PHYSICAL-LAYER MODELING AND SIMULATION OF WDM FIBER OPTIC NETWORK ARCHITECTURES FOR AEROSPACE PLATFORMS

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We report on architectural requirements for an avionics WDM network, a proposed reference architecture, metrics required from modeling and simulation, and physical-layer simulation studies of this reference architecture.

Introduction

It is desirable to develop a new WDM fiber optic network architecture standard for aerospace platforms to maximize the benefits of fiber optic network technology and revolutionize networking in aerospace platforms. Consequently, the SAE Avionic Systems Division has launched an effort to develop the Aerospace WDM LAN Standard AS-5659. Initial activities have been in the areas of specification of architectural requirements and required modeling and simulation capabilities. We report on work we have contributed towards this effort.

Architecture Requirements

The network investigated in this work is meant to carry all types of traffic envisioned onboard an aircraft, including flight controls and other mission critical information. Not only does the network need to accommodate the traffic presently on an aircraft; it needs to be able to support future equipment with significantly increasing traffic demands over the lifetime of the airframe. A high degree of fault tolerance and redundancy is also required. The network investigated in this paper must be able to sustain 3 faults and still be operable, which dictates the required number of connections for each node in the network. A network architecture suggested by these requirements is shown in Figure 1, containing network nodes, termination points (TP), and aggregators (AG) that connect low-data rate signals to the network. It is a meshed network with a maximum of 256 nodes, full interconnectivity, supporting mixed digital and analog transmission, with each line capable of handling greater than 1 Tbps using DWDM. This network is mainly focused on the interconnectivity of the switching nodes; however, the end goal is to ensure the traffic integrity from termination point to termination point, i.e. from radar to radar screen or from cockpit flight control to flight control actuator.

Required Metrics of Modeling and Simulation

Modeling and simulation is required to determine metrics for potential network architectures including the following: optical power/loss budget, signal quality, eye diagrams, signal spectra, signal to noise ratio (SNR), crosstalk/channel isolation, bit error rate (BER), latency, and data throughput. Tools to provide these metrics range across several levels of abstraction from physical layer up through the network and analytical layers. In this paper, we discuss the physical-layer system simulation of a reference architecture. Future work will also include network-level modeling and simulation.

Physical-layer Modeling and Simulation

The physical-layer modeling and simulation of a network focuses on the propagation of optical signals through the network elements, and the quality of the signal which can be described in terms of signal to noise ratio or bit error rate. This can include time-domain simulation of the signal waveforms representing individual transmitted bits, or wavelength-domain simulation of the average optical powers of each optical channel, crosstalk, and optical noise spectrum. This level of simulation provides confidence in the physical network link performance taking into account physical effects such as signal rise and fall time, transients, jitter, nonlinearities, dispersion, polarization, crosstalk, noise, etc. It enables detailed analysis

1-4244-0408-8/06/$20.00 ©2006 IEEE

of component and topology design trade-offs, and establishes performance constraints that can be utilized in network-level modeling.

Simulation Results

Based on the architectural requirements and the necessity for the network to survive multiple faults, a reference network is proposed in which each node will connect to 4 other nodes, essentially guaranteeing that even if 3 fiber breaks occur, there will still be full connectivity. The current investigation does not address the survivability of the termination points, but only the main switching nodes. Future work will address this issue and also the situation in which the switching nodes themselves fail.

A 40 channel DWDM network path running at 1 Gbps per channel was simulated to determine the impact of the number of nodes in the ring on the signal integrity and BER. In this simulation, the 40 channels were specified according to the ITU grid in the C band with 100 GHz spacing. Simulations assuming no splice and node loss with the number of nodes ranging from 1 to 256 showed that fiber loss, dispersion, and nonlinearities were not a factor in the network performance. Simulations with node and splice loss ranging from 0 to 1.5 dB per node for 256 nodes in series showed that to ensure a BER of 10^{-12} across the top, middle, and lowest wavelength channels, the total attenuation of all nodes together is 19.1 to 19.6 dB. This works out to less than .075 dB per node (each of which has two connections) if each node splice loss is assumed to be equal. Based on these results, there may be justification for optical amplification at each node, and certainly within the network overall, to counteract the losses associated with the node. The simulated BER vs. total node loss for the top, middle, and bottom wavelength channels is shown in Fig. 2.

Another simulation study was performed in which optical amplification was used at each node to counter the impact of its associated optical losses. The primary issue with optical amplification is the accumulation of ASE noise. The simulation was designed to study the impact of optical noise on the signal integrity and BER for the DWDM channels. Simulations were performed in which the node loss ranged from 1 dB to 6 dB, with optical amplification, having a noise factor of 4, being used at each node to compensate for the node loss. The larger the loss that must be compensated for, or the larger the gain of the amplifier, the greater the noise floor. In these simulations, the dynamic range between the signal peak and the noise floor ranged from 33.3 dB to 29.1 dB, and the measured BER was 0 for all cases. Based on these results, we do not anticipate a limitation in a reasonable number of nodes in a lightpath.

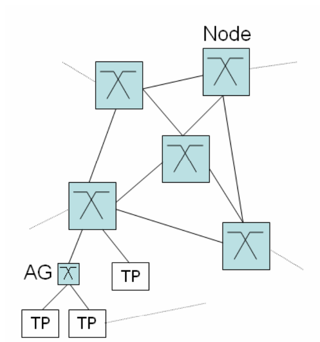

Figure 1. Meshed network with interconnected nodes

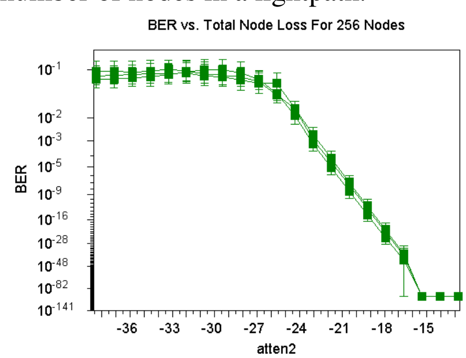

Figure 2. BER graph for three channels

Conclusions and Future Work

To address the requirements of an avionics WDM LAN, a reference architecture has been proposed and evaluated through physical-layer simulations. Based on these simulations, fiber dispersion and nonlinearities are not expected to be limitations. Future work is planned to include physical-layer investigation of transients and latencies, as well as network-layer simulations and more detailed investigations into network architectures in conjunction with the work of the SAE ASD AS-5659 group.

This work has been supported by the Office of Naval Research under contract N00014-05-M-0215.