IEEE MELECON 2004, May 12-15, 2004, Dubrovnik, Croatia

Adaptive Station Grouping: A High Performance Protocol for WDM Star Networks

Georgios I. Papadimitriou, *Senior Member, IEEE*
Department of Informatics, Aristotle University, Box 888, 54124 Thessaloniki, Greece.

Abstract—**A new medium access control protocol for WDM Star Networks, which is capable of achieving a high performance under bursty traffic conditions, is introduced. According to the proposed protocol, the access of stations to the wavelengths is based on their grouping. A separate set of groups is maintained for each wavelength. All the groups are granted permission to transmit to the corresponding wavelength in a round-robin fashion. The main objective of the grouping algorithm is to have in each group exactly one station which is ready to transmit on the corresponding wavelength. In this way, idle slots and collisions are minimized and a nearly optimal throughput-delay performance is achieved. The grouping of stations is dynamically modified at each time slot according to the network feedback information. Due to the dynamic nature of the grouping algorithm, the protocol is capable of being adapted to the sharp changes of the stations' traffic. Extensive simulation results are presented which indicate that the proposed protocol achieves a significantly higher performance than other well-known medium access control protocols for WDM Star Networks.**

I. INTRODUCTION

Traffic in gigabit LANs [1]-[12] is highly bursty. Under bursty traffic conditions, TDMA-based protocols suffer from low performance, since a large number of slots remain idle. Adaptive protocols [2],[3] overcome this problem by assigning the available bandwidth to stations according to their needs. However, these protocols suffer from two major drawbacks:

1) Packets suffer a relatively high delay when operating under low load conditions.

2) Their performance degrades when the number of stations per wavelength ($\frac{N}{W}$) becomes high.

In this paper, a new medium access control protocol for WDM Passive Star Networks (fig.1), which overcomes the above drawbacks and is capable of achieving a high performance under bursty traffic conditions, is introduced. According to the proposed protocol, the access of stations to the wavelengths is based on their grouping. A separate set of groups is maintained for each wavelength. All the groups are granted permission to transmit to the corresponding wavelength in a round-robin fashion. The main objective of the grouping algorithm is to have in each group exactly one station which is ready to transmit on the corresponding wavelength. In this way, idle slots and collisions are minimized and a nearly optimal throughput-delay performance is achieved. The grouping of stations is dynamically modified at each time slot according to the network feedback information. Due to the dynamic nature of the grouping algorithm, the protocol is capable of being adapted to the sharp changes of the stations' traffic.

The paper is organized as follows: The proposed Adaptive Station Grouping (ASG) protocol is presented in Section II. In Section III the proposed ASG protocol is compared to other well-known medium access control protocols for WDM Star Networks, via extensive simulation results. Finally, concluding remarks are given in Section IV.

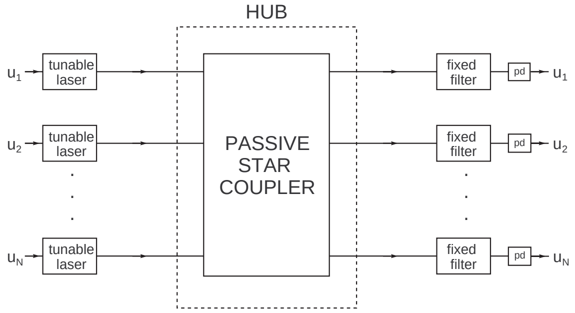

Fig. 1. A WDM Passive Star Network using tunable lasers and fixed optical filters.

II. THE ASG PROTOCOL

A WDM Passive Star Network using tunable transmitters and fixed receivers (fig.1) is considered in this paper. Let $A = \{a_1, \ldots, a_N\}$ be the set of stations, where N is the number of stations. The set of wavelengths is defined as $\Lambda = \{\lambda_1, \ldots, \lambda_W\}$, where W is the number of wavelengths.

Each transmitter is provided with a tunable laser which can be tuned to each one of the W wavelengths. Optical fibers are used to connect the outputs of the lasers to the network hub. There, the optical signal is fed to a Passive Star Coupler which broadcasts all incoming signals to all output ports. Each output port of the star coupler is connected to the corresponding receiver, by means of an optical fiber. Each receiving station a_k ($k = 1, \ldots, N$) is provided with a fixed optical filter which passes only one wavelength $\lambda_{i_k} \in \Lambda$, which is called "home wavelength". Therefore, each station is capable of receiving only those packets which are transmitted on its home wavelength. The output of the optical filter is connected to a photodetector which performs O/E translation of the incoming signal. Two possible allocation schemes for the home wavelength λ_{i_k} of a given receiving station a_k are proposed in [4]:

a) Neighbor Allocation: $i_k = \lfloor \frac{k-1}{\lceil N/W \rceil} \rfloor + 1$

b) Interleaved Allocation: $i_k = ((k-1) \;\; mod \;\; W) + 1$

The latter scheme is considered in this paper.

When a station wants to send a packet to station a_k, then,

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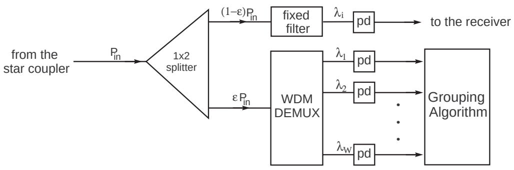

Fig. 2. The feedback mechanism of ASG.

it tunes its laser to wavelength λ_{i_k} and transmits the packet.

The ASG protocol is applied to WDM Passive Star networks of the form described above. Each station is provided with a waiting queue, where the arriving packets are buffered before being transmitted. Arriving packets are transmitted in a FIFO fashion. The traffic which is offered to the stations is assumed to be bursty. Thus, each station can be in one of two states: active or idle. When a station is active it has one packet arrival at each time slot. On the other hand, when a station is idle it has no packet arrivals. Each station operates independently from the others and has no knowledge of their states.

In order to control the access to wavelength λ_i ($i = 1, \ldots, W$) the set of stations A is divided into N subsets $A_{i,1}, A_{i,2}, \ldots, A_{i,N}$ with: $A_{i,1} \cup A_{i,2} \cup \ldots \cup A_{i,N} = A$ and $A_{i,1} \cap A_{i,2} \cap \ldots \cap A_{i,N} = \emptyset$. Some of the subsets $A_{i,j} (j = 1, \ldots, N)$ may be empty sets. All the nonempty subsets are granted permission to transmit on wavelength λ_i in a round-robin fashion. The main objective of ASG is to have exactly one ready station in each nonempty subset. In this way, idle slots and collisions are minimized and the throughput-delay performance is significantly improved.

In order to achieve the above objective, the grouping of stations into subsets for wavelength λ_i ($i = 1, \ldots, W$) is updated at each time slot, according to the network feedback information of wavelength λ_i in line with the following rules:

1) If the previous time slot t was idle then the subset $A_i(t)$ which was granted permission to transmit on wavelength λ_i in this time slot is assumed to contain no ready stations and consequently, it is merged with a nonempty subset. *Note*: A station is assumed ready for wavelength λ_i if the top (oldest) packet of its queue is waiting to be transmitted on wavelength λ_i.

2) If a collision took place during the previous time slot t, then $A_i(t)$ is assumed to contain more than one ready station and consequently it is split into two subsets of equal size in an effort to avoid further collisions.

3) If a successful transmission took place in wavelength λ_i during the previous slot then the grouping of stations into subsets for this wavelength is assumed to be satisfactory and remains invariant.

All the stations execute the same grouping algorithm and, due to the broadcast nature of the network, the feedback is common for all the stations. Therefore, all the stations arrive at the same conclusion on which subset of stations is granted permission to transmit on each wavelength at each time slot.

The algorithmic description of the ASG protocol is presented below. In the following description, the network feedback information of wavelength λ_i ($i = 1, \ldots, W$) at time slot t is: $slot_i(t) \in \{success, idle, collision\}$. Initially, each group contains exactly one station. The variables $selected\_group[i]$ ($i = 1, \ldots, W$) are initialized by taking values at random from set {1,...,N}.

```
PROCEDURE ASG;
REPEAT
  $t := t + 1$;
  $F := \emptyset$;
  $R := \Lambda$;
  WHILE $R \neq \emptyset$ do
  BEGIN
    Choose at random one wavelength $\lambda_i \in R$;
    $R := R - \{\lambda_i\}$;
    $j := selected\_group[i]$;
    $A_{i,j}(t) := A_{i,j}(t) - F$;
    $F := F \cup A_{i,j}(t)$;
    All stations in $A_{i,j}(t)$ are granted permission to transmit on wavelength $\lambda_i$ in slot $t$;
    If $slot_i(t) = idle$ then
    BEGIN
      $k := j$; repeat $k := (k \bmod N) + 1$; until (($A_{i,k}(t) \neq \emptyset$) or $(k = j)$);
      if $k \neq j$ then
      BEGIN (* Merge $A_{i,j}$ with a nonempty set *)
        $A_k(t+1) := A_k(t) \cup A_j(t)$;
        $A_j(t+1) := \emptyset$;
      END
      repeat $j := (j \bmod N) + 1$; until ($A_{i,j}(t+1) \neq \emptyset$);
    END
    else if $slot_i(t) = collision$ then
    BEGIN
      $k := j$; repeat $k := (k \bmod N) + 1$; until (($A_{i,k}(t) = \emptyset$) or $(k = j)$);
      if $k \neq j$ then
      BEGIN (* Split $A_{i,j}$ into two sets *)
        $A_{i,k}(t+1) := \{a_{i,j,1}(t), \ldots, a_{i,j,\lceil \frac{|A_{i,j}(t)|}{2} \rceil}(t)\}$;
        $A_{i,j}(t+1) := A_{i,j}(t) - A_{i,k}(t+1)$;
      END
    END
    else if $slot_i(t) = success$ then
    BEGIN
      repeat $j := (j \bmod N) + 1$; until ($A_{i,j}(t+1) \neq \emptyset$);
    END
    $selected\_group[i] := j$;
  END
FOREVER;
```

In order to implement the above algorithm, each station must be informed of the state of each wavelength (idle, success or collision), at each time slot. In order to be provided with this feedback information, each station uses the simple feedback mechanism which is presented in figure 2.

A small fraction ϵ of the incoming signal is fed to a WDM Demultiplexer, which separates the different wavelengths. The output ports of the Demultiplexer are fed to an array of photodetectors which detect whether the corresponding wavelength is idle, a packet transmission is taking place, or more than one optical signals are transmitted (collision).

Note, that no full reception of the incoming signals is performed in the feedback mechanism. Only the optical power of the incoming signal needs to be sensed. Therefore, the splitting ratio ϵ [5] can be very small. Consequently, the power of the incoming signal is practically unaffected by the presence of the feedback mechanism. Of course, ϵ must be common for all stations.

III. SIMULATION RESULTS

In the following, the proposed ASG protocol is compared to protocols SALP [2] and APS [3]. Each station is assumed to be provided with a queue of fixed length Q. In the simulation results presented here, Q is assumed to be equal to 20 packets.

The protocols which are under comparison were simulated to be applied to three different networks (N_1, N_2 and N_3) under bursty traffic. Many ways of modeling bursts have been described. Recently, Leland et al. [9] have demonstrated that measured network traffic is bursty at any level and that burstiness in Local Area Networks intensifies as the number of active traffic sources increases. We model the burstiness of the offered traffic by using the packet train model used in [10],[11] and [12]. Each station alternately produces a burst (train) of packets (all with the same destination) followed by one or more empty slots. The bursts contain a geometrically distributed number of packets. The model contains two parameters: the average burst length and the load offered to the network. The mean burst size B was assumed to be equal to 20 packets.

The number of users N and the number of wavelengths W, were taken to be as follows:

a) Network N_1: N=80, W=40.

b) Network N_2: N=200, W=40.

c) Network N_3: N=240, W=30.

We have used the following two broadly used performance metrics in order to compare the two protocols:

1) The delay versus throughput characteristic.

2) The throughput versus offered load characteristic.

The delay versus throughput characteristics of the compared protocols when applied to networks N_1, N_2 and N_3 are appeared at figures 3, 5 and 7, respectively. The throughput versus offered load characteristics of the compared schemes when applied to networks N_1, N_2 and N_3 are appeared at figures 4, 6 and 8, respectively. Each point of the above graphs was created by simulating the system for 100,000 slots and taking the mean values of throughput and delay. Due to the large simulation time, the confidence intervals almost negligible.

The following results can be extracted from the above graphs:

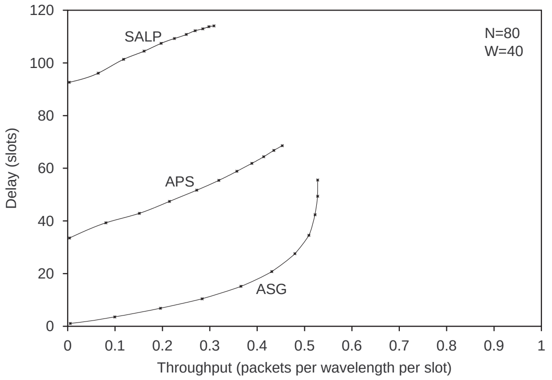

Fig. 3. The Delay versus Throughput characteristics of protocols ASG, APS and SALP when applied to network N_1.

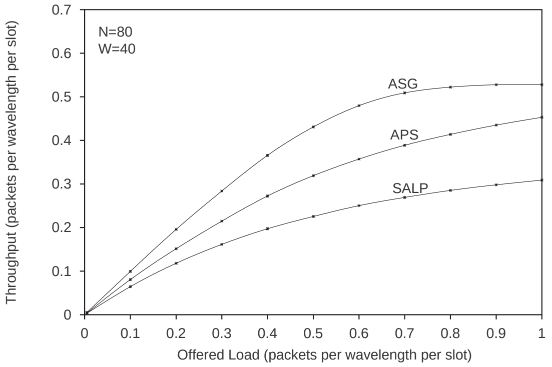

Fig. 4. The throughput versus load characteristics of ASG, APS and SALP when applied to network N_1.

1) In all simulated networks the proposed ASG protocol achieves a superior throughput-delay performance than protocols APS and SALP.

2) The performance advantage of AGS over APS and SALP is stronger when the network operates under medium or low load conditions. As the network load decreases, the groups of stations become larger and the ASG protocol gradually degenerates to slotted ALOHA. Therefore, the ASG performance under medium or low load conditions is nearly optimal.

3) The performance improvement of the AGS protocol over APS and SALP is higher when the number of stations per wavelength ($\frac{N}{W}$) becomes high. This is due to the high adaptivity of the ASG protocol. When a station transits from idle to active state, APS and SALP take a significant amount of time to "sense" this transition. On the other hand, when the ASG protocol is used, such a transition is "sensed" immediately, because it usually causes a collision.

4) It is interesting to note that under heavy load conditions, the delay of ASG is increasing faster than in protocols APS and SALP. This is due to the presence of collisions in ASG, while APS and SALP are collision-free.

In other words, although the three protocols which are under comparison are based on the network feedback information, ASG achieves a superior performance, because

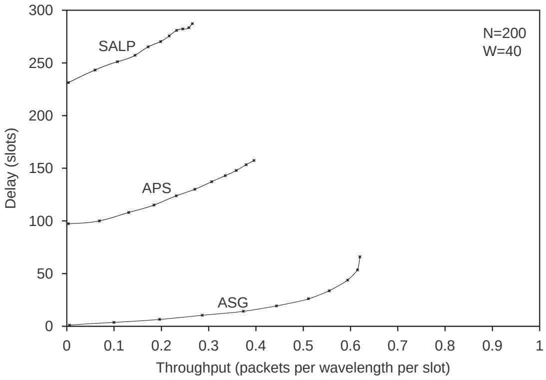

Fig. 5. The Delay versus Throughput characteristics of protocols ASG, APS and SALP when applied to network N_2.

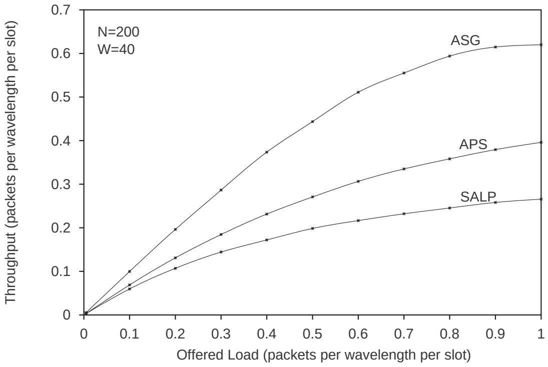

Fig. 6. The throughput versus load characteristics of ASG, APS and SALP when applied to network N_2.

it makes a more efficient use of this information.

IV. CONCLUSION

This paper has presented a new multiple access protocol for WDM Passive Star Networks. The main characteristics of the proposed ASG protocol are summarized below:

a) It achieves a high throughput-delay performance, even when the offered traffic is bursty.

b) The protocol is self-adaptive. It continuously tracks the channels' states and adapts the grouping of stations accordingly.

c) No centralized control of the stations is required, since the protocol is fully distributed.

d) It is fault-tolerant, since its operation is not affected from a possible station failure.

e) No increase of the implementation cost is introduced in relation to SALP and APS.

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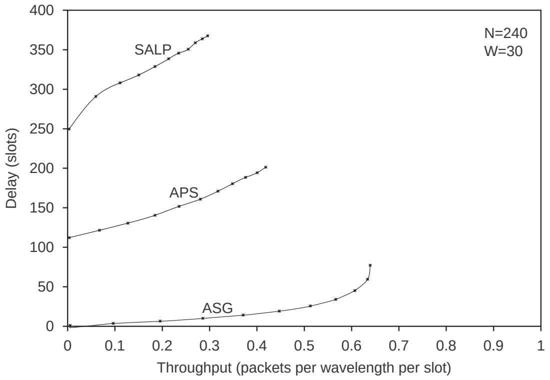

Fig. 7. The Delay versus Throughput characteristics of protocols ASG, APS and SALP when applied to network N_3.

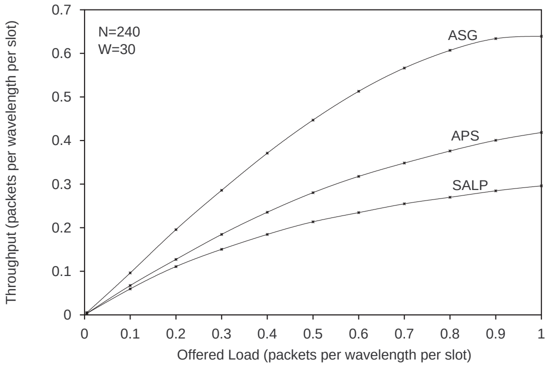

Fig. 8. The throughput versus load characteristics of ASG, APS and SALP when applied to network N_3.

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