Content Aware Burst Assembly – Supporting Telesurgery and Telemedicine in Optical Burst Switching Networks

Henry OROSCO, Lei WANG and Yuhua CHEN
Department of Electrical and Computer Engineering, University of Houston
Houston, TX 77204-4005, USA

ABSTRACT

The emerging Telemedicine and Telesurgery technologies allow patients to share medical experts remotely through communication networks. However, network bandwidth, network latency and jitter (variation of latency), are the obstacles to the widespread use of this technology remotely. Optical Burst Switching (OBS) networks greatly expand network bandwidth in existing network infrastructure by utilizing multiple DWDM channels within a single fiber, enabling high bandwidth applications. However, the burst assembly process in OBS networks introduces latency and jitter, making it unsuitable for high bandwidth, latency sensitive applications such as telesurgery and telemedicine. In this paper, we propose a content aware burst assembly scheme which dynamically adjusts the burst assembly parameters based on the content being assembled. The proposed content aware burst assembly minimizes the latency and jitter within a video frame, as well as across the left-view and right-view frames for 3D vision generation. Simulation results have shown that the proposed scheme can effectively reduce the latency and jitter experienced by video streams, making OBS a promising candidate for supporting telesurgery and telemedicine applications.

Keywords: Dense Wavelength Division Multiplexing (DWDM), Optical Burst Switching, OBS, Content Aware, Burst Assembly, Telesurgery, Jitter.

1. INTRODUCTION

The emerging Telemedicine and Telesurgery technologies allow patients to share medical experts remotely through communication networks. For example, telesurgery allows a surgeon to perform surgery on a remote patient with the help of robots. In fact, surgical robots are currently being used by surgeons worldwide (but just a few feet away from the patient) to conduct minimally invasive surgeries, which replace traditional open surgeries with 1-2 cm incisions. Theoretically, robotic surgery systems such as *da Vinci* Surgical Systems [1] can be operated over long distances. However, network bandwidth, latency and jitter (variation of latency) are the obstacles to the widespread use of this technology remotely.

Dense Wavelength Division Multiplexing (DWDM) allows multiple wavelengths, essentially different colors of light, to carry data over a single optical fiber. Each DWDM channel can carry data at 10 Gb/s and beyond, greatly expanding the network capacity over the existing network infrastructure. Optical switching technologies can efficiently support DWDM signals by allowing data to be transported over router nodes without *Optical*/*Electrical*/*Optical* (O/E/O) conversion.

Optical switching technologies can be characterized into optical circuit switching, optical packet switching, and optical burst switching. *Optical circuit switching* (OCS), also known as lambda switching, makes switching decisions at the wavelength level, and passes data through routers in pre-established lightpaths. *Optical packet switching* (OPS) [2][3] can switch data at the packet level optically. However, it is unlikely that optical packet switching will be available in foreseeable future; this is largely due to the lack of random access optical buffers, and the synchronization issues associated with the packet header and payload. *Optical burst switching* (OBS) [4][5][6] provides a granularity between optical circuit switching and optical packet switching. It allows the control header to set up an optical path before data arrives at the optical switching fabric. The decoupling of control header and the data (burst) also bypasses the synchronization problem that OPS experiences. Currently, OBS is considered the most promising optical switching technology.

Although OBS can support high bandwidth applications, they are not suitable for applications that require both high bandwidth and low latency. One of the reasons is that in OBS networks, packets are assembled at the ingress router into bursts, and are disassembled back to packets at the egress edge router [7]. The burst assembly process introduces additional latency and jitter [8] which threatens the safety of telesurgery.

In this paper, we propose a content aware burst assembly scheme which dynamically adjusts the burst assembly parameters based on the content being assembled. To support multi-view high definition (HD) video used in telesurgery for 3D vision, the proposed content aware burst assembly minimizes the latency and jitter within a video frame, as well as across the left-view and right-view frames for 3D vision regeneration. Simulation results show that the proposed scheme can effectively reduce the latency and jitter experienced by video streams, making OBS a promising candidate for supporting bandwidth demanding and latency sensitive applications such as telesurgery and telemedicine.

The rest of the paper is organized as follows. Section 2 provides the background of OBS networks and burst assembly process. The proposed content aware burst assembly scheme is described in Section 3. In Section 4, we evaluate the performance of the proposed scheme using software simulation. We conclude our work in Section 5.

2. OPTICAL BURST SWITCHING (OBS) NETWORK BACKGROUND

Optical Burst Switching (OBS) Network Overview

As stated earlier, OBS is able to achieve the benefits of both OCS and OPS without the drawbacks of either. It affords the user a physical connection for the duration of the burst, and offers the flexibility of a packet switched network. A major part of OBS is the DWDM technology [9], which allows multiple wavelengths to be carried in a single optical fiber. Currently each wavelength is capable of rates at 10Gbps and beyond. It is easy to see how DWDM technology can greatly enhance the bandwidth without infrastructure changes.

OBS differs from current networks by changes made to the edge node routers and the core node routers. In traditional networks, the transmissions between routers are sent over optical fibers, but at each node the data packet must undergo O/E/O conversion. In comparison, in OBS networks, the data burst does not have to undergo this process and is able to travel optically end-to-end, while the *burst header cell* (BHC) [10] is processed electronically. Packets are collected at the ingress edge routers and, according to a particular burst assembly algorithm [6], assembled into bursts. The burst assembly algorithm determines when to send the burst through the network.

OBS is similar to OCS as there is a reserved wavelength for the data in the burst to travel along, but it is only reserved for the duration of the burst. This gives OBS flexibility to handle bursty traffic. Another key point about OBS is that unlike packets where the header and the data are connected and sent together, the header is physically and temporally separated from the data burst. Because of DWDM, BHCs are sent across reserved control wavelengths, and correspondingly data bursts are sent across data wavelengths as shown in Figure 1. The BHC is created after the burst is formed and is sent ahead of the data burst. The difference in time between the BHC and the data burst is called the *offset* time. This offset between the BHC and the data burst is determined by how long it takes for the burst header to set up an optical path for the data burst in the OBS core network. The offset should be large enough such that data burst never catches the burst header before reaching the egress edge node. If the data burst reaches a router or node before the BHC is processed, it will be dropped.

It should be noted that work has been done utilizing the offset time as a way to guarantee a certain QoS [11][12][13][14][15][16][17]. For example, in the offset-based QoS scheme [12], bursts can be assembled by priorities and each priority will have a certain offset time. Bursts of higher priority will have a longer offset time while lower priority bursts will have a shorter offset time. Even though this increases the latency, the increased offset time ensures the burst reaches its destination. The thought behind this method is that the increase in latency through the offset time is small when compared to the time to reassemble the burst and send it through the network.

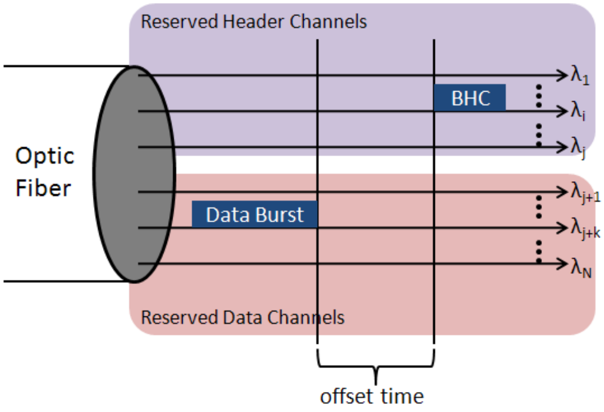


Figure 1: OBS Header Channels and Data Channels

The core routers use information carried in the burst header to determine where to send the burst and when to reserve a wavelength for the corresponding data burst. There are several wavelength resource management schemes: explicit setup, estimated setup, explicit release, and estimated release [11][18]. With explicit setup, a connection for the data burst is made immediately upon receiving the burst header at the core router node. In estimated setup, the core router takes the offset information from the burst header and calculates when it needs to reserve the connection in coordination with the arrival of the data burst. With explicit release, the edge node sends another burst control signaling the end of the transmission of the data burst. Consequently, resources are released after receiving such connection termination requests. Estimated release, similar to the estimated setup, will calculate when the resources can be released based on the data burst length carried in the burst header. *Just-in-Time* (JIT) [19] and *Just-Enough-Time* (JET) [20] are the two major protocols based on the configurations of the set up and release of resources described above. More specifically, JIT utilizes the explicit setup and explicit release. JET utilizes the estimated setup and estimated release configuration [11][18] [19].

Burst Assembly in OBS Networks

The basic processing unit in OBS core networks is a burst. A burst is simply a collection of thousands of packets. Packets arriving at the ingress edge router are assembled into bursts based on their destinations. Once a burst is formed, it is transported as an entity in the OBS core network until it reaches the egress edge router, where it is disassembled into packets. The criteria of forming a burst in the burst assembly process include [21]: (1) time-based assembly, (2) burst length-based assembly, (3) mixed time/burst length-based assembly, and (4) dynamic assembly. Time-based assembly has a time threshold that, when passed, stops assembling the burst and prepares it for transmission across the network. This algorithm is useful when the traffic load is light at the assembler. Burst length-based, or sized-based, assembly has a maximum burst length, or size, threshold which triggers the formation of the burst when the threshold is crossed. As a result, bursts will form faster under heavy traffic. In the mixed burst time/length-based assembly, a burst is formed when it reaches the maximum burst size, or the timeout threshold is crossed. The mixed burst assembly works under both light and heavy traffic cases, and it is the most popular burst assembly scheme [6]. Dynamic burst assembly can reduce burst loss probability by adjusting the parameters based on the feedback from the measured burst loss in the core network.

3. SUPPORTING TELESURGERY AND TELEMEDICINE OVER OBS NETWORKS

We have described the basics of OBS in the previous section. In this section, we investigate how OBS can be applied to telesurgery. We first cover the basics of telesurgery, and how current OBS technologies apply to telesurgery. Then, we proposed a content aware burst assembly scheme where burst assembly parameters are adjusted according to the content being assembled, minimizing latency and jitter experienced by delay sensitive applications such as telesurgery and telemedicine.

Telesurgery Basics

Telesurgery allows surgeons to perform surgery on remote patients with the help of a surgical robot. Many advances in telesurgery have been made in past years. The world's first telesurgery was performed by researchers at NASA's *Jet Propulsion Laboratory* (JPL) and the Telerobotics Laboratory of the Politecnico di Milano on July 7th, 1993 [22]. A robot in Italy was controlled from the USA to perform a biopsy on a model. The setup utilized two geosynchronous satellites and optical fibers to complete the network across continents. The use of satellites and optical fibers to perform surgery with an approximate delay of 2 seconds was been demonstrated. Other possibilities using various technologies have also been investigated [23][24].

However, all above mentioned efforts are still far from making telesurgery a reality. Nevertheless, some lessons have been learned. Some recognized the need to segregate data and use different protocols accordingly [24], while others looked into the requirements of the network [23][25]. Putting all the pieces together, a practical solution to telesurgery will require the use of optical networks, the segregation of data, and network support of QoS to reduce latency and jitter and to ensure the transmission bandwidth of data. Two other great concerns are the amount of data produced by the system, as well as round-trip delay which is crucial to the safety of telesurgery.

Through previous research and current technologies, a telesurgery setup is established in this paper as shown in Figure 2. At the remote patient side, multi-view high definition (HD) video cameras are used to produce the left and right vision for 3D vision at the surgeon side. There is, of course, the surgical robot to be controlled remotely by the surgeon. Other equipment and personnel will include vital sign monitors, microphones/speakers and nurses to help with the surgical procedures. HD video, and usually 4xHD video (four times the resolution of HD video) are recommended for medical use. Multi-view video helps to reconstruct 3D vision at the surgeon site, providing the surgeon with the depth perception necessary to carry out an accurate operation.

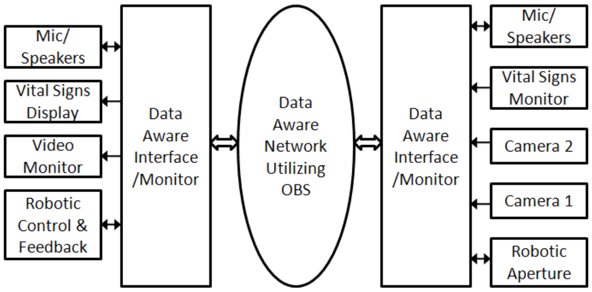


Figure 2: Sample Telesurgery Setup

At the surgeon site, there will be the 3D viewer allows the doctor interpret the stereo vision, a surgical robotic control interface, vitals display, and a microphone/speaker are necessary. The HD video and vital signs will be transmitted from the patient site to the surgeon site, while the robotic control data is sent from the surgeon site to the remote patient site. Voice communication is bidirectional.

While all above mentioned types of data are of great importance to the success of telesurgery, the round-trip latency from the issuing of a robotic control signal to the resulting video displayed at the surgeon's site determines the safety of telesurgery. If the robotic control signal gets delayed, it will result in a delayed action of the surgical robot. The result of delaying a stop command could be catastrophic. Video transmission from the patient site to the surgeon site is of equal importance. Being unable to see the result of a robotic control command on patient will hinder the surgeon's ability to make a decision on the next movement.

Transmitting multi-view HD video over the network presents a challenge. Multi-view video consists of the left view and the right view, each of which consists of a series of video frames. Each frame contains millions of pixels. In the case of HD video, each video frame is 1920 by 1080 pixels. When stereo vision is used, it is important to maintain the correlation between right and left frames to keep the integrity of the video displayed. If this correlation is lost, right and left images would be from different times and would incorrectly represent the observed object, causing blurred vision. To transmit the video over the network, the video frames are broken into smaller packets. The video data can also be encoded or compressed to reduce the amount of data transmitted over the network. For example, the MPEG-2 format is a common compression format. We have explained the telesurgery setup. In the next subsection, we will exam how OBS can be applied to this setup.

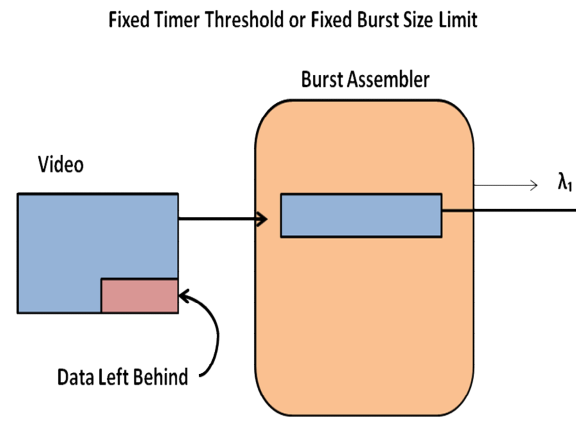


Figure 3: Fixed Timer Threshold or Fixed Burst Size Limit in Traditional Burst Assembly

Problem in Transporting Telesurgery Data in OBS Networks

As mentioned before, an OBS network is probably the best candidate for providing bandwidth in a flexible way. However, although OBS network can provide necessary bandwidth for telesurgery, latency and jitter are the two major obstacles in such an endeavor. The reason is that the traditional burst assembly process introduces latency and jitter into the telesurgery system.

For example, the burst assembly process can introduce jitter within a video frame, as a result of different delays experienced by different pixels. Figure 3 shows a time-based burst assembly process. In the figure, only a single video stream is illustrated. When a video frame is being assembled into a burst, the time threshold may be crossed before the entire frame is included into the burst. Once a burst is formed, triggered by a timer, the remaining pixels in the same frame must wait to be assembled in the next burst. This results in a large discrepancy in latency experienced by different pixels in the same frame. At the destination node, when the first burst is received, the receiving video buffer has to wait for the remaining portion of the frame to be received before forwarding the frame for display. The resulting delay in video frames can cause stalled video, threatening the safety of telesurgery.

Similarly, the same problem exists in a fixed size-based burst assembly process shown in Figure 3. If the burst length threshold is reached before the last few pixels are assembled into the burst, the remaining part has to wait until the next burst is assembled. This will result in jitter at the destination. Although the problem might be eased by increasing the maximum burst size, such an approach does not work well with a compressed video stream, and can increase burst assembly time unnecessarily.

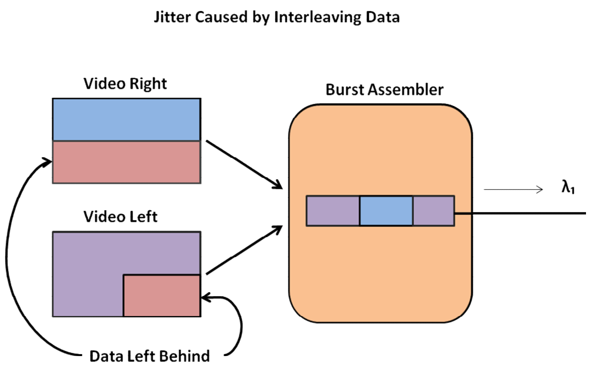


Figure 4: Problem with Interleaving Frames.

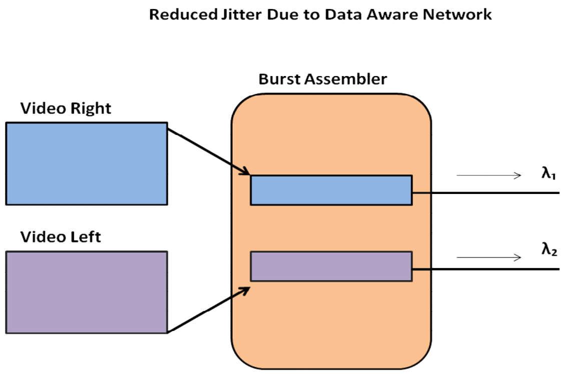


Figure 5: Effect of Proposed Content Aware Burst Assembly

The problem will be worse if multi-view video is used. Figure 4 shows the case of assembling the stereo vision video streams into bursts. Using traditional burst assembly schemes, both the left and the right view video frames will be assembled into the same burst, as they are going to the same destination. This will cause an interleaving of the left and the right video streams. The interleaving will increase the probability that either or both of the frames will be incomplete when a burst is formed according to either time-based or burst size-based thresholds. Consequently, the video buffer at the destination node would have to wait for one or more bursts before the multi-view video frames could be displayed. Another consequence of interleaving is the left and the right frames may be out of synchronization and are no longer correlated when displayed. This could produce a current image for the left video but a stale image for the right video or vice versa.

Proposed Content Aware Burst Assembly for Telesurgery

In this paper, a content aware burst assembly scheme to reduce the jitter caused by the burst assembly process is proposed. The proposed content aware burst assembly process dynamically adjusts the burst assembly parameters, such as the timeout value or the maximum burst length, based on the content being assembled. The maximum allowable burst length can be dynamically adjusted to take into account the completeness of the frames being assembled. For example, the actual burst length can be stretched to include the last few pixels within the same video frame, reducing the time that the pixels spend at the receiving buffers. The content aware burst assembly scheme also takes inputs from the video encoder to accommodate different video encoding schemes.

In addition, the proposed content aware burst assembly allows two or more bursts to the same destination to be assembled simultaneously. For example, the left and the right view frames can be assembled into two separate bursts, and *transmitted*

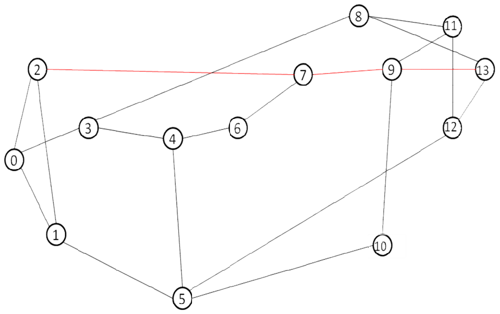


Figure 6: Network Topology

concurrently on the DWDM channels, minimizing the jitter experienced by the pixels across the two views. As a result, the proposed content aware burst assembly scheme can effectively minimize the latency and jitter within a video frame, as well as across the left-view and right-view frames for 3D vision regeneration.

Figure 5 shows an example of assembling the left and the right view video frames into two separate bursts, even though they are of the same destination. Once the bursts are formed, they will be transmitted on two different wavelengths simultaneously, greatly reducing the cross view jitter. It also reduces the complexity at the receiving end to separate the two views.

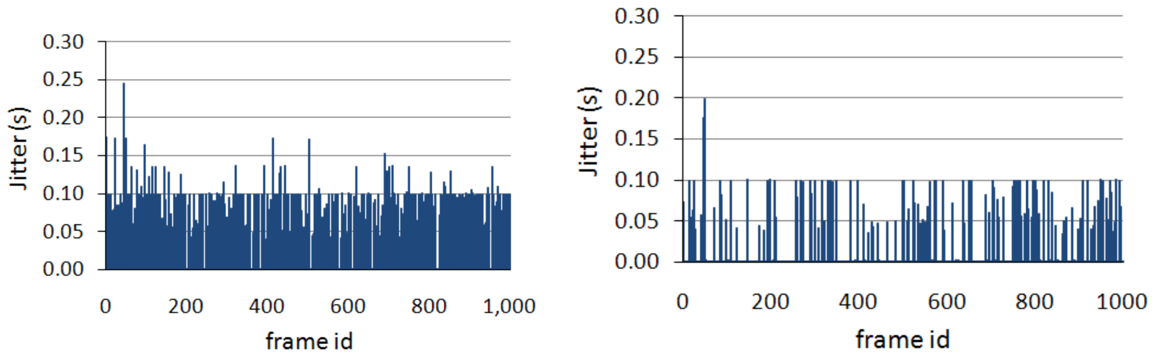
The proposed content aware burst assembly dynamically adjusts the number of bursts being assembled for each destination, as well as how to trigger the formation of the bursts being assembled based on the content of the data. To gain knowledge of the content being assembled, the proposed architecture utilizes content monitoring agents for individual data type received by the edge router. The monitoring feature can be dynamically turned on and off for each type of data. The content monitoring agent will generate proper tags for the data type it monitors, which will in turn affect the burst assembler's decision in the burst assembly process.

4. PERFORMANCE EVALUATION

In this section, we evaluate the performance of the proposed content aware burst assembly scheme using a modified version of ns2-OBS simulator. The jitter information of the proposed scheme is gathered, and is compared with the traditional burst assembly process.

Jitter Definition

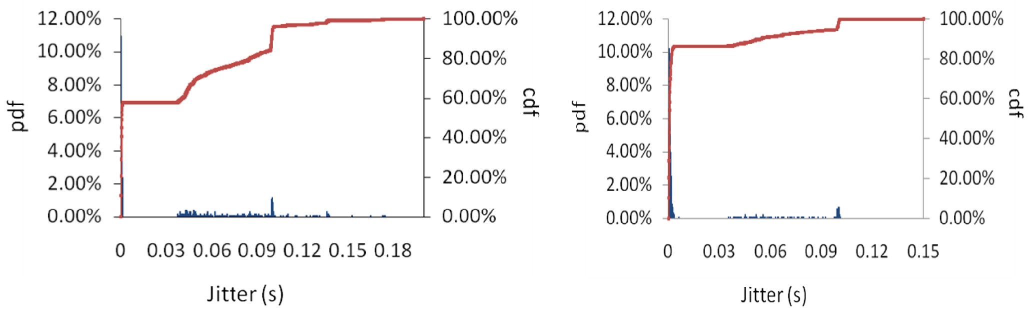
Before moving on to the simulation results, a formal definition of the jitter to be analyzed must be made. Jitter, in this paper, is what is known as intra-frame jitter, which is the time difference between the arrival of the first bit of data (φ_F) and the last bit of data (φ_L) from the same frame. Jitter for the left view (Γ_L) and the right view (Γ_R) are formally described as



(a)

(b)

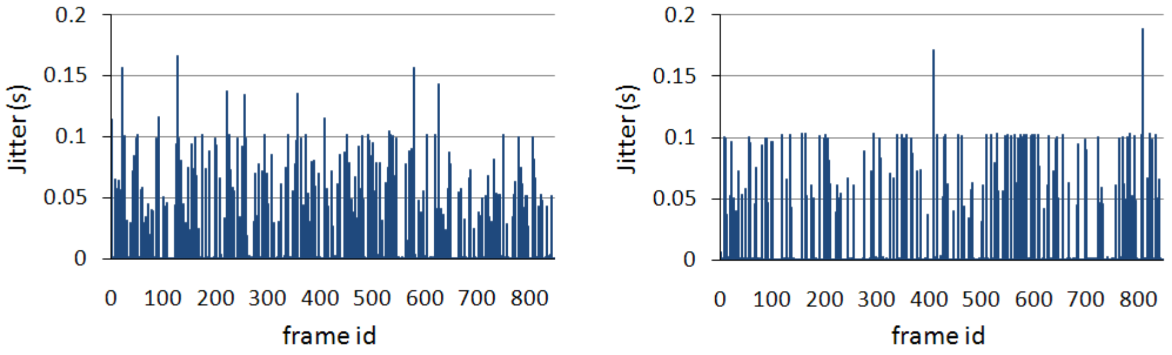
Figure 7: Jitter, Single View: (a) Traditional Burst Assembly (b) Proposed Content Aware Burst Assembly



(a)

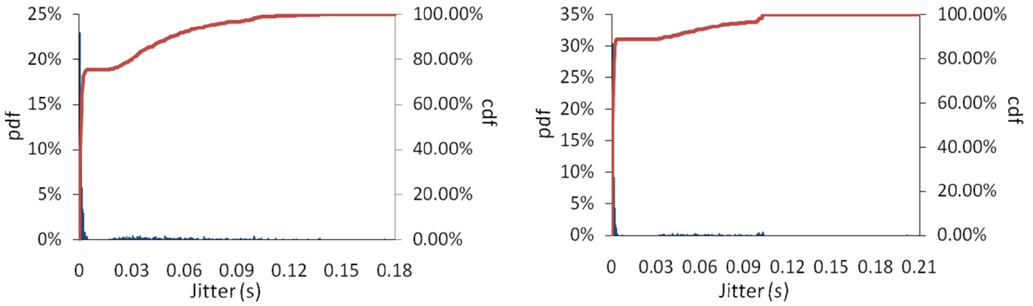
(b)

Figure 8: Jitter Probability Distribution, Single View: (a) Traditional Burst Assembly (b) Proposed Content Aware Burst Assembly



(a) **(b)**

Figure 9: Jitter, Left View: (a) Traditional Burst Assembly (b) Proposed Content Aware Burst Assembly



(a) **(b)**

Figure 10: Jitter Probability Distribution, Left View: (a) Traditional Burst Assembly (b) Proposed Content Aware Burst Assembly

$$\Gamma_L = \varphi_{LL} - \varphi_{LF}, \tag{1}$$

and

$$\Gamma_R = \varphi_{RL} - \varphi_{RF}. \tag{2}$$

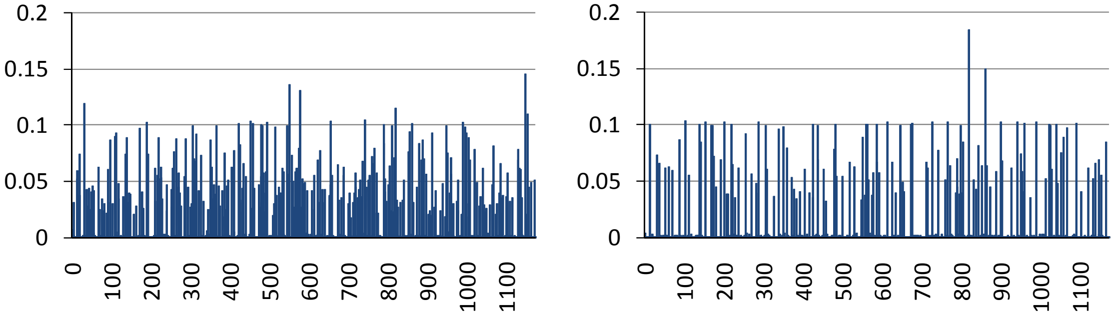
Simulation Setup

We simulated both the traditional burst assembly and the proposed content aware burst assembly processes using a 14-node, 21-link NSFNET topology as shown in Figure 6. Each link carries 4 DWDM channels at 1 Gb/s in each direction. Two video streams composed of HDTV video, compressed using the MPEG2-TS format are used to compare the dynamic size threshold scheme with the traditional scheme. The first stream tested, scenario 1, is 1080p25 (e.g. resolution 1920x1080 at a 25Hz frame rate), 18Mbps average, and has a 30Mbps peak. The second stream, scenario 2, is 1080p29.97 (e.g. resolution 1920x1080 at a 29.97Hz frame rate), 25Mbps average, and has a 37Mbps peak.

Video packets arrive at the burst assembler following a Poisson process, and the average frame size is calculated as a function of the average stream rate divided by the frame rate. The resulting average frame sizes are 90,000 bytes and 104166 bytes for the 1080p25 and 1080p29.97 streams, respectively. To account for the variation in the frame size due to compression, it is modeled as exponentially distributed.

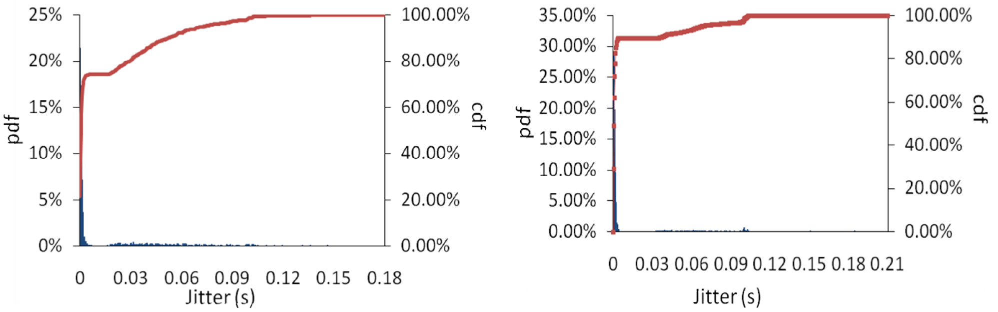
According to the MPEG2-TS format, each packet has a constant size of 188 bytes. For the traditional burst assembly methods, the burst size threshold is 160,000 bytes and the timeout threshold is 0.1s. Since focus is given to the burst size threshold in this particular experiment, the data aware assembler will utilize a dynamic burst size threshold, allowing the pixels at the end of a frame to be included in the burst even if the burst size threshold is crossed. To avoid supersized bursts, a limit is placed on the dynamic threshold: the remainder of the frame must not be longer than one-third of the original burst size threshold to be sent with the current burst. This is to keep latency for data at the beginning of the burst from growing too large. The offset time between the burst header and the data burst is 1μs. A randomly chosen Nodes 2 and 13 are set to be the video initiating node, and the receiving node, respectively.

The second testing set adds the dynamic time threshold and another HD video stream to represent the left and right view video streams. This setup first utilizes traditional OBS methods by assembling bursts according to destination. Then the results are compared with that of the proposed content aware burst assembly process, where the left and right video streams are assembled in their respective bursts.



(a) (b)

Figure 11: Jitter, Right View: (a) Traditional Burst Assembly (b) Proposed Content Aware Burst Assembly



(a) (b)

Figure 12: Jitter Probability Distribution, Right View: (a) Traditional Burst Assembly (b) Proposed Content Aware Burst Assembly

Simulation Results

Plots for the jitter performance of the traditional approach and the dynamic size threshold approach can be seen in Figure 7(a) and Figure 7(b), respectively. The effect on jitter is even more pronounced on the probability distribution graphs shown in Figures 8(a) and 8(b). In Figure 8(a) and 8(b), the *probability distribution function* (pdf) is a bar graph using the left vertical-axis and the horizontal-axis (jitter). The *cumulative distribution function* (cdf) is a line graph using the vertical-axis on the right and the bin values of jitter along the horizontal-axis. Because the aim of this paper is to highlight the differences between the traditional and proposed methods, there are more bins than normal to provide a greater resolution.

From the histogram plots shown in Figure 8 (a) and Figure 8(b), a noticeable difference in jitter is seen between the fixed and dynamic burst size threshold assembly algorithms. From these histograms, it is easy to see that for the traditional fixed burst size threshold algorithm, 40% of jitter is more than 0.03s and 20% of jitter is more than 0.09s. In comparison, the proposed dynamic burst size threshold algorithm has significant improvement on jitter performance, with more than 80% of jitter close to 0s.

Figures 9, 10, 11 and 12 display the jitter analysis for the multi-view 3D video streams. Two HD video feeds (the left view and the right view) utilize the traditional burst assembly process and the proposed content aware burst assembly process respectively. The results are compared side by side to show the benefits of the proposed scheme.

In traditional burst assembly, both left and right video feeds are aggregated into the same burst because they have the same destination. The jitter and jitter probability distribution for the left and the right views are shown in Figure 9(a), 10(a), 11(a) and 12(a).

In the proposed scheme, the right and left HD video feeds are assembled into separate bursts even though they share the same destination. Figures 9(b), 10(b), 11(b) and 12(b) shows the results for the proposed content aware burst assembly process. Compared with the results of traditional burst assembly scheme, it is easy to see the improvement gained by the proposed scheme.

A summary of the simulation results with additional traffic load test scenarios is listed in Table 1. The configuration section is represented as follows: number of data streams – number of λ channels – avg. frame rate – peak frame rate (right or left vision). The “percent less” column shows the percent difference from the single channel case to the two channel case average jitter by their corresponding right or left video stream. For the test load case of 18Mbps average and 30Mbps peak, an improvement of 28.81% to 19.49% is seen from the single

Table 1: Summary of Simulation Results

Config	AVG	Percent Less	Percent Under			
			0.0003s	0.0006s	0.0009s	0.03s
2-2-18-30L	0.013616	28.81	27.74	47.46	58.68	83.83
2-2-18-30R	0.012661	19.49	28.89	46.28	60.84	84.76
2-1-18-30L	0.017415		22.08	39.32	49.11	75.91
2-1-18-30R	0.015726		22.2	39.67	50.41	77.69
2-2-25-37L	0.008617	36.82	30.36	50.51	64.29	88.86
2-2-25-37R	0.008351	38.65	29.13	48.81	62.01	89.27
2-1-25-37L	0.013638		22.96	39.8	50.26	79.85
2-1-25-37R	0.013612		21.47	38.84	49.32	80.24

channel to the dual channel setup. The second load case of 25Mbps average with a 37Mbps peak sees an improvement of 38.65% to 36.82% from the single channel to the dual channel setup. It should be noted that the higher the loads, the better the improvement of the proposed scheme on jitter due to the dynamic size threshold.

5. CONCLUSION

To effectively support telesurgery in OBS networks, a new content aware burst assembly scheme which dynamically adjusts the burst assembly parameters based on the content being assembled has been proposed. The proposed content aware burst assembly minimizes the jitter within a video frame, as well as across the left-view and right-view frames for 3D vision regeneration. The simulation results have shown that the proposed scheme can effectively reduce the latency and jitter experienced by video streams, making OBS a promising candidate for supporting telesurgery and telemedicine applications as well as other high bandwidth latency sensitive applications.

6. ACKNOWLEDGEMENT

This work is supported in part by the National Science Foundation (NSF) under Grant CNS-0708613, and the Texas Advanced Research Program (ARP) under Grant G096059.

7. REFERENCES

[1] http://www.intuitivesurgical.com.

[2] D. Blumenthal, P. Prucnal, and J. Sauer, “Photonic packet switches: Architectures and experimental implementations,” **Proc. IEEE**, vol. 82, no. 11, Nov. 1994, pp. 1650–1667.

[3] P. Gambini et. al., "Transparent optical packet switching: network architecture and demonstrators in the KEOPS project," **IEEE Journal on Selected Areas in Communications**, vol. 16, Sept. 1998, pp. 1245-1259.

[4] J. S. Turner, “Terabit burst switching,” **Journal of High Speed Networks**, vol. 8, no. 1, 1999, pp 3-16.

[5] C. Qiao, M. Yoo, “Optical Burst Switching (OBS) – A New Paradigm for an Optical Internet”, **Journal of High Speed Networks**, Vol. 8, Issue 1, 1999, pp. 69-84.

[6] Y. Chen, P. Verma, “Optical burst switching – an emerging core network technology,” **Internet Networks – Wired, Wireless, and Optical Technologies**, K. Iniewski, Ed. CRC Press, Taylor & Francis Group, pp. 265-290, 2010.

[7] Y. Xiong, M. Vandenhoute, H. C. Cankaya, “Control architecture in optical burst-switched WDM networks,” **IEEE Journal on Selected Areas in Communications**, vol. 18, Oct. 2000, pp. 1838–1851.

[8] R. Rajaduray, S. Ovadia, D. J. Blumenthal, “Analysis of an Edge Router for Span-Constrained Optical Burst Switched (OBS) Networks,” **IEEE/OSA Journal of Lightwave Technology**, Vol. 22, No. 11, Nov. 2004, pp. 2693-2705.

[9] Y. Mei, C. Qiao, “Efficient Distributed Control Protocols for WDM Optical Networks”, Proc. **Int’l Conference on Computer Communication and Networks**, Sept. 1997, pp. 150-153.

[10] Y. Chen, J. Turner, and P. Mo, “Optimal burst scheduling in optical burst switched networks,” **IEEE/OSA Journal of Lightwave Technology**, vol. 25, no. 8, Aug. 2007, pp. 1883-1894.

[11] T. Battestilli, H. Perros, “An Introduction to Optical Burst Switching”, **IEEE Optical Communications**, Aug. 2003.

[12] M. Yoo, C. Qiao, S. Dixit, “QoS Performance of Optical Burst Switching in IP-over-WDM Networks”, **IEEE Journal on Selected Areas in Communications**, Vol. 18, Oct. 10th, 2000, pp. 2062-2071.

[13] M. Yoo, C. Qiao, S. Dixit, “Optical Burst Switching for Service Differentiation in the Next-Generation Optical Internet”, **IEEE Communications Magazine**, Vol. 39, Feb. 2nd, 2001, pp. 98-104.

[14] Y. Chen, M. Hamdi, D. H. K. Tsang, “Proportional QoS over OBS networks,” **Globecom 2001**, vol. 3, 2001, pp 1510-1514.

[15] Q. Zhang, V. Vokkarane, B. Chen, J. P. Jue, “Early drop and wavelength grouping schemes for providing absolute QoS differentiation in optical burst-switched networks,” **Globecom 2003**, Dec. 2003, vol. 5, pp. 2694-2698.

[16] F. Farahmand. J. P. Jue, “Supporting QoS with look-ahead window contention resolution in optical burst-switched networks,” **IEEE Globecom 2003**, vol. 5, San Francisco, CA, Dec. 2003, pp. 2699 – 2703.

[17] Y. Chen, J. Turner, Z. Zhai, “Contour-based priority (CBP) scheduling in optical burst switched networks,” **IEEE/OSA Journal of Lightwave Technology**, vol. 25, no. 8, Aug. 2007, pp. 1949-1960.

[18] M. Maier, **Optical Switching Networks**, Cambridge Press, 2008, pp. 103-112.

[19] I. Baldine, M. Cassada, A. Bragg, G. Karmous-Edwards, D. Stevenson, “Just-in-Time Optical Burst Switching Implementation in the ATDnet All-Optical Networking Testbed”, Proc. **IEEE GLOBECOM**, Vol. 5, 2002, pp. 2777-2781.

[20] M. Yoo, C. Qiao, “Just-enough-time (JET): A high speed protocol for bursty traffic in optical networks,” **IEEE/LEOS Tech.. Global Info. Infra.**, Aug. 1997, pp. 26–27.

[21] J. Yu, J. Li, X. Cao, Y. Chen, C. Qiao, “Traffic Statistics and Performance Evaluation in Optical Burst Switched Networks”, **IEEE/OSA Journal of Lightwave Technology**, Vol. 22, Dec. 12th, 2004, pp. 2722-2738.

[22] A. Rovetta, R. Sala, F. Cosmi, X. Wen, D. Sabbadini, S. Milanesi, A. Togno, L. Angelini, A. Bejczy, “The First Experiment in the World of Robotic Telesurgery for Laparoscopy Carried Out by Means of Satellites Networks and Optical Fibres Networks on 7th July 1993”, Proc. **Int’l Conference on Industrial Electronics, Control, and Instrumentation (IECON) ‘93**, Vol. 1, Nov. 1993, pp. 51-56.

[23] M. Smithwick, “Network Options for Telesurgery”, **IEE Colloquium on Towards Telesurgery**, June 20th, 1995, pp. 3/1 - 322.

[24] X. Xiaohui, D. Ruxu, S. Lining, D. Zhijiang, “Internet based Telesurgery with a Bone-Setting System”, Proc. **2007 IEEE Int’l Conference on Integration Technology**, Mar. 2007, pp. 218-222.

[25] N. Dowler, C. J. Hall, “Safety Issues In Telesurgery – Summary”, **IEE Colloquium on Towards Telesurgery**, June 20th, 1995, pp. 6/1-6/3.