New Photonic System for Optical Packet Switching

F. Rudge Barbosa, A. Campos Sachs, R. Silva Ferreira, M. Tosi Furtado

Fundação CPqD, Campinas SP, 13088-902, Brasil

ABSTRACT

Fast optical switching (µs timebase) is realized by using a RF frequency tone inserted in the optical packet that carries a digital payload. By using a highly selective RF filtering for optical packet header frequency recognition, we have obtained excellent performance in optical switching function.. The RF header is detected at optical node input, and signals the node switching control, which instantly directs the packet to a prescribed output. No electronic processing of the digital payload is performed. The optical circuit is noise-free, has very low crosstalk, and is extremely selective in header frequency detection. BER measurements for payload consistently yield figures as low as 10^{-12} . This system is applicable to optical metropolitan and access networks, and is fully compatible with DWDM systems.

Keywords – Optical networks, Photonic switching, digital communications.

1. INTRODUCTION

It is well-known that future all-optical networks will require photonic switching [1], with opto-electric conversion only at or near end users. By using optical packets to perform “connectionless” communication in the optical network, following the principles of IP packet routing, a demand for optical packet generation and transmission, and optical packet switching naturally comes into scene. Moreover, such photonic networks will require very fast packet switching functions throughout, with minimum amount of buffers in optical nodes. The absence of electronic processing allows unlimited bit rate with any data format. Under such context, the switching functionality is performed within the optical layer, without access to higher electronic layers in the network. On the other hand, traffic demands have been increasing considerably in access networks, because broadband services are rapidly expanding their customer base [6]. For instance, future third and forth generation mobile systems will require packet radio services with diverse offering of bandwidth demands [7]. Besides mobile handsets, nomadic wireless services represent a great potential market for growing mobile applications. Optical fiber is the most appropriate medium to provide the necessary bandwidth to attend the increasing demand of end users with higher data rates in access networks. Fiber radio technology demonstrates great potential to improve user mobility, with variable user densities in a reconfigurable network, driven by changeable traffic demands [8]. However, it must be considered that traffic in access networks requires less aggregation than in core network, to allow for distribution and collection form end users, and tend to present a burst like characteristic due to a variable demand of services. Optical packet switching technology offers great potential to provide wider flexibility for bandwidth efficiency, scalability and finer granularity. But, optical packet switching still remains quite unexplored in optical access networks. In order to realize a practical implementation, simple and low cost switching nodes are required, operating with low loss, easy control and good throughput performance. Thus, the principle of self-routing of packets having header and payload architecture is now extended to the optical layer. Various techniques can be used to address header recognition [1,4,5], whether in time domain, code domain, frequency domain, or wavelength domain. In all cases, it is just the header, not the payload, that is processed in a network node. This means that the optical network is truly rendered transparent to information content, data rate or format carried in the optical signal; and the optical nodes are then immensely simplified, because only straightforward switching and routing is performed.

In previous works [2] we have demonstrated generation, transmission and recovery of optical packets using a frequency header. In the present work we significantly improve the optical switching function by totally redesigning the header recognition and switch control system. We also present further work implementing multiple packet generation and detection. Our approach is to find alternatives that may lead to practical solutions for next-generation packet based optical networks.

2. EXPERIMENTS

The node structure for which our optical packets are targeted is the 2x2 node, where two input ports are connected to two outports, and can be configured in parallel or crossed state [3]. Such node structure requires header detection and RF frequency tone recognition at node entrance, and precise generation of a control signal that will keep gate open for packets with correct tone. If tone is off or if tone is "wrong", gate will not open, and packet will not go to outport.

The experimental setup is shown in Fig. 1, which is divided in (a) optical packet generation; (b) packet detection, header recognition, switch control and packet routing. The new design allows simultaneous generation of two optical packets having frequencies f_1 and f_2 . We present packets from the independent arms being loaded with f_1 and f_2 separately, and alternately loaded with digital signal. We do not at present have the availability of equipment to load separate digital signals. In both cases (f_1 and f_2) the high-capacity digital payload of 2,5 Gb/s is successfully transmitted with BER measurements consistently yielding results as low as 10^{-12} .

The relevant features or requirements that the opto-electronic control unit must have for proper switching operation with optical packets using frequency tone headers are:

- frequency selectivity ;
- on/off clarity (*on* and *off* states clearly defined);
- packet integrity (no part of packet is lost or cut).

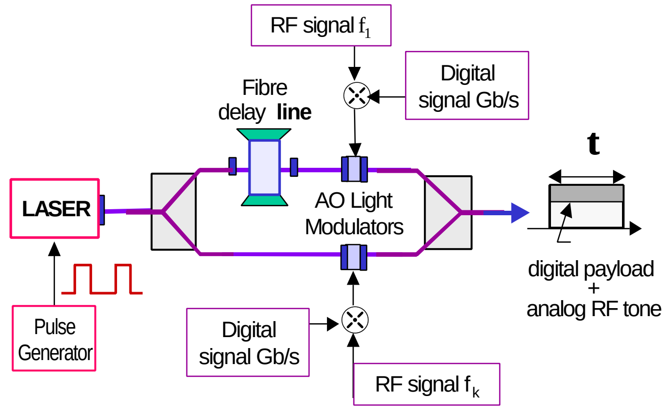


Fig. 1 (a) – Optical packet generation .

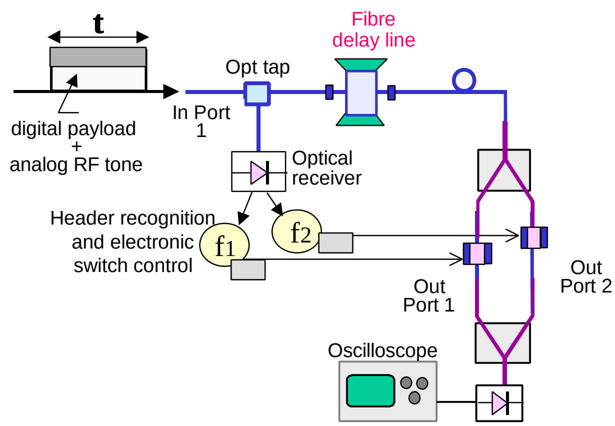
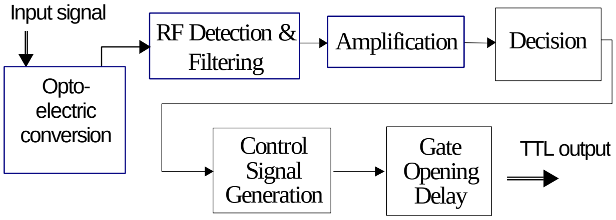


Fig. 1 (b) – Optical packet detection and switching .

The new electronic control circuit for the optical packet switch that has been designed and implemented is now fulfilling all these requirements. The previous circuit hitherto used [2], had only partial fulfillment of these requirements, though it served well in demonstrating basic principles in optical packet switching. Also, it allowed the development of experimental work in optical packet switching using a frequency tone header [2]. The main limitations were poor selectivity in frequency and poor on/off clarity; even though it strictly preserved packet integrity.

The optical packet switching control unit obeys the block diagram, shown following.



The new circuit, which performs all three requirements as staded above, has the specific diagram shown in Fig.2. In this new configuration, not only the RF tone presence is detected, but also the packet amplitude level is taken into account. It is only when both are present that the AND logic allows control signal (TTL level) generation that will actuate on the switch. We have observed that the packet envelope detection occurs with ~2 ns risetime, which is basically the same as the packet risetime itself. Therefore this signal waits on for the RF tone recognition, which takes a few µs to arrive; then decision occurs. This internal delay in the switch control circuit is different from the line delay of the optical packet in the delay fiber; that is precisely controlled and adjusts the packet arrival at the optical gate just after it opens.

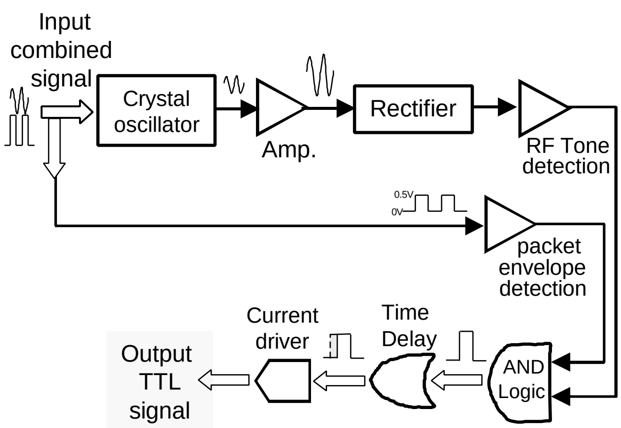


Fig.2 – Block diagram of the header control circuit for optical packet switching.

The details describing generation, transmission and detection of optical packets in the optical circuit of the experimental setup have been given previously [2]. Here the main differences are, the simultaneous double packet generation, and the improved switch control circuit based on a crystal oscillator, as described above. The new circuit guarantees a sharp frequency selectivity, perfect on-off clarity and packet integrity. Such results can be seen in Fig.3. The double packet configuration, where both arms generate packets simultaneously, requires an additional delay fiber necessary to avoid packet overlap at the fiber amplifier.

It should be noted in the experimental setup, Fig. 1 that one and same fiber amplifier (EDFA) is shared by all packets, which simplifies the system and reduces cost. Moreover, the presence of the amplifier renders the optical node practically "lossless". Cross-talk in the system is kept very low, below –20 dBm optical, and remains much below any decision level along the optical and electronic circuits. The optical packet time duration can be any value between 2 and 4 µs, and repetition between 6 and 12 µs; adjustments are made to fit packets duration and repetition on oscilloscope screen for visualization and control.

3. RESULTS AND DISCUSSION

The oscilloscope traces in Fig. 3 show optical packets with combined RF tone and digital signal alternatively loaded on the short and on the long arm. Notice that both packets in both cases show sharp edges, due to both the fast rise/fall times of the optical packet and also to presence of guard times that guarantee packet integrity. These features are obtained by first, having a double decision circuit which in one section detects amplitude of packet envelope, and in another section detects the presence of RF tone frequency; and only when both conditions are met the circuit generates the TTL signal for optical gate control. Rise and fall times of the gate, which is an acousto-optic modulator, are ~ 0,1 µs. The adjustment of the guard times is realized by adjusting the length of the delay fiber, and by adjusting the control circuit output delay that maintains gate opening to ensure packet integrity. In others terms, a packet is never chopped in the node. Once it enters the optical switch, it either passes through or is completely blocked (Fig.4) in the present configuration.

Frequency selectivity is confirmed by varying the input RF tone with a precision signal generator. We obtain selectivity better than 0,1 kHz for RF tone frequencies in the range of several MHz, which allows for implementation of many tone frequencies or addresses in the optical network. The independent nature of the generation arms can be used to create several packets with different header tones simultaneously.

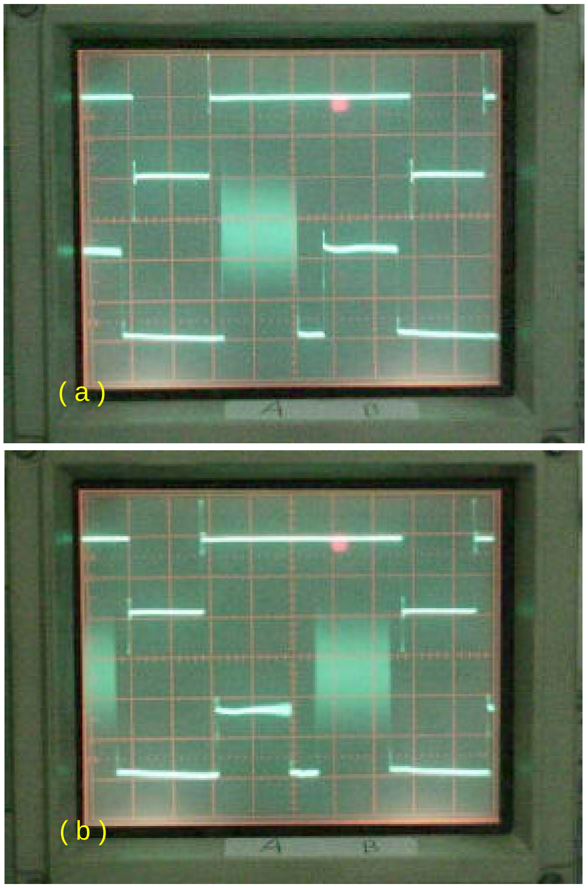


Fig. 3 - Oscilloscope traces showing optical packets with RF *on* state, and reference signals: upper traces in a) and b) are the electrical envelope negative pulse; lower traces are fully loaded packets in a) short arm, b) 2,5 μs delayed arm.

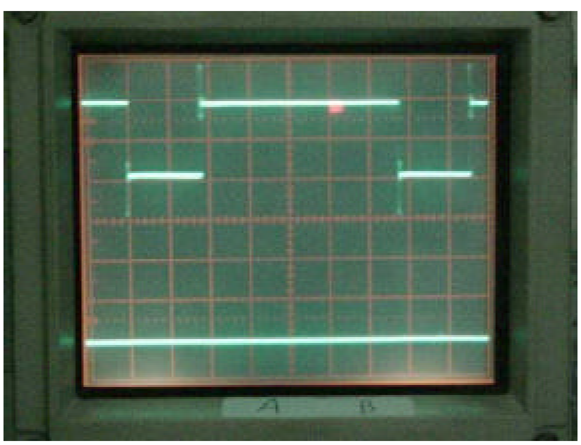


Fig. 4 – The RF *off* state (lower trace) showing, as expected, no output signal.

We have also loaded the digital signal on one arm, and the RF tone on another arm, placing the header in one packet and the digital payload in another. Although this has the interesting appeal of pure tone and pure digital in separate packets, it has low bandwidth efficiency because one group of optical packets is just carrying the frequency tone header, when it could be carrying also high capacity payload. The pure digital signal cannot be considered an advantage compared to waste in bandwidth, because low BER transmission has already been demonstrated [2], with the presence of RF tone header. From [2] results have been extended to include various relative amplitudes, ranging from 0 to 35%, depicted in Fig. 5. We conclude that an RF tone amplitude clearly less than 20% of the digital signal amplitude will not degrade significantly the error rate, even for a limit as low as 10^{-10}, which is far below the usual metro-access levels (typically 10^{-7}-10^{-8}).

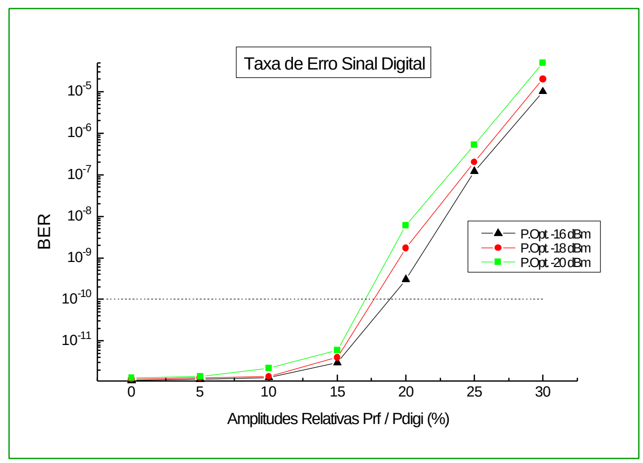


Fig. 5 – Effect of relative amplitudes of RF and digital signal on BER measurements.

4. CONCLUSION

We have presented in this work the improvement and evolution of optical packet switching, including generation, transmission, and header detection and recognition for switch control. The switching process is very fast, with few μs duration, and rise and fall times much faster <0,1 μs. A new system for packet recognition based on a crystal oscillator has proved to be extremely selective, with passband <0,2 kHz for RF tone frequencies in the MHz range. This improved feature leads to the possibility of many simultaneous header frequencies in the same network. Packet recognition is also improved with gate on-off states more clearly defined, preserving packet integrity by allowing guard times of 0,2 µs before and after packet. Next step is to implement simultaneous f_1 and f_2 operation, and apply to the 2x2 optical switch.

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5. REFERENCES

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