Simulation of Optical Burst Switching Protocol and Physical Layers

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Abstract: This paper describes the simulation of the performance of an Optical Burst Switching (OBS) network. First the description of an OBS model created by implementing multiple simple n-channel network models in OPNET Modeler is presented. Then, the Physical Layer performance of an OBS network is investigated using VPItransmissionMaker, and performance predictions based on realisable technology and dependent on parameters such as distance between nodes and number of nodes presented.

1. INTRODUCTION

The increasing transmission rates in optical networks, with channel rates increasing to 40Gb/s and beyond and link capacities rising to the order of Tb/s, places increasing demands on the switching equipment to be used. All-optical networks are proposed to avoid the familiar "electronic bottleneck". As it is envisaged that future networks will be Internet Protocol (IP) based, the development of all-optical packet switches has attracted much interest. An intermediate step, however, involves the use of Optical Burst Switching (OBS) where packets are aggregated into longer bursts and switched together, and where the control information is sent on a separate channel, usually in the form of what is referred to as a Burst Header Cell (BHC).

In the first part of this paper we will describe the development of a model for an OBS network using the Just-Enough-Time (JET) protocol [1]. This protocol makes use of an offset delay between the BHC and the data burst. The BHC is sent immediately after the burst has been created, while the data burst follows after a designated delay time. The BHC contains information required to route the data burst through the optical transmission core, as well as the length of the burst and the offset delay value. The effect of different offset times has previously been investigated to satisfy the requirements of different traffic types [2], [3]. The BHC is processed electrically (optical-electrical and electrical-optical conversions take place) at each of the intermediate core nodes to make routing decisions. The core nodes are configured to switch the data burst, which is expected to arrive after the time interval given by the offset field in the header. When the data burst arrives it is switched entirely in the optical domain. The BHC, on the other hand, is regenerated with the information of the next node to which the data burst has to be sent [4]. Section 2 of this paper describes the OPNET model being developed and its relevance to the investigation of OBS protocol performance.

In Section 3 the implementation of a model for the physical layer of an Optical Burst Switching (OBS) network is described. As OBS allows switching of data channels entirely in the optical domain, the physical layer performance of these channels, through an all-optical network, is of vital importance. In the VPI model implemented, parameter values for optical components that might be used to create a burst-switching network in a real world scenario have been used. Finally, results concerning the BER of such a network and how it is affected by different network parameters are presented.

2. PROTOCOL IMPLEMENTATION OF OBS

This section will describe how an OBS network model has been implemented in OPNET Modeler.

The first step was to define the BHC format. According to [5] the BHC format can be similar to an ATM cell as this makes possible the use of existing ATM switch components. The control channels over which BHCs are sent should then operate at ATM rates (600 Mb/s in our case). The OBS network being modelled then consists of links from edge nodes to core nodes, with each link assumed to multiplex several channels (through WDM), of which only one channel is used for the BHCs. The data rates for the data channels can vary from 2.4Gb/s up to 100Gb/s.

One of the example designs that have been created consists of 10 edge nodes and 1 core node. The data links operate at 4.8Gb/s and multiplex 4 channels. In this preliminary model, no optical buffering or wavelength conversion components have been included in the nodes. The core and edge nodes have a similar architecture; the core node is effectively a combination of multiple edge nodes but only forwards the bursts instead of destroying them. A simplified architecture of a core node with 4 input/output links is represented in figure 1. There are 8 inputs and 8 outputs each represented by a point-to-point receiver and transmitter, respectively. Four of the receivers and transmitters have four channels which represent 4 data WDM channels. The other receivers and transmitters are single channel and represent the BHC channels on each link. Thus each combination of BHC transmitter and receiver, and 4 channel data receiver and transmitter represents the connection to a fibre link to an edge node. All of the receiver/transmitter components are connected to a central process model via packet streams. In the process model, decisions are made depending on if a BHC or a burst is received. When a BHC is received all of its information is extracted and recorded in a file; then it is reassembled with all new necessary information and sent to the destination edge node. If, on the other hand, a burst is received, a check is made with the file to extract the destination of the burst. This information is then deleted from the file and the burst is sent to the destination node with the appropriate delay. If there was an error in the received burst, the core node asks for a retransmission by sending a retransmission request cell on the control channel back to the sender node. Bursty sources may be used to generate traffic in the edge nodes; the sources used vary between ON and OFF states as proposed by Duser [2]. The distributions used in these sources are Poissonian and use a mean interarrival time of 15ms, with a mean burst length variation of 3000bytes. The results of the simulations are concerned with the throughput and the utilisation of a link and the end-to-end delay (see Table 1) and delay variation of the data bursts. In the case where a retransmission has occurred the end-to-end delay is calculated from the transmission of the original burst until the retransmitted burst is received correctly.

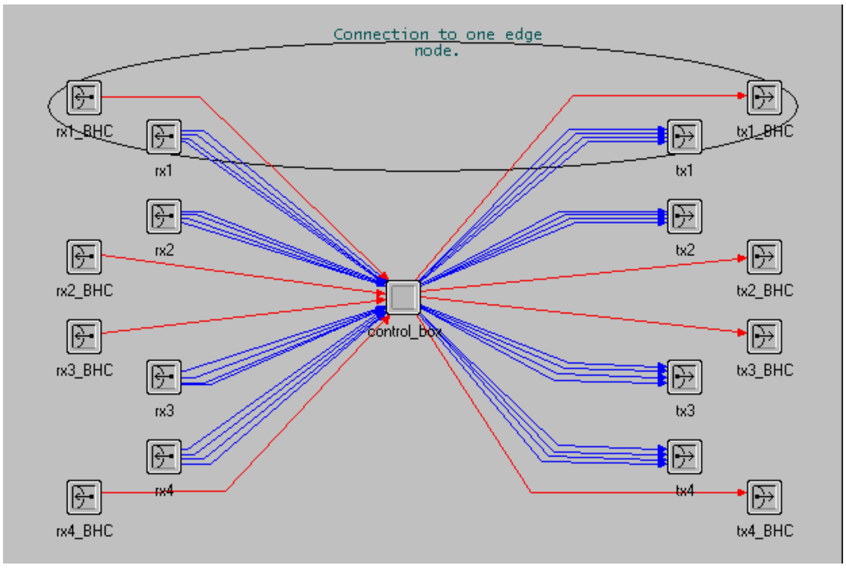

Figure 1. *Simplified simulation model of a core node in a Burst-Switched network.*

In the OBS model the assembly of data bursts in edge nodes can also be investigated. Data burst assembly involves decisions on two important parameters: first on the (maximum) burst length and second on the wait time before a burst is sent even if the maximum burst length has not been reached. The choice of these parameters will basically trade-off throughput/utilisation with end-to-end delay and delay variation. Thus, the values chosen will typically be different, dependent on the higher layer information being transported. Initial, sample results shown in Table 1, for example, confirm that offset delay (2 x 1ms) and propagation delay (through 2 fibre transmission lengths of 80km) dominate end-to-end delay except for very large burst sizes.

Burst Size (bytes)	End-To-End Delay (ms)	Burst Size (bytes)	End-To-End Delay (ms)
5000	2.808	100000	2.967
50000	2.883	500000	3.663

Table 1. *Example simulation results on ETE for different burst sizes.*

The other main problem to be investigated is the contention resolution problem that exists in all-optical networks. Optical buffering can be introduced either by itself or together with wavelength conversion [3]. Further, deflection routing can be employed. Each of these methods leads to variations in the delays of bursts being transported across the OBS network, requiring some adaptation of the OBS protocol (to ensure BHCs continue to correctly predict the arrival times of the bursts). The delay variations will also lead to QoS impairments which must be investigated.

3. OBS PHYSICAL LAYER MODELLING

In the design of the physical layer of the OBS network, it is assumed that low bit-error rate is the main target. It is further assumed that for transmission through a network that may consist of a number of nodes, optical amplification and dispersion compensation would be employed at each node in order to compensate for loss and dispersion in the preceding link and in the node itself. Thus the signals exiting each node should be similar to those originally transmitted except for the accumulation of noise and nonlinear distortion effects which are not compensated for.

The model of this optical network is presented in figure 2. Header (BHC) and data transmitters (Txs), all with WDM spacing of 50 GHz, generate 1 mW optical signals, which are 10 Gbps NRZ-modulated. Although higher optical power could have been used for the current network being simulated, in real implementations, large numbers of wavelength channels are likely to be used and nonlinear optical effects will limit the optical power levels. The header and data bursts are WDM multiplexed and transmitted over a 90 km single mode fibre until they reach the first optical core node. Before entering the node, the composite signal is amplified by 35 dB. Then, the composite signal is optically filtered into separate header and data burst paths. Both signal paths employ cascaded fibre Bragg grating filters immediately after the demultiplexing to optimise the passband responses.

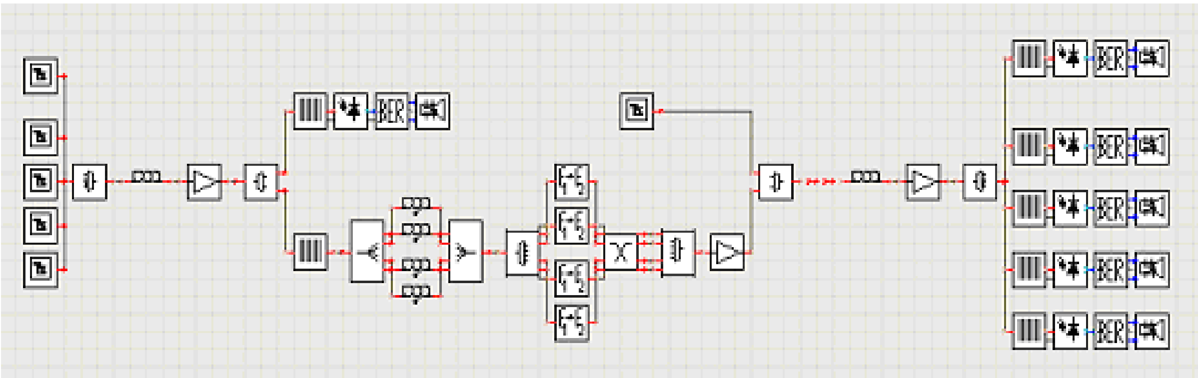

Figure 2. *OBS network Physical Layer representation in VPI Systems software: one optical core node*

In the node, the header is converted into the electrical domain via a PIN photodiode and is terminated. It is assumed that higher layers introduce the new header, represented by a new optical transmitter. Unlike the header, the data burst will experience no O-E and E-O conversions, but it may sustain additional delay. The delay is accomplished by introducing delay lines. Several delay lines exist, each with a different delay time. They are connected into the data path via a splitter, before them, and a combiner, after. It is assumed that higher layers decide which delay line to use and for Physical Layer simulation purposes it is simply assumed that any one is used at a time.

After the delay lines, the four channels are demultiplexed and each channel may be converted to a different wavelength before entering a switch. The wavelength converters are based on those reported in the literature [6]. The switch has several input and output ports, and any wavelength on an incoming port can be switched to any outgoing port. It is assumed that MEMS (Micro-Electro-Mechanical Systems) consisting of collimator arrays, aligned with mirrors are used for the switching. The collimator transforms the optical mode of a single-mode fibre into a light beam of suitable waist diameter for the micro-mirrors [7]. It is assumed that the micro-mirror configurations have been set up by higher layers after processing of the BHCs [8]. The micro-mirrors redirect the beams coming from the optical fibres, to the required outgoing port. Before exiting the node, channels from all outgoing ports are multiplexed and amplified by 26 dB. By this time the new header is defined, and so at the output of the node, the new header and the data bursts are WDM multiplexed together and transmitted to the next node. The average channel power level at the output of the node is –7.2 dBm is very close to the average channel power level at the output of the fist multiplexer in the transmitting edge node (–7.7 dBm).

In the component models throughout the network, all connector and splice losses have been taken into account. These have been modeled by using amplifiers with negative gain values and with noise figures set to zero. Components with fibre pigtails are assumed to have splice losses of 0.2 dB, whereas components with cable outputs are assumed to have connector losses of 0.8 dB. Typical insertion loss values have also been used, of around 2 dB for MUX/DEMUX, 3 dB for MEMS, 0.4 dB for filters. Noise figure values for optical amplifiers have been set to 5.5 dB. Finally, dispersion compensators have been modelled by using fibre lengths with high negative dispersion. The value and length of dispersion compensating fibre were found simply from the length and dispersion value of the preceding transmission, standard single mode fibre. In general, the parameter values of the VPI modules have been chosen according to the data sheets of real devices.

In the model of figure 2, with only one optical core node, the signals are propagated a further 90km before being received at the receiving edge node. As shown in Figure 3, eye diagrams may be displayed for the received data channels. For this case, of one optical core node only, the BER was found to be of the order of 10^{-10} or better for all of the data channels.

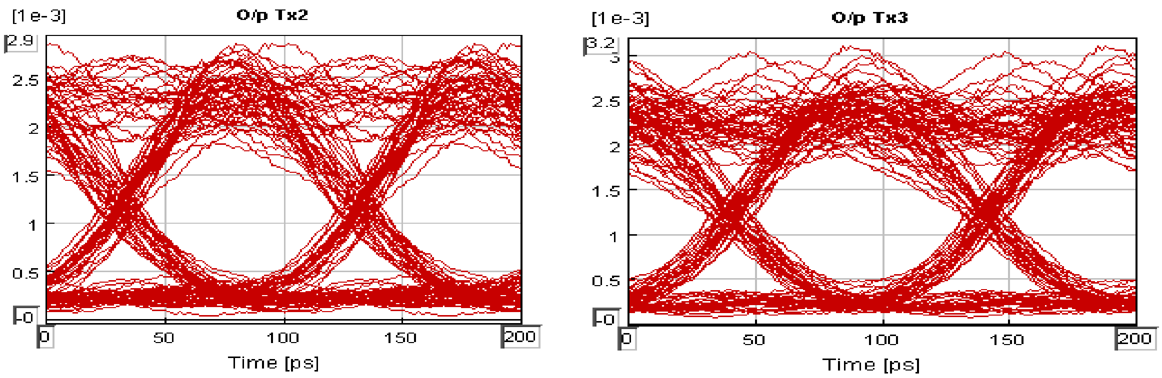

Figure 3. *Received eye diagrams for Tx2 and Tx3 in model of Figure 2.*

In the more general case, the signals from an optical core node will be sent to subsequent core nodes before finally reaching the destination edge node. Although, amplification and dispersion compensation can be adjusted for the different link lengths achievable, the accumulation of noise and nonlinear distortion limits the link length. For two optical core nodes, BER of the order of 10^{-10} or better has been achieved with 70km lengths of fibre between the edge and core nodes and between the two core nodes.

4. CONCLUSION

In this paper, the development of models for core and edge nodes in OPNET Modeler has been described. These models are capable of delivering analyses for the performance of an optical burst switching network taking into account burst switching parameters, including burst assembly and contention resolutions. It has also been shown through simulation of the Physical layer that all-optical (OBS) networks with satisfactory BER can be realised with current component technology.

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