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A Metro WDM Star Network with a Hybrid MAC Protocol Based on an Arrayed Waveguide Grating

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In this paper, we introduce a reliable, scalable, and cost-effective switchless wavelength division multiplexing (WDM) network based on a quality-of-service supporting reservation-based medium access control (MAC) protocol. The protocol not only provides both packet and circuit switching but also supports multicasting. The network efficiency is significantly increased by spatially reusing wavelengths and exploiting multiple free spectral ranges (FSRs) of arrayed waveguide grating (AWG) employed in the architecture. We have demonstrated the feasibility of this architecture by simulating in Optsim^{TM}.

OCIS codes : 060.0060, 060.4510

I. INTRODUCTION

To overcome metro gap and enable new applications and services to utilize huge bandwidth available in the long haul backbone networks, many new network architectures and protocols are presented in the recent years [1-3]. The majority of the presented WDM network architectures are either based on a physical ring topology or a physical star topology. There are also bus networks, for example AMTRAC [4], which have not received much interest. It is shown that the AWG star networks clearly outperform the ring networks in terms of throughput, delay, and packet loss for unicast traffic at the expense of the single point of failure which could be overcome by redundancy [5]. In this paper we introduce a metro WDM star network with a hybrid MAC protocol using multiple free spectral ranges of AWG. The proposed network can supplement the existing metro networks and increase their capacity to overcome the metro gap as shown in Fig. 1 [6].

In the following section, we briefly describe the network and the node architecture. In section III, the MAC protocol for the above mentioned network architecture is described. In section IV, the Optsim^{TM} simulation results are summarized.

II. NETWORK AND NODE ARCHITECTURE

The basic architecture of the single-hop WDM star network is based on a D×D AWG, as shown in Fig. 2. At each AWG input port, a wavelength-insensitive S×1 combiner collects data from S attached nodes. Similarly, at each AWG output port, signals are distributed to S nodes by a wavelength-insensitive 1×S splitter. An erbium doped fiber amplifier (EDFA) is placed at the output of each combiner and the input of each splitter to compensate for the splitting/combining and fiber losses. Each node is equipped with a laser diode (LD) and a photodiode (PD) for data

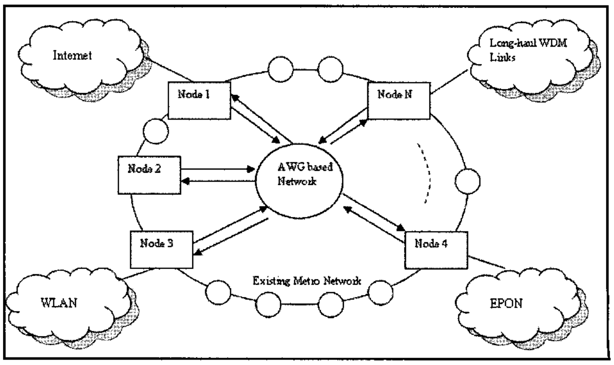

FIG. 1. Network architecture.

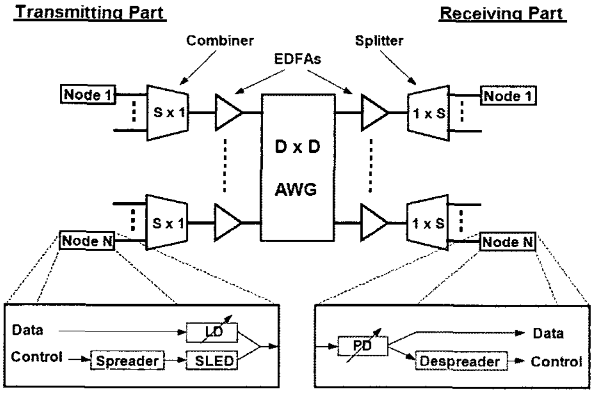

FIG. 2. Detailed network and node architecture.

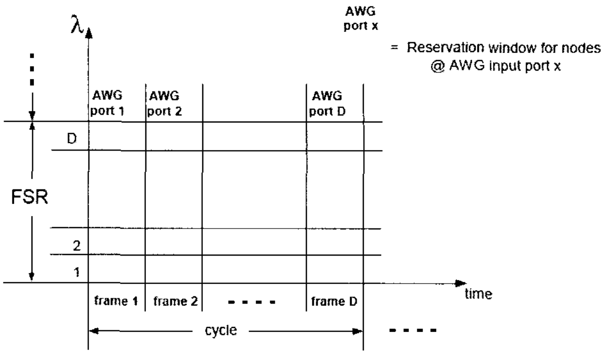

FIG. 3. Wavelength assignment.

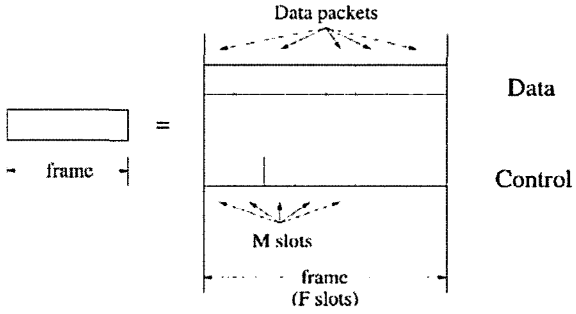

FIG. 4. Frame format.

transmission and reception, respectively. Both data transmitter and receiver are tunable over λ wavelengths which are not pre-assigned to nodes. Each node is composed of a transmitting part and a receiving part. The transmitting part of a node is attached to one of the combiner ports. The receiving part of the same node is located at the opposite splitter port. The network connects N=D×S nodes. At each AWG input port we exploit R adjacent free spectral ranges (FSRs) of the AWG. Each FSR consists of D contiguous wavelengths. The total number of wavelengths at each AWG input port is λ=D×R. Note that the AWG allows for spatial wavelength reuse. As a result, the λ wavelengths can be simultaneously applied at each of D AWG input ports, for a total of D×λ wavelength channels connecting the D AWG input ports with the D AWG output ports. Also, note that there are R wavelength channels connecting each AWG input-output port pair. The MAC protocol makes use of a control channel to broadcast control information. The control channel is implemented as an in-band control channel by exploiting the spectral slicing of a broadband light source (like Super Luminescent Diode (SLED)) in conjunction with spectrum spreading of the control signals [7].

III. MAC PROTOCOL

The network runs an attempt-and-defer type of MAC protocol, i.e., a data packet is only transmitted after the corresponding control packet has been successfully transmitted. In the MAC protocol, time is divided into cycles as shown in Fig. 3. Each cycle consists of D frames. Each frame contains F slots. The slot length is equal to the transmission time of a control packet. As shown in Fig. 4, each frame is partitioned into the first M, 1≤M<F, slots and the remaining (F-M) slots. In the first M slots, control signals are transmitted based on a modified slotted ALOHA protocol and all nodes must be tuned (locked) to one of the SLED slices carrying the control information. In every frame within the cycle, the nodes attached to a different AWG input port send their control packets.

Specifically, all nodes attached to AWG input port o, 1≤o≤D, (via a common combiner) send their control packets in frame o of the cycle. During the first M slots of frame o, control and data packets can be transmitted simultaneously by the nodes attached to AWG input port o. Transmissions from the other AWG input port cannot be received during this time interval. In the last (F-M) slots of each frame, no control packets are sent. The receivers are unlocked, allowing transmission between any pair of nodes. This allows for spatial wavelength reuse [7].

IV. SIMULATION AND RESULTS

We demonstrated the performance of our architecture by simulation in the commercially available optical communication systems software Optsim^{TM}.

Some of the important parameters and their respective values used for simulation are listed in Table 1. We simulated a 16 node architecture based on a 4×4

AWG, 4×1 combiner and 1×4 splitter. The transmission distance was 50 km and no EDFA's were used.

TABLE 1. Important parameter values used for Optsim$^{\mathrm{TM}}$ simulation.

Parameter	Value
Number of Nodes	16
Degree of AWG	4
Degree of Combiner / Splitter	4
Transmission Distance	50 km
LD Power	10 mW
Node 1,5,9 and 13 frequency	1549.2 nm
Node 2,6,10 and 14 frequency	1550.0 nm
Node 3,7,11 and 15 frequency	1550.8 nm
Node 4,8,12 and 16 frequency	1551.6 nm

The network architecture that was simulated in Optsim$^{\mathrm{TM}}$ is shown in Fig. 5. We used just 4 wavelengths to communicate between 16 nodes simultaneously without any loss of data. This wavelength reuse is possible because of the network architecture based on the AWG. Nodes attached to different AWG ports can use the same wavelength to communicate with other nodes without any channel collision. However, nodes attached to the same AWG port must use different wavelengths in order to avoid channel collision.

The eye diagram of the received signal at node 1 is shown in the Fig. 6. We observed that the signal can be transmitted successfully to a distance of 50 km with a reasonable BER of 10^{-14} (calculated for Node 1). We also found that the power loss of the optical signal in the network is 23 dB approximately.

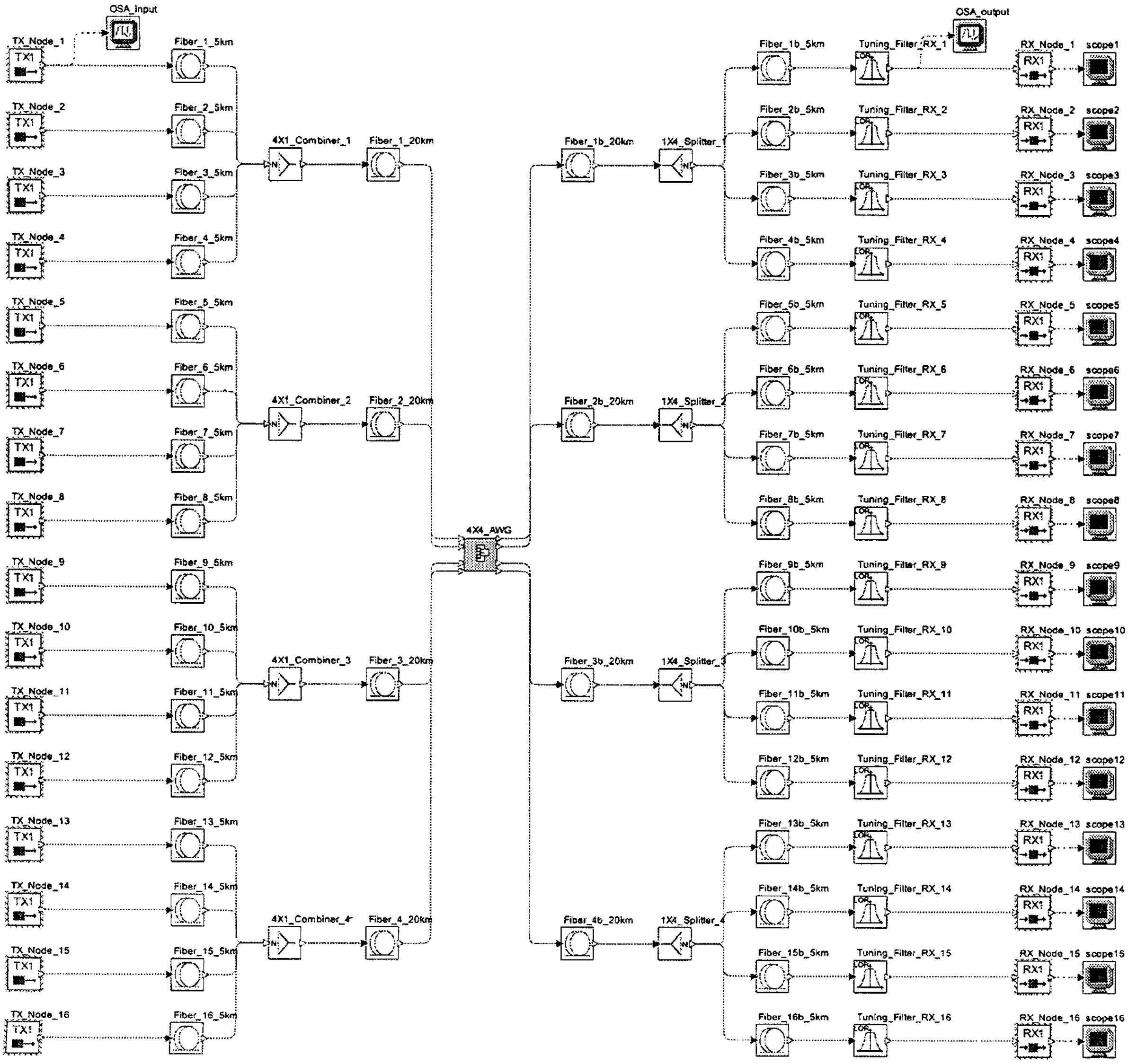

FIG. 5. Network architecture simulated in Optsim$^{\mathrm{TM}}$.

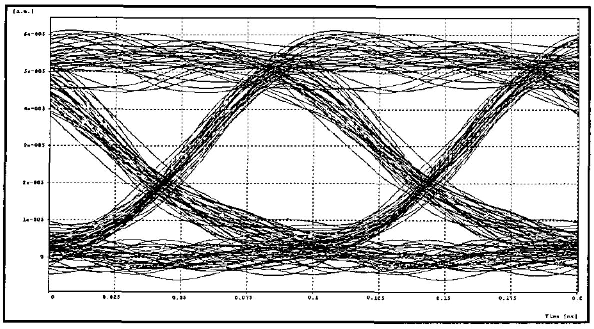

FIG. 6. Eye diagram of received signal at node 1.

V. CONCLUSION

Most of the traffic in the future telecommunication networks would be predominantly IP-based [8]. This would most likely result in the need to replace the current IP/ATM/SONET/WDM layer structure with a significantly less complex IP/WDM protocol stack. Since ATM and SONET both suffer from inefficiencies in carrying IP traffic [9]. The architecture and protocol presented in this paper can replace the current SONET and ATM network layers and provide a much simpler way to directly transmit IP datagrams over fibers using WDM.

Our future concern is to make a testbed of the proposed AWG based star network architecture, in order to resolve the technological challenges in the way of its implementation.

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