

Multiple - PON Access Network Architecture

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Abstract

A novel access network architecture based on a coarse wavelength division multiplexing array waveguide grating router for switching up to 32 optical network units per passive optical network over a single coarse wavelength band is described. The cost effective network architecture is simulated, using a physical-layer model of two passive optical networks, each comprising 16 ONUs, employing 12nm-wide passband windows in the array waveguide grating. In this manner low error rate transmission 2.5 Gbit/s for distances up to 20 km is demonstrated.

1 Introduction

Bandwidth demands to support new broadband applications require an upgrade of the existing copper access infrastructure comprising the local loop. Perceived wisdom dictates that fibre to the Home/Premises will provide the final wireline access medium. In addition many of the forthcoming services are interactive and therefore need symmetrical connection. Examples include business services (virtual networks, IT-outsourcing, teleworking), healthcare, telemedicine, social and some entertainment services.

Passive Optical Networks (PONs) have growing attractions from the network operators' viewpoint in terms of first installed cost, maintenance cost and operation [1]. To utilise the available bandwidth effectively and therefore increase subscriber volume, wavelength division multiplexing (WDM) is an important ingredient to future networks. WDM PONs have been reported incorporating up to 128 users at 1.25 Gbit/s to 2.5 Gbit/s per user/wavelength, offering good security and protocol transparency [2,3]. However, the economic model for a densely penetrated PON deployment in the access network has not yet been justified mainly due to the high cost of components in the optical network unit (ONU) and optical line terminal (OLT) [4].

Recently there have been some useful advances in using statistical multiplexing to allocate bandwidth among end users scattered over four physical PONs comprising 64 end users [5]. This approach employs dynamic wavelength allocation to shift bandwidth back and forth across the separate PONs by using a stack of tunable lasers to address

any ONU at any given time. In this case the major improvement compared to standard TDM-PONs, is in downstream where dynamic point-to-point connections between the OLT and ONUs provide for increased bandwidth utilisation for end users. Upstream bandwidth is still shared on a TDM basis though and hence end-user practical bandwidth depends critically on network utilisation.

The focus of the network presented here is to capture the merits of dynamic bandwidth allocation using a novel architectural approach to achieve a cost effective, highly scalable multiple PON configuration. The architecture employs coarse WDM (CWDM) [6] to overcome the perceived drawbacks with existing and proposed network topologies.

2 Network Architecture

The new network architecture, shown in Fig. 1, is highly scalable since network load is managed with the assistance of a single, de-centralized routing device based on an array waveguide grating (AWG) placed in the OLT in contrast to other proposed topologies which utilise two or more AWGs [2,7]; one of which is usually located in the field resulting in higher cost and complexity. A significant benefit of the architecture is that the AWG router can manage the load of several physical PONs simultaneously by directing each through different input/output ports and also that each of these PONs can support up to 32 ONUs by using point to point connections upstream and point to multipoint downstream. In this scenario, when a 4x4 AWG is employed then a total of 128 subscribers can be served by the network. At the individual PON level, CWDM with TDM will be deployed in the downstream with optical multicarriers scattered across the coarse ITU-T grid [6] in the upstream.

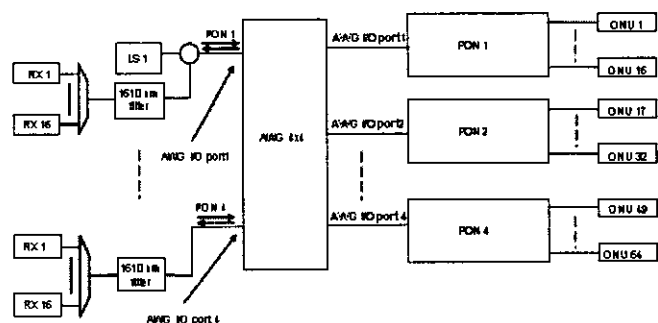


Fig. 1 Network Architecture (used in the simulation)

The architecture shown in Fig. 1 utilises only 16 ONUs per PON for simulation purposes where each ONU is provided with a closely spaced wavelength channel, each of which are centered $\pm 3.2\text{nm}$ around a single coarse ITU-T grid wavelength and then is applied to the appropriate AWG WDM input port. Each AWG channel spectrum can therefore create a 12nm 3dB passband window over which the ONUs are mapped and as a result they are all routed over the AWG as a single WDM channel. Depending on the AWG input/output port to which they will be applied, the coarse optical multicarriers will be routed over different paths. PON1 in Fig. 1 represents data from physical PON1, applied to upstream AWG port 1, routed through the AWG to output port 1 and subsequently terminated in the OLT. Each PON is routed in the upstream following the same process.

By contrast to upstream, downstream transmission can be achieved in a CWDM-TDM broadcasting manner where all ONUs in each PON are served by sharing the same wavelength in time to access specific services. CWDM is utilised since it is the most cost effective mechanism to access the different physical PONs. Considering the entire coarse ITU-T grid, 12 coarse wavelength channels are available to transmit data downstream, allowing up to 3 channels to be dedicated to each PON location in the basic network configuration shown in Fig. 1.

The new architecture is highly dynamic since a single tuning source or array can support all PONs in the downstream and hence manage network load effectively. The use of a linear vertical cavity surface emitting laser array provides for high modulation bandwidths at low cost [8]. Reflective Semiconductor Optical Amplifiers (RSOAs) are also incorporated for use in the ONUs to provide a cost effective alternative to dedicated lasers/receivers [9]. To increase ONU penetration 25 GHz-spaced devices are readily available to scale each PON to 32 wavelengths. In the new architecture this can be easily achieved with no change in the routing hardware. This novel aspect together with the wavelength routing component being located at the OLT adds tremendous network flexibility and potential scalability.

3. Network modelling and results

A physical layer simulation for the new architecture was devised to model the upstream routing performance of the AWG using the Virtual Photonics Inc simulation platform. In particular it was used to demonstrate the network's capability to multiplex all ONUs comprising two physical PONs on a single coarse ITU-T channel, at 1610 nm. Subsequently, several PONs were switched over different routes using explicit, 12 nm passband windows of a single de-centralized AWG router. In each ONU, a 2^7-1 PRBS sequence at 2.5 Gbit/s was used to externally modulate a fixed laser source at 3.5 dBm output power to allow a safety margin of 3dB. A 2^7-1 long sequence was applied at the mach-zender (MZ) modulator RF input to reduce the simulation time.

In each PON the modulated wavelength signals, corresponding to all 16 ONUs ranging from 1607.04 nm to

1613.50 nm were combined at a 16:1 combiner and transmitted over 20 km single-mode fibre before being applied to the AWG router. All channels of PON1 were applied to input port 1 and those of PON2 to input port 2. Consequently, a circulator modeled by a fixed attenuator, was used to separate between upstream and downstream transmission for PON1 followed by a 1x16 demultiplexer which was utilised to couple to each ONU. Upon reception, additional attenuators were used to obtain BER performance characteristics. Insertion losses of 5 dB and 4 dB were incorporated for the routing AWG and demultiplexer respectively.

Channels from PON2 at AWG output port 2 were utilised for the purpose of routing evaluation in the form of spectral analysis. A 12 nm passband window characteristics (3 dB point) was observed exhibiting 7 nm at 1 dB flat response which demonstrated the appropriate routing performance. Furthermore, crosstalk isolation between the passband windows was measured to be greater than 30 dB. Power penalties of less than 0.5 dB were also observed between upstream channels in each PON indicating that no power compensation was required. As expected all 16 wavelength signals were positioned within the port's flat response window.

Bit Error Rate (BER) performances for 3 ONUs located at the sides and the centre of PON1, 7 nm AWG flat response window, are illustrated in Fig. 2. Channels 1, 8 and 16 corresponding to wavelengths 1607.04, 1613.50 and 1610.49 nm respectively, demonstrated an error rate of 10^{-9} at -26 dBm with less than 0.5 dB penalty. A clear open eye diagram may also be observed as the inset for all curves.

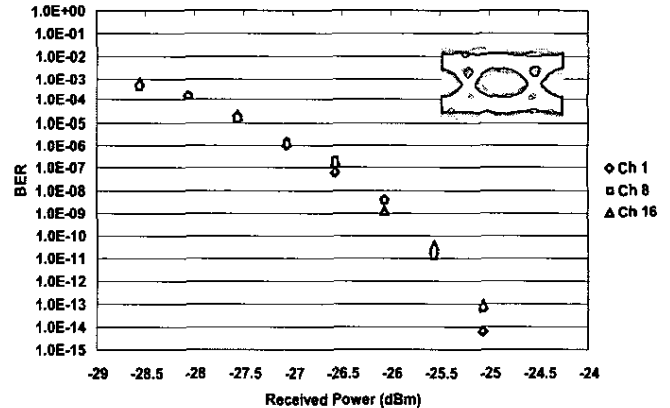


Fig. 2 BER curves for channels 1, 8 and 16 at a signal wavelength of 1610 nm

Finally, to demonstrate the upstream routing capability of the novel network architecture, Fig.3 shows spectrum plots of the AWG input ports 1 and 2 and their corresponding outputs. Both input ports are applied to the same analyzer and so are illustrated on the same trace. The simulation indicates that all 3 wavelengths representing each PON are routed together as a single coarse ITU-T channel demonstrating the potential of the new architecture to provide different paths for each

physical location and therefore handle multiple-PONs simultaneously.

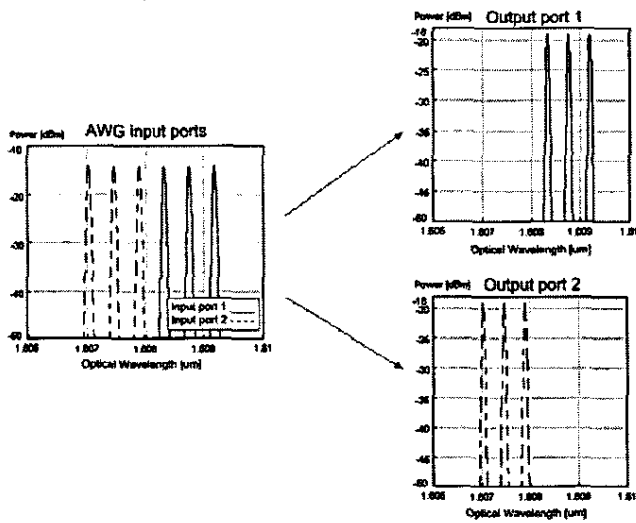


Fig. 3 AWG input and output ports spectra

4. Conclusions

The novel, cost-effective access network architecture described in this paper is based on a single AWG routing device to provide upstream and downstream service simultaneously. In the upstream 12 nm AWG windows enable routing from all ONUs comprising each PON through a coarse ITU-T grid wavelength to alternative destinations via different paths. Simulation results using 16 ONU channels have indicated power penalties of less than 0.5 dB between upstream channels in each PON, and therefore it is predicted that the architecture will support standard 32 ONU PONs. BER analysis for 3 channels demonstrated an error rate of 10^{-9} at -26 dBm receiver sensitivity confirming the capability of the new, single AWG routing architecture to serve multiple physical PONs.

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