LR-PON

Brief survey upon long reach passive optical network

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September 2013

Review 0.3

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Introduction

The demand for new high bandwidth services such as internet protocol (IP) television and video on demand, as well as changing competitive and regulatory forces, is beginning to drive the deployment of fiber access networks around the world. One of the most attractive optical access network architectures is the passive optical network (PON), which is highly cost-effective because the network infrastructure is shared by many customers and has no active components, such as electronic switches or routers, in the path between the telecommunication provider's central office or local exchange and the customer.

The PONs are now standardized and commercially available, the most advanced of these (XG-PON) typically offer 10Gbit/s downstream and 2.5Gbit/s upstream, shared between 64 customers via passive optical splitters and a time division multiple access (TDMA) protocol, over a reach of up to 20 km.

While these PONs offer significant bandwidth increases compared to copper-based approaches, they may not provide the best ultimate solution for service providers seeking to significantly reduce the cost of delivering future broadband services to residential and business customers in order to sustain profit margins.

A new technology, called Long-Reach Passive Optical Network (LR-PON), was proposed as a cost-effective solution for the broadband optical access network [1]. LR-PON extends the coverage span of PONs mentioned above from the traditional 20 km range to 100 km and increase the split ratio (~1000) by exploiting Optical Amplifier and WDM technologies. A general LR-PON architecture is composed by an extended shared fiber connecting the CO and the local user exchange, and optical splitter connecting users to the shared fiber (Figure 1).

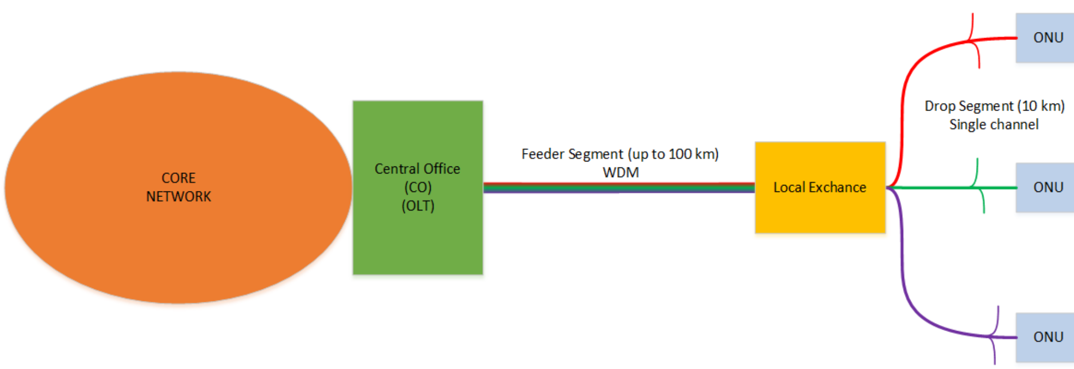

FIGURE 1. LONG REACH PON (LR-PON) ARCHITECTURE [1].

By providing extended geographic coverage, LR-PONs would replace the separate metro and access portions of the current network with a single, integrated, all optical communication system. This approach is predicted to generate significant capital and operational cost savings for network operators, since the number of network elements and interconnection interfaces is reduced, along with the design complexity, footprint and electrical power consumption of the network as a whole [2]. Thus, cost savings are also achieved by replacing the Synchronous Digital Hierarchy (SDH) with a shared optical fiber.

Topologies

A typical "tree-and-branch" LR-PON contains three parts, optical line terminal (OLT), optical network unit (ONU), and remote node (RN), which resides between the OLT and ONUs. While the point-to-multipoint topology of LR-PON resembles that of a traditional PON, the RN design is different and more complex. Because wavelength-division multiplexing (WDM) is used to exploit the vast bandwidth of fibers, the arrayed waveguide grating (AWG) is deployed in the RN, serving as a passive wavelength router. Power splitters could be placed after the AWG in RN, or inserted in the drop section to increase the capacity, by enabling statistical sharing of bandwidth in one wavelength among multiple ONUs. Optical amplifiers, usually multi-stage erbium-doped-fiber amplifiers (EDFA) are also used at the RN to compensate for the huge power loss due to long transmission distance in feeder section and high split ratio (Figure 2) [3].

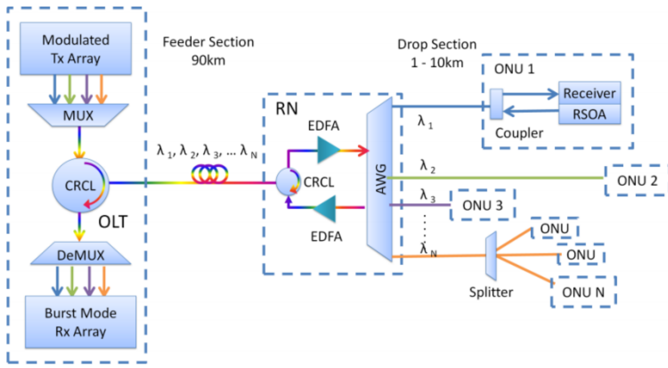

FIGURE 2. TYPICAL "TREE-AND-BRANCH" ARCHITECTURE [3].

Instead of the traditional "tree-and-branch" topology, researchers are also investigating a "ring and spur" topology for LR-PON, as shown in Figure 3, where a PON segment consists of the OLT and a set of ONUs operating on different wavelengths. Each PON segment exhibits a logical FTTX tree topology and several PON segments coexist. The OLT and ONUs are connected through a fiber ring with AWG-based RNs deployed on the ring. An advantage of this design is that it can reuse the metro ring networks with fiber already deployed by substituting the RN equipment and thus achieve great savings on CapEx. The ring topology can also provide the LR-PON two-dimensional coverage for failure protection, which is very important these days as strict quality of service (QoS) may be specified in a user's service level agreement (SLA) [3].

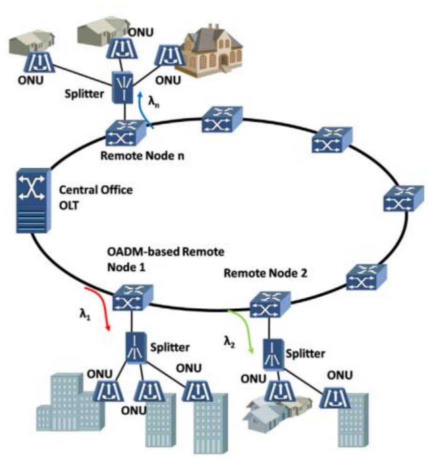

FIGURE 3. AN EXAMPLE OF "RING AND SPUR" LR-PON [3].

Research challenges

Amplification

In order to compensate for the power loss due to long transmission distance and high split size, optical amplifiers are used at the OLT and the local exchange.

The amplifiers introduce two challenges [1]:

- Amplified spontaneous emission (ASE): Excess ASE is an unwanted effect in lasers, since it limits the maximum gain that can be achieved in the gain medium. ASE creates serious problems in any laser with high gain and/or large size. In this case, a mechanism to absorb or extract the incoherent ASE must be provided;
- EDFA slow speed: EDFA has a low noise figure, a high power gain, and a wide working bandwidth, which enable it to be advantageous in a LR-PON employing WDM. But the relatively slow speed in adjusting its gain makes it disadvantageous due to the bursty nature of upstream time-division-multiple-access (TDMA) traffic in a LR-PON, where the optical amplifier needs to adjust its gain fast when packets with different DC levels due to different ONU distances pass through it, in order to output packets with uniform signal amplitude.

Optical source

In order to lower the CapEx and OpEx, a standard PON may choose lower-cost uncooled transmitters in the ONU, because a major investment for an optical access network is the cost associated with installation of an optical transmitter and receiver in the ONU at the customer premises. However, the uncooled transmitter is temperature dependent; as a result, it could transmit a wavelength with a possible drift of 20 nm. In a standard PON, the performance may be unaffected as no component is wavelength critical. But in a LR-PON which exploits WDM to satisfy the huge amount of traffic, the wavelength drift becomes crucial, especially for certain components such as optical filters [1].

Burst mode receiver

The different ONU-OLT distances mean different propagation attenuations for signals from ONUs to the OLT, which in turn result in varied DC levels of bursty packets from the ONUs at the OLT. A burst-mode receiver is designed for this circumstance. The problem is LR-PON has to scale up in speed (10Gbps and beyond) and number of customers supported (up to 512 users could share the same channel) compared to current architectures and devices. Therefore, challenges might occur in the following aspects [1]:

- Dynamic range: as the optical amplifier increases the difference of the DC level of upstream signals from different ONUs, the burst-mode receiver is required to support a wider dynamic range;
- Sensitivity: as the signal power may be attenuated significantly due to a large split ratio and a long distance transmission, the burst-mode receiver is required to have a high sensitivity;
- Timing control: with the increased sharing ratio of the same channel, a more strict timing control of the guard time between successive ONU transmission slots is required, in order to achieve higher bandwidth efficiency.

Upstream resource allocation

In LR-PON, the end users and the Central Office (CO) are separated by a significant distance, typically 100 km and beyond. Hence, control-plane delays are significant. This can have an impact on the medium access control adopted for upstream traffic. In fact, ONUs send transmission request to CO and transmit upstream data upon receiving acknowledgement from CO. Meanwhile, the delay budget in an access network is approx. 1-2 milliseconds for real-time applications. In order to mitigate the effect of the control-plane delay, efficient remote-scheduling algorithms (e.g., dynamic bandwidth allocations) need to be developed which overcome the large CO-user distance, which support different classes of service, and which are scalable in terms of the number of users supported as well [1].

Protection

As LR-PON exploits the huge transmission capacity of optical technology, and is oriented for long-range coverage to serve a large number of end users, any network failure may cause a significant loss for customers and the network operator. The LR-PON protection becomes necessary and important [1].

Architectures

Different multiplexing schemes, such as time-division-multiplexing (TDM), wavelength-division-multiplexing (WDM) and orthogonal-frequency-division-multiplexing (OFDM) are usually used in the LR-PON to increase the number of supported ONUs. In the following, we show a summary of main solutions developed in recent years.

TDM/WDM solutions

A comparison between solutions based upon TDM and/or WDM is summarized in Table 1.

	PLANET SuperPon	**Hybrid DWDM/TDM PON**	**British Telecom LR-PON**	**PIEMAN**
Reach Distance	100 km	100 km	100 km	100 km
Splitting Ratio	2048	4352 (17 x 256)	1024	16384 (32 x 512)
Bit rate (DS,US)	2.5 Gbps, 311 Mbps	10 Gbps, 10 Gbps	10 Gbps, 10 Gbps	10 Gbps, 10 Gbps
Bit rate/user (DS,US)	1.22 Mbps, 0.15 Mbps	39 Mbps, 39 Mbps	9.76 Mbps, 9.76 Mbps	19.5 Mbps, 19.5 Mbps
BER	10^{-9}	Better than 10^{-10}	10^{-10}	10^{-10}
Wavelenghts	1550 DS, 1300 US	DWDM grid	1550 DS/US	DWDM grid
Year	2000	2005-2006	2007	2007-2010

TABLE 1. DIFFERENT FEATURES OR LR-PON ARCHITECTURES [4], [2].

OFDM solutions

Orthogonal-frequency-division-multiplexing (OFDM) signal has shown its usefulness for next-generation PON and long reach hybrid WDM/TDM PON. Due to its high spectral efficiency, low cost and low bandwidth optical components can be used. It has a strong tolerance to the fiber chromatic dispersion, and this feature is very important to PON and LR-PON since these networks usually cannot be fully dispersion compensated. It has high flexibility on both multiple services provisioning and dynamic bandwidth allocation, allowing easy bandwidth management in different ONUs [5].

Recent publications on LR-PON and OFDM propose and demonstrate:

- An adaptive four-band OFDM 40 Gb/s, where the downstream data rate can be changed adaptively from 6.25 to 40 Gb/s depending on the different fiber transmission lengths from 0 to 100 km between CO and each ONU [6];
- An aggregation of 120-Gb/s signal with high splitting ratio, up to 1:128 [7].

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