UNIVERSIDADE DO ALGARVE
Faculdade de Ciências e Tecnologia

Signaling strategies for consumer oriented Grid over Optical Burst Switching networks

Mark Emanuel Cavaco Guerreiro

Master in Electrical Engineer and Telecommunications

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Dissertation supervised by:

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Declaration

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Abstract

The concept of Grid networks has recently emerged as an infrastructure able to support, both scientific and commercial applications. The Grid is a dynamic, distributed collection of heterogeneous computational, storage and network resources geographically distributed and shared between organizations.

Optical Burst Switching (OBS) networks have been identified as a technology with potential to support the requirements of the Grids. This approach, known as Grid over Optical Burst Switching (GOBS) is currently the object of intensive research.

This dissertation focus is on GOBS architectures employing Active OBS Routers with centralized control. This approach enables the balance of the overall network traffic potentially minimizing congestion and consequently reducing job blocking. Two different strategies are explored.

The first strategy is a novel signaling scheme applied to a GOBS network employing Active Routers. The Active Router reduces the job blocking probability, because the path used by the Data Burst to reach the Grid Job Resource is selected based on the network actual status. Since the Active Router maintains the network status always updated, the bursts are only dropped when is not possible to connect the source to the end node. Another study associated with this signaling scheme is the reservation time. It is demonstrated that this approach decreases the network blocking probability at the same time that decreases the time delay that a job suffers until it reaches the Grid service provider.

In the second strategy, the Active Router only select the Grid Resource used to resolve the job, the path used to reach it is selected by the Grid client based on the probabilistic model for the link demands. The probabilistic model is used to predict a possible network usage based on the demands from all nodes to all nodes. The results obtained show overall performance improvement.

Key words: Grid, OBS, Grid over OBS, consumer oriented Grids, signaling scheme, path selection strategies and OMNeT++.

Resumo

Nas telecomunicações a fibra óptica é uma escolha interessante, porque permite taxas de transmissão com uma ordem de grandeza de 1000 vezes superiores às suportadas pelo cobre, onde cada fibra suporta vários terabits por segundo (Tbps). A tecnologia *Wavelength Division Multiplexing* (WDM) permite separar a largura de banda disponível numa fibra óptica em vários canais que permitem a transmissão independente de dados. *Optical Burst Switching* (OBS) é um paradigma introduzido por [1] para as redes ópticas. Os seus autores propõem um esquema onde vários pacotes com o mesmo nó de destino e iguais requisitos são agrupados num super pacote denominado *burst.* Nas redes OBS, os recursos de rede são reservados previamente para a transmissão do *burst*. Para reservar os recursos de rede, antes de enviar o *burst*, um pacote de controlo é transmitido ao longo do mesmo itinerário. Desta forma quando um nó recebe o *burst* encaminha-o imediatamente para a porta e comprimento de onda correctos de saída. Nas redes OBS podem ser utilizados vários esquemas de sinalização para reservar os recursos de rede, tais como por exemplo os *Just Enough Time* (JET), *Just In Time* (JIT) e o *Wavelenght Routed* (WR-OBS).

Uma Grid é um conjunto de recursos computacionais (armazenamento ou processamento) espalhados ao longo da rede. Nas Grids, os clientes enviam para a rede os processos para serem resolvidos. Numa Grid, os nós centrais não precisam de ter informação sobre a disposição dos vários servidores responsáveis por resolver trabalhos específicos, basta possuírem informação suficiente para encaminharem o processo para um servidor com capacidade para a sua resolução. No início, as Grids eram utilizadas por aplicações académicas, que necessitavam de muitos recursos. Recentemente, as vantagens inerentes as redes Grid foram estendidas a aplicações comerciais, caracterizadas por uma duração curta. Nos modelos comerciais as capacidades de encaminhamento rápido são muito importantes, pois os recursos de rede vão estar ocupados somente durante curtos espaços de tempo para cada aplicação.

As vantagens propostas pelas Grids podem ser suportadas pelas redes OBS. A utilização das Grid sobre as redes OBS denomina-se Grid *over* OBS (GOBS). Nessas redes são utilizadas funcionalidades específicas das redes OBS para os clientes acederem aos serviços de Grid. A principal diferença entre uma Grid e uma GOBS é que nas Grids, o cliente não necessita ter conhecimento de onde está localizado o nó que fornece serviço, enquanto

nas GOBS, antes da transmissão do *burst* com os *jobs* é necessário que no inicial conheça a localização dos servidores de recursos seja identificada.

Os esquemas de sinalização mais utilizados nas redes OBS são o *Just In Time* (JIT) e o *Just Enough Time* (JET). As características de ambos os sistemas são apresentadas em detalhe no capítulo 5. Nas redes OBS os *bursts* de dados são transmitidos um atraso *t* depois do *Control Packet* (pacote de controlo) ambos utilizando o mesmo itinerário. A informação contida no *Control Packet* é utilizada para reservar os recursos de rede utilizados para a transmissão do *burst* de dados. Em ambos os esquemas de sinalização a informação contida no *Control Packet* é utilizada para garantir que os nós estão preparados para a transmissão dos dados quando for necessário. A maior diferença entre o JIT e o JET é como são reservados os recursos de rede. No JET o canal está reservado somente no momento de passagem do *burst*, enquanto no JIT, os recursos estão reservados desde que o *Control Packet* chega até que os recursos são libertos por um pacote específico para esse efeito. No caso do JET, os recursos podem ser libertos de uma forma programada, ou tal como no JIT utilizando um pacote especifico para libertar os recursos anteriormente reservados.

Outro esquema de sinalização utilizado nas redes OBS é o *Wavelength Routed* – OBS (WR-OBS), onde um nó central é responsável pela reserva dos recursos de rede.

Nesta dissertação de mestrado propomos um esquema de sinalização para redes *Grid over OBS* baseado em *Active Routers*. O sistema proposto é semelhante ao utilizado em [2] e [3]. As principais diferenças entre o esquema proposto por [2] e [3] e o considerado neste trabalho é que para além da localização dos servidores de Grid, o nó central (*Active Router)* tem um papel preponderante na reserva dos recursos de rede. O Active Router tem um conhecimento global arquitectura da rede e de todas as ligações existentes. Como o *Active Router* é responsável por seleccionar o melhor local para resolver o *Job* escolhe a melhor rota para ligar o cliente e nó responsável por resolver o *Job.* Podendo ser atribuídas diferentes rotas para atingir o *Grid Resource* baseados nos requisitos de cada Job contidos no *Control Packet.* O *Active Router* após seleccionar a rota começa o processo de reserva de recursos de rede. A reserva iniciada pelo *Active Router* permite antecipar a transmissão do *burst*. Como a escolha das rotas é baseada no conhecimento global da rede, a ocorrência de perda de *burst* é reduzida. As vantagens inerentes à rede considerada são redução da taxa de bloqueios e a diminuição do atraso de transmissão. A escolha dos caminhos utilizados para atingir o nó de destino é muito importante na redução das perdas de pacotes na rede. As técnicas utilizadas podem ser ou não adaptativas. As técnicas de escolha de caminhos adaptativas normalmente utilizam protocolos de *routing* para manter actualizadas as tabelas de *routing*. A informação contida nas tabelas de *routing* é utilizada para escolher os melhores caminhos. As estratégias não adaptativas usam informação estática, como por exemplo a topologia da rede ou a distancia dos ligações para escolher quais os melhores rotas para alcançar o nó de destino. Nesta dissertação de mestrado é implementada uma técnica para escolher rotas baseadas num modelo probabilístico introduzido em [4]. Esta técnica para escolher rotas é não adaptativa, é aplicada quando a rede é iniciada e funciona do seguinte modo. Define-se a métrica peso do link que corresponde à probabilidade desse *link* ser utilizado e o custo de uma rota que corresponde à soma dos pesos dos seus links. Quanto maior for o custo da rota, maior é a probabilidade dos seus *links* serem utilizados. A escolha da rota tem por base o seu custo.

A medida de desempenho em redes OBS mais utilizada é a taxa de bloqueios de *bursts*. Por isso é importante estudar técnicas que minimizem a ocorrência de perdas de *bursts* nestas redes. Nesta dissertação de mestrado fazemos o estudo de duas técnicas distintas utilizadas para reduzir a taxa de bloqueio em cenários comercias de redes GRID *over* OBS. O primeiro esquema proposto (WR-OBS), também reduz o tempo de reserva das redes GOBS. A redução do tempo de reserva é muito importante para os sistemas comerciais e redes OBS, pois diminui o tempo total de transmissão, permitindo antecipar a transmissão dos dados.

Palavras chave: Grid, OBS, Grid over OBS, Grids para consumidores, estratégias de sinalização, estratégias de escolha de rotas e OMNeT++

Acknowledgments

First I would like to acknowledge my supervisor Professora Doutora Carmo Medeiros, who since my graduation studies gave me the opportunity to do research work and offered me new opportunities. During this Master her advice was important, giving me information, strategies and solutions during all the work.

I also like to acknowledge to my friends and CEOT colleagues, for all support, friendship, fellowship and a lot of good time spent.

Last but not least, my family, for all the support during this master. A special thank you to whom that I "obligate" to read my report without understanding the technical matters in order to improve the quality of my English.

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Abbreviations

ADM	Add-and-Drop Multiplexer
ATM	Asynchronous Transfer Mode
AWG	Arrayed Waveguide Grating
BBMs	Buffered Burst Multiplexers
BCP	Burst Control Packet
BER	Bit Error Rate
BHP	Burst Header Packet
BM	Burst Module
CCG	Control Channel Group
CIM	Common Information Model
CP	Control Packet
CPP	Control Packet Processor
CWDM	Coarse Wavelength Division Multiplexing
DB	Data Burst
DCG	Data Channel Group
DMTF	Distributed Management Task Force
DR	Delayed Reservation
DWDM	Dense Wavelength Division Multiplexing
DWNV	Dynamic Weighted Nonbinary Voting
EEP	End-to-End Path Priority-Based
EGA	Enterprise Grid Alliance
EON	European Optical Network
FCFS	First Come First Served
FDL	Fiber Delay Line
FDL-BBMs	Fiber Delay Line- Based Buffered burst Multiplexers.
FECs	Forward Equivalent classes
FIFO	First In First Out
GGF	Global Grid Forum
GOBS	Grid over Optical Burst Switching
G-OUNI	Grid User Optical Network Interface

GridDiffServ	Grid Differentiated Services
GRNI	Grid Resources Network interface
GUNI	Grid User Optical Network Interface
IEEE	Institute of Electrical and Electronic Engineers
IP	Internet Protocol
ITU	International Telecommunications Union
ITU-T	International Telecommunications Union - Telecommunications
JET	Just-Enough-Time
JIT	Just-In-Time
JRR	Job Resource Request
LAUC	Latest Available Unscheduled Channel
LAUC-VF	Latest Available Unscheduled Channel Void Filling
LM	Line Modules
LSA	Link State Advertisement
MBV	Majority Binary Voting
MEMS	Micro Electro Mechanical Systems
Min-EV	Minimum Ending Void
Min-SV	Minimum Starting Void.
MPI	Message Passing Interface
MPLS	Multi Protocol Layer Switching
NPs	Network Processors
OBS	Optical Burst Switching
OBSN	Optical Burst Switching Networks
OCS	Optical Circuit Switching
OGSA	Open Grid Services Architectures
OPS	Optical Packet Switching
OXC	Optical Cross Connect
QoS	Quality of Service
RAM	Random Access Memory
RWA	Routing and Wavelength Allocation
SM	Switch Module
SOA	Semiconductor Optical Amplifier
SOAP	Simple Object Access Protocol

TAG	Tell and Go
TTL	Time To Live
W3C	World Wide Web Consortium
WADM	Wavelength Add-and-Drop Multiplexer
WDM	Wavelength Division Multiplexing
WBLU	Weighted Bottleneck Link Utilization
WNV	Weighted Nonbinay Voting
WLC	Weighted Link Congestion
WR-OBS	Wavelength-Routed Optical Burst Switching
WRONs	Wavelength-Routed Optical Networks
WSDL	Web Services Description Language
WSRF	Web Service Resource Framework
WWW	World Wide Web
XML	Extensible Markup Language

Chapter 1. Introduction

1.1. Optical networks

We live in an information era, where the massive uses of the World Wide Web (WWW) cause an everyday increase of the demands for network bandwidth. The Internet traffic high congestion and long delays makes the current infrastructure unable to support these every growing demands [1].

The optical networks are the natural choice to cope with this massive bandwidth growth demand. Optical networks are a perfect choice, because the fiber has several Tbps of operation, low signal attenuation, low signal distortion, low power requirements and slow aging. For optical networks be the perfect choice, they need to offer reliability, transparency, simplicity and scalability [5].

A key technology in developing optical networks is Wavelength Division Multiplexing (WDM). WDM exploits the wide communication bandwidth in the optical fiber. It allows separate the available bandwidth in different wavelengths, allowing the transmission of different signals over the same fiber[6].

WDM systems may be classified as Coarse or Dense WDM, referred to as CWDM or DWDM respectively. This classification depends on the wavelength spacing and compliance with the International Telecommunications Union (ITU) [7]. Figure 1.1 presents the evolution of WDM networks over time. The classification is in the following order:

- First Generation Optical Networks;
- Second Generation Optical Networks;
- Optical Packet Switching Networks;
- Optical Burst Switching Networks.

First generation optical architecture only supports point-to-point configurations. At each node, the entire traffic needs to be converted from optical to electrical, and if the data need to be retransmitted for the next node, it is necessary another conversion from electrical to optical. The specific network devices used are Add-and-Drop Multiplexer (ADM). The ADMs are costly and introduces higher delay and possibly electronic bottleneck [5].

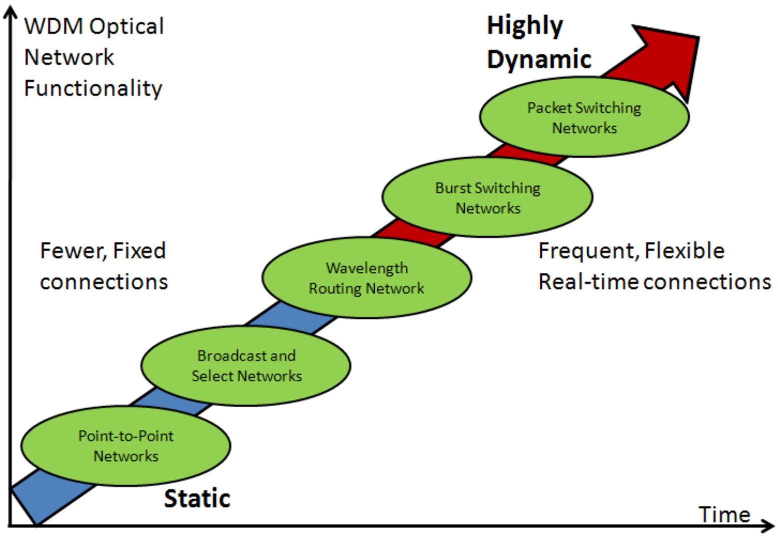

Figure 1.1 – WDM network evolution [5].

The second generation optical networks are classified in two categories: *broadcast and select architecture* and *wavelength routing architecture* [9].

Broadcast and selected networks use tunable transmitters and *passive (active) star coupler* to receive and transmit signal to all other nodes. Consequently, only the node with the appropriate receiver can detect the signal. These networks are classified as either single-hop or multi-hop. In single hop, the data only transverse optical switching components on the end-to-end path while in multi-hop, the signals transverses a combination of optical and electronic switching components.

Wavelength Routed networks use Wavelength Add-and-Drop Multiplexers (WADM), that enable the incoming traffic at each wavelength to either pass to the next node, or to be dropped. WADM technology allows optical signals to be transmitted uninterrupted over longer distances. Wavelength routed networks can also be implemented using Optical Cross Connects (OXC). The OXC basic function is to optically switch the incoming wavelengths on input ports to the appropriate output ports. Wavelength routed networks can also be categorized as Optical Circuit Switching (OCS) networks [5].

Optical Packet Switching (OPS) provide packet switching services at the optical layers. OPS networks goals are to provide in the optical domain, the same services as their electric counterparts packet-switched networks. This goal can be achieved eliminating electronic switching and using WDM transmission capabilities. In OPS, optical packets are transmitted along the optical network without need to be converted to electric at the intermediate nodes [5].

Optical Burst Switching (OBS) combines the advantages presented in circuit switching and packet switching. In OBS networks, the incoming data is assembled in super size packets called Data Bursts (DB), which are transmitted over the optical core network. Signaling is transmitted out of band. The Control Packet (CP), which carry information such as the length, the address destination and the Quality of Service (QoS) requirements of the burst and are used for the path configuration. The Control Packets and the Data Bursts are transmitted along the same path. The signaling is transmitted using a separate wavelength exclusively reserved for signaling. The CP is transmitted an offset time before the DB. This offset is used to guarantee that the Control Packet is processed at each intermediate node before the burst arrival.

1.2. Grid over OBS network

Grid over OBS (GOBS) networks use the OBS network to enable Grid services. Grids are dynamic distributed collection of heterogeneous computational, storage and networks resources geographically distributed and shared between organizations [8].

In GOBS one or more application requests, also named as jobs, are assembled in super size packets called Data Bursts, which are transported over the optical network until reach the appropriate Grid Resource. In OBS networks, every node needs to communicate in order to satisfy a traffic demand, while in GOBS, only the source node is predetermined and the Grid Resource is discovered using a fast resource discovery mechanism. After the Grid resource discovery mechanism, in case of resource availability, Grid jobs in the form of Data Bursts are transmitted to the designated Grid Job Provider, using the OBS networks.

The OBS use for the Grid Jobs transmission presents several advantages, such as: support of existing DWDM infrastructure, minimize the need of optic to electric convertors in the intermediate nodes, ability to utilize efficiently the link bandwidth and the Grid resources and provides a low end-to-end latency. The disadvantage of using the OBS network is that OBS present low reliability, since it normally uses one-way reservation schemes, where the burst is transmitted without receiving the confirmation that the entire paths was successfully reserved. Different DBs contenting for the same resource causes burst drop.

Because the unreliability presented in OBS network, this master dissertation proposes two different strategies to minimize the Data Burst dropping probability. The first strategy presented in Chapter 6, considers a WR-OBS network controlled by an Active Router. The Active Router selects the paths using the global knowledge of the network status and physical structure. The second strategy proposed, is presented in Chapter 7 where the paths are selected by the source node using a probabilistic model for the link demand. The paths are classified according to their usage probability. Based on this classification, the path selection strategies are implemented.

1.3. Dissertation organization

Beside this introduction chapter, the remainder of this dissertation is organized as follows.

Chapter 2 presents a general overview of OBS networks. Special attention is given to path reservation mechanisms.

In Chapter 3 Grid over OBS networks are discussed. This chapter starts with the introduction of Grid. Then the Grid over OBS network is explained. This chapter describes the network scenario used in this dissertation.

Chapter 4 is dedicated to Grid over OBS networks employing Active Routers and to the control plane of such networks.

In Chapter 5, we present the signaling scheme developed in this work.

Chapter 6 contains the proposed scheme implementation details. This chapter is concluded by the signaling scheme performance evaluation, comparing the job dropping probability and the reservation time with a JET-OBS similar scheme.

Chapter 7 is dedicated to path selection strategy schemes. A path selection strategy based on the probabilistic model for the link demands, developed in this work is presented, implemented and its performance is evaluated.

To conclude this dissertation, the chapter 8 contains the conclusions and future work.

Chapter 2. Optical Burst Switching networks

2.1. Introduction

Optical Burst Switching is a technology that combines the best features of Optical Packet Switching (OPS) and Optical Circuit Switching (OCS) networks. One of the OBS networks advantages is that the data remains in the optical domain along the entire path. This feature is enabled by the path reservation before the data transmission.

The OBS networks nodes can be classified into: OBS Edge Routers and OBS Core Routers. The Edge Router aggregates various types of client data into variable-size bursts [1]. The variable-size bursts are also named Data Bursts (DB). To configure the network resources a Control Packets (CP) is transmitted along the path. The CP is transmitted an offset time ahead the DB transmission. The offset time is used to guarantee that the network is already prepared for the burst when it arrives. The CPs are electrically processed at each node along the path from the source to the end node. While the DB remains in the optical domain along the entire path. OBS networks normally use a one way reservation scheme, where the DB is transmitted without waiting for the positive acknowledgements from the intervenient nodes. This strategy minimizes the end to end transmission time.

The OBS dynamic resource reservation allows for network scalability and adaptability, which make OBS more suitable to the busty traffic from the Internet [1].

In the following sections OBS networks are discussed in detail. Particularly, the connection setup mechanism, several burst operations and OBS application scenarios.

2.2. OBS Fundamentals

OBS was designed to support operation in all-optical transmission for WDM networks. In general, an Optical Burst Switching Network (OBSN) is composed by Edge and Core OBS Routers. The Edge Routers consists in an electronic router and a burst assembler, while Core Routers are composed by optical switching matrix, a switch control unit, routing and signaling processors [10].

The Edge Router is responsible to collect data from upper layer users, such as Asynchronous Transfer Mode (ATM) switches, Internet Protocol (IP) routers, etc. The data is collected, sorted and assembled in super size packets called bursts (DB) based on the destination address and its QoS requirements. For each DB is created a Control Packet, which is transmitted to the destination address an offset time before the burst for the network resources configuration. The CP contains information about the burst length, destination address, offset time, etc. OBS use out-of-band signaling, using different wavelengths for the data and the signaling, because the Control Packets are significantly smaller than the bursts, a single control channel is enough to carry the Control Packets associated to multiple data channels. Figure 2.1 proposed by [11], present how the CP and the DB are transmitted using different channels. The CP is converted from the optical domain to the electrical domain and next for the optical domain again, while the burst remain in the optical domain. The offset time is used to guarantee that the network resources are already reserved when the data burst arrives to a node that belongs to the path. The offset is necessary because the Control Packet need to be electrically processed. The information carried by the CPs is used to configure the path nodes used to transmit the DB. OBS uses a one way reservation scheme; the Data Bursts are transmitted without receiving a positive acknowledgement from the network. This network configuration enables OBS DB to be transmitted optically, without the need of buffers (optical Random Access Memory (RAM) or Fiber Delay Line (FDL)). The all optical transmission without the need of buffers is only possible if the offset time is enough to guarantee that the DB is transmitted without waiting at any intermediate node for its resources configuration.

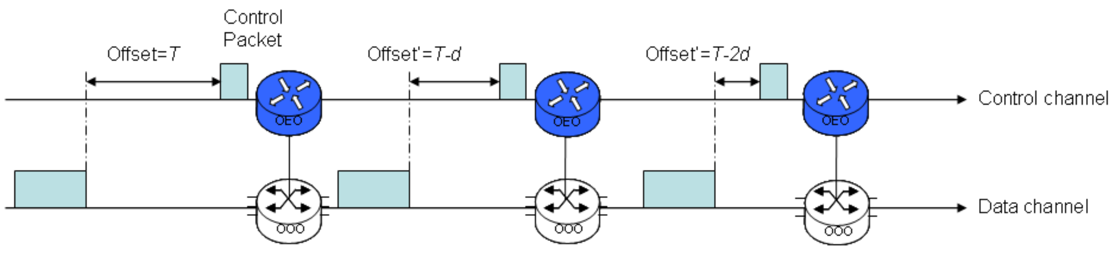

Figure 2.1 – Representation of the data and control signals transmitted over different channels [11].

Alternatively the OBS signaling protocol may choose not use any offset. In this case it is required that at each intermediate node the burst suffers a constant delay. These protocols are referred as Tell and Go (TAG)-based, since their basic concepts are the same that TAG [12] [13] itself.

In OBS, the reserved wavelength channel is normally released as soon as the burst passes through the reserved link. This release can be automatic, using Just Enough Time (JET) reservation scheme or by an explicit release packet. These techniques enable an efficient share of the wavelength bandwidth between different nodes to different destinations.

The one-way OBS reservation scheme main advantage is the minimization of the propagation delay used by the two-way reservation schemes. For this reason the one-way reservation scheme is used by most OBS networks in order to enable high data rate transmission. On the other hand, one-way reservation schemes present high burst loss rate. Since the Control Packet does not reserve the entire path, if it encounters a busy link the bandwidth already reserved at the previous nodes is wasted. The very fast OBS transmission rates make impossible to retransmit the dropped Data Bursts or Control Packets. In OBS networks the retransmission functionality is left to the upper network layers [1] [11].

2.3. OBS network architecture

Figure 2.2 presents an OBS network with DWDM links. The OBS network is composed by several Edge and Core Routers. The ingress Edge node aggregate traffic from the adjacent client networks and transmit it trough high capacity DWDM links over the core network. Edge nodes provide legacy interfaces such as Gigabit Ethernet, ATM, and IP, and are responsible for DBs assembly and disassembly. The Data Bursts assembly consists in aggregating the incoming packets into Data Bursts, and the reverse operation is referred as disassembly process.

The OBS uses out of band signaling, the signaling packets are transmitted on separated dedicated Control Channel Group (CCG). The Data Bursts are transmitted on a dedicated set of channels called Data Channel Group (DCG). The Burst Header Packet (BHP) indicated in the figures corresponds to the already introduced BCP; both names will be used in this dissertation.

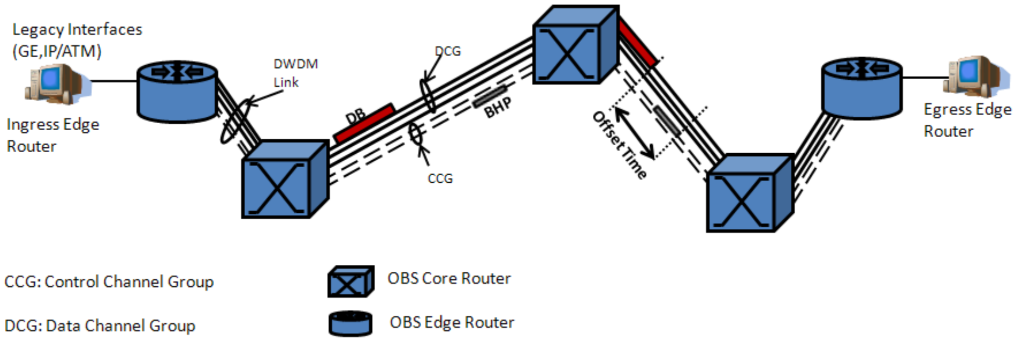

Figure 2.2 - An OBS network example [5].

2.3.1. Edge node architecture

Figure 2.3 present the basic four modules of the Edge Router. These modules are Line, Switch, Bursts and Optical Assembly Modules.

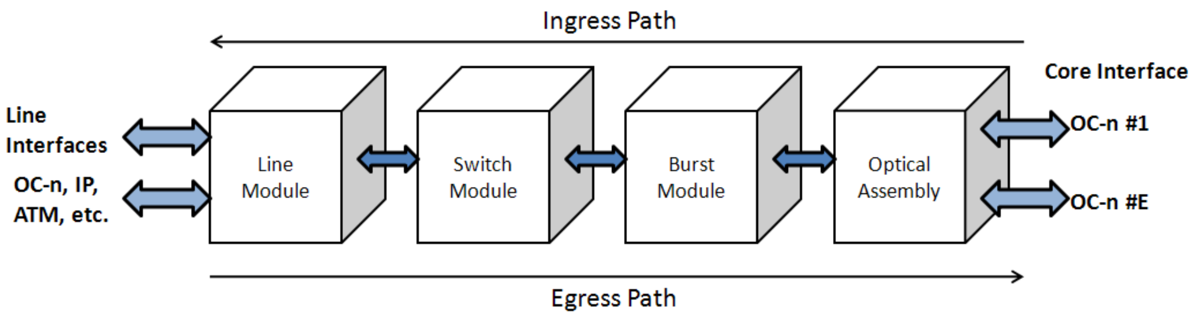

Figure 2.3- Edge node basic modules [5].

The Line Modules (LM) provides the interface between the OBS network and the other attached legacy networks (for example ATM, IP, or SONET rings). The LM primary function is convert different interfaces into a common protocol for the switch module (for example IP Interface).

The Switch Module (SM) route the IP packets to the proper burst module. The criteria used for this routing can be the IP packets destination, or IP packets priority. These routing functions are performed entirely in the electric domain.

Burst Module (BM) is responsible for the assemblage of IP packets into bursts and decomposing incoming bursts into IP Packets. BM is also responsible to determine when the burst must be released and schedule the burst in an available channel [5].

2.3.2. Core Node architecture

A generic Core OBS Router [5] is presented in Figure 2.4. In this hybrid architecture the core node is fully transparent to optical Data Bursts, while in the control channels, the signals need to be converted to electric. Each ingress link is initially demultiplexed and all data and control channels are separated. In each optical channel, the signal characteristics are tested (optical power level and signal noise ratio).

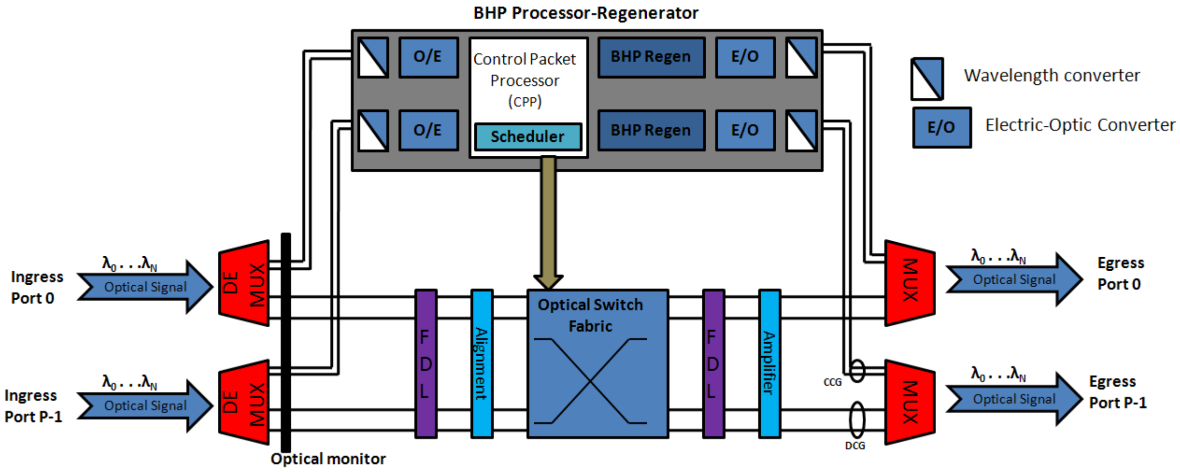

Figure 2.4 - Typical architecture of OBS core switch node with optical burst alignment capacity [5].

Fiber Delay Lines can have multiple usages; for example, delay the DB when multiple bursts are contending for the same switching fabric egress port. Another use for FDLs is compensating the BHP processing delay; the bursts are delayed to maintain the necessary offset times.

The Control Packet Processor (CPP), presented in Figure 2.4, can be centralized or distributed. In the centralized (pipelined) architecture, each received BHP information (data burst length, destination, offset, QoS) is extracted and then the BHP is placed on a priority queue. In the priority queue the requests with higher priority are given a service priority. The requests are processed individually based on the destination. In a CPP distributed (parallel) architecture each egress port has their independent scheduler blocks. Each incoming BHP after the destination check is forwarded for one of the destination queues. The destination queues are connected to the BHP receiver block. All the destinations with the same index numbers are interfaced to the same scheduler block. The scheduler blocks process the requests, and store the reservation until the associated burst is serviced.

2.4. Connection setup mechanisms

In OBS the connection setup up is separated in three steps. The first is the Burst Control Packet creation and transmission an offset time ahead of its corresponding Data Burst; the other two steps are the R (Routing) and the WA (Wavelength Allocation) for each burst.

2.4.1. Signaling for OBS

The signaling schemes can be classified into distributed with one-way reservation or centralized with end-to-end reservation.

Distributed signaling with one-way reservation

The one-way signaling reservation is the strategy that is most commonly used in OBS networks.

This signaling reservation scheme is composed by two steps; the first is the BCP transmission and the second is the DB transmission, Figure 2.5.

The BCP is transmitted along the path that will be used for data transmission and is used for the reservation of the network resources. The BCP is electrically processed by each intermediate node along the path. During this signaling step, the DB remains in the source node where it is delayed by an offset time (*TOffset*). The offset time is used to guarantee that the node is prepared for the DB transmission when it arrives.

Next, the DB is transmitted after waiting the respective offset time without waiting for a positive acknowledgment (ACK) informing that the entire path is successfully configured. This scheme is appropriate because OBS will be use in long-haul networks and therefore the one-way reservation scheme decrease significantly the time used for the connection establishment [1].

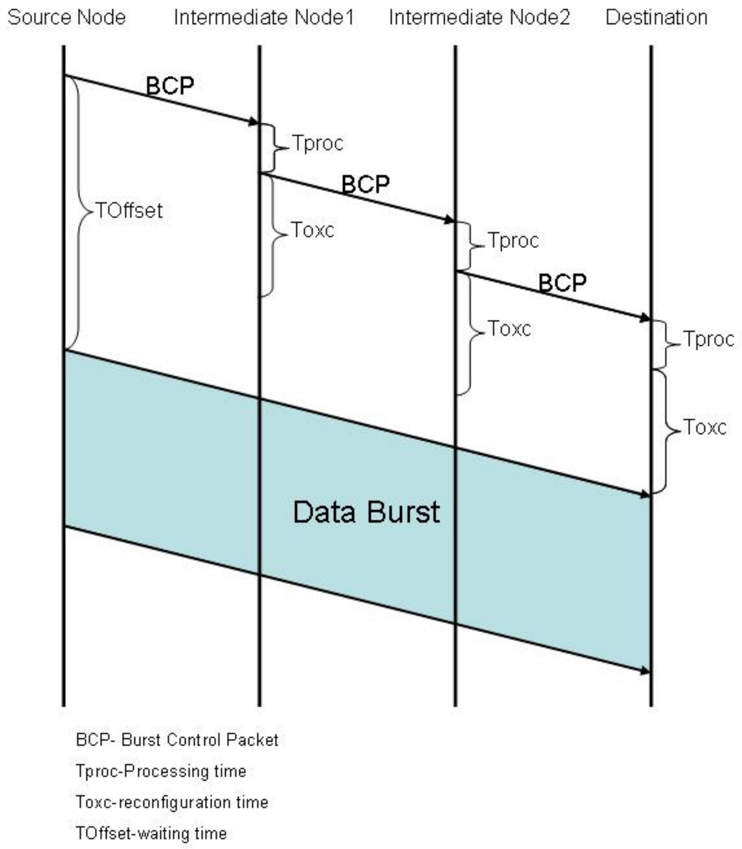

Figure 2.5- One-way signaling reservation scheme flow.

The connection setup time in the one-way reservation scheme is the sum of the reservation delay with the processing and reconfiguration times from all the nodes used to connect the source to the end node. In the two-way reservations scheme (eg. circuit switching), the connection setup time is the sum of the two-way propagation delay, the reconfiguration and setup time of all nodes [1].

Centralized signaling with End-to-End Reservation

The authors of [15][16][17][18][19] propose a centralized connection scheme, named Wavelength-Routed Optical Burst Switching (WR-OBS), which uses an end-to-end reservation scheme. In WR-OBS there is a centralized request server responsible for the entire OBS network resource scheduling that has total knowledge about the state of the OBS nodes and the wavelength availability of all the network fiber links. The edge node transmits a CP to the centralized server. The server queues and processes the CP, using the network global knowledge to select the best path to connect the source node to the end node. After the path selection, the network status is updated.

In the centralized control with end-to-end reservation the Edge Router only transmits the DB if receive a positive ACK from the centralized scheduler [1].

2.4.2. Routing

Very high OBS transmission rates require very fast route calculation. Therefore, Edge Routers must have the ability to pre-determine and pre-calculate routes.

In OBS architectures, the routing algorithms must respect two requirements:

The first requirement is the very fast route calculation. Conventional hop-by-hop IP routing is not suitable for OBSN; otherwise Multi Protocol Layer Switching (MPLS) is more advantageous. The authors of [20][21][22] discuss the MPLS implementation in an OBSN. The idea is at the Edge node assigns the CPs to Forward Equivalent Classes (FECs) to reduce the intermediate routing time to the time used to swap labels.

The second requirement is the ability to the Edge node pre-determines and pre-calculates the routes. The MPLS addiction is beneficial, because it makes possible to explicitly assign the switching labels and route the traffic over the pre-engineered routes. Explicit routing feature is also very useful in constrain based routing OBS networks, where the traffic routes have to meet certain QoS requirements, such as delay, hop count, Bit Error Rate (BER) or bandwidth. In OBS architectures the pre-calculation is required, some OBS schemes use end-to-end count to estimate the pre-transmission offset times (*TOffset* of Figure 2.5).

2.4.3. Wavelength Allocation

The wavelength allocation can be realized using two strategies, with or without wavelength conversion. Using wavelength conversion, the DB is transmitted using a single wavelength between the source and the end nodes. This strategy results in a high burst loss because the selected wavelength needs to be free along the entire path. The second strategy uses wavelength conversion capability at each node. In this scenario, when two burst are contending the same output wavelength, the OBS node may convert optically the wavelength of one of the bursts to a different output wavelength. Several published work assumes wavelength conversions capability at each node for better wavelength utilization over the schemes where no wavelength conversion is used. All-optical wavelength converters are quite expensive devices and remain a topic of study.

WR-OBS presented by [22] use a First-Fit wavelength-continuity without wavelength conversion, where the wavelengths are used as routing labels. This idea was first used in Wavelength-Routed Optical Networks (WRONs). WR-OBS networks use centralized control. In the WR-OBS networks the controller node has the entire network status knowledge, and uses this knowledge to search for wavelength available over the selected route. With all the nodes configured, it is expected that when a burst arrives using a specific port and wavelength is switched to the appropriate output port using the same wavelength [1].

2.5. Offset time

The offset time guarantees that when the DB arrives, the node is already prepared to process it. The Edge node sends the BCP an offset time before the DB. Ideally the offset estimation should be based on the number of hops from the source to the end nodes and the network congestion. The offset time estimation is very important, because the incorrect estimation can increase the burst loss. This happens because the DB may arrive to the OBS Core Router before it is already prepared for it.

The offset time can be fixed, statistical or WR-OBS. In the following subsections it will de explain in more detail this offset estimation techniques.

2.5.1. Fixed offsets

The JET scheme proposed by [1], use fixed Offset time. Its estimation is based in the sum of the one-way propagation delay, the total processing and configuration time of all the intermediate OBS nodes.

The OBS Edge node has to be able to calculate precisely the total number of hops toward the destination. The nodes processing and configuration time is assumed to be equal for all the nodes. This approach is not corrected, because the inevitable jitter caused by the queuing delays in the OBS control channel [1].

2.5.2. Statistical offsets

The authors of [23] claim that the fixed offsets increase the loss probability, since the fixed offsets can enable two OBS edge nodes became completely synchronized and therefore to continually content for the same networks resources. The solution is *variable (statistical) offset generation*. In this scenario the Edge node generate transmission tokens based on the process average rate. To avoid the synchronization, the node address is used as the random Poisson process seed.

2.5.3. WR-OBS offsets

In the WR-OBS architecture, the offset time is calculated as the sum of the time it takes an OBS Edge node to request resources from the centralized server, the RWA algorithm computation time and the path signaling time.

Most of the offsetting techniques are based on the assumption that the CP is transmitted when the entire DB is assembled. A variation of this technique consists in the CP transmission before the entire DB is collected from attached networks. The advantage presented in this technique is the pre-transmission delay; moreover, burst length is not included in CP information, since the entire burst is not assembled when the CP is transmitted.

2.6. Burst aggregation

Burst aggregation is performed at the Edge node. The Edge node collects data from the attached networks traffic to the same end node and with the QoS requirements and aggregates it into super-size packets named bursts. Burst aggregation algorithms can have a great impact in the overall network operation, since they shape the traffic. Various traffic aggregation techniques have been proposed, the most common are timer-based and threshold-based [1].

In the timer-based techniques, the Edge node uses a timer to determine when exactly the new burst will be assembled. When the timer expires, the Edge node constructs the new burst and the corresponding Control Packet is immediately transmitted to the destination node [1].

The threshold-based approach use the maximum packets number contained in the burst as metric. When the number of packet reach the maximum, the Edge Router assembles the packets in a new burst and create the respective CP [1].

If the Edge nodes only operate with timers, the traffic load can increase when the burst are small, or the burst loss probability can increase to, because large bursts will occupy the network resources for a long time, larger bursts can also enlarge the Edge node delay time used to assemble the entire burst. Hybrid schemes have been proposed to avoid these problems. Hybrid techniques use a timer, the minimum and maximum burst sizes to assemble the bursts. When the timer expires, if the burst is smaller than the minimum burst size, the burst is completed with *dummy* bits. Otherwise if the burst reach the maximum burst size, the burst is assembled before the timer expires [1].

2.7. Burst scheduling algorithms

When a wavelength conversion strategy is used, the incoming burst may be scheduled onto multiple output ports. A burst scheduler is used to select the proper wavelength channel for the Data Burst transmission; taking into consideration the existing reservations.

The scheduling *horizon* is defined as the latest time that the wavelength is currently scheduled to be used. Figure 2.6 visualizes the *horizon*, for example in the LAUC-VF/Min-SV representation, t''_2 is the *horizon*.

The *horizon* algorithm is also known as LAUC (Latest Available Unscheduled Channel). For each wavelength the *horizon* precedes the new bursts arrival time. The wavelength with the latest *horizon* is the one selected. Then the new scheduling *horizon* is updated for a new burst reservation. The LAUC basic idea is minimize the bandwidth gaps crated by new reservations.

The main advantages of *horizon* based algorithms are the implementation and operation simplicity. However the bandwidth gap between two existing reservations is wasted. When new reservations are made, the void filing algorithms are the best choice to minimize the gaps between bursts. One void filling algorithm example is the Latest Available Unscheduled Channel Void Filing (LAUC-VF) [24].

Several LAUC-VF variants are proposed by [25] , such as Minimum Starting Void (Min-SV), Minimum Ending Void (Min-EV) and Best Fit. MIN-SV is a LAUC-VF faster implementation using computational geometry. The Min-EV minimize the voids between the end of the new burst and the existing reservation, and the Best Fit tries to minimize the total length of starting and ending voids generated after the reservation, choosing the gap that waste less bandwidth [11].

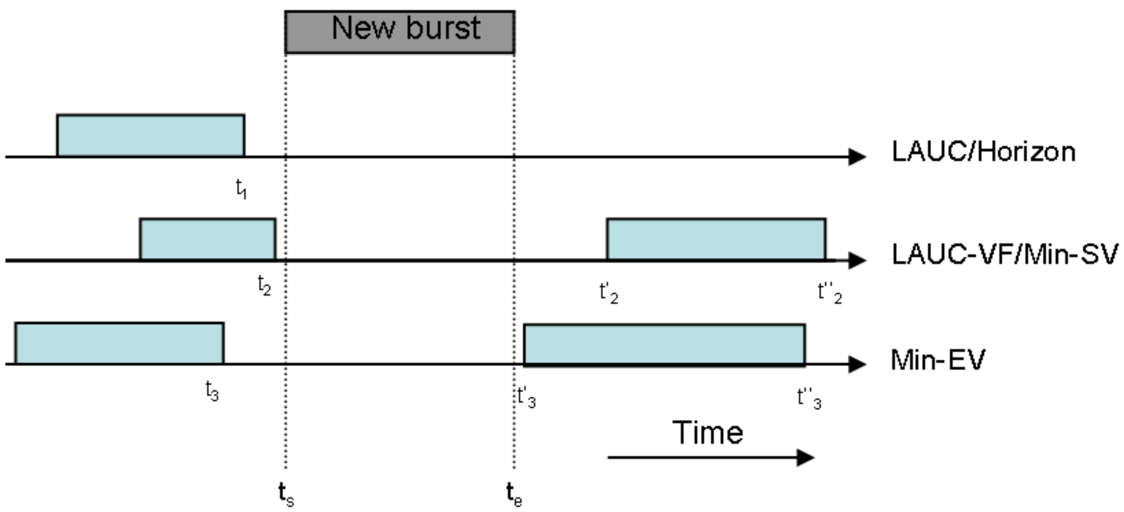

Figure 2.6- An illustration of scheduling algorithms.

2.8. OBS signaling schemes

This section is reserved for the OBS signaling schemes most commonly used, the Just Enough Time (JET) and the Just In Time (JIT). It is presented the signaling messages flow and other important information for these strategies.

2.8.1. Just-Enough-Time signaling scheme

The Just-Enough-Time (JET) signaling scheme is characterized by two main features, namely, the DR (Delayed Reservation) and the ability to integrate the DR in Fiber Delay Line (FDL)-Buffered Burst Multiplexers (BBMs). These features make the JET and the JET based variations especially suitable for OBS networks when compared to other Tell and Go (TAG) based OBS protocols and other one-way reservation based OBS protocols [1].

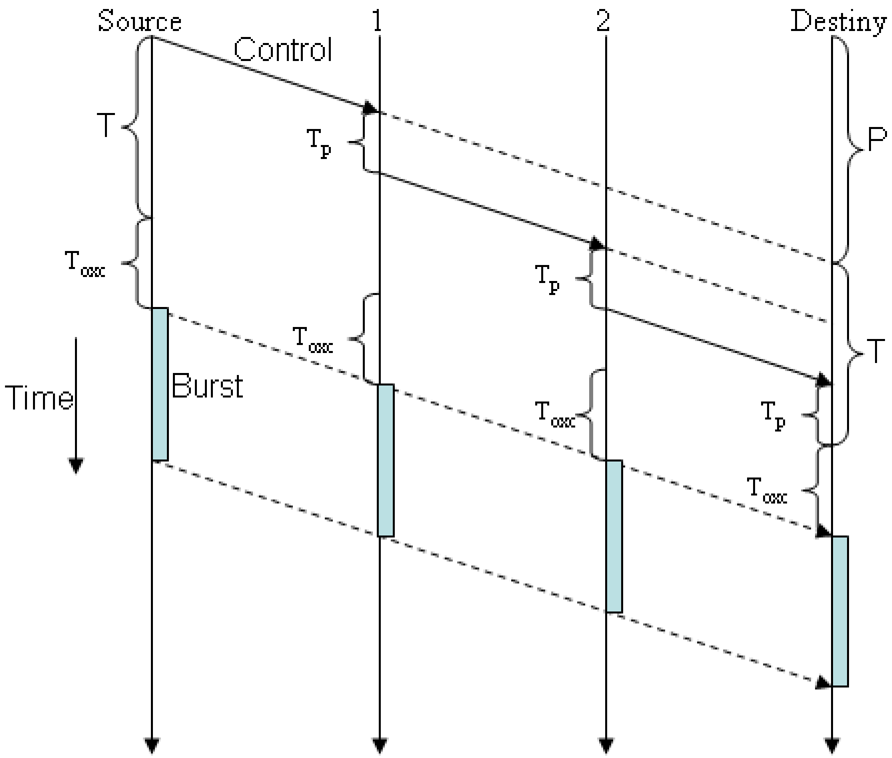

Figure 2.7 - JET signaling scheme flow.

Figure 2.7 presents the JET scheme packet flow. The JET reservation scheme starts with the Control Packet transmission by the source node. All the intervenient nodes electrically process the Control Packet to establish an all-optical path for the Burst transmission. The information contained in the Control Packet is used to select the appropriate wavelength on the outgoing fiber, reserve the necessary bandwidth and sets up the optical switch. The Burst and the Control Packet are transmitted on the same path using different wavelengths, (out of band signaling). During the reservation process, the source node retains the Burst at an electric buffer.

Offset Time

The offset time is used to guarantee that the Burst is transmitted on the optical domain without any delay along the entire path. It is used to the give enough time to the node reconfiguration before the burst arrive.

In TAG based reservation schemes (Optical or Photonic Packet Switching) the burst is transmitted by the source node with the Control Packet without using any offset time. In this case at each intermediate node, the DB waits for the networks reconfiguration and both are transmitted to the next node without use of any offset time. With this technique the Data Burst and the Control Packet are delayed at each node Δ time units. Δ is the processing time used by the nodes reservation.

In JET schemes a simple way to represent the offset time T is $T_p \times H$, where T_p is the Control Packet processing time at each node, and H is the number of hops used by the Burst to connect the source to the end node. This technique guarantees that the offset time is enough to the burst arrive at each node after it is prepared to transmit it in the optical domain without the use of any optical buffer.

The T_p, above referred as processing time is more than the time used by the node to process the Control Packet, it is also the time used to initiate other operations, such as switching settings. After processing the Control Packet, it is transmitted to the next node while the node initiates the configuration process.

Delayed Reservation for efficient Bandwidth utilization

The delayed reservation is useful for an efficient bandwidth usage. In TAG based schemes, the bandwidth is allocated since the node finish the Control Packet processing, while in JET the bandwidth can be allocated using the same technique, or using Delayed Reservation (DR) for a better use of the bandwidth resource. Figure 2.8 illustrates this process.

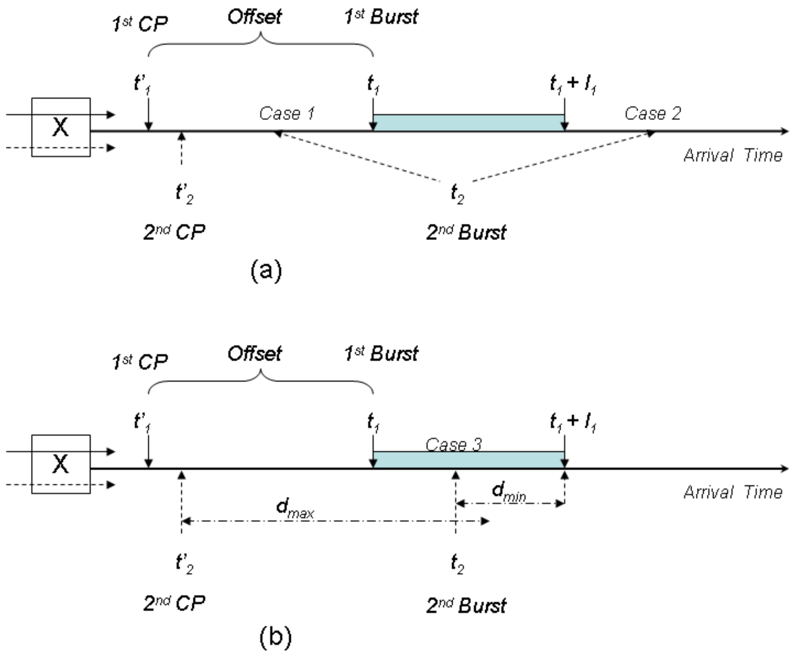

Figure 2.8 – An example of the Delayed Reservation and its usefulness with or without buffer [1].

In JET, the bandwidth allocation is made based on the burst duration. In Figure 2.8 (a) the 1^{st} *Burst* duration is represented from t_1 to t_1+l_1, where t_1 is the time when the burst starts, and l_1 is the burst duration. Reserving the wavelength only for the burst duration reduces the burst drop probability.

Because the Control Packet processing time might be different at each node, the offset time can be updated at each node, and used by the following node.

In the Figure 2.8 (a) it is considered that the burst duration is already known. In JIT when the burst length is unknown, the source node delays the CP until it receives the entire Burst from the attached networks, or until a certain length is reached.

In order to reduce the burst pre-transmission latency, the CP is transmitted as soon as possible using an estimation of the burst length. If it is an over-estimation, another Control Packet is transmitted to release the extra bandwidth reserved. If it is under-estimation, then the remaining data is transmitted in one additional burst. The JET bandwidth reservation can also be made to the infinite, and use an explicit relise packet when the transmission session ends and the circuits are no more needed [1].

2.8.2. Just-In-Time reservation scheme

The Just In Time (JIT) OBS signaling scheme is an immediate reservation scheme [26][27]. In the immediate reservation an output wavelength is reserved for the burst transmission just after the Control Packet arrival (see Figure 2.9); if a wavelength cannot be reserved at that time, then the Control message is rejected and the corresponding burst is dropped.

Figure 2.9 presents the JIT-OBS reservation process. The reservation process, start with the source sending a Control Packet with the reservation requirements along the used path. When a node receives the CP, after processing it, forward the CP to the next node until the Control reaches the end node. When a OXCs receive the CP start immediately the reconfiguration process. This is one of the differences between JIT and JET, where the wavelength reservation is delayed to waste the less bandwidth as possible. When the CP reaches the end node, it sends a Connect message along the reverse path to inform the source node that the CP reaches its destiny. After the source node waits an offset time (*T*), and configures itself for the burst, it starts the DB transmission. The OXC resources release is performed by a release message that the source node transmits along the path when the burst transmission end. When the release message is received by a node the used wavelength is released.

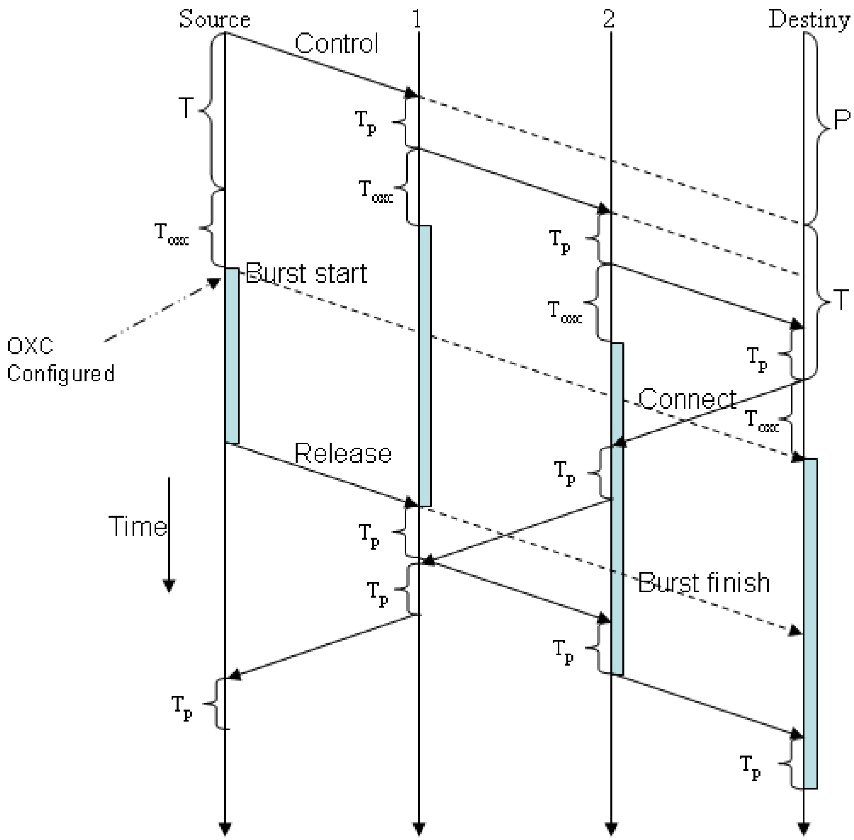

Figure 2.9 – JIT signaling scheme flow

The wavelength release is another difference between the JIT and JET. In JET the release is normally programmed, when the reservation timer finishes the wavelength is released, while in the JIT, the wavelength is released using an explicit release message transmitted by the source node.

Another immediate reservation representation performed by JIT is represented by Figure 2.10. Figure 2.10 presents two bursts reserved in a single wavelength. There are two states, reserved or free, after the node receives the setup message (Figure 2.9 Control message) and reconfigure itself, the wavelength status pass automatically from free to reserved, and just after receiving the release message, the wavelength status pass to free again. In Figure 2.10 the wavelength is reserved between t_1 and t_3 and between t_4 and t_6, corresponding to the bursts *i* and *i+1* transmission. The reservation process is a First Come First Served (FCFS); the burst is dropped when the new reservation time is in a wavelength time slot already reserved.

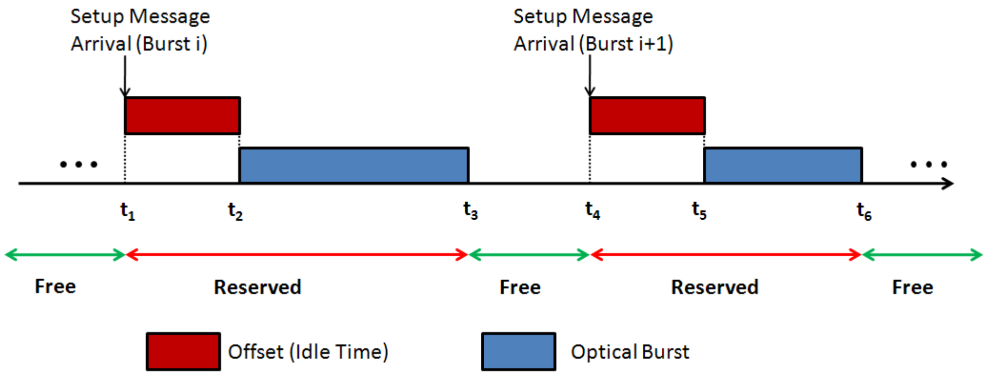

Figure 2.10 - An operation example of the immediate reservation performed by JIT [27].

In JIT-OBS, the DB is electrically buffered at the source node where the electric memory is abundant and cheap, rather than at the intermediate nodes where optical delay is limited and expensive. JIT signaling also provide a best-effort explicit acknowledge of end-to-end path setup [27].

Signaling scenarios

Signaling messages exchange using the JIT protocol may create several signaling scenarios. The JIT connection request may succeed end-to-end or it may fail due to connection request rejection or the signaling message lost. The resources unavailability on the outgoing channel in the intermediate nodes is the most common reason for rejecting a JIT setup request, resulting in burst drop. In [26] are explored several possible connection scenarios for a JIT signaling protocol, successful connection establishment, connection teardown, connection failure due to request rejection and connection failure due to message lost.

The successful connection is a scenario where the Data Burst reaches the end node without any problem. The Data Burst is transmitted estimating the transmission time using the estimated feedback and the used wavelength received from the second node, with this feedback information and the output wavelength (also received from the second node), the source node choose the right time to start the DB transmission. When the end node receives the setup message, it informs the source node that the path was successfully configured using the Connect message.

The connection teardown is processed after receive the release message transmitted by the source node just after finishing the burst transmission. When the resources are successfully tear down, the node transmits for the previous node a packet informing a successful tear down.

When the setup packet does not reach the end node, the burst is drooped. In this case, the node is unable to continue the circuit transmits in the reverse path a release packet. The source node start the burst transmission using the estimated delay, when the burst is transmitted before it receives the realise message, the data is dropped when reaches the node unable to retransmit the setup. When the source node receives the release packet it can retry the connection or abort the connection request.

The connection failure due to message lost occur when the setup packet is lost in a link between two nodes or one of the signaling agents has crashed and is unable to respond. If this occurs after the second node, the start node receives the packet with the necessary information used to start the burst transmission. In this case, the DB is transmitted and dropped on the unconfigured node. Eventually the source node detects that it did not receives the Connect message from the end node it start the network resources release transmitting along the path a Release Comp. Again there is no automatic recovery support from the signaling protocol, and it is the source node that select retry or abort the connection.

2.9. OBS Applications

Before the OBS technology development, burst switching concept had been proposed as an extension of packet switching. Basic advantages present in burst switching are reducing loop length and increasing data rate transmission [28]. OBS networks are a burst switching extension for optical networks. The main motivation for the OBS creation is to reduce (or even eliminate) the need of optical buffering, as well as minimizing the network overhead [5].

One application is distributed database, where OBS can achieve efficiently assemble data and path setup while the network overhead is reduced.

Another attractive area where OBS has been considered as an effective underlying technology is Grid Computing as a mean of providing global distributed computing for applications with large bandwidth, storage and computational requirements

2.10. Chapter summary

In this chapter an overview about the OBS technology was presented. OBS networks are an appropriate technology to use in long haull networks with limited delay requirements. An advantage of OBS is the out-of-band signaling. Using the out-of-band signaling it is guaranteed that the Control Packets reach the end node even when the data channels are strangled. In OBS networks, Burst Control Packets is transmitted in advance to prepare the network resources for the Data Bursts transmission. Usually OBS networks use one-way reservation schemes, which the drawback of OBS technology, because the DBs are transmitted without knowing that the path were successfully reserved. The One way reservation protocol does not present only disadvantages, this technique allow lower networks setup latency.

Chapter 3. Grid over OBS network architectures

3.1. Introduction

In this chapter Grid over OBS (GOBS) are introduced. First, Grid networks functions and architecture are presented followed by the introduction of Grid over OBS networks.

3.2. Grid

A Grid network is a flexible and distributed information technology environment that enables the creation of multiple services with a significant degree of independence from the specific attributes of underlying support infrastructure [29].

Initially, Grid infrastructures where designed to support and compute intense science projects. With the technological evolution, nowadays, Grids support several different services with an abstraction level that make possible support an almost unlimited number of services without the dependencies restrictions inherent to the delivery mechanisms, local sites or particular devices.

3.2.1. Grid networks attributes

The Grid network attributes are used to guarantee that the network resources are closely integrated in the Grid environment. The attributes are the following [29]:

Abstraction- One of the most important Grid features is the abstraction capability to underlying resources and integrates Grid capabilities to support customized services. Grid architectural model presupposes an environment in which available modular resources can be detected, gathered and utilized without any restriction imposed by low level infrastructures.

This architecture does not specify the possible resources complete details; it describes the classes of Grid Components requirements.

Resources virtualization is a powerful tool for creating advanced data network services. The major advantage to the Grid Network virtualization through abstraction techniques is increase the flexibility in service creation, provisioning and differentiation. It allows specific application requirements to be more directly matched with network resources. Virtualization also enables networks with very different characteristic to be implemented within a common infrastructure, and enables network processes and resources to be integrated directly with other types of Grid Resources.

Using high-level abstraction for network services and integrating network capabilities through Grid middleware provides to Grid Computing flexibility that it is not possible to achieve with traditional data networks. Traditional data networks support only a limited range of services, because they are based on rigid infrastructure and topologies, with restricted abstraction capabilities.

Resource sharing- The entities responsible to Grid Networks development are engaged to implement Grid infrastructures software with web services components. The Web service components have the function to enable the access to sets of building block that can be combined easily into different services combination. One example of this is the Web Service Resource Framework (WSRF) created by the Global Grid Forum (GGF) [30].

Flexibility through programmability- The programmability provides a more flexible environment to Grid networks. Only recently the flexibility became a Grid network characteristic, because previously the network infrastructure was designed to support static services with fixed parameters. In the last few years, several initiatives to crate Gird architectures with a more flexible communication services were made. Using those methods, Grid networks can be provisioned as programmable, allowing dynamic services changing and resource allocation with dynamic reconfigurations.

Determinism in network services- Determinism is the ability to request and receive required resources and to define precisely matching service levels. The primary Grid network research goal is create more diverse communication services, including services that are more deterministic and adjustable, not only for the most commonly use. Deterministic networking is important to achieving optimal application performance and is also a technology that enables many classes of applications that cannot be supported through traditional QoS mechanisms. This capability includes mechanisms for requesting individual network services with specific set of attributes and when is required reconfigure the network resources to obtain those specific services.

Decentralized management and control- An important Grid environment capability is the decentralized control and resources management. This decentralization allows the resource provisioning, utilization and reconfiguration without the intersection of the centralized management or other authorities. Emerging Grid networking techniques define methods that provide determinism allowing applications to have precision control over network resource elements when required.

Dynamic integration- The Grid architecture was designed to allow an expansive set of resources to be integrated into a single, cohesive environment. The integration can be made in advance, usually is a challenge making the integration in architectures that require real time ad-hoc changes, because networks was not designed for dynamic reconfiguration. However new architectures and techniques enable communication services and network resources to be integrated with other Grid resources and continually changed dynamically.

Resource Sharing- The primary motivation for design and Grid architecture development is enhance the resource sharing capabilities, for example, spare computation cycles for multiple projects utilization [31]. The major advantage of Grid networks is the option provided for resource sharing, that are very difficult, if not impossible, to implement in traditional data networks. The networks resources virtualization allows the new Grid network to create resource sharing facilities that have not been possible to implement until recently.

Scalability- The scalability can be referred in many ways, the expansion over the geographical locations, enhanced performance, increase the number of services offered and the communities served, etc. By definition, Grid environments are highly distributed and therefore highly scalable geographically. Grid networks can be geographically extended since metro networks, passing trough regions or nations, but Grid networks can also be world-wide. The advanced Grid networks scalability has been tested by global science applications on high-performance international research and education. The scalability was tested at the infrastructure and service level.

High performance- Because many Grid applications are extremely resource intense, Grid networks requires extremely high-performance capabilities to support data-intensive flows that cannot be supported by traditional networks.

Security- Security has always been a high-priority requirement that has been continually addressed by Grid developers [32]. To guarantee that Grid networks are highly secure, new techniques are being produced. For example different types of segmentation techniques used for Grid network resources, especially at the physical level, allow high-security data traffic to be completely isolated from other types of traffic. Also recently new techniques of encrypting data ensure security levels difficult to obtain in traditional networks.

Pervasiveness- Grid environments are extensible to wide geographic areas, including distributed edge devices. Grid network services are designed for ubiquitous deployment, including as overlay services on flexible network infrastructure. Multiple research and development projects are focused on extending Grids using new types of edge technologies, such as wireless broadband and edge devices, including consumer products, mobile communication devices, sensors, instruments and specialized monitors.

Customization- New Grid architecture and methods provide the creation and implementation of multiple customized Grid communication services that can be implemented within a common infrastructure. Grid networks based on capabilities for adaptative services, resource abstraction, flexibility and programmability can be used to create many types of communication services that were not possible have in than traditional networks.

3.2.2. Grid standards

Several entities are responsible to develop standards for Grid networks. This section presents these entities Grid projects.

The Global Grid Forum (GGF) [30] is a company which the main objective is the Grid-related standards. The GGF is responsible for several highlighted documents, see [29].

One of the GGF highlighted documents is the Open Grid Services Architecture (OGSA) [33]. OGSA articulate eight categories of services (infrastructure, resources management, data, context, information, self-management, security services and execution management) used to obtain a shared, secure and dependable access to available Grid resources. WS-Agreement [34] is another GGF highlighted document WS-Agreement is a design pattern that defines how the service producer and the consumer can reach an agreement.

Several Grid vendors and customers have organized a consortium which considers the many facets of Grid adoption within an enterprise. The consortium is called Enterprise Grid Alliance (EGA) [29].

The World Wide Web Consortium (W3C) [35] is an entity responsible for specification, guidelines, software and tools used in the World Wide Web. W3C develop specifications like XML (Extensible Markup Language) [36], SOAP (Simple Object Access Protocol) [37] and WSDL (Web Services Description Language) [38] that are the foundation for Grid toolkits as well as other web services applications.

In IPSphere forum [39], network vendors and providers have converged to define an intercarrier automation tool for policy, provisioning and billing settlement. The IPSphere objective is search for strategies to resolve providers long standing difficulties in obtaining financial returns from QoS service classes stretching across multiple providers.

Other standards bodies such as: Message Passing Interface (MPI) Forum [40]; Distributed Management Task Force (DMTF); Common Information Model (CIM) [41] the International Telecommunication Union (ITU) [42] and the Institute of Electrical and Electronics Engineers (IEEE) [43] have also Grid projects.

3.3. Grid over OBS

OBS networks supporting Grid networks present several advantages, such as:

- Native mapping between burst and Grid jobs. OBS networks offered a bandwidth granularity that permit a efficient users jobs transmission with different traffic profiles;
- Data and control plain separation allow an all optical data transmission with ultra-fast user/application-initialized setup;

- The BCP electronic processing at each node which can enable the network infrastructure to offer Grid protocol layer functionalities (e.g. intelligent resource discovery and security).

3.3.1. Grid OBS network elements

Core OBS router: OBS relies on fast switching technology and a relatively slow setups times (milliseconds rather than nanoseconds). This setup time are small compared to the payload durations, normally hundreds of milliseconds or seconds.

The introduction of Grid services over OBS networks require some constrains for the switching speed requirements, which became particularly important when high speed transmissions are considered.

A flexible Grid network will require also to support user with small job requests. Small jobs (100 to 1000 bytes) require an ultra fast switching, in nanoseconds. It is particularly advantageous to use multicasting to enable parallel Grid processing services as well as the resource discovery [45]. For these reasons the fast switching technology deployment is essential for future high speed OBS networks with support for Grid applications. Grid Core OBS Routers require control information and BCP intelligent processing, which can only be performed using specially designed fast electronic circuits. Recent advances in the integrated circuits technology allow complicated processing of bursty data directly up to 10 Gbps [46].

High transmission rates used by the BCP and the control information enable transparency during the burst switching (i.e. no conversion to the electric domain). The optical bursts can be transmitted at ultrahigh bit rates (40 or 160Gb/s), providing by the switching elements that can support these bit rates. These high bitrates need fast active elements, like Semiconductor Optical Amplifier (SOA). The switching process consists in broadcasting the signal and selects the appropriate route using fast gating or converting the signal wavelength and routing to the appropriate passive routing device (Arrayed Waveguide Grating (AWG)) output port [44].

Fast switching allows efficient bandwidth utilization. Fast switching does not give any advantages when it used in long bursts, e.g. burst originated by large Grid clients. A proper solution for OBS networks is a fast and slow switching combination. For example the fast switching elements can be SOA-based switches and for the slow switching MEMS (Micro Electro Mechanical Systems)-based switches.

Optical Cross Connect (OXC) is a solution for the Grid Core OBS nodes. These OXCs have some output ports connected only to fast optical switch. Several OXCs and fast switched can be placed in a scalable wavelength modular architecture. A switch per input fiber is used to spare the wavelengths.

When a BCP arrives to the OXC, the control mechanism verifies the BCP type. If the BCP belongs to a long burst, the OXC is reconfigured and when the burst arrives is automatically routed to the appropriate output port. Otherwise if the BCP belongs to a short or active burst, the burst are directly routed to the fast switch port (through the predefined paths) and immediately switched to the next node. This set-up requires all the switching paths inside the OXC to be initially connected to the fast switching ports and is necessary to have special design concerns to avoid collisions [44]. This scheme reduces the requirements on fast switching and therefore only smaller and cost-efficient matrixes are required.

Figure 3.1 [29] presents the OBS core router discussed above, this architecture combine slow switching (OXC) with fast switching elements.

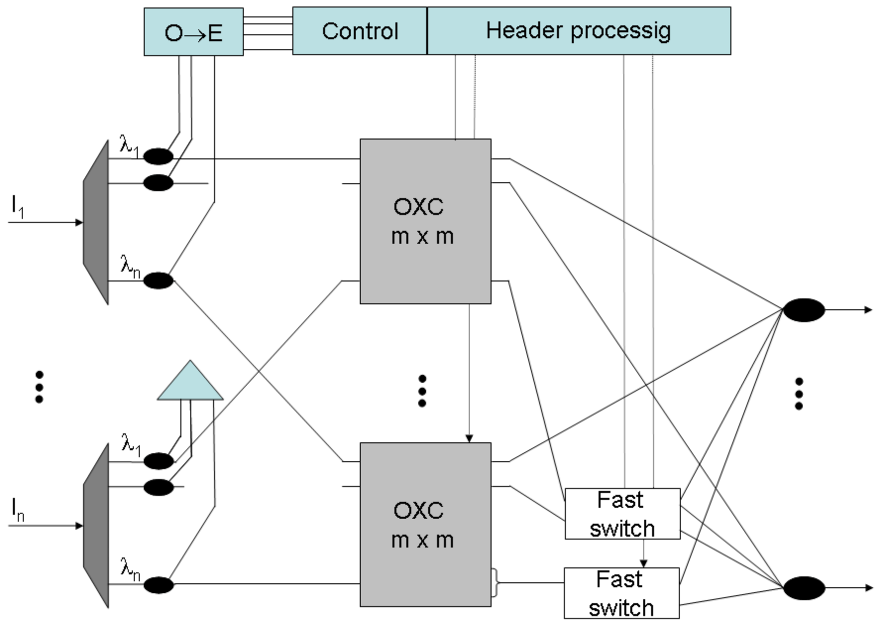

Figure 3.1- Core OBS router architecture that combines slow switching (OXCs) and fast switching elements [29].

Edge Grid-OBS router: the Edge node must be able to fulfill the Grid application requirements and use the OBS technology to efficiently use the network resources. The router architecture should introduce a mechanism able to process Grid-IP traffic for Grid Differentiated Services (GridDiffServ) provisioning and maps it onto optical burst [44].

An Edge Grid-OBS Router must be able to perform the follow functionalities:

- Grid Job Classification;
- Traffic aggregation and optical burst assembly;
- Optical burst transmission;
- Grid user to network as well as Grid resource to network signaling;

Grid Job Classification- The Edge OBS node at the job classification process must provide fair and specialized services (GridDiffServ). The Application performance and Grid network utilization can be enhanced by a combination of computational and network resources to user/application requirements. A flexible and scalable Grid job classifications mechanism process the jobs based on Grid requirements The jobs classification combines independently three parallel processing schemes, Network-oriented Classification Scheme, Grid Oriented Classification Scheme and Time Oriented Classification Scheme. These classifications schemes are all synchronized and are triggered only by Grid Job Requests. The job classification speed is vital for providing intelligent services the Edge Router. The classification process is complex and time consuming, efficient queuing schemes as well as wire speed classification became important factors to avoid buffers overflow at the Edge Routers [44].

Burst Aggregation- The burst aggregation features in the Grid-OBS Edge Routers are the same that are used by the OBS nodes. These features are discussed in the section 2.6 of this dissertation.

To facilitate the on demand access to Grid services is necessary to develop interoperable procedures between the Grid user and the optical network for agreement negotiation and Grid service activation. These processes constitute the Grid User Optical Network Interface (G-OUNI or GUNI). The G-OUNI functionalities and implementation will be influenced by the following parameters [44]:

- Service invocation scenarios: the request form the user can be from the optical network control plane either directly or through Grid middleware[47];

- Two-Optical transport format, which determines transmission format of the signaling and control messages as well as data from Grid user to optical network [29].

The main functionalities provided by the GUNI in a Grid over OBS network are the following:

- Flexible bandwidth allocation: the GUNI support various bandwidth services;
- Support for claiming existing agreements: GUNI must facilitate the incorporation of information that relates to an existing agreement. This covers the support of lambda time-sharing mechanism to facilitate bandwidth scheduling over a time slot for a Grid user/service (i.e. wavelength times sharing for an efficient and low cost bandwidth utilization). The GUNI signaling will also be required to bandwidths ownership support and the transport of authentication and authorization-related credentials;
- Automatic and timely lightpath setup: Grid user use the GUNI to automatically schedule, provisioning and setup ligthpaths across the network;
- Traffic classification, grooming, shaping and transmission entity construction: the GUNI must be able to at the transport layer (physical layer), map the data traffic to a Data Burst. In the in-band signaling, the GUNI provide a mapping mechanism for the control messages transmission.

In Grid networks, Grid resources (i.e. storage and processing) are geographically distributed along the networks. Grid Resources can dynamically enter and leave the OBS network based on pre-established agreements. These Grid resources are denominated Grid Resources Network Interfaces (GRNI). A dedicated signaling and control interface is used between the Grid resources and the Grid network. Like GUNI, the GRNI must perform interoperable procedures between external networks and the OBS networks. Unlike GUNI, the GRNI interfaces are placed between the resources (processing and/or storage distributed across the network) and the optical network. The similarity between these two elements (GUNI and GRNI) make possible extend the GUNI model to provide required functionalities for the resource network interface.

In Figure 3.2 present a Grid over OBS network with OBS routers. The OBS router can perform only the OBS functionalities or can perform the OBS functionalities and also Grid functionalities. The job resources are represented as GRNIs and the Grid users are represented as GUNIs. If a node can perform at the same time both functionalities is represented as GUNI/GRNI.

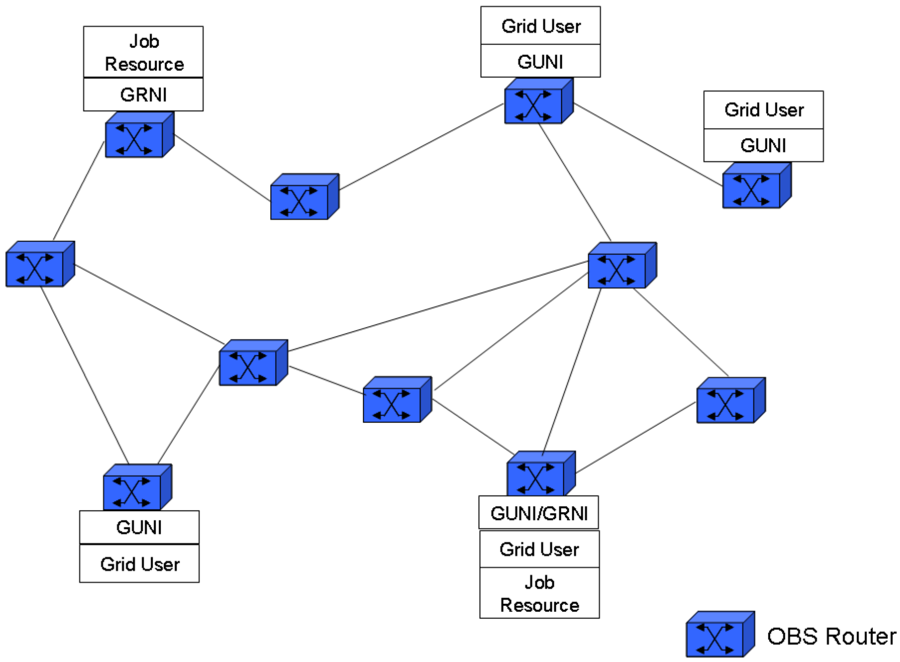

Figure 3.2- A Grid over OBS network example.

GRNI main functionalities are the following:

- Support for existing agreements;
- Job submission to local Grid Resources;
- Support for advance resource reservation schemes;
- Local resources propagation state (available storage / processing resources);
- Service related elements propagation;
- Sending back results to source or multiple alternative destinations.

GUNI and GRNI are related to Grid user or Grid resource. Their functionalities must be integrated at an Edge OBS Router device. The Edge OBS Router must be an agile and user controlled interface, able to map user traffic into the optical domain at sub-wavelength granularity (i.e. in the form of optical bursts) [44].

3.3.2. OBS for consumer Grid applications

The Optical Circuit Switching (OCS) is the network solution currently used. OCS networks are unsuited to provide Grid services. The dedicated infrastructures are wasteful and inflexible, while request/grant architectures with Grid resources electronic management are too complex. OBS is a possible technology to solve these problems because it is suitable to tasks with low processing, high resource utilization and simple control.

In OBS networks it is assumed that the shortest routing paths are used to minimize the end-to-end delay. However, such networks can be inefficient, since certain links might have a low usage, while others became severally congested, which leads to sub-optimal network performance. This is especially visible when the main metric is the burst dropping probability, as it is usual in OBS networks. The solution proposed to resolve this problem in OBS is deflection routing and multi-path routing, but in both cases, the sender and the receiver are usually known in the data transfer. In Grid OBS networks the destination is not always known.

In Grid consumer scenarios it does not matter where the job is processed. The same job may have several destinations. The user is only interested in the job being resolved respecting its requirements. This represents a shift in the nature of the employed routing algorithm, whereas previously bursts had an exact destination (unicast routing), in this scenario, the only requirement is the burst transmission to any node capable to resolve it, this strategy is named anycast routing [2][48][49].

When a node is not able to resolve a job, it require to Grid services to resolve the job and accelerate this process. Initially the job is transformed in an optical burst (DB), accomplished by a header (BCP) with various burst parameters, such as processing, storage and policy requirements. The burst parameters carried by the header are used for the network resources configuration. When a burst arrive to a router, it retransmit it on the fly to the next router based on the job header and on the network status information, until the job arrive to the node responsible to resolve it. The information used by the router to select the next node is for example the link load and blocking probability, delay requirements, estimated free computing storage capacity reached for a certain interface, estimated computing and storage requirements of the burst. Because the end node is unknown at the beginning, the Grid architecture need to be completely distributed, which implies better network scalability and robustness. The information use by the intermediate nodes to select the next one does not need to be very detailed. They do not need to know where the resources are located, or how much free resources have. They only need enough information to push the burst closer to a suitable destination.

Every intermediate node goes through the same process, and eventually when the burst arrive to the Grid resource, if it is able to resolve the burst it will process it. Otherwise, the burst is transmitted to the OBS network until it reach a Grid resource able to resolve it or the burst is dropped if exceed the useful time to be processed.

With the job resolved, the result returns to the source node. Because the node that starts the job is already known, the result is directly transmitted to the burst source node. The used path depends on various factors, for example, if is a real time job, the result is transmitted using the shortest time path possible, otherwise if is an offline, it can return to the source node using a longer path. The fact that from the source to the Grid resource is used anycast and in the reverse way the data is transmitted directly to the source node, this is an example of the asymmetry in Grid OBS consumer scenarios.

The Consumer Grid network robustness is usually measured in job blocking probability. The resources unavailability is the cause for dropping the jobs. The resources unavailability can be network resources (i.e. links and routers) or server resources (i.e. processing elements).

Robustness in the networks can be introduced using two methods:

- Spare capacity: before the deployment, the network is usually dimensioned based on the load estimation or experienced job requests. Once is necessary to introduce more network or resource servers, there are only introduced only the necessary ones;
- Duplicate submission: if the same job is transmitted to the network more than once, the possibility of it reaches different recourses, or the same recourse using different path is non-negligible. This method introduces robustness in Grid OBS networks. But use more capacity than the necessary.

The consumer Grid network must be able to support all application types, because is not economical create a Grid network for each application. A network that supports all applications types use different resource patterns to differentiate each one. The infrastructure should offer relatively simple components and sufficient flexibility to deploy new applications quickly and efficiently. It will also need to support traditional OBS users requiring a plain data transfer functionality, whereby the burst contain, for instance Grid Packets instated of Grid jobs [2].

The authors of [2] propose the following proprieties of the job-generation process in consumer Girds:

- A large number of jobs are generated;
- Each job have modest resource requirements;
- The job sizes are small, introducing small holding times compared to optical switching times;
- The job submission time and location are highly unpredictable. This result in frequent mismatches in available versus generated load.
- Several application types will be interactive in nature, indicating a strict deadline must be met for a successful completion. While other have a less restrict requirements. This means that are considered several QoS classes.

3.4. Chapter summary

This chapter presents an overview of Grid networks, and Grid over OBS networks features. Grids provide computational distributed resources (storage and processing). Grid over OBS networks extend the Grid functionalities to an OBS network, using the OBS network to resolve the Grid jobs Recently the Grid features were extended to commercial applications, which require low computational resources. In a GOBS consumer scenario, the OBS network is used to provide a Grid resource to resolve the consumer jobs. The consumer jobs require low computational resources and usually have small durations. The work presented in this master dissertation is based on a GOBS consumer scenario.

Chapter 4. Grid over OBS network architecture using Active Routers

4.1. Introduction

Optical network resources reservation is a complex process that usually involves several entities cooperation.

The problem of offering optical network resources as Grid services has been considered in [54]. Where three different approaches have being proposed:

a) the Grid management and the optical-layer resources are considered separately using an overlay model;
b) extended model where the optical control plane integrates Grid resources provisioning;
c) and OBS network that use Active OBS Routers

The work presented in this dissertation considers a Grid over OBS network employing Active Routers.

4.2. Active OBS infrastructure for Grids

The networks proposed by [2] and [50] are an OBS network architecture composed by Active and non Active OBS Routers. The non Active Routers are conventional OBS routers and perform burst forwarding according to the information contained in the BCP. The Active Routers intercept the data carried by the Active Packets, which packets specific of Grid applications and perform dedicated Grid networking functions. In a Grid over OBS network with Active Routers, both traditional data and Grid traffic are supported. All OBS nodes can perform burst forwarding when the normal traffic transits across the network while the Grid traffic is supported by the Active Routers.

The network topology represented in the Figure 4.1 is very similar to the one proposed by [2] and [50], a network with conventional OBS Routers and Active OBS Routers. Each Active OBS Router is responsible for one Active region having the complete knowledge of the region topology and all nodes and links actual status. The Active Router is also responsible for the Grid resource discovery. Grid users can be Grid resource users with a Grid User Network Interface (GUNI). Grid resource providers with a Grid Resource Network Interface (GRNI) or users with both GUNI and GRNI interfaces can perform both functionalities.

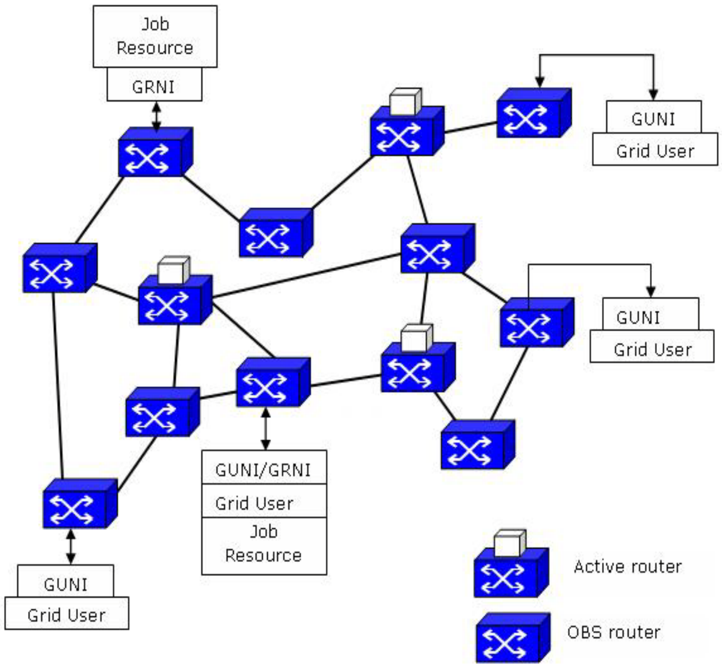

Figure 4.1 - Active OBS network topology for Grid services.

Signaling scheme in the Figure 4.2 present the signaling scenario proposed by [2] and [50]. This strategy is based in the JET OBS signaling scheme. The JET reservation scheme is the most appropriate protocol for the Grid Architecture employing Active Routers [51], because with JET, the resources are reserved just before the DB arrive and only for its duration.

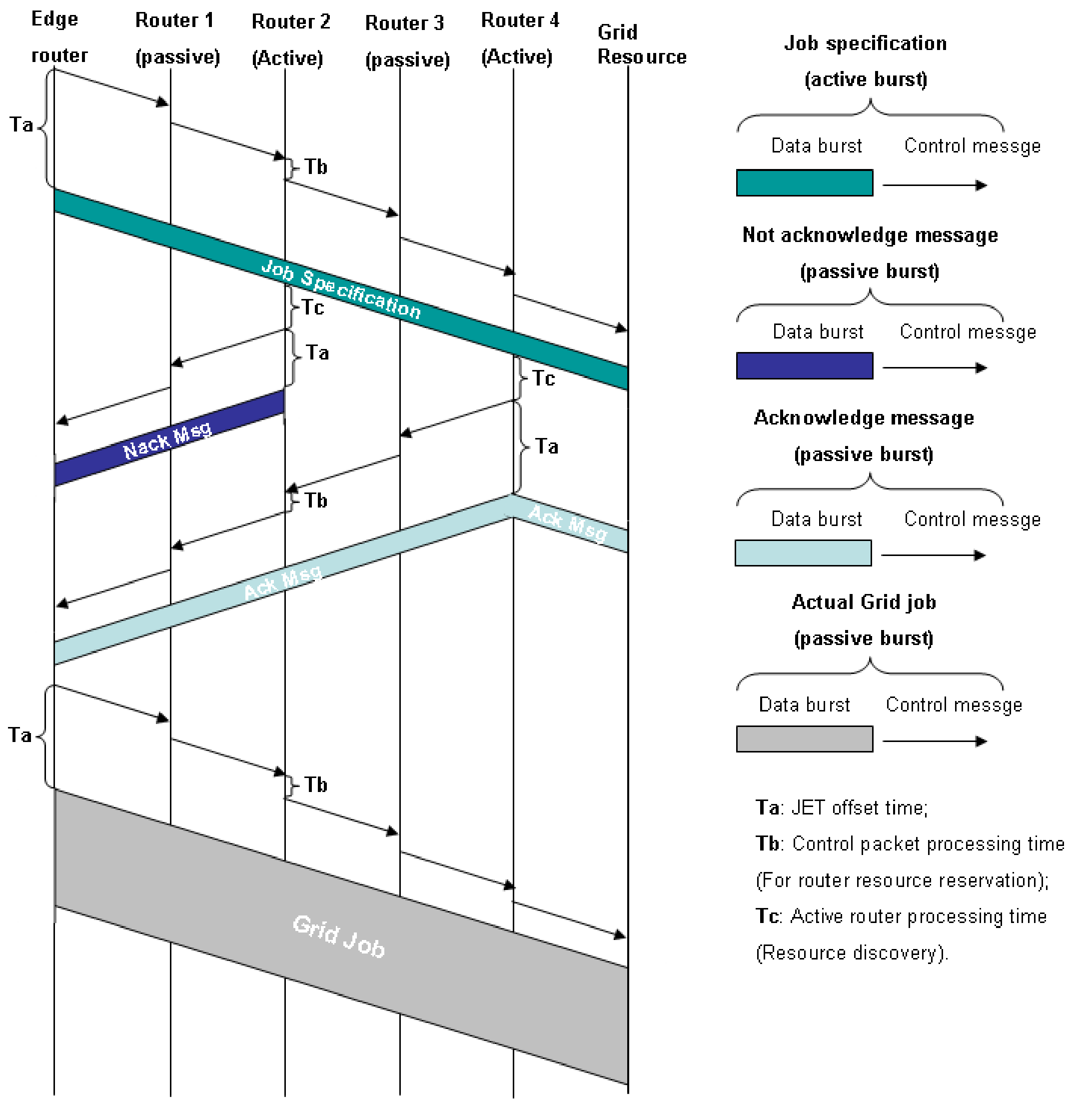

Figure 4.2 - Grid resource request and Grid job submission process based in JET in a GOBS network employing Active Routers [2][50].

In this scheme the data is transmitted in two stages, the active stage (control info/job specification) and non-active stage (user data/actual job), as represented in the Figure 4.3.

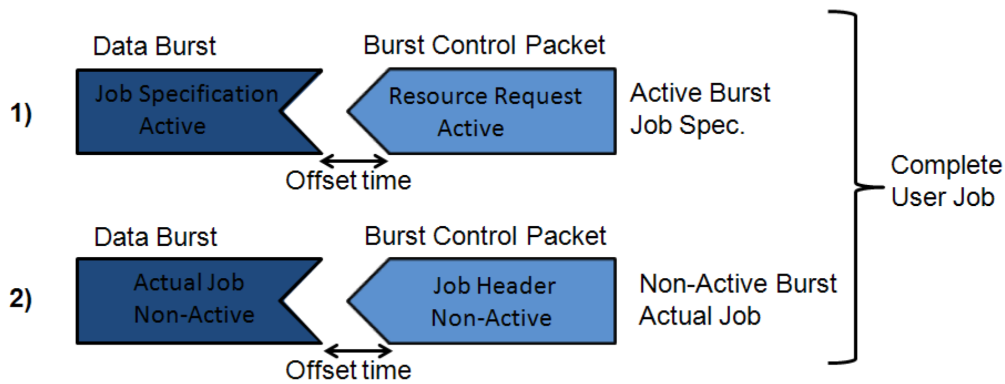

Figure 4.3 - A complete Grid job comprises the job-specification burst (active) and the actual job burst (non-active) [2][50].

The user sends to the Edge Router a request containing information about the Grid job specification and the resource requirements. The Edge Router constructs the Active Burst Control Packet (se Figure 4.3-1) and transmits it. The Active Burst Control Packet is processed at the Active Routers. Once the Active Router receives the Grid job specification it starts the resource discovery algorithm to find out whether there are enough Grid Resources available in its Active domain able to perform the required job.

The users are informed about the resource discovery process by an Acknowledgement if exists a resource able to resolve the job, otherwise a Non Acknowledgement is transmitted.

This signaling reservation scheme consists of two steps as indicated in Figure 4.2:

1. A BCP Active Burst is transmitted to all Active Routers through intermediate nodes (active and non active). The BCP is transmitted to the network an offset time before the DB transmission. At each Active Router, resource discovery algorithm results in the creation of an Acknowledgement (Ack) or a Non Acknowledge (Nack). These messages are transmitted back to the user after through a non-active optical burst. If a positive Acknowledgement is transmitted, the Active OBS Router informs the corresponding resource manager. From this moment the resource manager reserves the resource for a limited period of time.
2. After receiving all the Ack or Nack messages, the source node select one or multiple appropriate destinations among all the available. The actual job is now transmitted within the reservation period to the destination using a non active optical burst format.

This scenario provides high bandwidth utilization, especially when large bursts need to be transmitted, because the data is only transmitted though the networks after the resources have being reserved. Stages networking scheme offers an intelligent and user controlled Grid resource utilization through the active OBS stage, while in the non active OBS stage the Grid is established instantly after the resource discovery process. It also provide a secure and policy based Grid environment where the users can select the Grid resource in different domains across the network. One important advantage is that, after the resource discovery, there is no more delay associated to the wavelength path setup.

4.3. Active OBS Routers

Active OBS Routers are able to analyze data traveling through the network at the wire speed. The use of Network Processors (NPs) is a usual strategy in the Active Routers architecture. In [2] the Active Routers are used for an efficient routing of the Grid jobs according to their specifications using high performance NPs. The NPs are capable of executing specific processing functions on data contained within Active Bursts at line rates (for example Grid resource-discovery algorithms). Active OBS Routers are key enablers for the support of user-controlled networking functionalities, such as QoS provisioning, reliable multicasting and constrained base routing.

In Active Grid network environments, multicasting perform an important role, where interactive and distributed applications are deployed. A reliable and scalable multicast framework is deployed, in order to minimize the traffic load across the network and also to reduce the recovery latency [52].

In Figure 4.4 is presented an Active OBS Router architecture based on a scalable switching fabric which connects the physical link through the Active Router Interface. The Active Router presented consists of the following blocks; the physical link is splited in two parts, the active (upper arm) and the non active (lower arm). In the non active, the data remains in the optical domain and is transmitted to the switch. While in the active part, the data is converted from optic to electric. The active port process and classify the bursts, update the queue scheduler and transmits the information to the electronic interface. The electric interface connects the active port as the switch controller configures the switch ports.

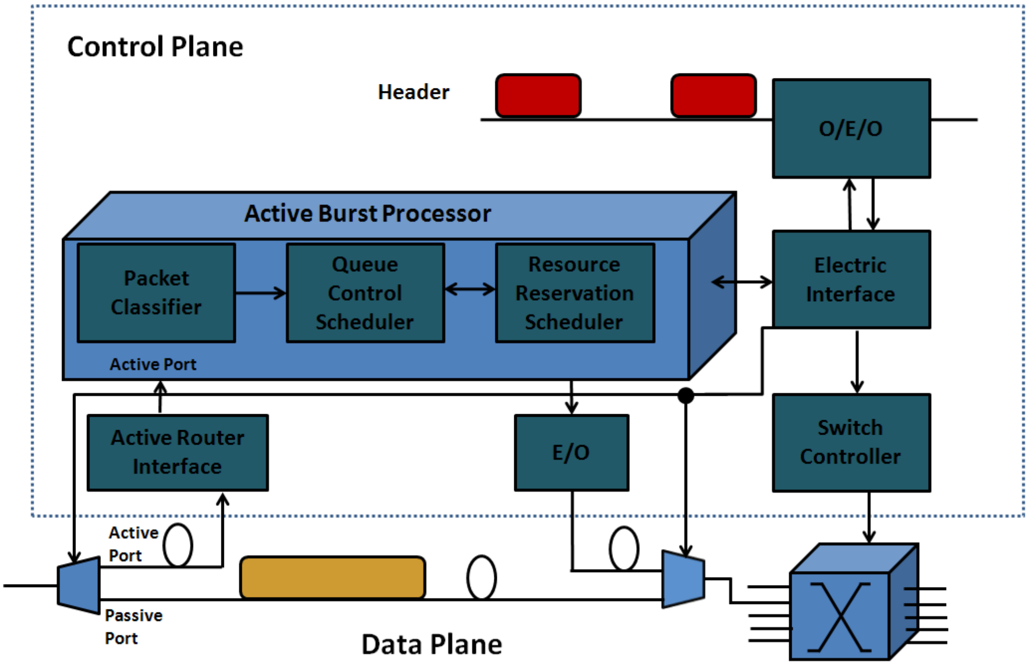

Figure 4.4- A generic model for an Active OBS Router [50].

4.3.1. Resource discovery mechanisms

The resource discovery and allocation is facilitated by Grid job classification mechanisms. The active bursts contain the information used to determine the jobs requirements. The classification triggers the Active Routers intelligent mechanisms (job scheduling, queuing and resource discovery), for GridDiffServ provisioning. The Grid job parameters that mostly affect the resource discovery are the resource requirements, parallelism and priority.

The resource requirements are the period of time and the speed that the job requires to be processed. The job requirements also identify the type of resource (storage or processing) to be allocated and efficiently serve these demands.

Parallelism determines the types of applications program and data. Each application type has different requirements for optimal performance. Granularity and communications frequency between these programs specifies the nature of application distribution approach is affected by the applications programs dependency [53].

Priority is photonic Grid networks is considerably different than the priority concept in traditional photonic networks. For example, the requests made by resource members have always higher priority than the ones performed by non-members. The requests with less priority are made by unauthorized users. Priority triggers the Grid authorization policies and prompts the scheduler to decide on appropriate resources for efficient resource reservation and allocation.

This classification schemes can significantly improve the performance by scaling the applications out to as many resources on the Grid. Class of service ensures that the resources are optimally matched to applications needs and thus improve Grid and network performance. The class ID takes account the Gird job parameters (resource requirements, parallelism and priority) and drives the subsequent processes for GridDiffServ provisioning [50].

The burst classification speed is vital for provisioning an intelligent service at the router level. Lack of wire speed classification will result in queuing active bursts before they are processed. Important traffic will be dropped, or unfair queuing will occur [54].

4.4. Chapter summary

This chapter presents the Grid over OBS networks employing Active Router and the signaling performed for these networks.

The final section of this chapter was dedicated to resource discovery, which is one of the Active Routers functions.

Chapter 5. Proposed signaling reservation schemes for Grid over OBS

5.1. Introduction

This chapter describes the signaling scheme proposed in this work. The application scenario considered is a Grid over OBS network with Active Routers. The signaling scheme is a centrally controlled Wavelength Routed – Optical Burst Switching (WR-OBS) scheme, where the Active Router acts as the control node [63][64].

In order to clarify the operation of the proposed scheme, it is compared with a JET-OBS modified version. The JET-OBS modified version is an adaption of the usual JET (see section 2.8.1) for a Grid over OBS network controlled by Active Routers.

5.2. Signaling Scheme description

Dynamic connections request in the WR-OBS networks can be handled in a distributed or centralized way. In the centralized manner, the network information is available at a single point in the network and the lightpath establishment is made in a more efficient way, as long at the optical networks remain small, this is because large networks create a great quantity of information to be processed in a single point. However, either in the centralized or distributed control, the ability to update global network information about link connectivity and wavelength availability is very important.

In a centralized WR-OBS, the control node is responsible for setup and tear down its administrative domain lightpaths. In the WR-OBS, the central node selects the best path for each job using its full knowledge about the network link state. In the proposed WR-OBS scheme, the central control is performed by an Active Router with its Active Region global knowledge (networks connectivity, links and nodes status). The Active Router correlates all that information to select the best Grid job Provider and the best path to reach it.

5.2.1. Packet description

The proposed signaling scheme is composed by three basic signaling control packets, the *BCP*$_A$, *OXC_config* and *ACK*. Figure 5.1 illustrates the packet fields structure. The *Control Packet*, Figure 5.1 (a), is the reference packet with general fields used by *BCP*$_A$, *OXC_config* and *ACK* that are encapsulated in the *Information Field*.

In Figure 5.1 (a), the *BCP TYPE* is used to identify which packet type is encapsulated in the *Control Packet* (*BCP*$_A$, *OXC_config* and *ACK*), the Time To Live (TTL) field represent the maximum number of hops, this field is used to guarantee that the packets do not travel in the network to the infinity wasting networks recourses. *CHEK SUM* is used to verify the packet integrity after the transmission and the *FRAMING HEADER* contains information like the source node, which wavelength is used, etc.

BCP$_A$, Figure 5.1 (b), is the Control Packet description; it is used by the source node to request to the Active Router a Grid job resource and the best path to reach it. The *Message ID* and *Job ID* are used to identify the message and the job (this fields are used by the routers to avoid processing the same packet more than once). *Source* is the source node identification; *Duration* is the time that the network resource needs to be reserved for this specific job and the *Class of Service* is used to classify the job in terms of class. The class classification enables attribute QoS levels to the network.

Figure 5.1 (c) illustrates the *OXC_config* structure. This packet is used by the Active Router to configure the nodes and reserve the wavelength along the used path. *Destination*, *Job ID* and *Duration* fields have the same functionality that in the *BCP*$_A$ packet. The *Ingress Port* and *Egress Port* fields are filed with respectively the ingress and egress ports that will be reserved for the respective this job, the *wavelength* is the wavelength used by the job along the path. In this scheme is considered a non wavelength conversion strategy, when the chosen wavelength is not free along the path, the job is dropped. The *Offset* is the compensation time used by the start node. This offset is used to avoid that the node is not prepared for the job, this OBS network characteristic is explained with more detail in section 2.5.

The *ACK* is represented in Figure 5.1 (d). This packet has the same fields as the *OXC_config* plus one, the *Job resource*, contains the places where the job is resolved, this message is used to inform the source node where job is resolved and which path is used to reach it.

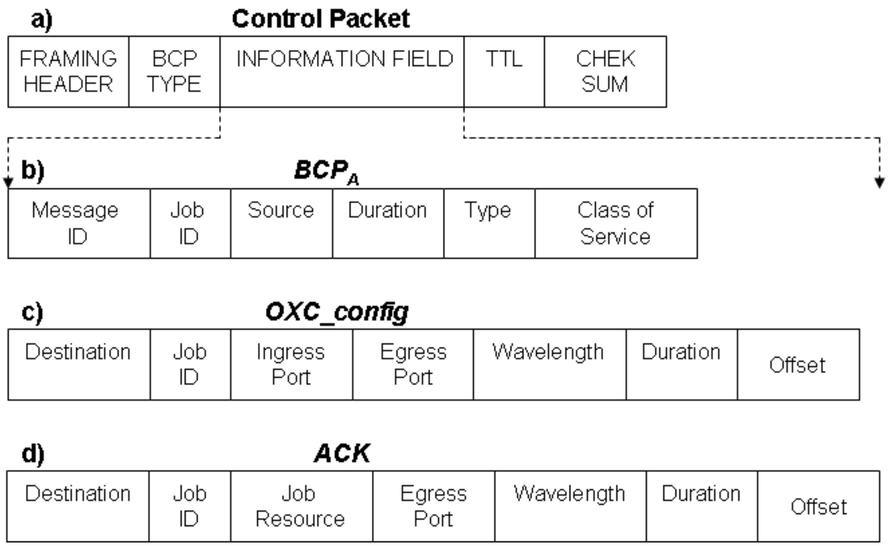

Figure 5.1- Generic framing structure of the control packet. (a) generic control packet, (b) active BCP, (c) BCP for OXC configuration and (d) BCP ACK.

The signaling scheme starts with the GUNI transmitting to the Active Router a Grid request (BCP_A) to initiate a Grid job request. The Active router sends the *OXC_config* to the nodes where the burst is route to enable the reconfiguration of the OXC switching matrix. *ACK* is created and transmitted to the Grid client when the Grid resource is discovered, informing the used Grid Job resource. The Signaling Control Packet have a variable length generated randomly, therefore a framing header is necessary.

5.2.2. Resource reservation

The resource reservation is performed by the Active router as illustrated in Figure 5.2. In this example there is only a Grid Resource and a single Grid User. The Grid Resource is able to resolve all the Grid requests performed by the Grid User. The passive routers do not generate Grid traffic.

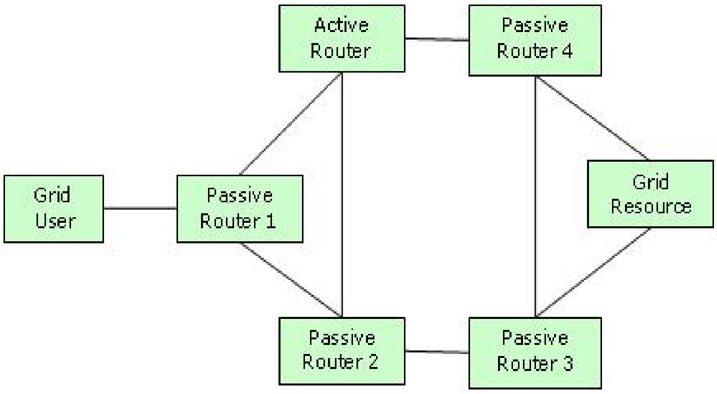

Figure 5.2- Example of a simple mesh active domain network.

In traditional OBS networks, the BCP contains the path used by the signaling and the data, in this scheme this path is selected by the Active Router. Like the OBS, this scheme use out of band signaling.

The passive OBS routers have the knowledge about the network connectivity, and the local wavelength usage on its outgoing links also known. Although, they can compute explicit link disjoint paths between each network node pair, they may not be able to set a lightpath since they do not have information about the wavelength usage of the overall network.

5.2.3. Grid job request and Grid assignment

In a highly dynamic environment is possible that a Grid user sends a job request to the network without being registered in the network and therefore without knowing the Active Router location. To accommodate this situation the BCP_A is broadcasted to the network.

To avoid the signaling switching loops and the network signaling flooding each BCP_A have a unique ID (identification) field and a TTL field. With the unique ID it is guaranteed that the packet is processed by each node only once and the TTL ensure that the packet is discharged if the packet does not reach the Active Router after a given time.

Considering the network in the Figure 5.2 it can be explained how the ID and the TTL field are used to avoid signaling switching loops and *BCP's* flooding. Consider that the Grid User initiates a Grid request broadcasting the BCP_A to the network.

The Passive Router 1, upon receiving the BCP_A proceeds as follows:

1. Identifies that it is an Active BCP_A;

2. Verify if it is the first time that this BCP_A passes through it;
3. Verify the TTL field;
4. If the steps 2 and 3 are valid then broadcast the BCP_A to the network.

The proposed scheme differs from the one proposed by [2][50] in two ways. First the job specifications are transmitted inside the Active BCP frame, while in [2][50] the job specifications are transmitted in the data burst transmitted after a JET offset time. The second difference is that in the proposed scheme the Active Router manage the Grid resources as well as the network resources, while in [2][50] the Active Router only perform as a Grid Resource finder.

If a Grid resource that satisfy the client requirements is found, and there is network transmission resources (wavelengths channels) availability to the Grid User reach the Grid Resource, the Active Router sends an *ACK* packet to the source node using the shortest path.

5.2.4. Signaling flow

This section presents the signaling messages flow in the WR-OBS proposed scheme and the most common signaling strategy used in OBS networks, JET-OBS. The JET-OBS presented is an adaption of the usual JET (see section 2.8.1) to work in a Grid over OBS network controlled by an Active Router.

Proposed WR-OBS strategy

Considering the network topology in Figure 5.2 and the Figure 5.3 which presents the time scale of a job request from the Grid User to the Grid resource, the path selected by the Active Router to satisfy this job is *Grid User→ Passive Router 1 → Active Router → Passive Router 4 → Grid resource.*

The reservation process starts with the *Grid User* broadcasting to the network the *BCP* packet until it reach the Active Router. This packet is broadcasted by every node until it reach is destiny. When the Active Router receives the *BCP*, it processes it, and with its information (i.e. job requirements) selects the *Grid Resource* and the appropriate path to connect the *Grid User* to the *Grid Resource*. After this the reservation process starts, the *Active Router* send to the routers that participate in the transmission an *OXC_config* packet, with the necessary information (wavelength, duration, offset, ingress port and egress port) in order to the routers be able to forward the burst when it arrive. The *Offset* indicates the time that the node waits since it receives the *OXC_Config* message until it starts the OXC reconfiguration. During the Offset time (T_{offset}), if necessary, the OXC can be used by other lightpaths. Beside the intervenient nodes configuration, the *Grid User* will also be configured using an *ACK* CP that the *Active Router* sends to the *Grid User*. All the packets used for configuration are transmitted by the *Active Router* using the shortest paths, in this way the reservation process is performed as fastest as possible.

The reconfiguration process is performed only if exists enough resources. In this case the *Active Router* send a negative *ACK* to the *Grid User* informing it about the unavailability of resources to satisfy the job, in this scenario, the job is dropped by the Grid User.

The Figure 5.4 shows the JET-OBS schemes packets flow representation used by this dissertation to compare with the WR-OBS performance. This scheme is a JET adaption to operate in a GOBS network with *Active Routers*. In this scheme, the *Active Router* is only responsibility to select the Job Resource used to satisfy the job. This feature is illustrated in the beginning of the timescale presented by the Figure 5.4 with the *Grid User* sending a *BCP* to the *Active Router*. When the Active Router receives the *BCP* packet it selects the *Grid Resource* based in the job specification. The Active Router send an *ACK CP* to the *Grid user* informing the *Grid Resource* location, if exists a Grid Resource able to satisfy the jobs. Otherwise, the Active Router informs the resource unavailability to the source node using a negative ACK. Once the information about the *Grid Resource* arrives to the *Grid User*, it selects the best path to reach the *Grid Resource* and transmit the *BCP* along the path. The *BCP* and *Grid Job* are transmitted along the same path. The Grid job is transmitted after waiting the enough time to guarantee that the BCP already reserve the network resources along the path.

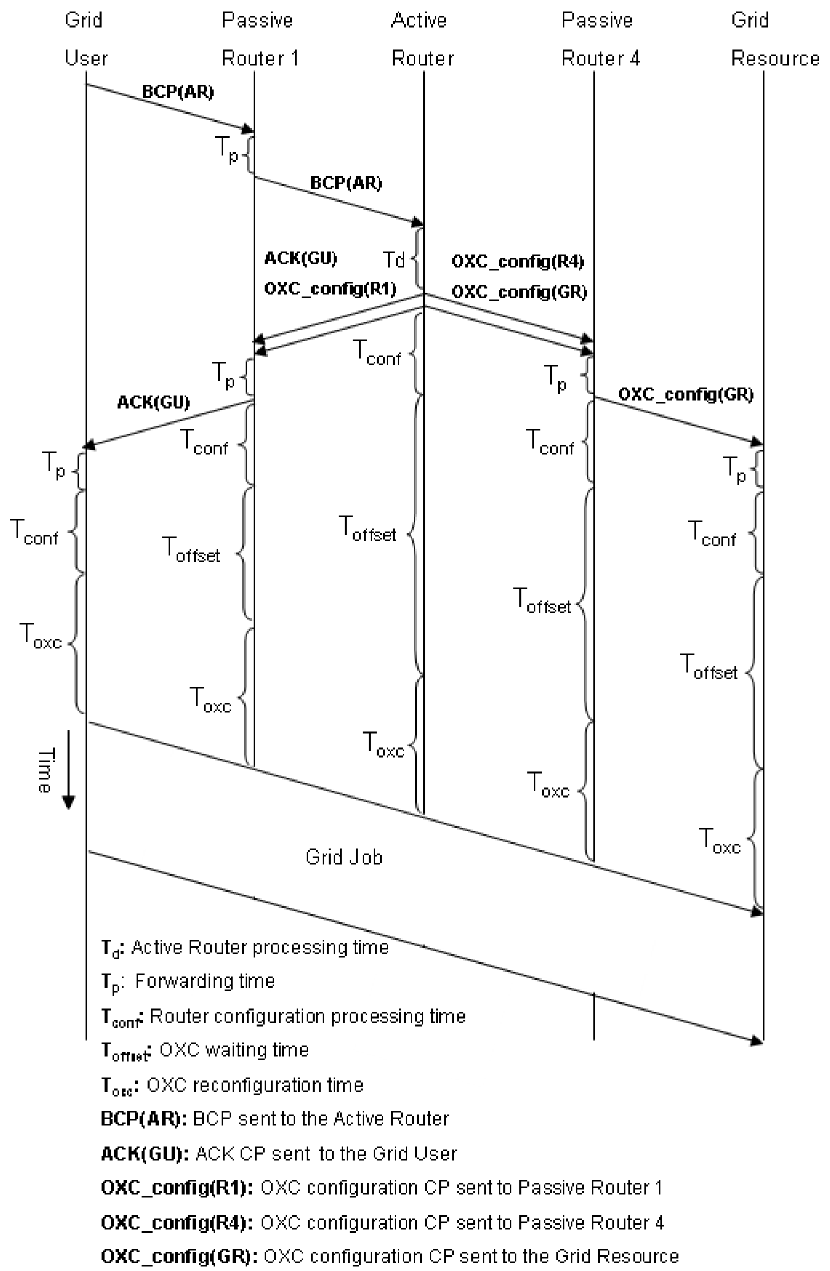

Figure 5.3 - Time scale illustration of a Grid Job submission using the proposed scheme.

All the routers that belong to the path, when receive the *BCP* reconfigure their resources to be prepared to forward in the optical domain the *Grid Job*. The *Offset* is used to guarantee that the nodes are configured in the right moment wasting the less network resources possible.

The *Grid User* only has the network physical connectivity information. The path selection is only based on this information, because the *Grid User* only has local connectivity knowledge. The selected path is chose by the Grid user without knowing the real availability along the entire path. If during the BCP journey is not possible to reserve the network resources, it is transmitted in the reverse path a negative *ACK*. This packet is used to delete the configuration. Using this strategy, the network resources that where reserved for the failed *Grid Job* are used to satisfy another *Grid Job*.

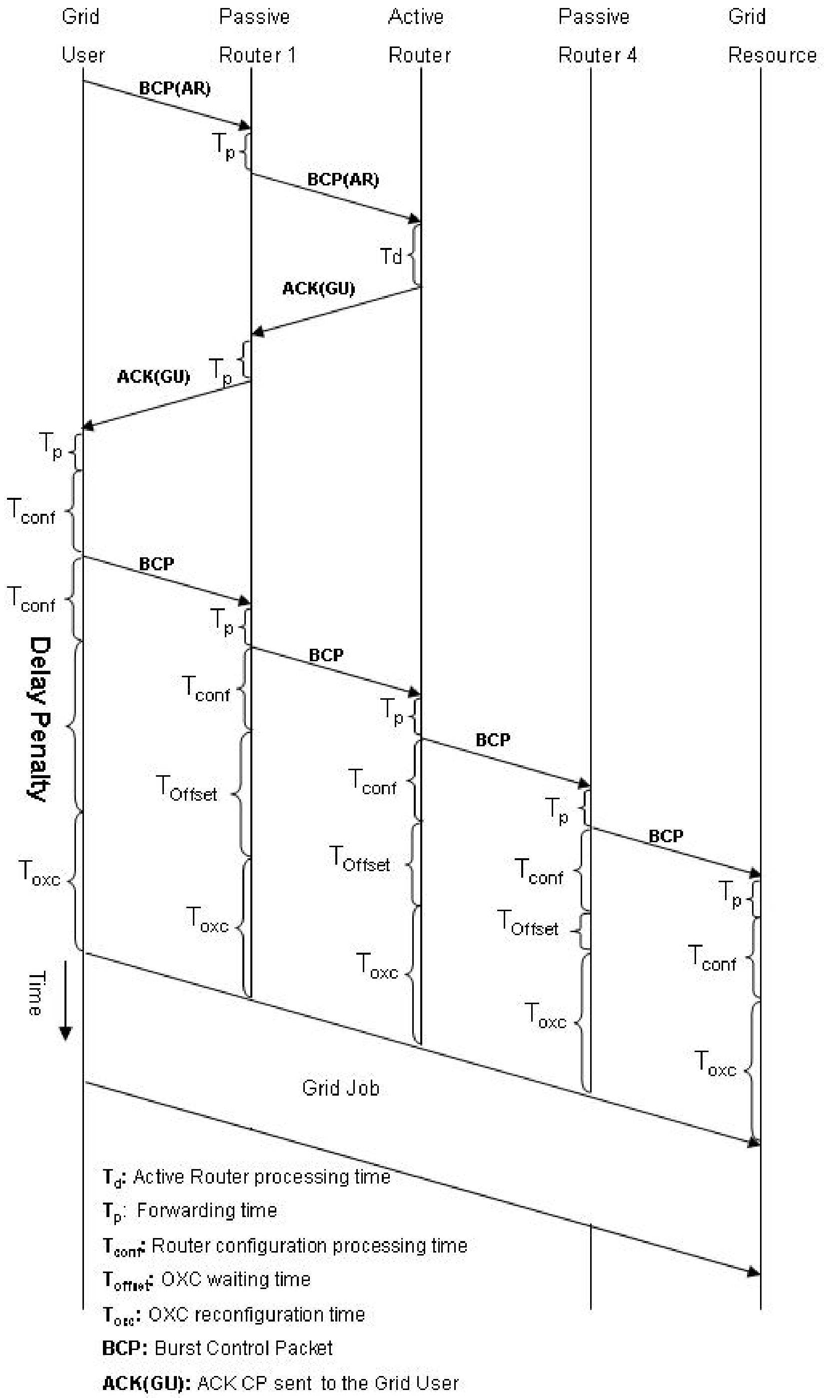

Figure 5.4- Time scale illustration of a Grid Job submission using the JET-OBS scheme.

5.2.5. Delays Introduced

In the time scale illustrations (Figure 5.3 and Figure 5.4), several delays are represented. The total time is the time consumed with the propagation and processing of the packets (T_d, T_p, T_{conf}, T_{offset} and T_{OXC}).

T_d is the time used by the *Active Router* to process the *BCP* packets. This function corresponds to selecting the best *Grid Resource* for the *Grid Job* requirements. In our signaling scheme it corresponds also to select the best path for the *Grid Job*.

T_p is the time used to forward the packets for the next node.

The time that the nodes use to process the *BCP* packet is represent by T_{conf}. Corresponds to the time used to read the BCP information. The information read from the *BCP* is used to the OXC physical reconfiguration, and the time used is presented by T_{OXC}. The physical reconfiguration consists in the physical preparation to forward the job always in the optical domain.

T_{ofsset} is the offset time. It represents the time delay since the router receives the configuration packets until it starts the OXC reconfiguration process. It is used to guarantee that all the network resources are reserved when the Grid Job arrives to the node. The offset time is used also to waste the minimum network resources, since the resources can be used by another Burst until the configuration process beginning.

In the JET-OBS can incur a *Delay penalty* as it can be seen comparing the Figure 5.3 that represents the proposed scheme and the JET-OBS scheme figured in the Figure 5.4. The *Delay penalty* depends on the network connectivity, since a network with higher connectivity have less delay penalty.

5.2.6. Proposed scheme advantages

The principal proposed scheme advantage is the burst lost probability reduction; this will be shown in more detail in Chapter 6. This reduction is obtained because the path used by the burst is selected by the Active Router based on the Active Region connectivity and the respective wavelength occupation. The wavelength usage and the network connectivity permit the Active Router select the best path from the Grid User Network Interface to the respective Grid Resource Network Interface based on the job requirements.

Another advantage is that the Active Router responsible to reserve the network resources. Since the Active have the information about the Burst duration, and the used path and wavelength. The Active Router updates the network status immediately when the burst transmission finishes. The reservation process performed by the Active Router consists in sending the *OXC_config* packet to all the nodes used by the Data Burst to connect the Grid user with the Grid Resource. With the information, the nodes will reconfigure themselves to in the respective time slot be prepared for the burst. The configuration process made by the Active Router permit a reduction in the offset times, because since this process isn't started by the GUNI like in the most common OBS strategies. In, the *BCP ACK* is transmitted to the GUNI, at the same time that the *OXC_config* packets are transmitted to the other path nodes. Using this strategy, the reconfiguration process can be anticipated, since the *OXC_Config* can reach all the nodes sooner than when the configuration process is started by the Grid User. In JET-OBS the reconfiguration starts when the *Grid User* receive the *BCP ACK,* while in our scenario, this process is started by the Active Router, permitting anticipate the DB transmission

5.3. Chapter summary

This chapter presents the signaling schemes implemented in this master dissertation. The signaling scenarios implemented are a JET-OBS to our GOBS network controlled by an Active Router and the novel WR-OBS signaling scheme proposed by this master dissertation.

In our JET-OBS, the Active Router is responsible to select the Grid resource and the path to reach it is selected by the source node, while in the proposed scheme, the Active router selects the Grid resource and the best path to reach it.

Chapter 6. Implementation and performance assessment of the reservation signaling scheme

6.1. Introduction

This chapter describes the implementation of the proposed reservation signaling scheme presented in the previous chapter. OMNeT++ is the network simulator used for the scheme implementation.

Using the simulation model the performance of Grid over Optical Burst Switching (OBS) networks employing Active Routers is evaluated and compared with the JET-OBS scheme. The results show that the centrally controlled WR-OBS signaling scheme always outperforms the JET-OBS scheme in terms of job blocking rate and the time delay that a job suffers until it reaches the Grid service provider.

6.2. OMNeT++ simulation model

OMNeT++ is a discrete event simulator, which primary application area is communication networks. It is used for the simulation of several areas, such as: IT systems, queuing networks, hardware architectures and business processes [57].

The simulation model was implemented in two levels: network and protocol. The network level uses a specific OMNeT++ programming language, the *ned language*. The *ned language* enables the definition of the nodes and the network physical structure. The links are also defined using the *ned language*. The nodes functions are implemented in C++ programming language. OMNeT++ makes a perfect interaction between the network modules and its functions implemented in C++.

Omnet.ini file have several simulation parameters declaration allowing the parameters change without the necessity of recompiling the source code.

All the messages used in the simulation are created using files ***.msg**. The messages are defined using the C++ cMessage class. The message declaration consists in defining the message attributes. OMNeT++ permit also encapsulate a message in another.

6.3. Network

The network topology used in the simulations is presented in Figure 6.1. It is the twenty nodes European Optical Network (EON). The distances between all the nodes are equal, 30 km. This results in propagation delay of 0.1 *ms* for each link. The EON is a network topology usually used in the academic research, because it has a relatively high connectivity between the 20 nodes. The network connectivity allows several path possibilities for node connection.

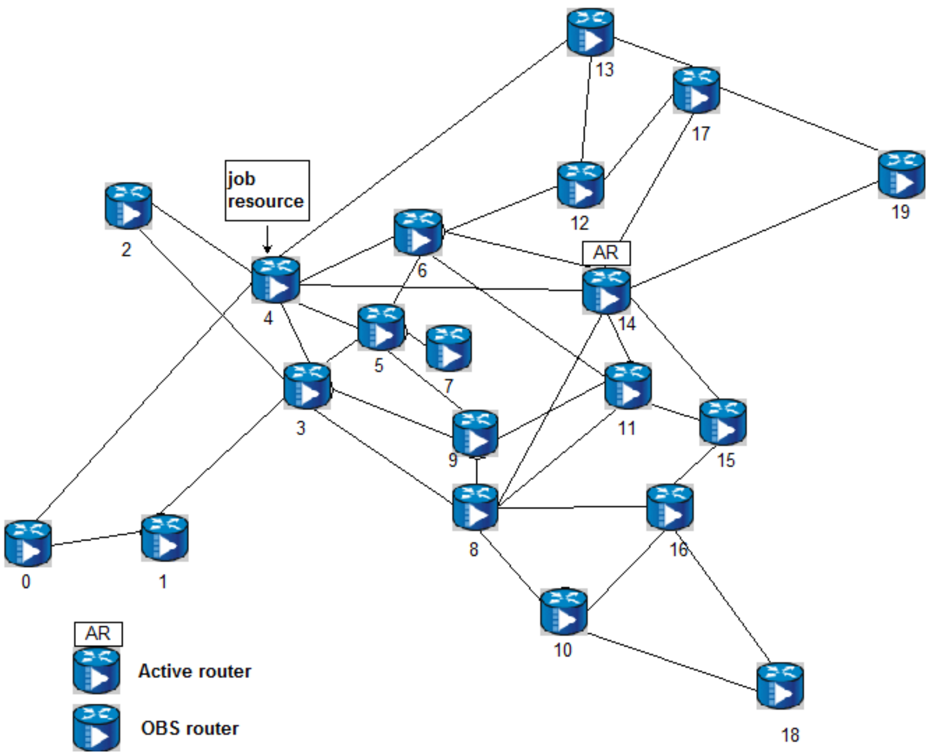

Figure 6.1- 20 node EON controlled by an Active Router.

The fiber links used to connect the nodes employ Wavelength Division Multiplexing (WDM). Fiber links are defined using ned language. Fiber propagation introduces delay. Each fiber has four bidirectional wavelengths, one of which is exclusively reserved for signaling purposes, The wavelength reserved exclusively for the signaling allow the signaling to reach the respective destiny even with all the data wavelengths reserved for the jobs transmission.

The networks have two different types of nodes, the OBS Router and the Active Router. The OBS Router is simpler than the Active Router. The OBS Routers can be Job Resources or Grid Clients. The Grid Client collects traffic from the attached network in the form of jobs. For each job, a Control Packer is created and used to reserve the network resources along the path. When it is performing as Job Resource it is capable to resolve the jobs created by the Grid clients. The Active Router is a more complex entity; it has the same function of the Grid client OBS Router, plus all the managing functions. The Active Router is a network entity with a global knowledge of the network physical connectivity and status. When the Active Router receives the Grid job specification, it uses the network information to select the appropriate Job Resource and path to connect the source node to the Job Resource using one of the shortest paths.

We consider the network represented in Figure 6.1 a single Active Region. The Active Router controls the Active Region and maintains updated the network status. A single Grid job resource is used to resolve the jobs requested by all the other nodes within the Active Region.

6.3.1. OBS Router

The OBS Router can be a Grid Job Resource or Grid client. When acting as a Job Resource its main function is resolve Grid Jobs. In our model only one OBS Router is the Gird Job Resource able to resolve all the types of jobs. In a network with several Job Resources they are able to interpret the Control Packets information and forward jobs to the appropriate end node. We consider a Grid Job Resource with no capability to start job resources requests.

The Grid client is responsible for job creation and to transmit to the Active Router a Control Packet with the job specifications. The jobs are maintained in an electric buffer until the Active Router receives an Ack message. If the Active Router informs that it is not possible to find a path to satisfy the job request, the job will be dropped. Otherwise a positive acknowledgement with a Grid Job Resource and the information necessary to the job transmission is received. Every OBS Router that belongs to the selected path receives a

Control Packet with the information necessary for configuration, offset time, the ingress and egress ports, the wavelength used and the duration of the job.

All the signaling messages are transmitted by broadcast. To avoid signaling flooding, each message has a unique ID and a Time to Live (TTL) fields. The ID is used to guarantee that the messages are processed only once by each node. The TTL and the restriction to not broadcast to the inbound port reinforce our anti flooding strategy.

Figure 6.2 presents the OBS Router internal structure. It is the representation of node 16 with its connections to the four adjacent nodes. The submodules and their functionalities are the following:

rx receives the traffic from the network and sends it to the processing unit (*proc*). It also makes a duplication of each message and sends it to the statistical unit.

tx is a simple module that represents the output interface of the node; it is responsible to send the traffic for the network. For each message that it transmits it sends duplication for the statistic unit.

proc is the main entity of the Core OBS Router, where all the processing is made. With the specifications received from the *msgGen*, the Control Packet with the job specifications is created and transmitted to *tx* module, while the job is sent to the *jobQueue* buffer. For the reconfiguration process if the node is the CP destiny, it will use the incoming information to be prepared for the job; otherwise the Control Packet is transmitted to the respective node. In the Job Resource mode, the jobs with its destiny are resolved, while all the others are retransmitted to the right destiny.

jobQueue is the block responsible to keep the jobs in the source node during the Job Resource discovery process and network configuration.

stat receives a copy of all the nodes inbound and outbound traffic and makes a statistical analysis of the traffic generated, transmitted and forwarded by the node.

msgGen is the entity responsible to generate the traffic for the network. The traffic is generated using a Poisson process, representing the jobs collected from the attached network. The job duration and the interval between jobs are the parameters of this module, defining the amount of traffic in the network.

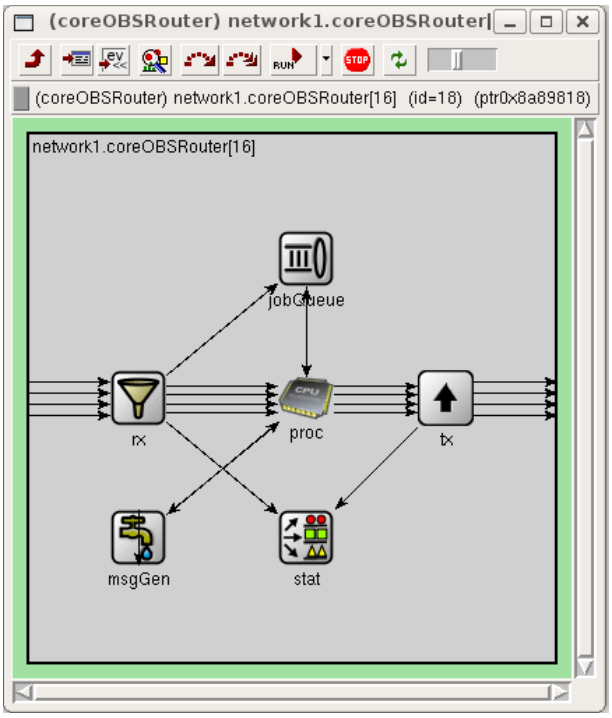

Figure 6.2- OBS Router internal submodules.

6.3.2. Active Router

The Active Router is responsible to manage the network and its resources. This node has the same functionalities that the Core OBS Router, plus the ones necessary for the network management. One extra submodule is added, the *sigQueue*, which is responsible to buffer Jobs Resource Requests. The Job Resource Requests are buffered, because the Active Router only process one Control Packet at the time. The main function of this node is the network management, for this proposes it needs to have a global knowledge of the network physical structure and status. The physical structure is discovered using the Dijkstra's algorithm in the simulation start-up. With this knowledge it will select only the shortest paths to resolve the jobs.

With the job characteristics, the Active Router selects the best Grid Job Resource to resolve the job. When a signaling packet with the job characteristics arrives is queued. The queuing process is necessary because the Active Router is only capable of resolving one job at a time. After the queuing process, the best node to execute the job is selected based in the knowledge of all the Grid Job Resources placed in the network. After selecting a Job Resource, one of the free shortest paths is chosen. Wavelength continuity is assumed. When is not possible to find a path to connect these two nodes, the job is dropped. In this situation, the Active Router sends a negative Acknowledge to the source node, informing that is impossible resolve the job. Otherwise if a free path exists the Active Router reserves the path for the necessary amount of time and sends a positive Acknowledge to the source node and Control Packets with the configuration specifications to all the intervenient nodes. The Active Router internal structure is represented in the Figure 6.3. Most of the submodules are shared with the Core OBS Router, except the extra *sigQueue* and the enhanced *proc* which have the following functionalities:

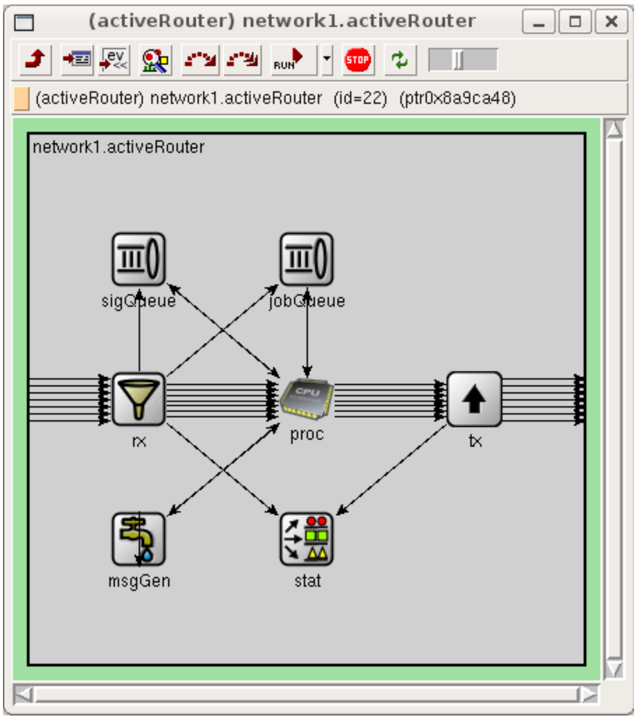

Figure 6.3- Active Router internal structure.

sigQueue is a first in first out queue used by the Active Router to store the incoming Job Resource Requests.

proc is the main component of the node, responsible to all the processing, just like in the Core OBS Router. This module has the same functions of the one presented in the Core OBS Router plus the managing network functions and the ability to find job resources for the jobs.

6.4. Signaling scheme overview

In this section, we explain all the signaling functions, the messages used and the tasks performed during the signaling process.

The signaling scheme consists in the signaling packets transmission along the network and all the tasks started by them. The process starts when a node receives a job from an attached network. Both the OBS and the Active Routers can start job requests. This event is simulated by the *msgGen*.

Figure 6.4 presents the signaling scheme with all the tasks and the interaction between the two types of nodes.

Booth node types can start the signaling process. To explain the signaling process behavior we first consider a job created by OBS Router *msgGen* block. When the OBS Router *proc* receives the job, a Job Resource Request (JRR) is created based on the job specifications. After that, the job is saved in the *jobQueue* and the JRR is broadcasted in the network until it reaches the Active Router. When the JRR arrives is buffered in the *sigQueue*. The *sigQueue* is a First In First Out (FIFO) queue used to guard all the incoming JRR during the resource find and network status update by the Active Router. After the queuing process, a JRR is popped from the queue. The Active Router *proc* module gets the job information from the JRR and finds a network resource able to execute the job. If it cannot find a resource able to satisfy the job specifications, a NACK message is transmitted to the Source node informing the unavailability of a Job Provider able to resolve the job. Once the OBS Router receives the NACK, the job is dropped from the queue, and the signaling process for this job ends. If a job provider is selected, the Active Router verifies if a free path using a single wavelength exists between the source node and the Job Resource. If it does not exist, the Active Router sends a NACK to the source node.

With a Job Resource and the path to reach it, the configuration process can start. The first step is the Active Router network resource database status update. This update consists in marking the path unavailable during the transmission time slot. Next an ACK message is created and sent to the start node. Control Packets with the necessary specifications for the network resources configuration are transmitted to all the OBS Routers belonging to the path.

The ACK and the Control Packets are forwarded by the OBS Routers until they reach the respective destination. When the start node receives the ACK, it starts the network resources configuration and job transmission. First it gets the job from the queue. After waiting the offset time, it starts the resources configuration. The next step is the job transmission. With this, another part of the signaling scheme ends, now the source node is prepared for the job transmission without the exchange of another signaling packet.

When an OBS Router receives a configuration Control Packet with his destination means it is just a passing router. Then it will get the specifications from the Control Packet, wait the appropriate offset time and configure the network resources with the specifications carried in the signaling packet. With this, another signaling process ends, now the node is prepared to forward the data carried in the job.

The Active Router, after sending the Control Packets and the ACK messages verifies if it is the job sender. If so, it starts preparing for the job transmission, gets the job from the *jobQueue* and uses the job specifications to configure its resources just after waiting the respective offset time. Now the Active Router is prepared for the job transmission.

If the Active Router is not the source node, but belongs to the selected path, it prepares for forwarding the job after waiting the offset time reserve the specific network resources. Next, verifies if the *jobQueue* is empty. If it is, the signaling process finish there, otherwise, the signaling process is repeated since a JRR is popped from the *sigQueue*.

If the Active Router is the source node, the signaling beginning is equal to the one performed when the start node is an OBS Router. It starts with the JRR creation, following by the job transmission to the *jobQueue*. At this point, the JRR is buffered in the *sigQueue*, while when the OBS Router is the source node it is transmitted to the Active Router. After this the signaling follows the normal flow, explained above in this section, and presented in the Figure 6.4.

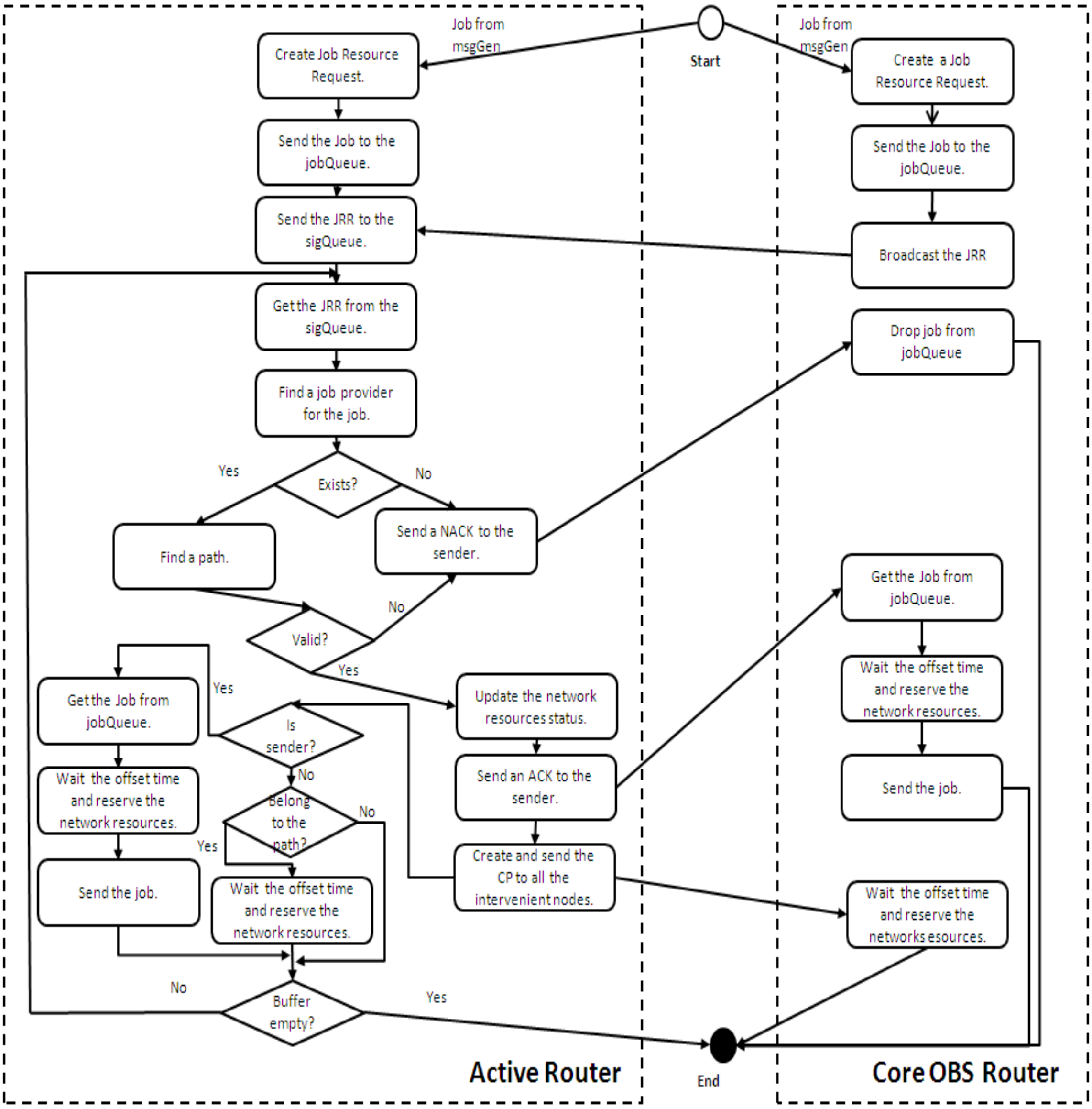

Figure 6.4 –A fluxogram with all the tasks performed by the signaling scheme.

6.5. Performance evaluation

The network employing the proposed signaling scheme performance is evaluated and compared with the JET-OBS with source routing, while the routing decisions in our model are performed by the Active Router. In JET-OBS, the selected path is randomly chosen between the group of shortest paths.

The job blocking probability and the time used for the configuration process are the parameters used and compared between the two signaling schemes.

The job requests are generated as a Poisson process with mean arrival rate λ arrivals/ms. Job sizes are distributed according to a exponential distribution with mean 1/μ.

6.5.1. Blocking probability

We consider two different network scenarios: in the first scenario is considered an Active Router with no *sigQueue*, while in the second strategy the *sigQueue* have queuing time equal to the time used by the Active Router to select the job resource for a job (Td).

Figure 6.5 and Figure 6.6 represent blocking probability for the first scenario. When the Job Resource Requests arrive to the Active Router, are resolved immediately. If the Active Router receives more than one Job Resource Request at the same simulation time, all the requests are resolved at the same simulation time in the entrance order. For example if the Active Router receive two Resource Requests ate the same simulation time, the second request is performed after the resource select and update of the first request. The second Job Resource Request resource selection is based on the Active Router information after the first requests update.

Figure 6.5 and Figure 6.6 are the blocking probability of two different Active Router and job resource configuration. In Figure 6.5 is represented the Active Router in the node 17 and the job resource in node 18, while in Figure 6.6 the Active Router is the node 14 and the job resource is node 4.

In Figure 6.5, plot, the Active Router and job resource are both edge nodes with the less connectivity in the network, two adjacent nodes, the Active Router is placed in node 17 and the Grid Resource is the node 18. In Figure 6.6 both Active Router and job resource are placed in a central location in the network (nodes 14 and 4). Both nodes have the higher connectivity in the network, seven adjacent nodes.

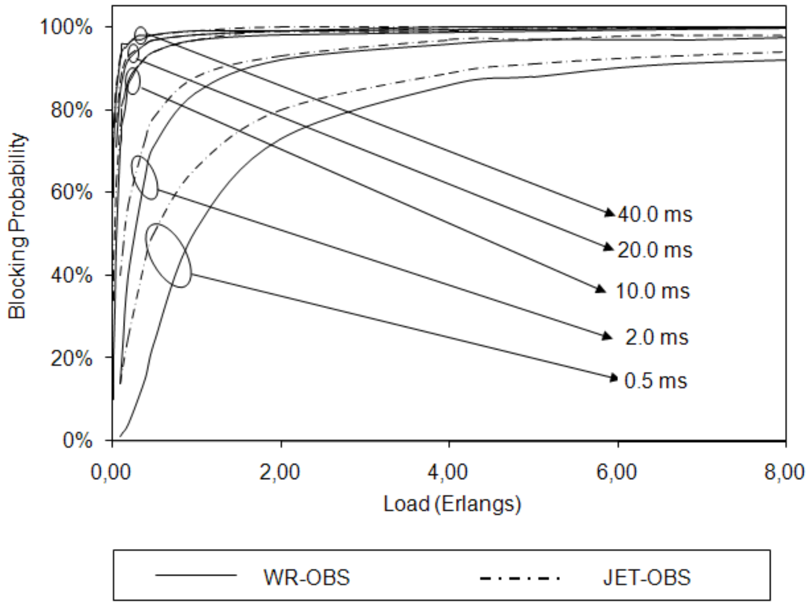

Figure 6.5- Job blocking probability versus load for Grid job durations of 40, 20, 10, 2 and 0.5 ms for network scenario Active Router is the node 17 and job resource is the node 18.

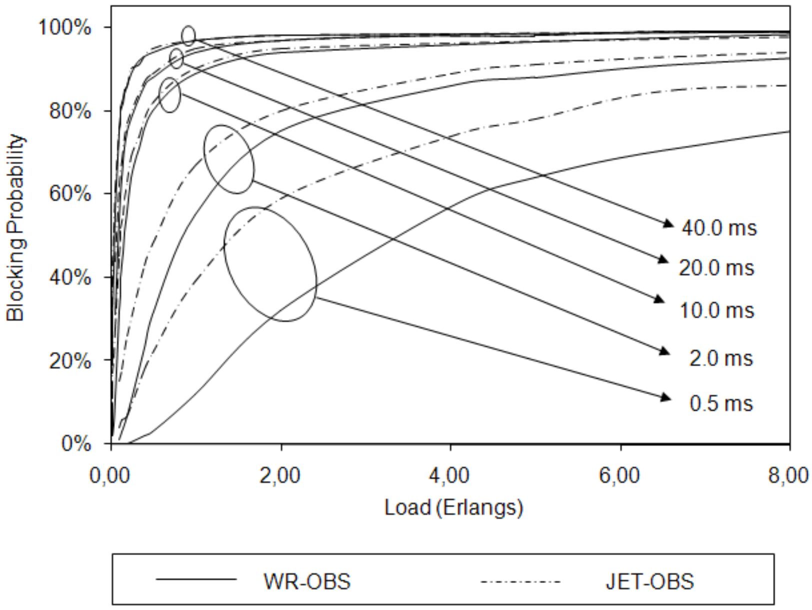

Figure 6.6 -Job blocking probability versus load for Grid job durations of 40, 20, 10, 2 and 0.5 ms for network scenario Active Router is the node 14 and job resource is the node 4.

In both network configurations (Figure 6.5 and Figure 6.6), the proposed scheme outperforms the JET-OBS. In Figure 6.6 the blocking probability is lower than Figure 6.5. This occur because the location of the Active Router and Job resource. In the first scenario (Figure 6.5), the Active Router and the job Resource are placed in the network edge and in nodes with the lower connectivity. This scenario produces a higher job blocking probability, because the job resource has less connected links, producing faster links congestion, resulting in more jobs without free resources for the transmission.

In the other scenario (see Figure 6.6) scenario, both are placed in a network central location, in the nodes with seven adjacent modes. These nodes have the higher connectivity in the network.

Figure 6.7 present the job blocking probability versus load plot when the queuing time used by the *sigQueue* is equal to the time used to select the job resource. In this scenario, the Active Router is the node 14 and the job resource is the node 4. The job blocking probability of our signaling scheme is much lower than the one presented in Figure 6.5 and Figure 6.6. The reduction in the job blocking probability is the result of the Grid job requests are resolved one at the time by the Active Router. This give the possibility of the job have a free path when in the previous cases the resources are used by the previous jobs.

In Figure 6.7 we compare the JET-OBS with the proposed scheme, both using the *sigQueue* buffer in the Active Router. Like in the plots presented in Figure 6.5 and Figure 6.6, the proposed scheme has fewer jobs blocking occurrence. This happens because the Active Router used by the proposed scheme use the global knowledge to select the network resources used to satisfy the job. The path selection based on the global network knowledge in addiction with the delay introduced by the buffer make our signaling scheme introduce a much lower job blocking probability than the JET-OBS, where the source node selects the path randomly only using its local knowledge.

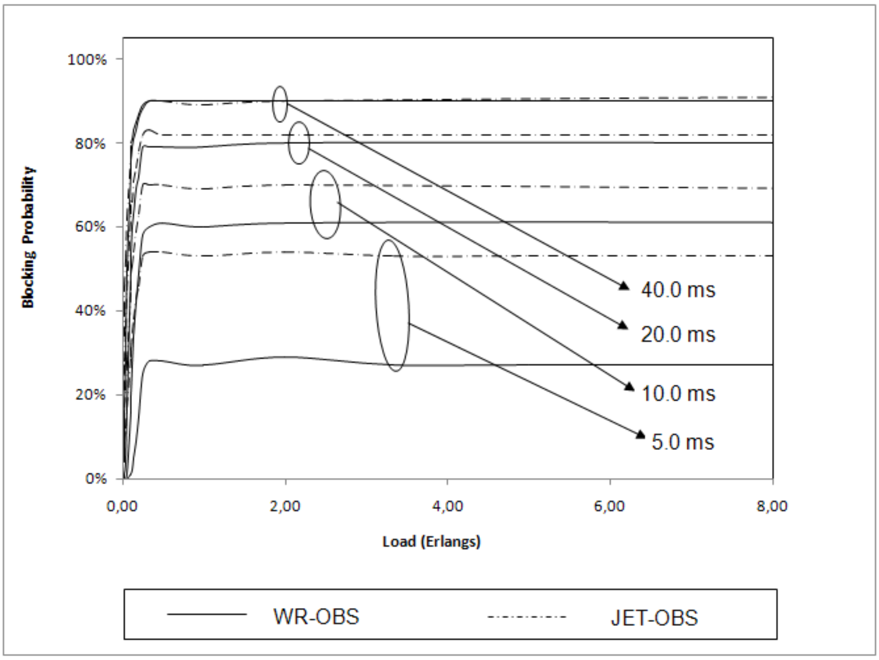

Figure 6.7- Job blocking probability using *sigQueue* for Grid Job durations of 40, 20, 10 and 5 ms.

The proposed scheme have always less blocking probability than the JET-OBS. The gain increase when the job duration decreases. This proves that our model is very suitable for Grid consumer scenarios, where the job durations are small.

6.5.2. Reservation time

One of the OBS features is a fast reservation process, the bursts should be retained in the source node the minimum possible time, maximizing the network resources usage.

In this master dissertation we study four reservation time scenarios in a Grid over OBS network. The reservation time considered is the time used since the burst creation until it transmission after the respective offset time and reconfiguration process. The four scenarios tested are the proposed scheme and JET-OBS in a buffer and buffers less network. The buffer used is in the Active Router for the BCP Job Resource Packets. It is considered a buffer with infinite capacity. Using the infinite buffer, the jobs only are dropped because the network resources for the job transmission are not available.

The network delays are those represented in the Table 6.1. These delays represent the propagation delay and all the times used by the nodes for processing and configuration during the network configuration.

	Time (ms)
Propagation delay	0.1
Configuration Processing Time (Tconf)	0.08
Configuration Time (Toxc)	1
Active Router Function Time (Td)	0.2
Signaling delay (Tp)	0.01

Table 6.1 – Delays introduced by the network during the simulation.

In Table 6.2 and Table 6.3- are presented the first two scenarios, using a bufferless Active Router. It was tested two network configurations, in Table 6.2 the Active Router is placed in the node 17 and the Job Provider is the node 18, these two nodes are placed in the network edge and both have low connectivity. The network configuration used for the results presented in Table 6.3- is the Active Router placed in the node 14 and the Job Provider the node 4, these nodes are placed in a central location in the network, and both are the nodes with higher network connectivity. In both cases, the proposed scheme has better results than the JET OBS, because the Active Router is responsible to start the configuration process, while in JET OBS this process is started by the source node just after the positive Acknowledge reception from the Active Router. The configuration process started by the AR reduces the necessary offset used by the source node to retain the job in an electric buffer. The time used to retain at the source node is presented in Figure 5.4 by *Delay Penalty*. The *Delay Penalty* is higher in the Table 6.2 scenario. This has a great impact especially when the source nodes are far away from the Active Router, for example the node 0. Since in JET OBS scenario, the source node start the BCP transmission after receiving the positive Acknowledge from the Active Router with the Job resource location, while in the proposed scheme, the Active Router starts the configuration process at the same time that transmits the positive Acknowledge to the source node.

In the cases where the source node and the Active Router are far away, most probably when the source node receives the positive Acknowledge, all the nodes used to reach the Job resource already receive the BCP with the resource reconfiguration information, or are about to receive it.

Node	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
JET	2.77	2.28	2.06	2.05	1.84	2.06	1.84	2.29	1.82	2.05
Proposed Scheme	1.94	2.16	1.94	1.95	1.72	1.94	1.72	2.17	1.74	1.95
Node	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**J R**	**A R**	**19**
JET	2.03	1.83	1.63	1.63	1.61	1.82	2.03		1.40	1.62
Proposed Scheme	1.95	1.73	1.54	1.54	1.53	1.74	1.95		1.32	1.53

Table 6.2 – Reservation time in milliseconds in a bufferless network where the node 18 is the Active Router and the node 17 is the Job Resource.

Node	**0**	**1**	**2**	**3**	**J R**	**5**	**6**	**7**	**8**	**9**
JET	1.81	2.04	1.81	1.81		1.81	1.59	2.04	1.60	1.82
Proposed Scheme	1.72	1.94	1.72	1.72		1.72	1.51	1.94	1.51	1.74
Node	**10**	**11**	**12**	**13**	**A R**	**15**	**16**	**17**	**18**	**19**
JET	1.83	1.60	1.82	1.81	1.37	1.60	1.83	1.60	2.06	1.60
Proposed Scheme	1.74	1.51	1.74	1.72	1.29	1.51	1.74	1.51	1.97	1.51

Table 6.3- Reservation time in milliseconds in a bufferless network where the node 14 is the Active Router and the node 4 is the Job Resource.

As was shown in the section 6.5.1 the burst dropping probability in the scenarios employing buffers is much lower than the scenarios without buffers. The buffered scenarios introduce delay; it is interesting study the delay introduced by the buffers, because this delay corresponds to the time that is necessary retain the jobs in the source node by an electrical data buffer.

To study the delay introduced by the buffer we select a job average duration and vary the interval between the job resource requests. The job duration only interferes with the blocking probability, since larger jobs use the resources during more time, increasing the blocking. The *sigQueue* buffer is an infinite buffer, where all the job requests are processed by the Active Router. The following job resource request is only processed when the current is already served (select the Grid Resource, select the path from the source node to the Grid Resource, update the network status, transmit the Acknowledge for the source node and the BCP's to all the other intervenient nodes). All the jobs have the same processing time, Td (0.2 ms).

The reservation time of the network with buffer is tested in the network presented in Figure 6.1. The Table 6.4, Table 6.5, Table 6.6 and Table 6.7 present the reservation time for four different average Job Resource Request generation times and a fixed average job duration. It is studied for each node, the average, maximum and minimum reservation times. It is presented the average time, as well as the time wasted for the first job, and the maximum delay introduced by the buffer for each source node.

Table 6.4 presents the reservation time used for an average generation interval of 10 ms. Since the burst generation rate is low, the buffer has low usage. The average reservation times are very similar to the minimum. The minimum reservation time presented in Table 6.4 are equal to the one performed by a bufferless network (see Table 6.3-). In the scenario presented in Table 6.5, where the average interval is 5 ms, the buffer has more influence in the reservation times. The minimum reservation time is equal to the one performed by the bufferless scenario, while the average time are slightly higher.

Node		**0**	**1**	**2**	**3**	**J R**	**5**	**6**	**7**	**8**	**9**
JET	**Average**	1.88	2.10	1.87	1.88		1.88	1.65	2.10	1.68	1.89
	Max	2.64	2.74	2.70	2.55		2.47	2.30	2.72	2.50	2.84
	Min	1.81	2.04	1.81	1.81		1.81	1.59	2.04	1.60	1.82
Proposed Scheme	**Average**	1.77	2.05	1.78	1.77		1.78	1.58	1.99	1.57	1.79
	Min	2.57	2.46	2.41	2.34		2.41	2.18	2.60	2.14	2.30
	Max	1.72	1.94	1.72	1.72		1.72	1.51	1.94	1.51	1.94
Node		**10**	**11**	**12**	**13**	**A R**	**15**	**16**	**17**	**18**	**19**
JET	**Average**	1.89	1.66	1.88	1.87	1.42	1.66	1.89	1.67	2.11	1.66
	Max	2.50	2.27	2.67	2.62	1.95	2.31	2.65	2.47	2.83	2.22
	Min	1.83	1.60	1.82	1.81	1.37	1.60	1.83	1.60	2.06	1.60
Proposed Scheme	**Average**	1.78	1.58	1.80	1.77	1.34	1.57	1.79	1.56	2.02	1.57
	Max	2.42	2.54	2.43	2.46	2.15	2.37	2.57	2.14	2.49	2.25
	Min	1.74	1.51	1.74	1.72	1.29	1.51	1.74	1.51	1.97	1.51

Table 6.4- Average, Maximum and minimum reservation time in a buffered network where the node 14 is the Active Router and the node 4 is the job resource, with 5ms of average message duration and 10 ms of average time between the generation of the job requests.

Node		**0**	**1**	**2**	**3**	**J R**	**5**	**6**	**7**	**8**	**9**
JET	**Average**	2.11	2.34	2.12	2.11		2.08	1.87	2.34	1.87	2.13
	Max	5.17	4.82	4.56	4.39		3.69	3.60	5.16	3.33	458
	Min	1.81	2.04	1.81	1.81		1.81	1.59	2.04	1.60	1.82
Proposed Scheme	**Average**	1.98	2.23	2.01	2.02		1.96	1.78	2.17	1.79	2.00
	Min	3.78	3.70	3.38	3.84		3.63	3.32	3.58	3.50	3.64
	Max	1.72	1.94	1.72	1.72		1.72	1.51	1.94	1.51	1.74
Node		**10**	**11**	**12**	**13**	**A R**	**15**	**16**	**17**	**18**	**19**
JET	**Average**	2.14	1.87	2.14	2.11	1.66	1.91	2.12	1.88	2.33	1.91
	Max	4.36	3.61	5.13	4.29	4.35	4.59	4.39	3.50	4.36	4.86
	Min	1.83	1.60	1.82	1.81	1.37	1.60	1.83	1.60	2.06	1.60
Proposed Scheme	**Average**	2.02	1.77	2.03	2.00	1.54	1.78	2.02	1.79	2.23	1.78
	Max	3.71	3.77	3.82	3.74	3.01	3.54	3.71	3.46	3.68	3.33
	Min	1.74	1.51	1.74	1.72	1.29	1.51	1.74	1.51	1.97	1.51

Table 6.5- Average, Maximum and minimum reservation time in a buffered network where the node 14 is the Active Router and the node 4 is the job resource, with 5ms of average message duration and 5ms of average time between the generation of the job requests.

Node		0	1	2	3	J R
JET	Average	711.89	715.78	654.09	695.76	
	Max	1315.57	1354.24	1343.34	1382.78	
	Min	4.49	2.58	3.04	2.10	
Proposed Scheme	Average	697.58	642.14	687.87	735.74	
	Max	1333.13	1257.46	1368.79	136.873	
	Min	4.00	2.38	2.75	2.01	
Node		**5**	**6**	**7**	**8**	**9**
JET	Average	711.13	667.00	695.39	706.66	685.44
	Max	1383.44	1375.90	1377.14	1383.38	1326.55
	Min	7.11	5.06	2.68	6.35	5.53
Proposed Scheme	Average	661.44	699.60	695.83	688.68	727.84
	Max	1359.19	1368.08	1338.47	1340.64	1368.59
	Min	8.02	5.18	2.58	6.86	5.65
Node		**10**	**11**	**12**	**13**	**A R**
JET	Average	689.53	715.88	719.93	660.13	664.18
	Max	1384.01	1383.81	1383.92	1322.20	1339.47
	Min	9.20	3.94	5.89	5.02	2.88
Proposed Scheme	Average	725.57	734.58	696.69	741.86	691.93
	Max	1366.21	1367.44	1364.05	1368.88	1356.89
	Min	7.91	3.65	6.21	4.53	2.60
Node		**15**	**16**	**17**	**18**	**19**
JET	Average	699.54	725.50	701.44	647.35	690.77
	Max	1383.74	138’.74	1383.82	1345.53	1363.72
	Min	2.66	4.66	1.60	3.89	1.70
Proposed Scheme	Average	672.48	624.59	694.68	693.98	713.22
	Max	1328.38	1289.07	1357.37	1335.77	1365.01
	Min	237	437	151	360	161

Table 6.6- Average, Maximum and minimum reservation time in a buffered network where the node 14 is the Active Router and the node 4 is the job resource, with 1ms of average message duration and 5ms of average time between the generation of the job requests.

The network behavior with the buffers in the Active Router presented in Table 6.4 and Table 6.5 is very similar to the network with no buffer (see Table 6.3-). The proposed scheme has always a reservation time smaller than the JET scheme.

Table 6.6 and Table 6.7 present the reservation time for the 1 ms and 0.1 ms of average time between the Job Recourse Requests generation. As the interval decrease, the reservation times increase, since the buffer have more Grid job requests waiting to be resolved.

Node		0	1	2	3	J R
JET	Average	907.54	927.93	930.99	933.78	
	Max	1828.47	1829.84	1820.45	1792.83	
	Min	4.99	6.79	3.84		
Proposed Scheme	Average	986.97	938.83	948.35	891.89	
	Max	1844.98	1836.31	1838.85	1827.13	
	Min	4.70	6.69	4.35	3.98	
Node		**5**	**6**	**7**	**8**	**9**
JET	Average	805.54	912.93	900.26	953.31	932.06
	Max	1655.66	1838.00	1749.39	1845.46	1839.69
	Min	9.47	3.05	6.99	5.38	7.94
Proposed Scheme	Average	923.03	973.82	957.04	977.15	907.75
	Max	1794.50	1845.51	1800.32	1835.71	1768.16
	Min	15.24	3.97	6.89	4.89	7.66
Node		**10**	**11**	**12**	**13**	**A R**
JET	Average	929.76	897.90	884.32	980.55	965.45
	Max	1768.66	1789.18	1782.54	1844.83	1829.95
	Min	10.46	2.48	8.12	5.78	1.37
Proposed Scheme	Average	895.86	853.45	919.61	935.78	832.93
	Max	1802.23	1756.57	1819.67	1836.46	1738.46
	Min	10.77	3.39	8.64	5.69	1.29
Node		**15**	**16**	**17**	**18**	**19**
JET	Average	953.92	941.57	877.76	923.85	906.15
	Max	1829.98	1837.87	1757.44	1835.68	1827.66
	Min	2.33	6.00	1.71	8.75	1.96
Proposed Scheme	Average	940.39	873.11	960.37	973.44	885.59
	Max	1811.59	1809.10	1828.82	1844.90	1799.13
	Min	2.44	5.91	1.88	9.06	2.27

Table 6.7- Average, Maximum and minimum reservation time in a buffered network where the node 14 is the Active Router and the node 4 is the job resource, with 0.1ms of average message duration and 5ms of average time between the generation of the job requests.

Until now, it was compared the performance between the JET-OBS and the proposed scheme always under the same network parameters. The relation between both remains almost identical in the networks with and without buffer in the Active Router; this is particularly noticeable when Table 6.3- , Table 6.4 and Table 6.5 are compared.

6.6. Chapter summary

In this chapter we present the proposed scheme OMNeT++ implementation and evaluate its performance in terms the job blocking probability and reservation time.

The performance of the proposed scheme was compared with the JET-OBS with random source routing.

The proposed scheme job blocking probability always outperforms the JET-OBS under the same circumstances, because the path selection is made by the Active Routing using the network global knowledge.

In a bufferless Active Router network, the proposed scheme has a reservation time shorter than JET-OBS networks. Using networks where the Active Router have the *sigQueue* buffer for the Grid job resource requests, the proposed scheme reservation time is lower than the one used by JET OBS when the jobs are generated with a low frequency, while when the generation frequency increases the buffer introduces a larger delay in both cases.

Chapter 7. Path selection strategies

7.1. Introduction

In this chapter a novel path selection strategy based on a probabilistic model for the link demands is presented. The objective of this strategy is to minimize the burst dropping probability. In the proposed scheme, during the network startup, the shortest paths are sorted based on a probabilistic model. This scheme avoids all the signaling packets exchange to update the actual network status used by adaptive path selection strategies.

The reminder of this chapter is organized as the follows. First an overview of several path selection strategies is presented; next the path selection strategy based on the probabilistic model is presented and explained. The chapter concludes with the path selection strategy performance evaluation.

7.2. Static contention avoidance strategies

There are several contention avoidance techniques that use load balancing techniques to avoid contention. The contention avoidance techniques based on load balancing can be static or dynamic. In static, the paths are selected using static metrics, such as hop counting or physical distance. In the dynamic strategy, the paths are selected using the number of congestions or the place of the congestions in the network as parameters [58].

7.3. Adaptive path selection strategies

The adaptative strategies objective is minimize the OBS burst dropping probability using the actual network status. The adaptative routing avoids the burst dropping using contention avoidance techniques.

In adaptative routing, the actual network status is updated. The network status is propagated along the network using link state signaling protocols witch use Link State Advertisement (LSA) messages to propagate the updated network status along the network. The path selection is based on the actual network status. In traditional networks, protocols like RIP [59][60], OSPF [61], IS-IS [62] and IGRP/EIGRP [63][64] used to archive networks with adaptive routing.

Adaptative path selection strategies can be classified as pure or hybrid.

7.3.1. Pure path selecting strategies

In pure path selection strategies, the source node maintains a small list of paths used to route the bursts from the source to the end node. There are several parameters used to measure the network congestion, for example: link usage and end to end path drop rate. With that information, the paths are ranked using different strategies to avoid the maximum burst drop. In [65] are presented three pure path selecting strategies. The *Weighted Bottleneck Link Utilization (WBLU)*, the *Weighted Link Congestion (WLC)* and *End-to-End Path Priority-Based (EPP)* strategies.

In WBLU, the links utilization is the metric used to rank the paths. The author intention is to select the paths less used to reduce or prevent the contention in the network. In WBLU, the selected path is the one with the higher ratio of available bottleneck link capacity to path length. If the bottleneck ratio is similar between two paths, the shortest path is selected. The longer path is preferred only when the utilization of it bottleneck link is much lower than the shorter one.

In WLC, the burst is routed in the path that most likely leads to a successful transmission. The source node decision is made based on the link congestion along each path to infer the path burst drop rate. This strategy needs a link state protocol to propagate the links usage along the network. Like in the previous strategy, the longer paths are preferred over shorter only if offer a substantial improvement in drop probability.

The EPP is similar to WLC, the busts are routed in the paths with less dropping probability. In this case instead of measuring the individual link congestion to infer the dropping probability, the dropping probability is measured in the all path based on the burst transmission feedback.

7.3.2. Hybrid path selecting strategies

The problem present in pure path selection strategies is that each strategy only uses a partial part of the network state to select the path. In the hybrid strategies, for each burst transmission combines the decision of several pure strategies into an overall decision. Combining several pure strategies, the overall burst drop probability can be minimized.

In [65] three hybrid path selection strategies are presented. The *Majority Binary Voting (MBV)*, *Weighted Nonbinary Voting (WNV)* and the *Dynamic WNV (DWNV)* strategies.

In MBV are considered a group of pure path selection strategies. For each strategy is verified if it is used to select the path. The strategy selected by the MBV is the one which is used to resolve most paths.

In WNV like in MBV are considered a group of pure path selection strategies. For each selection strategy is assigned a degree of confidence to each candidate path through a probability distribution. The WNV sort the strategies for each path, based on the degree of confidence. The performance of the various pure strategies depends on systems parameters, such as the network topology, traffic load and pattern. Each pure strategy has a different error rate, this hybrid strategy sort them by the respective weight.

The drawback in WNV is that the pure path selection strategy selected remains fixed all the time. The DWNV select which pure path strategy used, based on the burst dropping probability. The feedback information about the previous bursts transmitted along the path is used to calculi the path dropping probability.

7.4. Path selection strategy based on a probabilistic model for the link demands

In this section is presented the proposed path selection strategy based on a probabilistic model. The proposed scheme is a non adaptative strategy, where the paths are selected based on the network connections and the possible demands between all source-destinations combinations.

The probabilistic model for the link demands predicts a possible network load based on a probabilistic model. The paths usage discovery is made in the network configuration process, during the simulation no additional information with the network usage is exchange between the nodes.

With the probabilistic model, the shortest paths are sorted based on the overall weight of the path. We compare the performance of four techniques to rank the paths, increasing, decreasing, round-robin and alternating between increasing and decreasing.

7.4.1. Probabilistic model mathematical representation

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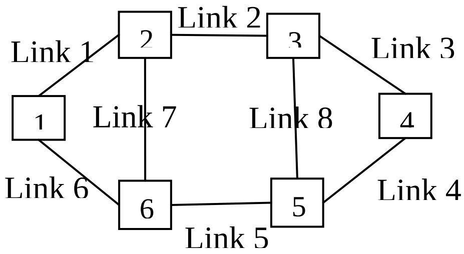
The network topology is modeled as a graph *G(N,L)*, where *N* is the set of nodes and *L* is the set of links. The path, *v*, over which a burst travels from source, *s*, to destination, *d*, is composed by series of links, and is represented as $v : s(v) \rightarrow d(v)$. The Dijkstra algorithm is used to find equal hop paths between the source and the destiny nodes. This set of paths can be used by a burst from s to v is defined as $V_{s,d} = \{v : s(v) \rightarrow d(v) \mid s = s(v), d = d(v)\}$ and the set including all $V_{s,d}$ is defined as V.

A demand matrix T is also considered, where $t_{s,d}$ represents a relative load from source node s to destination node d.

A probability matrix $\left[p^l\right]$, one matrix per link is also defined [4]. Each element of the probability matrix, p^l_{ij}, represents the probability of using the link *l* to support one demand between node *i* and *j*. The elements of the probabilities matrixes can be obtained using a search algorithm. Because we use a uniform demand matrix, the search algorithm consists in for each link, verify if the link is used to satisfy demands between all the nodes, the probability of the link is used will be placed in the probability matrix $\left[p^l\right]$ index relative to the nodes position.

Figure 7.1 a) presents a six node network topology with eight links and Figure 7.1 b) shows link one probability matrix $\left[p^l\right]$, where each position represent the probability of the link one is used to satisfy demands between the nodes relative to de matrix indexes. The Figure 7.1 b) is used to explain how the probability $\left[p^l\right]$ is created. For example, the probability of the link one is used to satisfy demands between the node one and two is 1, because there is only one possible path between them, and the probability of the link one is used is to satisfy demands between the nodes one and four is ½, because there are two equal hop paths between this nodes. All $\left[p^{l}\right]$ matrixes are constructed using this technique.



$$\left|p^{1}\right| = \begin{bmatrix} 0 & 1 & 1 & 1/2 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 \\ 1/2 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

a) b)

Figure 7.1- a) A network topology, represented by a graph; b) the matrix $\left[p^{l}\right]$ for *link 1 (l=1)*.

The probability matrix $\left[p^{l}\right]$ is the most important element of the probabilistic model because it will sum all the matrix fields to obtain the links weight. The *link l* weight mathematical representation is:

$$W_l = \sum_{i=1}^{N} \sum_{j=1}^{N} p_{i,j}^{l} \ .$$

The weight of a given path composed by L links is the sum of the weight of the links that compose the path. This weight is directly proportional with the probability of the link being used.

The next step before the simulation start is sorting the paths by its weight. The probabilistic model performance is tested sorting the paths using different strategies.

7.5. Probabilistic model performance evaluation

The sorting strategy influences the overall job dropping probability. This section presents the performance evaluation of four sorting strategies.

The path weight is obtained summing the weight of all the links that belong to the path. For each source end node pair, the shortest paths are ranked. The sorting techniques used to rank the paths are increasing, decreasing, round robin and alternate from increasing to decreasing. The probabilistic model sorting techniques are compared with the most common path selection strategy in Grid over OBS networks, the source shortest path random selection.

The source node selects the paths from the ranked list, and based on its local network status. The burst is dropped when the source node is unable select a free wavelength in all the paths from the sorted list.

7.5.1. Network

The probabilistic model performance is evaluated using two different network topologies, the EON and the cost239. The EON is the same topology presented in the section 6.3 (see Figure 6.1). Figure 7.2 presents the Cost 239 topology. Both topologies are European networks, the EON connect 20 cities along all the Europe, while the Cost 239 connect 10 central European cities. The major difference between these two topologies, beside the number of nodes is the network connectivity. The cost 239 topology has a greater connectivity level than the EON.

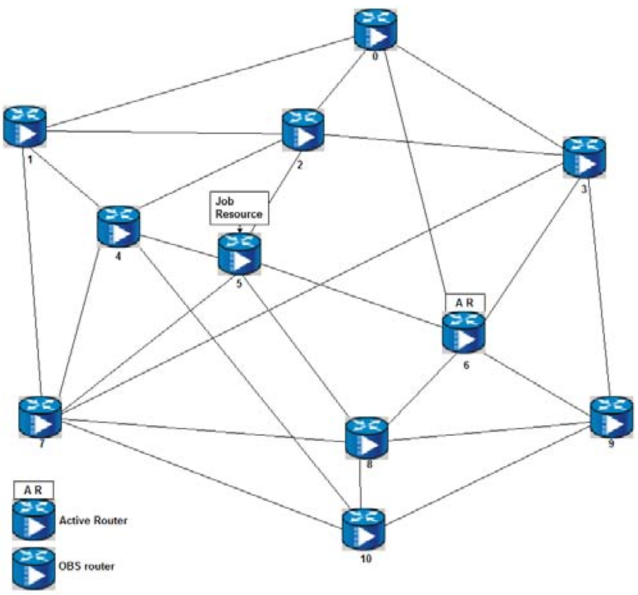


Figure 7.2 - Cost239 Grid over OBS topology, where the node 6 is the Active Router and the node 5 is the Grid Job Resource.

WDM fibers with four wavelengths are considered, one of which is used exclusively for signaling transmission, while the other 3 are used for the data transmission. A non wavelength conversion scenario is considered.

The job requests are generated as a Poisson process with mean arrival rate λ arrivals/ms. Job sizes are distributed according to a exponential distribution with mean $1/\mu$.

The performance is compared with the JET-OBS signaling which selects the paths randomly from the shortest paths.

7.5.2. Sorting technique: increasing

In this strategy the paths are ranked based on their weight; the first chosen is the one with less overall weight. To test the path selection strategy performance we use three different network scenarios. The scenario presented in Figure 6.1 and in Figure 7.2 with the node 6 the Active Router and two different locations for the Grid Job Resource (node 5 and 7). This two locations are considered in order to assess the performance of the Cost 239 topology using a resource in a central location with less connectivity (node 5), or the Grid job resource in a network edge with higher connectivity (node 7).

Figure 7.3 present the job blocking probability for the EON scenario presented in Figure 6.1. We fixed the job duration (0.2, 0.6, 1.0, 2.0, 5.0, 10.0, 20.0 and 40.0 ms) and variable interval between the generation of the Jobs.

Figure 7.4 and Figure 7.5 show the equivalent results for the cost 239 network topology scenarios. In Figure 7.4, we verify the performance of the network with the Active Router placed in the node 6 and the Grid Job Resource in the node 5, while in Figure 7.5; the Active Router is also the node 5, while the Job Resource is the node 7.

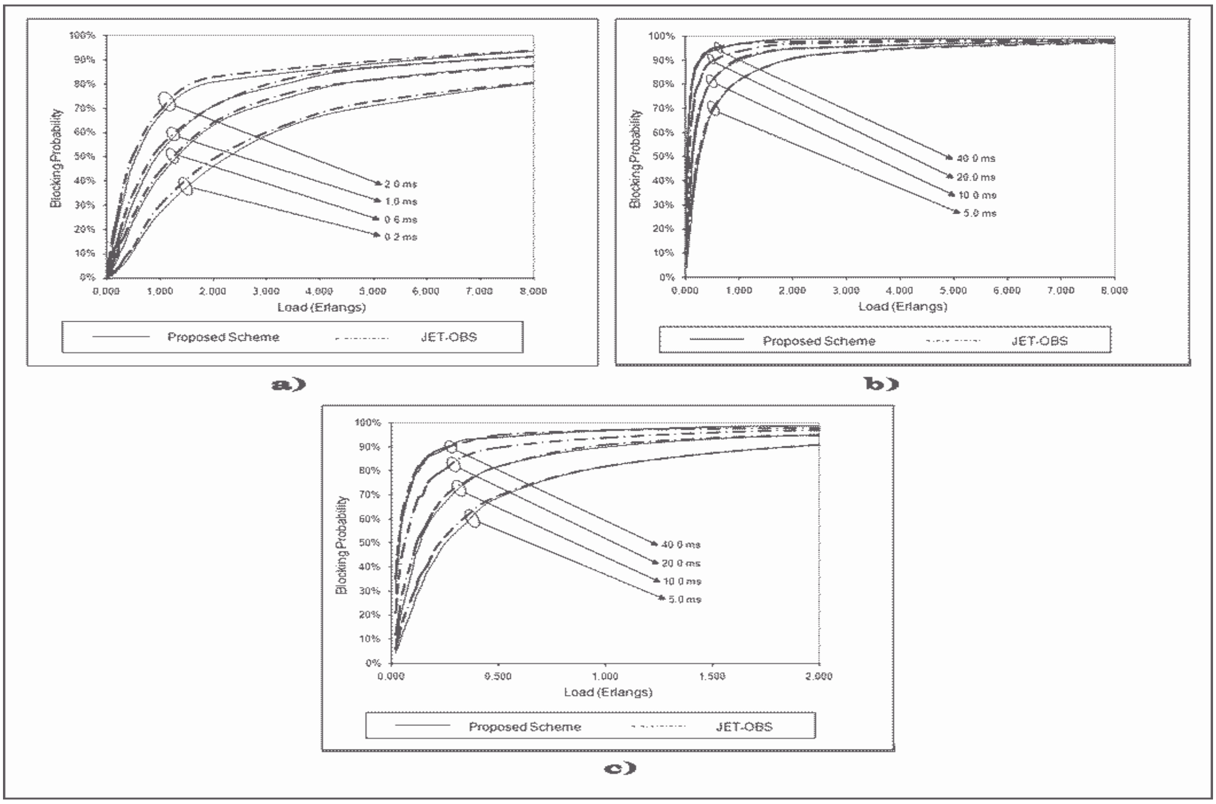


Figure 7.3 - Job blocking probability versus load using EON network with the node 14 as Active Router and the node 4 is the job resource. The paths are ranked by is weight for the job durations of *a)* 0.2, 0.5, 1.0 and 2.0ms, *b)* 5.0, 10.0, 20.0 and 40.0 ms and *c)* 5.0, 10.0, 20.0 and 40.0 ms for lower loads.

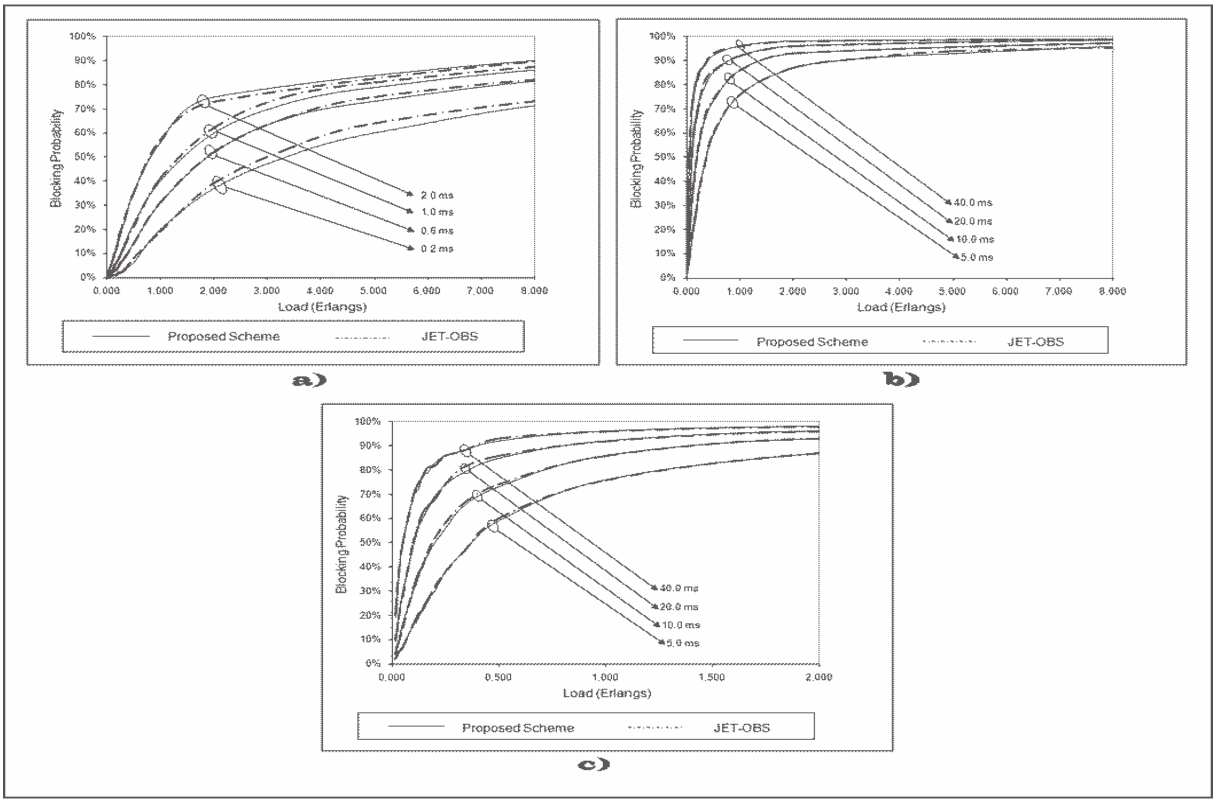


Figure 7.4 - Job blocking probability versus load using Cost 239 network with the node 6 as Active Router and the node 5 is the job resource. The paths are ranked by is weight for the job durations of *a)* 0.2, 0.5, 1.0 and 2.0ms, *b)* 5.0, 10.0, 20.0 and 40.0 ms and *c)* 5.0, 10.0, 20.0 and 40.0 ms for lower loads.

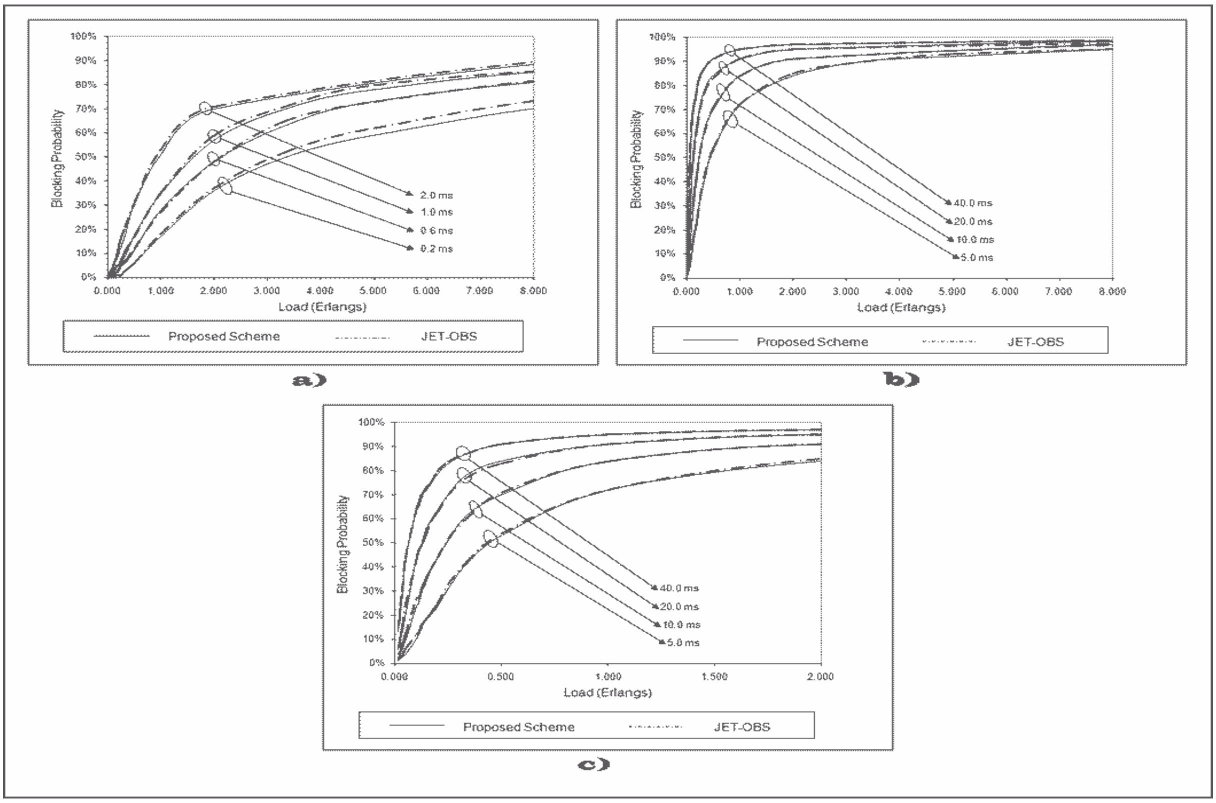


Figure 7.5 - Job blocking probability versus load using Cost 239 network with the node 6 as Active Router and the node 7 is the job resource. The paths are ranked by is weight for the job durations of *a)* 0.2, 0.5, 1.0 and 2.0ms, *b)* 5.0, 10.0, 20.0 and 40.0 ms and *c)* 5.0, 10.0, 20.0 and 40.0 ms for lower loads.

For smaller jobs, the proposed scheme outperforms JET-OBS (see part *a)* of the Figure 7.3, Figure 7.4 and Figure 7.5). For the longer jobs (*b)* and *c)* of Figure 7.3, Figure 7.4 and Figure 7.5), the job blocking occurrence is very similar and stabilize at the same value. The *c)* represents the scenario with longer jobs for low loads. The proposed scheme for the EON network (see Figure 7.3 *c)*) has less blocking probability that the JET-OBS. In all other scenarios, the difference between both path selection strategies for longer jobs is very small.

Since the Cost 239 has less nodes and higher connectivity level than the EON, the job blocking probability is smaller. The EON topology has links that are used by different nodes to satisfy its demands; the higher connectivity level presented in Cost239 topology avoids the bottlenecks created by a link being used to satisfy demands from a large number of nodes.

Comparing the two cost 239 scenarios, it is verified that the Job Resource in the node 7 (the node with higher connectivity), the job blocking probability is lower than the other case. This occurs because the node 7 has more input ports, giving to the network more physical network resources to reach the Grid Job Resource.

7.5.3. Sorting technique: decreasing

In this section we present another possibility to rank the paths using the probabilistic model, where the paths are ranked by the inverse order. This is the worst possible case using the probabilistic model to select the paths, because the paths are ranked by the inverse order, the path with more probability of being used is always the first choice.

The network scenarios in this section are the same that were presented in the previous section The Figure 7.6 shows the job blocking probability versus load for the EON topology with Active Router placed in the node 14 and the Grid Job Resource is the node 4. Figure 7.7 is the cost 239 scenario with the Active Router and the Grid Job Resource placed respectively in the nodes 6 and 5. Finally the Figure 7.8 present another cost 239 network scenario with the Job Resource switched to the node 7.

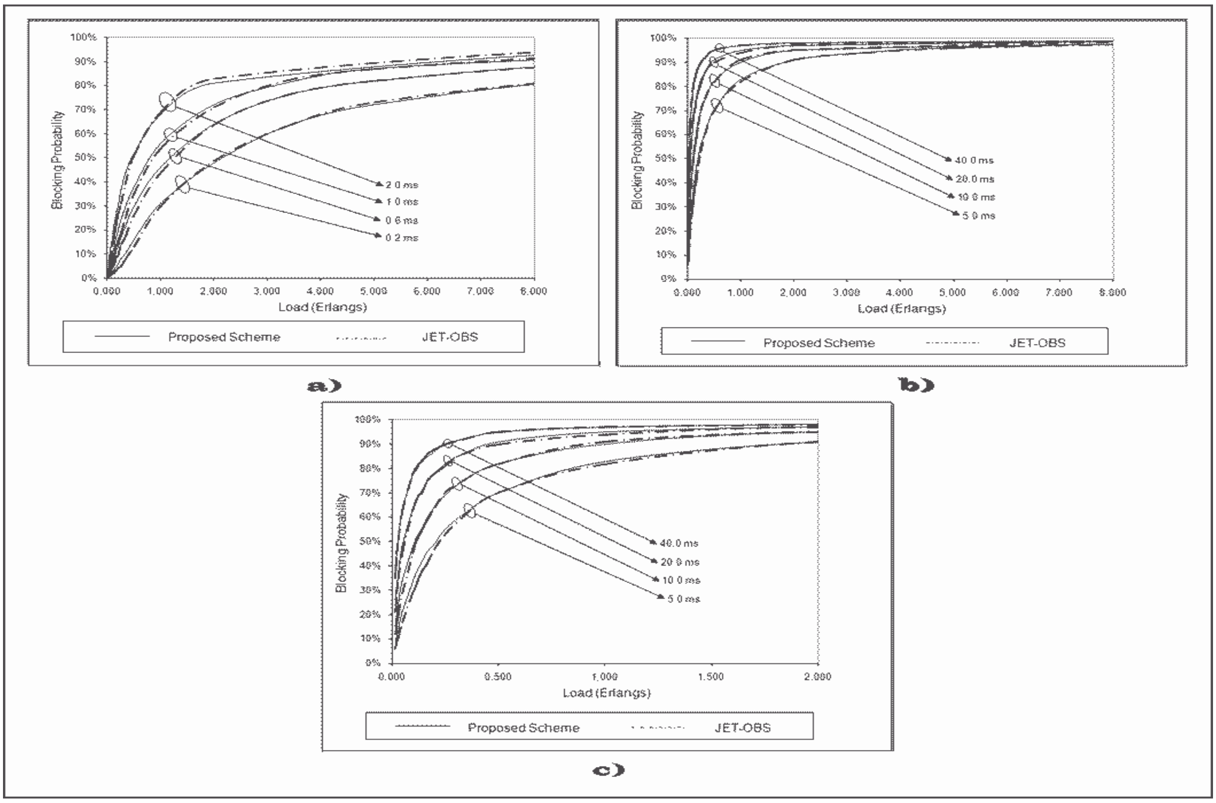


Figure 7.6 - Job blocking probability versus load using EON network with the node 14 as Active Router and the node 4 is the job resource. The paths are ranked by the inverse weight for the job durations of *a)* 0.2, 0.5, 1.0 and 2.0ms, *b)* 5.0, 10.0, 20.0 and 40.0 ms and *c)* 5.0, 10.0, 20.0 and 40.0 ms for lower loads.

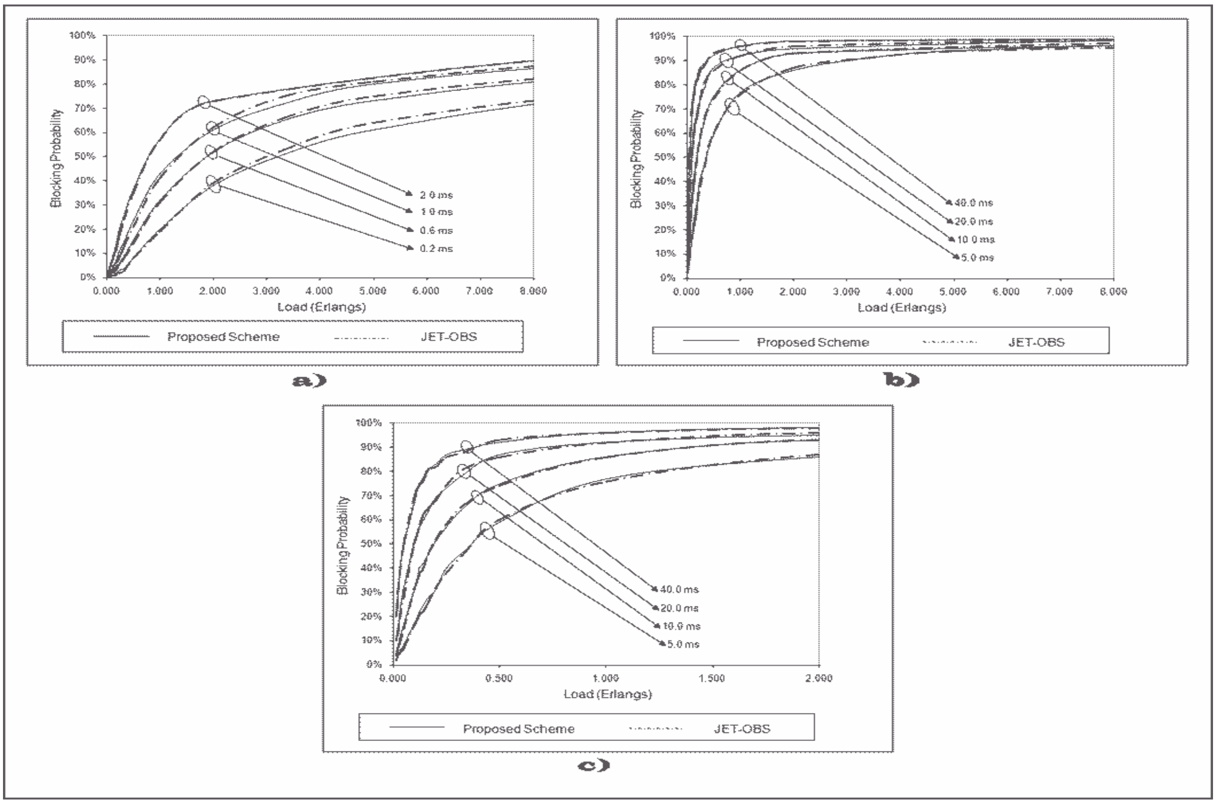


Figure 7.7 - Job blocking probability versus load using Cost 239 network with the node 6 as Active Router and the node 5 is the job resource. The paths are ranked by the inverse weight for the job durations of *a)* 0.2, 0.5, 1.0 and 2.0ms, *b)* 5.0, 10.0, 20.0 and 40.0 ms and *c)* 5.0, 10.0, 20.0 and 40.0 ms for lower loads.

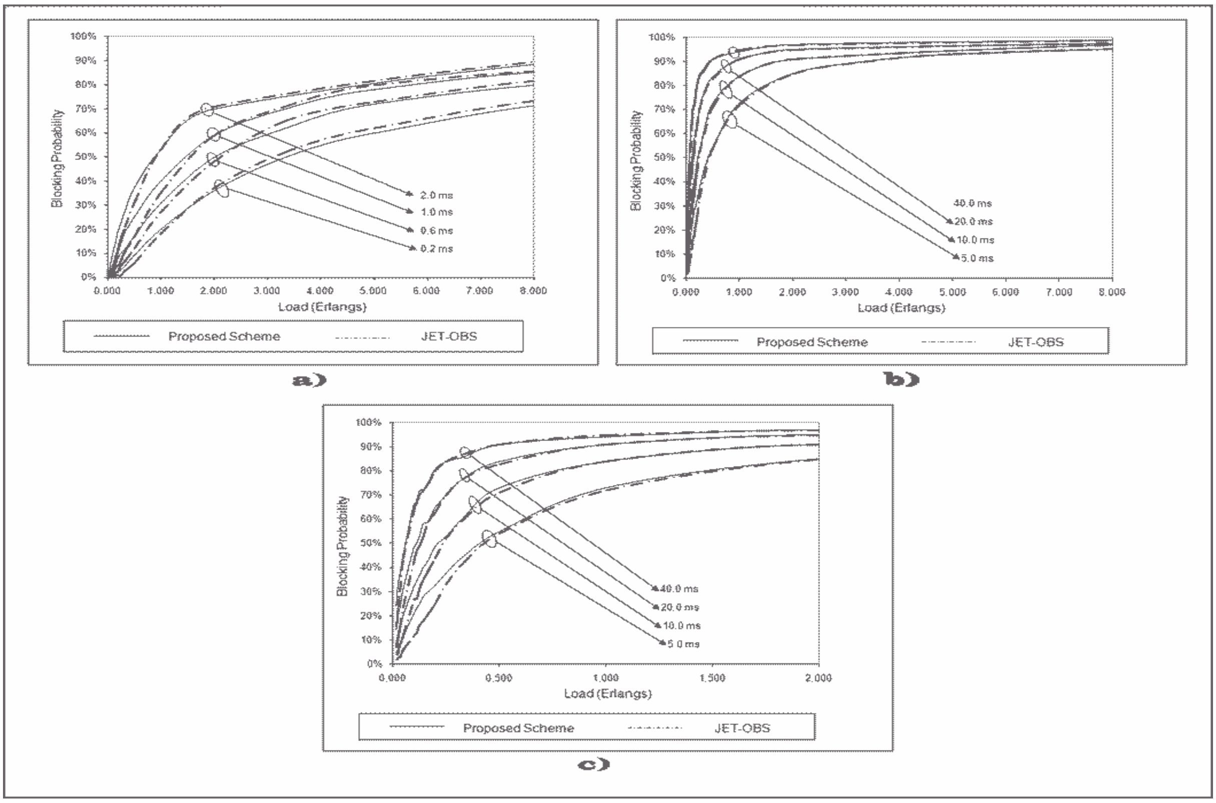


Figure 7.8 - Job blocking probability versus load using Cost 239 network with the node 6 as Active Router and the node 7 is the job resource. The paths are ranked by the inverse weight for the job durations of *a)* 0.2, 0.5, 1.0, 2.0ms and *b)* 5.0, 10.0, 20.0 and 40.0 ms and *c)* 5.0, 10.0, 20.0 and 40.0 ms for lower loads.

In the three scenarios presented in this section for the higher job durations (part *b)* and *c)* of the Figure 7.6, Figure 7.7 and Figure 7.8), and higher loads (part *a)*) the both schemes stabilize at the same value, and for lower loads (part *c)*) the random path selection used by the JET-OBS presents a lower job blocking probability.

For small job duration (part *a)* of the Figure 7.6, Figure 7.7 and Figure 7.8) the job blocking probability is smaller for the proposed scheme, although the gain is small. The cost 239 scenarios, the difference between job blocking probabilities is higher than the obtained with the EON, because the cost network present a higher connectivity. The gain of this path sorting strategy is smaller than the one obtained sorting the paths by its weight (comparing the *a)* part of Figure 7.4 and Figure 7.5 with *a)* part of Figure 7.7 and Figure 7.8).

A random choice is a better choice than the inverse order sorting, because the paths with higher dropping probability are always the first choice, while in JET, the paths are selected randomly. All the paths have the same probability of being chosen.

7.5.4. Sorting technique: round robin

The round robin path selection strategy consists in each node; sorted by the weight the paths used to reach the Grid Job Resource. Next, for each job, the source node select the path by a round robin way, first use the first path, for the second job, the second path, and so on until the last available path, and then it will return to the first path, restarting from the beginning again. Using a round robin strategy, the nodes do not use always the optimums paths. The optimum path can be the optimum path of several source–end node pare. All the nodes will use all the paths in the list, once at a time. With this technique we try to avoid the possible bottlenecks created on the most popular links, selecting the paths in a circular technique.

Figure 7.9, Figure 7.10 and Figure 7.11 present the job blocking probability versus load. In Figure 7.9 use the network scenario presented in Figure 6.1. Figure 7.10 and Figure 7.11 use a cost 239 topology with the Active Router placed in the node 6 and the Job Resource are the nodes 5 and 7 respectively.

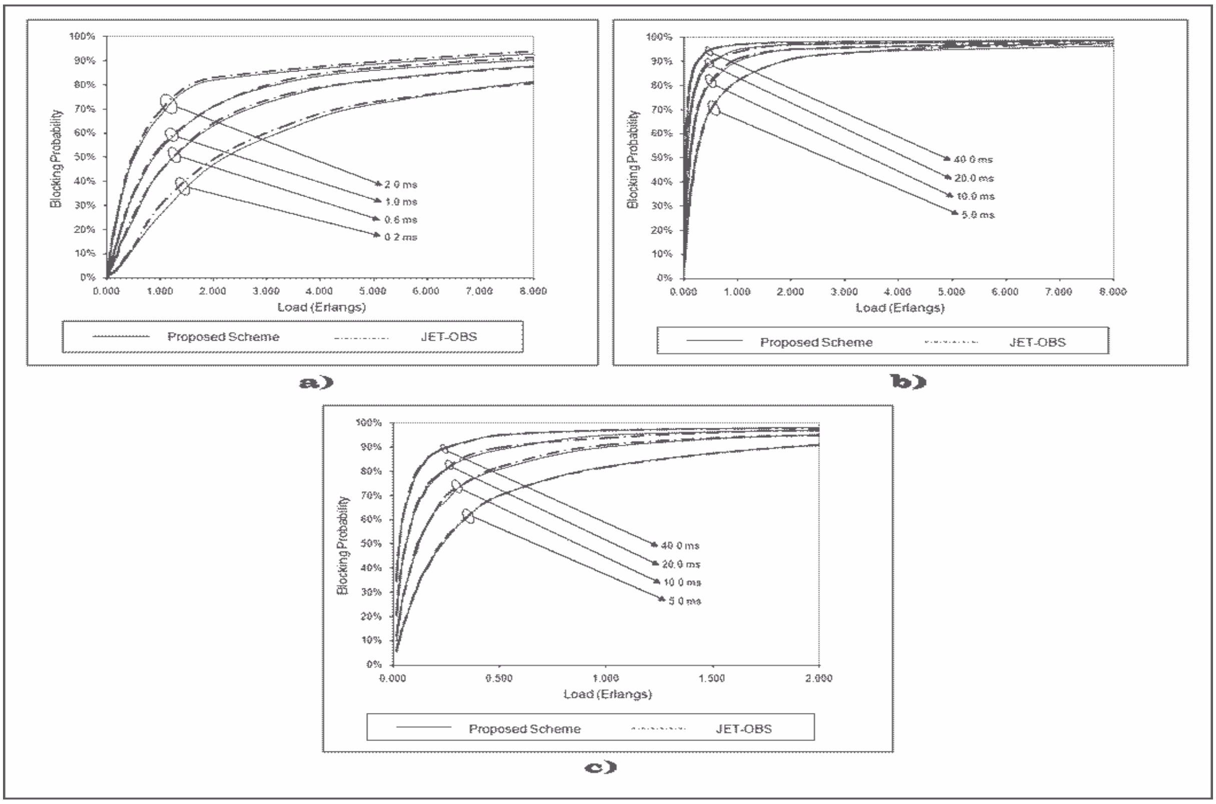


Figure 7.9 - Job blocking probability versus load using EON network with the node 14 as Active Router and the node 4 is the job resource. The paths are ranked using the round robin for the job durations of *a)* 0.2, 0.5, 1.0 and 2.0ms, *b)* 5.0, 10.0, 20.0 and 40.0 ms and *c)* 5.0, 10.0, 20.0 and 40.0 ms for lower loads.

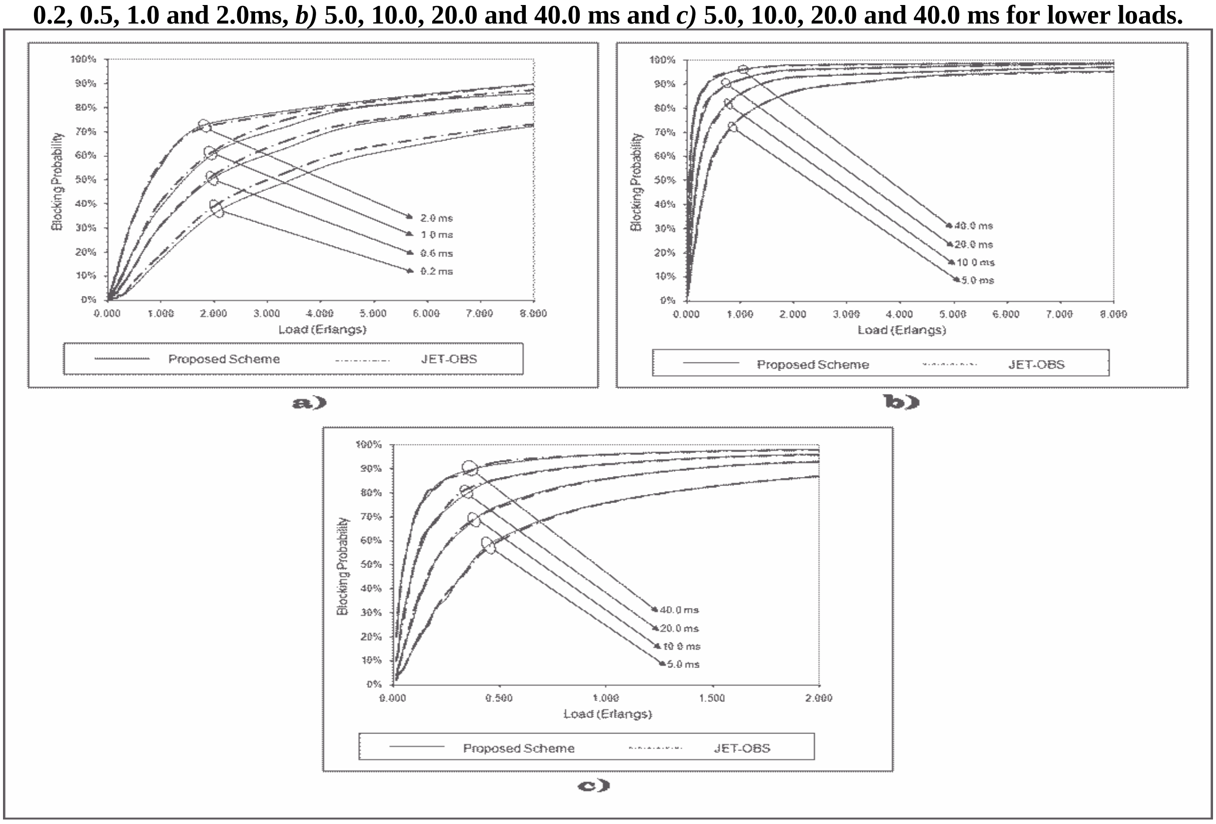


Figure 7.10 - Job blocking probability versus load using Cost 239 network with the node 6 as Active Router and the node 5 is the job resource. The paths are ranked using the round robin for the job durations of *a)* 0.2, 0.5, 1.0, 2.0ms, *b)* 5.0, 10.0, 20.0 and 40.0 ms and *c)* 5.0, 10.0, 20.0 and 40.0 ms for lower loads.

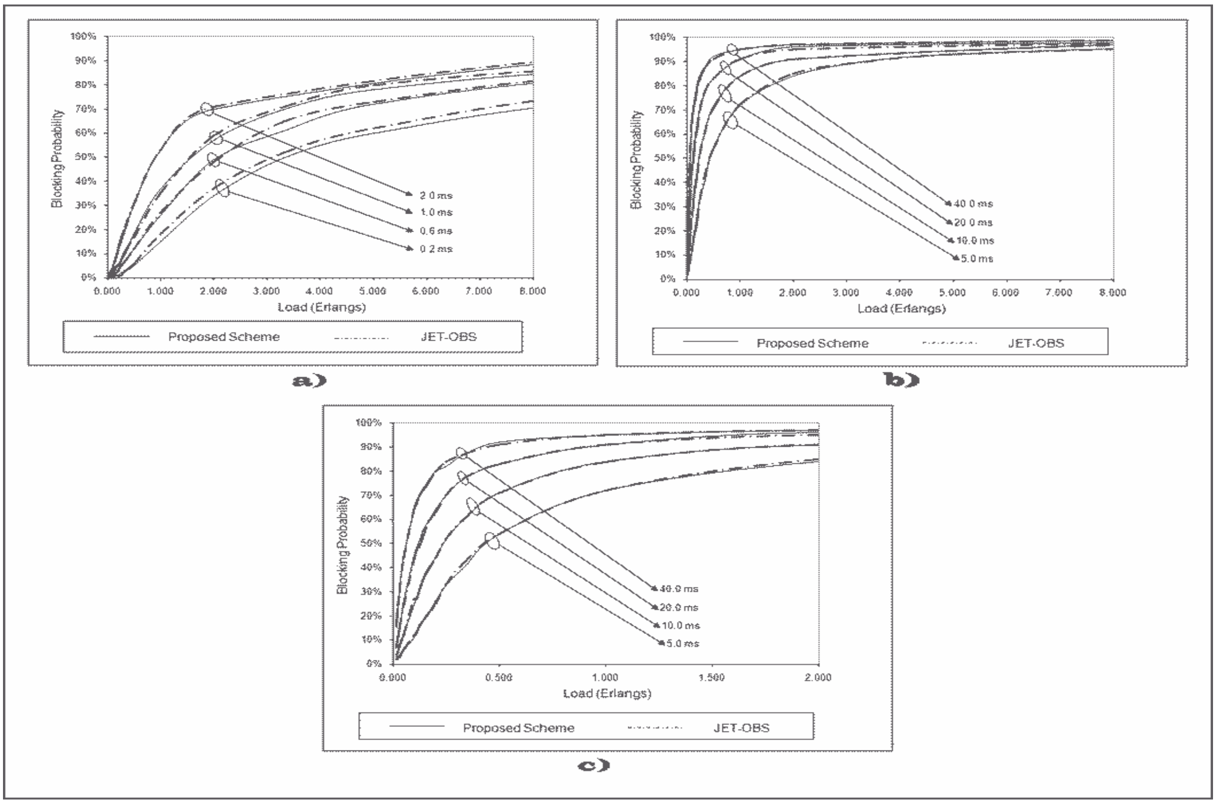


Figure 7.11 - Job blocking probability versus load using Cost 239 network with the node 6 as Active Router and the node 7 is the job resource. The paths are ranked using the round robin for the job durations of *a)* 0.2, 0.5, 1.0 and 2.0ms, *b)* 5.0, 10.0, 20.0 and 40.0 ms and *c)* 5.0, 10.0, 20.0 and 40.0 ms for lower loads.

The Round-Robin path selection strategy, for the small jobs, the proposed scheme outperforms the JET-OBS. The job dropping probability for the job durations with longer jobs is very similar for both schemes, since the lower loads (see *c)*) until the higher loads (see *b)*).

7.5.5. Sorting technique: alternate from increasing to decreasing

In this section we present the final sorting technique. This strategy is the combination of the increasing and decreasing techniques. When the source node selects the path, if the previous was chosen by the increase order, it will sort the paths by the decrease order, and vice versa. This strategy is used to avoid the bottlenecks created in the most popular links, like the round robin strategy (section 7.5.4).

Figure 7.12 presents the job blocking probability versus load for the EON network topology with the Active Router and the Job Resource placed ate the nodes 14 and 4.

In Figure 7.13 is presented the plot with the job dropping probability of the proposed scheme and the JET OBS using the cost 239 topology with the node 6 as Active Router and node 5 as Grid Job Provider.

Figure 7.14 is presented a network scenario similar to the one presented by Figure 7.13, where the Job provider is switched to the node 7.

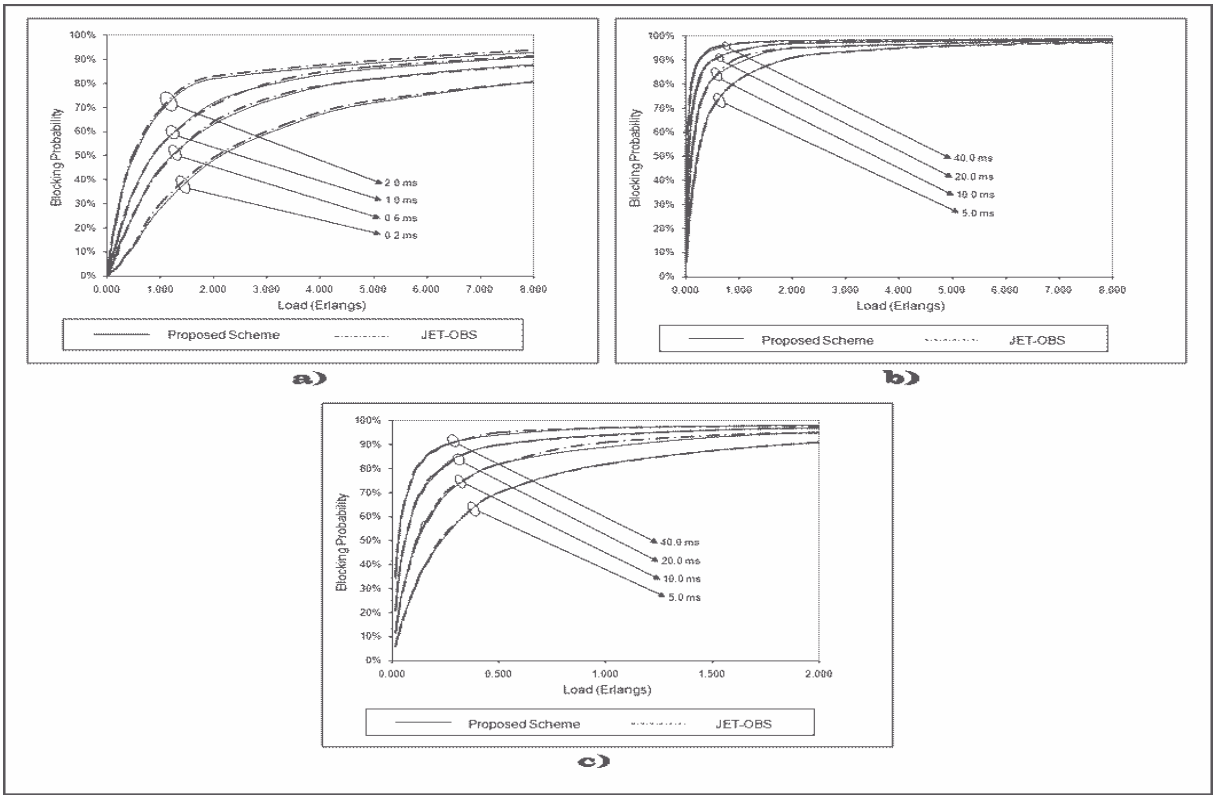


Figure 7.12 - Job blocking probability versus load using EON network with the node 14 as Active Router and the node 4 is the job resource. The paths are ranked alternating from increase to decrease order for the job durations of *a)* 0.2, 0.5, 1.0 and 2.0ms, *b)* 5.0, 10.0, 20.0 and 40.0 ms and *c)* 5.0, 10.0, 20.0 and 40.0 ms for lower loads.

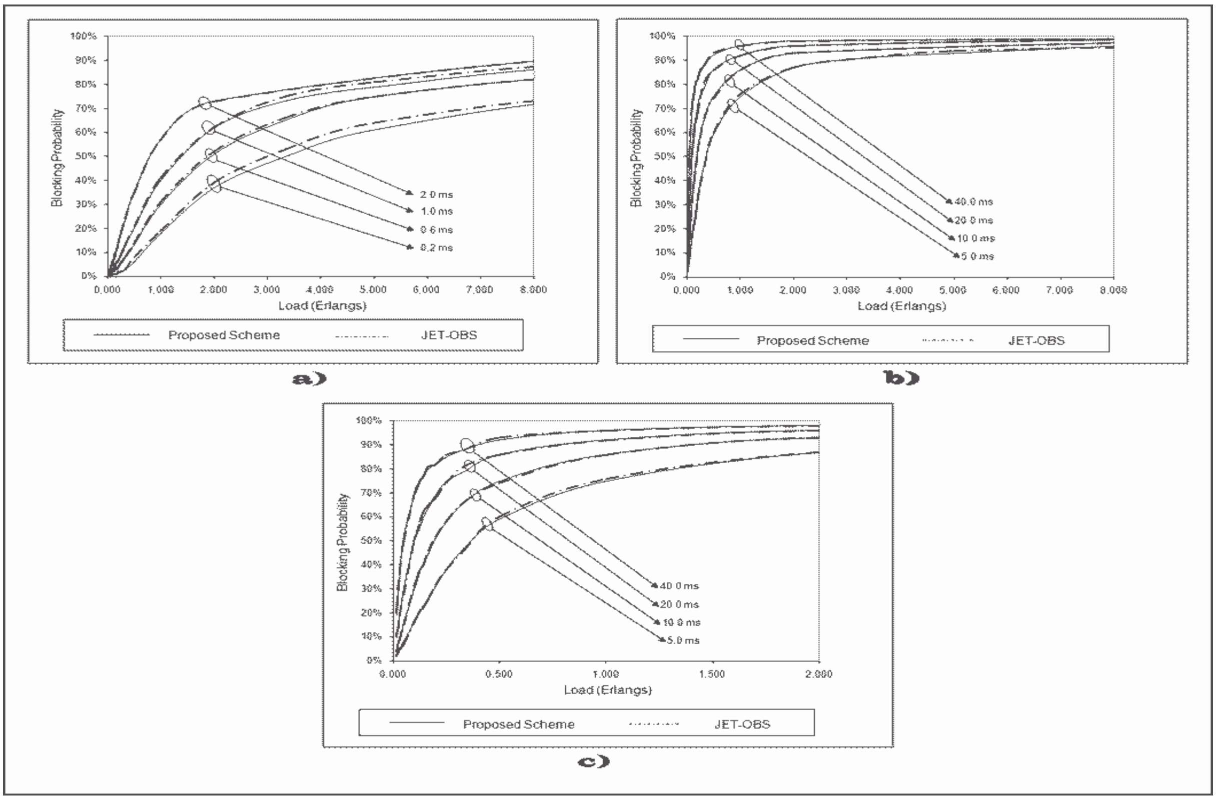


Figure 7.13 - Job blocking probability versus load using Cost 239 network with the node 6 as Active Router and the node 5 is the job resource. The paths are ranked alternating from increase to decrease order for the job durations of *a)* 0.2, 0.5, 1.0 and 2.0ms, *b)* 5.0, 10.0, 20.0 and 40.0 ms and *c)* 5.0, 10.0, 20.0 and 40.0 ms for lower loads.

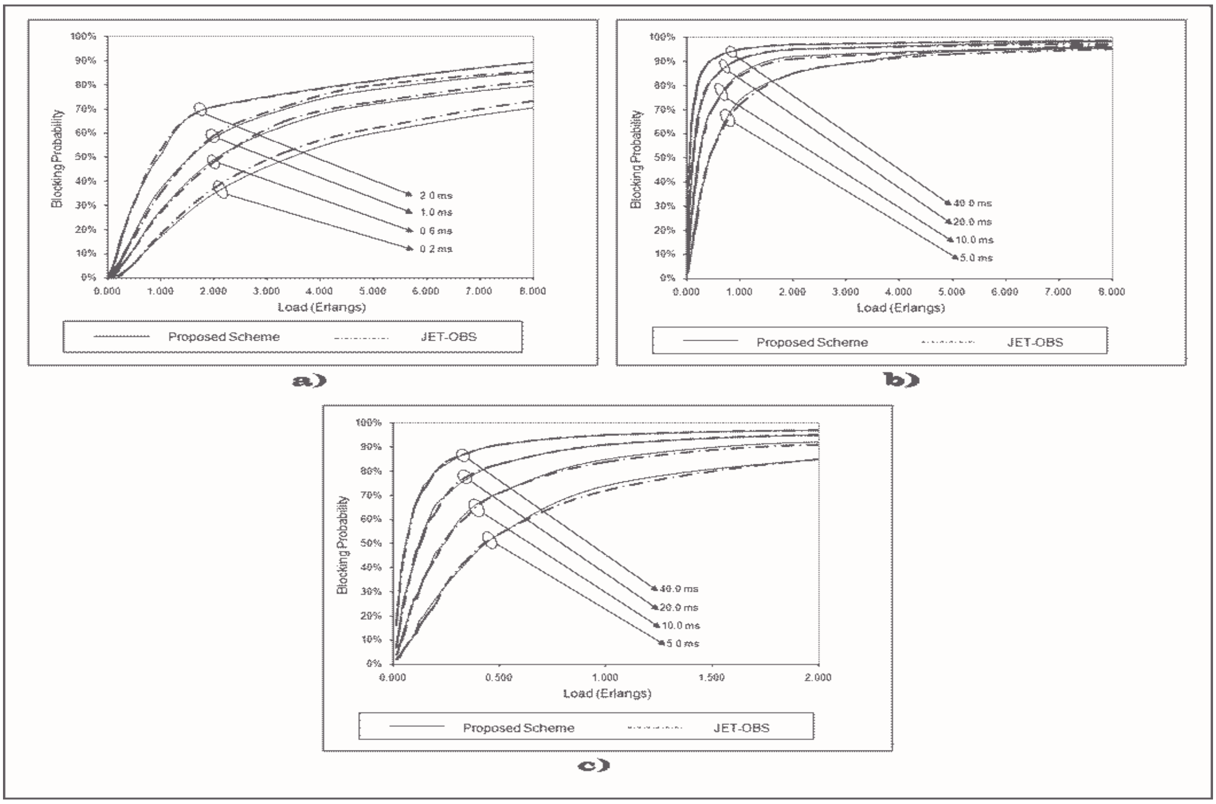


Figure 7.14 - Job blocking probability versus load using Cost 239 network with the node 6 as Active Router and the node 7 is the job resource. The paths are ranked alternating from increase to decrease order for the job durations of *a)* 0.2, 0.5, 1.0 and 2.0ms, *b)* 5.0, 10.0, 20.0 and 40.0 ms and *c)* 5.0, 10.0, 20.0 and 40.0 ms for lower loads.

For small jobs duration, the proposed scheme outperforms the JET-OBS (part *a)* of Figure 7.12, Figure 7.13 and Figure 7.14). The gain is more significant in the Cost 239 scenarios, because the higher network connectivity make select a larger group of different links to reach the Job Resource, producing an inferior overall job dropping percentage.

For larger jobs, presented in *b)* and *c)* plots of the Figure 7.12, Figure 7.13 and Figure 7.14, the proposed scheme have a job dropping probability very similar to the one obtained by JET-OBS and both schemes stabilize at the same value, for lower (see plots *c)*) and higher loads (see plots *b)*).

7.5.6. Comparison between sorting techniques

Figure 7.15, Figure 7.16 and Figure 7.17 show the comparison between the four sorting techniques, for small jobs (0.2, 0.6 and 1.0 ms) and lower loads. This scenario was chosen, because it is the scenario that presents the most significant differences between them. Each of the graphics represents a different network topology. The results for the EON are shown in Figure 7.15, Figure 7.16 corresponds to cost239 with the node 6 acting like Active Router and the node 5 is the Job Resource and finally Figure 7.17 corresponds to cost239 with node 6 acting as Active Router and node 7 the job provider.

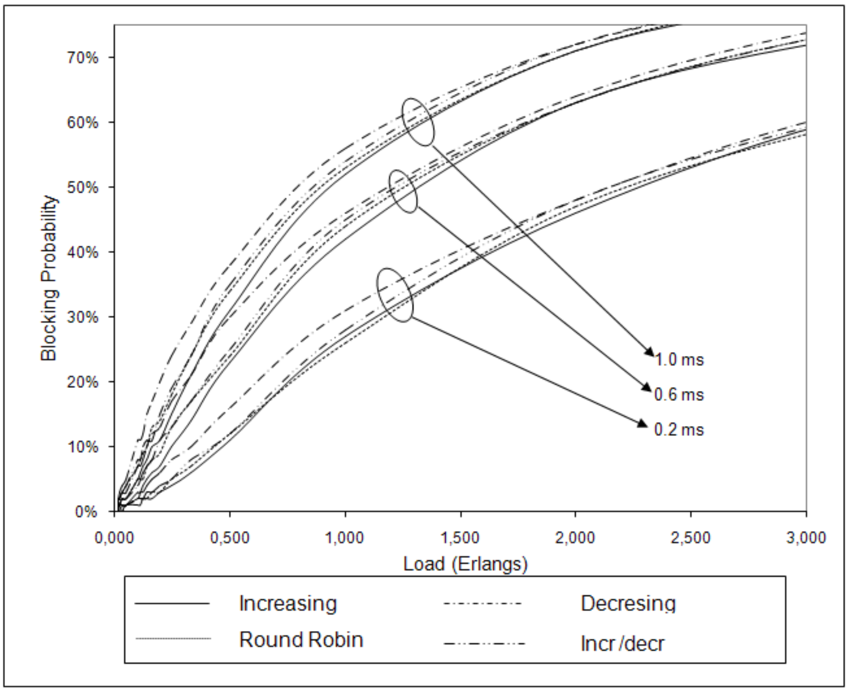


Figure 7.15 - Comparison between the 4 strategies for small bursts durations and low loads, for EON topology with the Active router in node 14 and the node 4 Job Provider.

In the EON scenario, the increasing sorting is the best choice, followed by the round robin, increasing-decreasing and the worst sorting strategy as expected is the decreasing order.

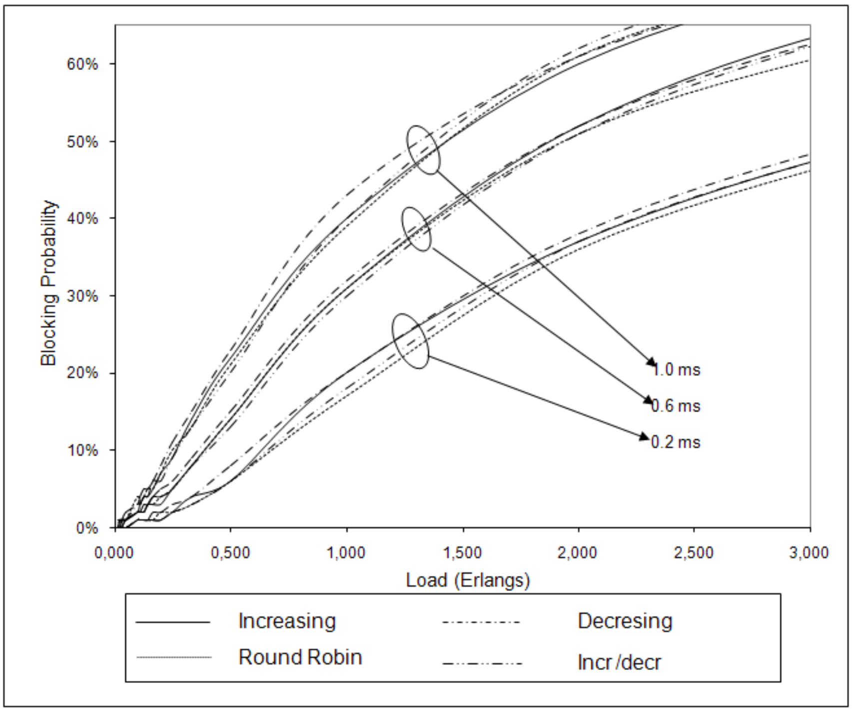


Figure 7.16 - Comparison between the 4 strategies for small bursts durations and low loads, for cost239 topology with the Active router in node 6 and the node 5 Job Provider.

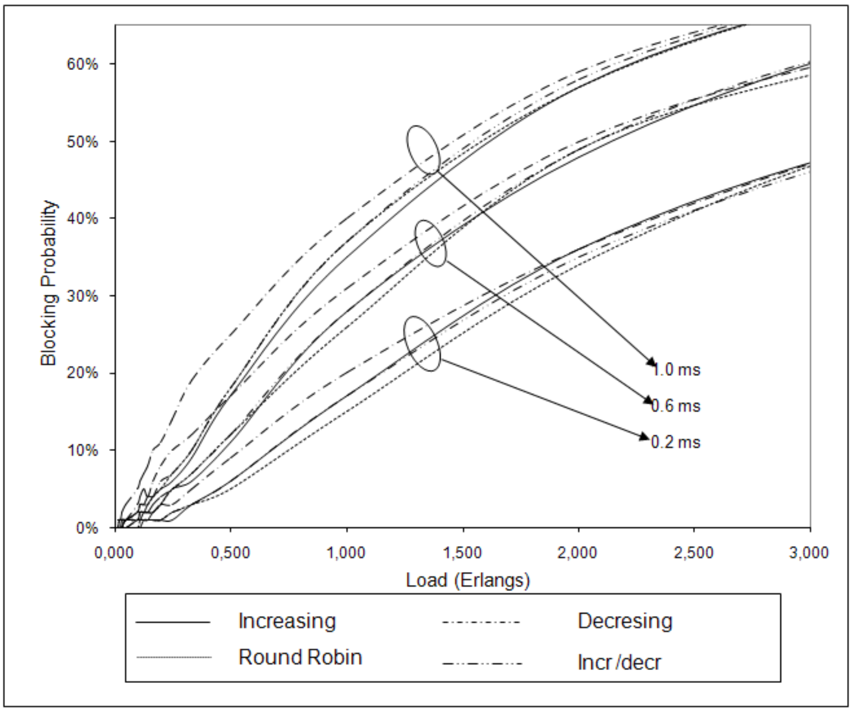


Figure 7.17 - Comparison between the 4 strategies for small bursts durations and low loads, for cost239 topology with the Active router in node 6 and the node 7 Job Provider.

Comparing the Figure 7.16 and Figure 7.17, both have a result very similar, since the network used is the same only the job resource is place on a different place. The job provider location makes the difference between the sorting strategies. Blocking is higher when the job provider is place in the node 7, the one with higher connectivity level in the network. Except for low job durations (0.2 ms), the increasing order and the round-robin are almost the same. For the Cost239 topology the increasing order is only the best choice when the jobs are larger (1 ms), for all the other cases, the round-robin or the increasing decreasing are the best sorting strategies. Like in the EON, the worst sorting strategy is the decreasing, because the paths with higher probability of being used are always the first choice.

The difference between the results presented in the Figure 7.15 which use the EON topology and the figures that use cost239 (Figure 7.16 and Figure 7.17) occur because the cost239 has a higher connectivity level.

7.6. Chapter summary

In this chapter we present our path selection strategy. It is a non adaptative strategy which use a probabilistic model for the link demands to predict the network load. This strategy estimates the probability of the usage of a link by make the probability of every links is being used to satisfy demands from all nodes to all nodes. The path selection strategy performance was verified sorting the paths by it weight using four techniques (increasing, decreasing, round robin or alternating from increasing to decreasing).

Analyzing all the sorting strategies evaluated in the sections 7.5 we verify that our path selection strategy for lower packet size the job blocking probability is smaller to the one obtained by the JET-OBS in all the scenarios except using decreasing sorting in the EON network (Figure 7.6). Because the path selection strategy based on the probabilistic model using the small job sizes outperform the JET-OBS using random source routing, is very suitable for the GOBS consumer scenarios, where the used jobs are small. We have shown that the most efficient path sorting techniques for all the scenarios considered is the increasing.

Chapter 8. Conclusions and Future work

8.1. Conclusion

This dissertation proposes, discusses and evaluates a signaling scheme for Grid over Optical Burst Switching networks controlled by an Active Router. The Active Router is a network entity with a global knowledge within a network domain. The Active Router is responsible to select the Grid Job Resource used to resolve the jobs.

We present two different strategies to reduce the job dropping occurrence. The first strategy is the novel signaling scheme presented in Chapter 6. The second strategy is presented in Chapter 7. In this second strategy, the Active Router only select the Grid Resource used to resolve the path, and the path used to reach it is selected based on the probabilistic model for the link demands.

In the first strategy, the Active Router has an important role in the job dropping reduction. The Active Router selects the path used by the Data Burst to reach the Grid Job Resource based on the network actual status. The Active Router maintains the network status always updated. Since the status is always updated, the bursts are only dropped when is not possible connect the source to the end node. In section 6.5.1 it is compared the job blocking probability of the proposed scheme with the JET-OBS with random path selection, which is the signaling scheme most commonly used in OBS networks. The proposed scheme presents always a lower job blocking probability. In this strategy it is also studied the influence of a signaling buffer in the Active Router. The signaling buffer is used by the Active Router to retain the Grid Resource Requests. The signaling queue usage makes the Active Router perform only one request at a time. Comparing the scenarios with signaling queue or without, the scenario with the buffer have less dropping occurrence, because the paths are resolved using resources that were not free in the bufferless scenario. The resource availability occurs because the Active Router only resolves one request at each processing time.

Another study associated with this signaling scheme is the reservation time. The reservation time considered is the used time since the job creation until start the burst transmission. The reservation time is an important study because the reservation time in OBS networks needs to be as low as possible. We consider two reservation time scenarios, use the signaling buffer in the Active Router or use a network with no buffering scenario. The reservation time in the network without buffer is always inferior to the one performed by JET-OBS. This reduction in the reservation time is caused because the Active Router is responsible to start the reconfiguration process, while in JET-OBS the Grid Client start the network configuration process. In the buffered scenario, the principal consequence introduced by the buffer is the reservation time increase. The buffer introduction causes a reduction in the job dropping probability introducing longer reservations times.

The second scenario is presented in Chapter 7. The Active Router is responsible to select Grid Job Resource for each job. The path used to connect the Grid client to the Grid Resource is selected by the Grid client based on a probabilistic model for the link demands. The probabilistic model is used to predict a possible network usage based on the demands from all nodes to all nodes. The probabilistic model results in a weight for each link. The weight represents the possibility of the link being used. The paths weight is obtained summing the weight of the used links. The source node rank the group of the shortest paths based its overall weight. The strategies presented to sort the paths are increasing, decrease, round robin and alternate from increasing to decreasing. The probabilistic model performance is tested comparing the ranking strategies based on the probabilistic model job blocking probability with the random path selection. The strategy with better performance is the increasing order, because the paths are ranked by their weight, the path with less weight is the first to be selected. The worst strategy is the decreasing order where the worst paths are always the first choice.

This master dissertation presents a consumer scenario for Grid over OBS networks. The consumer scenarios are characterized by having low computational requirements and smaller durations. The strategies presented in this work are very suitable for consumer scenarios, because present the fewer job blocking probabilities for smaller jobs duration.

8.2. Future work

The proposed scheme presented in Chapter 6 and Chapter 7 reduces the burst blocking probability when compared with the JET-OBS. To increase the wavelength reservation efficiency it would be interesting to explore the burst scheduling algorithms presented in section 2.7. With the introduction of the burst scheduling algorithms the wavelengths usage is improved and consequently the burst blocking probability reduced.

The buffers used in this work are infinite. In real networks infinite buffer do not exist. A more real approach is introducing a buffer with different classes of services. The services with higher priority are always resolved first and when the resolution time expires the requests should be popped from the buffer and the job retransmission or dropping is left for upper network layer resolution.

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