Routes towards enabling Optical Packet Networks

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Abstract: All-optical-networks (AON) could one day be a reality, enabling the transport of high bit rate signals transparently and hence allowing multi-services over a single network infrastructure. The bottleneck in optical networks today is the mismatch between the current electronic processing speed and the optical line rates in WDM transmission networks. Wavelength routed networks have been shown to simplify routing and processing functions in WDM networks by providing end-to-end optical links (lightpaths), but still lack the necessary functionality for the envisioned AON. This paper assesses one of the key technologies, tunable lasers, required for optical packet transport network, and outlines the work that will be carried out to define an architecture with the functionality required to realise practical all-optical packet network.

1. Introduction

It is estimated that bandwidth usage of the Internet is doubling every 6-12 months. It has also been well documented that data traffic is surpassing voice traffic, and the growing demand for network bandwidth is expected to continue in the coming years. Optical fibres employed within networks have made available huge amounts of bandwidth through the introduction of WDM technology. However, this is causing a bottleneck at the switching nodes due to the mismatch between the current electronic processing speed and the optical lines rates which are currently at 10 Gb/s and are expected to exceed 160 Gb/s in the future. Research into wavelength routed optical networks (WRON's) has shown that such routing architectures could potentially simplify routing and processing functions in high-capacity, high bit-rate WDM networks by providing end-to-end optical channels, known as lightpaths [1]. However, wavelength routed networks lack the necessary functionality required in future flexible transport networks such as increased bandwidth granularity, the possibility of statistical multiplexing and Traffic Engineering (traffic grooming and load balancing). Optical packet-switched networks may offer these whilst delivering the advantages of optical technology such as potentially higher node capacities, less optical-electrical-optical conversions, and therefore lower network costs

Such a network should still be able to provide circuit-switched services and datagram services, much like what is provided by ATM and IP networks. The essence of such a network would be to provide "packet-switching capabilities at rates that cannot be contemplated using electronic packet switching" [2]. However, the difficulties in achieving all-optical packet networks lie in the complexity of building fast enough all-optical devices suitable for packet switches, as well as processing functions to cope with the ever increasing transmission line rates and node throughputs.

Some of the most important underlying technologies that would make this possible are tunable transmitters (tunable lasers), which would enable network operators to provision connections through the network dynamically when and where required, wavelength conversion which would enable flexible networks and ease control and management, and semiconductor optical amplifiers (SOA), tunable filters and space switches which are essential in reconfigurable transport networks.

The aim of the UCL Adastral Park project on optical packet switching (OPS) is to study the pros and cons of different network architectures for optical packet switching in metro and core networks, and with the available technology define architectures with the functionality required to realise optical packet switching. To this end, the OPS project will include an analysis of the characteristics of key enabling technologies, defining their strengths, limitations and suitability for OPS, and will use a range of traffic models to assess system and network performance and define optimum network architectures in terms of their flexibility, scalability and bandwidth utilisation efficiency. This will also include understanding control issues to overcome technology shortcomings such as the lack of optical RAM, control plane issues such as signaling, and service control issues to ensure the required QoS is achieved.

This paper describes an initial review of current state-of-the-art tunable lasers and their application in optical packet networks and estimates the packet size that would be feasible with current transmitter switching speeds.

2. Review of tunable transmitters and lasers

One of the most important components of tunable transmitters is the tunable laser employed. The desired performance for such lasers to be used in enterprise, metropolitan and long-haul networks would require: high output power, wide tuning range, rapid speed wavelength tuning, direct or integrated modulation at high bit rates (≥2.5GB/s), high reliability, high accuracy, and high lasing stability [3].

The tunable lasers used in the transmitters must ideally cover the entire C and L bands. In order to be suitable for metro and long-haul transmission networks, the output power of such lasers should be in excess of a few milliwatts and the switching speeds required for packet switching should be in the range of a few nanoseconds [4].

The seven main laser technologies[1] (and their derivatives) that have emerged for tunable lasers in the 1550nm region for WDM optical communications and a summary of their features are given below. Their wavelengths can be varied mechanically, by changing the temperature, or opto-electronically. The lasers can be divided into two categories: Edge emitting and surface emitting devices. All of the lasers listed are edge-emitter devices, except the last one which is a surface emitting device [5].

Laser Type	Switching Speed	Tuning Range	Output Power	Tuning Method
DBR[5]		< 10 nm	~ 30 mW	Elec
SG-DBR[2]	< 10 ms	44 nm	~ 30 mW	Elec
SSG- DBR [6]	500 ns	20 nm	~ 30 mW	Elec
GCSR[6]	> 100 ns	44 nm	-5 dBm	Elec
ECL [5]	>> 10 ms	> 40 nm		Mech
VCSEL [5]		28 - 32 nm	<< 1 mW	Mech
DFB [5]		< 5 nm		Temp

Some of the leading commercial tunable lasers available

Company	Technology	Switching Speed	Tuning Range	Output Power	Tuning Method
ADC/Altitun[5]	GCSR	<10 ns	30 nm	<10 mW	Elec
Intune INT1100 [7]	SG-DBR	<1μs	50 nm	10 mW	Elec
Agility[3]	SGDBR	< 10 ms	C-band	~30 mW	Elec
Iolon [4]	ECL	25 ms	35 nm	10 mW	Mech
Nortel [5]	VCSEL	10 ms	32 nm (C or L band)	10-20 mW	Mech
Alcatel's 1935 TLS [4]	DBR	100ms	12nm	20mW	Temp

[1] Distributed Feedback Laser (DFB), Distributed Bragg Reflector (DBR), Sampled Grating-DBR (SG-DBR), Super Structure Grating DBR (SSG-DBR), Co-direction Coupler Sampled Grating Reflector (GCSR), External Cavity Diode Laser (ECL), Vertical-Cavity Surface-Emitting Laser (VCSEL).

It is clear from the tables above that only electrical tuning is suitable for OPS, due to the speed limitations of mechanical and temperature tuning (10 ms tuning time). The fastest device is the ADC/Altitun GCSR laser, with sub-10 ns tuning times; however, this is achieved at the expense of tuning range, output power and fabrication complexity. In the following section, some applications of tunable lasers in OPS testbeds are described, and the implications of the tuning speeds on the packet payload size are assessed.

3. Tunable lasers used in OPS testbeds

There are a number of collaborative research projects investigating OPS carried out by various academia and industry consortia. The main features of the tunable lasers used in the tunable transmitters are given below.

WASPNET

In the WASPNET project [8], DFB lasers were used to accomplish all-optical wavelength conversion. The integrated device fabricated by Nortel Technology consists of an optical booster amplifier (SOA) with a DFB laser. The output wavelength is temperature tuned (~0.1 n m/°C), but has a slow tuning speed. However a multi-section DFB laser has been demonstrated to allow tuning over ~ 6nm.

HORNET

The tunable transmitters used in the Hybrid Opto-electronic Ring Network, HORNET [9] project incorporate GCSR lasers with a tuning range of ~30nm in the C-band, a tuning current of < 10mA and a maximum tuning speed of 15ns.

SONATA

The tunable transmitter used in the SONATA project [10] employed a current-driven (selected between SG-DBR and GCSR) tunable laser with an output power typically higher than –7 dBm over a tuning range of 6 nm, with 0.4 nm spacing and a tuning time lower than 1 µs.

4. Implications for packet payload size

Using a generic optical packet format and the equation below, Nord was able to demonstrate that by using different optical packet bit rate schemes and maintaining an optical overhead below 10% of the total packet size, a switching time of 20 ns was acceptable for payloads above 570 bytes (*Tpacket* ~ 0.5 µs) at a line rate of 10Gb/s [11].

$$T_{packet} = T_{payload} + T_{label} + T_{guardtime} + T_{synch} = \frac{Payload_{bits}}{Bitrate_{payload}} + \frac{Label_{bits}}{Bitrate_{label}} + T_{guardtime} + T_{synch}$$

$$Overhead = \frac{T_{packet} + T_{switch}}{T_{payload}} - 1$$

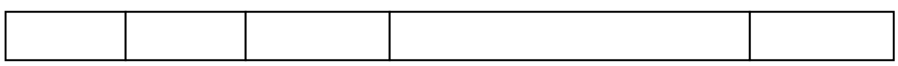

Figure. 1. Generic optical packet format

For the minimum switching time (T_{switch}) of 100 ns offered by the GCSR laser described in [6] the minimum optical packet payload at 10 Gbit/s allowing 10 % overhead, with T_{synch} + $T_{guardtime}$ = 12 ns and T_{label} = 4 byte (note that the 4 byte label is transmitted at 2.5Gb/s and hence requires 12.8 ns to transmit), is 1404 bytes. Using $T_{guardtime}$ and T_{synch} times of 50 ns and 100 ns respectively [11] and assuming a switching time of 100 ns as in [6], a minimum packet payload size of 2956 bytes would be required at 10 Gb/s. Clearly, traffic shaping at ingress nodes is needed to achieve the minimum optical payload size. In comparison to the 53 byte size of ATM cells and 40 byte minimum size of IPv6 packets, the optical packet payload is at least an order of magnitude greater, and hence concatenation of a number of ATM cells or IP packets to form the payload of each optical packet would be required.

Conclusion

Fast wavelength-tunable lasers are vital components to achieve high speed optical packet switching, allowing increased bandwidth granularity, the possibility of statistical multiplexing and improved traffic engineering in future transport networks. This paper has presented a survey of tunable laser technology, including device performance and their implications for the design of OPS systems. Tuning times under 10 ns have been reported, which offer the possibility of efficient packet switching. However, at 10 Gbit/s line rates and beyond, the packet payload is likely to be an order of magnitude or more larger than the higher layer packets, due to the ns switching, synchronization and guardtimes, and hence traffic shaping at ingress nodes is likely.

The project on optical packet switching underway at Adastral Park aims to assess a range of optical technology required to implement optical packet switching, and additionally investigate network control issues to overcome technology shortcomings such as the lack of optical RAM.

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