Virtual Prototyping of WDM Avionics Networks

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1. INTRODUCTION

Optical communications technologies have continued to advance and mature since the early 1980s. Due to their high performance and decreasing costs, optical networks are now being considered for use in emerging avionics systems. As with any new technology, an efficient, accurate, and cost-effective method for investigating and evaluating candidate systems is needed, and computer-based simulation with rapid virtual prototyping can be ideal. With the proper set of tools, a combination of low-level details (e.g. link budgets) and high-level network concepts (e.g. QoS) can be integrated to obtain a detailed design evaluation. This paper introduces a library for simulation modeling of optical communication networks, focusing on performance analysis for advanced aerospace platforms, and features a case study of virtual prototyping for comparison of several system design strategies.

2. LIBRARY FOR INTEGRATED OPTICAL NETWORKS

Advances in commercial optical network technology and increased application demands have led avionics network designers to explore the use of optical components in future avionics systems. However, due to the high cost of prototyping and integration with existing systems, a simulation environment to perform tradeoff analysis can be the most cost-effective approach. A careful review of existing simulation tools revealed that no single tool could fulfill these requirements without modification. Therefore, a new optical component library was developed and added to an existing commercial tool to bridge the gap between optical-centric and network-centric simulation and performance analysis tools.

The Library for Integrated Optical Networks (LION) provides researchers with an extendable tool to assess both lower- and upper-layer networking issues simultaneously by providing a set of accurate optical components within a powerful network simulation environment. Developed at the University of Florida, LION was created in a discrete-event simulation environment called MLDesigner from MLDesign Technologies. The latest version of the library consists of 39 components in 13 categories, such as couplers, splitters, filters, amplifiers, etc. These components allow for accurate modeling of timing and some physical effects inside optical devices. LION provides users with flexibility in designing systems with varying high-level components and architectures. New and legacy network protocols can be implemented on top of components to realize and evaluate almost any system design.

3. AIRCRAFT LAN CASE STUDY

A tradeoff study is performed to compare the cost vs. performance of new and emerging technologies for high-speed optical networking for future military avionics systems to demonstrate LION's features. We developed models of an aircraft LAN to compare today's technology with several virtual prototype designs. The baseline system consists of typical aircraft networking components connected with a switched Ethernet architecture, which is considered state-of-the-art on modern aircraft. Our two candidate models represent a future direction for aircraft interconnects where all components are interconnected via a switchless optical backbone using wavelength-division multiplexing, or WDM.

An example configuration with traffic layout and set of communication patterns between aircraft modules is used to stimulate the network of each system. Thirty-nine Virtual Link Identifiers (VLIDs) are defined for communication between these modules, with source traffic types including bursty, random, periodic, and continuous, and source data rates ranging between 10 Kb/s and 250 Mb/s. The aggregate throughput (i.e. total offered load) required for the aircraft LAN network traffic used in this study is 1.27 Gb/s.

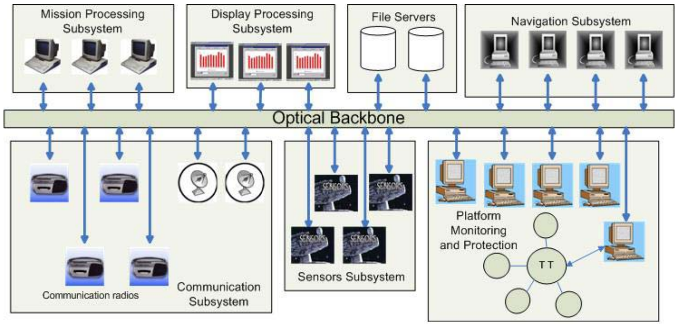

Figure 1. Candidate WDM Aircraft LAN

In the baseline aircraft LAN, the Line-Replaceable Modules (LRMs) that constitute a typical aircraft system are connected with three 16-port IP/Ethernet switches (Gigabit or Fast Ethernet, as traffic requirements dictate), which support multicast, buffered queues, and QoS. The system could be built with only two switches, but would require additional cable lengths and leave no room for scaling. Nodes in the network all have unique IP and MAC addresses. Each VLID is associated with a set of QoS requirements and a unique multicast address. Routing is performed based on QoS demands.

In the candidate WDM aircraft LAN, as shown in Figure 1, the same mixture of LRMs used in the baseline system is also used to stimulate this system. Two WDM systems are derived

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This work was made possible by support from Rockwell Collins Inc. in Cedar Rapids, IA, and MLDesign Technologies in Palo Alto, CA.

from this configuration and both feature a switchless optical backbone to interconnect modules, with traffic assigned to one of seven wavelengths, and all transmitters operating at 1 Gb/s. In WDM System A, each node has one fixed-wavelength laser and five optical filters in the receiver. Wavelengths are assigned by subsystem (e.g. all sensor subsystem nodes are assigned wavelength 1, all communication subsystem nodes are assigned wavelength 2, etc.). In WDM System B, each node is equipped with two fixed-wavelength lasers, but only three optical filters are needed in the receiver. Here, wavelengths are assigned to VLID groups, with most inter-subsystem traffic contained within a single wavelength. While System A only requires a single laser per node, an additional filter is needed for traffic received from a different subsystem.

Table 1: Summary of Case-Study Results

Attribute	**Baseline System**	**WDM System A**	**WDM System B**
Average End-to-End Traffic Latency (μs)	5,128.96	119.46	87.50
High-Priority Traffic (μs)	141.35	112.49	80.93
Medium-Priority Traffic (μs)	5,613.18	127.22	84.82
Low-Priority Traffic (μs)	8,137.90	505.61	491.51
Standard Deviation of Overall Latency (μs)	3,352.69	70.87	48.67
Standard Deviation of High-Priority Traffic Latency (μs)	99.11	66.03	43.48
Theoretical Aggregate System Throughput (Gb/s)	10.20	7.00	7.00

The results of injecting the traffic patterns onto the baseline and the two WDM architectures are summarized in Table 1. Both WDM systems produce average latencies that are significantly better than those observed in the baseline system. The performance of the baseline system suffers due to increased overhead requirements, and traffic contention at heavily congested destination nodes resulting from traffic load imbalance. Unlike the Ethernet case, several traffic streams simultaneously headed for the same destination cause no contention in the WDM systems. Messages in the WDM systems do not require packet processing while in transit, as opposed to packets in the baseline system which are processed and delayed at each switch for routing and QoS purposes.

In addition to lower averages, the jitter experienced by the traffic (i.e. variance in latency) is also observed to be better in the WDM systems. Using time-division multiplexing (TDM) as the access method within each wavelength, expected waiting periods are more deterministic compared to the switched-Ethernet system. This behavior is vital in military applications with mission-critical requirements. Moreover, much of the jitter experienced by high-priority traffic on the WDM systems was observed to be caused by delivery under the mean time. The WDM systems are also potentially more scalable than the switched-Ethernet network. Instead of requiring more switches and ports, additional wavelengths can be employed in the optical backbone. The use of faster components is another option, since many WDM systems today operate at 10 Gb/s per wavelength instead of the 1 Gb/s rates used in this study.

A significant difference was also seen between the two WDM systems under study. System B achieved an overall average latency approximately 30 μs below that of System A. As shown in Figure 2, System B delivers more packets in less than 100 μs, and far fewer in the 100-300 μs range, which is a major reason why lower variances are seen in system B as well. Although difficult to ascertain from this chart, System A produced no latencies over 1 ms, as opposed to ~0.1% for System B. The difference in performance can be largely attributed to the flexibility that the extra laser per node in System B offers in balancing the traffic efficiently between wavelengths. The low-priority traffic streams suffer little, since they occupy fewer TDM slots. In System A, the higher-priority traffic was often assigned a smaller portion of time slots than in System B due to wavelength load imbalance. Designers will have to decide if the gain in performance seen in the approach of WDM System B is worth the extra hardware, especially when fault-tolerance needs might dictate the requirement for a duplicate of every communications component (e.g. laser) in the system. This case study merely represents a small subset of one example of how simulation with LION can be used to design and evaluate future optical networks for aerospace.

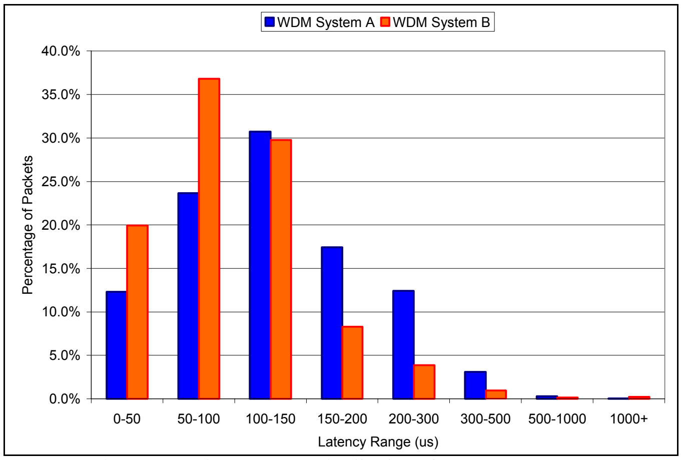

Figure 2: Packet Latency Distributions for WDM Systems

4. CONCLUSIONS

A brief description of the LION library including its motivation and components was provided. Three examples of an aircraft LAN network were presented to demonstrate system-level modeling and performance tradeoffs using the tool. The examples included a switched-Ethernet system and two WDM optical backbone systems. Results from the case study demonstrated that WDM networks offer superior performance, scalability, and global synchronization. The simulation modeling approach we describe is not limited only to military avionics networks – it is applicable to other design alternatives for complex communication systems where optical networking can offer advantages, such as commercial aircraft, ships, automobiles, communications and computing centers, etc. Future directions for research include expanding the LION component library and undertaking a broader range of system case studies, including design factors such as fault tolerance, as well as alternate control schemes and protocols.

5. ACKNOWLEDGEMENTS

Several former students in our lab made substantial contributions to models in LION, including Jeremy Wills, Chalermpong Dilakanont, Chris Catoe, and Ramesh Balasubramanian.