CONTENTS

# Congestion Control Mechanisms for Optical Burst Switched Networks

Fei Wang

***Abstract*—Among the current several optical switching network. OBS have been received extensive attention by taking advantage of statistical multiplexing and easily achieved. However, when congestion occurs in the OBS core. Large amount of burst have to be dropped because of bufferless. In this master project, I propose a close-loop congestion control scheme . On core routers side, they track network status and broadcast messages to edge nodes in certain period. Edge routers adjust transmission rate according to the feedback information. Through leaky bucket, the source flow-rate will be in control and this scheme will keep the network away from high blocking rate and then stay a stable state by avoiding congestion. Burst blocked rate, throughput trade-off are focus of this paper. Simulation results are also present to show the above scheme improve network performance and reduce the burst blocking probability.**

***Index Terms*—Leaky Bucket, OBS, Congestion Control.**

## I. Introduction

OBS has been proposed as strong candidate for the next generation optical internet. OBS can achieve high statistical multiplexing and provide flexible and dynamic bandwidth allocation required to support highly dynamic and burst traffic[1]. In OBS networks, all input data are assembled into a burst according to their destination in edge side, referred to as data burstsd(DB), Shortly before the burst transmission begin, a burst header cell(BHC) is sent on the control channel that is processing on electric domain. The control packet BHC which contains information such as the destination address, the length of burst, the number of hops it pass through and the burst offset time. BHC channel is separated from the data burst channel. It take offset time to let the header cell be processed at each intermediate router before the data burst arrives. When all router along the path between source and destination complete resource reservation. DB can go through the path within whole high-speed optical domain. The main different difference between an optical network and a conventional packet switching network are without optical buffer on the intermediate router. Once the network is congested, some or all of bursts have to be dropped since bufferless on OBS. Hence, contention is inherent to the OBS technique and contention issue could affect tremendously the network performance in terms of burst blocked rate and throughput. Recently, contention and loss ratio may be reduced by implementing contention resolution policies, such as time defection (using fiber delay line [2]), space deflection (using deflection routing [3]), and wavelength conversion [4]. These mechanisms can reduce burst blocked rate in short-term burst congestion. But if the burst congestion lasts longer, the contention resolution policies can't handle any more. Some or all conflict bursts must be dropped. And then there are several soft contention resolution policy can be applied for determining which bursts to drop.

The contention resolution policies are considered as reactive approaches in the sense that they are invoked after contention occurs. But also increase the complex implementation issues. An alternative approach to avoid network contention and reduce burst loss is by proactively attempting to prevent network from overload through traffic management. This paper focus on how to keep the rate of burst blocked rate of a network around a controllable level. An ideal congestion control mechanism should achieve some objectives: enhance the throughput, reduce the average end-to-end burst delay, reduce data burst blocked rate, fair to all users and react timely. Basically, the congestion problem is due to the lack of information at the nodes and the absence of global coordination between the edge nodes and core nodes. As we know, in OBS, all intelligence resides in the edge nodes, which provides the buffer and the processor at the same time on the network. To solve these problems and consider about the feature of OBS, I develop a detect-feedback-react loop congestion control mechanism.

The rest of the article is organized as follows.Section 2 stats the background of problem and related studies. The proposed congestion control scheme is illustrated in Section 3. Section 4 presents and analysis the computer experiment results. Finally, I concludes this paper in Section 5.

## II. Background, specification and related studies

### A. *Background and specification*

When there are too many bursts enter network, the performance of network will drop quickly. This phenomenon is known as congestion.

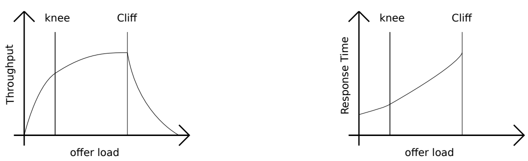


Fig. 1. Congestive collapse

As figure 1 shown, when the offer load is low, the throughput of network increases linearly with offer load. The growth of response time is also slow. But when the offer load is higher than knee, the growth of throughput is slow but the response time increase sharply. When the offer load higher than cliff, the throughput fall sharply and response time shard rise. So the object of congestion control is to avoid network enter congestion and take action to clear out congestion if it occurs. That is said keep the offer load stay between knee and cliff as long as possible.

### B. Related studies

General speaking, there are two paradigms to handle congestion control. One with feedback message and the other without feedback message. For a non-feedback-based mechanism, also known as open-loop control, the edge routers have no information about the state of network and then cannot react to adjust the network offer load. All edge nodes regulate traffic load into network through traffic shaping or traffic rerouting and load balancing based on predefined traffic description [5]. The challenge to implement the congestion control by non-feedback-based networks is to pre-determine the traffic parameter, such as average rate and distribution of arrival process at each edge. But also non-feedback-based control scheme can't adjust dynamically. The study of [6] is a typical open-loop mechanism. Recently, many researchers pay attention to feedback-based network, also refer as close-loop control. There are three stages in feedback-based control, that is detect,feedback,react. The paper [7] compare three detection algorithm. The first based on current traffic information, the second based on single statistic, the third based on multiple statistics. The author conclude that the multiple statistics help improving the estimation accuracy.

## III. Feedback-based congestion control

### A. Feedback control packet format

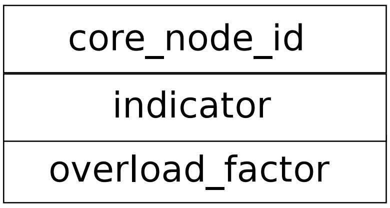


Fig. 2. Feedback Control Packet

Figure 2 shows the feedback control packet fields.

core_node_id: indicate which core router send the feedback control packet. Edge node can reroute to other available link according to this value.

indicator: the congestion status indicator. If congestion occurs, set to 1. Otherwise, set to 0.

overload_factor: the percentage of burst blocked probability exceed the threshold. Edge node can determine the most congestion link with this value.

The feedback packets are broadcast to all associate ingress nodes periodically. In simulation, it is carried by a ICI format packet and assume without loss. On real network, they may transmitted within BHPs but with higher priority [8].

### B. Detection on core router

Core routers are responsible for two main tasks: monitoring incoming bursts, broadcasting feedback control packet to the edge nodes.

The study of [7] suggest multiple statistics improve estimation accuracy and react quickly. After balance the complexity and accuracy. I adopt the single statistic estimation algorithm. That is:

$$
\begin{aligned}
B_{avg}(t) &= (1-\alpha)\times B_{avg}(t-1)+\alpha\times B(t) \\
&\qquad\qquad\qquad\qquad 0<\alpha<1
\end{aligned}
$$

Let $B_{avg}(t)$ denote the average data burst blocked probability of the samples at time $t$ with memory factor $\alpha$, where $B(t)$ is the current data burst blocked probability in a sample period $\tau$.

Then, the detection based on single statistic is,

1) if $B_{avg}(t)\geq B_{th}$, then congestion occurs
2) otherwise, congestion clear out

The implementation of this monitor can be found at [9].

### C. Reaction on edge router

The edge routers are responsible for receiving feedback congestion packet and adjust transmission rate inject into network through leaky bucket traffic shaping. As we know, each ingress router contains flow classifier, burst generation queue, leaky-bucket traffic shaper. Arriving BHPs move into corresponding burst queue according to their destination.

Transmission rate are decided at the leaky bucket traffic shaper based on the feedback control packet at every core routers. For a given path, an optimal transmission rate is determined by the most-congested node on the path.

$$
R_{j,k}(i)=\begin{cases} R_{j,k}(i-1)\times(1+a) & B(i)\geq B_{th} \\ R_{j,k}(i-1)\times(1-b) & B(i)<B_{th}\end{cases}
$$

Let $R_i$ denote the transmission rate of a certain path at the $i$th period. Where $a$ is the rate increasing factor and $b$ is the rate decreasing factor. Generally, $0<a<b<1$.

The implementation of this leaky bucket rate controller can be found at [10].

### D. Determine parameter

As the study of [5] suggest, the feedback mechanism and the parameter setup is very high relevant. So we need to determine the system parameter very carefully. In this part, I will explain how to determine the congestion threshold value and detect period.

Assume the inter-arrival time and service time of data burst meet the poisson distribution. Every fiber line contain $m$ available wavelength. The average arrival rate of DB is $\lambda$. The serve rate is $\mu$. Assume any input port DB scheduled to any wavelength of any output port. Thus, the output port can be considered as `M/M/m/m` queueing system. Denote the traffic load $A=m\rho=m\frac{\lambda}{\mu}$. We can calculate the corresponding theory block probability according to `Erlang-B` formula.

$$P_{block} = \frac{\frac{A^m}{m!}}{\sum_{i=0}^{m} \frac{A^i}{i!}}$$

We can test this in single node value, When network load scale factor is 0.8, $\rho = 1.2$, $m = 10$, $P_{block} = 0.10$, when network load scale factor is 1.0, $\rho = 1.5$, $P_{block} = 0.136$. We can find that is very closed to simulation result. As we know, if the congestion threshold value too low, it will impact the performance of network. On the opposite side, if this value is too high, the mechanism is restricted. So we can estimate the threshold value base this formula for performance trade-off.

Another important parameter is the period of detection and feedback. If this value low, the number of feedback control packets will increase and the performance of network will jitter sharply. If this time window last longer, the react of edge node will be slow. In this paper, I determine this value base on the end-to-end delay. That is

$$\tau = kT_{ete}$$

Where $T_{ete}$ is end-to-end delay. $\tau$ is the sampling period. For single node scenario, let $k = 1000$. Through simulation result, I find that work well. How to determine this value is a complex problem, the study of [11] introduce a dynamic time windows congestion control.

## IV. SIMULATION RESULT

This section present the simulation result based on the feedback-based congestion control. To simplify the problem. I start from a small network just contain single core router but with multiple edge routers. And then go through a normal network. The result demonstrated that congestion control police can reduce burst block ratio and prevent network from entering congestion status.

TABLE I
COMMON PARAMETER

| Parameter | Value |
|---|---|
| Average Burst Length | 0.0001s |
| Number of Link Wavelengths | 10 |
| Use FDLs for Ingress Bursts | no |
| Offset time | 0.0001s |
| Signaling and scheduling mechanisms | LAUC-AF |
| Weighted factor $\alpha$ | 0.5 |
| Congestion detect period | 0.2 |
| Simulation Run Length | 5s |

Table I show the common key parameters share with two scenarios. I also assume the inter-arrival time and burst service time of burst meet the exponential distribution.

### A. Single node scenario

Figure 3 shown the single node scenario topology and the routing table is shown below:

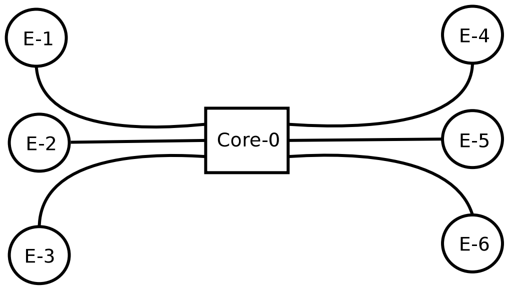


Fig. 3. Single Node Network Model

$$\begin{vmatrix} 1, & 4, & 1, & 0.5, & 1, & 0, & 4 \\ 1, & 5, & 1, & 0.5, & 1, & 0, & 5 \\ 1, & 6, & 1, & 0.5, & 1, & 0, & 6 \\ 2, & 4, & 1, & 0.5, & 2, & 0, & 4 \\ 2, & 5, & 1, & 0.5, & 2, & 0, & 5 \\ 2, & 6, & 1, & 0.5, & 2, & 0, & 6 \\ 3, & 4, & 1, & 0.5, & 3, & 0, & 4 \\ 3, & 5, & 1, & 0.5, & 3, & 0, & 5 \\ 3, & 6, & 1, & 0.5, & 3, & 0, & 6 \end{vmatrix}$$

The format of each row is:
{`src, dest, svc_level, load, path`}

So there are nine paths. Every path pass through the single core node. For comparison purpose, I evaluate the performance of without congestion control mechanism and that employ feedback-based congestion control. Before us begin, we need to define some terms:

Network Load Scale: Specifies scaling factor for traffic offered to network. Each source generate rate calculate as (Network Load Scale) x (normalised load value) x (Link Wavelengths) / (Average Burst Length).

Burst block rate: average rate of data bursts that are blocked due to fail to schedule without available channel.

Throughput: average rate of data bursts that are successfully transfer from source node to destination node.

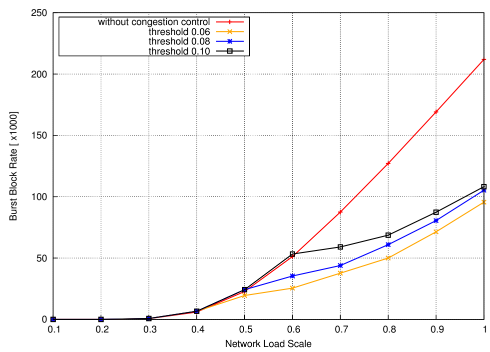


Fig. 4. Burst Block Rate

The burst block rate trend with the network load factor which start from 0.1 to 1.0 is show in the figure 4. To the case without congestion control mechanism, the burst block rate keeps linearly increasing with the network load factor. When reach the bottleneck capacity of network, all arriving bursts will be blocked without any control. The performance would be reduced and network resource will be wasted. The case with congestion control and congestion threshold as 0.06 achieve the lowest burst blocked rate. Since the data burst inject into network will be limited at a lower rate. The figure shown the burst block rate also increases with network load factor. The ideal result will stay a certain value. This because of the simulation time is a little short. If it last longer, the shape of line would trend to be a horizontal line.

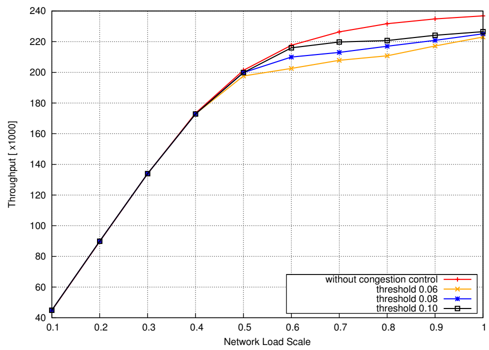


Fig. 5. Throughput

Figure 5 compares the throughput of some case. As it illustrated, the throughput of case without congestion control gain the highest throughput. However, the growth of throughput is the expense of a highest burst block rate as shown in figure 4. When network don't enter congestion, the throughput increase with the growth of network load scale. But if network is saturated, the throughput doesn't increase any more. The excess burst have to burst. This figure also tell that the higher congestion threshold. Network can get higher throughput with higher blocking probability. Throughput and blocking probability trade-off should be consider.

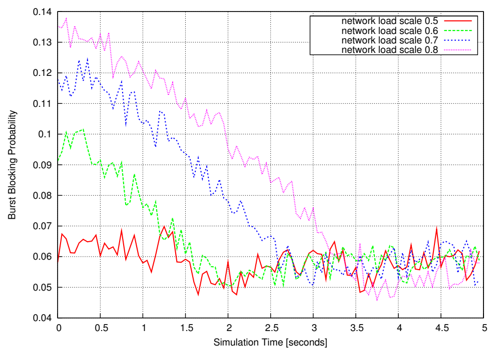


Fig. 6. Block Probability Trend with Congestion Control

Figure 6 shown the effect of feedback-based mechanism with congestion threshold 0.06. When network load scale factor is 0.5, the burst blocking probability jitter around the threshold with congestion control. With the growth of network load scale factor, the initial burst blocked probability increase sharply. That is said it will take longer to clear out the congestion status. But when it enter stable state, The feedback-based congestion control scheme will limit the number of data burst inject to network and leaky bucket on edge side will smooth the traffic. The simulation result demonstrated that the mechanism can reduce the burst blocked probability even thought the network load scale increase high.

## B. Network scenario

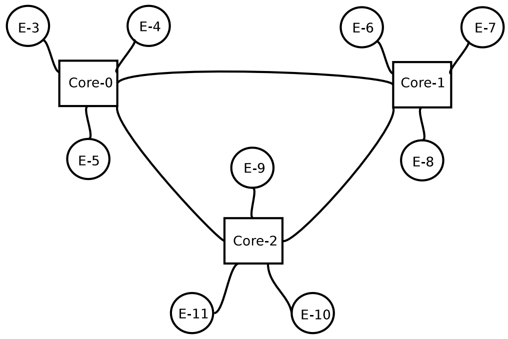


Fig. 7. Network Model

Figure 7 shown the network scenario topology and the routing table is shown below:

$$\begin{vmatrix}
3, & 6, & 1, & 0.5, & 3, & 0, & 1, & 6 \\
4, & 7, & 1, & 0.5, & 4, & 0, & 1, & 7 \\
5, & 8, & 1, & 0.5, & 5, & 0, & 1, & 8 \\
6, & 9, & 1, & 0.5, & 6, & 1, & 2, & 9 \\
7, & 10, & 1, & 0.5, & 7, & 1, & 2, & 10 \\
8, & 11, & 1, & 0.5, & 8, & 1, & 2, & 11 \\
9, & 3, & 1, & 0.5, & 9, & 2, & 0, & 3 \\
10, & 4, & 1, & 0.5, & 10, & 2, & 0, & 4 \\
11, & 5, & 1, & 0.5, & 11, & 2, & 0, & 5
\end{vmatrix}$$

There also are nine paths. However, every path pass through two core nodes. By analysing the routing table, these three core nodes are symmetrical to each others. So we just need to test if the mechanism works on any one of three core nodes. In this paper, I choose core node zero.

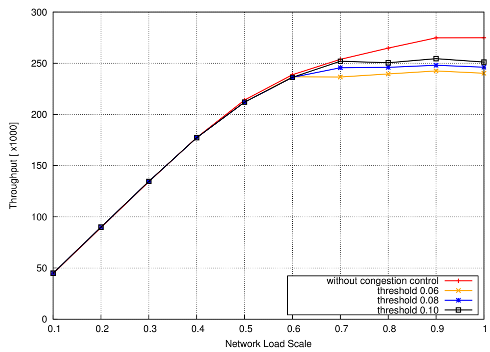


Fig. 8. Throughput

As Figure 8 shown, the throughput of without any control is higher than with congestion control. The reason is similar to single node scenario.

Figure 9 shows the burst block probability of different network load scale factor during the simulation time with congestion threshold 0.1. It demonstrate that this mechanism can reduce the burst blocked probability in network environment. The cases with different network load scale factor almost

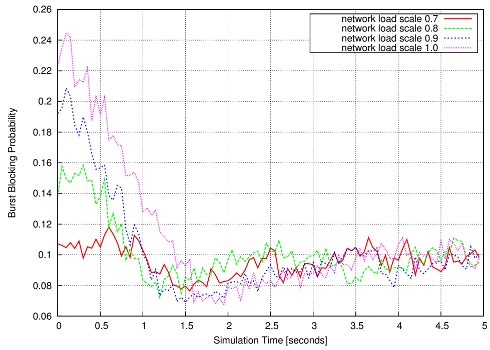


Fig. 9. Block Probability Trend with Congestion Control

achieve the threshold level at the same time. That is said the react delay doesn't increase with the arrival rate.

## V. CONCLUSION

In this paper, I proposed a congestion control mechanism based on feedback message sent from core router for OBS networks. Through the simulation result, I compared the overall data burst blocked rate for two cases, one with congestion control and the other without any control in single core node scenario and a small network scenario. It has been proven that this mechanism can reduce the burst blocked probability significantly. But also the throughput of network reduction, due to limit exceed data burst inject to network, is tolerable. These and other topics, including implemented this mechanism with early dropping, behavior in larger network and what effect if core employ FDL line will focus on the future work.

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# Appendix A

# A Survey of Congestion Control Mechanisms for Optical Burst Switched Networks

# Abstract

In this studies, I review burst congestion control problems in optical burst switching networks from the viewpoint of network throughput maximizaation and to reduce additional signal requirement while minimizing burst loss. Burst collision occurs when two or more bursts access the same wavelength at the same time, and the occurrence becomes more frequent with the offered load increases. Burst must be dropped since OBS don't provide buffer on intermediate core router. That is said contention is inherent to the OBS network. There are a lot of predecessors have done a lot of research on this topic. General speaking, it has two jointly operating mechanisms, namely a burst congestion detection and a burst control algorithm. In this work, I want to overcome the shortcoming of previous research and develop a new mechanism to enhace OBS network stability and make congestion controllable.

**Keyword:** Optical Switching Networks, Congestion Control

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# Chapter 1

# Introduction

## 1.1 About optical burst network

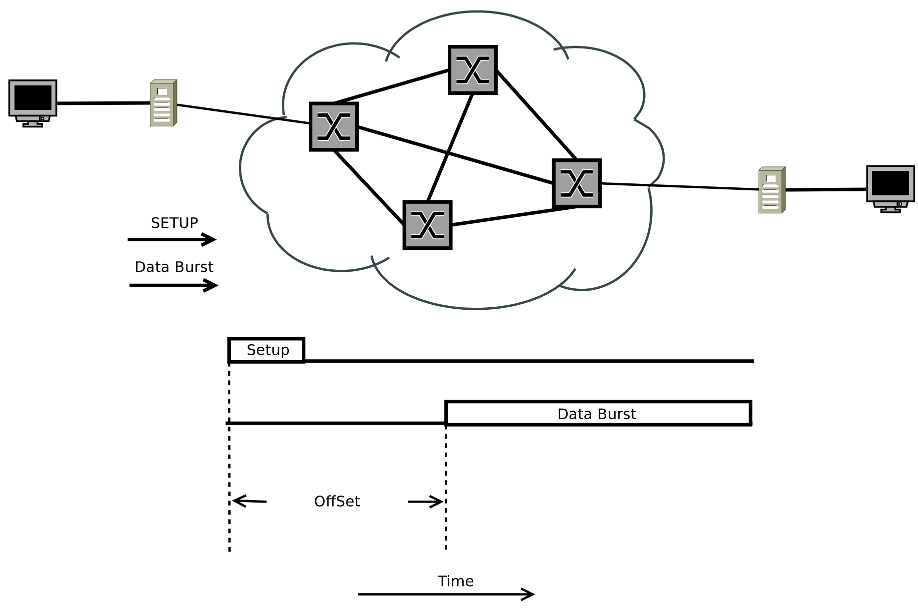


Figure A-1.1: Burst assembly,Burst reservation

Among all optical switching technology, OBS seek to enhance the statistical multiplexing. It has proposed as a new paradigm switching technology for next generation Internet backbone network. Before we get closed to it. We need to get some foundational knowledge, such as what are the big characteristics of this form of exchange of technology. What is the biggest difference compare with traditional switching technology? Does it have born deficiency?

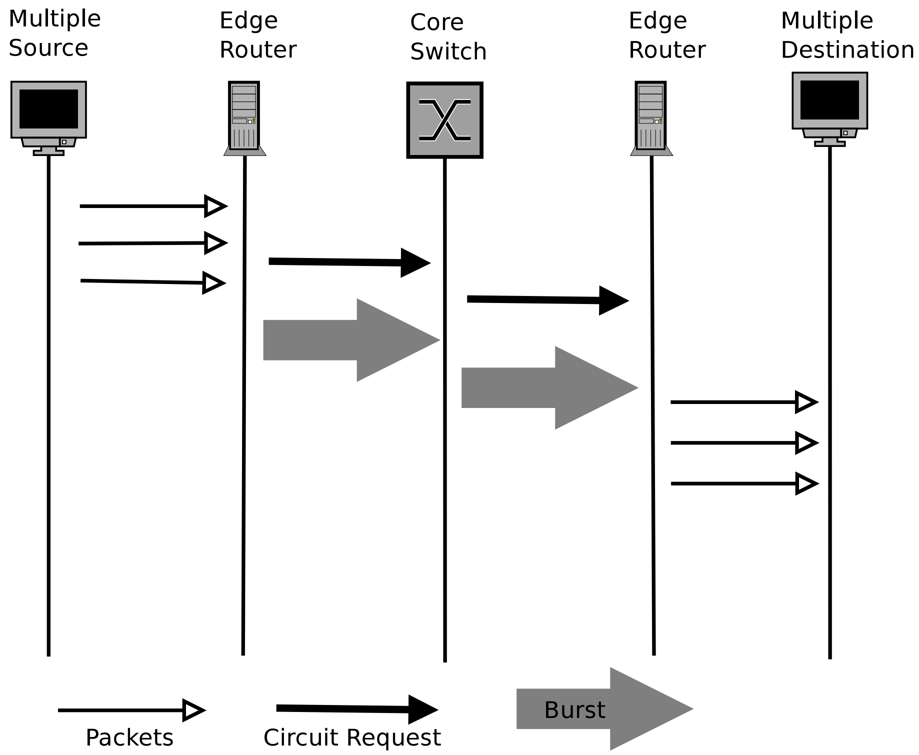


Figure A-1.2: Sample time diagram of a network using OBS

| |
|---|
| src_node_id |
| dest_node_id |
| burst_duration |
| burst_offset_time |

Figure A-1.3: OBS burst format sample

The main different compare to conventional packet switching is bufferless on core node. OBS put all intelligent such as buffer, electronic processor, to edge side. As figure A-1.1 show. All input data bursts are collected into bursts. There may be a classifier to classify packet to different burst according to their destination and

Qos requirement or something else. After complete burst assemble and before the burst transmission begins, a Burst Header Cell (BHC) is sent on the control channel that is separate from data burst channel, carry information about the destination of the burst, duration of the burst, the number of hops it pass through. A sample burst format is shown in figure A-1.3

A burst switcher, once receiving the BHC, schedule and determine an outgoing link for leading toward the desired destination with an idle channel available, and then establishes a connection between the channel specified in BHC and the channel through schedule algorithm by core switcher to transmit the burst. It also pass the BHC to next hops on the control channel of the selected link. After the core router prepare for arriving burst, the burst go through core router without additional operation. It also refer as one-way reservation. The burst just wait a certain offset time and don't need to check the ACK from reservation process. Once burst arrive to core router, It can be transmit in whole optical domain. That is the reason why OBS better than others mechanism. The mechanism for resource reservation and release has been study for a long time. In simple term, There are four major combinations as table A-1.1 show.

| setup / release | Immediate setup | Delay setup |
|---|---|---|
| Immediate release | Immediate setup<br>Immediate release | Delay setup<br>Immediate release |
| Explicit release | Immediate setup<br>Explicit release | Delay setup<br>Explicit release |

Table A-1.1: Classification of reservation/release schemes

There are two main scheduling mechanism, that is so called `LAUC` and `LAUC-VF`, `LAUC` is abbreviation of First-Fit, Horizon, Latest Available Unscheduled Channel. And `LAUC-VF` is abbreviation of `LAUC` with Void Filling. Since `LAUC-VF` is the improvement of `LAUC`, I employ `LAUC-VF` algorithm in simulation.

## 1.2 About congestion control

To understand what is congestion control. The first question what causes congestion must be answer. Fortunately, the answer is simple, congestion occurs when the total traffic load is greater than network bottleneck capacity. Especially, OBS take one-way reservation to avoid the long end-to-end setup times and without buffer on intermediate router. Once contention occurs, some or all of data burst have to be dropped. Hence, contention is inherent to the OBS technique and contention issue could affect tremendously the network performance in terms of burst blocked rate and throughput.

General speaking, the contention problem is due to the lack of communication between the nodes and the absence of global coordination between the edge routers and core routers. Congestion issue will lead to a large waste of resource due to drop of bursts on last one router before destination since fail to compete fail. Even worse, the network is statistical multiplexing, many burst may share a link, that lead to load is not balance over all core routers. Some core router may overload, the others may be idle.

There are two approaches to handle burst contention problem: bursts contention resolution and burst congestion control. The burst contention resolution approaches should have capacity to store burst with fiber delay lines (FDLs) [1], deflection routing [5], and wavelength conversion [3]. These approaches can reduce burst loss rate by absorbing short-term burst congestion. But if the burst congestion lasts long, all of above approaches can't reduce burst loss rate anymore. Even worse, they may introduce longer end-to-end delay and enhance congestion impact.

The burst congestion control mechanism handle the burst congestion by controlling the data burst transmission rate at the optical network edge. There are two paradigm to limit the source flow rate, refer as open-loop and closed-loop congestion control. The main different between these two mechanism is that closed-loop is dynamic adaptive system with feedback message. Open-loop is a per-define system without dynamic adjust stage. There are two jointly operating mechanisms, namely a burst congestion detection and a burst control algorithm in closed-loop network[4]. Thus, in the feedback-based network it is required for the core router to work out 3W1H (what,where,when,how) question. What information should feedback to network edge router? Which router should monitor the network information and report to edge router? When this statistic result can detect the congestion and tell the edge router to reduce transmission rate? On the other side the core router should tell when the edge router increase transmission rate to keep network throughput high? The last question is how to detect and predict the network congestion? How to guarantee fairness and self-organizing?

## 1.3 Motivation

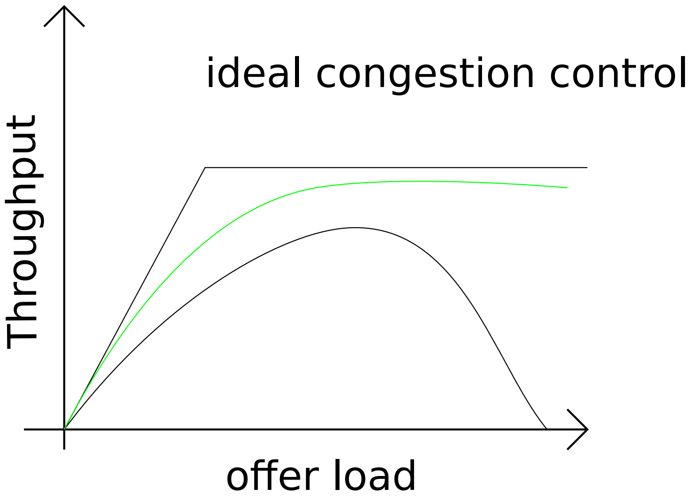


Figure A-1.4: Congestion Control

As figure A-1.4 shows, The performance of network would reduce to zero if without any control. The ideal congestion control will enhance the network stability, and gain the capacity of network. However, in real network, the reaction delay much be token account. It only be closed to the ideal line. The green line show the real world congestion control. It may jitter since control packet loss or expired. In this study, I will develop a congestion control to improve the throughput of network and reduce burst blocked probability.

There are several goals that congestion mechanism should achieve, the cost of implementation and deploy is cheap. That is said minimize additional hardware requirement and limited by router ability. Be fair among to all user.

Congestion control is a comprehensive problem. The effective is very limited by control with any single method. Monitor and rate controller should co-operate to expand the effective. It may work with other mechanism, something like early drop packet, soft contention strategy.

## 1.4 Summary

Overview the history of the development of OBS technology. The original goal is to compete with ATM network which have great potential in electronic domain. Compared with primitive Burst switching, ATM is more cost effective. But when WDM technology can provide huge bandwidth. It posed a challenge to current switch technology, that is how to use this bandwidth efficiently. The switch technology become the network bottleneck. OBS is a new technology that is currently under study. It has not as yet been commercialized and standardized. But It has great potential to replace current switch technology. It has some advantages:

1. More flexible and efficient compared with wavelength routed network
2. More scalable and cost effective compared with opto-electronic approaches
3. Smaller overhead and more practical compared with OPS

It also have some prominent feature:

1. Separation of transmission and control, Each user transmits data in bursts
2. Basically, assumes the network is bufferless
3. Network nodes(OXC) allocate resources for just this single burst

By contrast, we can find that OBS has a lot of advantages for packet switch. However, unfortunately contention is inherent to the OBS technique. The contention problem is due to the lack of information at the nodes and the absence of global coordination between the edge routers and core routers. In one word, I want to proposed a new scheme to avoid and control congestion effectively in this study. And then drive OBS into standardized earlier.

# Chapter 2

# Literature Review

## 2.1 Methodology

As mention above, the study intends to develop a new congestion control scheme for OBS. Thus, the following main question arise:

1. How to indicate congestion state
2. Design the feedback message packet
3. How to determine edge router reaction
4. How to measure the result
5. Does it work for any type of network application

Each of the main questions was investigated by considering the following sub question:

| No. | Questions |
|---|---|
| 1 | How to indicate congestion state |
| | What information should collect? |
| | Where can store this information? |
| | How to calculate the congestion threshold? |
| | The threshold can adjust dynamic? |
| | To finish this job, is it necessary to enhance core node? |
| 2 | Design the feedback message packet |
| | What field contain in the message packet? |
| | Is the size of message body minimum? |
| | When this congestion control message send to edge router? |
| | How often this message send to edge router? |
| | Which channel wiil be used to send this message? |
| 3 | How to determine edge router reaction |
| | Reduced delivery rate |
| | Select other idle path |
| 4 | How to measure result |
| | Assign various rank for different performance factor |
| | Fairness to each factor |
| | Is effective when traffic load become higher |
| | Fairness to each edge router |

Table A-2.1: Questions and Sub-Questions

In this study, `OPNET` and simulation will be utilized. Simulation is a cheap and quick method. It could also suggest analysis method. Nonetheless, it would a little hard to do a quantitative analysis. But it use to make a qualitative analysis to verify the simulation result.

In the stage `Model` and `Implementation`, Use `OPNET` as main tool. Because of `OPNET` have provide a basic platform before progressing to the `OBS` model. `OPNET` simulation model library provide a series of simulation model for customer. On the basis of these simulation model, we can customize our network model and run a simulation. `OPNET` simulation model library separate with the network simulation engine(`OPNET` Modeler,`ITGuru`,Application DecisionGuru). This architecture is very convenient for model change and upgrade. For this study, we can deploy our congestion control algorithm to a `OBS` network which build with `OPNET` easily.

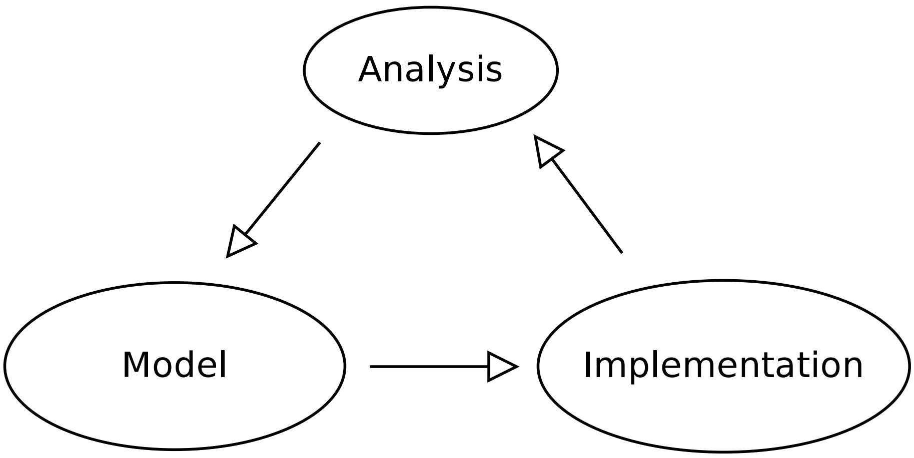


Figure A-2.1: Instructional Simulate model for this study

To generate burst from all ingress node, we need to assume the arrive process follow certain distribution. That may be some common randomness processes. Such as negative exponential distribution, geometric distribution, drop-tail distribution. Thus we need to know how to generate this randomness process meet some distribution requirement.

In order to measure our congestion control mechanism achievements. We need to setup a optimal target. In this study, that is maximum throughput and minimum burst loss and block ratio. It is hard to work out through pure analysis method. So we need to collect data from simulation. We can do some comparative experiments. Such as compare the throughput of two case. One with congestion control, the other without congestion control. Also, use some generally knowledge truth in queuing theory and probability theory to let us get closed optimal target step by step. It is a very good idea to make our data intuitive with data visualization technology.

## 2.2 Finding & Trends

As we know, in OBS, all intelligence resides in the edge nodes, which are at the same time the buffer and the processor on the network. Simply put, current congestion control scheme are same pattern. They all gathering network state information first. Setup a certain threshold to estimate the congestion state. And then send a customize message to edge router according to the current network state.

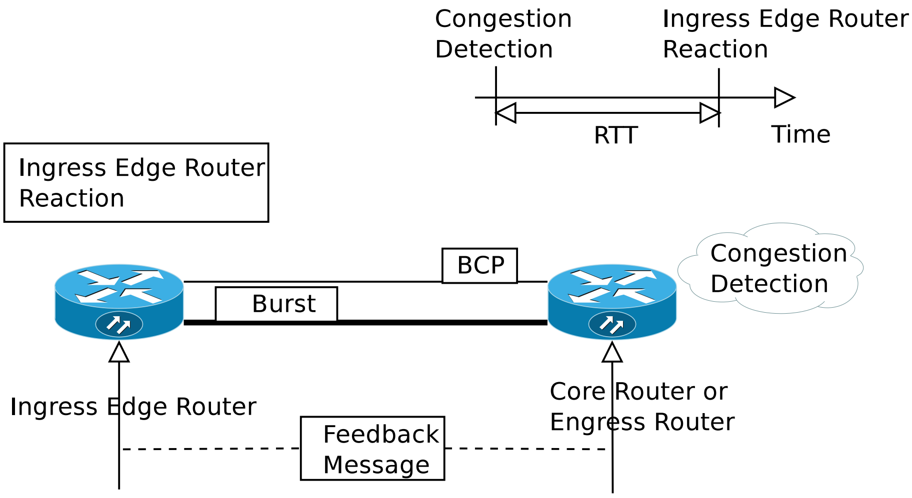


Figure A-2.2: Pattern to control OBS congestion

Figure A-2.2 not only tell us the current popular pattern on research about OBS congestion control. It also tell us the steps to control congestion. This patter is practical and correct. So it will also be used in this study. Although the petter of vary congestion control mechanism are same. But there are a large amount difference among vary scheme in implementation detail. Such as different frequently to send feedback message to edge router, different way to determine the congestion state threshold, different feedback message body. Certainly, they result in different performance.

In their paper, they don't tell how to setup the threshold. They just give a final result. The value maybe have test a lot of times and they think that is proper for their model. It also is a constant value. But I think this value should adjust with the change of network topology. Besides, They don't tell how long is the RTT. The `RTT` can use to measure the speed of ingress react. The `Threshold` is a most important factor to affect the scheme to indicate congestion state or not. But there is not a formula to got these two value through pure analysis. Current scheme just by trial and error to find a proper value for their simulation model.

Moreover, Once their model is determined. All parameter is definite during simulation time. Include the most important `Threshold` value. In my opinion, Congestion control is a dynamic optimization problem. This `Threshold` should self-adjust accordingly. Burak Kantarci and Sema Oktug propose a congestion control scheme base on adaptive threshold [2]. The improvement is also very good.

The previous researcher use throughput and loss ratio to measure their result. The higher throughput and the lower loss ratio. That will be propose as a better congestion control scheme. There also very important factor should be consider to determine whether a new scheme is better. That is whether as effective at high load as at low load. All previous researcher have pay much attention to this point.

Previous mostly assume the burst arrive process follow the Poisson process and their lengths are negative exponentially distributed. But base on the some newest study. It has been shown that whereas flow arrivals are Possion (or close to Possion), flow sizes are not exponential, but rather heavy-tailed, and thus they are closer to a Pareto distribution than an exponential one.

## 2.3 Issues May Encounter

Note that in OBS networks, intelligent functions such as burst assembly, burst scheduling and generation of control packets are implemented at edge nodes while core nodes perform less complex functions such as processing control packets, resource reservation and switching bursts. However, many existing works have proposed to implementation some simple extra functions at the core node such as load calculation, burst segmentation and priority-based burst dropping for service differentiation. It is hard to predict whether it is necessary to add extra function to core node in this study. If yes, is it complicate so that the core node is reject to add it.

To meet QoS requirement such as bounded delay or guaranteed delivery is part of new scheme objective. But it is incompatible to achieve guaranteed delivery rate and congestion control by reduce transmission rate at the same time. It is clear that even in ideal networks, where the switches use number of buffers and can perform wavelength conversion, congestion collapse still occurs when the load gets higher. On this moment, it seem impossible to resolve this contradiction.

## 2.4 Related Work

As a new switching technology which has not been standardized yet, OBS faces many problems and challenges. However, there are also many researchers and new achievements. In resolving the issues of contention and the associated loss bursts issue. There are some other related studies.

The most important and related study is contention resolution. As mention above, there are three ways to resolve burst contention. Fiber delay line, wavelength conversion and deflection routing by now. They are for a same goal. When contention occurs, they can buffer it instead of drop it. But these three method are not viable now. They all have their own shortcomings. Optical buffering currently can only be implemented using FDL. But this type of optical buffer is usually small and it does not scale up. The wavelength may have some potential since the number of wavelengths that can be coupled together onto a single fiber continues to increase. In view of deflected routing, the end-to-end delay for an optical burst may be unacceptably high. But fortunately research on these contention resolution are going on. Once the breakthrough of these problems will also provide help for congestion control.

Nowadays, IP packet switching already dominates global communications. But it cannot keep up with the Internet traffic demand. Many researchers are studying a new scheme to replace it. In electronic domain, ATM network has matured and is not far from being feasible. Other researcher have proposed integrate circuit switching in the core and packet switching in the edges as next generation network architecture. All of these efforts are aimed at accommodating for the traffic growth in the Internet. Study on the OBS can draw on their achievements. Also include conventional TCP congestion control.

# Chapter 3

# Conclusions

Up to now, we have know that DWDM take the bottleneck of networks from bandwidth to switching technology. OBS emerge as this requirement. OBS have many advantage with the advance of DWDM technology. It have great potential to be next generation switching technology in the core network. Since it have some special feature. Such as not require buffer, separation of transmission and control packet.

As mention above chapter, contention is very possible occurs in ideal network without congestion control. OBS have no standardize yet. Many researcher work on this challenging topic. The main research method is simulation. Overview of all previous, they have build a theory framework to solve congestion collapse for OBS. That is three steps: detect, feedback, reaction. They are different in implementation detail. All mechanism are tightly coupled with the burst assembly mechanism at the ingress edge router. This was decided by two reasons. The First is all intelligence resides in the edge router, which are at the same time the buffer and the processor. The second is the hurdle for congestion is lacking of communication between the nodes and the absence of global coordination between the edge routers and core routers. Hence, monitor on corn router and controller on edge router will be focus on the future work.

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# Appendix B

# Process model of leaky bucket

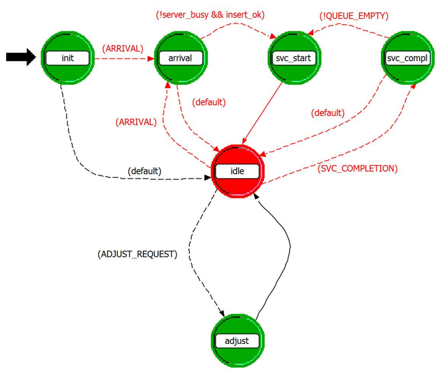


Figure A-2.1: process model of leaky bucket

Leaky bucket is similar to finite queuing system. So I implement leaky bucket based on `acb-fifo` queue model. Each burst generation queue equip a leaky bucket as traffic shaper or rate controller. The rate-determine algorithm reside in `adjust` state. It is responsible for receiving feedback message from core node and direct to adjust transmission rate.

# Appendix C

# Process model of monitor

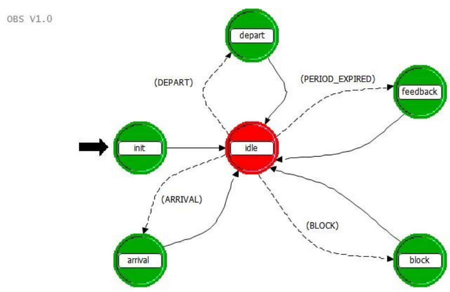


Figure A-3.1: process model of monitor

The monitor of core node detect each output-port congestion status and broadcast feedback control packet to all associate edge node periodically. As shown in figure A-3.1, it track the number of blocked burst and the number of arrival and departed burst. And there a self interruption as timer.