Resource Reservation in Optical Burst Switching: Architectures and Realizations for Reservation Modules

Sascha Junghans and Christoph M. Gauger
University of Stuttgart
Institute of Communication Networks and Computer Engineering
Pfaffenwaldring 47, 70569 Stuttgart, Germany
{junghans, gauger}@ikr.uni-stuttgart.de

ABSTRACT

This paper presents an architecture and a realization of a burst reservation module for optical burst switching using the just-enough-time (JET) reservation scheme. JET is a reserve-a-fixed-duration reservation algorithm, i. e., wavelength channels are allocated exactly for the burst transmission time. As the exact start and end times of all bursts have to be recorded and processed for JET burst reservation, several publications assumed its realization to be prohibitively complex. This paper proposes an architecture for a hardware-based reservation module for JET. This architecture has been described in VHDL and synthesized on an FPGA representative for today's programmable logic technology. The proposed solution is evaluated under dynamic traffic based on timing and resource utilization results taken from the FPGA realization. The results of the performance evaluation prove that with this reservation module JET can even be realized for burst durations in the microsecond range.

1. INTRODUCTION AND MOTIVATION

Optical burst switching seems to be a promising candidate for a more dynamic optical transport network layer. In OBS, subwavelength granularity is provided by optical data bursts which cut through intermediate nodes, i. e., data stays in the optical domain at all times.[1–3] However, in contrast to optical packet switching, OBS aggregates and assembles packets electronically into bursts of variable length according to destination and QoS class at the edge of the network. Information for reservation of resources and switch control is signalled out-of-band using burst header packets. A control packet is sent out a certain time — called offset time — before the data burst. This offset time is used to compensate processing of the control packet, setting up of the switching matrix and generating a new control packet in core nodes.

A burst reservation module searches an idle wavelength channel on the respective output port for the burst transmission time and performs the actual reservation i. e., it manages the wavelength channels of the output fiber. To date, a lot of work has been devoted to evaluation and optimization of burst scheduling schemes[4–6] but to the best of our knowledge no work has looked into the problem of realizing these burst scheduling schemes for burst durations in the range of microseconds. Due to the extremely short processing times allowed for control packets hardware-based solutions are needed. This paper proposes an architecture for a hardware-based reservation module which has been described in VHDL and synthesized on an ALTERA FPGA target. Results for timing and resource usage taken from the FPGA realization are used to evaluate the proposed solution under dynamic traffic.

2. THE JET RESERVATION SCHEME

The reservation algorithm JET is a very general algorithm. JET is a so-called RFD-algorithm (reserve-a-fixed-duration). This means, that the arrival time of the burst at the node and the duration of the transmission is well known at the node. The wavelength is reserved exactly for the time, the burst really needs the transmission link, but not longer and not earlier (Aside from some guard times at beginning and end of the burst for compensating jitter and switching time of the optical cross connect.). When a control packet arrives, the reservation module searches for a free wavelength for the burst in the desired time interval. As wavelength converters are expensive components, it would be desirable to assign the burst to the same wavelength on the output link like on the input link. If the wavelength is already busy, other wavelengths are checked for their status in the time interval of transmission. If one or more wavelengths are not occupied to the allocated time one of them is selected and reserved for the belonging burst.

3. ARCHITECTURE OF THE RESERVATION MODULE

As reservations for bursts which are directed to different output fibers can be performed independently we propose to apply a seperate reservation module per output fiber. Thus, multiple burst reservations can be processed in parallel which reduces the load on each individual reservation control module.

The processing time of a control packet for reserving a burst should be as short as possible. Therefore, a hardware based solution is designed and realized here. The proposed solution processes control packets within a constant and deterministic processing time. It is based on a large combinatorial network which performs a lot of comparisons of time informations for determining free wavelengths and reserving one for the corresponding burst. All informations about the status of wavelengths are represented in a decentralized fashion in dedicated logical burst reservation entities. The data for reserved resources is stored for each wavelength separately in dedicated logic components. When a new control packet arrives the information about the corresponding burst is provided to the logic elements for all wavelengths. Each wavelength compares the provided data with the local stored data for reserved bursts. If the new burst intersects with one or more bursts which are allready reserved, a block-signal is set. A central reservation manager checks for all wavelengths, which did not set the block-signal. According to the JET algorithm proposed by Yoo und Qiao,[7] the burst is assigned to the first available wavelength and its data is stored in the logic entity for the selected wavelength.

The status informations for a single burst are stored in dedicated entities BRes. Several BRes-entities are assigned to one wavelength exclusively for reserving more than one burst per wavelength. It is possible to cascade as much BRes-entities as necessary. The actual system time is provided to all reservation entites. With this time information the entity checks, if the stored reservation is still valid or outdated. In the latter case the information is deleted and a new burst reservation can be stored in the entity. An additional combinatorial network signals, if all entities of a wavelength are in use. In this case it is not possible to buffer an additional burst, even if the wavelength is not used during the transmission interval of the new burst.

The architecture of the reservation module is shown in Figure 1. Here, the principle is shown with two wavelengths and two BRes-entities are used for each wavelength. The complete procedure is performed in one clock cycle. With the following clock edge the reservation information is stored and the next search for the

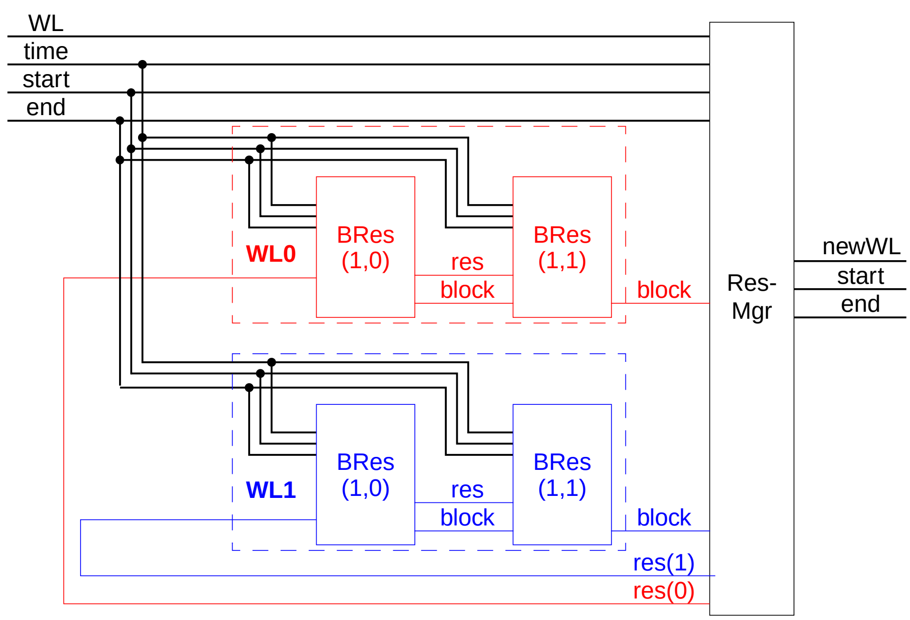

Figure 1. Buffering of wavelength status and searching for free wavelength: Start and end times of new reservation requests are applied to all wavelengths. Wavelengths with intersection with allready reserved bursts activate their block-signal. The Res-Mgr selects one of the free wavelengths and activates the corresponding res-signal.

following control packet can be done. With growing number of wavelengths and BRes-entities per wavelength the size of the combinatorial network increases and the critical paths get longer. So the maximum clock frequency of the reservation module decreases with increasing number of reservation entities.

As simulation results show, the probability of having more than eight bursts reserved for one wavelength is very small even for high load situations. In this paper four and eight entities of BRes per wavelength are used during the synthesis of the reservation module.

4. SCALABILITY ANALYSIS

The proposed architecture was synthesized on a today's logic device. The synthesis results where analyzed regarding resource usage, processing time and performance under dynamic traffic.

4.1. Analysis of FPGA resources and burst reservation time

The reservation module was modeled and described in VHDL and synthesized for a Field Programmable Gate Array (FPGA). The APEX 20KC family from Altera was selected as target platform. The synthesis was made for different numbers of wavelengths and for four and eight reservable bursts per wavelength. The time information was represented as 20 bit words which cover a time range of 1 ms with a resolution of 1 ns. Figure 2 shows on the left side the number of used logic elements in the APEX device. The devices provide a maximum capacity of 38400 logic elements, which is represented by the dashed line in the graph. The graph shows, that the number of used logic elements grows linear with the number of wavelengths.

Figure 2 shows on the right the combinatorial delays which limit the maximum operation frequency of the reservation system. The reservation takes several tens of nanoseconds and the delay grows linear with the number of wavelengths. The version with eight reservable bursts per wavelengths needs about 5 ns more than the version with 4 bursts per wavelength. For the given maximum number of wavelengths the maximum delay stays under 60 ns. This value of 60 ns is used for the performance evaluation in the next section.

4.2. Scalability analysis under dynamic traffic

A reservation module processes the control packets of all bursts directed the corresponding fiber. While a large number of bursts is transmitted in parallel on a fiber using DWDM control packets are processed by a single control module. The arrival rate of control packets λ_{res} to the reservation module can be calculated from the number of wavelengths w per output fiber, the load per wavelength ρ_λ and the mean burst duration $E[T_{\text{burst}}]$ as $\lambda_{\text{res}} = (w\rho_\lambda)/E[T_{\text{burst}}]$. It can be immediately seen that the arrival rate to the reservation module increases with the number of wavelengths, higher values of data load and smaller mean burst durations.

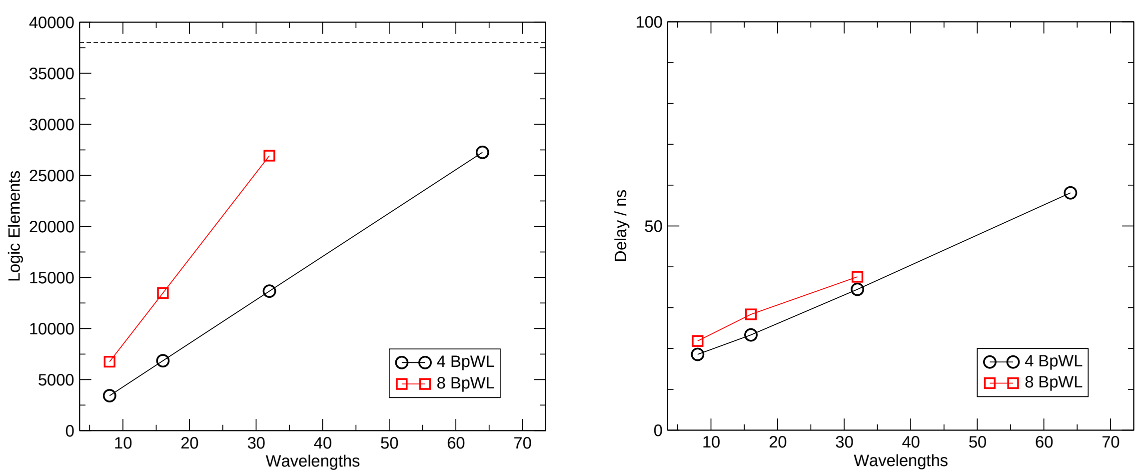

Figure 2. Results of synthesis process: Usage of Logic Elements in the FPGA (left) and combinatorial delay (right).

In the reservation module, arriving control packets are queued and processed on a first-come first-serve basis. In case the waiting and processing times of control packets exceed the predetermined latency which is compensated by the offset time or an FDL delay the corresponding burst is lost. In a well dimensioned system, the probability to violate the latter control packet time constraint should be very small compared to the burst loss probability due to contention. In the following analysis, we assume that the maximum waiting time of a control packet in the queue of a reservation module has to be less than $1\,\mu s$ in order to satisfy the control packet time constraints. The probability of exceeding this value and thus losing the burst should be less than or equal to 1% of the burst loss probability due to contention.

Burst loss probability due to channel contention can be calculated according to the well-known Erlang B formula for Poisson arrivals and independent of the burst length distribution.[4] The assumption of Poisson arrivals is common and has been supported in the case of OBS by work on traffic characterization of burst assembly strategies.[8] For performance evaluation under Poisson traffic, the combinatorial realization of the reservation module can be modelled as a M/D/1 single server queue with arrival rate λ_{res} and constant service time $T_r = 60\,ns$. The probability for a control packet to exceed a certain value of the waiting time is described by the complementary waiting time distribution.

In Figure 3, the probability that the waiting time of a control packet exceeds $1\,\mu s$ is plotted versus the number of wavelengths for different values of load (dashed). Also, curves representing 1% of the burst loss probability are included (solid) for different values of load in order to be able to apply our criterion set above. It can be seen that almost independent of the load respective curves intersect for a wavelength count around 140, i. e., the combinatorial realization can scale up to this wavelength count even for high values of load and a mean burst duration of $10\mu s$. For a larger wavelength count burst loss probability due to violation of the control packet time constraint becomes critical.

5. CONCLUSION

An architecture for a reservation module for wavelength resources has been proposed and evaluated with respect to realization, performance and scalability. The architecture was modeled and described in VHDL and synthesized for determining the demand of hardware resources. As the processing time for the reservation of one burst takes only 60 ns, this architecture scales very good with respect to dynamic traffic conditions. Even with today's devices and without additional optimization up to 100 - 140 wavelengths can be realized. With next generation

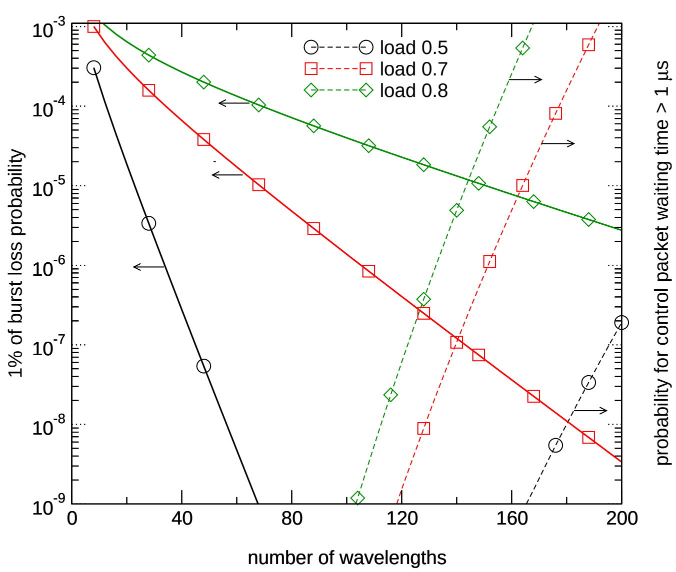

Figure 3. Performance of the reservation module: 1% of burst loss probability (solid lines) and probability for exceeding waiting time limit of 1 μs (dashed lines) for different load cases.

FPGAs allowing lower delays with higher complexity, the wavelength count will increase without any additional optimization.

In general, the solutions could be used for higher numbers of wavelengths if several instances of the module are used in parallel. Several wavelength bands could be defined and for each of them, one reservation module is used. Only if no reservation in the same band is possible, the request is forwarded to other reservation modules. This approach suits ideally to wavelength converters with limited conversion range. As the actual realization of the combinatorial solution is a very large combinatorial net, the segmentation in several pipeline stages could increase the maximum frequency and performance of the system. With a higher throughput of control packets the maximum number of wavelengths per output port is increased. From our point of view, the use of JET in core nodes is possible and won't limit the network performance. So, in principle the JET reservation protocol is not prohibitively complex.

ACKNOWLEDGMENTS

This work was funded within the TransiNet project under contract No. 01AK020C and within the MultiTeraNet framework program by the German Bundesministerium für Bildung und Forschung.

REFERENCES

1. C. Qiao and M. Yoo, "Optical burst switching (OBS)—a new paradigm for an optical Internet," *Journal of High Speed Networks* **8**, pp. 69–84, January 1999.
2. M. Yoo and C. Qiao, "QoS performance in IP over WDM networks," *IEEE Journal of Selected Areas in Communications* **18**, pp. 2062–2071, October 2000.
3. J. S. Turner, "Terabit burst switching," *Journal of High Speed Networks* **8**, pp. 3–16, January 1999.
4. K. Dolzer, C. M. Gauger, J. Späth, and S. Bodamer, "Evaluation of reservation mechanisms for optical burst switching," *AEÜ International Journal of Electronics and Communications* **55**, pp. 18–26, January 2001.
5. J. Xu, C. Qiao, J. Li, and G. Xu, "Channel scheduling algorithms in optical burst switching networks," in *IEEE Infocom*, (San Francisco), April 2003.
6. M. Iizuka, M. Sakuta, Y. Nishino, and I. Sasase, "A scheduling algorithm minimizing voids generated by arriving bursts in optical burst switched WDM networks," in *IEEE Globecom*, (Taipei), November 2002.
7. M. Yoo, M. Jeong, and C. Qiao, "A high speed protocol for bursty traffic in optical networks," in *3rd SPIE Conference on All-Optical Communication Systems*, pp. 79–90, (Dallas), November 1997.
8. M. Izal and J. Aracil, "On the influence of self-similarity on optical burst switching traffic," in *IEEE Globecom*, pp. 2308–2312, (Taipei), November 2002.