# The WASPNET optical packet switching node and its testbed realization

**Mike J. O'Mahony**
*University of Essex, Department of Electronic Systems Engineering, Colchester CO4 3SQ, UK*
*Telephone: +44 1206 872380 fax: +44 1206 872900 e-mail: mikej@essex.ac.uk*

**Ken M. Guild**
*Ilotron Ltd., Ilotron Engineering Centre, John Tabor Building, Wivenhoe Park, Colchester CO4 3SQ, UK*
*Telephone: +44 1206 227309 fax: +44 1206 862074 e-mail: keng@ilotron.com*

**David K. Hunter, Ivan Andonovic**
*University of Strathclyde, EEE Department, 204 George Street, Glasgow G1 1XW, UK*
*Telephone: +44 141 548 2527 fax: +44 553 1955 e-mail: d.hunter@eee.strath.ac.uk*

**Ian H. White, Richard V. Penty**
*University of Bristol, EEE Department, Merchant Venturers Building, Woodland Road, Bristol BS8 1UB, UK*
*Telephone: +44 117 954 5187 fax: +44 117 954 5206 e-mail: Richard.Penty@bristol.ac.uk*

**Abstract:** This paper reports on an optical packet switching network demonstrator, constructed under the EPSRC-funded WASPNET project. Header deletion and insertion, routing, switching and contention resolution were demonstrated, facilitating optical packet transmission over 14 nodes.

**OCIS codes:** (060.2330) Fiber optics communications; (060.4250) Networks

## 1. Introduction

Research into optical packet switching has been conducted over a number of years [1,2], to support the rapidly increasing bandwidth demand, and the shift from voice-optimized TDM networks to IP-centric networks. For realization within 5 years, coarse packet or container switching is promising [3], where a number of ATM cells or IP packets are assembled within an optical container. An optical label is then attached to the container payload to form the basic optical packet structure. Within an optical packet switch (OPS) the container label is read and compared with a look up table. The payload is then routed to the appropriate output port with a new label attached. The payload stays within the optical domain, but label processing and switch control are electronic.

OPS can be deployed as a natural evolution of the Optical Transport Network (OTN), where the OXCs developed for the OTN can evolve to implement optical packet switching. Designated wavelengths supporting optical packets can be dropped from the OXC, processed within the OPS and then either be inserted back into the core or dropped off locally.

## 2. WASPNET Concept

WASPNET is an optical packet networking project established to facilitate understanding of the key networking and hardware issues associated with the technology. Optical packet switch design poses many problems, for example the lack of optical memory for buffering places a more demanding requirement on design than might be the case in electronics. However an optical approach permits use of wavelength [4], thus, for example, different wavelengths may be assigned to contending packets, allowing them to co-exist on the same output port.

The WASPNET scenario envisages a network of optical packet switches effectively embedded within a WDM network. Wavelengths are also used within the switch node to alleviate contention and therefore interfacing between switch and network is necessary to ensure appropriate matching to transmission wavelengths. Packet routing between nodes is controlled by a technique called Scattered Wavelength Path (SCWP), which is essentially a multiplexing scheme for optical packets carried over WDM. In SCWP each optical packet path is not allocated the same wavelength across its entire path, but dynamically converted to a suitable wavelength in each network link. The decision is influenced by the availability of free time slots on each wavelength when forwarding to the next node. Such dynamic wavelength allocation permits sharing of capacity between wavelengths, yielding lower packet contention probabilities and requiring smaller optical buffers at each node than other techniques [5].

## 3. Packet Switch Realization

An optical packet network demonstrator comprising an optical packet switch within a re-circulating loop was used to investigate and demonstrate key aspects of the network approach, for example concatenation limitations. Fig. 1 shows the *N*-fiber multi-plane architecture used to support the SCWP strategy, each plane being responsible for routing and buffering packets arriving on a particular wavelength. Fig. 2 shows the detailed architecture of the wavelength plane, which broadly comprises two stages of processing. In the first a fast wavelength converter followed by an arrayed-waveguide grating (AWG) supports contention resolution, and switches the payload to the correct output port. The second stage of wavelength conversion followed by a many-to-one space switch ensures switching of the packet to the correct output plane at the correct wavelength. The input ports are connected through wavelength converters to a 16×16 AWG; a 4×4 output space switch was used [6].

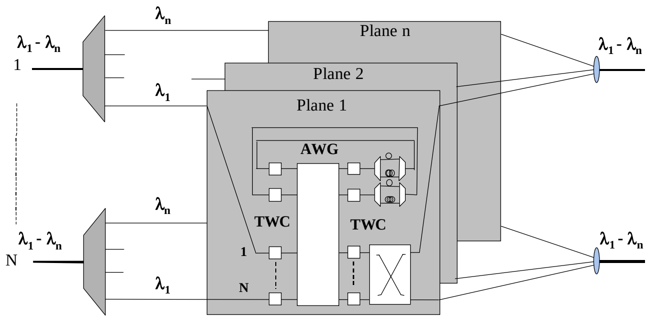


Fig. 1. The multi-plane architecture; each plane handles one input wavelength. Multiple packets may leave a plane output simultaneously on different wavelengths.

As an optical packet enters the plane its header, which contains the address label defining the required output port, is gated out (using the SOA associated with the input wavelength converter) and decoded electronically. The label information controls the fast tunable input wavelength converter, which then assigns an appropriate wavelength to the payload. The payload entering the AWG is passively routed to the appropriate output port, its route determined by its wavelength. At the output a further stage of wavelength conversion ensures that the output packet wavelength matches the external network requirements. Label insertion is achieved in conjunction with the output wavelength converter, through modulation of the carrier prior to the payload.

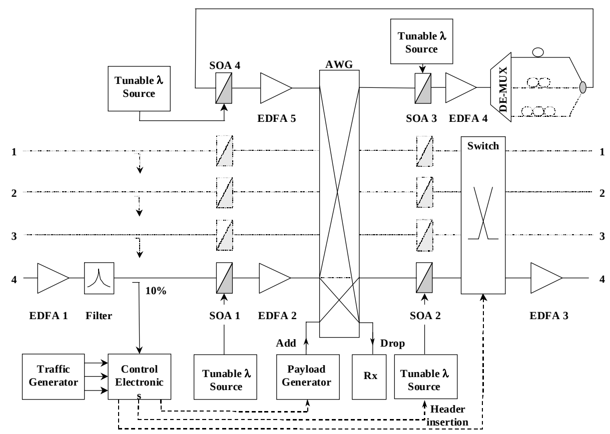


Fig. 2. The single wavelength plane implemented in the demonstrator.

Several techniques for implementing the optical header were investigated. Sub-carrier multiplexing was favored, where a low bandwidth header is placed on an electrical sub-carrier above the baseband frequencies occupied by the packet payload. The header is also placed in time before the payload, facilitating header removal by simply activating an optical gate, such as a semiconductor optical amplifier, to remove the header at the appropriate instant. The header sequence is then detected and processed electronically. In the demonstrator, which operated at a bit rate of 2.5 Gb/s a subcarrier frequency of 2.8 GHz was used. The label contained eight bits (at 155 MHz), a start and stop bit plus six address bits.

A variation of this approach involves DPSK modulation of the sub-carrier. As the SOA cross-gain modulation wavelength converter used in the switch (see below) only responds to amplitude modulated signals, the DPSK header is automatically removed, providing excellent label extinction [7].

The packet format used in the experiment comprised a 52 ns header, a guard band of 8 ns between header and payload and a conservative guard-band of 60 ns between packets. The header duration corresponds to 1 byte at 155 Mb/s; and the payload size was set to approximately 100 bytes at 2.5 Gb/s. For the purposes of the demonstration the guard bands were left large enough to ensure they did not impact on the network performance.

For wavelength conversion, cross-gain modulation (XGM) in semiconductor optical amplifiers (SOAs) operating in the counter-propagating mode was used, not requiring output filtering, and enabling nanosecond conversion speeds. Investigation showed that the use of wavelength converters in the architecture introduced insignificant penalty in a network even for over 50 concatenations, if a wavelength up-conversion stage is always followed by a wavelength down-conversion stage [8].

The packet loss probability of the switch has been determined both by analysis and by simulation [9]. Furthermore, Fig. 3 shows experimental results illustrating the technique used to overcome contention. The left hand side shows traces of two packets in contention at the AWG input; the right hand side shows how one packet has been delayed by a packet duration, the two contending packets now appearing serially at the output

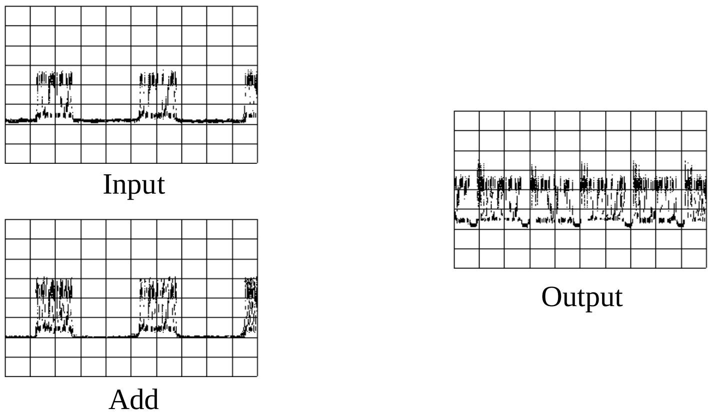


Fig. 3. Resolution of packet contention.

In Fig. 2, the payload generator inserts a stream of payloads (the number sufficient to fill the loop, at a bit rate of 2.5 Gb/s) into the add port of the 16×16 AWG. By a suitable wavelength choice the payloads are routed to SOA2, where appropriate headers are inserted (by modulation) using a subcarrier multiplex technique. SOA2 is also used as a tunable XGM wavelength converter to condition the packet to the appropriate network wavelength, as determined by the node/network control algorithm. The out-of-band header is an 8 bit sequence comprising a stop and start bit plus 6 data bits; the subcarrier frequency is 2.8 GHz.

Packets from the AWG enter the fast cross-point space switch [10], which controls access to the output fibers. In this experiment output fiber 4 is selected and the output packets traverse the loop and re-enter the switch at input fiber 4. The header is detected and evaluated in a look up table, which determines the payload wavelength necessary to route the packet through the AWG to the appropriate output port, and this information controls the SOA1 XGM converter, which also performs the function of header removal (through gating).

Fig. 4. Eye pattern after 10 circulations (1350km).

For the demonstrator the wavelength plane was positioned within a recirculating loop, which comprised three fiber amplifiers with an inter-amplifier spacing of 45 km, yielding a total distance of 135km; this enabled evaluation of the switch performance when cascaded in a network environment. The optical packet structure consisted of a header and payload separated in time by guardbands, with a 52 ns address label and a 300 ns payload. The payload comprised data at 2.5 Gb/s and the address label of 8 eight bits was at a rate of 155 Mb/s. If needed, label addresses could be changed at each circulation and contention simulated such that resolution strategies would be enabled as discussed above. The variation of Q as a function of circulation has been measured. For example 14 circulations, representing a distance of 1890 km, are possible with a decrease in Q value corresponding to 1 dB penalty. Fig. 4 shows the eye diagram corresponding to ten circulations, with very little degradation visible. The transmission path includes, for each circulation, 2 wavelength conversions, the AWG path, and the optical space switch. 14 circulations corresponds to 28 wavelength conversions; achievable with little penalty.

## 4. Conclusions

The paper discussed the WASPNET optical packet network demonstrator. A sub-carrier modulation technique was employed very successfully and a technique using DPSK modulation was devised which enables automatic removal of the header in the wavelength converter. Contention resolution was demonstrated experimentally through a combination of network control and hardware implementation. Routing was achieved using fast wavelength conversion followed by wavelength selection, with over 50 converters cascaded without any noticeable penalty. In the final demonstrator, which employed a re-circulating loop and a 2.5 Gb/s payload bit rate, a cascade of 14 nodes was achieved with a 1 dB penalty.

## References

[1] C. Guillemot *et al*, *ECOC 95*, Brussels, pp 765-68
[2] D. Chiaroni *et al*, *Photonics in Switching 95*, paper PThC3, Salt Lake City, April 1995
[3] N. Ghani, S. Dixit, T. S. Wang, *IEEE Communications Magazine*, March 2000, pp72-83
[4] K. M. Guild, M. J. O'Mahony, *Electronics Letters*, vol 35, no 2, January 1999, pp 161-162
[5] D. K. Hunter *et al*, *IEEE Communications Magazine*, March 1999, pp. 120-129
[6] K. M. Guild, M. J. O' Mahony, *ECOC 99*, Nice, Vol 1, pp8-9, 1999
[7] S. Yu *et al*, Paper TuA1.6, *ECOC 99*, Nice, 1999
[8] A. Tzanakaki *et al*, *ECOC 99*, Nice, TuC3.5, September 1999 pp1554-56
[9] M. C. Chia *et al*, *to appear in the IEEE/OSA Journal of Lightwave Technology*, 2001
[10] S. Yu *et al*, *CLEO 99*, postdeadline paper CPD24, Baltimore, USA, 1999.