Economic Analysis of Repeater-Based Optical Access Network Architecture

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Abstract— **An economic model was developed to study the cost effectiveness of the regenerator based passive optical network architecture and the results were compared with the economic models of other fibre-to-the-home architectures including conventional passive optical network and active optical network architectures.**

Keywords- Ecomonic model,digital subscriber line, fibre to the home, passive optical network, regenerator

I. INTRODUCTION

Due to the requirement for increase in bandwidth, service providers are compelled to push fibre deeper into the access networks to offer the emerging high bandwidth services to the customers. Fibre-to-the-home (FTTH) architectures have been proposed as an ultimate solution for future broadband access networks [1 - 3]. There have been several schemes proposed for the FTTH architectures such as passive optical networks (PONs), point-point fibre links, and active optical networks (AONs). PONs are considered as the future proof FTTH architecture of all the technologies as it is capable of providing higher bandwidth at a minimal cost compared to others while enabling smoother and flexible upgrade towards higher bit rate wavelength division multiplexed PON (WDM-PON) systems. There have been several attempts to extend the transmission distances of the PON links and increase the split ratio from a conventional 32 to a higher value [4 - 7]. We have recently proposed and experimentally demonstrated a regenerator based passive optical network (RG-PON) architecture that could potentially increase the number of subscribers served by a single PON infrastructure to 256 and extend the feeder fibre transmission distance upto 100 km [8]. Fig. 1 shows a typical architecture of the RG-PON. In this RG-PON architecture, a repeater is used at the remote terminal (RT) for the regeneration of the upstream and downstream data signals. As the data signals in both directions are regenerated at the RT, a high-split star coupler (SC) can be used to simultaneously support a larger number of subscribers using a single PON infrastructure. Moreover, longer feeder fibre upto 100 km can also be used. The RG-PON architecture requires low cost optical sources at the optical network units (ONUs) that are located at the customer premises as the upstream signals are regenerated at the remote repeater. The practical capability of the RG-PON has already been experimentally demonstrated with the existing Ethernet PON test kits from "Teknovus" and this demonstration showed that this scheme is operational with existing optoelectronic interfaces.

Supporting a larger number of subscribers using a single PON infrastructure is more cost effective and an economic model has been developed to study the cost effectiveness of this particular architecture in comparison with the conventional PON architecture and AON architecture that incorporates

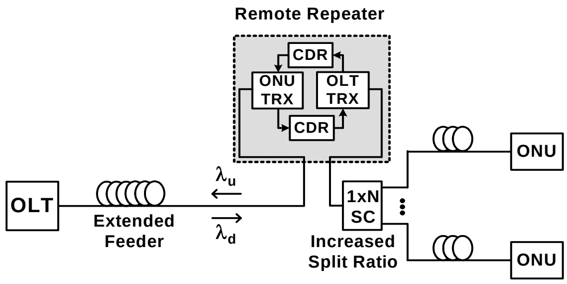


Fig. 1: FTTH system with remote repeater.

digital subscriber lines (DSL) from the RT to the customer units (CUs). The goal of this paper is to identify the essential costs of building passive optical access networks and to perform a comparison of different technologies using varying performance criteria. Simple generic models are used to calculate trenching and cable costs taking into account different deployment cases. The technologies being considered in our economic analysis are RG-PON, PON and AON. It is similar to the tree type PON architecture with an addition of the remote repeater at the RT. AON architecture is a point-to-point architecture from the optical line terminal (OLT) to the RT. At the RT, an active switch such as a digital subscriber line access multiplexer (DSLAM) is placed for the collection and distribution of signal from/to each of the CUs through the already built-in DSL lines.

II. NETWORK MODEL

A model framework of generic connections, housings, and equipment are considered for this study. In this model, all links between OLT, RT and ONU are via single-mode (SM) fibre. The distance between the OLT and the RT is taken as 100 km. Moreover, it is considered that the RT node is placed between the subscriber's optical network unit (ONU) and the OLT. The RT is the equivalent of the active switch in the AON structure, the SC in the PON structure and the regenerator and the SC in the RG-PON. As these types of FTTH architectures are more

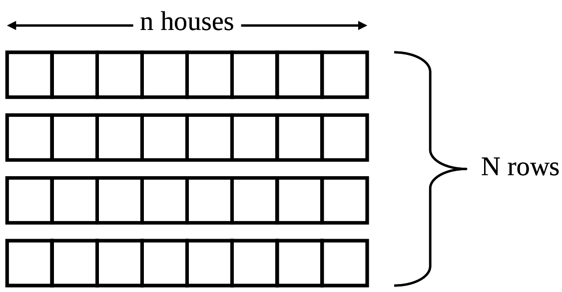


Fig. 2: Layout of the houses in a floor of the building.

suitable for the multi-tenant buildings, it is considered that the RT is placed at the basement of the building while the houses are located at each floor. Fig. 2 shows the layout of the houses in a floor of the building. There are n (typically n = 8) houses in one row, while the N rows (typically N = 4) in the single floor. The size of each house is 15 x 15 m. If there are m floors in a building, then the average fibre cable length between the RT and the CU can be given as

$$\text{Average cable length} = \frac{(n+1)(m+1)}{4} \times 15 \text{ m.}$$

$$\text{Average trench length} = \frac{n(m+1)}{4} \times 15 \text{ m.}$$

III. Network Economics

Fig. 3 shows the architectures that are considered for the economic model analysis. The conventional PON architecture uses multiple SCs in the RT and they are connected to the OLT using multiple feeder fibres and ONUs using distribution fibres. No active electronics is used in the RT. The RG-PON architecture is similar to that of conventional PON architecture, however uses a simple repeater at the RT. Moreover, a higher split (1 x 256) SC is used instead of multiple (1 x 32) SCs. Hybrid fibre to the node and DSL (FTTH - DSL) based AON architecture uses a point-point link optical fibre link between the OLT and the RT. At the RT, the CUs are connected using DSL lines and a DSLAM is used at the RT for the aggregation of the upstream signal from each subscriber.

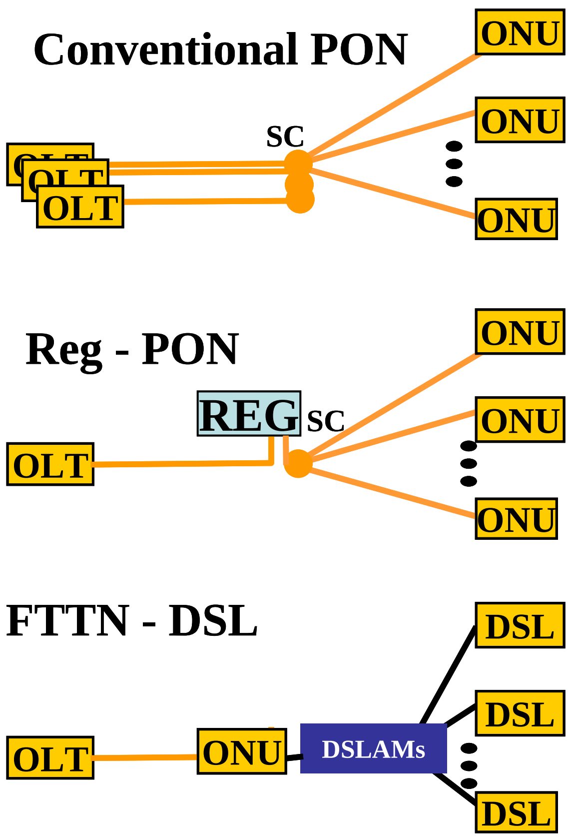


Fig. 3: Conventional PON, Regenerator based hybrid PON, and xDSL based AON architectures for the economic analysis.

	RG-PON	PON	AON
OLT Parameters			
Housing cost ($)	50000	50000	50000
Transceiver cost ($)	10000	10000	10000
RT Parameters			
Housing cost ($)	1000	500	8000
Chassis cost ($)	500	100	2000
Remote powering cost ($)	250	0	2500
Transceiver cost ($)	1000	0	2000
Output port cost ($)	N/A	160	N/A
Max house per RT	256	32	256
Max RT boxes	1	8	---
SC cost ($)	9000	3000	---
Switch cost per port ($)	---	---	80
Cable costs ($/km)			
OLT to RT	128	128	128
RT to CU	128	128	---
Cost per splice ($)	24	24	24
Trenching Costs ($/km)			
OLT to RT	5000	5000	5000
RT to CU	1000	1000	0
ONU Costs			
Install cost ($)	100	100	100
CU cost ($)	150	200	100
Interface cost ($)	500	500	500

TABLE 1: Component and Installation Costs

Table 1 shows the parameters that are used for the equipment cost for each network model. The optical transceiver cost for each scheme remains the same even though RG-PON supports a larger number of CUs. This is because the downstream and upstream signals are regenerated at the RT and therefore high power lasers and high sensitivity receivers are not required at the OLT. In the conventional PON, 32 CUs are supported through a single OLT interface while RG-PON supports 256 CUs through a single interface. Therefore, 8 optical transceivers with interfaces are required for the conventional PON to support 256 CUs using a single infrastructure. The housing cost of the RT is higher for the AON as it contains an active optical switch such as DSLAM requiring larger space with higher installation costs. In RG-PON, the power requirement and the chassis costs are higher than that of conventional PON; but lower than that of AON. The cost of the optical transceiver used at the RT for RG-PON is lower than that of in AON. In RG-PON, as the number of splits is higher compared to that of in the conventional PON, the cost of the SC used in the RG-PON is also higher. In the AON, it is considered that the DSL lines are already in place however requires further rearrangement.

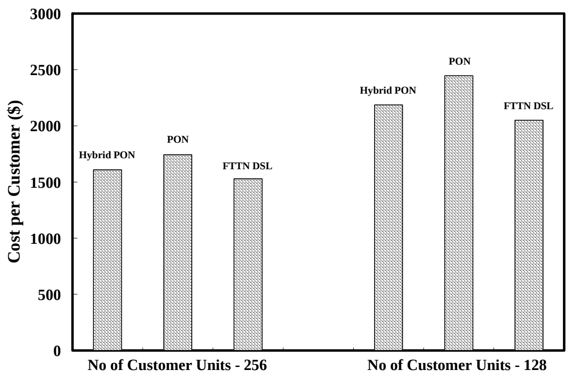


Fig. 4: Cost per customer for RG-PON architecture with 128 and 256 CUs for 100% take rate.

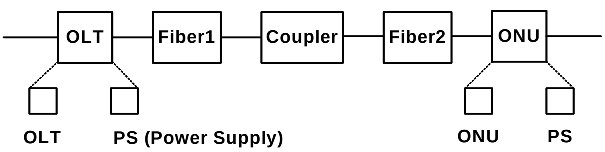
Fig. 4 shows the cost of each CU for the FTTH systems for 256 CUs and 128 CUs for the take rate of 100%. In both scenarios, conventional PON architecture requires higher cost for each CU while the AON requires the lowest cost for each CU of all architectures. All the FTTH architectures with 128 CUs require higher cost for each CU compared to that with 256 CUs as the infrastructure is shared by many CUs. For the RG-PON architecture with 256 CUs the cost per customer is approximately $2459 while it is $3412 for the AON. Similarly, the cost per customer in the RG-PON is approximately $137 higher than that of in AON with 128 CUs.

We define take rate is the percentage of homes covered by the access network infrastructure that subscribe to the service. As a consequence, all infrastructure costs (e.g. housing construction, electronics, and trench deployment) are incurred for all homes, even though they can only be recovered from the revenue by those that subscribe.

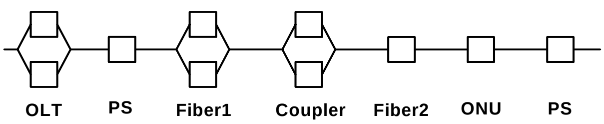
The network cost per subscriber is calculated as:

$$\text{Cost per Subscriber} = \frac{\text{Infrastructure Cost per Home}}{\%\ \text{Take Rate} / 100} + \text{per - subscriber costs}$$

We now use the model framework with the above parameters, cost elements, and calculation of shared trench and cables to evaluate the deployment costs of various access technologies with/without protection. The protection model for each of the considered FTTH architectures is shown in Fig. 5.



(a) Unprotected architecture



(b) Protected architecture

Fig. 5: Protection models.

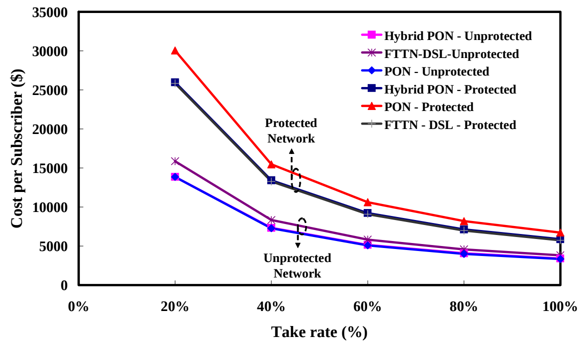


Fig. 6: Cost per subscriber for different access architectures vs. take rates.

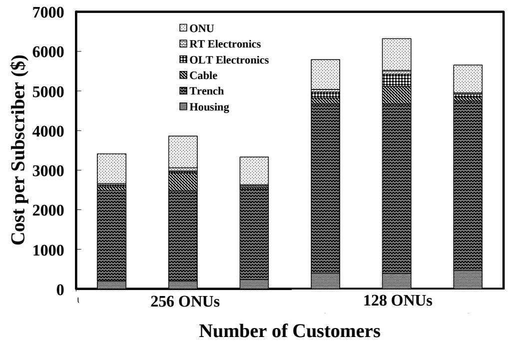


Fig. 7: Cost per subscriber for different access architectures for take rate of 100 %.

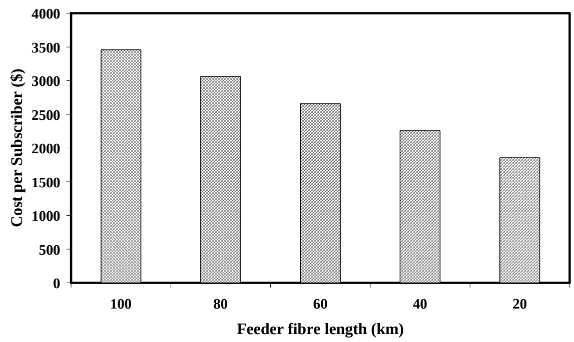


Fig. 8: Cost per subscriber for RG-PON architecture for varying feeder fibre length for a take rate of 100 %.

In this model, OLT, feeder fibre, and RT costs are duplicated whereas the ONU and the distribution costs are not. Fig. 6 shows the cost per customer for varying take rate for the considered architectures in both protected and unprotected cases. As expected the protected networks cost higher than that of unprotected networks. The protected networks require more than 34 % cost increase compared to the unprotected architectures for the take rate of 100 %. The conventional PON architectures require more than 40 % increase in costs for the protected architecture. Fig. 7 shows the cost per subscriber for the architectures for the take rate of 100 % showing the cost splits. As can be seen, the ONU costs and the trenching costs dominate the total cost per subscriber for each scheme. As the feeder fibre length is 100 km, the trenching costs dominate the total CU costs and approximately are more than 67 % of the total costs, while the ONU cost is more than 21% of the total cost.

The RG-PON architecture can be used in an urban area whereby the customer premises are located far away form the CO. In these scenarios, multiple cascaded repeaters can be used to support a larger number of subscribers over a longer transmission fibre. Fig. 8 shows the subscriber costs for 256 subscribers for a take rate of 100 % for varying feeder fibre distances for the RG-PON architecture. As it can be seen, as the feeder fibre distance is reduced, the total cost per subscriber is also reduced. This is largely due to the cost reduction in the trenching costs. Therefore, if the feeder fibre distances are to extended much longer than the conventional PON distances (above 20 km), then more than 256 subscribers have to be supported over a single fibre infrastructure. To obtain the subscriber cost for 256 customers with 20 km feeder fibre length ($ 1857), more than 477 subscribers are required in the RG-PON architecture with 100 km feeder fibre transmission distances. However, it should be noted that increasing the feeder fibre distance to serve a large number of subscribers reduces the number of COs that are required. Therefore, extended transmission distance in an optical access network provides huge cost savings through the reduction in the COs.

For this economic modelling, the cost of the OLT transceiver is considered to be $ 10,000 while the cost of the ONU transceiver is $500 for all architectures. If the optical transceiver cost used at the CU for the RG-PON architecture is $ 453 or less while the optical transceiver cost used at the CU in the AON architecture is $500, then the total cost per subscriber for both RG-PON and AON architectures is $ 3459. Therefore, the optical transceiver cost used the CU in the RG-PON has to be less than $453 to enable this architecture cheaper than other considered solutions.

IV. Conclusions

The economics study of different FTTH technologies is presented taking into account 1+1 protection. It is shown that RG-PON architecture is competitive with FTTN based DSL architecture in terms of the cost per subscriber whereas the conventional PON architecture requires higher costs. The trenching costs and the ONU costs are far more dominant of all costs in all kinds of architectures. It has also been shows that longer feeder fibre incurs more cost per subscriber and therefore to make a feasible and more economical solution to provide broadband services, a larger number of customers have to be supported over a single infrastructure.

V. References

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