PrimeNet - A concept for a WDM-based fiber backbone

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Abstract:
This paper presents a concept for a Multi-Gbit/s WDM-based fiber backbone. Stations are interconnected by the means of an Arrayed Waveguide Grating Multiplexer (AWGM). It shows the possibility to evolve from unidirectional virtual ring structures to a fully meshed interconnection. The number of nodes n and hence the number of inputs of the AWGM has to be a prime number to lead to n-1 parallel ring structures of equal size n. A SONET/SDH based system architecture and a strategy to map ATM service classes on it is proposed.

1.0 Introduction

Basic goal in broadband networking is to deliver high bandwidth at low latency [1]. Over the last few years Wave Division Multiplexing (WDM) has been seen as a proper workaround for the electro-optical bottleneck, i.e. the low electronic processing speed (a few Gbit/s) compared to the high possible bandwidth of a single fiber (several Tbit/s). WDM networks are often seen as circuit switched networks, because of the long laser tuning times and the aim to provide a "dark fiber" to the end user.
The disadvantages of circuit switching are well known (reservation for the peak rate...), but currently outweighted by the plenty of bandwidth WDM is able to provide.
This paper tries to emphasis the combination of TDM and WDM to allow for a packet switched optical network.

2.0 Arrayed Waveguide Grating Multiplexer

We propose to use an Arrayed Waveguide Grating Multiplexer to interconnect the stations of the network. The advantage of such a solution is that this passive device offers n times the bandwidth of a passive star coupler and it is completely collision free. The device and the possible ring structures on it have been described in [2] and [3], resp.
In principle all routing is done by the selection of the input port and the input wavelength. A signal on wavelength λ_1 from input A (see figure 1) is routed to output B, while the same wavelength from input B is routed to output C and from input C to output A. That way each wavelength can be used n times for n inputs in parallel.
The output port for a certain signal depends on the distance of the inputs and on the selected wavelength. In other words, to select the channel to a specified station, we have to "know" the distance of the input ports on the AWGM.

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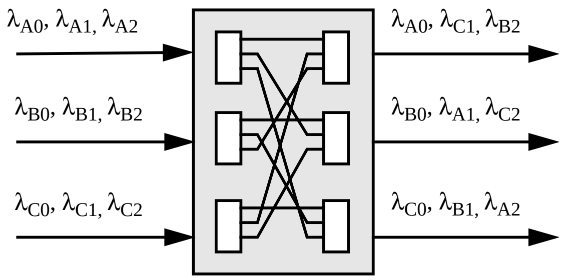

FIGURE 1. The logical structure of a 3x3 Arrayed Waveguide Grating Multiplexer

3.0 Basic Network Structure

The proposed basic network structure is a set of virtual rings on the underlaying physical star topology. In figure 2 a network of 3 stations A,B and C is shown. The two wavelengths form a bidirectional ring structure. This can be seen as a fully meshed configuration, too.

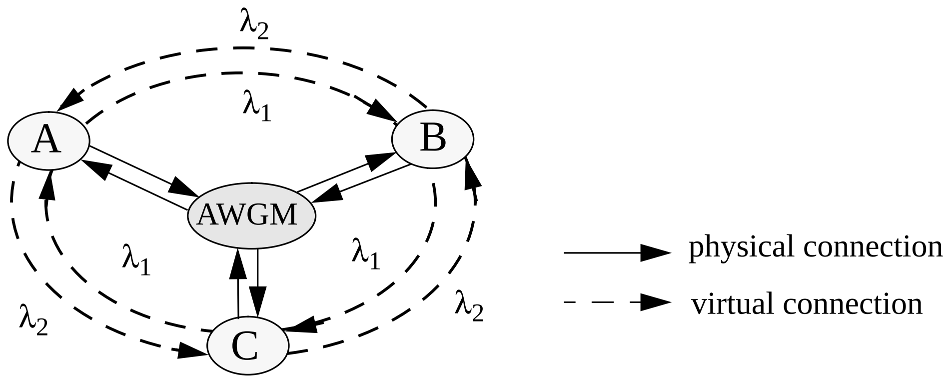

FIGURE 2. Basic topology of a network made up by a 3x3 AWGM

For integer numbers m,n and x with:
m = hop number (1<=m<n)
n = number of wavelengths
x = 0..n
distance = distance between receiver and sender
the wavelength λ to send on equals to:

$$\lambda = (x*n+distance)/m \qquad \text{(EQ 1)}$$

In a case where m=x*n, that means n is an integer multiple of m, there are wavelengths, which can not be used for transmission to a certain station. This is shown in figure 3, where λ_2 makes up two separate rings (A-C and B-D) which are not connected to each other. This feature could be used to set up subnetworks, but in our approach we consider it an unwanted effect. Therefore we conclude that the number of wavelengths n in the network and hence the number of inputs of the AWGM has to be a ***prime number***. With n being a prime number the network consists of (n-1) parallel rings with all stations connected to all rings.

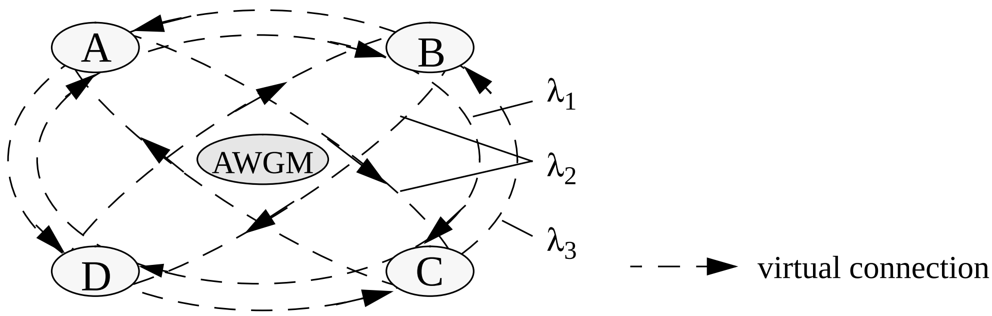

FIGURE 3. Basic topology of a network made up by a 4x4 AWGM. For better visibility only virtual connections are shown.

4.0 Design of the network

In general, we do not need to have as many Transmitter/Receiver-pairs as wavelengths in the system. It is possible to start up with only one fixed Tx/Rx pair per station, which results in a unidirectional ring (e.g. only using λ_1 in figure 2). By adding additional Tx/Rx pairs we increase the possible throughput of each station. If n is a prime number, the wavelengths λ_x and λ_{n-x} (x=1..(n-1)/2) form counterdirectional rings. If we assume that we send to one out of (n-1) stations in an unidirectional ring structure, each selected with equal probability, the mean transmission delay relates to (n-1)/2. If we now add a second wavelength to form a bidirectional ring, the delay relates to (n-1)/4.

4.1 Point-to-Point Connections

There are 3 possible designs of connections in this network: The first possibility is to split the rings up into single point-to-point connections. SONET/SDH crossconnects or ATM switches or IP routers could use the advantages of multiple bandwidth. The underlaying physical structure could be a SONET/SDH connection.[1] On the other hand, if the network is packet switched, the queueing delay for each packet adds up for each switch between the source and destination of the packet.

One possibility would be to simply put ATM switches into what is referred to as stations in chapter 3.0. There would have to be a separate Receiver/Transmitter-pair for each input and output, resp. , each on a separate wavelength. So if we would use only one wavelength, the architecture would essentially look like the distributed ATM switch proposed in [4].

The routing decision could easily be done by evaluating (EQ 1). Incoming packets would be routed to the ring with the smallest hop number to the destination. A distinction in the routing decision can be made for different ATM service classes. CBR and VBR traffic should always be routed to the shortest path, whereas ABR traffic might take a longer way to its destination.

The strategy of splitting the rings into point-to-point connections is an easy and deployable way to make use of AWGMs. Still, the bandwidth allocation is not very flexible. For a small number of Transceivers per station

1. We stick to SDH connections here because of their scalability into the Gbit/s area.

4.2 Static Bandwidth Allocation

Since the basic functionality of an Add-Drop-Multiplexer is to be a 2x2 switch, we could employ ADMs for each wavelength. A one chip solution for this is shown in [2]. It would be possible to have parallel SONET rings with a fixed bandwidth allocation between the stations in a ring. The corresponding station design is shown in figure 4.

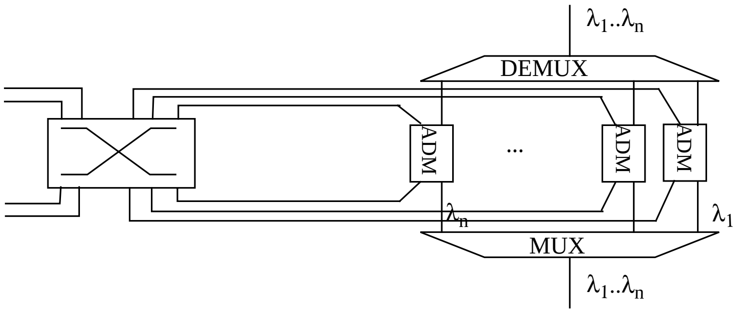

FIGURE 4. Station design using SONET/SDH rings

4.3 Dynamic Bandwidth Allocation

In order to support the bursty nature of packet traffic bandwidth has to be assigned to stations on their demand. This is the point where access protocols for a shared medium like the proposed ring structure come into consideration. Many proposals like FDDI, DQDB or CRMA [5] address the problem of fair bandwidth sharing across a ring or a folded bus. [1] The question which of the existing protocols will be appropriate for the needs of the network remains for further studies. The basic demands of a Media Access Control Protocol for this architecture are:

- Ability to work equally well for point-to-point connections and unidirectional rings
- Low or no reservation overhead in the (standard) case of point-to-point connections
- Ability to support QoS - Ability to guarantee for bandwidth

The corresponding station design gets more complicated. The result of the existence of a separate MAC protocol for the network is a new station architecture. It consists of a set of ADMs and a protocol machine to perform routing decisions as well as the actual parallel MAC. A basic concept for this is shown in figure 5.

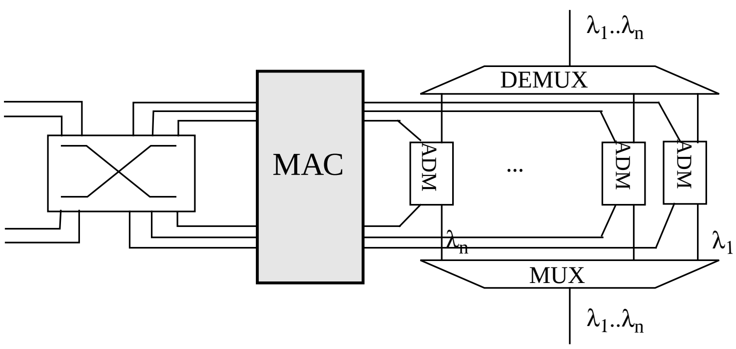

FIGURE 5. Station design using a parallel MAC machine

1. In fact, every two counterdirectional rings could be seen as a folded bus

5.0 Extending the Network/Cascading AWGMs

So far, we only considered a network with a number of stations equal to the number of inputs of the AWGM. These devices are currently available with input numbers up to 64. Therefore we see the need to cascade several AWGMs to come to a network in the order of, say 1000 stations. A direct connection of AWGMs does not seem to be the proper way because of their modest crosstalk properties. Even if one could employ some kind of signal recovery between the AWGMs, it would essentially be the enlargement of every ring on each wavelength involved. So for two networks of 6 stations each the direct interconnection of the AWGMs would result in a network of 12 stations on 6 parallel rings, which clearly reduces the available bandwidth for each station.
The easiest way to connect two of these networks would be to stick to the point-to-point connections and to have a switch (ATM or IP) which is connected to both.
In the case of fixed SONET/SDH bandwidth allocation (chapter 4.2) we would need to have a buffer of at least a SONET/SDH frame size per wavelength to deal with synchronization problems between the two rings.
When using the approach of a special parallel MAC protocol, the station connecting the two networks would have to have a second set of ADMs and a second parallel MAC machine. There may be the need for buffering, too, but this depends on the design of the MAC and the reservation policy.

6.0 Conclusions

We showed a concept for a backbone network based on WDM. The WDM concept is here translated into virtual ring structures on every wavelength. That way we can avoid wavelength conversion within the network. By adding Tx/Rx pairs in the stations we can scale the available bandwidth from 1 to (n-1) times the bandwidth of a single wavelength, possibly even higher due to the periodic nature of the AWGM (Wavelength x, n+x, 2n+x are all routed to the same output). Virtual topologies range from an unidirectional ring to a fully meshed topology. The transmission delay decreases with the number of transceivers per station to the optimum case of a point-to-point connection.
We looked at several possibilities for the connections on the rings and vote for a special parallel MAC which allows for a flexible bandwidth allocation. The suitability of existing standards like DQDB or CRMA has to be revisited and is a field for further studies.

7.0 References

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