Scheduling in a Packet-switched WDM PON with Reduced Delay and Low-Jitter Performance

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Abstract: *We study the scheduling schemes in a packet-switched WDM PON under quasi-static traffic condition. Two algorithms are evulated in terms of throughput, delay, and jitter, and they are compared to a previous dynamic algorithm.*

Introduction

In optical access area, passive optical networks (PONs) have become a promising architecture. Conventional PONs operate in a time division multiplexing (TDM) manner employing a single wavelength. To further increase the capacity and the scalability of the networks, wavelength division multiplexing (WDM) technique can be applied in PONs [1]. Conventional WDM PONs are based on circuit switching, which cannot provide high bandwidth utilization in most cases since the end-to-end traffic demand is typically smaller than the capacity of a wavelength. A packet-switched WDM PON has been proposed to solve this problem. Fig. 1 shows the architecture of the network. The experimental prototype of such a network with a generalized topology was demonstrated in [2] using a novel synchronization scheme. The central component of the network is an NxN arrayed waveguide grating (AWG) router that connects an optical line terminal (OLT) and N-1 optical network units (ONUs). Each node is equipped with a wavelength-tunable laser and a broadband receiver. The packets with a fixed length time slot are self-routed in the AWG according to their colours. This packet-switched WDM PON offers a few attractive features. Firstly, compared to the conventional TDM PONs where passive splitters are employed, the AWG provides higher capacity and better scalability since the insertion loss is independent of the number of nodes. Secondly, compared to the conventional WDM PONs, the packet switching scheme enables higher bandwidth efficiency. Thirdly, the NxN AWG provides intra-network communication capability among the ONUs, which is not possible in the conventional TDM and WDM PONs.

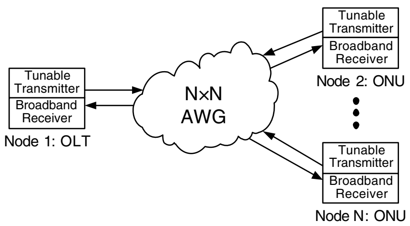

Fig. 1 Packet-Switched WDM PON

In [2], a proof-of-concept experiment was carried out at 10 Gb/s with data bursts of 2-µs duration to show the feasibility of such a network and the synchronization of the packets originating from all the nodes. However, an important issue remained to be addressed: the scheduling of the time slots to achieve high network performance. Previous studies were based on the request/grant type. One example was a Preferential/Random (PR) slot allocation algorithm for dynamic traffic patterns[3]. PR functions with preferred allocation at destination nodes and random selection if the grants collide at a source node. However, PR has certain drawbacks. It requires 3-way signalling in every scheduling period even though the traffic pattern does not change frequently, thus increasing the delay of the data transfer. Furthermore, it limits the scheduling period to be an integer multiple of N-1 time slots.

In this paper, we propose two scheduling algorithms for packet-switched WDM PONs. We reduce the scheduling problem in such networks to that in a cross-bar switch and then evaluate the performance of the proposed algorithms under a quasi-static traffic condition. This condition can often be satisfied in large-scale high-capacity networks because of the averaging effect through traffic aggregation, proper data buffering and scheduling period expansion. Comparisons with the PR algorithm are carried out in terms of throughput, delay, and jitter, which are of great concerns of Quality of Service (QoS) in practical applications.

Scheduling Algorithm

As shown in [2], by assigning different timing offsets to network nodes, propagation delays of packets from different nodes are compensated. Therefore, the network can be reduced to an input-queued cross-bar switch as long as the network nodes are synchronized and scheduling periods of all nodes are properly aligned at the input of the NxN AWG.

We consider a traffic demand matrix **R**, whose element r_{ij} is the number of slots that node i needs to send to node j in a maximum scheduling period P. Our objective is to obtain a time scheduling table **S**, where an element s_{it} denotes the destination node to which a source node i can send data within a time slot t. The problem is subject to the collision constraint that any two elements s_{it} and s_{jt} cannot be the same for $i \neq j$ at any time t. A schedule (column) s_t in **S** corresponds to a permutation matrix. Fig. 2 is an example for a four-node network, whose scheduling period is 6 slots.

In this study, we define the throughput as the total number of slots that carry data bursts in a scheduling period in the network. Here we consider total delay as the sum of request, grant, and queuing delays. The request and grant delays are the round trip propagation delay from the source to the destination. For simplicity, we assume that each node has N-1 individual destination queues and the service request arrives at a constant rate. Thus the queuing delay is the average scheduling interval in the **S**. Jitter is defined as the difference between maximum and minimum scheduling intervals in the **S**.

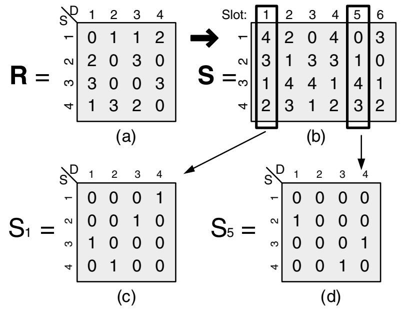

Fig. 2 (a) Traffic Demand Matrix (b) Time Scheduling Table (c) Full (d) Non-Full Permutation Matrix

The scheduling of a traffic demand matrix is generally divided into four steps: 1) Decomposition; 2) Time slots allocation; 3) Adjustment of scheduling period; 4) Elimination of redundant schedule elements.

Decomposition is to divide **R** into a sum of permutation matrices with their corresponding weights. The required scheduling period P is defined as the sum of all the weights. Here, we evaluate Birkhoff Von-Neumann (BV) [4] and greedy low jitter (LJ) [5] decomposition algorithms, which were previously studied in cross-bar switches. BV theorem indicates that any doubly stochastic matrix that has the same row and column sum can be expressed as a convex combination of full permutation matrices. Thus, P is minimized to be the maximum row and column sum of **R**. The complexity of BV is O(N^4.5). Note that, there exist the same elements in different permutation matrix by using BV. The objective of LJ is to minimize P so that the elements are not redundant in different permutation matrices. These permutation matrices are not required to be full. Originally, LJ is an integer linear programming problem. A greedy heuristic was proposed with the complexity of O(N^3) in [5].

After decomposing, each schedule (permutation matrix) is allocated in the time scheduling table **S** based on its weights. Clearly, a uniform distribution scheme for LJ can provide low jitter performance since the same element does not exist in different permutation matrices. However, there is no optimal distribution scheme for BV as BV decomposition has no such requirement. In this paper, we use a random distribution scheme for BV.

If the required scheduling period P is less than the maximum scheduling period T, we set P as the scheduling period because all the schedules greater than P are null. Otherwise, the schedules greater than T have to be truncated for fair comparisons.

The transformation of doubly stochastic matrix introduces useless stuffing traffic for BV. Similarly, there are redundant scheduling elements in **S** for LJ. For example, the sum of scheduling elements t_{ij} in **S** may be greater than its expected traffic demand r_{ij} from source i to destination j. In this situation, these redundant scheduling elements have to be eliminated. To ensure fairness, the middle element in the two neighbouring intervals with the minimum sum is dropped until t_{ij} is equal to r_{ij}.

Numerical Results

We examine the performance of the above algorithms by comparing them with PR algorithm. We also note that BV and LJ are centralized, while PR is distributed. BV and LJ are more suited as medium access protocol in PONs since the OLT acts as the master node.

Following [2], the time-slot duration and the data rate are assumed to be 2 µs and 10 Gb/s, respectively. The simulation is performed in a 16-node network (N = 16) with 20-km distance from ONU and OLT to the central AWG. Traffic demand **R** is generated randomly with the zero values for the diagonal elements. **R** is changed every 10 scheduling period to mimic quasi-static traffic. T is set to (N-1)*20 = 300 time slots to satisfy the requirement of PR. The network load, which is defined as the total traffic demand divided by TxN, is varied from 0.1 to 0.9. For each data point in the figures, 10 experiments were performed.

Fig. 3 shows the performance comparison for the 3 scheduling algorithms. The throughput does not change much with the network load for BV and LJ algorithms, but increases linearly for PR scheme. BV provides the highest throughput, while LJ degrades 15% compared with BV. When the network load is less than 0.8, the throughput of PR is less than that of BV and LJ. The delay and jitter results are the average of all node pairs. The delay performance using BV or LJ is better than PR since they do not need request and grand in every scheduling period. LJ exhibits the lowest jitter among 3 algorithms, as expected.

Conclusions

We evaluate three scheduling schemes in a packet-switched WDM PON under quasi-static traffic condition. In most cases where the traffic load is less than 80%, the LJ algorithm shows significant improvement in the delay and jitter performance.

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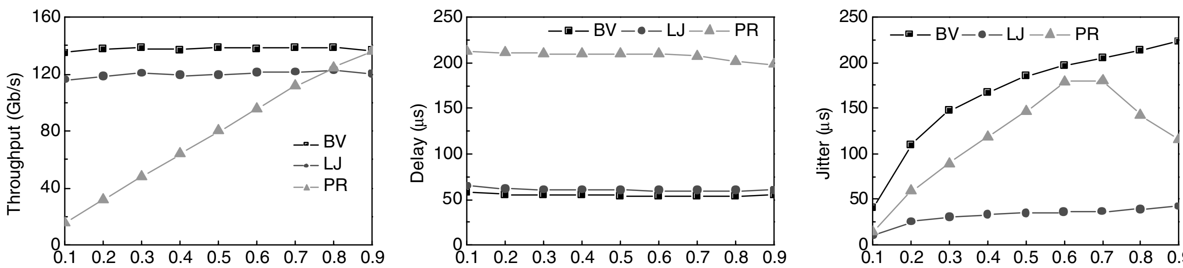

Fig. 3 Performance Comparison for 3 Scheduling Algorithms