

The WONDER Testbed: Architecture and Experimental Demonstration

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Abstract We present the latest experimental results within the WONDER project, aiming at the demonstration of an advanced packet-based WDM architecture that recently reached its full maturity. Our results show the feasibility of all-optical networking using commercially available optoelectronic components.

Introduction

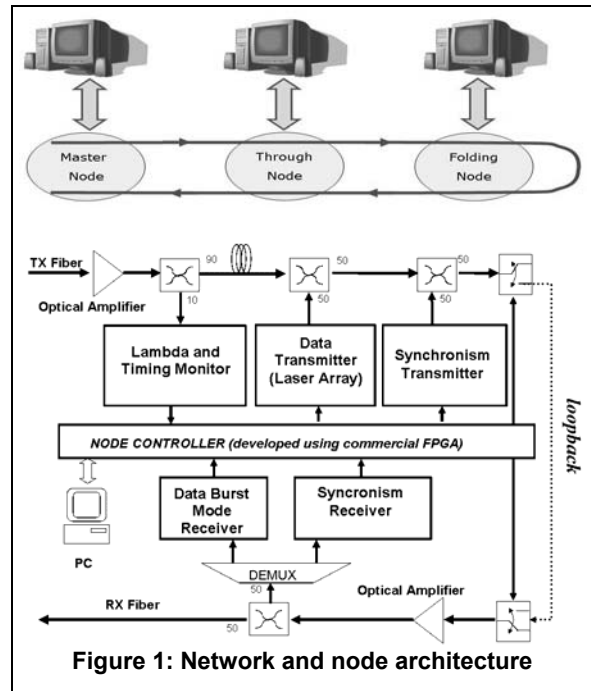
Metropolitan area networks are one of the best arenas for an early penetration of advanced WDM optical technologies. Indeed, their large traffic dynamism requires packet switching to efficiently use available resources; their high capacity requirements justify WDM use, while their limited geographical coverage lowers the impact of fiber transmission impairments, such as fiber dispersion and nonlinearities. From a research view point, designing innovative architectures for metro networks often means finding cost-effective combinations of optical and electronic technologies, and new networking paradigms that better fit the constraints dictated by available photonic components and subsystems. In the framework of the WONDER project [1,2], the OptCom and Network groups at Politecnico di Torino have designed and prototyped a new network architecture for metro applications, taking an approach based upon optical packets, but limiting optical complexity to a minimum and using only commercially available components, thereby avoiding advanced optical technologies (such as 3R optical regeneration) that, even though demonstrated in research labs, are still far from real commercial availability.

The WONDER testbed, after a 4-years effort, has reached its maturity and it is now available as a fully-equipped 3-node experimental demonstrator. This paper reports on recent experimental results obtained in our prototype.

WONDER Architecture and rationale

The WONDER architecture has been presented in several previous papers [1,2], to which the interested reader should refer for further information. Due to space limitations, we only remind here that the architecture, shown in Fig. 1, is based on a bidirectional optical ring (dynamically) folded at one node, thus resulting in a folded bus with fault protection capabilities. Access to WDM channels adopts the paradigm of tuneable transmitters and fixed-wavelength receivers. The WONDER architecture has been designed according to the following guidelines:

- 1) efficient and dynamic packet multiplexing, thanks to a direct packet-over-optics slotted approach (no intermediate protocol layers) and virtual-output queuing at the transmitter side
- 2) maximum simplification of the physical layer so as to:



- minimize accumulation of physical-layer impairments due to components in the optical path, such as self-filtering effects, PDL, PMD and noise
- electronic complexity largely independent from the number of used wavelengths and, consequently, from total network capacity. Basically, the high-speed electronic sections of nodes must process only the traffic corresponding to one wavelength, and not the full aggregated network traffic
- implementation using commercially available components, avoiding optically complex functions, such as 2R or 3R optical regeneration, fast optical switching, and wavelength conversion

Main architectural choices to achieve these goals were:

- at the TX side: use of an array of standard DFB lasers to obtain wavelength tuneability (this can be upgraded to fast-tuneable lasers as soon as these will become commercially available)
- on the optical path: use only of optical amplifiers and passive optical couplers/splitters
- on the RX side: use of standard DWDM demultiplexers and GPON burst-mode receivers (see below)

Our design requires optoelectronic components coming either from standard (static) DWDM technologies, or from GPON (Gigabit Passive Optical

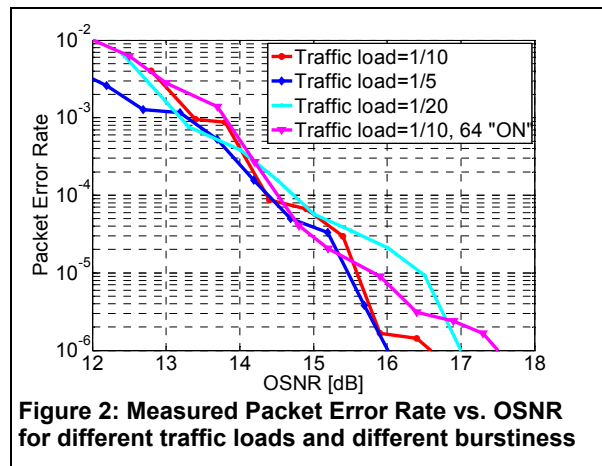
Network) systems. This is a key point for our project: DWDM technologies are today mature, and GPONs are becoming widely used, so that several companies have commercialized very low-cost GPON components. For our setup, we used the burst mode receiver needed for GPON upstream traffic reception. Due to (potential) mass production, today GPON burst mode receivers have basically the same cost of a more standard continuous-wave receiver of the same speed. Moreover, current plans for next-generation 10 Gbit/s PONs allow to envision that very soon 10 Gbit/s burst mode receivers will become available.

Testbed description and experimental results

The WONDER testbed is currently based on three fully-equipped nodes using four wavelengths (with 100 GHz spacing in C-Band) each running at 1 Gbit/s data rate (1.25 Gbit/s line rate after 8B/10B coding). This bitrate has been selected since only 1 Gbit/s burst-mode receivers are today easily available, but the testbed is ready for an upgrade to 10 Gbit/s. Currently, packet are 2 μ s long, with 100 ns guard-time between packets (packets are thus 2000 data bits long). Each node implements all layers from the physical up to the application layer. In fact, in the WONDER testbed packet traffic is generated from standard Internet applications running in a Linux-based PC with a suitably modified device driver, so that application layers "see" the WONDER testbed as a "standard" Ethernet network card. Packets are passed by this driver through the PCI-X bus to a high-performance FPGA board where the WONDER proprietary Medium Access Control is implemented, and finally data bits are sent to the optical layer. At the receiver side, all protocol layers are traversed in the reverse order. We believe that having implemented an experimental packet-based optical network demonstrator running over all protocol layers is in itself an important achievement, which may help in "disseminating" the perception that next-generation optical packet networks are indeed feasible. Other optical networking experimental projects, even though often more complex than WONDER in the physical layer design, do not demonstrate transmission of *actual* traffic, but only individual subsystems with no real network integration.

In order to demonstrate the correct system operation, we performed packet loss measurements. We emphasize that these measurement were done on the full system, and reported results were obtained directly from a Linux software driver (the test packets have thus passed through all network layers). Fig. 2 shows the measured Packet Error Rate (PER) as a function of the OSNR (over 0.1nm) at the input of the receiver for different network loads (ranging from 1 packet every 20 slots, to 1 every 5), and traffic burstiness (from isolated packets to long bursts of 64 consecutive packets).

The OSNR was re-normalized to be directly comparable with continuous transmission (the actually measured average OSNR on an optical spectrum analyzer is lower, depending on load and traffic



burstiness). Considering that each packet is approximately 2000 bit long, we have a bit error rate $BER \approx PER/2000$ (a measured $PER=10^{-6}$ thus requires a BER below 10^{-9}). Fig.2 shows that the system is quasi-error free for an OSNR larger than 18 dB, which is a typical level even for a standard (non-burst mode) receiver. This is an important result, showing that GPON chips are fully usable even for optical setups that are significantly different from the one for which they were designed, such as the optically-amplified WONDER architecture. Moreover, the required OSNR level (18 dB for quasi-error free operation) is compatible with the assumptions made in [3], where physical-layer scalability study was theoretical assessed, showing that 32 nodes using 32 wavelength are compatible with the WONDER architecture.

Conclusions

We have demonstrated a fully operational optical packet demonstrator exhibiting very low complexity of its optoelectronic components. We believe that our architecture can find interesting applications also in areas other than metro networks, like interconnect networks of next-generation high-capacity computing systems, as it is today investigated in [4] and in our current national Italian project "OSATE" (partially supporting our work).

References

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