Optical Packet Switching: a transmission and recovery demonstration using an SCM header

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ABSTRACT

We have successfully implemented in our labs the generation, routing and detection of optical packets for next generation all-optical networks. Ultrafast switching function (ms timebase) is demonstrated by using an RF sub-carrier modulation (SCM) tone, inserted in the packet and optically detected at the node switching control, which directs the packet to a prescribed output. The optical circuit is noise-free, with BER measurements yielding figures better than 10^{-12}. This system is expected to be fully compatible with DWDM systems.

Index Terms – **Optical networks, digital communications.**

INTRODUCTION

It is expected that in the near future all-optical networks, where opto-electric conversion takes place at or near end points, will prevail, following the “connectionless” principles of IP packet routing. In this way, a demand for optical packets and optical packet switching naturally comes into scene. Our objective is to demonstrate optical packet transmission and recovery as a solution for optical network transport and switching.

WDM networks have already provided important benefits of increased available bandwidth for point to point optical links, but the processing capabilities of electronic switches and routers are expected to impose serious bottlenecks on future optical networks [1]. The bandwidth offered by the optical fiber combined with the flexibility of WDM and optical switching technology offers the potential for implementing optical packet switched networks, which are expected to avoid such bottlenecks.

Optical packet switching provides greater flexibility and easier management for the network because data remains in the optical domain from source to destination, and therefore avoids delays in opto-electronic conversion and electronic processing at switching nodes. Photonic switching combines higher switching speed with greater bandwidth which are expected to provide throughputs above Tb/s [2]. Some important issues that are still under investigation, include packet routing, flow control and contention resolution, and synchronization at switch input and output ports [3].

At present, electronic processing of packet headers, without any impact on payload content, remains an attractive alternative to perform switching functions such as addressing and forwarding. One of several coding techniques introduced for optical packet switching is sub-carrier multiplexing (SCM) [3]. SCM involves the transmission of a signaling or control channel on a frequency band separate from the payload data, such that the header and payload are encoded as separate frequency bands on the optical carrier. An important consideration in such cases is the synchronization of the payload and header during the routing process and the complexity of the switch node, which might increase due to the need of active microwave mixing components[4],[5].

In this work, we investigate traffic addressing and forwarding at optical nodes, using an SCM header of RF frequency as pilot tone in an optical packet. This maintains the payload transparency and contributes for demonstration of packet switching in optical networks. In section 2, we describe the experimental setup for photonic packet switching architecture that we have implemented; and in section 3, we present the results that were obtained and the discussion and analysis of our data.

EXPERIMENTAL SETUP

To implement optical packet switching, the experimental setup in Fig.1 was constructed. It consists of a section where the packet is generated, and a section where it is detected. These two sections can be several kilometers apart, simulating a transmission node and a routing node. At the present configuration the routing node is just 1x2, and an arriving packet must decide output port 1 or 2. The time-domain frame for the optical packet is provided by a single longitudinal mode ITU-grid DFB laser directly modulated with a square pulse of fixed duration (typically 2.4 μs, spaced 14 μs). Next, the sub-carrier modulation (SCM) tone f_1 is inserted in the packet through an RF combiner, over an EOM (electro-optic modulator) ensemble, consisting of modulator, driver and polarization control. At this point the digital load signal is inserted, combined with the RF tone, thus assembling the complete optical packet. An optical arm for temporal reference is also provided, linked directly to the final receiver.

Fig.1 – Experimental setup (please see end of paper)

The packet is amplified by an EDFA to overcome modulator and polarization control losses, which add to ~11 dB; at the EDFA output an optical filter inserted to avoid ASE (amplified spontaneous emission) noise in the optical circuit. The optical packet can now travel for several kilometers (at least 10 km), before reaching the next node. At present, we have limited this distance to 3 km to the node where it is detected and routed.

RESULTS AND DISCUSSION

The oscilloscope traces showing optical packet and reference signals is shown in Fig.2 . Trace *a* is the original (inverted) electrical pulse envelope, with duration 2.4 μs, and fixed spacing of ~14 μs. Trace *b* shows both the direct reference optical signal (not a packet), aligned in time with the input electrical signal, and the optical packet, shifted in time by exactly 4.1μs, which is the travel time through the complete optical circuit. Inside the packet are contained the digital load signal and the analog RF tone signal. In Trace *b* the tone signal is *on*, and gate 1 will open and close exactly for the packet duration, because the TTL signal will keep it open only when and while the signal tone f_1 is present. Gate 2 is maintained closed by a simultaneous TTL (complementary negative) signal. In Trace *c* , the tone signal is *off*, and gate 1 remains closed, so the packet cannot go through. Thus we demonstrate the optical packet detection and routing.

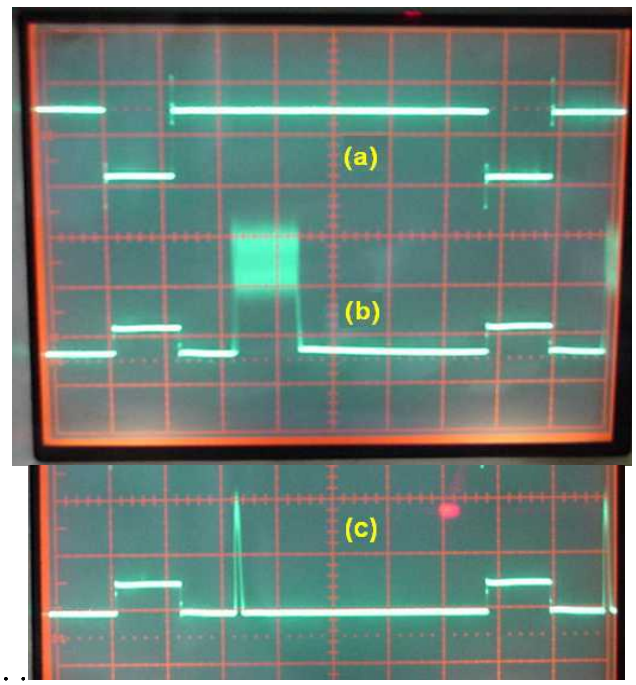

Fig.2 - Oscilloscope traces showing optical packet and reference signals. (See text for *a*, *b* and *c*)

It must be noted that several adjustments and conditions must be met. First the RF tone must be above 100 mV for the gate to open and close precisely; also the pattern generator signal must not exceed 600 mV amplitude, otherwise some of the digital signal component frequencies will mask the tone in the decision circuit. The proper input to decision circuit from the optical tap receiver must be between 30 and 60 mV, otherwise it will simply not trigger the gate or will be saturated, respectively. The latter condition leads to the undesirable situation where the decision circuit input filter is overruled, with an overall degradation of output signal.

To ensure that the digital transmission has low error rate, the BER measurements were realized under controlled conditions. In order to check whether the presence of the tone is detrimental to the error rate, measurements where performed with the tone *on* and *off*. Care was taken to stabilize polarization control, as well as relative powers of tone and signal. We observed that tone signal *on* or *off* did not influence error rate. Eye diagram remained wide open, as can be seen in Fig.3. The best BER results were better than 8 x 10^{-13}, and typical results were ~2 x 10^{-12} for received optical power in the range –15 to -16 dBm. A precision optical attenuator was introduced at gate output to verify performance with lower received power. When optical power value falls below –20 dBm, the error rate increases markedly. We are now investigating performance behaviour for various levels between these limits.

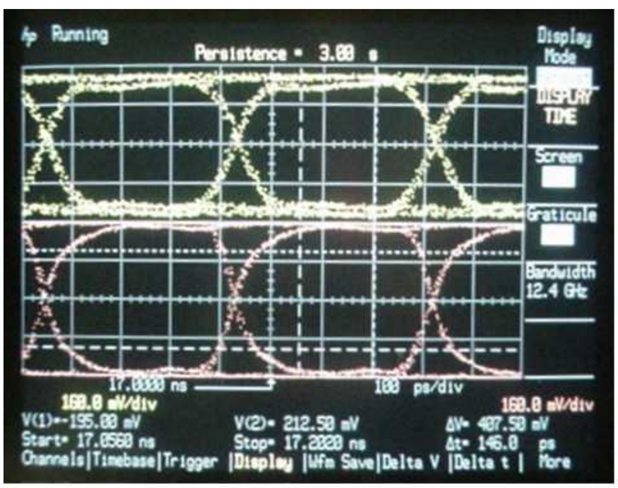

Fig.3 – Digital Oscilloscope traces showing eye-diagrams: upper, input reference; lower, optical signal at port 1.

CONCLUSION

In this work we have experimentally demonstrated the generation, detection and routing of optical packets with few μs duration and spacing. Measurements included packet switching performance with the RF tone on and off, with different values for digital signal and RF tone relative amplitudes, and system sensitivity to various tone frequencies. BER measurements using combined signals yielded results better than 10^{-12}, with wide open eye diagrams.

In summary, by using an in-band low-frequency tone as header for transmission and recovery of optical packets in quasi-transparent networks, we anticipate a cost effective solution for local and metropolitan next-generation optical networks.

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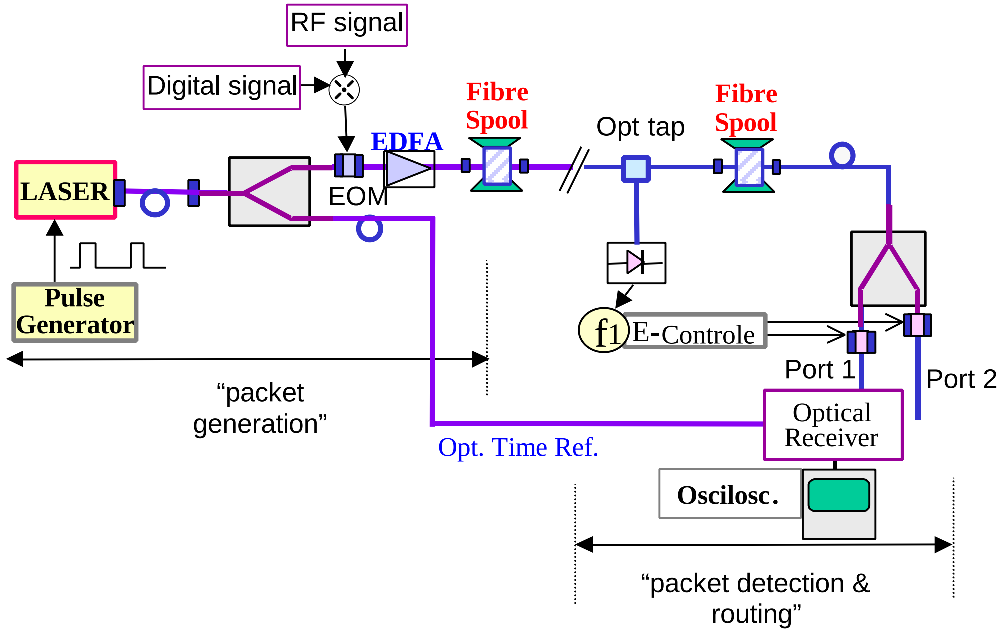

Fig. 1 – Experimental setup .

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