Adaptive Burst Assembly with Dynamic Ratio Control for Improved QOS and Fairness in Optical Burst Switching Networks

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Abstract:

Optical Burst Switching (OBS) is a promising technology for next-generation Internet backbones. Ensuring Quality of Service (QoS) for real-time traffic within OBS networks while maintaining fairness for all traffic classes remains a significant challenge. Existing composite burst assembly schemes often rely on fixed ratios of high-priority traffic, which are often suboptimal for dynamically varying network conditions leading to increased packet loss, increased latency, and unfairness to lower-priority traffic. This paper addresses these limitations by introducing an enhanced Adaptive Burst Assembly (ABA) scheme. The ABA scheme builds upon established techniques, such as burst segmentation, to dynamically adjust the proportion of high-priority traffic within bursts. The key improvement is the addition of a dynamic ratio adjustment mechanism based on real-time network traffic load measurements. Simulation results demonstrate that the ABA scheme outperforms traditional fixed-ratio methods in reducing high-priority traffic packet loss. While this work builds on well-established concepts in OBS networks, its unique contribution lies in the adaptive nature of the burst assembly process and its focus on balancing both performance and fairness.

Keywords: Optical Burst Switching (OBS), Quality of Service (QoS), Contention Resolution, Burst Segmentation, Adaptive Burst Assembly (ABA), Traffic Engineering, Fairness, Packet Loss, Dynamic Ratio Adjustment, Real-Time Traffic, Network Stability.

التجميع التكيفي مع التحكم الديناميكي في نسب البيانات لتحسين جودة الخدمة والعدالة في الشبكات الضوئية (OBS)

الملخص:

تعد الشبكات الضوئية (OBS) من التقنيات الواعدة لبناء بنية تحتية للإنترنت قادرة على تلبية متطلبات الجيل القادم. إلا أن ضمان جودة الخدمة (QoS) وتحقيق الإنصاف العدالة بين مختلف أنواع البيانات في هذه الشبكات لا يزال تحديًا كبيرًا. تعتمد الطرق التقليدية لتجميع حزم البيانات الضخمة على نسب ثابتة للبيانات ذات الأولوية العالية، مما يجعلها غير مرنة في مواجهة التغيرات الديناميكية في الشبكة. مما يؤدي إلى زيادة معدل فقدان البيانات، وزيادة معدل التأخير، وعدم الإنصاف للبيانات ذات الأولوية المنخفضة. ولذلك، تقترح هذه الورقة آلية جديدة لتجميع حزم البيانات الضخمة بشكل تكييفي (ABA). يعتمد مخطط ABA على تقنيات متعددة، مثل تقسيم حزم البيانات الضخمة، لضبط نسبة البيانات ذات الأولوية العالية المئوية بشكل ديناميكي داخل الشبكات الضوئية. ويكمن التحسين الرئيسي لهذه الورقة في إضافة آلية تعديل نسبة ديناميكية بناءً على النسبة المئوية للبيانات ذات الأولوية العالية. تظهر نتائج المحاكاة أن مخطط ABA يتفوق على الطرق التقليدية ذات النسبة الثابتة في تقليل فقدان معدل فقدان البيانات ذات الأولوية العالية. في حين أن هذا العمل يعتمد على مفاهيم راسخة في شبكات OBS، فإن مساهمتها الفريدة تكمن في الطبيعة التكيفية لعملية تجميع البيانات وتركيزها على تحقيق التوازن بين الأداء والعدالة.

الكلمات المفتاحية: الشبكات الضوئية (OBS)، جودة الخدمة (QoS)، حل النزاعات، تقسيم حزم البيانات الضخمة، التجميع التكيفي لحزم البيانات الضخمة (ABA)، هندسة البيانات، العدالة، فقدان البيانات، تعديل النسبة الديناميكية، بيانات الوقت الحقيقي، استقرار الشبكة.

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1. Introduction

Optical Burst Switching (OBS) has emerged as a promising technology for building the next generation of high-speed Internet backbone networks, primarily due to its efficiency in handling bursty traffic and its ability to effectively utilize wavelengths [1-2]. As OBS networks become more prevalent, ensuring robust Quality of Service (QoS) guarantees, particularly for real-time traffic, is paramount. A key challenge lies in managing network packet loss, which is a crucial metric for maintaining the integrity of delay-sensitive applications. Various signaling schemes have been proposed to allocate network resources and minimize congestion among data bursts [3-5]. However, contention can still arise when multiple bursts from different input ports simultaneously contend for the same output port, and these signaling mechanisms do not fully resolve this fundamental problem.

To address contention, several techniques have been developed [4,6]. One prominent approach is burst segmentation, which aims to mitigate packet loss by selectively dropping only segments of contending bursts, instead of discarding the entire burst [7]. This method allows for fine-grained traffic management, and allows for a partial delivery of bursts, improving overall resource utilization. The composition of these bursts plays a critical role in the effectiveness of this technique. Simply aggregating high-priority traffic in a single burst is not always optimal, as it can increase the average packet loss for high-priority traffic. This requires a more balanced approach for handling traffic of varying priorities. Recognizing this, Vokkarane et al. [8] introduced a prioritized contention resolution method that combines packets of different traffic priorities into a single burst while ensuring that lower priority traffic is placed at either the head or the tail of the burst. The aim of this approach was to fully isolate the high priority traffic by prioritizing its delivery, thus improving its QoS.

However, prior methods fail to address the limitations of fixed ratio approaches, which does not accommodate the dynamic nature of network traffic [9]. This fixed ratio may not be suitable for all traffic loads and network scenarios, leading to suboptimal performance and unequal treatment of traffic flows. Despite these advancements, several critical limitations remain unaddressed. A significant challenge is to guarantee fairness among different types of traffic classes while simultaneously solving the contention problem. The existing composite burst assembly schemes typically rely on pre-determined and fixed

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ratios of high-priority traffic, and these fixed-ratio approaches do not perform optimally under dynamically changing traffic conditions. They fail to adapt to changing network loads, resulting in significant fluctuations in packet loss, increased latency, and potential unfairness towards lower-priority traffic, all which can be detrimental to network performance. The inadequacy of fixed-ratio schemes is particularly evident during periods of high traffic volume, where congestion may lead to inconsistent and unpredictable delivery for higher and lower priority traffic classes. Therefore, it is clear that approaches which rely on fixed ratios, suffer from specific inadequacies that limit their ability to effectively address contention while guaranteeing fairness.

To address these issues, this paper proposes an enhanced Adaptive Burst Assembly (ABA) scheme, a dynamic strategy designed to reduce the packet loss probability while preserving fairness among different types of traffic classes. Building on established techniques, such as burst segmentation, ABA introduces a dynamic ratio adjustment mechanism that adapts burst assembly according to real-time network traffic loads, thereby optimizing the delivery of high-priority packets while maintaining fairness to low-priority traffic. Leveraging existing techniques such as burst segmentation, ABA provides a robust solution to the challenges posed by fixed-ratio approaches. By dynamically adjusting the traffic composition within data bursts according to network conditions, the goal is to improve network stability and overall QoS, and to achieve an overall improvement in the network›s performance.

To provide a clear roadmap, this paper is organized as follows: Section 2 presents a detailed review of related work on contention resolution schemes, emphasizing their limitations and highlighting the research gap. Section 3 describes the proposed ABA scheme in detail, including its dynamic adaptation mechanism and implementation. Section 4 discusses the simulation model, including the traffic models, network topology, parameters, and metrics used in the experimental evaluation of the ABA scheme. Section 5 details the results and discussion of the simulation results to demonstrate the effectiveness of the ABA approach. Finally, Section 6 concludes the paper, summarizing its contributions and providing avenues for future research.

2. Literature Review

Optical Burst Switching (OBS) networks have emerged as a promising solution for the next-generation Internet backbone infrastructure due to their ability to handle high data rates and reduce latency. However, one of the critical challenges in OBS networks is contention resolution, which directly impacts the Quality of Service (QoS) for various traffic types, especially high-priority traffic such as real-time applications. Several contention resolution mechanisms have been proposed in the literature, which can be broadly classified into proactive and reactive techniques.

We will categorize them by their characteristics, and identify their limitations, particularly regarding fairness and adaptability. Furthermore, we will explicitly explain the research gap that this paper intends to address, and introduce core concepts necessary for this paper, including burst segmentation, which form the basis of the proposed Adaptive Burst Assembly (ABA) scheme.

2.1 Contention Resolution in OBS Networks

Contention resolution is a critical mechanism within OBS networks designed to minimize packet loss [1-2], ensuring reliable and efficient data delivery. Contention arises when multiple data bursts compete for the same network resources, such as output ports, which can lead to packet loss. These mechanisms can be broadly categorized into two main classes: proactive and reactive approaches. Proactive contention resolution strategies aim to prevent contention before it occurs by optimizing resource allocation and traffic flow. Reactive approaches, on the other hand, focus on mitigating the effects of contention after it has occurred.

- **Proactive Contention Resolution:**

Proactive techniques aim to avoid contention before it happens, thus minimizing the probability of packet loss [1-2]. These techniques are further divided into feedback [2] and non-feedback [5] mechanisms. Feedback mechanisms rely on information obtained from core nodes, to inform edge nodes about network status. This feedback enables the edge nodes to adjust the transmission of data bursts to minimize congestion. Non-feedback techniques focus on optimizing burst creation and routing processes to avoid potential contention points [11-12]. Adaptive routing, for example, balances the load on the network to reduce points of contention [11,15]. Prioritized burst assembly also falls under this category.

Another proactive technique is the adaptive burst assembly technique proposed by Sarwar et al. [9], where high-priority packets are aggregated in the middle of the burst, while low-priority packets are placed at the head and tail. This arrangement allows for selective dropping of low-priority packets

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during contention, thereby reducing the loss of high-priority traffic. However, this scheme does not consider the dynamic nature of network traffic, as it uses a fixed ratio of high-priority traffic, which may not be suitable for varying traffic loads.

- **Reactive Contention Resolution:**

Reactive approaches tackle contention after it has already happened, using strategies like burst dropping [6], wavelength conversion [4], Fiber delay lines (FDLs) [6], route deflection [4], and burst segmentation [7]. Each of these techniques targets specific aspects of the contention problem. For instance, burst dropping involves simply discarding bursts when contention arises, while wavelength conversion attempts to reroute contending bursts by changing their wavelength. FDLs introduce a delay to allow competing bursts to transmit without contention, and route deflection involves redirecting bursts along an alternative path [6]. In 2009, Hongyun et al. [10] proposed a delayed burst segmentation technique where segments are dropped based on the order of burst arrival times rather than control packet arrival times. This method improves the fairness of packet dropping during contention but does not address the issue of fairness among different traffic types. Furthermore, burst segmentation provides a means to avoid packet loss by dropping only the overlapping portion of contending bursts. Despite the variety of existing contention resolution strategies, ensuring both effective contention management and fairness among different types of traffic remains an open research area.

2.2 Fairness and QoS in OBS Networks

Fairness among traffic types is a critical aspect of QoS provisioning in OBS networks. Several studies have focused on improving fairness while ensuring QoS for high-priority traffic. For instance, Sarwar et al. [9] proposed a composite burst assembly technique that places high-priority packets in the middle of the burst, ensuring that low-priority packets are dropped first during contention. However, this approach does not dynamically adjust the ratio of high-priority traffic based on network load, which can lead to inefficiencies under varying traffic conditions.

In 2014, Guan et al. [16] proposed a priority-based composite assembly scheme where high-priority packets are placed in the middle of the burst, while low-priority packets are placed at the head and tail. This scheme improves QoS for high-priority traffic but does not address the fairness issue for low-priority traffic. Similarly, Awasthi et al. [17] proposed a fiber delay line (FDL)-based OBS router that estimates burst length and uses FDLs to buffer contending bursts. While this approach reduces packet loss, it does not consider the dynamic nature of network traffic.

2.3 Burst Segmentation

A Core Concept of Burst segmentation [7] is a reactive contention resolution technique that mitigates packet loss by dropping only a part of a contending burst, instead of discarding the entire burst. It involves dividing bursts into basic transport units called segments, each containing a header and payload. During a contention event, only the overlapping segments or the segments at the end of the bursts may be dropped, allowing the remaining segments to pass through and reach their destination. This technique has been proven to be effective for minimizing packet loss, especially in cases where the overlap between bursts is minimal. We are highlighting this technique, because the ABA scheme is based on the core ideas of burst segmentation. Furthermore, the composition of these segments, with regards to the priority they are carrying, is also very important.

2.4 Limitations of Fixed-Ratio Burst Assembly

Existing composite burst assembly schemes often utilize a pre-determined and fixed ratio for aggregating high-priority traffic within a burst. While seemingly straightforward, this approach has several critical limitations when dealing with variable traffic conditions [9]. A key inadequacy is its lack of adaptability to real-time network load variations. For example, a composite burst with a fixed ratio designed for a low-traffic situation may perform sub-optimally under high traffic load, leading to increased congestion and packet loss for high-priority traffic. Furthermore, relying on a fixed ratio may lead to unfair allocation of network resources, affecting the delivery of low-priority traffic. Specifically, the following issues can occur:

- **Suboptimal Packet Loss Rates:**

As previously mentioned, simply aggregating high-priority traffic may lead to increased packet loss for that particular class of traffic.

- **Unfairness:**

By utilizing a fixed ratio, lower priority traffic can either be excessively penalized, or they may contribute to the reduction of the performance for higher priority traffic.

• **Poor Adaptability:**

Fixed-ratio burst assembly is fundamentally unable to react to real-time variations of the network load. The performance cannot be optimized for every condition.

2.5 Prioritized Contention Resolution and Composite Burst Segmentation (CBS)

Vokkarane et al. [8] introduced a Non-Composite Burst Segmentation (NCBS) and Composite Burst Segmentation (CBS) prioritized contention resolution approach, where the edge node combines different traffic priorities into a single burst, placing the lower-priority traffic packets at the tail or head of the burst. This method sought to provide isolation to the higher priority traffic, by prioritizing the delivery of the packets for that traffic. This scheme further sought to address the issues of previous methods, but it also relied on fixed ratios, which limited its performance under varying traffic conditions. Building on this technique, Sarwar et al. [9] introduced a method where high-priority packets are positioned in the middle of a burst, while low-priority packets are placed at the head and tail. This modification aimed to allow for the dropping of low-priority packets without disrupting the transmission of high-priority traffic. However, this method also failed to address the core problem of fairness and poor adaptability. Hongyun et al. [10] suggested dropping segments in burst segmentation based on the order of their arrival time instead of control packet arrival time. This method sought to improve the dropping performance in OBS networks, however, it did not consider the issues of fairness or adaptability. In 2022, Naji et al. [14] use NCBS and CBS to compare the Performance analysis of optical burst switching networks’contention resolution techniques The issue with all the above is that they employ fixed-ratios which leads to suboptimal performance in highly variable environments.

2.6 Research Gap

Despite the advancements in contention resolution techniques, there remains a significant gap in ensuring fairness among different traffic types while maintaining QoS for high-priority traffic. Most existing schemes use a fixed ratio of high-priority traffic, which is not suitable for varying traffic loads. Additionally, these schemes do not dynamically adjust the burst assembly parameters based on real-time traffic conditions, leading to inefficiencies in network performance.

Building on these limitations, we propose the Adaptive Burst Assembly (ABA) scheme that dynamically adjusts the ratio of high-priority traffic in the burst based on the current network load. The ABA scheme classifies network traffic into three categories: high, normal, and low traffic load. Based on the traffic load, ABA adjusts the ratio of high-priority traffic in the burst, ensuring reduced packet loss for high-priority traffic while maintaining fairness for low-priority traffic. This approach provides better QoS and stability in network performance under varying traffic conditions.

3. Adaptive Burst Assembly (ABA) Scheme

This section presents the proposed Adaptive Burst Assembly (ABA) scheme, which is designed to adjust the ratio of high-priority traffic within a burst based on the real-time network traffic load, aiming to reduce packet loss for high-priority traffic while ensuring fairness for low-priority traffic. This adaptive approach directly responds to the limitations of the fixed-ratio methods previously described. The following subsections describe the different phases of the ABA scheme including the dynamic classification of network traffic load, how it determines a membership value, and how it adjusts the ratio of high-priority traffic within the bursts to mitigate identified problems [12].

3.1 Motivation for a Dynamic Ratio Adjustment Approach

The effective management of Quality of Service (QoS) in network traffic hinges on the intelligent allocation of high-priority traffic within assembled bursts. This process is critically influenced by the actions of the edge node. A key limitation of traditional burst assembly schemes lies in their reliance on fixed ratios for high-priority traffic allocation at the edge node, making them unsuitable for adapting to fluctuating real-time network conditions. For instance, if an edge node consistently allocates a small percentage, such as 10%, of each burst to high-priority traffic, it risks increased packet loss for this critical class during periods of high network load, thereby undermining its QoS and increasing latency. Conversely, if the edge node statically allocates a large percentage, like 90%, to high-priority traffic, it unnecessarily limits the delivery of low-priority packets when network congestion is low, resulting in inefficient resource utilization and the potential starvation of lower-priority flows. This clearly demonstrates the inherent inflexibility of pre-determined ratios assigned at the edge, as these allocations cannot respond to traffic volatility.

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Therefore, a dynamic approach is essential, whereby the proportion of high-priority to low-priority traffic within each burst is adaptively adjusted at the edge node based on real-time network conditions. The edge node dynamically increases the space dedicated to high-priority traffic during periods of high load, ensuring its timely and reliable delivery, while also optimizing the utilization of network resources for low-priority traffic during low-congestion scenarios. This dynamic process at the edge node is crucial for optimizing network performance, ensuring the dependable transmission of time-sensitive data, and promoting an equitable resource distribution among diverse traffic classes. This dynamic adaptation of traffic ratios, managed at the edge node, is therefore essential for simultaneously upholding QoS for critical applications and ensuring overall network efficiency and fairness.

3.2 Adaptive Burst Assembly (ABA) Scheme

The Adaptive Burst Assembly (ABA) scheme addresses the identified limitations of fixed-ratio burst assembly by introducing a mechanism that dynamically adjusts the proportion of high-priority traffic within bursts based on real-time network traffic load. As shown in Figure 1, which was also included in the previous part of this document, ABA classifies network traffic into three categories -high, normal, and low traffic load- within the edge node. This classification is done based on the measured network traffic. According to the measured traffic, the ABA scheme calculates a membership value for each traffic category. The membership value is an indicator of the network load within each category. This membership value is then used to dynamically adjust the ratio of high-priority traffic within the data bursts, aiming to reduce high-priority traffic packet loss while guaranteeing fairness for low-priority traffic packets.

3.3 Dynamic Traffic Load Classification

The ABA scheme operates at the optical network edge node. It classifies traffic load into three distinct categories: high, normal, and low, which are determined by calculating the network traffic load (L_{avg}). To determine network traffic load, the following equations are used: First the total transmission time is computed using Equation (1):

$$T_{time} = \sum_{time=0}^{1\,S} A_{time} \quad (1)$$

where A_{time} is the aggregation time for each burst.

Then, the size of transmitted data is calculated as follows:

$$\begin{cases} T_{size=} T_{temp} \ , & if\ T_{time=>1} \\ T_{temp} = \sum B_{size} \times 8\ , & if\ T_{time<1} \end{cases} \quad (2)$$

where B_{size} is the size of the bursts.

Finally, network traffic is computed using Equation (3):

$$L_{avg} = \begin{cases} T_{size}\ 1/Bw \times 100, & if\ T_{time} => 1 \\ L_{avg}, & if\ T_{time} < 1 \end{cases} \quad (3)$$

where Bw is the bandwidth of the network. L_{avg} represents the current network traffic load rate compared with the bandwidth.

These target values are used as guidelines in the design of ABA. The ability to handle any target ratio values in different environments and scenarios gives ABA the necessary flexibility for practical implementation.

Figure 1 shows the complete flow chart of the ABA scheme.

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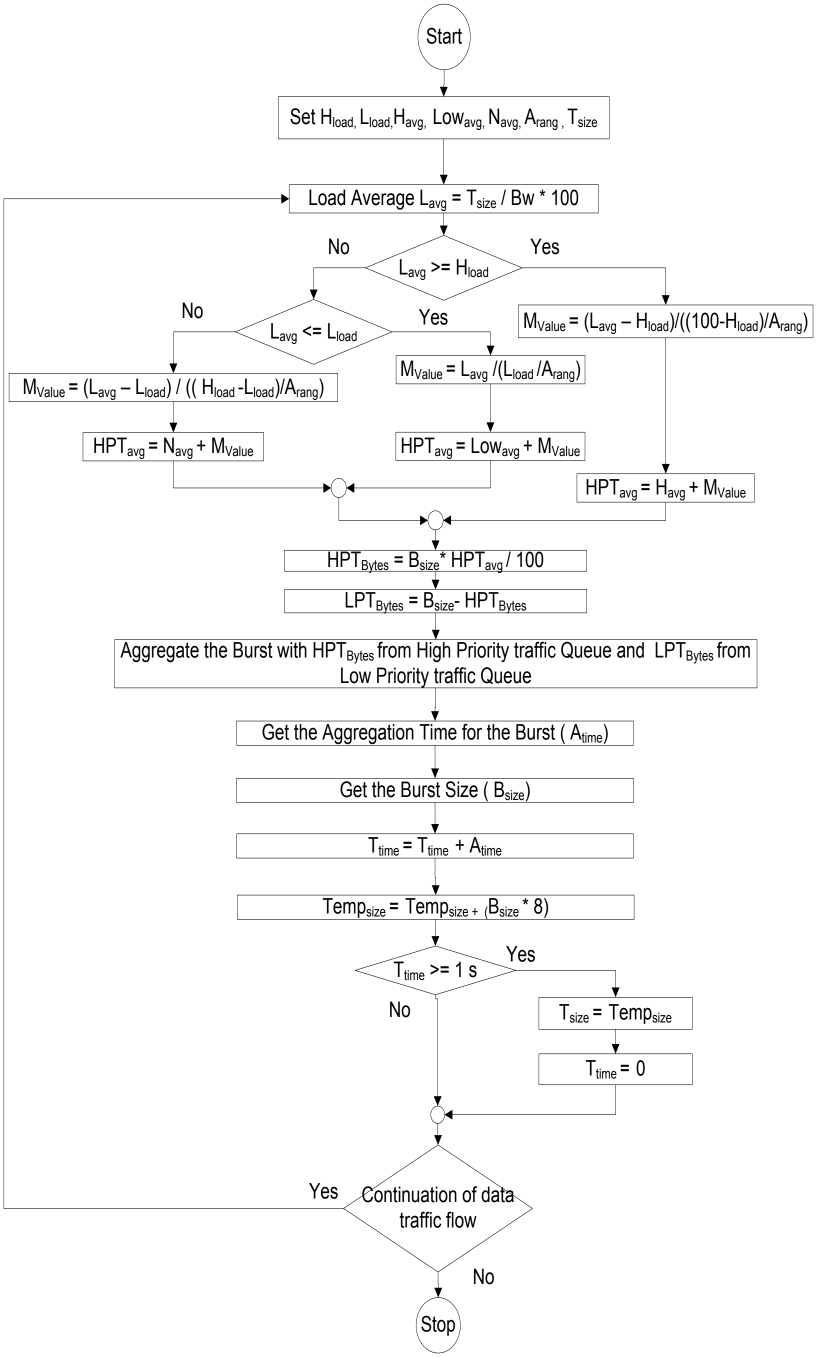

Figure 1: Flow Chart Describing the ABA Scheme

3.4 Membership Value Calculation:

After the traffic load has been determined, the next step is to adjust the ratio of high-priority traffic within bursts, ABA uses a "membership value". This value is an indicator of the network load in each category. The membership value is assigned to the traffic load for each load sub-category. The membership value M_{Value} is calculated based on the measured traffic load (L_{avg}) using Equation (4):

$$M_{Value} = \begin{cases} \dfrac{L_{avg} - H_{load}}{\frac{100 - H_{load}}{A_{rang}}}, & if\ load = high \\ \dfrac{(L_{avg} - L_{load})}{1}\left(\dfrac{H_{load} - L_{load}}{A_{rang}}\right), & if\ load = normal \\ L_{avg}\ \dfrac{1}{L_{load}\frac{1}{A_{rang}}}, & if\ load = low \end{cases} \quad (4)$$

where, L_{avg} determines the network traffic load rate per 1 second. H_{load} determines the value of the beginning (minimum value of high traffic load) of the high traffic load. A_{rang} determines the maximum value of the membership value. L_{load} determines the highest value of the low traffic load parameters.

The M_{Value} ranges from 0 to 10 based on the statistical studies and indicates the intensity of traffic. For example, the membership value is 0 when no data is transmitted, and it is 10, when the network is congested at the highest point in each traffic category. In the high traffic category, a node may assign different membership values based on whether the traffic load reaching the edge node is, for example, 75% or 100% of the bandwidth. Similar membership values are assigned to the traffic load in the other categories.

3.5 Adaptive Ratio Adjustment

Once the membership value has been calculated, the final step in the ABA scheme is to adjust the ratio of high-priority traffic. The high priority traffic average (HPT_{avg}) for each burst is computed by adding the M_{value} to the base ratios based on the traffic load:

$$HPTavg = \begin{cases} H_{avg} + M_{Value}, & \text{if load} = \text{high} \\ Low_{avg} + M_{Value}, & \text{if load} = \text{low} \\ N_{avg} + M_{Value}, & \text{if load} = \text{normal} \end{cases} \quad (5)$$

where, H_{avg} is the base ratio of high priority traffic inside the burst for a high traffic load, and this value is between 50% to 60%. Low_{avg} is the base ratio of high priority traffic inside the burst for a low traffic load, which is between

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10% to 20%. N_{avg} is the base ratio of high priority traffic inside the burst for a normal traffic load, and it is between 30% to 40%.

After calculating the HPT_{avg}, the actual number of bytes for the high-priority traffic (HPT_{Bytes}) is computed as equation (6):

$$HPT_{Bytes} = B_{size} \times HPT_{avg}/100 \quad (6)$$

The bytes for the low-priority traffic (LPT_{Bytes}) are computed as the difference between the B_{size} and HPT_{Bytes}:

$$LPT_{Bytes} = B_{size} - HPT_{Bytes} \quad (7)$$

Finally, the burst is aggregated using HPT_{Bytes} and LPT_{Bytes} from the high-priority traffic queue and LPT_{Bytes} from the low-priority traffic queue. The process repeats every second by re-evaluating the network conditions and traffic loads. This enables dynamic adjustment of burst parameters to balance performance and fairness across different traffic types. The range for high, normal and low traffic were chosen to provide a better performance of the overall network. The ABA scheme uses these ranges in different conditions, thus providing a dynamic approach that is adaptable to a wide variety of conditions. By adjusting the ratio of high-priority traffic in real-time based on network conditions, ABA effectively mitigates the limitations of fixed-ratio burst assembly techniques. ABA effectively prioritizes high-priority traffic while guaranteeing fairness among other traffic types. In the following section, we will present our simulation model, and show the effectiveness of our approach using experimental results.

4. Simulation Model

This section provides a comprehensive overview of the simulation model used to evaluate the performance of the proposed Adaptive Burst Assembly (ABA) scheme [6]. The simulation aims to assess the effectiveness of the ABA scheme compared to traditional fixed-ratio burst assembly and non-composite burst segmentation. The experiments were performed using two traffic types: Constant Bit Rate (CBR) and Variable Bit Rate (VBR). In addition, the simulations include the performance evaluation of ABA against the fixed ratios of 80%, 50%, and 20% high-priority traffic ratios.

4.1 Simulation Environment and Setup:

A discrete-event simulation environment was developed to assess the performance of the ABA scheme. The simulation has used NCTUns simulator to develop, evaluate the performance of proposed schemes and compare them with other schemes. The simulations were run over a duration sufficient to achieve statistical stability, ensuring accurate and reliable results. The selection of simulation parameters was based on a review of previous studies, and they were chosen to represent a realistic scenario, while also facilitating comparisons with existing work.

4.2 Network Topology

The simulated network is a single OBS node network designed to assess the performance of the proposed schemes. The network consists of several edge nodes with connections to one core node. The edge nodes send bursts to the core node with random destinations. The traffic is directed between the edge nodes through the core node based on each destination address. The capacity of the core node links is 1000 Mb/s. This single core node topology is used to focus on the behavior of the burst assembly schemes and to isolate the effects of various parameters of the burst assembly schemes.

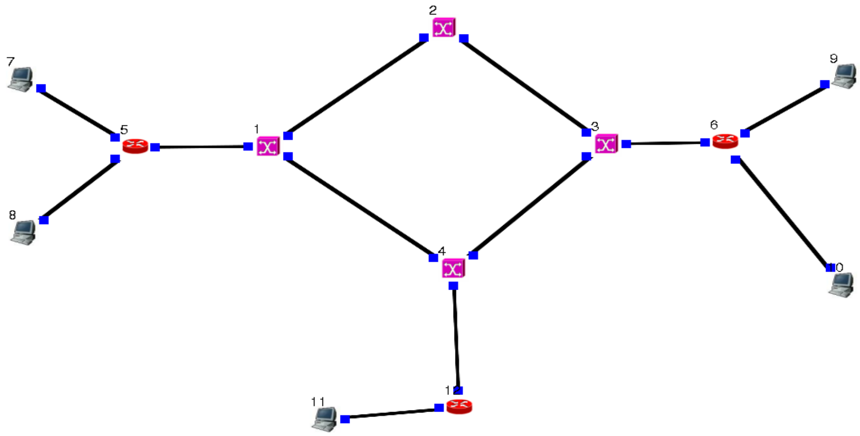

Figure 2: The Four Node OBS Topology

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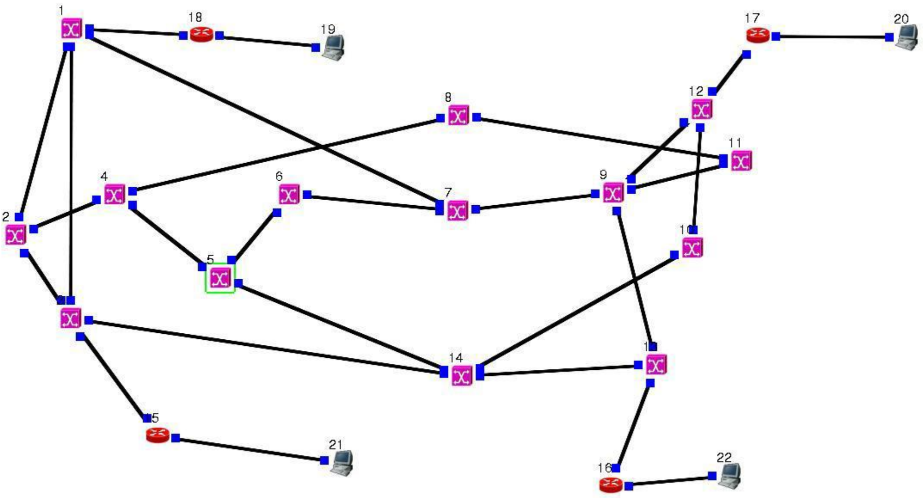

Figure 3: The NSFNET Topology

4.3 Traffic Models

To evaluate the performance of the ABA scheme under a variety of traffic patterns, the following traffic models were used:

• **Constant Bit Rate (CBR):** CBR traffic is characterized by a constant data rate. This type of traffic provides a stable traffic pattern to understand the basic performance of our method. CBR bursts were created using fixed-size packets of 1000 bytes, with inter-arrival times that follow an exponential distribution.

• **Variable Bit Rate (VBR):** VBR traffic simulates real-time applications where the bandwidth requirements fluctuate over time. VBR bursts were created using a packet size that follows a uniform distribution, between a minimum and maximum value, which were set at 500 and 1500 bytes, respectively. The inter-arrival time for VBR bursts were also chosen to be exponentially distributed. This model provides a more variable traffic scenario that is realistic to represent real time traffic.

The traffic load was varied between 0.1 to 1.0 (10%, 20%, 30%,…100%), providing a range of network conditions from low-load to high-load. For each of the traffic sources, the destination edge node was randomly selected.

4.4 Simulation Parameters

The simulations were conducted using a combination of parameters to ensure comprehensive testing that mimic the performance of the OBS network. These parameters included:

- **Traffic Type:** CBR and VBR traffic were used to evaluate the performance of the ABA scheme under varying traffic characteristics.
- **Maximum Cell Transfer Delay (MaxCTD):** Four different values of MaxCTD were used: 70 μs, 92 μs, 100 μs, and 125 μs. The MaxCTD represents the maximum tolerable delay for packets, which allows to study the performance of the network under different delay constraints.
- **Bandwidth Capacity:** The bandwidth capacity was set to 1000 Mb/s
- **Traffic Load Ratio:** The ratio of the traffic load varied from 0.1 up to 1 (10%, 20%, 30%,…100%). Traffic has been created with several traffic load rates as follows: increasing load, high load, low load, and bursty load
    - o Incremental load: 0.5 Mb – 1000 Mb.
    - o High load:1000 Mb.
    - o Low load:0.5 Mb.
    - o Bursty load: 0.5 Mb – 1000 Mb.
- **Burst Size:** Two values for mean burst size were used: 16 KB and 32 KB.
- **Network Topology:** Both a simple OBS topology and NSFNET topology were considered to evaluate the system performance under different network conditions.
- **Propagation delay:** The Propagation delay was set to 1 μs.
- **Bit error rate:** The Bit error rate was set to 0.
- **Use of Fiber Delay Line (FDL):** No Fiber Delay Line (FDL) were used.
- **Use of Wavelength Conversion:** No Wavelength Conversion were used.

The simulation time for all tests was chosen to be large enough to achieve statistical stability and obtain accurate results. These parameters were selected to ensure a thorough evaluation of the performance of the ABA scheme under realistic conditions, while also ensuring proper comparisons with existing works.

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4.5 Simulation Procedure

1. **Traffic Generation:** The traffic generator creates CBR and VBR traffic sources have been created with several traffic load rates as follows: increasing load, high load, low load, and bursty load.
2. **Burst Assembly:** The ABA scheme performs burst assembly at the edge nodes, adjusting the high-priority traffic ratio based on the current traffic conditions.
3. **Contention Resolution:** Contention at the core node is handled using burst dropping.
4. **Data Collection:** The simulation collects data about packet drops at various points in the network.
5. **Performance Evaluation:** The data is processed to evaluate the overall packet loss probability and high priority packet loss probability.

This simulation model provides a rigorous environment for evaluating the performance of the ABA scheme under different conditions and against traditional alternatives.

4.6 Performance Metrics

To evaluate the performance of the ABA scheme, the following key metrics were used:

- Overall Packet Loss Probability: This metric is defined as the ratio of the total number of packets dropped to the total number of packets sent. It indicates the overall effectiveness of a scheme in minimizing packet loss within the network.

  Overall Packet Loss Probability = Total Packets Dropped / Total Packets Sent (8)

- High-Priority Packet Loss Probability: This metric is defined as the ratio of the number of high-priority packets dropped to the total number of high-priority packets sent. It specifically measures the ability of a scheme to guarantee the delivery of high-priority traffic.

High-Priority Packet Loss Probability = Total High-Priority Packets Dropped / Total High-Priority Packets Sent (9)

4.7 Benchmark Schemes

To validate the effectiveness of the proposed ABA scheme, we compared its performance with the following benchmark approaches:

- Non-Composite Burst Segmentation (NCBS): As previously described in Section 2, this scheme is a basic burst segmentation method that does not distinguish between traffic priorities. During a contention, the NCBS scheme drops only the overlapping segments without regard to the priority of the packets. This allows for comparison with a method that does not consider priorities.
- Composite Burst Segmentation (CBS) with Fixed Ratios: We also tested our scheme with a variety of composite burst segmentation schemes with fixed high-priority traffic ratios of 80%, 50%, and 20%. The use of these fixed ratios allows us to compare our dynamic approach with an approach that uses static ratios, which is the foundation of most existing methods.

5. Simulation Results and Discussion

This section presents the results obtained from the simulation experiments. The results compare the performance of the Adaptive Burst Assembly (ABA) scheme against non-composite burst segmentation and composite burst segmentation with fixed high-priority traffic ratios (80%, 50%, and 20%). These comparisons are shown for both CBR and VBR traffic types. The analysis focuses on the overall packet loss probability, and the high-priority traffic packet loss probability. The results in Figures 4 through 11, which show the packet loss probabilities under different traffic conditions. These figures depict the Overall and High-Priority Packet Loss Probabilities for both CBR and VBR traffic using our proposed method, and the two benchmark approaches. Each of these figures shows a different scenario, which allows a detailed understanding of the performance of our method in each case.

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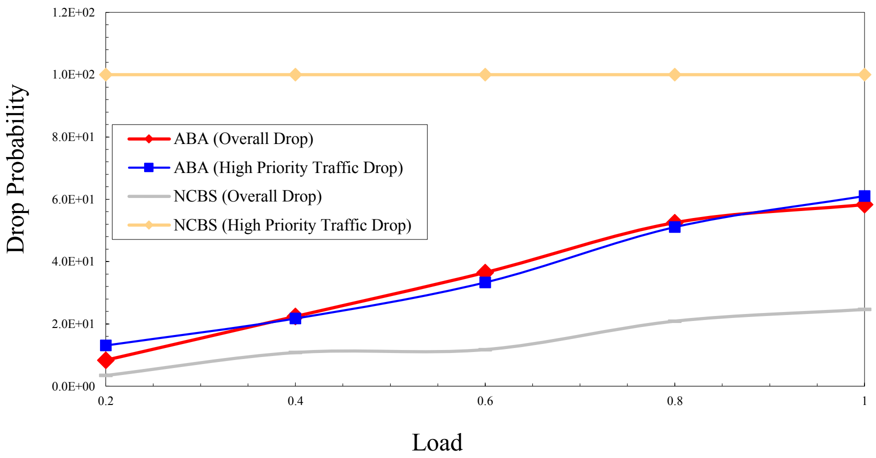

Figure 4: The Comparison of Overall and High Priority Packet Loss Between the ABA Scheme and NCBS for CBR Traffic

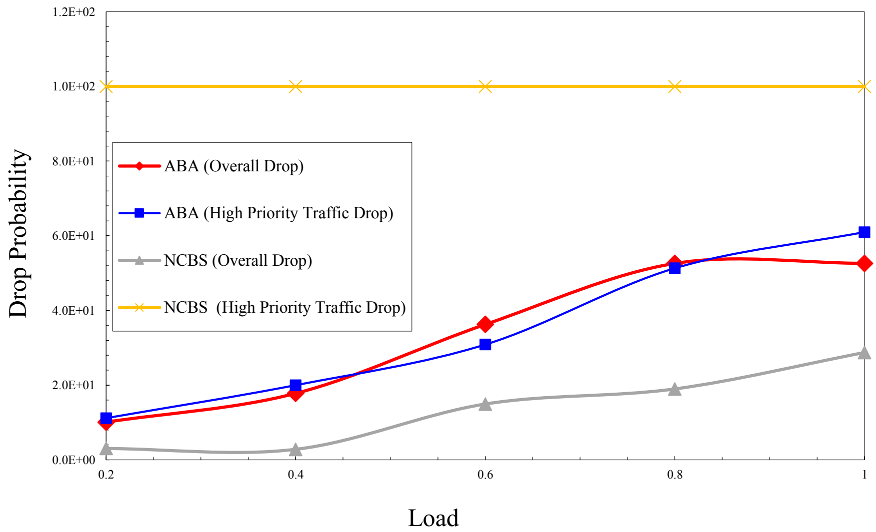

Figure 5: The Comparison of Overall and High Priority Packet Loss Between the ABA Scheme and NCBS for VBR Traffic

Figure 4 shows the packet loss probability comparison between the ABA scheme and non-composite burst segmentation using CBR traffic. The results show that the non-composite burst segmentation scheme reduces the overall loss. However, it is unable to guarantee low packet loss for high priority traffic.

Figure 5 shows the comparison using VBR traffic. Again, while the non-composite scheme reduces the overall packet loss, it does not guarantee the same performance for high priority traffic.

As shown in Figures 4 and 5, the NCBS approach fails to prioritize high-priority traffic. The ABA scheme effectively manages the resources to prioritize high-priority traffic.

Figures 6 and 7 compare the packet loss probability of the ABA scheme with that of a fixed-ratio (80%) composite burst segmentation scheme, for CBR and VBR traffic respectively. The results show that the ABA scheme provides a better trade-off. The ABA scheme demonstrates its ability to create stability in the performance of the network and ensure fairness between high-priority and low-priority traffic, which leads to better QoS and reduces the high priority packet loss rate.

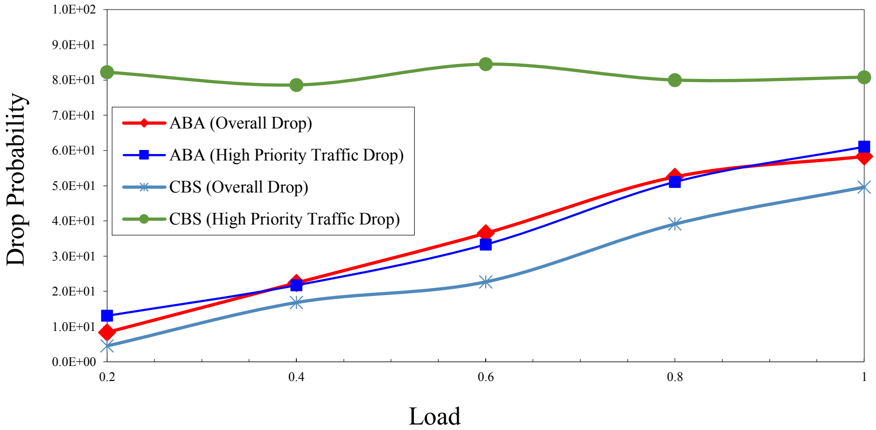

Figure 6: The Comparison of Overall and High Priority Packet Loss Between the ABA Scheme and CBS with a Fixed Ratio of 80% for CBR Traffic

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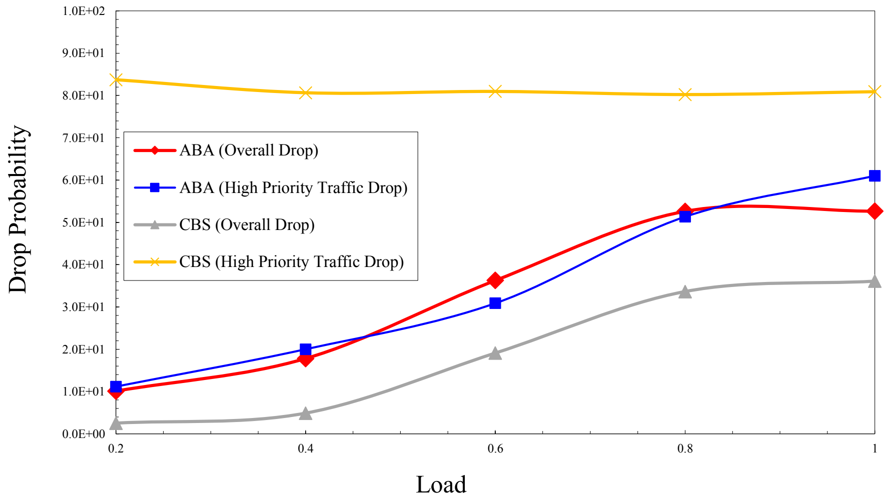

Figure 7: The Comparison of Overall and High Priority Packet Loss Between the ABA Scheme and CBS with a Fixed Ratio of 80% for VBR Traffic

Figures 8 and 9 show the packet loss probability for CBR and VBR traffic respectively with fixed ratio of 50%. Again, the ABA scheme shows superior performance compared to the fixed ratio composite burst scheme in both cases. The ABA scheme demonstrates better performance while preserving fairness for all traffic types.

Figures 10 and 11 show the performance of the ABA scheme when compared to a 20% fixed-ratio composite burst assembly scheme for CBR and VBR traffic. While the 20% scheme has less packet loss than other fixed ratio schemes, it has higher packet loss when compared to ABA, and it does not guarantee that the high priority packets are delivered with the required QoS. Moreover, the lower high priority traffic ratio leads to increase the overall loss, making the network performance unstable. The simulation results show that while a lower high priority traffic ratio provides slightly better results, it does not provide fairness for the other traffic types.

As shown in Figures 6 through 11, the ABA scheme consistently outperforms the CBS approach in all settings of traffic conditions. This result validates the dynamic traffic management and flexibility of the ABA approach. The ABA scheme dynamically adjusts the composition of bursts according to the current network conditions, while the CBS approach relies on fixed ratios.

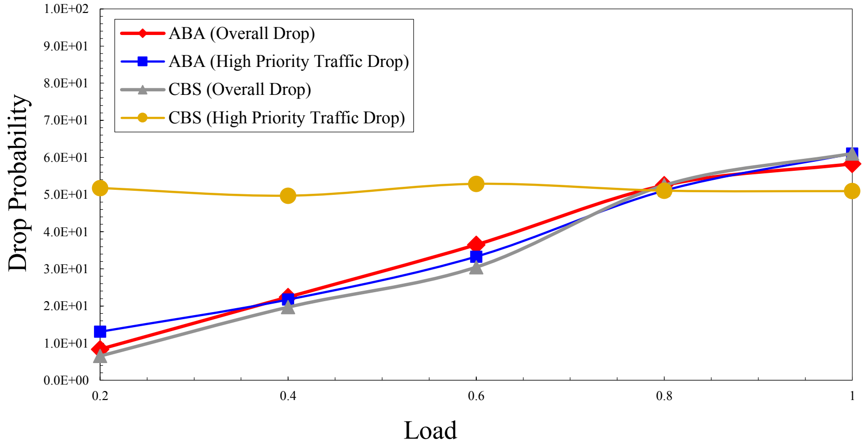

Figure 8: The Comparison of Overall and High Priority Packet Loss Between the ABA Scheme and CBS with a Fixed Ratio of 50% for CBR Traffic

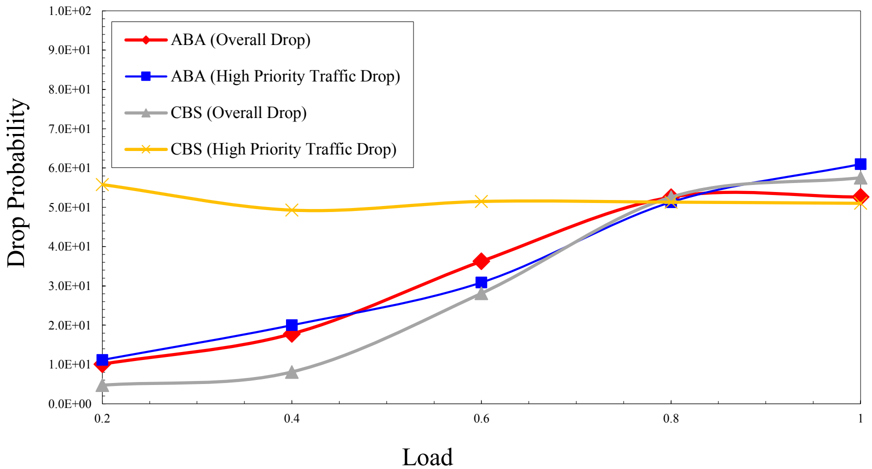

Figure 9: The Comparison of Overall and High Priority Packet Loss Between the ABA Scheme and CBS with a Fixed Ratio of 50% for VBR traffic

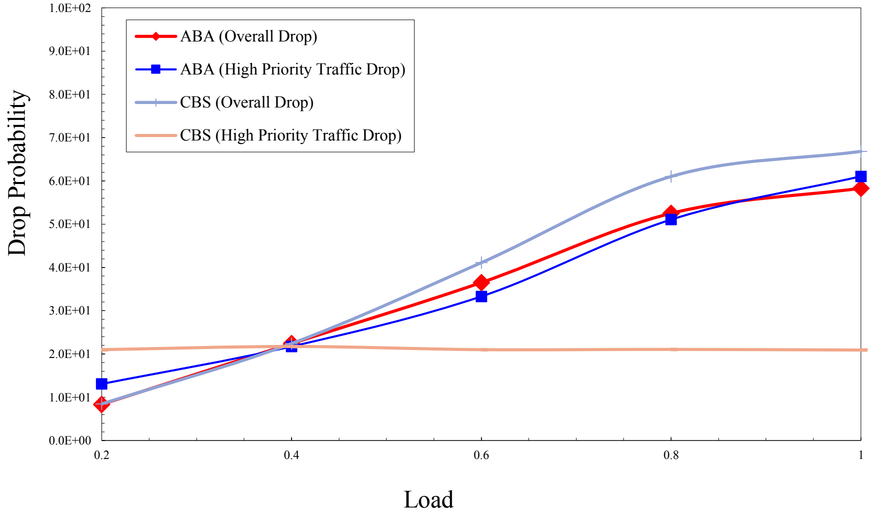

Figure 10: The Comparison of Overall and High Priority Packet Loss between the ABA Scheme and CBS with a Fixed Ratio of 20% for CBR Traffic

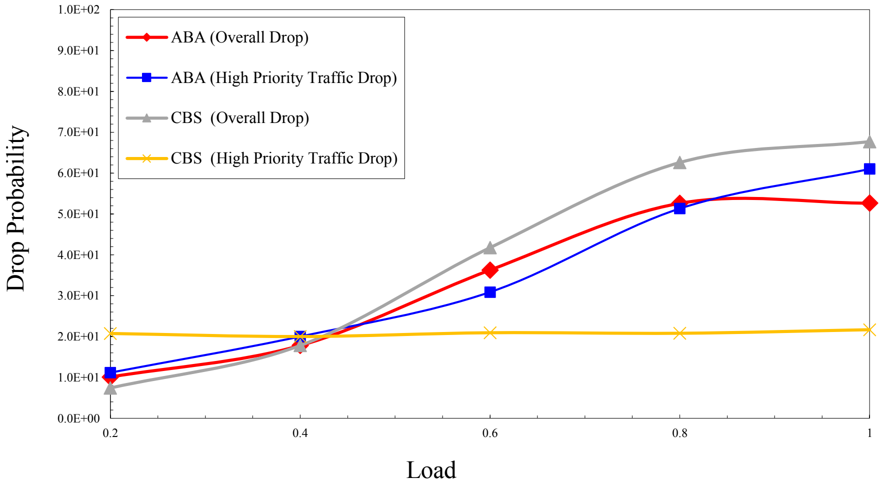

Figure 11: The Comparison of Overall and High Priority Packet Loss Between the ABA Scheme and CBS with a Fixed Ratio of 20% for VBR Traffic

The simulation results clearly demonstrate the benefits of the proposed ABA scheme. The results show that the ABA scheme outperforms the fixed ratio burst assembly schemes in reducing the high priority traffic packets loss probability. Moreover, it ensures fairness by dynamically adjusting the traffic ratio based on the load conditions of the network. The simulation also shows that the ABA provides stability to the network performance while ensuring a better QoS. The non-composite scheme reduces the overall loss but has less control over the high priority packet loss. Fixed-ratio composite schemes with 80% or 50% prioritizations can decrease the packet loss rate for high-priority packets but affect the overall performance and fairness. The scheme that uses a 20% fixed-ratio has better performance than the rest of the fixed-ratio schemes, but it has higher packet loss than the proposed ABA scheme. It can be said that the ABA scheme enhances the service quality of the real time traffic over OBS while enhancing the fairness for the lower priority traffic.

6. Conclusion and Future Directions

This paper addresses the limitations of fixed-ratio burst assembly schemes in Optical Burst Switching (OBS) networks, which struggle with dynamically changing network traffic conditions. Specifically, these limitations result in increased packet loss for high-priority traffic and an unfair allocation of network resources. To overcome these issues, the Adaptive Burst Assembly (ABA) scheme was introduced. ABA dynamically adjusts the ratio of high-priority traffic within bursts based on real-time network load. The simulation results demonstrated that the ABA scheme effectively reduces high-priority traffic packet loss compared to Non-Composite Burst Segmentation (NCBS) and Composite Burst Segmentation (CBS) which relies on fixed ratios. Notably, ABA consistently outperformed CBS across all tested scenarios and ratios (80%, 50%, and 20%) for both CBR and VBR traffic while also ensuring a degree of fairness among different traffic classes. These findings validate that dynamically adjusting the ratio of high-priority traffic within a burst based on current network conditions is critical for improving network performance and ensuring the efficient utilization of bandwidth and resources.

The dynamic nature of ABA provides a much better trade-off between packet loss, fairness, and adaptability. The primary contribution of this work is the introduction and validation of the ABA scheme, which provides a practical and robust method for improving the Quality of Service in OBS networks. The key benefits of this approach are: its ability to adapt to real-time network traffic load dynamically adjusting the high-priority traffic ratio, a significant reduction in packet loss for high-priority traffic, improved fairness, and robust performance under various network conditions. Furthermore, ABA is designed for implementation at the edge node of the network, allowing for dynamic adjustments using locally available information. These contributions highlight the practical and adaptable nature of the ABA approach for enhancing QoS in OBS networks.

While this research has contributed to the field and highlighted the effectiveness of dynamic burst assembly techniques, it also opens avenues for future research. One potential direction is to explore advanced machine-learning-based traffic prediction mechanisms to improve the accuracy and responsiveness of the scheme by anticipating congestion before it occurs. Also, further research is needed on how to integrate delay constraints, especially for real-time applications that have stringent end-to-end delay requirements. This can lead to further improvements by combining this method with advanced queuing mechanisms. Moreover, testing on more complex scenarios, including various network topologies and traffic patterns, is needed to better understand the effectiveness of ABA under real-world conditions. Further improvements can also be achieved by exploring adaptive membership functions and optimizing their values. Lastly, future investigations can focus on the real implementation and evaluation of the ABA scheme in real testbeds. These future research directions will help build a more comprehensive, realistic, and optimized dynamic approach to burst assembly in OBS networks.

In summary, this research introduced the Adaptive Burst Assembly (ABA) scheme, a novel approach for burst assembly that dynamically adapts to real-time network traffic conditions. By addressing the limitations of fixed-ratio approaches, ABA effectively reduces packet loss for high-priority traffic while ensuring fairness for lower-priority traffic. The findings underscore the importance of dynamically adjusting the burst assembly parameters for real-time traffic in OBS networks. The ABA scheme provides a practical and robust method for improving the Quality of Service in OBS networks and serves as a stepping stone for future research in this area [13-14].

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