NSOSS – The Non-Synchronized Optical Switch Simulator

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ABSTRACT

Contention resolution of optical signals in time and space domain plays crucial role in optical communication. To facilitate the sizing of large-scale all-optical packet switches using optics (larger than 1Tb/s), we have created a Non-synchronized Optical Switch Simulator (NSOSS). The realized simulator follows the behaviour of a multi-port/multi-wavelength DWDM switching module, where the contention resolution problem is solved with buffers made from fiber delay lines (FDLs). With the help of the simulator researchers can receive performance measurement results of investigated buffering solutions, various buffering strategies and contention resolution architectures. This paper gives in depth description about the developed model structure of the simulator and its simulation performance.

Keywords

All-optical packet switch, DWDM, discrete event simulation.

1. INTRODUCTION

With the technology called optical packet switching (OPS), optical packet switches can provide theoretically two order of magnitude higher capacities, than electronic ones. OPS can also improve the network utilization comparing to circuit-switched or burst-switched optical networks. As drawbacks statistical multiplexing of such traffic causes contentions, and packet drops decrease significantly the network performance. Contention happens, when multiple packets are heading to the same output wavelength at the same time. The fight against contention resolution is playing key role in all-optical switches. Contention resolution in time domain requires temporal storage of optical signal, which is a difficult task, due the lack of optical RAMs available. Buffering optical signals of medium/large size packets (in the range of a few hundred ns) could be realized nowadays only with the usage of fiber/optical delay lines (FDL). According to the literature [1-6] other options such as slow light or holographic storage are not feasible yet in this time range. FDLs are made from normal, cheap, easy-to-use optical fiber cables, with large element size as a drawback, so size-optimisation is highly required.

To facilitate the sizing and evaluation process of all-optical switches equipped with optical delay lines, we have created in OMNet++ framework [7] an optical switch simulator. The realized Non-synchronized Optical Switch Simulator (NSOSS) is modelling the behaviour of a multi-port/multi-wavelength DWDM switching module, which resolves contention by FDL buffers. NSOSS is equipped with numerous building blocks such as various buffer structures, packet sources, sinks and tunable wavelength converters. To explore more detailed the available optimisation possibilities of such complex switching systems we have not only developed the key elements, but also a broad range of multi level scheduling mechanisms with different algorithms. In the simulator we are also introduced special features such as variable size packets, non-synchronized packet handling, and non-zero tuning time. In this paper we are giving performance measurement results of the explored buffering solutions. In the first part we introduce the realized multi-port/multi-wavelength NSOSS simulator developed on the top of the OMNet++ discrete event simulator framework. Than we give detailed description of the model structure of the simulator. At the end of the paper we will show the simulation performance of the system.

2. Generic All-Optical Switch architecture

Generic OPS Switching/Routing node (shown in Figure 1.) needs to implement the following main functionalities in order to work in an all-optical network environment:

- Routing
  Maintaining information about network topology, inter node communication. Packet header processing with information gathering from routing table.
- Switching
  Switching the incoming packets according to their routing information to the appropriate output port and wavelength. Determined by the forwarding process.
- Congestion resolution/Buffering
  Storing and scheduling packets and utilize available resources

Main elements of a generic all-optical switch are: Input Processing Unit (IPU), Information Repository Unit (IRU), Control Unit (CU), Switching Unit (SU), Buffering Unit (BU). Processing of header/payload bits may be done electronically or optically. Most OPS systems are trying to separate routing information form the carried data [8], and process the small size header electronically.

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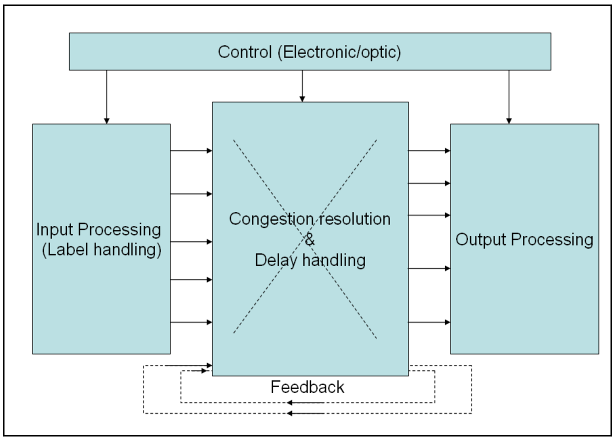

Figure 1. : Generic optical switch diagram

NSOSS is focusing on the contention resolution and buffering part of the generic optical switch.

3. OPS Simulators

In recent years only a few developed OPS simulators have been appeared in the literature. Most of these simulators are suitable only for small-scale simulations written in C++, or Simula. One example of such type of simulators is the **OPSnet Node Simulator** [9]. OPSnet is a C++ discrete-event simulator, which models the behaviour of a unit module of the OPSnet packet-switching node. This unit module is essentially a single-wavelength asynchronous optical packet switch. Buffering is done using a system of parallel, per-packet recirculating buffers. A set of FIFO's is used to control which packet can leave the buffer at any given time. Thus it is possible to conserve the packet order and to prioritise the traffic according to the DiffServ classes. The implementation can only support single wavelength with parallel (RPOBS like) buffers.
There are other type of simulators which are exploring the optical packet switched networks focusing on network scale impact of deflection routing and colouring problems, which are dealing with another very interesting research field of the OPS based network communication. The remaining set of simulator solutions in this topic, are using well-defined discrete event frameworks (such as OMNeT++, NS-2, etc.), and more comparable to the developed NSOSS simulator:

oPASS - Optical Packet Switch Simulator [10]. oPASS is a simulation tool specifically designed for the evaluation of slotted Optical Packet Switching (OPS) switching architectures. oPASS is implemented also in OMNeT++ (as NSOSS) and allows the evaluation of classical parameters in packet networks like packet loss probability (PLP) and distribution (PLD) of packet delay. Specific issues associated to OPS networks are also incorporated: a set of particular OPS network traffic regenerators, simulation modules for the evaluation of particular OPS switching architectures and the collection of specific statistics associated to packet order issues in OPS networks. oPASS development was supported by COST291 project. The implementation simulator can only support slotted/synchronous switching.

Physical layer simulators [11, 12]. Simulations of a various types optical packet space switches were done with OptSim [13]. OptSim is a commercial product from RSoft. It consists of intuitive modelling and simulation environment supporting the design and the performance evaluation of the transmission level of optical communication systems.

4. NSOSS Simulator

The developed Non-Synchronized Optical Switch Simulator (NSOSS) is acting like the internal switching unit of a real all-optical DWDM output-queued switch. It is able to handle both 40Gbps and 100Gbps simulation line speed. We have used n=1,5 as fiber refraction index for the line speed calculations. The simulator assumes that all the relevant packet modifications (e.g.: label swapping/switching) have completed a-priori before packet is entering into the switching unit. Such solution was used by many optical switching projects like KEOPS [14], or later the LABELS [15]. The simulator reads all necessary information from the packet (output port index, output wavelength index) and forwards it towards through the appropriate schedulers at wavelength/port. The assumption to use direct routing information retrieval and decision cause only minor problem simplification. In a real case scenario all information should be received from the label processing/routing unit (shown on the left side of Figure 2.). In our simulation model packet sending is successful, when the packet received and processed by the service unit. Contention resolution in time domain means that if the service unit is busy (single service unit is able to process only one packet at time), buffers are used to store other incoming packets (optical signal) for a predefined amount of time. The scheduler is controlling the fulfilment of the buffer structure and the way, how packets are flowing between the service unit and the sources. In NSOSS we are controlling the filling process of the buffers by multi-level scheduling mechanism. NSOSS is supporting three different levels of scheduling:

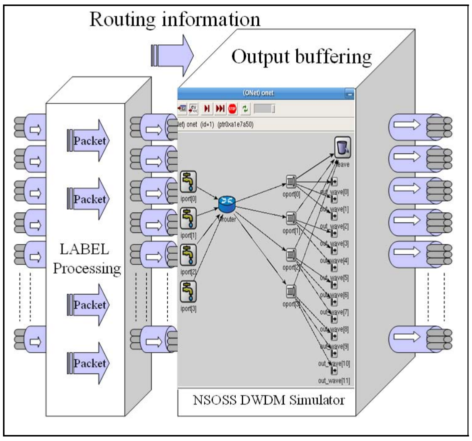

Figure 2. : NSOSS DWDM Optical Switch Simulator

- Top (port) level elements (named in NSOSS: ROUTER) can utilize deflection routing [16].
- Middle level elements (named in NSOSS: WARBITER) can do wavelength arbitration by utilizing TWCs.

- Lowest level elements (named in NSOSS: SCHEDULER) are working with optimised scheduling algorithms to effectively fill the active/passive buffer structures.

4.1 OMNet++ Framework

OMNeT++ is a public-source, component-based, modular, discrete event simulation environment. Its primary application area is the simulation of communication networks. Due its strong GUI support and embeddable simulation kernel it is frequently used for simulation of IT systems, queuing networks and for various business processes. OMNeT++ provides mainly component architecture for models. Components (modules) are programmed in C++, and then assembled into larger compound models using a high-level language (NED). OMNeT++ supports different platforms, such as Linux, various Unix-like systems and Windows (XP, Windows 2000). Originally it was developed at the Technical University of Budapest, Department of Telecommunications (BME-HIT) Hungary (In 2007 July the latest stable version was 3.3).

5. TCP based communication in NSOSS

TCP is currently still the dominating transport protocol in the Internet. The main task was in the further development of the NSOSS to support TCP based communication. OMNeT++ as is, does not has any internal module to simulate TCP communication (with flow and congestion control). TCP support is provided by external module such as the INET framework. INET contains models for several Internet protocols such as TCP, IP, UDP, Ethernet and PPP. However, since we were interested in performance over TCP and lossy links (as packets traversing through high-speed optical switch ports) it was straightforward to use another external framework namely the OppBSD [17], which is using a fully ported FreeBSD TCP stack (including ICMP, ARP, sockets and Ethernet frames). In the simulation models, every simulated host runs its own copy of the FreeBSD kernel's networking stack (with all kernel state variables). Integration of the two simulator modules has been done both on source code and on configuration level. Communication between NSOSS and the OppBSD framework was achieved with edge routers (at the border of the electrical/optical networks), which encapsulates/decapsulates.

6. NSOSS model structure

6.1 Basic elements

6.1.1 Optical Buffers (FDLs)

NSOSS contains the following developed buffer elements created from fiber delay lines:

- C-Buffer - Constant Length Buffer
  It is passive element, controlled remotely by the scheduler. It has a constant delay time, with constant attenuation parameter.
- D-Buffer - Degenerative Buffer [18]
  It is a passive element, controlled remotely by the scheduler. Similar to the constant size buffer, however its delay time/buffering capacity depends heavily from the place in the main buffer structure. D-Buffers introduce delays that are consecutive multiples of the delay time unit (D, 2D, 3D).
- R-Buffer - Recirculating Buffer [19-20]
  It is a looped buffer element. R-Buffer is an active element, and has active self-control. It can hold information until the downstream element become idle, or the maximized attenuation limit has been reached. The FDLs have a constant size, however the optical signal is able to “reuse” the same buffer element multiple times. Maximum packet size should be predefined and should be smaller than the recirculating buffer size. Optical signal attenuation can became an important upper bound for recirculating type buffers.

6.1.2 Scheduler

Schedules messages based on scheduling algorithm, and send them to the corresponding output gates. NSOSS has optimised schedulers for each buffer structure models.

- C-TOBS (C-Scheduler)
- D-POBS (D-Scheduler)
- R-TOBS/R-POBS (R-Scheduler)

6.1.3 Wavelength Arbiter (WArbiter)

It forwards packets to the appropriate wavelength buffer structures and initiate wavelength conversion [21-23] if required. It has two stages and the two stages have different service time:

- First state is when the output wavelength of the TWC equals the required wavelength. No configuration needed, and the “service” time of the TWC depends on the packet size.
- Second state is when the output wavelength of the TWC differs from the required wavelength and tuning needed. In that case the TWC can be seen as an optical buffer with constant tuning time + the packet length dependent “service” time.

6.1.4 Tunable Wavelength converter (TWC)

Such elements are used to convert signal as from one wavelength to another. TWCs can improve the utilization of the available wavelengths, binding different type of input/output wavelengths (even interfaces) together. Exploiting the wavelength dimension by using tunable wavelength converters the required number of FDLs in optical packet switches can be reduced compared to switches without TWCs. We should note here that the usage of TWC elements to handle the wavelength domain in an optimised way obeys the FCFS service rule of the system. For analytical models zero time TWCs are very common, for real case studies non-zero time TWCs are essential. NSOSS is supporting both types (zero and non-zero time) of TWCs.

6.1.5 Packet Generator

NSOSS is using multi-source packet generators for each wavelength. Each generator can be configured to:

- create packets with different type of inter-arrival time distributions (such as exponential or constant)
- support Packet Guard Time (minimum time between consecutive packets on the same wavelength, needed by the optical switch elements).
- generate packets with constant size
- generate packet with different type of packet size distributions (such as upper/lower bounded exponential)
- generate different type of packets

6.1.6 *Additional basic NSOSS elements*

- Router - It is working on Port level and routes packets based different algorithms between input and output Ports. By default it forwards packet according to the so-called deflection routing [24] from highly loaded ports to less loaded ones.
- Packet - Packets can arrive in different order from that in which they were transmitted. NSOSS is able to work with native IP (UDP) and TCP based packets. The default IP packet of OMNet++ was filled up with extra parameters such as attenuation and wavelength conversion counter.
- Sink - It receives discarded messages, and collects statistics.
- Service Unit - It gives service for the packets and collects statistics.

6.2 Compound elements

Compound elements are containing basic elements in a specific wiring structure.

6.2.1 *Buffer structure models*

Complex optical buffer structures made from FDLs can be organized into two main shapes (after the names we put in parentheses our notation):

- Tandem optical buffer structures (TOBS)
- Parallel optical buffer structures (POBS)

In the simulator we are using homogeneous TOBS and POBS type buffer structures, however we should note here, that complex mixed type buffer architectures could be also easily created. Individual building blocks of such structures can be passive or active type buffers. The main difference between buffer structures build up from active or passive type buffers is how the internal scheduling mechanism can be realized. In case of centralized scheduling, extensive status monitoring is necessary for all the buffers, which could be difficult in real implementations. In case of decentralized scheduling, buffers should be able to gather information from their downstream neighbour along the predefined packet-forwarding path.

6.2.1.1 *Passive buffer structure models*

NSOSS supporting two types of passive structures: constant buffers and degenerated type buffers:

- C-TOBS -- Constant Buffer in Tandem Optical Buffer Structure. Constant Length Buffer in Tandem Optical Buffer Structure can be seen as the simplest optical delay line buffer structure. Constant size (constant delay time) Buffer elements in the structure are connected together in a sequential manner.
- D-POBS - Degenerate Buffers in Parallel Optical Buffer Structure. Inside the structure buffers are connected together in a parallel manner, and FDLs introduce delays that are consecutive multiples of the delay time unit (D, 2D, 3D).

Scheduling packets into buffer architectures made of passive buffer elements can be realized in an automated way with centralized high precision timers inside the packet scheduler unit. For our measurements we have developed optimised packet scheduling both for tandem and parallel structure. In the implementation the packet scheduler is tracking the status of each passive buffer and the queue length by accounting the service time of each incoming packets.

6.2.1.2 *Active buffer structure models*

NSOSS is supporting two types of active structures both are recirculating buffers in different higher level shape:

- R-TOBS – Recirculating Buffers in Tandem Optical Buffer Structure. The structure contains looped fiber delay line elements, connected in a sequential manner. Optical signal attenuation became an important upper bound in such architecture. This type of buffer structure needs active (self) control.
- R-POBS – Recirculating Buffers in Parallel Optical Buffer Structure. The structure contains looped FDL elements connected in a parallel manner.

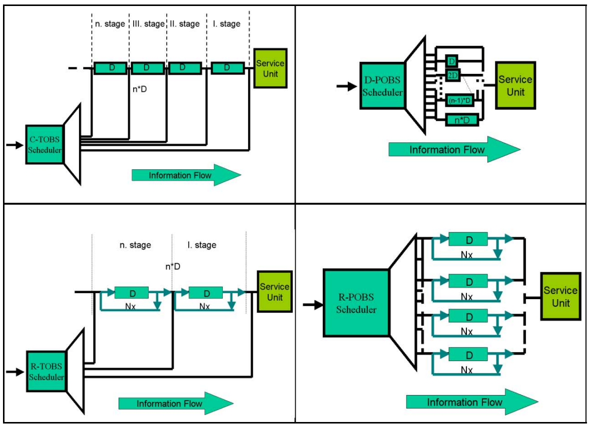

Figure 3.: Realization of various optical buffer architectures (C-TOBS, D-POBS, R-TOBS, R-POBS)

We should here note that Feedback Optical Buffer Structures (FOBS) are also valid solutions; however in this paper we are focusing only on the developed TOBS and POBS type buffer structures (shown in Figure 3.).

6.2.2 *Additional compound NSOSS elements*

One of the main advantages of OMNET++ framework is the high modularity. The reusable modules can be grouped together into hierarchical structured compound modules, which speeds up significantly the simulator development process. The developed main compound modules of the NSOSS simulator are described in Table 1.

Table 1.: Compound modules of the simulator

Compound Element Name	Alias	Consist of
Queue	nobufqueue tobsqueue dpobsqueue rpobsqueue rtobsqueue feedbackrpobsqueue	-scheduler (C / D / R) -service unit -buffer (C / D / R)
Output Port	multiwaveoport	-warbiter -twc -queue
Input Port	Iport	-generator -multiplexer

7. System Parameters

Effective structures to resolve contention can build up both from TOBS and POBS type buffers. The overall performance of the system depends heavily on the main system parameters (shown in Table 2.).

Table 2.: Contention resolution performance parameters

Network Traffic	• Packet size • Network load • Traffic pattern • Traffic burstness • Inter-arrival time
Buffer structure	• Structure type • Amount of buffers • Higher layer structure • Individual delay buffer size
Packet scheduling	• Algorithm performance • Algorithm robustness/fairness
Wavelength scheduling	• Algorithm performance • Algorithm robustness/fairness
Higher layer /deflection/ routing	• Algorithm performance • Algorithm robustness/fairness
Tunable Wavelength Converter	• Amount of (shared) TWCs • Individual TWC tuning delay
Feedback buffering	• Structure type • Amount of buffers
	• Higher layer structure • Individual delay buffer size

In the developed NSOSS simulator global parameters from Table 3. can be used:

Table 3.: Global parameters of the NSOSS simulator

Parameter name	Value	Unit
Internal/External line speed	40/100	Gbps
Guard Time between cons. packets	20	ns
Service Time	10	ns
Packet sizes	1.5K, 3K, 4.5K, 8K, 9K, 16K	Bytes
Buffers in the buffer structure	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 15, 20, 25, 30, 35, 40, 45, 50	Pcs
Minimum IP Packet Size	128	Bytes
Tuning Time of the Tunable Laser	0, 100, 150, 200, 250, 300, 350, 400	ns
Upper limit of loops (attenuation limit)	100	x (pcs)

8. Output results

Each module is monitoring and extensively logging how the system behaves during working time. From the measurement data of the simulations the following basic output information can be captured.

- Signal Attenuation Statistics
- Buffer Utilization Statistics
- Packet Processing Statistics
- Delay Time Statistics

The broad range of parameters help researchers to easily calculate network evaluation parameters such as packet loss probability, the packet delay distribution function. Simulation and measurement results about various system configurations can be found in [25, 26]

9. Simulator capacity

NSOSS is able to simulate complex DWDM base all-optical switching systems. Basically it supports UDP traffic, however with the extension to OppBSD it is able to work with PPP, Ethernet, and TCP based communication. Each module element is equipped with extensive logging capability. The NSOSS simulator is supporting single port/single wavelength measurements, and also multi-wavelength DWDM (2/4/8/16 and 32 lambdas) type measurement with up to 48x48 ports configuration. Arbitrary number (both port dedicated or shared) zero and non-zero tuning time TWCs are also supported by the system. For the evaluation of measurement statistics, we have developed code in the software Mathematica (from Wolfram Research).

10. Conclusions

In this paper we have introduced and described the developed Non-synchronized Optical Switch Simulator (NSOSS). We have showed the main elements of the simulator such as various types of optical delay buffer structure models, Tunable Wavelength Converters (TWCs), or packet schedulers. According to our performance results NSOSS is able to handle a broad range of simulation scenarios such as single measurements, or multi-wavelength performance measurements using TWCs. The latest version of the simulator can handle up to 48x48 DWDM like all-optical switching configuration with 32 lambdas on each port. The simulator can help researchers and hardware engineers to size more accurate FDL based contention resolution modules through simulations of all-optical DWDM network switches. Code is freely available for academic use on the official OMNet++ page and from the authors.

11. ACKNOWLEDGMENTS

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