness of this technology. In LROA, more users can be supported over a common optical component (e.g., a transmitter, a fiber, or probably both), i.e., small number of entities is employed in the access network for service provisioning, which is considered as an improvement in the cost-sharing concept. Our objective in this paper is to verify the cost-effectiveness of this technology. To this end, a statistical-based cost comparison was conducted. The comparison was between the currently deployed passive optical networks (PONs), i.e., the Broad band PON (B-PON [G. 983]), the Ethernet PON (E-PON [IEEE802.3ah]), and the gigabit PON (G-PON [ITU-T G. 984]) and one of the LROA architectures proposed in the literature. The comparison process confirmed that the LROA requires less cost and cost per subscriber as compared with the currently deployed PONs.

Keywords: Next Generation Optical Access, Passive Optical Networks PONs, WDM-PONs, Hybrid TDM/WDM-PONs, Long-reach Optical Access

1. Introduction

To compensate the decrease in its revenue, most telecom operators have adopted similar strategy which is to provide faster Internet to its customers. However, they will be required to hold out extra cost to do so. Of course customers will pay more for faster Internet, but the amount they are able to pay may not satisfy the operators' aspirations. In other word, the difference between the cost of producing faster Internet and the achieved revenue, which represents the operators' profit, will start to shrink with time. This is called margin erosion [1]. To avoid margin erosion problem, operators are required to either develop new services and applications that attract consumers' attention and thus stimulate them to spend more or find a way to reduce the cost of producing faster Internet. While developing attractive services and applications seems very challenging, reducing the cost of producing faster Internet might be easier and can be achieved if the cost of building the access networks is

reduced. In other word, the goal of reducing the cost of producing faster Internet can be realized by simplifying the whole network. Among the various technologies introduced for next-generation access, LROA is a promising solution that ensures simplifying the optical access networks [2]. This is due to the attractive approach adopted in this technology in which a large number of central offices could be consolidated in a single trunk office. Figure 1 clarifies this situation. In LROA, more users can be supported over a common optical component (e.g., a transmitter, a fiber, or probably both), i.e., small number of entities is employed in the network for service provisioning.

This is also can be envisioned as an improvement in the cost-sharing concept. In its early appearance, LROA was basically developed based on Time-Division Multiplexing (TDM) solution in which a single wavelength is employed to serve several Optical Network Units (ONUs). Later, it was introduced as hybrid schemes, i.e., Time-Division Multiplexing/Coarse Wavelength-Division Multiplexing

[(TDM)/(CWDM)], and Time-Division Multiplexing/Dense Wavelength-Division Multiplexing [(TDM)/(DWDM)]. This paper is devoted to verify the cost-effectiveness of LROA approach that might be achieved by improving the cost-sharing. To do so, a statistical-based cost comparison was conducted. The comparison was between the currently

deployed optical access technologies (TDM-based PONs), i.e., the Broad band PON (B-PON [G. 983]), the Ethernet PON (E-PON [IEEE802.3ah]), and the gigabit PON (G-PON [ITU-T G. 984]) and one of the LROA architectures proposed in the literature.

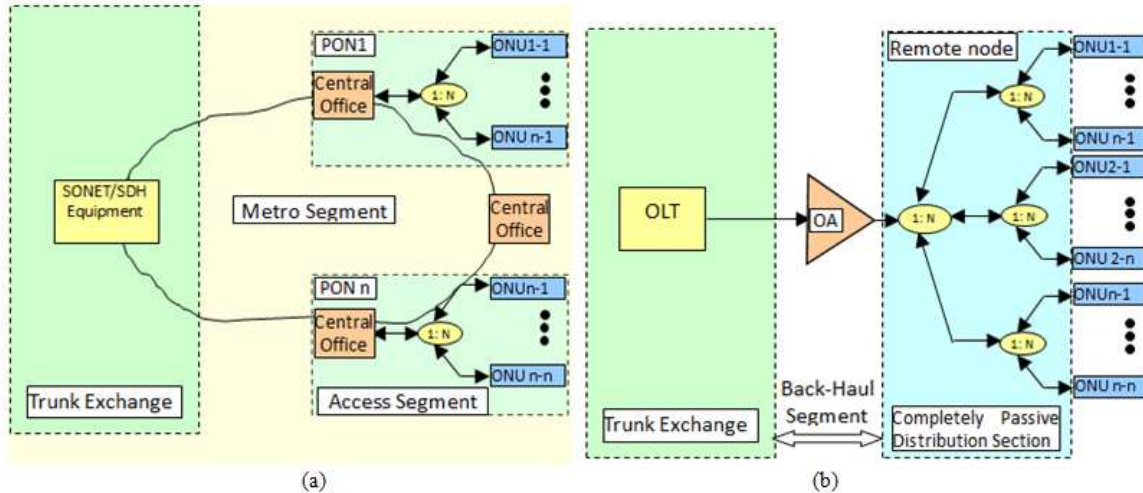


Figure 1. (a) Basic telecommunication, (b) Simplified LROA architecture.

2. Next-generation Optical Access

Higher data rate, larger capacity, and longer range represent specific features a next-generation optical access candidate should at least possess one of them in order to outperform the limitations imposed in the currently deployed optical access technologies [3-8]. A review of enabling technologies for these features are summarized below.

2.1. High Data Rate TDM-based PONs

To meet the requirement of higher bit rate that should be fulfilled in next-generation optical access, the Institute of Electrical and Electronics Engineers (IEEE) and the International Telecommunications Union's Telecommunication Standardization Sector (ITU-T) released their standards (IEEE803. av, 10GEPON and ITU-T. 987, XG-PON) in 2009 and 2010, respectively [9, 10]. Both 10GEPON and XG-PON specify symmetric 10 Gbps for downstream and upstream transmissions. They also specify asymmetric downstream and upstream transmissions. In this aspect, 10GEPON specifies asymmetric transmission with 10 Gbps for downstream and 1 Gbps for upstream, respectively; whereas, XG-PON specifies asymmetric transmission with 10 Gbps for downstream and 2.5 Gbps for upstream, respectively.

2.2. Wavelength Division Multiplexing WDM-based PONs

Wavelength Division Multiplexing WDM-based PONs were basically introduced to exploit the large number of wavelength an optical fiber can carry (its virtual unlimited bandwidth), which leads to increase the system capacity, i.e., were proposed to meet the requirement of larger capacity that

should be fulfilled in next-generation optical access. Examples of WDM-based PONs can be found in [11- 14]. Compared with TDM, WDM provides more privacy and security as each ONU in the PON system can use a single and dedicated pair of wavelength. Another worth-mentioning feature is that WDM leads to facilitate coexistence among different operators; i.e., new operators can share the same Optical Distribution Network (ODN) with legacy ones. As addressing the advantages and disadvantages of WDM is beyond the scope of this paper, detailed information on that can be found in [15, 16].

2.3. Hybrid TDM/WDM-based PONs

Hybrid TDM/WDM-based PONs were basically introduced as a solution to integrate and exploit the features offered by both TDM-based PONs and WDM-based PONs. On other word, a high data rate and huge capacity PON system can be developed in one hybrid scheme. Based on the specified wavelength spacing, hybrid TDM/WDM-based PONs can be categorized as either TDM/CWDM-based PONs or TDM/DWDM-based PONs. While hybrid TDM/CWDM-based PONs specify 20 nm for wavelength spacing, hybrid TDM/DWDM-based PONs specify either 0.8 or 0.4 nm for wavelength spacing. Hybrid TDM/WDM-based PONs can also be categorized as either static or dynamic schemes. In static schemes, a dedicated pair of wavelengths is allocated to each ONU for upstream and downstream transmissions; whereas in dynamic schemes, wavelengths are allocated dynamically during communication, i.e., each pair of wavelengths can be allocated several times and serve multiple ONUs. Examples of hybrid TDM/CWDM-based PONs and hybrid TDM/DWDM-based PONs can be found in [14-21].

2.4. Long-Reach Optical Access (LROA)

LROA was basically introduced as a solution to overcome certain limitations imposed in the currently deployed PONs, i.e., the small capacity and short range. It offers an attractive solution by which more users can be supported over a common infrastructure, which improves the cost-sharing and the efficiency of the access system. To extend the range and increase the capacity, solutions based on signal amplification would be required. Hence, the need for using amplifiers in LROA becomes substantial and inevitable. In the LROA, optical amplifiers are suggested to be employed in the field instead of conventional repeaters. The advantage of this approach is that optical amplifiers work completely in the optical domain, which leads to omit involving complex and expensive processes, such as photon-to-electron conversion, retiming, reshaping, electrical amplification, and electron to-photon conversion. A further advantage is that optical amplifiers are transparent to the bit-rate changes and the data format used. In its early appearance, LROA schemes were basically developed based on TDM solution in which a single wavelength is employed to serve several ONUs. Later, they were proposed as hybrid TDM/CWDM, or TDM/DWDM schemes. Examples of several LROA schemes can be found in [22-32].

3. Statistical-based Cost Comparison

To verify the cost-effectiveness of LROA, a statistical-based cost comparison was conducted. The comparison was between the currently deployed optical access technologies (TDM-based PONs), i.e., the Broad band PON (B-PON [G. 983]), the Ethernet PON (E-PON [IEEE802.3ah]), and the gigabit PON (G-PON [ITU-T G. 984]) and one of the LROA architectures proposed in the literature. The selected LROA architecture was proposed by the author in [30]. In this proposed architecture, the capacity was increased as a result of increasing the splitting ratio, which helps improve the cost sharing. The proposed LROA architecture contains five zones; each zone is capable to support 768 users. Two different approaches were followed for service provisioning (single-fiber or multi-fiber approach). In single-fiber approach, a single fiber was employed for service provisioning to each zone, whereas in multi-fiber approach, three fibers were employed for service provisioning to each zone. The optical equipments required to support each zone and its corresponding cost are listed below. The cost of the optical components was obtained through Internet by accessing Fiberstore website (www.fiberstore.com).

In Case of Adopting Single-fiber approach:

- a) Three DWDM transceivers, Cost = $3 \times 286 \text{ USD} = 858 \text{ USD}$
- b) One optical fiber cables that contains 2 SMFs (cost/meter = 0.42 US/m), Cost = $1 \times (0.37 \text{ US/m} \times 20 \times 103 \text{ m}) = 7,400 \text{ USD}$
- c) Three (1×4) power splitters, Cost = $3 \times 11.70 \text{ USD} = 35.1 \text{ USD}$

- d) Three (1×64) power splitters, Cost = $3 \times 59 \text{ USD} = 177 \text{ USD}$
- e) One EDFA, Cost = $1 \times 1842 \text{ USD} \rightarrow \text{EDFA cost/zone} = 1 \times 1842/5 = 368.4 \text{ USD}$
- f) 16 Channels AWG DWDM Mux/Demux, Cost = $1 \times 1104 \text{ USD} \rightarrow \text{Cost/zone} = 1104 \text{ USD}/5 = 220.8 \text{ USD}$
- g) Two of 4 channel AWG DWDM Mux/Demux, Cost = $2 \times 276 \text{ USD} = 552 \text{ USD}$

The total cost needed to support each zone = 9,611.3 USD, which yielding Cost/user = 12.5 USD

In Case of Adopting Multi-fiber approach:

- a) Three DWDM transceivers, Cost = $3 \times 286 \text{ USD} = 858 \text{ USD}$
- b) One optical fiber cables that contains 4 SMFs (cost/meter = 0.42 US/m), Cost = $1 \times (0.42 \text{ US/m} \times 20 \times 103 \text{ m}) = 8,400 \text{ USD}$
- c) Three (1×4) power splitters, Cost = $3 \times 11.70 \text{ USD} = 35.1 \text{ USD}$
- d) Three (1×64) power splitters, Cost = $3 \times 59 \text{ USD} = 177 \text{ USD}$
- e) One EDFA, Cost = $1 \times 1842 \text{ USD} \rightarrow \text{EDFA cost/zone} = 1 \times 1842/5 = 368.4 \text{ USD}$
- f) 16 Channels AWG DWDM Mux/Demux, Cost = $1 \times 1104 \text{ USD} \rightarrow \text{Cost/zone} = 1104 \text{ USD}/5 = 220.8 \text{ USD}$

The total cost needed to support each zone = 10,059.3 USD, which yielding Cost/user = 13.09 USD. The optical equipments and its corresponding cost required to support an equivalent number of users that can be supported in each zone in the selected LROA architecture in case of using currently deployed PONs are listed below.

In case of using B-PON, 16 user/pon segment:

- a) Forty eight transceivers, Cost = $48 \times 65 \text{ USD} = 3,120 \text{ USD}$
- b) Four optical cables with 12 SMFs for each (cost/meter = 0.61 USD/m), Cost = $4 \times (0.61 \text{ USD/m} \times 20 \times 103 \text{ m}) = 48,800 \text{ USD}$
- c) Forty eight (1×16) power splitters, Cost = $48 \times 16.2 \text{ USD} = 766.6 \text{ USD}$

The total cost needed = 52,686.6 USD, which yielding Cost/user = 68.6 USD.

In case of using E-PON, 32 user/pon segment:

- a) Twenty four transceivers, Cost = $24 \times 65 \text{ USD} = 1560 \text{ USD}$
- b) Two optical cables with 12 SMFs for each (cost/meter = 0.61 USD/m), Cost = $2 \times (0.61 \text{ USD/m} \times 20 \times 103 \text{ m}) = 24,400 \text{ USD}$
- c) Twenty four (1×32) power splitters, Cost = $24 \times 21.67 \text{ USD} = 520.08 \text{ USD}$

The total cost needed = 26,480.08 USD, which yielding Cost/user = 34.47 USD.

In case of using G-PON, 64 user/pon segment:

- a) Twelve transceivers, Cost = $12 \times 79 \text{ USD} = 948 \text{ USD}$
- b) One optical fiber cable with 12 SMFs for each (Cost/m = 0.61 USD/m), Cost = $1 \times (0.61 \text{ USD/m} \times 20 \times 103 \text{ m}) = 12,200 \text{ USD}$
- c) Twelve (1×64) power splitters, $12 \times 59 \text{ USD} = 708 \text{ USD}$

The total cost needed = 13,856 USD, which yielding Cost/user = 18.04 USD. To simplify the comparison process, the collected data were converted to charts using Excel. The

total cost required in each access scheme to support 768 users, and the cost per user is shown in Figure 2.

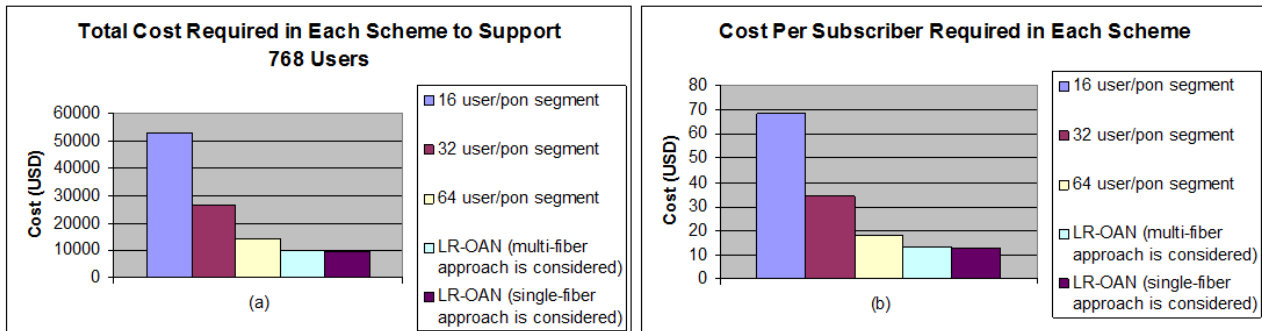


Figure 2. (a) Total cost required in each scheme to support 768 users, (b) Cost per subscriber required in each scheme.

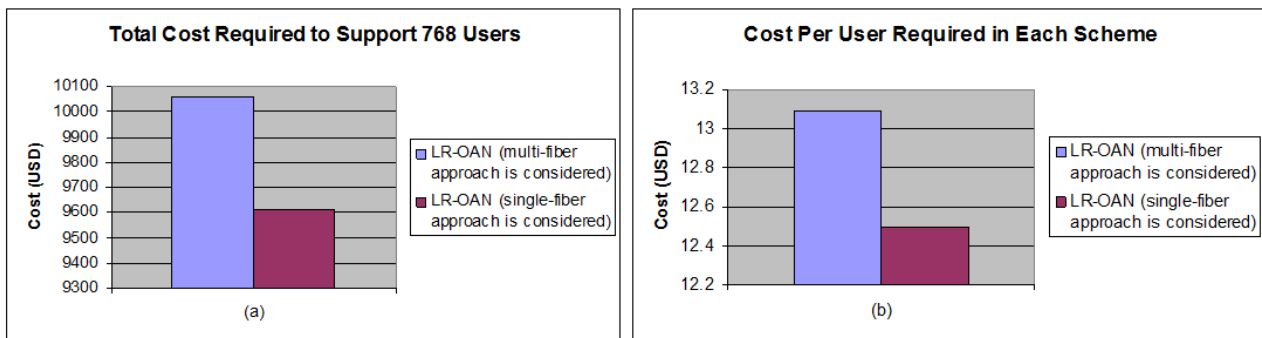


Figure 3. (a) Total cost required to support 768 users when single-fiber LROA and multi-fiber LROA are used, (b) Cost per subscriber required in each scheme.

It can be obviously seen from the charts that the long-reach access requires less cost as well as requires less cost per subscriber as compared with the currently deployed PONs. The charts also show that the single-fiber LROA approach requires the lowest cost and cost per subscriber. Figure 3 was included to show this observation clearly.

4. Conclusions

The cost-effectiveness of LROA was verified using statistical-based comparison. The optical equipments required to support a number of 768 users and its corresponding cost in case of using LROA and each of the PON systems deployed currently (B-PON, E-PON, and G-PON) were involved in the comparison. The comparison process confirmed the cost-effectiveness of the LROA as it requires less cost per subscriber compared with the currently deployed PONs. Specifically, the cost per subscriber was 12.5 USD in case of using LROA which was the lowest compared with that required in case of using B-PON, E-PON, or G-PON, which was 68.6 USD, 34.47 USD, or 18.04 USD, respectively.

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