Long Reach Passive Optical Networks

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***Abstract*— We discuss recent progress in the development of optically amplified, long reach passive optical networks, which aim to significantly reduce network complexity and cost by integrating metro and access into a single, all-optical communication system.**

I. INTRODUCTION

Fiber-to-the-premises (FTTP) has been envisaged for a long time as an attractive future access technology for delivering high bandwidths to customers. However, until recently the development and widespread deployment of copper-based broadband solutions such as digital subscriber line and cable modem had slowed down its introduction. Now, demand for new high bandwidth services such as internet protocol (IP) television and video on demand, as well as changing competitive and regulatory forces, are 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 first generations of PONs are now standardized and commercially available [1], the most advanced of these (GPON and GE-PON) typically offer 2.5 Gbit/s or 1 Gbit/s downstream and ~1 Gbit/s upstream, shared between 32 customers via passive optical splitters and a time-division multiple access (TDMA) protocol, over a reach of up to 20 km.

Whilst these first generation 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. As a result research attention has recently turned to more radical network solutions based on new types of optically amplified, large split (~1000), long reach (~100km) PONs (LR-PONs), which are designed to allow individual customers to directly access bandwidths of up to 10 Gbit/s upstream and downstream [2,3]. These 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.

In this paper we will discuss recent developments in LR-PON research, concentrating particularly on a system that is currently under development within the European Union-funded project PIEMAN (Photonic Integrated Extended Metro and Access Network, www.ist-pieman.org). Some of the key physical layer design issues are outlined below and the solutions studied within the project described.

II. SYSTEM ARCHITECTURE

PIEMAN is performing physical layer research aimed at a new generation of LR-PON with features totally beyond the capability of today's PONs:-

- bandwidth per customer of up to 10 Gbit/s downstream and 10 Gbit/s upstream
- each 10 Gbit/s wavelength is shared by up to 512 customers
- significant use of dense wavelength division multiplexing (DWDM) to provide further fiber efficiency in the metro with up to 32 wavelengths each carrying 10 Gbit/s – the project is therefore taking a hybrid DWDM/TDMA approach
- all-optical reach of 100 km using optical amplifiers – no use of optical-electrical-optical conversions at intermediate locations.

Figure 1 shows a high level view of the PIEMAN system architecture, which summarizes some of the main architectural features. An important design decision is the DWDM wavelength plan to use on the "backhaul" fiber between the service node and local exchange. A pure C-Band design, covering 32 wavelengths for the upstream and 32 wavelengths for the downstream on a 50 GHz grid, was found to give the optimal compromise between technical complexity and price. Figure 2 depicts the PIEMAN wavelength plan with the downstream wavelengths in the red part of the C-band, the upstream wavelengths on the blue side of the C-band spectrum and a 10 nm guard band in between. The video overlay, present in some current PON deployments, was

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omitted in PIEMAN in favor of an easier and cheaper realization of the overall system which will carry video on IP broadcast channels rather than on an additional analogue optical carrier.

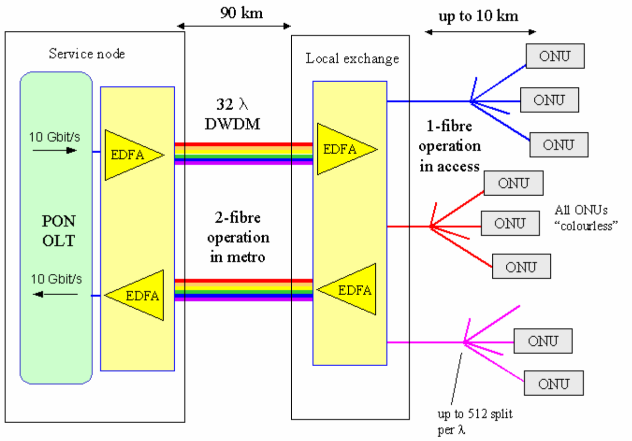

Fig.1. High level view of PIEMAN target system architecture.

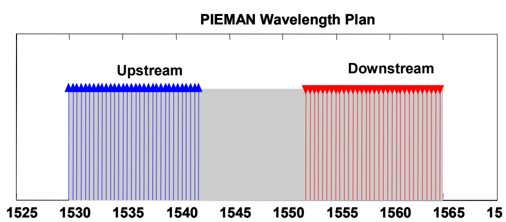

Fig. 2. C-band wavelength plan.

Focusing on the upstream part of the network, which is the most technically challenging to engineer, reveals the need for a number of new component and subsystem technologies, which are under development within the project. To avoid inventory issues associated with having 32 different types of customer optical networking unit (ONU) – each with different upstream wavelengths – PIEMAN implements "colorless" ONUs. The upstream wavelength for the respective ONU is determined by the optical line terminal (OLT) at the head-end of the system, either by optically delivering a wavelength-specific carrier which is then re-modulated (reflective-ONU), or by programming a tunable laser at the ONU. Both of these approaches are being studied within the project. In order to meet the reach, split and bit rate targets for the PIEMAN architecture, the reflective- and tunable-ONU designs employ monolithically-integrated combinations of an electro-absorption modulator (EAM) and a semiconductor optical amplifier (SOA), to achieve dispersion tolerant, 10Gbit/s modulation and high upstream launch powers, respectively. In the case of the tunable laser the EAM-SOA will be hybridly-integrated with an external cavity to achieve a low cost "set and forget" wavelength tuning capability [4].

Within the local exchange node, several possible configurations of the amplifier placing are possible. The configuration chosen for the upstream direction is shown in Figure 3. Each wavelength is amplified by a dedicated erbium doped fiber amplifier (EDFA) prior to multiplexing by the arrayed waveguide grating (AWG) onto the upstream fiber. Each single wavelength EDFA must be actively stabilized against the transients introduced by the bursty nature of the upstream TDMA traffic. This is also true for the EDFA preamplifier at the service node, but due to lower gain and output power requirements this can be implemented more cost-effectively as a single, multi-wavelength amplifier supporting all 32 upstream wavelength channels simultaneously. Stabilization schemes are under development, which employ an auxiliary input wavelength and active control circuitry to keep the total EDFA input power constant within the timescale of the gain response.

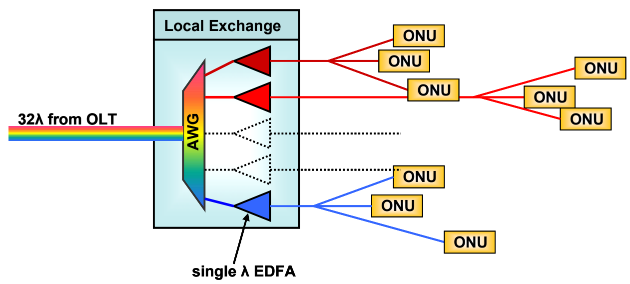

Fig. 4. Local exchange node amplifier placing for the upstream direction.

A further key component that is required for the upstream link design is a 10 Gbit/s burst-mode receiver (BM-RX), located at the service node, which must recover data from optical packets arriving in fast succession with varying signal level and phase. PIEMAN is developing a specifically-designed BM-RX including a burst-mode transimpedance amplifier and a burst-mode post-amplifier using 0.25micron Si-Ge Bi-CMOS technology. Recent progress on this and the other key physical layer technologies will be presented in further detail in the conference presentation.

III. Conclusion

Long reach passive optical networks as exemplified by the proposed PIEMAN system may radically change the way in which future networks are designed, leading to significant reductions in the cost of delivery of future broadband services.

Acknowledgment

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