



AEROSPACE INFORMATION REPORT

AIR6006™

Issued 2009-12
Reaffirmed 2024-10

Modeling and Simulation Capabilities for Aerospace WDM LAN Applications

RATIONALE

It is desirable to architect a new standard Wavelength Division Multiplexed (WDM) fiber optic network architecture for aerospace platforms that will not just supplement current networks, but completely replace all legacy networks to maximize the benefits of fiber optic network technology and revolutionize networking in aerospace platforms. One of the goals of the availability of a WDM Local Area Network (LAN) standard is to help put in place metrics to evaluate and compare candidate architectures, thereby providing an objective perspective on the various merits and complexities associated with each. Modeling and simulation tools are critical for addressing and realizing this goal. Designing, modeling, and simulating a high-speed WDM network to be deployed in an aerospace environment with its unique requirements is a challenging task that requires the use of sophisticated modeling and simulation tools.

AIR6006 has been reaffirmed to comply with the SAE Five-Year Review policy.

FORWARD

The Society of Automotive Engineering (SAE) Avionic Systems Division (ASD) Technical Committee on Aerospace Avionic Systems sub-committee on Fiber Optics and Applied Photonics (AS-3) formed a standards working group in April 2005 with the goal of developing a standard for WDM LANs (wavelength division multiplexed local area networks) for aerospace applications. The working group is chartered to develop a standard with broad applicability to both commercial and military (tactical) aircraft.

Wavelength division multiplexing provides many potential benefits as the infrastructure communications cable plant in an aircraft. Along with these benefits, there are significant challenges. WDM network architectures must be capable of supporting all communication needs aboard the aircraft. The different communications types may range from high priority with tight latency requirements, to low priority with loose latency requirements. High priority traffic may include flight controls, while low priority traffic may include data collection for post-mission analysis. Different communications types may also have a variety of quality of service (QoS) requirements.

Initial work in the standards group was broken down into two primary tasks, and a separate subtask group was formed to work on those two separate tasks. The first of these tasks was to develop a requirements specification for WDM LANs for aerospace applications. Several documents are in the process of being developed through the work in that subtask group. The second of these tasks was to develop a document identifying modeling and simulation capabilities required. This document is the output from this subtask group.

Following the completion of the work in these first two subtask groups, additional subtask groups will be formed. Documents produced by these first two working groups, including this present document, will be used to continue the work towards the development the aerospace WDM LAN standard and deployment of systems based upon it.

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1. SCOPE

This document provides an overview of currently available and need to be developed modeling and simulation capabilities required for implementing robust and reliable Aerospace WDM LAN applications.

1.1 Purpose

The purpose of this document is to provide relevant information on modeling and simulation capabilities to architects and designers of WDM LAN standards and systems. The document is intended to be utilized in conjunction with existing SAE standards documents, AIR-6004 "Optical Networking Glossary Terminology" [1] and AIR-6005 "General Requirements for Wavelength Division Multiplexed (WDM) Backbone Networks" [2].

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1.1 SAE Publications

2.2 Related Publications

The following publications are provided for information purposes only and are not a required part of this SAE Aerospace Technical Report.

2.2.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel. 877-606-7323 (inside USA and Canada) or 724-776-4970 (outside USA), www.sae.org

AIR6004 Optical Networking Glossary Terminology [1]

AIR6005 General Requirements for Wavelength Division Multiplexed (WDM) Backbone Networks [2]

AS1773 Fiber Optics Mechanization of a Digital Time Division Command/Response Multiplex Data Bus [5]

AS5603 SAE Aerospace Digital Fiber Optic Link Loss Budget Methodology for Aerospace Platforms [9]

AS5750 Loss Budget Specification for Fiber Optic Links [11]

2.2.2 Telecommunications Industry Association (TIA) Publications

Available from TIA, 2500 Wilson Boulevard, Suite 300, Arlington, VA 22201, Tel. 703-907-7700, www.tiaonline.org

TIA-529-1 Single-Mode Fiber Optic System Transmission Design [12]

2.2.3 ARINC Publications

Available from the Aeronautical Radio, Inc., 2551 River Road, Annapolis, MD 21401, www.arinc.com

ARINC 429 Mark 33 Digital Information Transfer System [4]

2.2.4 IEEE Publications

Available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, Piscataway, NJ 08854-1331, Tel: 732-981-0060, www.ieee.org

I. Roudas, et al., "Wavelength-Domain Simulation of Multiwavelength Optical Networks," IEEE J. of Sel. Topics in Quantum Electronics, vol. 6, no. 2, March/April 2000. [6]

B. K. Whitlock, et al., "Comprehensive Design Optimization of the Physical Layer of Optical Networks," in OSA/IEEE OFC/NFOEC2005 Technical Proceedings, paper NTuB3, March 8, 2005. [13]

M. W. Beranek, A. R. Avak, R. L. Van Deven, "Military Digital Avionics Fiber-Optic Network Design for Maintainability and Supportability," IEEE Aerospace and Electronic Systems (AESS) Magazine, Vol. 21, No. 9, pp 18-24, Sep. 2006. [16]

M. W. Beranek, A. R. Avak, "Improving Avionics Fiber Optic Network Reliability and Maintainability," IEEE Aerospace and Electronic Systems (AESS) Magazine, vol. 22, no. 5, May 2007. [17]

C. Reardon, I. Troxel, and A. George, Virtual Prototyping of WDM Avionics Networks, 2005 IEEE/LEOS Avionics Fiber-Optics and Photonics (AVFOP) Conference, Minneapolis, MN, Sep. 20-22, 2005. [21]

A. A. R. Lee and S. D. Rayner, "Avionics Architectures Incorporating Fibre Optic Technologies," Proceedings of the IEEE LEOS AVFOP 2006 conference, paper TuB2, pp. 10-11, 2006. [23]

M. Mezhoudi, C.-H. K. Chu, C. Jing, and C. Y. Long, "Integrating network quality, performance and cost control through reliability analysis in optical network design," Telecommunications Network Strategy and Planning Symposium NETWORKS 2004, pp. 397-403. [24]

B. K. Whitlock, H. N. Poulsen, D. H. Richards, D. J. Blumenthal, "Physical-layer Modeling and Simulation of WDM Fiber Optic Network Architectures for Aerospace Platforms," 2006 IEEE/LEOS Avionics Fiber-Optics and Photonics Conference, 2006. [25]

H. N. Poulsen, D. H. Richards, A. Ramapanicker, D. J. Blumenthal, "Network Layer Modeling of WDM Fiber Optics Network Architectures for Aerospace Platforms," 2007 IEEE/LEOS Avionics Fiber-Optics and Photonics Conference, 2007. [26]

2.2.5 SPIE Publications

Available from SPIE, 1000 20th St., Bellingham WA 98225-6705, Tel: 360-676-3290, www.spie.org

G. Boggio, M. Burzio, N. Portinaro, J. Cai, I. Cerutti, A. Fumagalli, M. Tacca, L. Valcarengghi, A. Carena, R. Gaudino, "NetworkDesigner - Artifex - OptSim: a suite of integrated software tools for synthesis and analysis of high speed networks," Optical Networks Magazine, September-October 2001, pp 27-41. [22]

2.2.6 U.S. Government Publications

Available from the Document Automation and Production Service (DAPS), Building 4/D, 700 Robbins Avenue, Philadelphia, PA 19111-5094, Tel: 215-697-6257, <http://assist.daps.dla.mil/quicksearch>

MIL-STD-1553 Aircraft Internal Division Command/Response Multiplex Data Bus [3]

MIL-STD-2052 Fiber Optic Systems Design [10]

MIL-HDBK-217F Reliability Prediction of Electronic Equipment, 1995 [15]

MIL-STD-3018 Parts Management

SD-19 Parts Management Guide

2.2.7 Web Site References

<http://www.techweb.com/encyclopedis> [7]

<http://wombat.doc.ic.ac.uk/foldoc> [8]

JDSU's DWDM Pocket Guide [14]

http://www.jdsu.com/test_and_measurement/technical_resources/technology_documents/pocket_guides/dwdm_pg_fop_tm_ae_1005.pdf

<http://www.weibull.com> [20]

3. OVERVIEW

This document will address the following:

- Describe the types of architectures that are capable of being evaluated within the scope of the modeling and simulation capabilities under consideration in this document
- Describe the criteria for evaluation of the architectures within the scope
- Describe the methodologies used to apply modeling and simulation capabilities within the scope of this effort
- List what tools are required
 - What tools exist
 - General description of tools in each category of the modeling and simulation abstraction hierarchy
 - List of major/common tools in category
 - Assumptions for each
 - Limitations for each
 - Validation status for each
 - What tools are yet required
 - General description of tools in each category of the modeling and simulation abstraction hierarchy
 - List of major/common tools in category
 - Anticipated assumptions
 - Anticipated limitations
 - Strategy for validation
- Designing a WDM Network for Avionics Applications Using Modeling and Simulation
 - Overall description of a design flow
 - Examples highlighting various segments of design flow

4. ARCHITECTURES CAPABLE OF BEING EVALUATED

There are a variety of architectures used to deploy optical networks. The architecture is chosen based upon the key requirements identified for the target network, such as the network performance and reliability, physical topology, and cost. Simulation and modeling can be used to aid in the definition of the architecture for a target optical network by quantitatively evaluating candidate architectures according to key metrics.

The primary purpose of a network architecture is to determine, evaluate, and optimize placement of network nodes and interconnections in a standard deployable manner. The optimal network node design can then be determined after the optimal network topology is determined. Furthermore, network node designs may change over the life of an aircraft, but how they are interconnected may not change. This is because the cable plant installed in the aircraft during initial construction may never be replaced during the life of the aircraft because the cost of doing so may be prohibitive. Therefore, it is critical that the choice of how the network nodes are interconnected is made well at the outset.

Without a detailed analysis through modeling and simulation, it is not clear what the optimal choices are. In this section, the primary network architecture topologies are discussed. The major network architecture categories are listed and described below. They include point-to-point, bus, star, ring, mesh, and various combinations of these. Each of these is capable of being evaluated through the use of appropriate modeling and simulation capabilities.

4.1 Point-to-point

The point-to-point architecture is characterized by each node connecting directly with all the nodes that it wishes to communicate with. Typically, one node in each link connects with only one other node. An example would be a sensor or actuator connecting with a processor. The processor may also have point-to-point connections with other sensors, actuators, processors, or I/O devices. Historically, this has been the primary architecture deployed for fiber optic communications in aircraft.

4.2 Bus

The bus architecture is illustrated in Fig. 1. The bus architecture is characterized as a communication channel (the “bus”) shared by many components (or “nodes”) simultaneously. There is a protocol that enables these components to access the bus and use it to communicate with other components on the bus without interference from the other components. The bus architecture has been utilized in electronics-based communications (e.g., copper-based interconnections in computer systems and networks, Ethernet, MIL-STD-1553 [3], ARINC 429 [4], etc.) for many years. An equivalent fiber-optic bus standard is AS1773 [5].

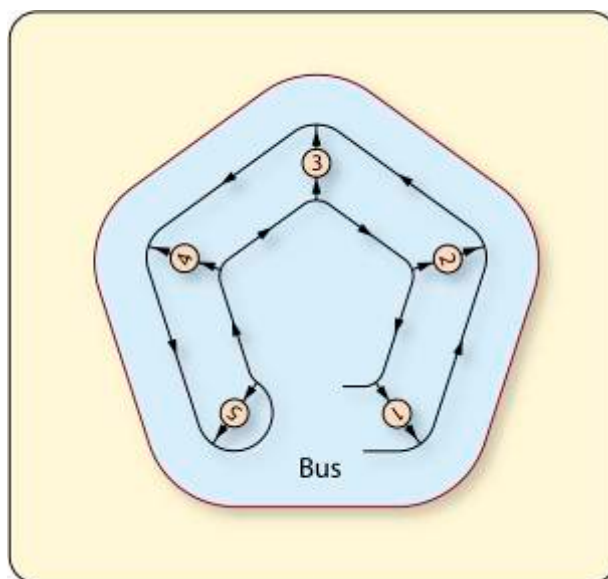


FIGURE 1 - A BUS TOPOLOGY

4.3 Star

The star topology is illustrated in Fig. 2. In the star topology, each network node communicates with all other network nodes through a shared network resource, the star coupler. The star coupler, which can be a passive optical device or an active switch, takes the incoming signal and broadcasts it to all nodes connected to the star. All communication between the terminal nodes must go through the star coupler. At least one implementation example of the Fibre Channel standard utilizes broadcast functionality in a star architecture. Another example of a star architecture is the central office of a telephone or CATV system as the star coupler and each home's telephone or cable box as the terminal node. A star topology has been successfully deployed in an airborne environment.

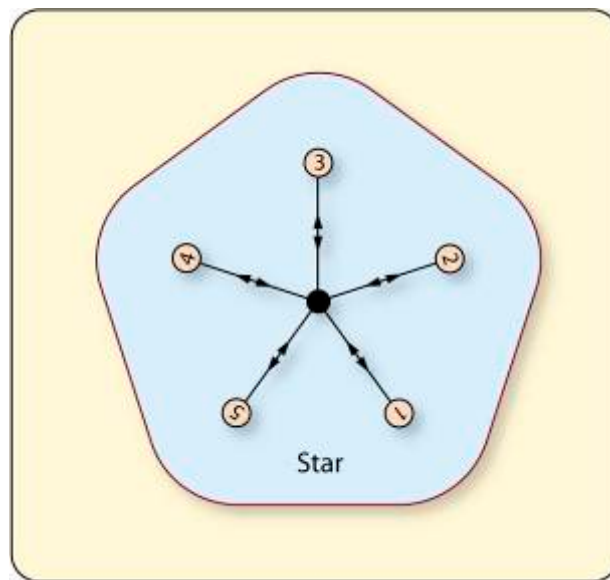


FIGURE 2 - A STAR TOPOLOGY

4.4 Ring

The ring topology is illustrated in Fig. 3. Ring architectures are characterized by a circular topology with network nodes, such as Add/Drop Multiplexers, connected to one another in a circular fashion. There are typically two fibers attached to each node (one upstream, one downstream). They are typically used to interconnect multiple access nodes to a hub. In general, they may be a good choice if most of the traffic is confined to within the ring, or the physical topology of the network is sparse. A ring topology has been successfully deployed in an airborne environment.

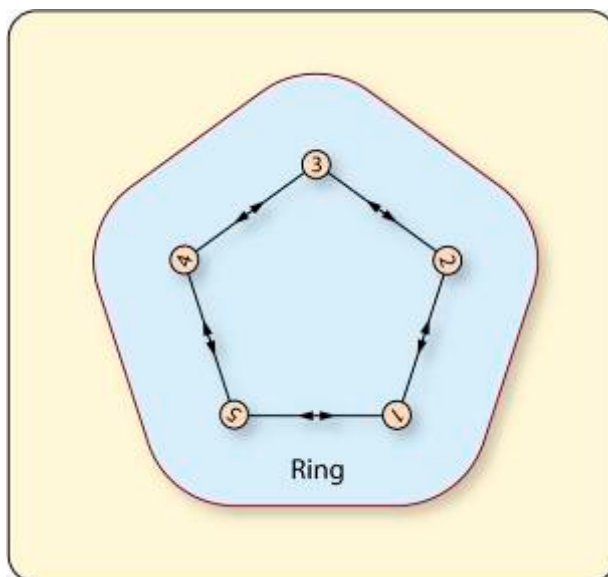


FIGURE 3 - A RING TOPOLOGY

4.5 Mesh

Mesh architectures are characterized by each network node connecting to many other network nodes directly. In the extreme case as illustrated in Fig. 4, each network node may connect to all other networks nodes, enabling direct paths through the network from point A to point B. In most large networks, this is not feasible. A major benefit of this topology is multiple paths through the network from point A to point B, to enable data to reach its final destination even if one of the paths becomes blocked due to a network failure. The multiple paths provide redundancy and minimal service interruption in the event of a network node failure. In addition, the network may meet high peak demands by utilizing multiple paths through the network for data transfers between point A and point B. Another major benefit that multiple paths provide is minimal latency through the network. However, because of the multiple paths that a data packet can take between point A and point B, the latency is nondeterministic and is difficult to predict or guarantee. This network architecture is also complicated to manage without a central control node. The mesh network topology has never been deployed in aircraft applications to date.

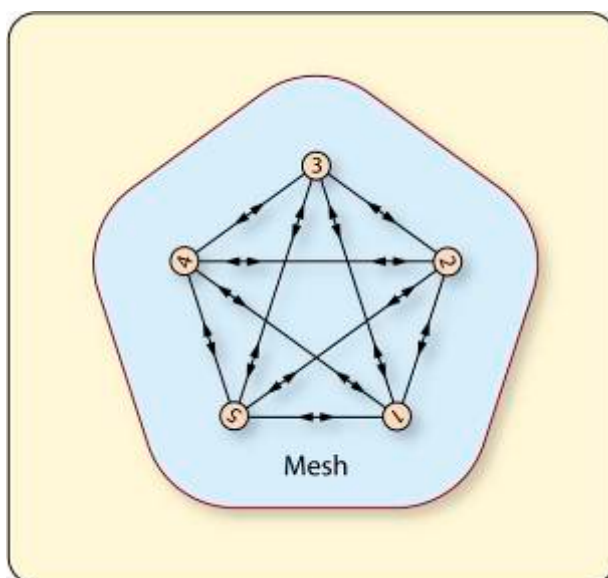


FIGURE 4 - A MESH TOPOLOGY

4.6 Combinations of the above

In practice, aspects of all of the above architectures could be combined to address the unique requirements of a network deployment.

Modeling and simulation capabilities need to have the ability to mix and match combinations and permutations of the above network topologies for thorough evaluation of WDM architecture candidates for deployment of optical networking in aerospace applications.

5. EVALUATION CRITERIA FOR ARCHITECTURES

There are a variety of criteria that can be used to evaluate optical network architectures. These criteria may be based upon metrics of component or network performance at some level, or upon whether certain metrics meet specifications. In this section of this document, we list a number of metrics that can be used to evaluate network architectures as well as some useful acceptance criteria.

5.1 Metrics

5.1.1 Eye diagrams

Eye diagrams are plots of signal waveforms in which the individual bit periods are overlaid on one another to graphically represent signal integrity characteristics such as jitter, noise, and rise and fall times. Assuming a particular noise distribution such as Gaussian, the Bit Error Ratio (BER) of a signal can be computed from the eye diagram. A variety of signal impairments can be diagnosed from the eye diagram.

5.1.2 Optical/RF spectra

The optical or radio frequency (RF) spectra is computed from the Fast Fourier Transform (FFT) of the time-domain signal waveform. It indicates the frequencies at which signal power exists. The frequencies at which data channels are present as well as signal degradations such as amplified spontaneous emission (ASE) noise and four wave mixing (FWM) are identified from the signal spectra.

5.1.3 SNR

The signal to noise ratio (SNR) is a numerical measure of the signal power relative to the noise power in a signal, and generally refers to the electrical signal to noise ratio. Assuming a particular noise distribution such as Gaussian, the signal to noise ratio can be used to compute the BER.

5.1.4 OSNR

The optical signal to noise ratio (OSNR) is a numerical measure of the optical signal power in a wavelength channel relative to the amplified spontaneous emission (ASE) noise power in the vicinity of the wavelength range of that optical signal.

5.1.5 Noise Figure (NF)

The noise figure (NF) of a component is a measure of the degradation of the signal to noise ratio (SNR) of a signal due to noise introduced by the component. An optical amplifier is an example of a component characterized by a noise figure. The noise figure is the ratio of the actual output noise to that which would remain if the component itself did not introduce noise.

5.1.6 Q values

The Q values of an optical communication channel are directly related to the BER of that channel assuming a particular noise distribution, such as Gaussian.

5.1.7 BER

BER refers to the Bit Error Ratio of a communication channel. The closer the BER value gets to 0, the better the communication channel. BER requirements are typically on the order of 10^{-12} . One thing to note in regards to simulation is that it is possible to simulate a much lower BER than could be measured in reality because of the time that it would take to perform the measurement. For example, measuring a BER of 10^{-12} on a 10 Gbps link would take 1000 seconds (about 17 minutes), but measuring a BER of 10^{-15} would take 1 000 000 seconds (about 278 hours or 12 days).

5.1.8 Jitter

Jitter is the measure of how much a pulse's location in time varies from bit period to bit period. Large amounts of jitter can reduce a channel's BER due to the resulting horizontal closing of the eye and narrowing of the time window in which an accurate signal value measurement can be made by the decision circuit in the receiver.

5.1.9 Power transients

Power transients in an optical channel are generally associated with adding and dropping of channels in a WDM network with optical amplifiers. The change in the average power entering the optical amplifier causes its gain to oscillate as it adjusts to a new operating condition, resulting in power transients in the output signals. This can have detrimental effects on the optical signals leading to bursts of errors that can last a few milliseconds.

5.1.10 Interference between channels.

Interference between channels can also be referred to as crosstalk. There are two forms of crosstalk considered here: linear crosstalk and nonlinear crosstalk. Linear optical crosstalk may be due to nonideal optical multiplexers/demultiplexers and optical space switches in add/drop multiplexers or optical cross-connects. Nonlinear optical crosstalk is due to nonlinearities in optical fibers and other components. These nonlinearities typically occur in telecom networks over lengths longer than those anticipated for aerospace applications. Therefore, nonlinear optical crosstalk may be less of a factor in aerospace applications than in telecom networks.

5.1.11 Spurious Free Dynamic Range (SFDR)

The spurious free dynamic range is a metric typically applied to analog signals. The SFDR is the ratio of the root mean squared (RMS) amplitude of the carrier frequency to the RMS value of the next largest noise or harmonic distortion component. The SFDR may typically be measured in decibels (dB) with respect to the carrier frequency amplitude (dBc).

5.1.12 Channel isolation

Channel isolation is a measure of how much power from another channel bleeds onto a given channel through a number of different mechanisms, including four wave mixing and cross phase modulation, for example.

5.1.13 Impairments within the same channel

A communication channel can have impairments within itself independent of other channels, such as dispersion (chromatic, modal, and polarization mode dispersion) and self-phase modulation.

5.1.14 Optical power/loss budget

This is a measure of how much power can be lost in the link from the optical source to the optical receiver while still maintaining the design performance (e.g., the loss allowed while maintaining a BER of 10^{-12}). The loss is typically budgeted across the various components in the link, with a value assigned to the couplers, fiber, splices, filters, etc. There is typically a design margin also added to the loss budget.

5.1.15 Latency

Latency is a measure of how long it takes a bit to go from the input of the transmitter to the output of the receiver. It includes the time required for processing, encoding, transmitting, traveling over the communication medium, being received, decoded, and processed.

5.1.16 Data throughput

The data throughput is a measure of how much data can be transmitted over a network in a given period of time. This differs from the bit rate, because the bit rate is a measure of the number of physical bits transmitted over a single channel in a point to point link. Data throughput includes reductions due to encoding such as 8B/10B encoding, Manchester encoding, Forward Error Correction (FEC) encoding; increases due to wavelength division multiplexing (WDM); and impacts of network routing and associated bottlenecks and resource conflicts.

5.1.17 Goodput

Goodput is the number of good data bits per unit of time transmitted through the network between source and destination. This does not include protocol overhead, retransmission, etc.

5.1.18 Operational availability – uptime

This is a measure of the availability of the network to its users. It can be reported as a percentage of time.

5.1.19 Mean time to recovery (MTTR)

This is the amount of time required for the network to recover and resume normal operations in the event of a failure. This metric is separate from another metric in avionics, mean time to repair, which also uses the acronym MTTR. A network may recover from a communications failure through the exercise of appropriate protocols, and not need physical repair of any network equipment. In other cases, physical repair may be required. The mean time to recovery metric encompasses both ends of the spectrum. In a scenario where a network includes redundant components such that a spare component can immediately take over when a primary component fails, the mean time to recovery for the network given that failure may be virtually zero. The mean time to repair of the failed component, however, may be significant.

5.1.20 Costs – cost of equipment, weight, total lifecycle costs

The measure of cost for a network is important for its economic viability. There are costs which must be considered in addition to the initial cost of acquiring and installing the network equipment. These costs include the impact of the network equipment's weight, which may include increased fuel consumption. These costs also include the total lifecycle costs, or the total ownership cost of an aircraft. The total ownership cost is significantly weighted by after-purchase operations and support, including maintenance and spare parts.

5.2 Acceptance Criteria

Modeling and simulation can be used to confirm that a network architecture meets acceptance criteria before physical prototypes are built. Acceptance criteria are typically based upon whether or not a network architecture meets the requirements. To ascertain this, there must be a requirements specification that explicitly and quantitatively lists the requirements. Requirements may be specified within a range to allow for solutions to be optimized for the most critical requirements such as performance or cost. Acceptance criteria may also be prioritized.

6. METHODOLOGIES FOR APPLICATION OF MODELING AND SIMULATION

Optical networks are designed using a wide range of technologies. Just as there are multiple layers in the Open Systems Interconnection (OSI) reference model, there are multiple levels of abstraction in modeling and simulation approaches for networks. At each OSI layer, a different set of tradeoffs in model detail, accuracy, and computational efficiency may be necessary. In this document, we don't consider the detailed physical modeling needed for the physical design and characterization of individual devices (commonly referred to as Computer-Aided Design for semiconductor manufacturing technology (TCAD) in electronic design automation, or device-level tools in photonic design automation), but rather the needs for network simulation. Simulations for network design typically cover the physical layer, data link layer, and network layer of the OSI reference model.

For the physical-layer evaluation of the end-to-end network performance of WDM networks, it is necessary to take into account the effect of transmission impairments. Transmission impairments to be considered include signal power variations, amplified spontaneous emission (ASE) noise accumulation, and crosstalk. For evaluation of individual links within the network, more detailed simulation of the nonlinear impairments within the link may be required. For some aspects of the system and its constituent components, even more detailed circuit- and device-level simulation is required. In any simulation approach, there are necessary trade-offs between speed on one hand and accuracy and completeness on the other. A comprehensive design optimization requires modeling, simulation, analysis, and optimization across these different levels of the system and network design. This is illustrated in Fig. 5 [6].

At the lower levels of abstraction, detailed modeling of the elementary units of a network requires a significant amount of data to specify and configure the model. This detailed modeling then imposes large computational requirements to perform simulations and design analyses. At higher levels, such as for network elements and their constituent components (collectively referred to as “blocks”), the blocks are treated more abstractly with models that require less data to specify and configure. Consequently, these higher-level models have reduced computational requirements. At these higher levels, the system and network performance are of interest. The collection of more abstract component models enables the study of large systems at higher levels which would not be practical at lower levels.

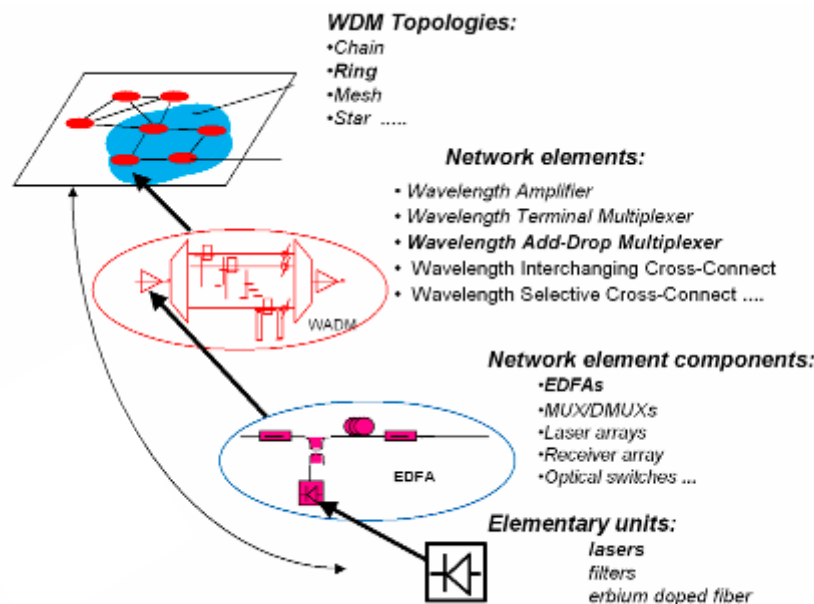


FIGURE 5 - LEVELS OF ABSTRACTION IN AN OPTICAL NETWORK

6.1 Business Case Analysis

These tools focus on helping people make strategic business decisions regarding network deployment. In the telecom world, users of these tools would include telecommunications carriers and internet service providers, for example. For the deployment of WDM optical networks in aerospace applications, the users of these tools could include the customers of the aerospace platforms (e.g., the Navy, the Air Force, airlines, etc.), as well as the manufacturers of the aerospace platforms themselves, such as defense prime contractors and commercial aircraft manufacturers.

The economics in terrestrial WDM network deployment differ from those in aerospace applications. In terrestrial WDM networks, business case decisions are based on the answers to questions such as the following:

- What is the population of the served area?
- How many users would the network serve?

- What capacity would the network provide?
- What would the revenue prospects for the network be?
- What would be the deployment cost for the network (technology, right of way, labor, etc.)?
- What would be the annual maintenance costs for the network (technology, right of way, labor, etc.)?
- What would be the impacts of inflation and deflation on the network's economic plan?

In aerospace applications, the deployed networks have different economic considerations. They also differ between tactical aircraft (i.e., defense applications) and commercial aircraft. In tactical aircraft, the primary considerations are the performance, the initial deployment costs, the ongoing maintenance costs, and a comparison with other alternatives. A balance between acquisition cost, performance, supportability, reliability and maintainability should be incorporated when planning, selecting and installing the network components on the aircraft. A balance must be achieved between the Life Cycle Cost / Total Cost of Ownership and acquisition cost, supportability, reliability, maintainability, and performance. These are also importance in commercial applications, but there may also be revenue opportunities from passengers in commercial airlines that affect the economic analyses.

6.1.1 Business case analysis model inputs

Inputs to models include the following:

- Time period
- Network demand
- Network services
- Network routing
- Network architecture
- Network technologies
- Node parameters
- Link parameters

6.1.2 Applications

These tools would be applied to determining the cost/revenue model for a given network. In commercial networks, the goal would be to design a network deployment that would provide a positive revenue stream for the company that deploys it. In the case of aerospace WDM networks, the goal is to determine if a particular network deployment would meet the deployment, maintenance, and operational cost targets over the lifetime of the network.

6.1.3 Methodologies

Many people perform cost analyses using spread sheet analyses. Potential commercial tools would be more sophisticated, enabling application-specific equations and models to be developed that make the tool more user-friendly and robust for its target application. The tools would be used by entering data about the planned network, constituent components, associated cost and performance data, and study parameters. The tool would then perform a study that would provide a report on the cost of the network deployment taking into account initial costs, maintenance costs, and operational costs.