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WDM LAN Optical Backbone Networks and Standards for Aerospace Applications

FiberFest 2009 Symposium – May 11, 2009

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Some of the results reported here pertain to a program sponsored by: Defense Advanced Research Projects Agency
Advanced Technology Office (ATO)
RONIA Program: WDM Networks in Avionics Platform
ARPA Order No. V202/00
Issued by DARPA/CMO under Contract HR0011-07-C-0028

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Outline

- **Motivation for Optical Networks in aircraft applications**

  Results of DARPA RONIA project
  - ✓ **Current practice limitations**
  - ✓ **Drivers for advances in networking solutions for data communications on-board aircraft**
  - ✓ **Vision for a future-proof optical network infrastructure: WDM LAN**
  - ✓ **Technology and network challenges (network architecture & management) to achieve WDM Optical Backbone Network (OBN)**
- **Opportunities for fiber optics and WDM in aircraft platforms.**
  - ✓ **Goal: enable design & implementation of fiber-based WDM LAN using standards that facilitate flexible, high bandwidth, low cost & low weight communications on aircraft platforms spanning military, commercial applications**
  - **WDM OBN in aerospace applications:**
  - ✓ **Optical Fiber and WDM technology challenges: meeting SWAP-c metrics & ability to withstand stringent environmental requirements**
  - ✓ **Review status of Standards development within WDM LAN Task Group of the Society of Automotive Engineering (SAE)**

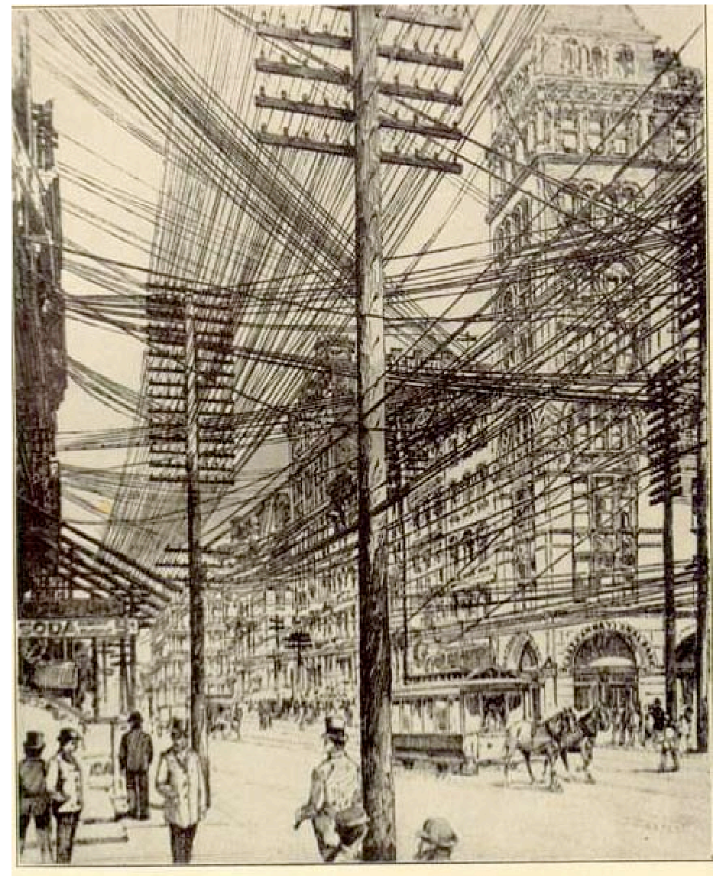
Goal: Avionic Networks with New Attributes

- Transparent, High Bandwidth: Support of heterogeneous legacy (analog or multiple digital formats) & new high-bandwidth signals
- Scalable and Secure: Scalable, reconfigurable, ***future proof*** and secure **aircraft backbone network**
  - ✓ Significantly reduce new application introduction timeline (e.g. for new sensors, antennae, and radios)
  - ✓ Physical layer supports multiple independent levels of security (MILS)
- Flexible Networking: Network with simple control & management functions – easy to use and upgrade
  - ✓ Streamline configuration provisioning (auto-discovery) for existing & new network links
  - ✓ Upgrade network for anticipated and unanticipated future capability without having to tear apart the airframe infrastructure
- Fault Tolerant: Optical network redundancy and diversity
- Reduce SWAP: Compact, reliable, low power and low cost

The challenge: increasing communications needs on a finite platform

- The need for communications is growing rapidly
  - More sources
  - Higher bandwidth
  - Incompatible formats
  - Need to support legacy signals
- In avionics, we have a platform that can support only limited
  - Size
  - Weight
  - Power demands
- There are other specialized requirements
  - Environmental --reliability
  - Security
  - Growth without replacing infrastructure
  - Ease of maintenance

The challenge is not new!



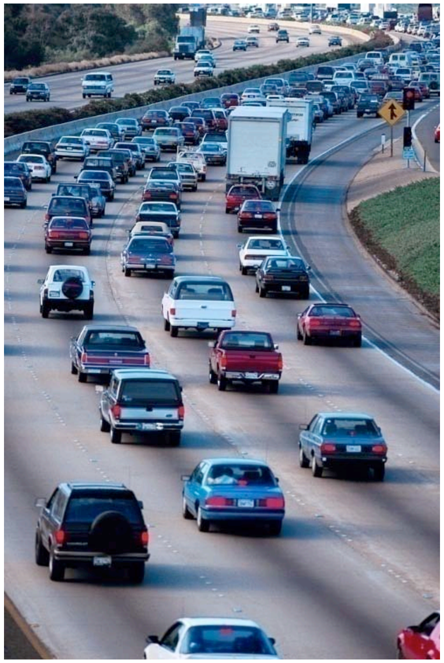
BROADWAY AND JOHN STREET, NEW YORK, IN 1890, SHOWING THE DENSITY OF OVERHEAD WIRES

thanks to :
Janet Jackel, Ted Woodward
Ravi Vaidyanathan
Haim Kobrinski

Telcorc

We can learn from Telecom solutions, without replicating them

- Optical fiber provides increased bandwidth
  - Optical fiber can also help with size/weight/power limitations
  - Fiber is immune to EMI, HPM
  - Fiber supports WDM



- WDM for even more bandwidth & flexibility in its use
  - Different wavelengths don't interact*
  - Different wavelengths can carry different data rates, formats ….
- WDM networking for even greater flexibility, survivability, ability to add applications

* To first order

RONIA Summary

- **RONIA: Requirements for Optical Networks in Avionics**

Acknowledgements

RONIA Project Program Manager – Adel Saleh, DARPA/STO Contract: HR0011-07-C-0028
Participants: Telcordia (prime), AFRL, Boeing, Lockheed Martin and NAVAIR

References

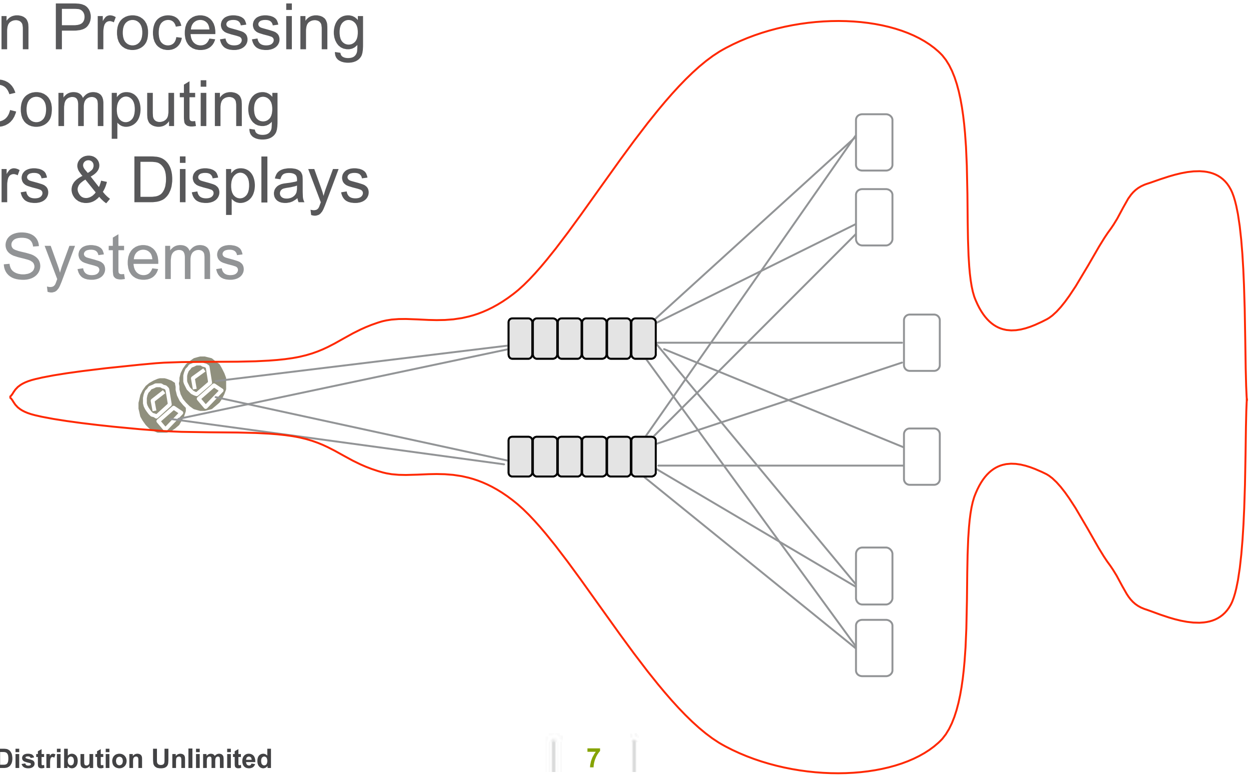
S. F. Habiby and M. J. Hackert "Motivation for WDM-based Optical Networks in Aircraft Applications," presented at SAE WDM LAN Task Group Meeting, Annapolis, MD, May 2007

S.F. Habiby and M. J. Hackert: "RONIA Results: WDM-based Networks in Aircraft Applications", IEEE-AVFOP Conference, Oct. 2008, San Diego, CA

Typical Avionics Systems

Current limitations restrict the ability to scale (capacity, applications) for many types of aircraft systems, including:

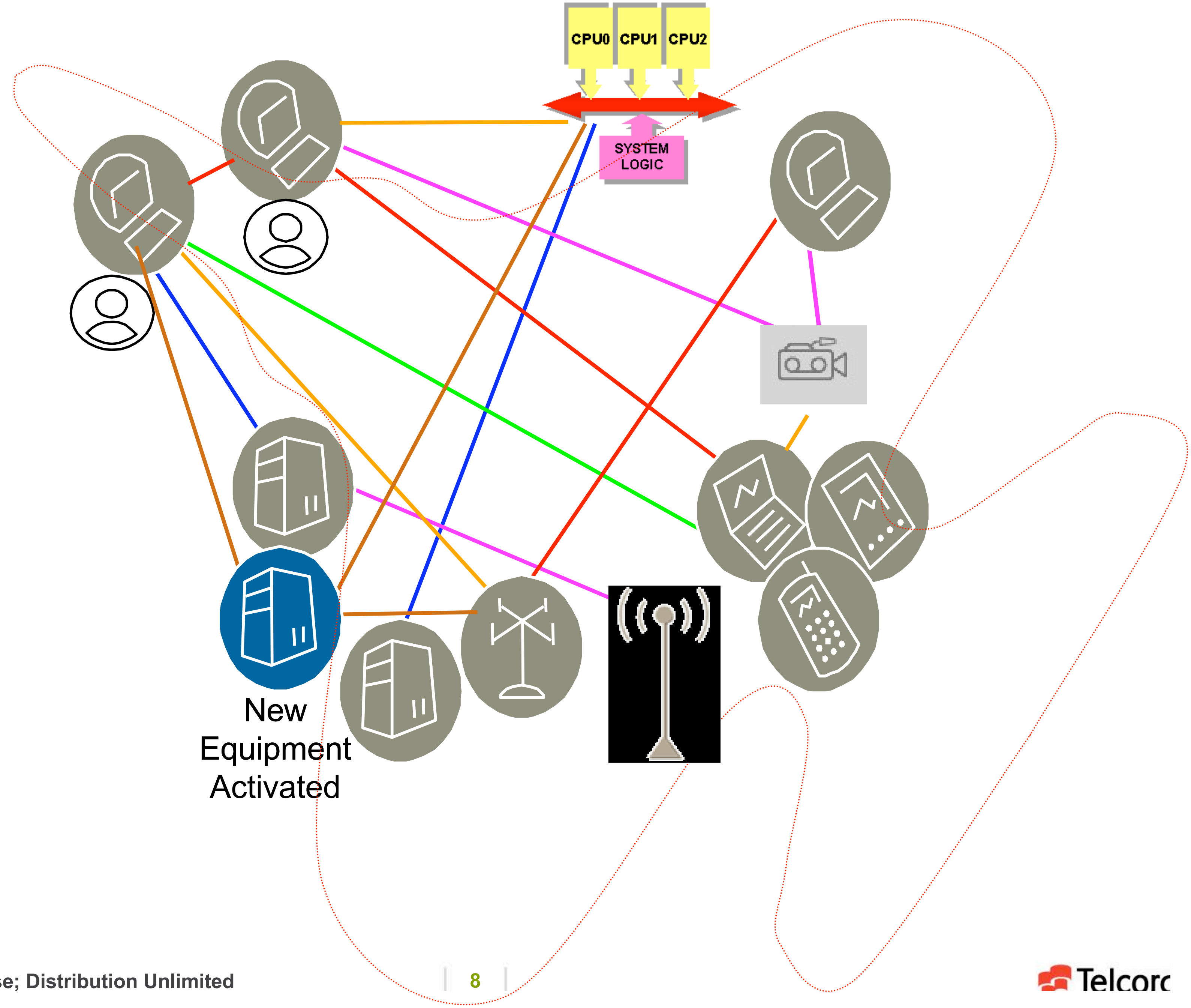
- CNI: Communication, Navigation and Identification
- EW: Electronic Warfare
- SMS: Stores Management Systems
- VMS: Vehicle Management System
- Mission Processing
- Core Computing
- Sensors & Displays
- Cabin Systems



Categories **A** through **F** shown later include these subsystems.

Aircraft System Interconnects -- Today

Physical layer uses multiple overlay links



Change cable or bus infrastructure

Physical Layer Connection

Current Practice Limitations

- Today avionics systems are connected by a set of dedicated links or buses (electrical & optical) similar to data center interconnects
- Increases in avionic data networking complexity, bandwidth and Multi-Level Security (MLS) demands are hard to achieve *collectively* with current approach
- Limitations, primarily as an **adverse impact on cost, schedule, weight, and retrofit**, lead to compromises in:
  - **Scalability:** Reduces application scalability due to weight, space, and cost constraints , e.g. new high bandwidth sensors
  - **Fault management and isolation:** diagnostics & health management
  - **Information Assurance:** Limits ability to support both redundancy & multiple independents levels of security without added weight & cost
  - **Multi-protocol support:** Protocol proliferation implies multiple physical layer infrastructures
  - **Interoperability:** Proprietary designs that do not support interoperable applications

Alternatives for platform evolution

- The current limitations can be addressed in a “piecemeal” or stovepipe fashion, e.g. one-for-one replacement of copper cables with optical fiber for a a subset of the aircraft systems

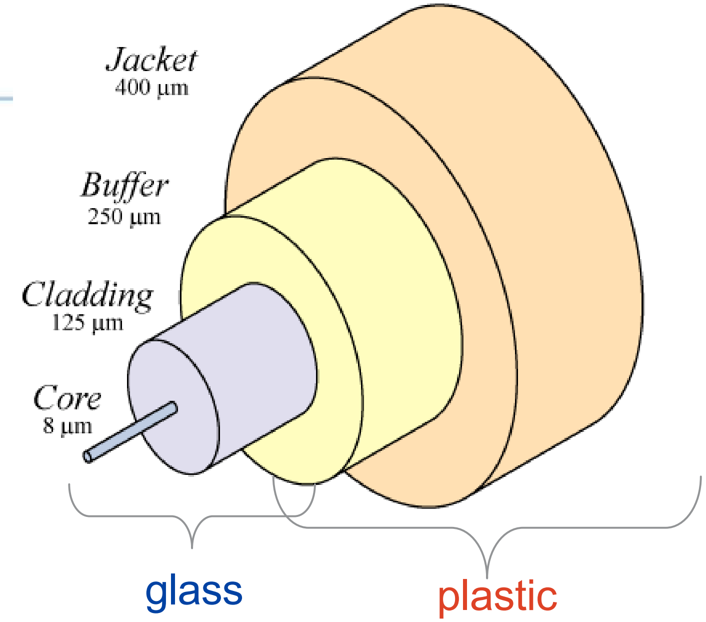
HOWEVER:

- While this approach may provide “intuitive” cable infrastructure weight reduction, the analysis must also include cost & weight of components at the ends of the link for O/E and E/O signal conversion, connectors within each link as well as redundancy requirements
- As the number of one-for-one replacements increase, this approach results in a new infrastructure bottleneck – managing the optical fibers links added to the aircraft

→ Similar to driver for migration to WDM in telecom networks, resulting in reduced complexity and cost, and improved reliability

Solution: Find a (unique) technology solution that can offer the features and functions needed with a SWAP improvement in a managed future-proof network infrastructure.

What fiber provides



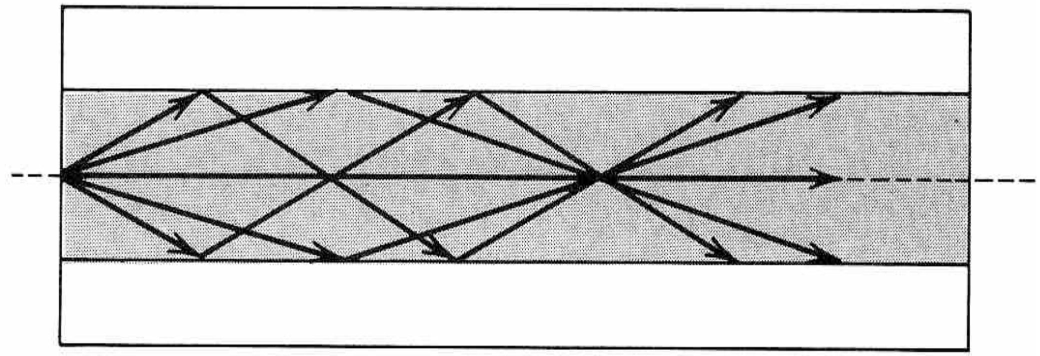
- Fiber is light, small …
- Fiber itself is immune to EMI & HPM
- No cable radiation
- Fiber provides tremendous bandwidth
  - Telecom wavelengths ≈ 193 THz (carrier frequency)
  - Telecom amplifiers allow aggregate bandwidth of several terabits on a single fiber
  - Individual telecom wavelength channels now carry 10 – 40 Gb/s
- Fiber carries high bandwidth signals with
  - Extremely low loss: ≈ 0.2 dB/km independent of signal rate or format
  - Extremely low distortion
- Fiber is "transparent" … and that allows WDM

  Transparency means:
  - Signals do not interact in the fiber (to first order)
  - Ability to carry signal does not depend on rate, format, polarization …

Some choices: multimode or single mode

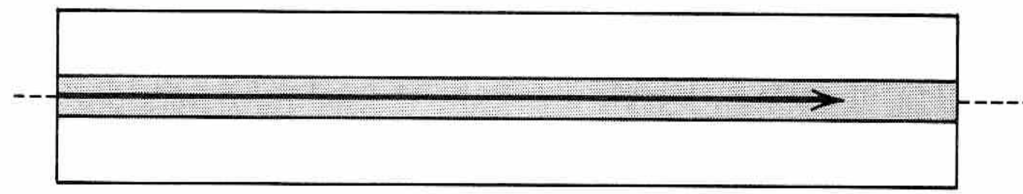
Multimode fiber guides many light rays

- Different arrival times of rays can distort optical pulses
- Used in short distances, low cost environments



Single mode fiber

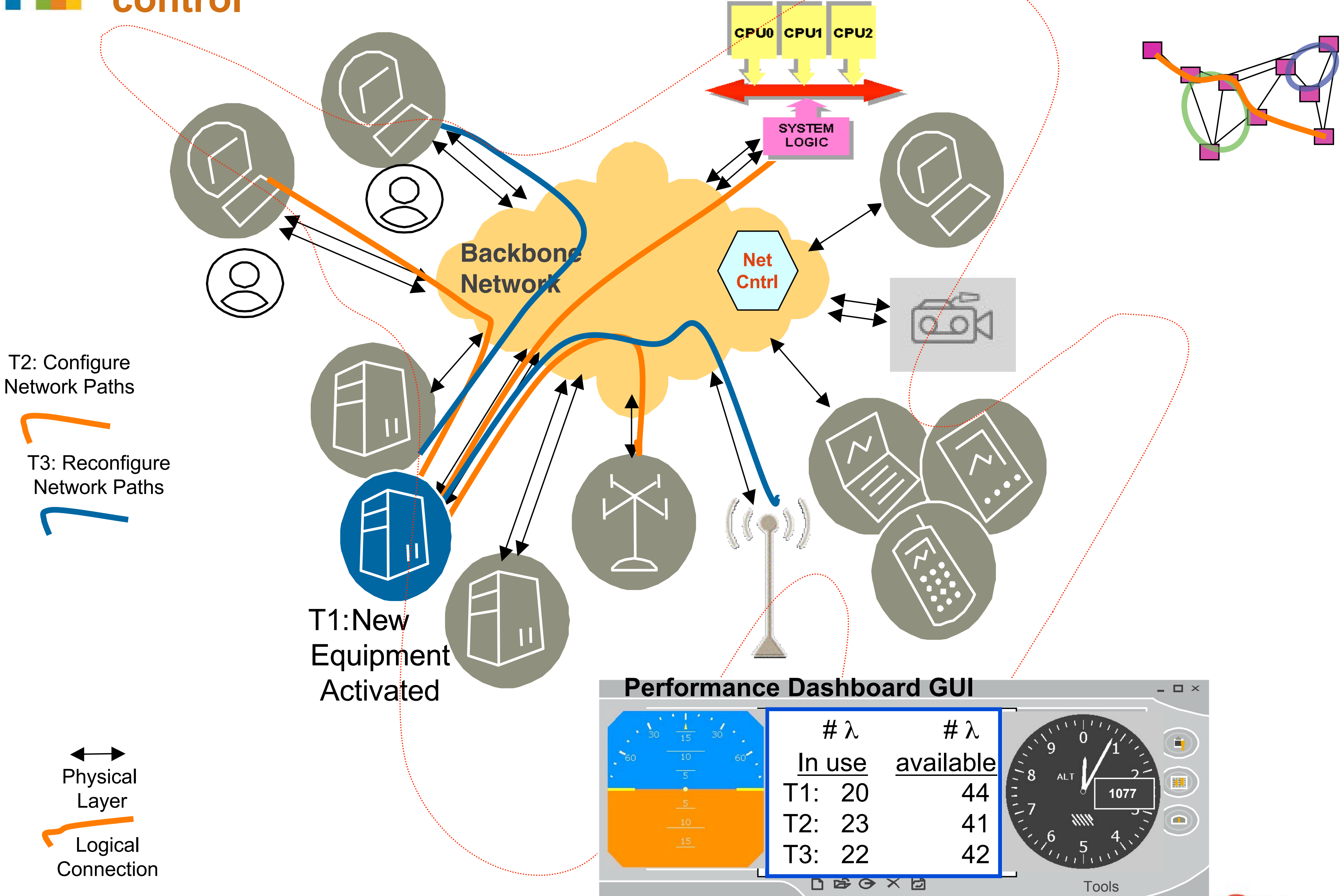
- highest quality transmission
- Used in high capacity, long haul lightwave systems
- Compatible with sophisticated optical processing and amplifiers



	Advantages	Disadvantages
Single mode	Huge upgrade potential, especially WDM and switching for networks; amplifiers are available	Standards needed for Connector designs suitable for avionics applications
Multimode	Cheap; easy to connect	Limited upgrade possible; amplifiers not usually available

Vision: Aircraft Backbone Network

Future Networking will require a novel infrastructure, access & control



Solution: Fiber-Optic WDM Network

WDM LAN as a managed network offers the potential to deliver networking advantages that can meet Aircraft application needs.

Expected Attributes:

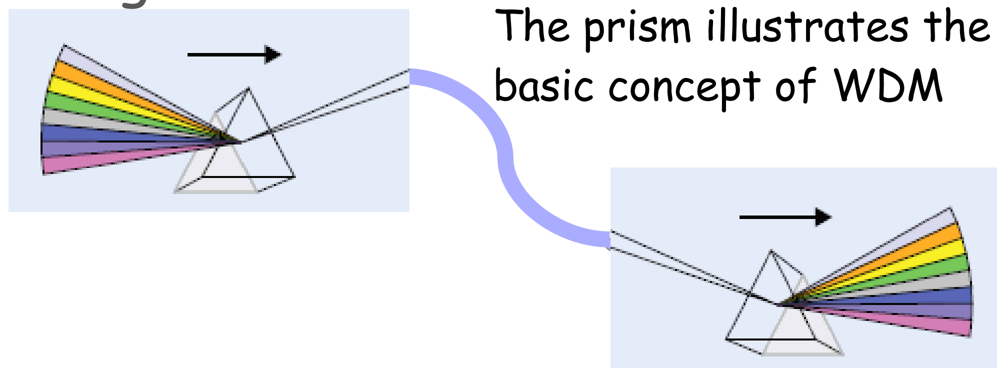
- **High Performance –** High capacity, low latency, dynamic networking with wavelength transparency, reconfigurability & improved EMI and HPM performance
- **Small size and low power:** replace multiple cables & reduce SWAP of aircraft networks using emerging integrated optical technology

  → achieved through use of optical fiber and WDM technology integration & miniaturization
- **Easy to support redundant networks:** Provide redundancy within the optical fiber infrastructure (wavelength layer) – minimal addition of optical fiber.
- **Reliable:** Passive WDM components and optical integration; reduce number of cables and connectors by migration to optical fiber infrastructure
- **Future Proof Migration Path:** Upgrade networks at end terminals (add nodes, components, wavelengths) without modifying the optical fiber infrastructure.

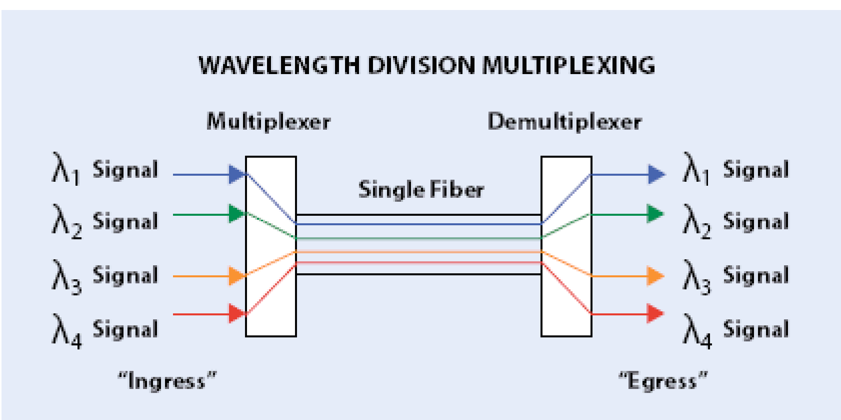
→ **Current practice requires high cost overhauls of cable plant that often prohibit network equipment upgrade; significant cost savings (life cycle cost) are expected by developing future-proof optical networks**

What WDM provides

- One fiber provides the capacity of many
- Channels do not interact, so a single fiber can support
  - Multiple formats
  - Multiple rates
  - Multiple levels of security



The prism illustrates the basic concept of WDM

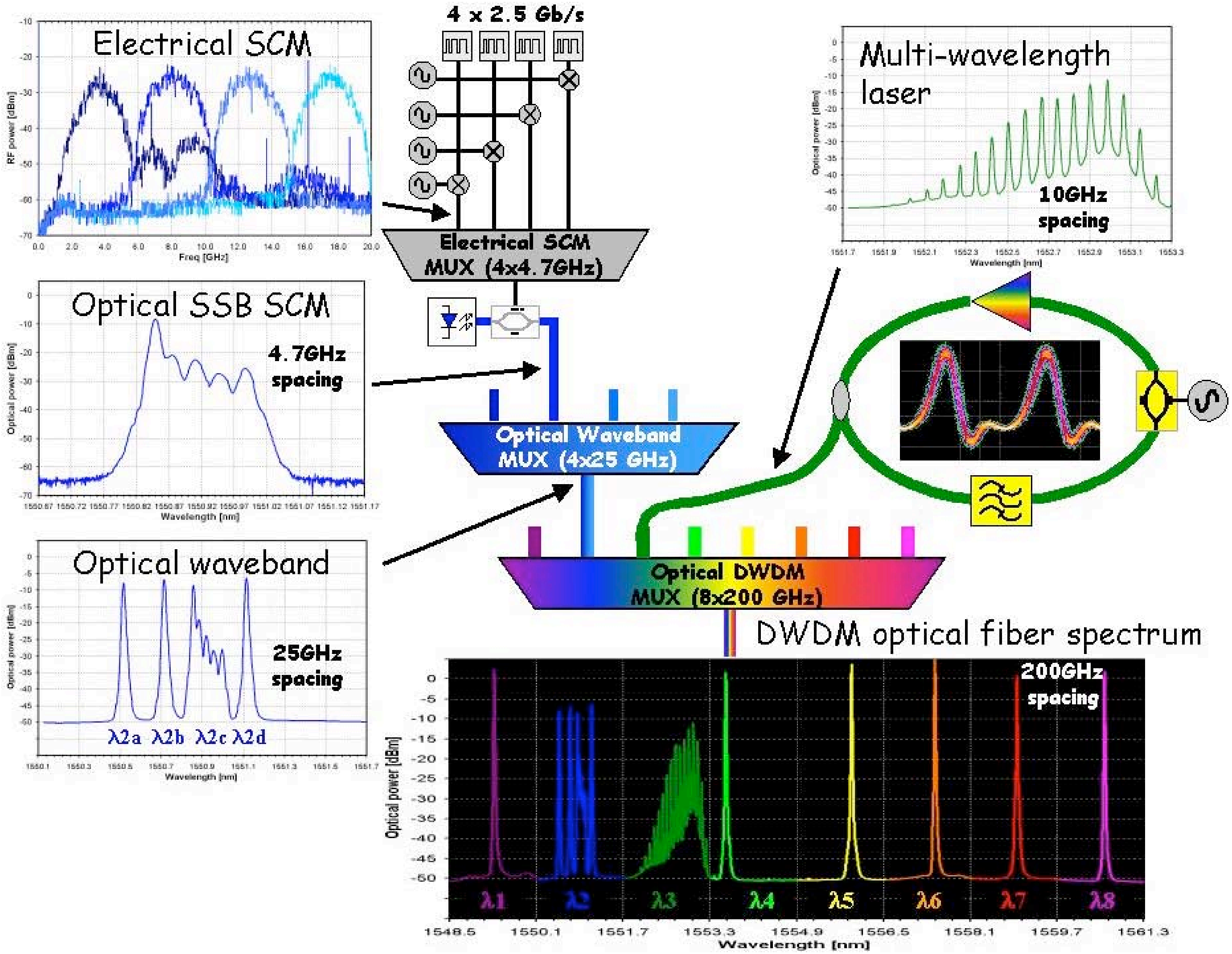


The multiplexer and demultiplexer are passive optical components. Single mode fiber has a larger choice of components with higher performance

A few – or many – wavelengths can use the same fiber.

For avionics: are the components compatible with the demanding environment?

WDM enables many ways to use the optical spectrum



WDM lets us break the huge capacity of fiber into manageable portions
Different applications can have their own dedicated wavelength(s).

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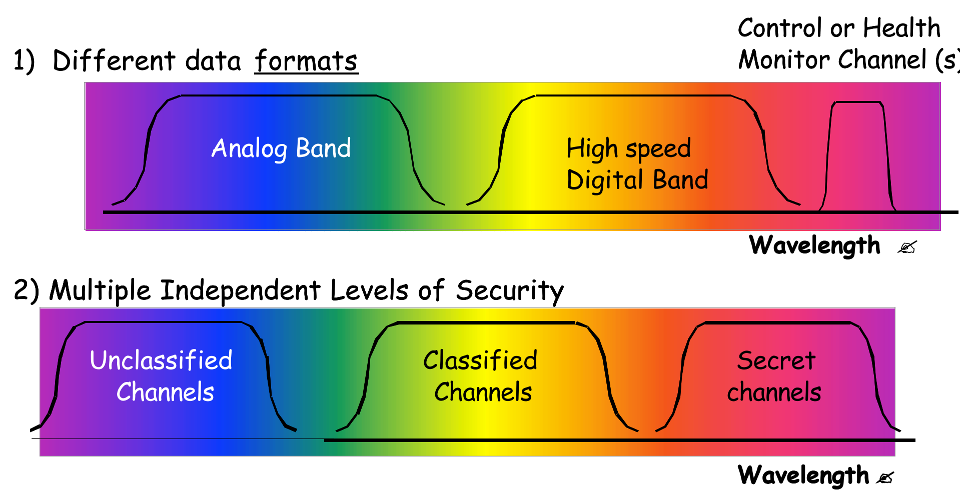
Advantages of Vision

The vision is to use a multi-purpose optical fiber backbone network on an aircraft as a foundation for a new high-capacity, transparent, robust, reconfigurable & secure avionics infrastructure.

Advantages include:

- Reduce physical layer connectivity complexity: Eliminate or reduce copper cable overlays (reduce weight) by using optical fiber
- Improve performance, fault management, redundancy, and reliability (integration)
- Potential to accommodate security (authentication & multiple levels of security) for multiple protocols as a network "service"
- Future proof: simplify capacity & connectivity upgrades to a common infrastructure, including support of legacy, analog and digital equipment



Project RONIA Summary (2006-2007)

RONIA: Requirements for Optical Networks In Avionics

- **DARPA Seed Project Results – RONIA documented data for tactical & widebody aircraft platforms for key networked subsystems**
  - CNI: Communication, Navigation and Identification
  - EW: Electronic Warfare
  - SMS: Stores Management Systems
  - VMS: Vehicle Management System
  - Mission Processing
  - Core Computing
  - Displays & Sensors

Categories A through F on following slide include these subsystems.

- **RONIA Seed project Data Sources**
  - Led by Telcordia: Collected and analyzed requirements obtained from system integrators
  - System integrators: Boeing and Lockheed Martin
  - End-user requirements provided by NAVAIR and AFRL
  - New applications from end users and DARPA
- **Miscellaneous Industry Inputs**
  - IEEE/AVFOP, Penn State Workshops, SAE Working Groups, STTR programs

Optical Layer Node & Bandwidth Requirements

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CORONIA RESULTS

High Capacity Systems (Estimate; unidirectional links) – Snapshot 2006/07

Application Category	Total # Nodes	Peak Bandwidth per link	Total # Links	Total Bandwidth
		Gb/s		Gb/s
A (5)	160	5	160	800
B (2)	68	2	264	528
E (4)	56	1	96	96
Total	**284**		520	**1424**

Aggregated Systems

Application Category	Total # Nodes (clusters)	Peak Bandwidth per link	Redundancy (Aggregated systems)	Total Bandwidth
		Gb/s		Gb/s
C (3)	36	1	4	12
D (1)	14	5	1	5
F (1)	30	1	2	2
Total	**80**			**19**

Total # Nodes: ~ 360 **Total bandwidth: ~1.440 Tb/s**

Capacity: Current and projected applications

- Aggregate capacity based on “current” data rates of current/legacy applications near 5 – 10 Gb/s
- Expected / projected capacity growth to 10 – 100 Gb/s; **drivers include:**
  - High speed analog and digital signal transmission (circuit & packet) to support aircrafts systems applications (video / sensors, weapons systems, core processing/computing)
  - Introduction of 1 and 2 Gb/s Fiber Channel or Fibre Channel over Ethernet (FCoE)
  - Projection for future: Plan for networks that support 10 to 100 fold increase in capacity → 100 Gb/s – 1 Tb/s

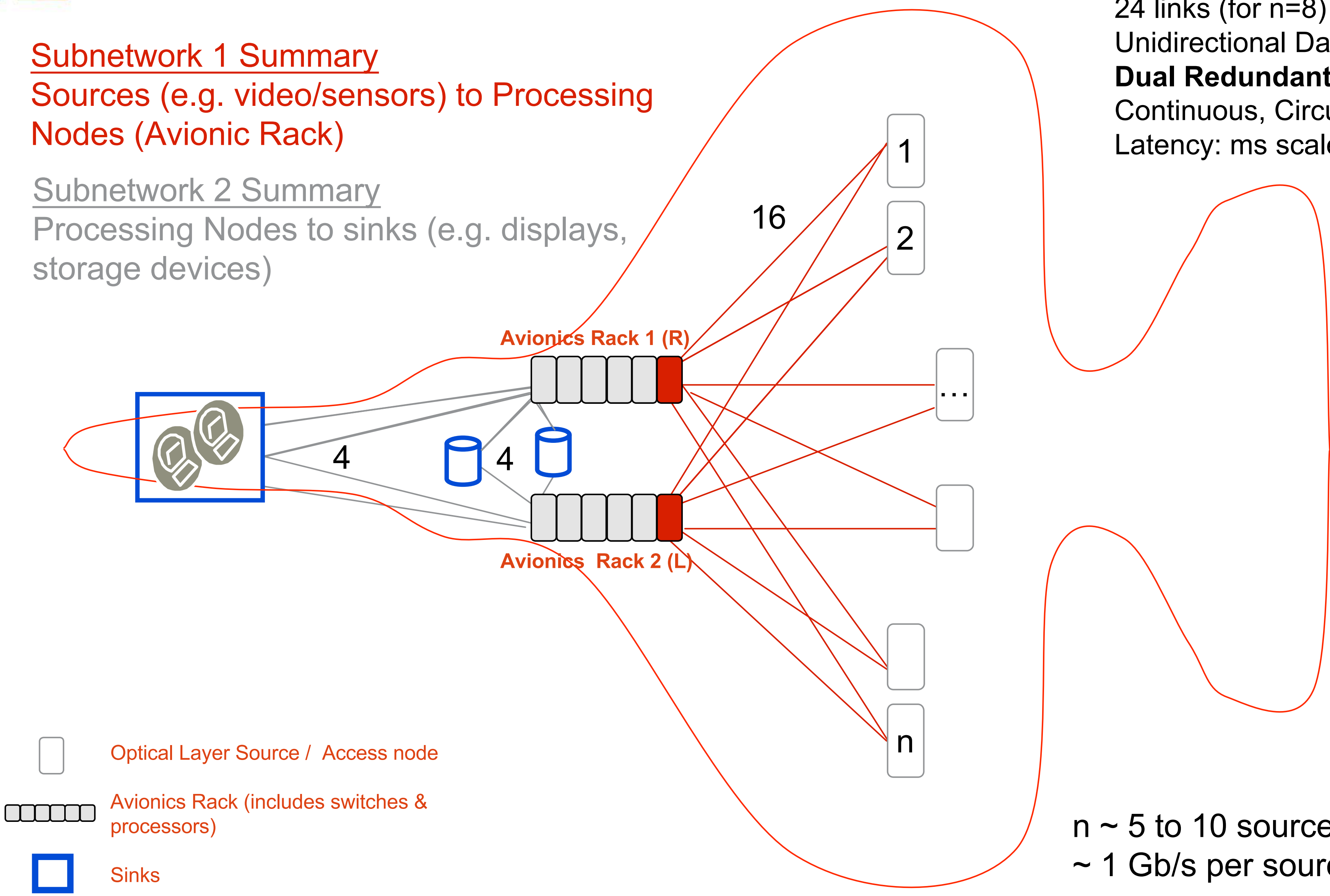
Representative Network Example

Functional Architecture

<u>Subnetwork 1 Summary</u>
Sources (e.g. video/sensors) to Processing Nodes (Avionic Rack)

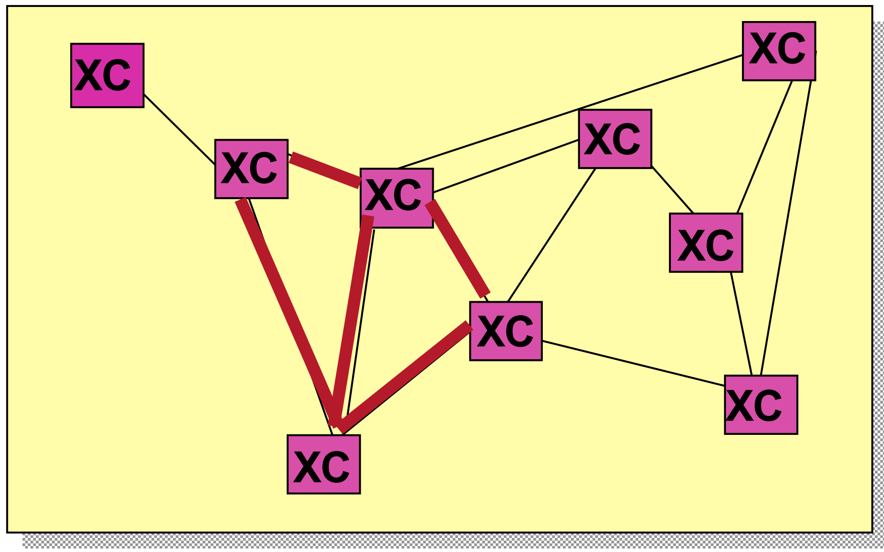
<u>Subnetwork 2 Summary</u>
Processing Nodes to sinks (e.g. displays, storage devices)

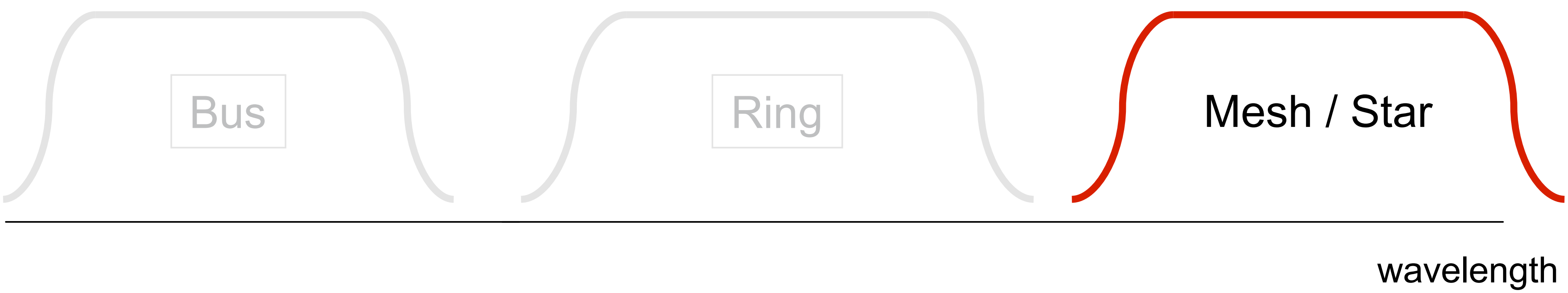
24 links (for n=8)
Unidirectional Dataflow
Dual Redundant
Continuous, Circuit Switched
Latency: ms scale



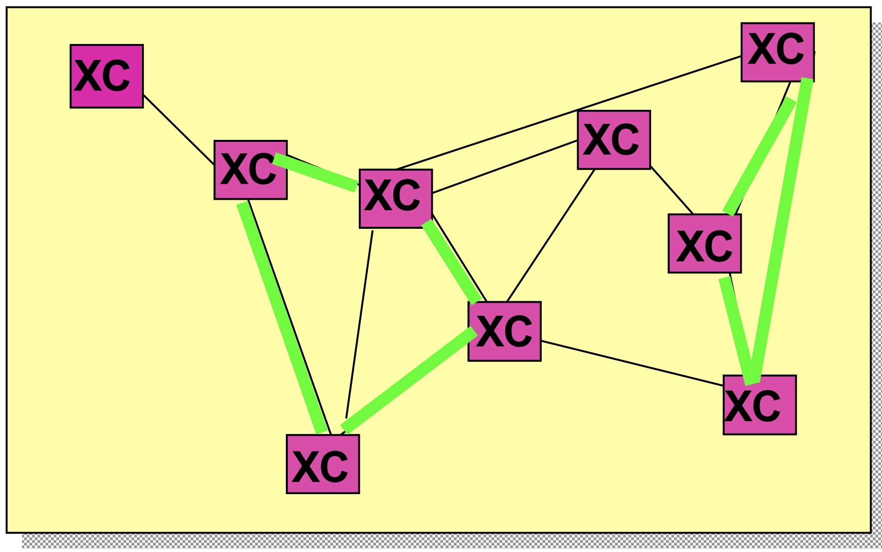
n ~ 5 to 10 source nodes
~ 1 Gb/s per source

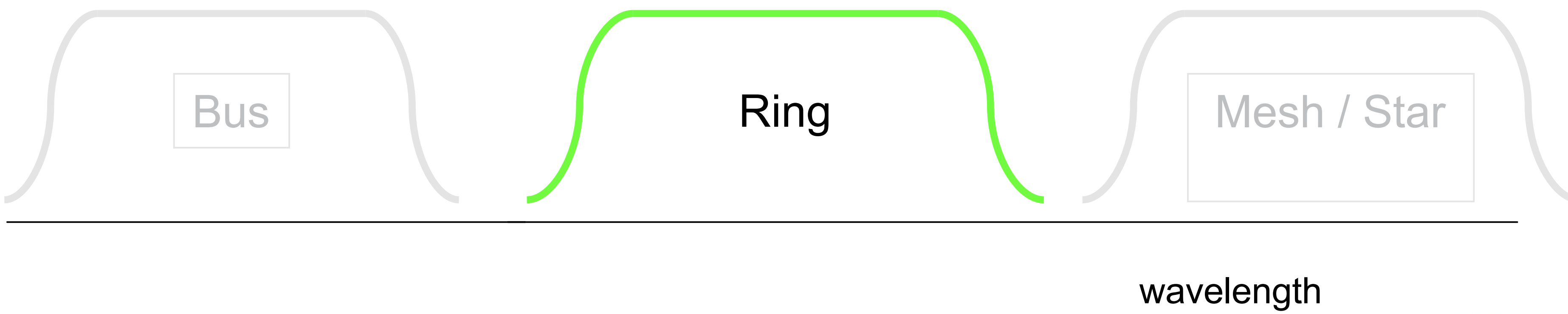
One can establish a mesh connecting a subset of the optical fiber backbone network nodes



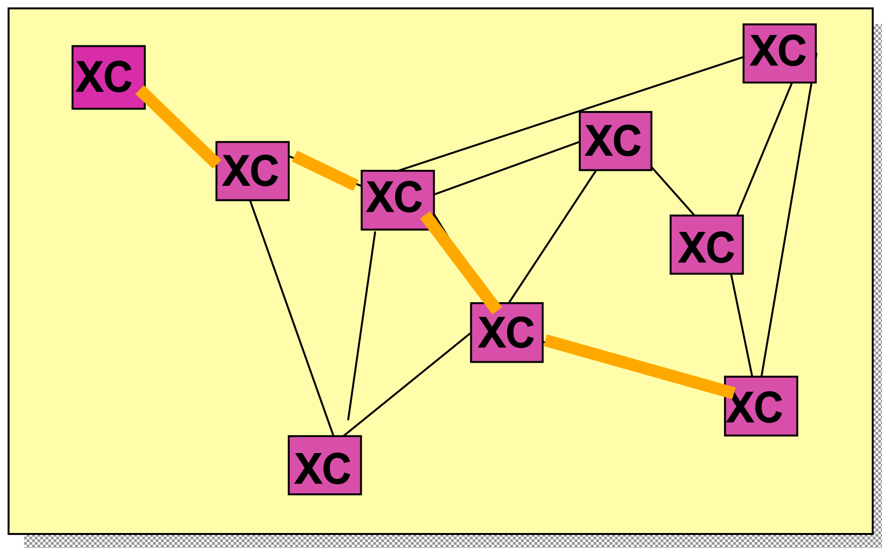


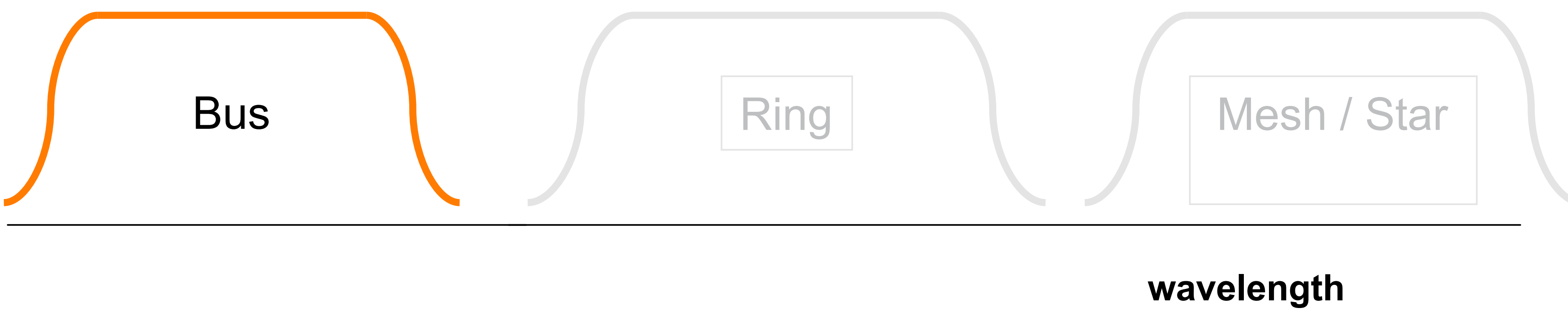
The backbone network nodes can support rings at the same time using another set of wavelengths



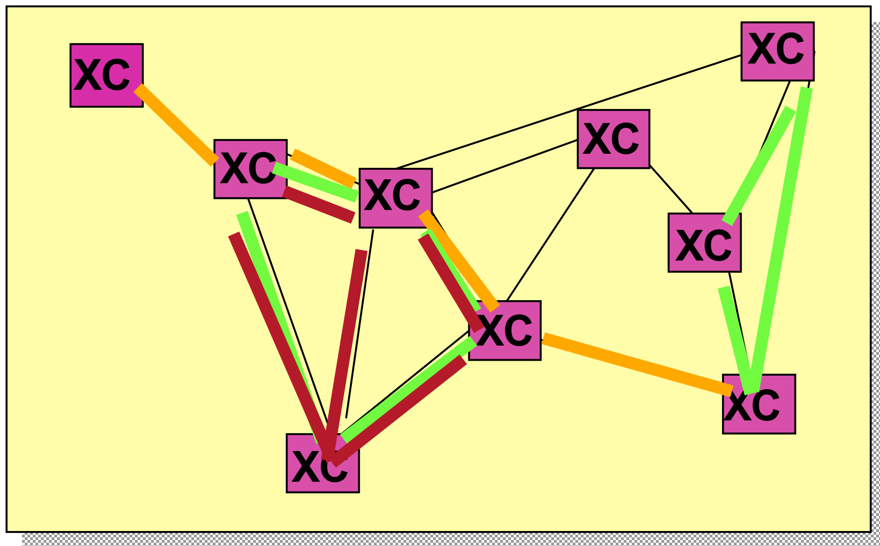


And a bus can be established, using another wavelength





All can exist at the same time, sharing the same fiber infrastructure, but not affecting each other



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Summary of Network Performance Objectives

- Nodes: ~ 400 (assuming some aggregation)
- Data Rate: 1 Gb/s or greater per node
- Links: > 500
- Capacity: ~ 1.4 Tb/s

Support 2 orders of magnitude increase in bandwidth compared to today's systems

- Latency: support multiple requirements in the same WDM infrastructure
- Redundancy: support multiple protection and restoration types in the same WDM infrastructure
- Connection type: support multiple connection types (e.g. random, bursty, continuous, circuit-switched and packet switched).

Design and implementation of an aircraft backbone network that meets the above objectives results in a future-proof infrastructure.

WDM Networks in Avionics

- **Technology advances needed to realize the benefits:**
  - Development of **networking architecture infrastructure** including standard interfaces (SAE is addressing requirements and specifications)
  - **Bend insensitive optical fiber; optical fiber connectors for aerospace environment (salt, fog, vibration, acceleration, temperature, humidity, …)**
  - **Optoelectronic components** with small footprint (integration) that can perform in and survive harsh mobile platforms and aerospace environments
  - Flexible Optical Infrastructure: wire once, upgrade network edge over lifetime of aircraft platform – **managed reconfigurable optical networks**

A managed WDM LAN infrastructure (optical backbone network) has the potential to be a viable technology solution. WDM LANs are being evaluated by industry participants and optical backbone networks are being standardized within SAE.

Evolution of Aircraft Backbone Networks

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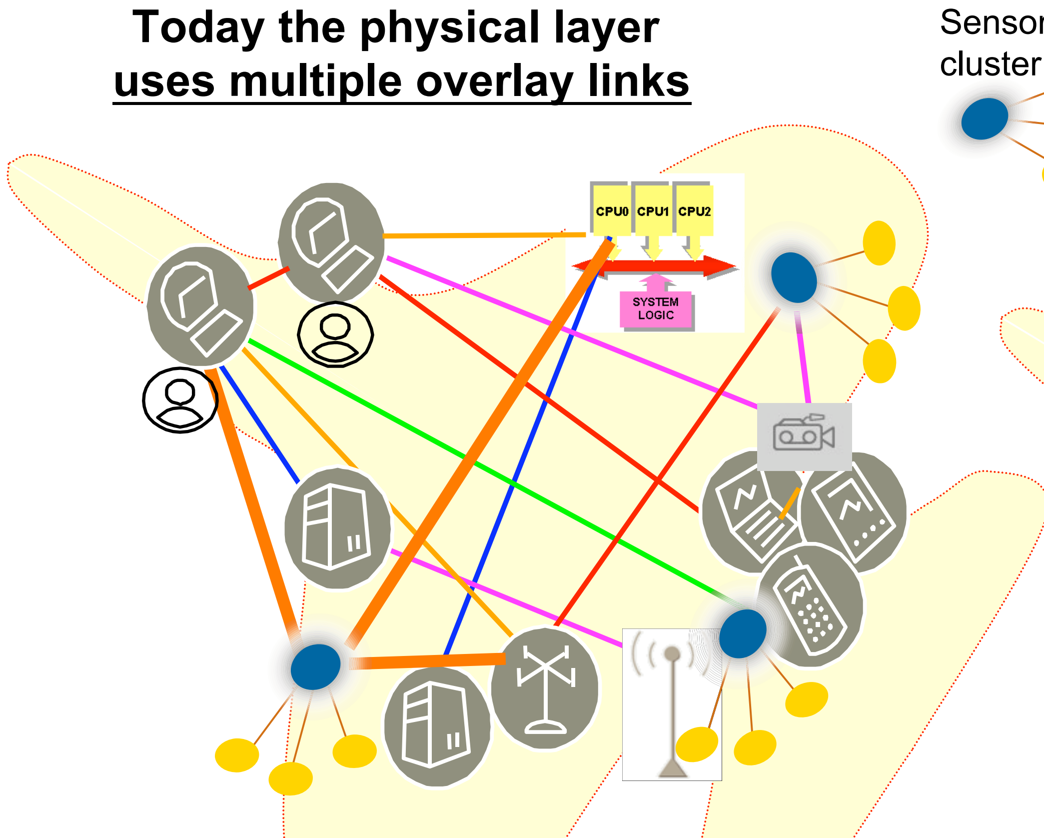
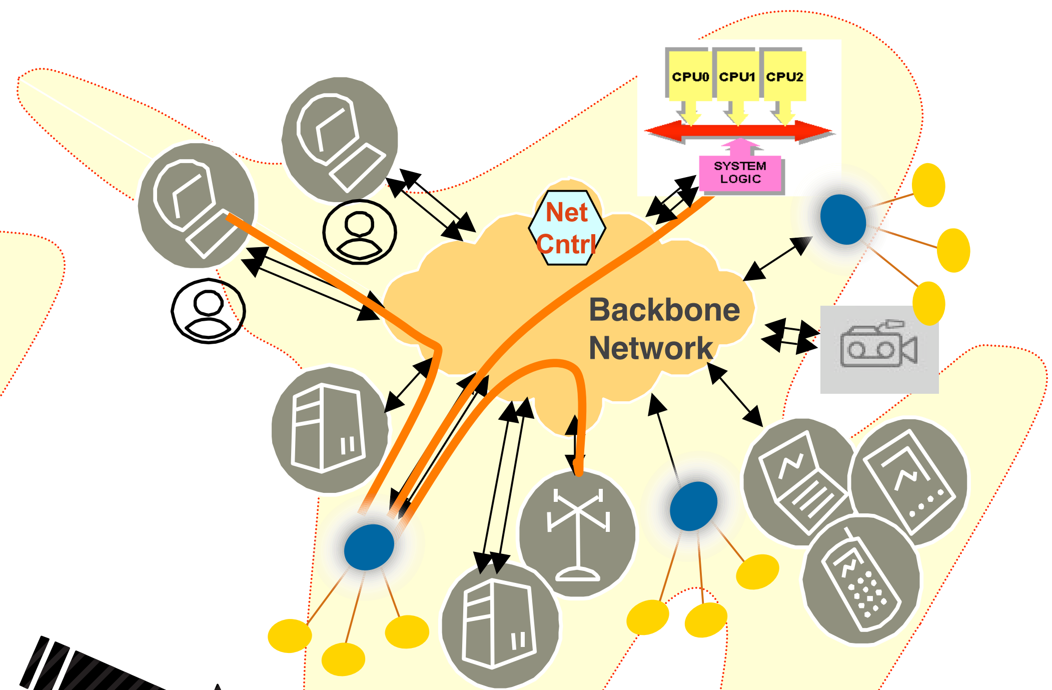
Today the physical layer uses multiple overlay links



Adding new equipment requires physical changes to cable or bus infrastructure

Vision: Aircraft Backbone Network

Networking requires novel infrastructure, access and controls



Adding new equipment is simplified via **standard interface** to a **managed** optical backbone network

Future Proof Networks: upgrade backbone cable (to fiber) and equipment; support new applications (e.g. new wireless sensors and sensor clusters) without costly changes to backbone infrastructure

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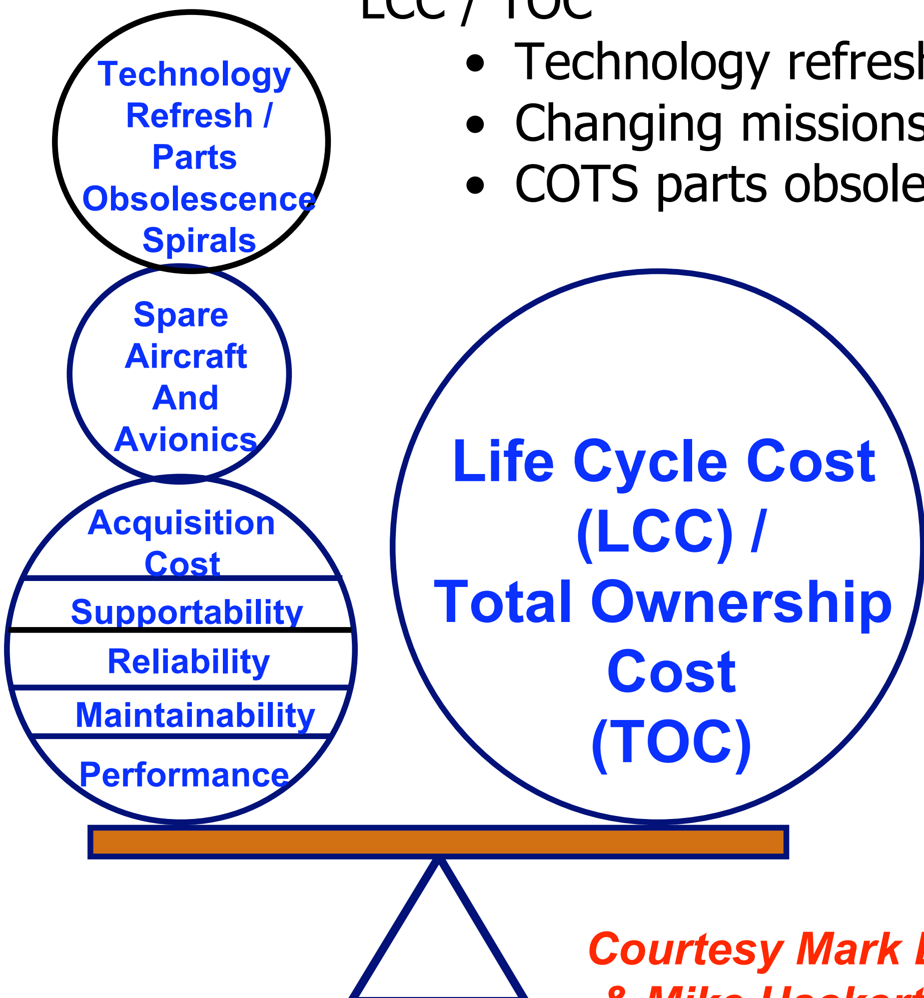
Economics: another barrier to overcome – requires fundamental change in infrastructure supporting aircraft system

Unavoidable upgrades increase LCC / TOC

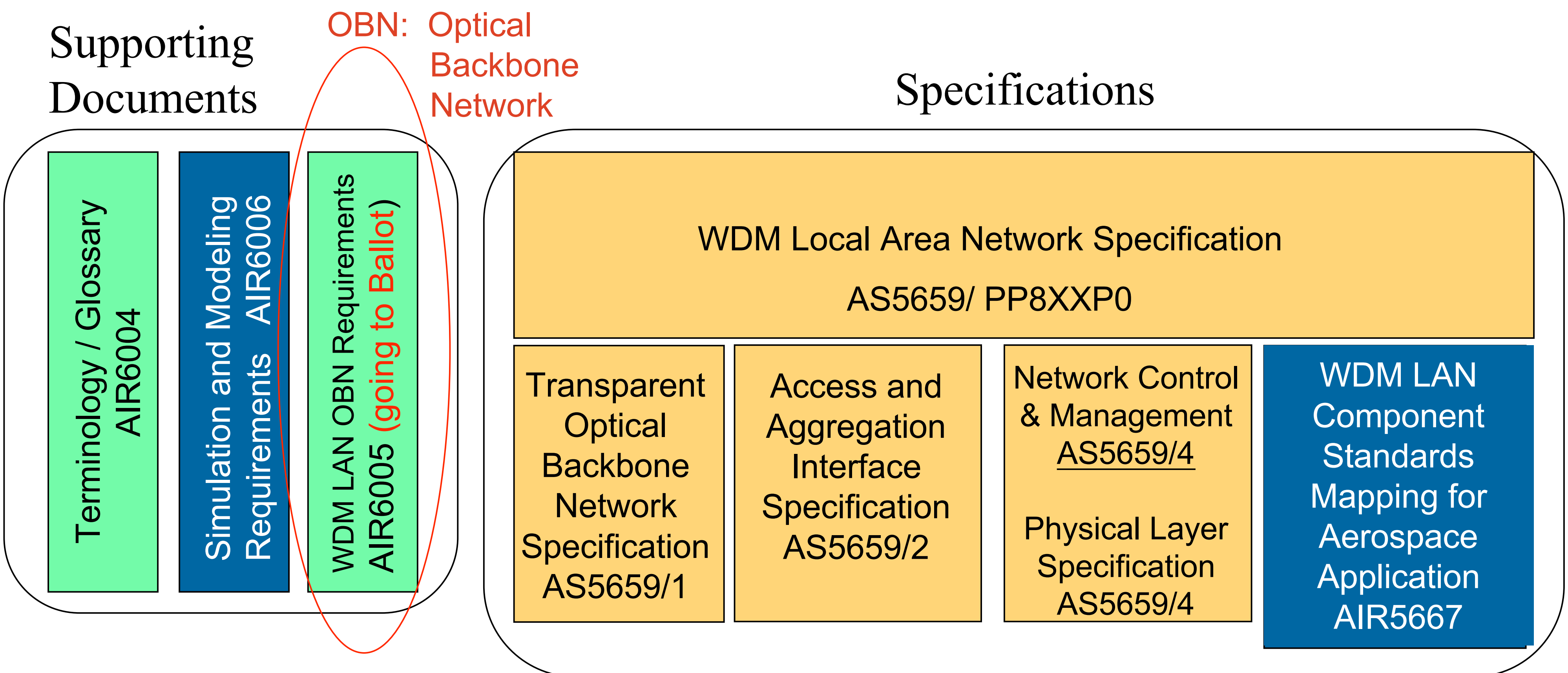
- Technology refresh
- Changing missions
- COTS parts obsolescence



Courtesy Mark Beranek & Mike Hackert, NAVAIR

- The US military has made substantial investment to enable solutions that can survive in the aerospace environment as well as reduce weight, space, and cost.
- Left unchecked, multiple, non-interoperable, proprietary optical network solutions will be developed. **The objective of an aerospace WDM LAN standard** is to define the minimum set of hardware functions and networking protocols necessary at each network node to allow the set up and establishment of connections to the network
- **Fiber optics is a key enabler for a WDM LAN.**

WDM LAN Documentation Tree



Planned document

Document in Progress

Completed document

AIR: Aerospace Information Report
ARP: Aerospace Recommended Practice
ARD: Aerospace Resource Document (limited time
AS: Aerospace Standard

WDM LAN OBN Standards Progress

- OBN Requirements document (AIR6005) and AIR6004 currently being prepared for Approval / publication
  (Ballot passed in Mar. 09)
- Over 60 OBN network interface and network management requirements defined
- Established Terminology and Templates for upcoming specifications documents

Participants: ... from 2007 - 2009 Meetings

- Boeing
- Defense Photonics Group
- L3 Communications
- Lockheed Martin
- APIC
- AIRBUS
- Oxsensis
- Mendez R&D Associates
- OptoNet Inc.
- Penn State Electro-Optics Center
- RSoft
- University of Florida
- USCB
- Rockwell Collins
- Accipiter Systems
- BAE Systems
- NAVAIR
- Northup Grumman
- Telcordia Technologies

→ Next Semi-annual meeting, Nov. 11-12, Seattle WA

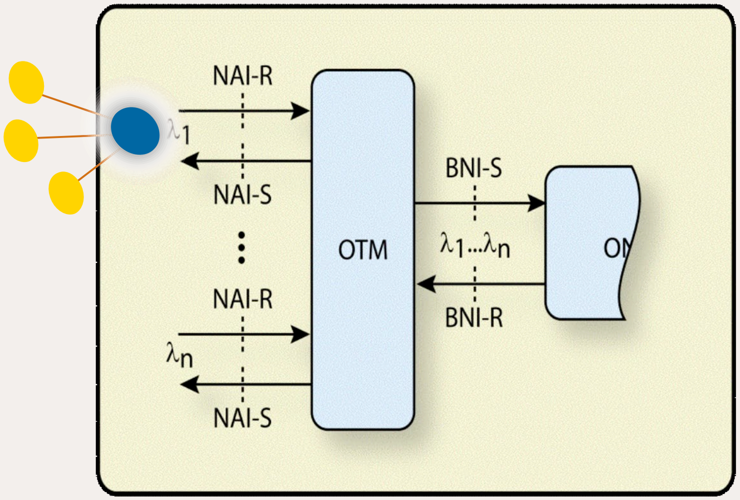
Key Requirements

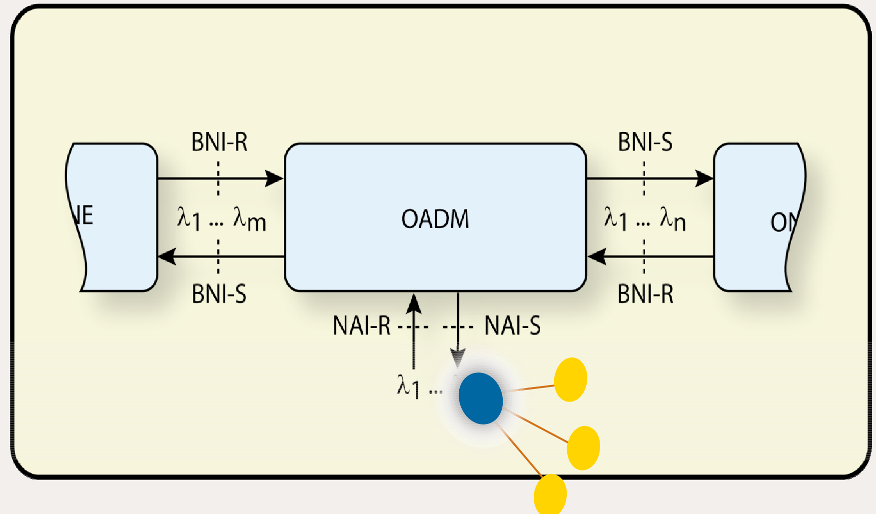
- Interfaces
  - ✓ BNI, NAI
  - ✓ Network management interfaces
- OBN: Optical Network Elements and Optical Fiber Interconnects
  - ✓ NAE: OADM, OTM, OXC, OPS
  - ✓ OLA, OFI
- Interface Application Codes
  - ✓ Templates for OBN performance
  - ✓ Wavelength Allocation
- Network Management and Control
  - ✓ 4 levels
  - ✓ Optical Supervisory Channel
  - ✓ Alarms Conditions → Redundancy / Protection

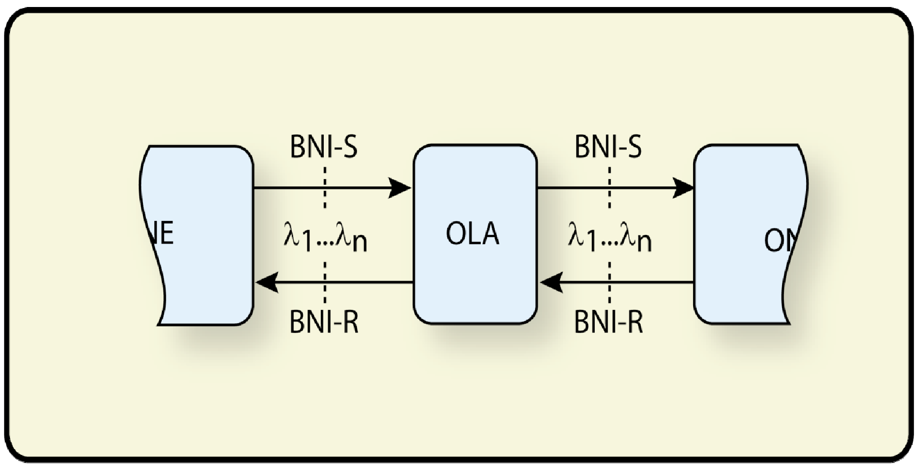
SAE Standards:

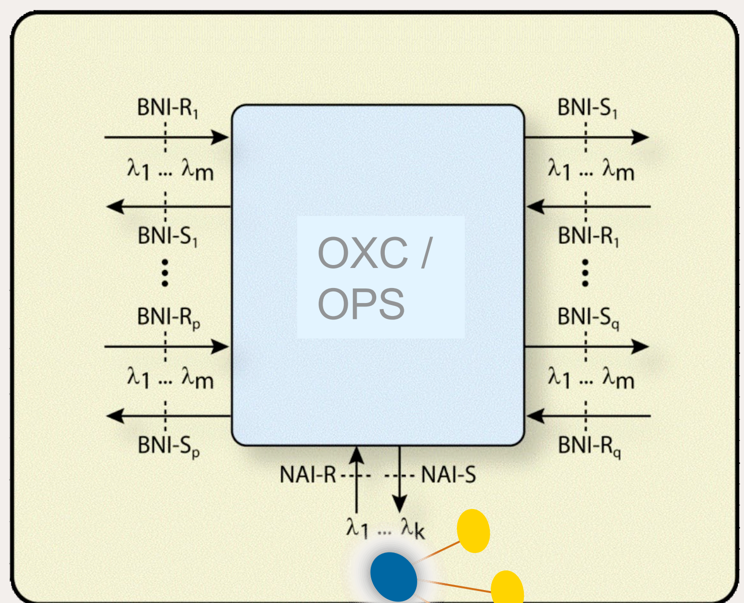
Defined WDM LAN Optical Network Elements

NAE: Network Access Elements









ONE: Optical Network Elements
BNI: Backbone Network Interface
NAI: Network Access Interface

OTM: Optical Terminal Multiplexer
OADM: Optical Add-Drop Multiplexer
OXC: Optical Crossconnect, **OPS:** Optical Power Splitter
OLA: Optical Line Amplifier

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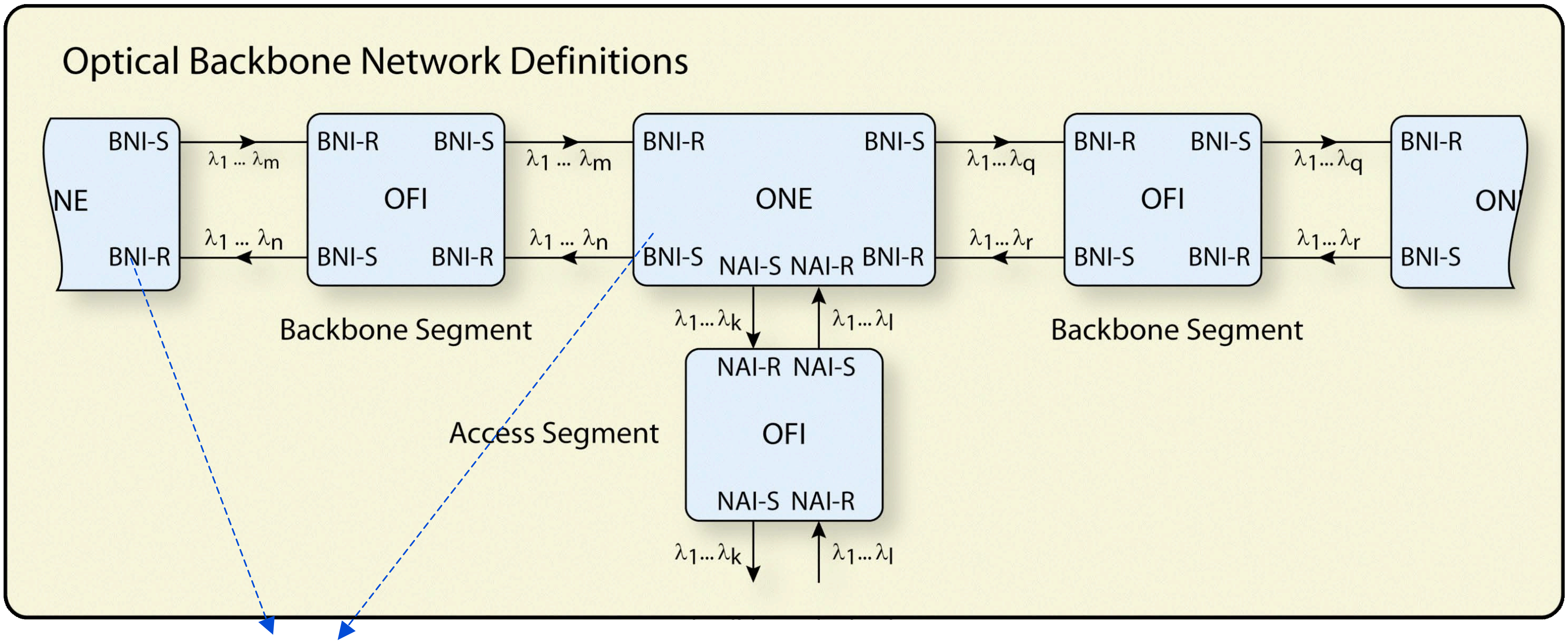
ONE, OFI, NAI and BNI Definition



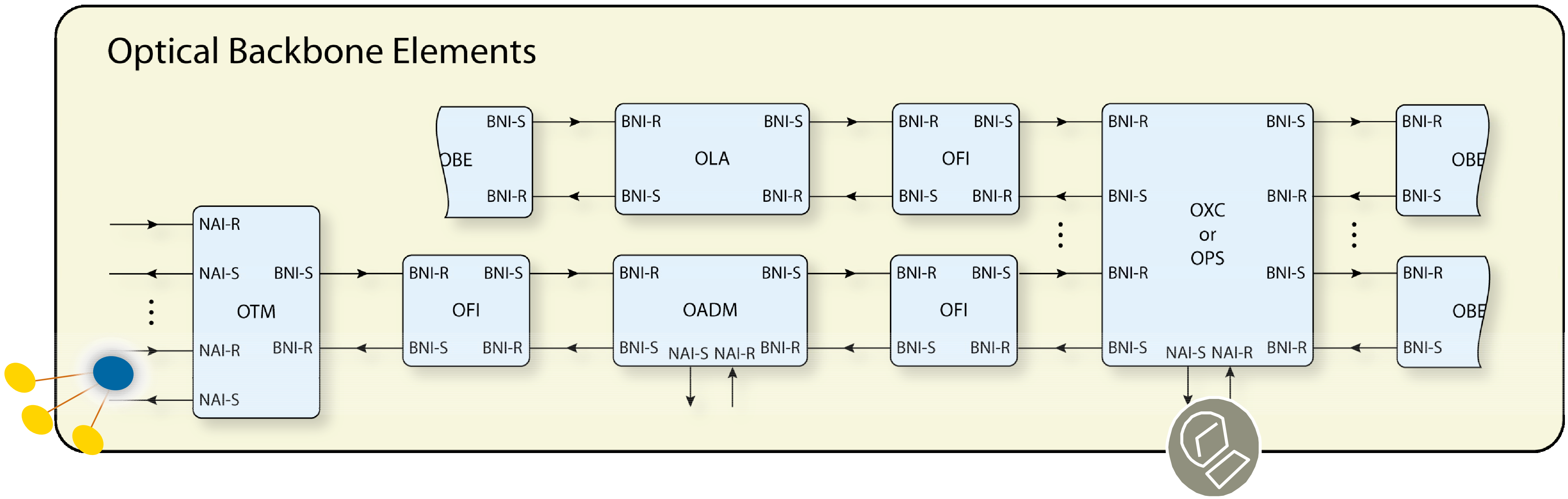
ONE include

Network Access Elements: OADM, OTM, OPS, OXC

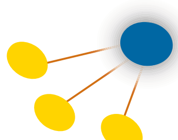
Optical Amplifier: OLA

OFI: Optical Fiber Interconnects

Optical Backbone Elements:
ONE and OFI in an Optical Backbone Network (OBN)



Representative Data source:
Sensor Network



Requirements:
→SAE is standardizing BNI, NAI definition as well as performance requirements across any of the WDM LAN Optical Network Elements (ONEs);
→ONEs can be reconfigurable to allow updates, protection

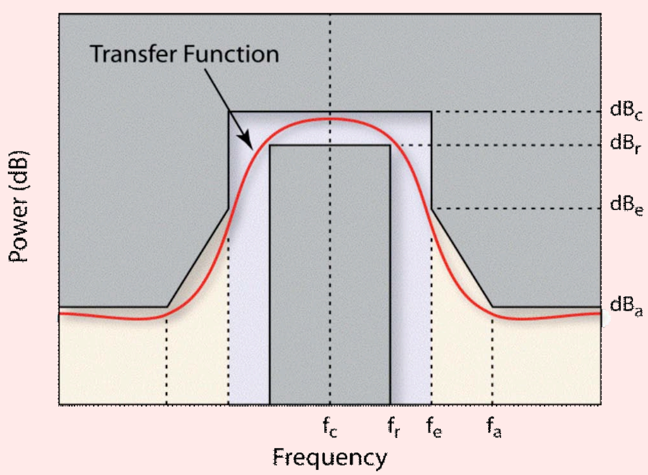
Representative Data Sink:
Display system

Examples of WDM LAN OBN Interfaces

ONE Transfer Function

Parameter	Min	Typ	Max	Units
Number of Channels	1		X	
Channel Spacing		X		GHz
f_c : Center frequency of first channel…(assumes channels are centered on ITU grid)		X		THz
dB_c : Attenuation at f_c	X			dB
f_r : Rolloff frequency relative to f_c		X		GHz
dB_r : Attenuation at f_r			X	dB
f_e : Channel Edge frequency relative to f_c		X		GHz
dB_e : Attenuation at f_e	X			dB
f_a : Adjacent frequency relative to f_c		X		GHz
dB_a: Attenuation at f_a	X			dB
Chromatic Dispersion		ffs		
Dispersion slope		ffs		
Noise Figure at f_c (See Note A)			X	dB
Noise Figure Tilt			X	dB/THz
Dispersion (ffs) - PMD - PDL				
Return Loss			X	dB

NAI / BNI Transfer function template (from Table 5.2 and Figure 5.2)
Table 5.3 defines BNI and NAI interface parameters



Network Control performs real-time control functions. Unlike Network Management, Network Control is autonomous: independent of human intervention. The WDM LAN is spanned by Network Control. Network control is performed either in-band, or out-of-band through the Optical Supervisory Channel (interface)

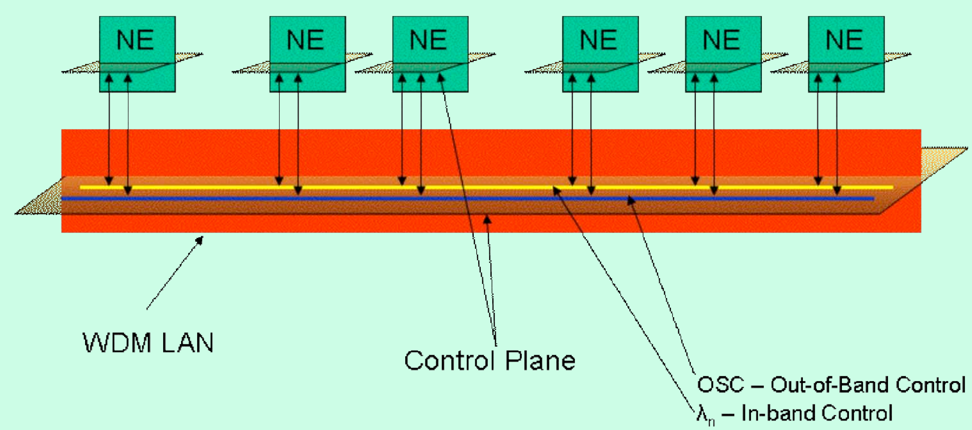


Figure 7.1

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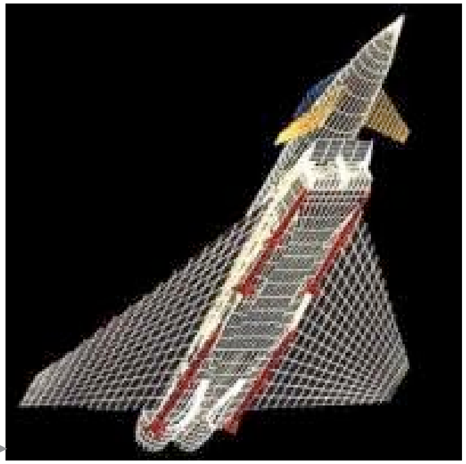
SAE Seville & Indianapolis Meeting Participants

April 2008 & April 2009 SAE AS-3C2 – Fiber Optics Sensors Task Group

- FOS-S: Belgium
  - Dimitri Saerens
  - Technology for fibre optic sensors for In-Flight Aircraft Structural Analysis http://www.fos-s.be/projectsadv/be-en/0/detail/item/10/cat/1

- Oxsensis: UK
  - david.gahan@oxsensis.com
  - http://www.oxsensis.com/
  - Optical instrumentation for precision controls in super harsh environments (car/aero engines, industrial, electrical & space applications)
- SmartFibres: UK
  - Michael Dockney
  - http://www.smartfibres.com/Aerospace.htm
  - Applications include: Health and Usage Monitoring System (HUMS)



Aircraft Backbone Network Summary

We propose to use a fiber optic WDM-based network for avionics systems to overcome current practice limitations identified; WDM can help achieve future generation avionics networks that are high capacity, transparent, flexible, scalable, future-proof, secure and low cost.

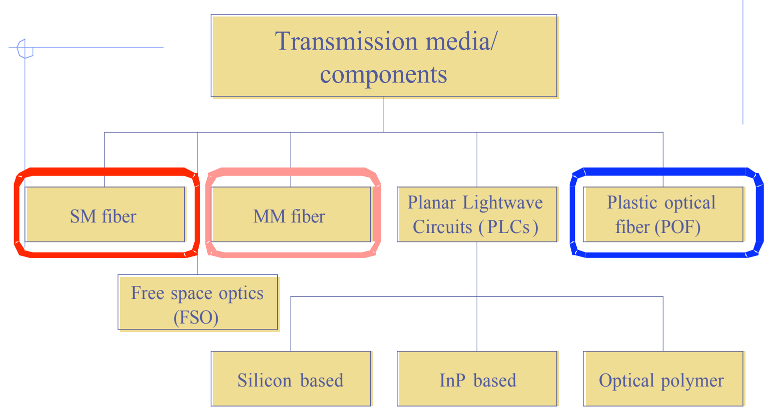
However, there are several challenges that need to be investigated:

- **Cost** associated with addition of a WDM layer; reduce cost through advances in technology (**fiber, WDM examples**) performance and integration
- **Size**; address through optical fiber use and component integration & miniaturization
- **Flexibility and scalability**, need WDM components that enable reconfigurability (e.g. tunable lasers, large scale low loss passive optical devices, ROADMS, optical switches) to support a future-proof infrastructure
- **Reliability**; design components that can achieve enhanced requirements associated with harsh avionics environment
- **Network Definition;** develop architectures, Protocols, Algorithms, Control and Management associated with insertion of WDM-based backbone layer
- **Security**; design WDM networks that cost-effectively support redundancy requirements and multiple independent levels of security (enable MLS policy enforcement)

Components for WDM networks are evolving rapidly

Some Technology Choices

- Choice of components
  - Filters: for local insertion of individual wavelengths
  - Grating-like structures: for multiplexing where many wavelengths are added/dropped in the same place
- Choice of optical fiber



- Dense or coarse WDM?
  - Coarse WDM costs less; dense gives more bandwidth & flexibility
  - Upgrades are always possible, and
  - One can always nest one level of wavelength selection inside another.

AIRCRAFT "WIRED" INFRASTRUCTURE – MEDIA CHOICES & IMPLICATIONS

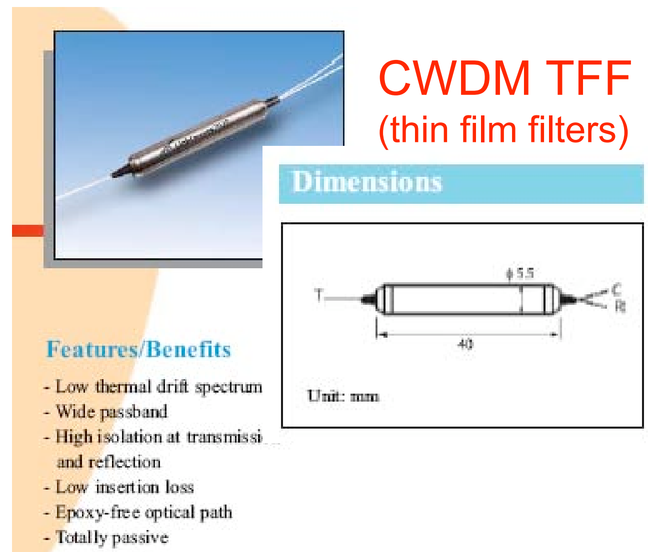
Media	Advantages	Disadvantages
Copper	Present mode of operation; Cheap; easy to connect; Copper CAT-7 offers lower weight and higher bandwidths	Limited capacity upgrade possible; weight restrictions: low weight cables have larger loss 30 to 45 g/m compared to ~4 g/m optical solutions
Multimode Fiber (MMF)	Cheap; easy to connect	Limited capacity upgrade possible; component complexity for WDM; difficult to integrated optoelectronic components compared to SMF
50 – 62.5 μm core	Can scale to multi-gigabit links (e.g ribbon cable)	Modal dispersion introduces severe penalties for some data types
0.5 – 1 mm core POF	Higher bend radius; simpler splicing and connection	Limited support of WDM, uses 650 - 800 nm wavelengths; environmental range
Single Mode Fiber (SMF)	Huge upgrade potential, with support for WDM and Millimeter wave over fiber; telecom grade components available	Connector design to be standardized for avionics applications, improved versions in progress; reliability and maintenance being investigated for avionics

Single Mode vs. Multi-Mode for WDM Applications

Glass optical fiber options include SM and MM fiber; qualifications for selecting use of MM or SM include:

- Many feature-rich components (COTS) and integrated components being developed for telecom applications are geared for SM applications
- Potential WDM options with MM are limited to systems with fewer wavelengths than SM (MM has limited ability to support fine-grained DWDM)
- Difficult to support MM amplified systems if amplifiers are needed to overcome connector and/or WDM network component losses.
- Hard to support desired bandwidth density and signal formats (e.g. for analog applications) in MM fiber.
- MM not as future proof as SM – may be able to support transport of signals over MM fiber, but limited in the types of devices and systems that can be interconnected over MM links.
- MM and SM systems can use similar laser and modulators; however many fiber types and amplifiers are designed for SM systems.

www.lightwaves2020.com



<u>SMF and MMF network components include:</u>
Laser, Modulator, Receiver/Detector, Amplifier(optional), Filter/Combiner including *CWDM components*
→ While SM components are more costly, DWDM and SM devices are likely to achieve lower size and weight through integration vs MM and/or CWDM devices. SM devices typically support a wider range of functionality and are widely available, leveraging telecom applications – generally easy to find desired functionality in existing components.

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Connectors for Aircraft Optical Fiber Networks

Performance characteristics for MC5 optical fiber connector from Deutsch.
The MC 5 is the standard multiway fibre optic connector for the European Fighter Aircraft, Typhoon

OPTICAL PERFORMANCE	
Insertion loss:	0.25dB typical
Return loss:	0.40dB typical
Repeatability:	better than 0.1dB
ENVIRONMENTAL SPECIFICATION	
Temperature shock/cycling:	-65° to +150°C
High temperature endurance:	+150°C, 760 hrs
Low temperature endurance:	-65°C, 500 hrs
Vibration:	Sinusoidal; 5-3000Hz, 40g, 10 hrs
	Random; 25-2000Hz, 5g2/Hz (50grms), 16 hrs
Mechanical endurance:	>1500 mating cycles

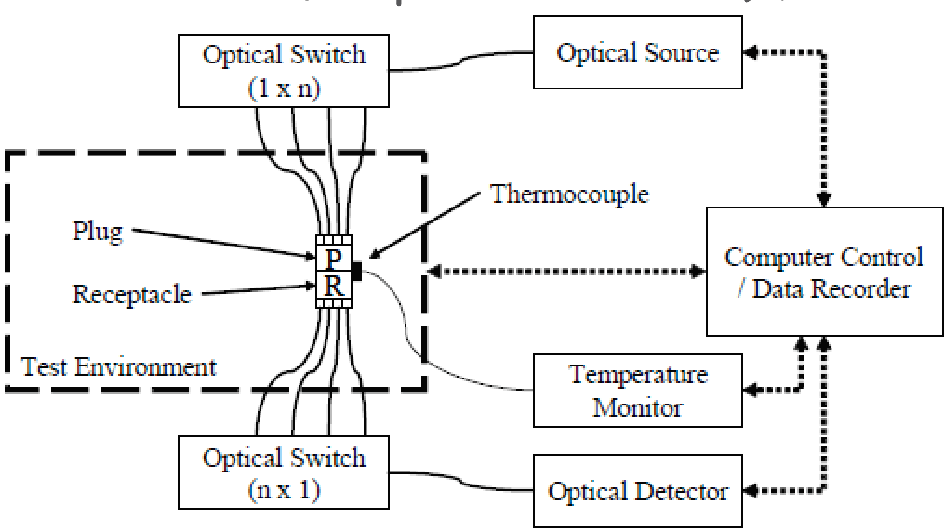
Source: Deutsch MC 5 Data Sheet

Deutsch MC 5 connectors

Connectors for Aircraft Optical Fiber Networks

- **Key Challenge**: Commercial Fiber Optic Connectors designed for operation in benign environments
- Recent industry progress in meeting Avionics grade environmental needs
  - Environmental aspects that are addressed include vibration, shock, temperature, humidity, sand/dust, and mechanical endurance
    - e.g. Souriau (ELIO termini connectors – prototype under development for SM), Deutsch (MC 5 connectors), Radiall

Setup for evaluating connector temperature sensitivity



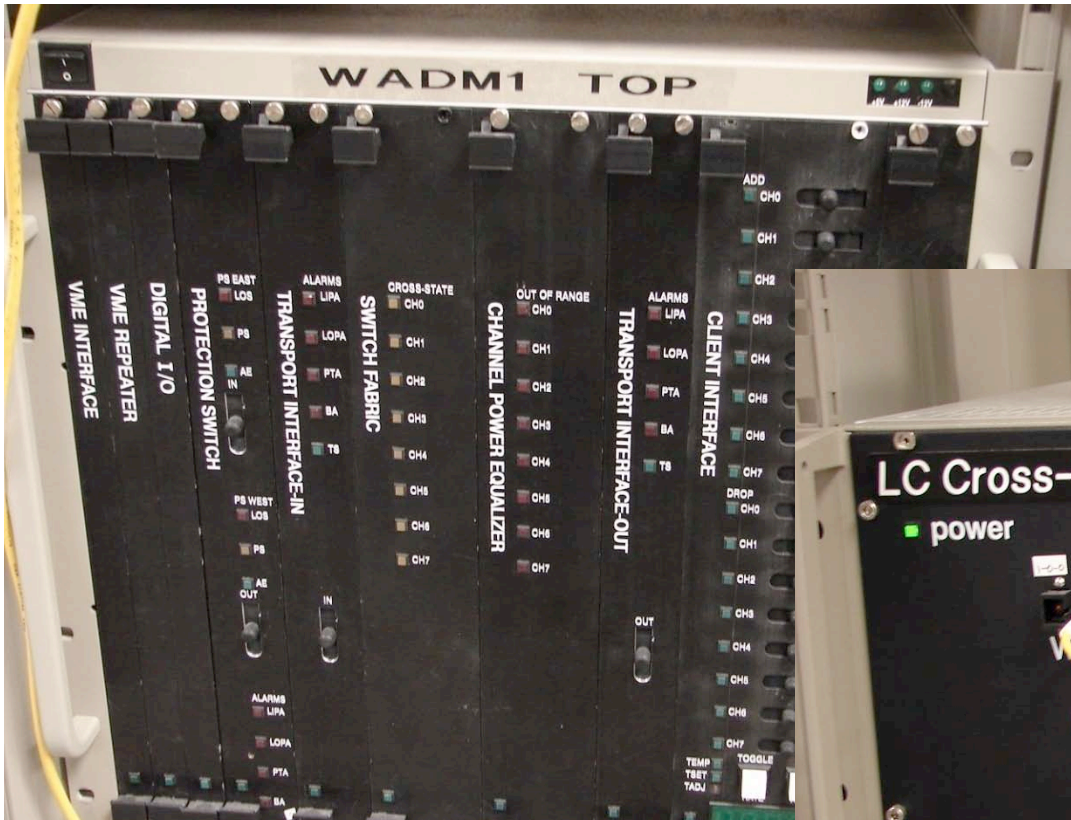
Parameter	Minimum for Consideration	Goal
Optical Loss	< 2 dB	< 1 dB
Return Loss	> 30 dB	> 45 dB
Cleaning	minimal	none
Pathways	4	> 8
Type	single mode	-
Wavelength	ITU C-band	-

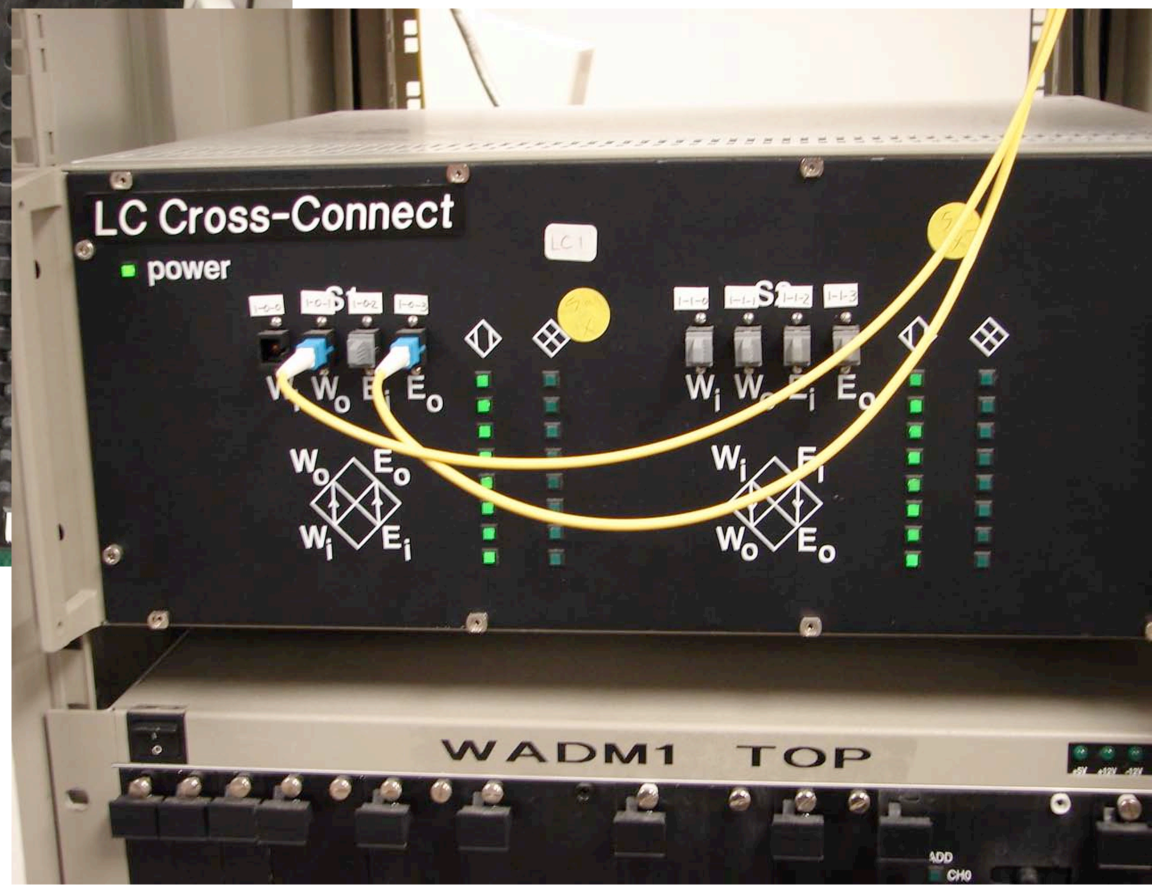
Source: Evaluation of Optical Connectors for Consideration in Military Avionics
Brian L. Uhlhorn, et. al., Lockheed Martin; IEEE/AVFOP 2005 Conference Proceedings

Fiber Splicing for Avionics Fiber Networks

- **Key Challenge**: Maintenance procedures for fiber optic cable in harsh avionics environments require simple techniques for fiber splicing and repair
- Developing mechanic fiber optic splicing technology for Avionics environments
  - Agiltron: PermLock ™ FiberOptic Mechanical Splice
  - All Optronics: "Rugged Connect"
    - mechanical fiber optic cable splice for rapid and permanent restoration of severed multimode or single mode fiber optic cables
- Connector positioning can have significant impact on fiber breaks and reliability
  - Fiber plant design to position connectors for ease of physical access
  - Positioning connectors close to equipment termination (high % of fiber breaks within 1-2 m of equipment termination)

WDM selective crossconnects – an historical view



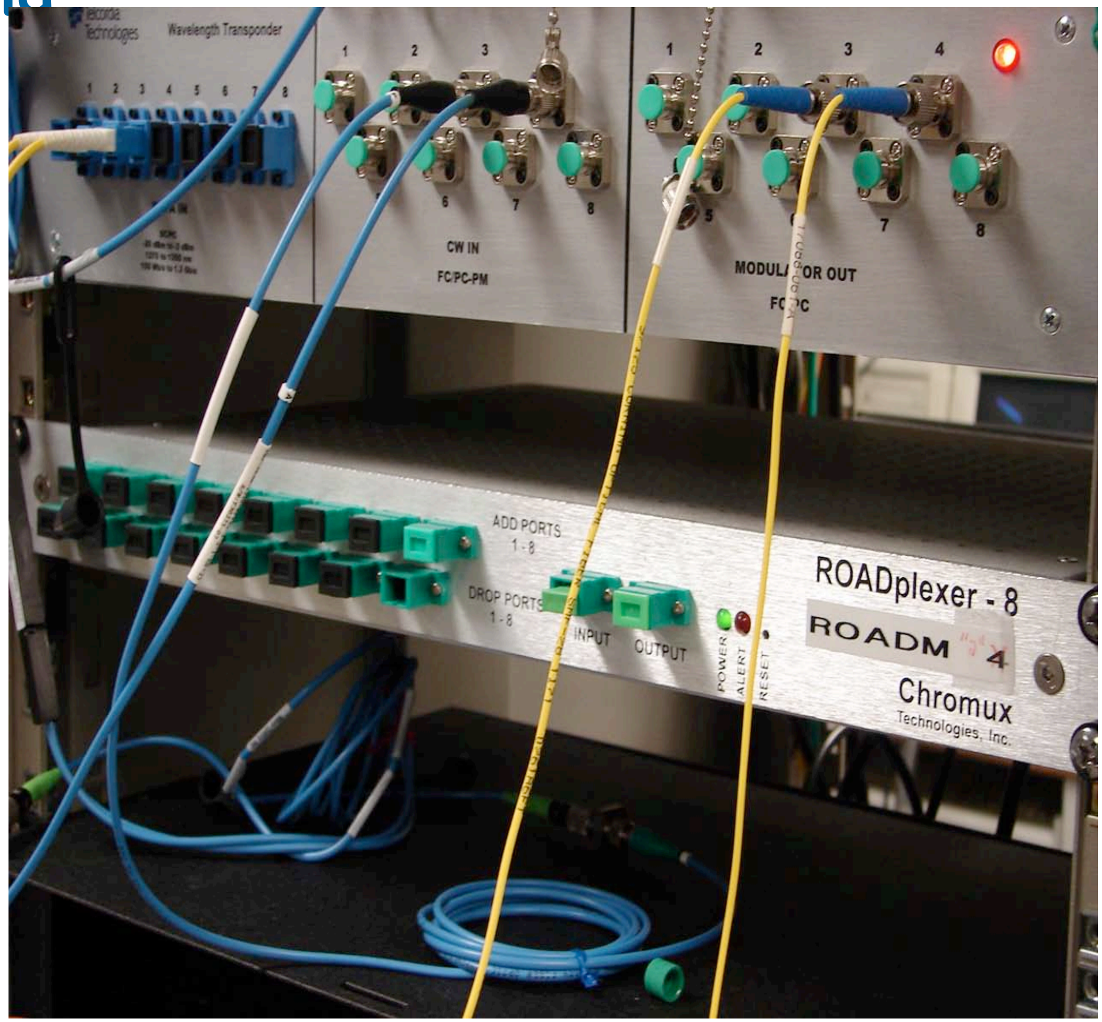


Experimental WDM cross connects built by Telcordia

Mid 1990s vintage

More recent Reconfigurable Optical Add Drop Multiplexer – a few years old

WDM switch



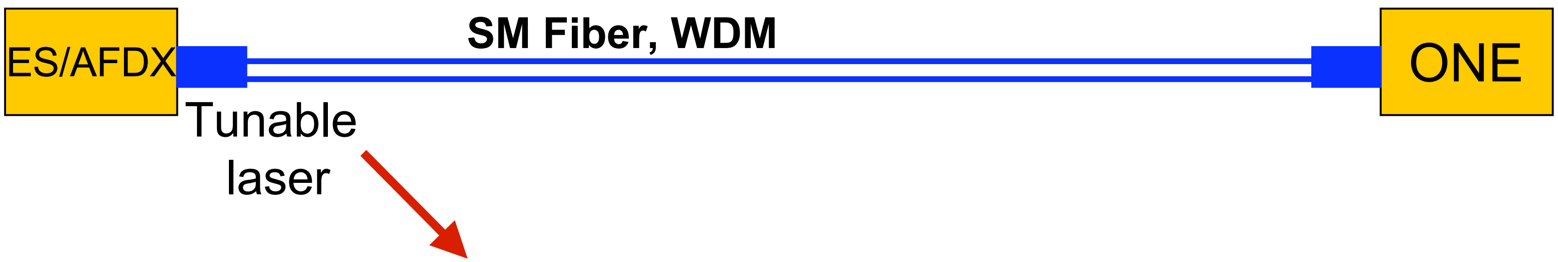
This kind of equipment is evolving quickly

Components are getting smaller

WDM amplifier

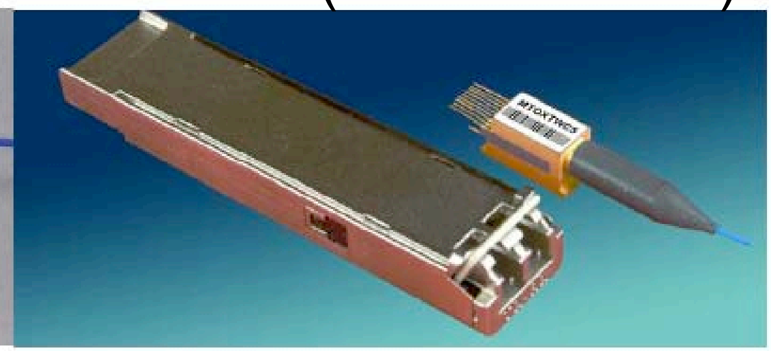
Telcordia

Wavelength agile transceiver



TRL 9 (Telecom)

TRL 5/6 (miniaturization)



Available Today

with Proven Performance

prototype

Multiplex

Photonics for Communications

Prototypes reported in IEEE AVFOP Conference paper based on results from Highly Integrated Photonics program

“Monolithically Integrated Tunable Laser Transmitters for WDM Avionics System”, K. Y. Liou, IEEE AVFOP 2008 Conference Proceedings, San Diego, CA

Avionics needs …

- Small/light components
- Low power requirements
- High reliability
- Network architectures that provide
  - Upgrade capability
  - Flexibility
  - Provision to support security
  - Redundancy, for protection/survivability
- Software for managing the networks.

Telcordia / Telecom experience can help the avionics industry to take advantage of this technology

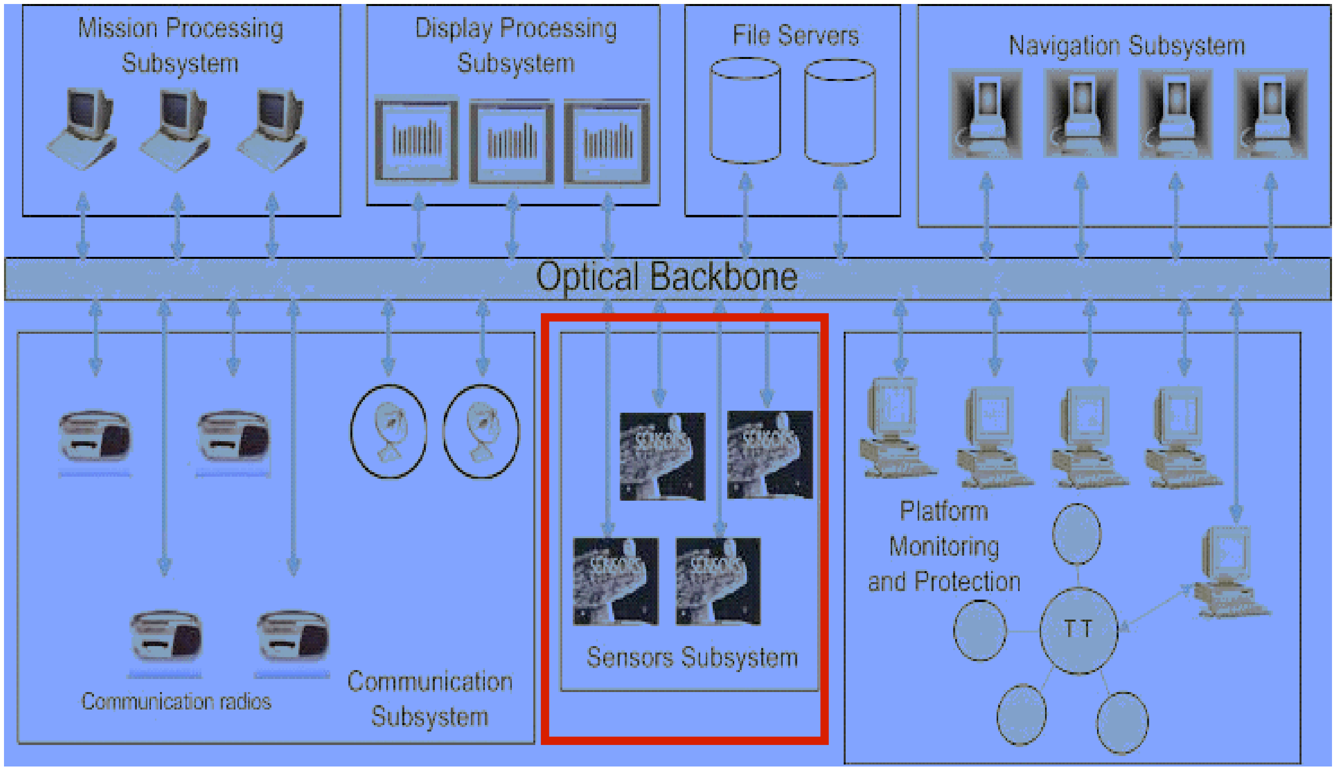
Benefits of Optical Fiber and WDM Networks in Avionics

Optical Fiber transmission media enables WDM LAN for:

- **Compact, lightweight** networking: *Weight reduction is a key decision driver*
- Support a variety of signal rates and protocols; **transparency** to applications – support legacy systems, and emerging applications (some of which require at least order of magnitude bandwidth growth in the network)
- **Capacity:** Accommodate large channel counts, connectivity, and aggregate **bandwidth**
- **Performance –** Improved EMI, HIRF and HPM susceptibility
- **Security** – support Multiple Independent Levels of Security (MILS)

Back-up slides

Optical Network Example – Commercial / military platforms



Representative Subsystems
- Navigation
- Mission Processing
- Platform Monitoring
- Communications
- **Sensors**
- File Servers
- Displays

From: "Virtual Prototyping of WDM Avionics Networks" Presentation by
Casey B. Reardon, Ian A. Troxel, and Alan D. George
HCS Research Laboratory, University of Florida;
September 2005,
IEEE AVFOP conference

Fiber Splicing for Avionics Fiber Networks

Agiltron

Performance Specifications

Fiber Optic Mechanical Splice	Typical	Unit
Insertion Loss	< 0.1	dB
Return Loss	< 40	dB
Cable Diameter	1.8, 2.2, 3.0	mm
Splice Dimension	< Φ 4.2 x 40	mm
Operating Temperature	-40 ~ 120	°C
Pull Strength	10	LB
Fiber Types	SM / MM	

http://www.algiltron.com

Data sheets for mechanical fiber-optic splicers

All Optronics

SPECIFICATIONS* (PRELIMINARY)

PARAMETER	SPECIFICATION (PRELIMINARY)
DIMENSIONS	6 mm diameter x 60 mm length
OPERATING TEMPERATURE	-40°C to +120°C
OPTICAL INSERTION LOSS	< 1.0 dB (during or after exposure to the environmental conditions specified below)
ENVIRONMENT	
HIGH TEMPERATURE LIFE	1,000 hours at 150°C (MIL-STD-1344)
TEMPERATURE SHOCK	-55°C to +125°C; 7 cycles (MIL-STD-810F)
TEMPERATURE-ALTITUDE CYCLING	-40°C to +125°C at 10°C/minute; sea level to 70,000 feet; 1,000 cycles
HUMIDITY-TEMPERATURE CYCLING	98% relative humidity and 65 °C temperature cycling with -10°C and -54°C sub-cycles (Tailored MIL-STD-1344)
SALT SPRAY	96 hours (MIL-STD-810F)
PULL-TWIST	Pull with 10 lbs weight, twist -180° to +180°, 10 cycles; at -40°C, +25°C, and +50°C (Tailored EIA-455-36A)
MECHANICAL SHOCK	Half Sine, 300 G peak, 3 ms duration, 3 axes 6 directions (Tailored MIL-STD-1344)
VIBRATION	25 to 2,000 Hz overall rms Gmin (44.8); 3 axes, 8 hours per axis (Tailored MIL-STD-1344 and MIL-DTL-38999K)

* The environmental specifications were developed by NAVAIR with military joint service effort, ensuring multiservice applicability. All Optronics prototype samples have been tested and passed these requirements.

http://www.alloptronics.com

Latency & Redundancy

Latency Summary

- Connection latency includes circuit set-up in circuit-switched applications (~10 ms) & routing/processing latency for packet-switched applications (several μsec)
- Transport latency: propagation delay, correlated to aircraft size is minimal on airplanes (1 μs or less). We assume 100 ns for tactical and 1 μs for widebody.
- Need to account for additional latency associated with the insertion of an optical network to support avionics systems. (→ Define latency budget contributors)
- Also analyze tradeoffs – e.g. compare optical connection setup time vs packet switching queuing/processing

Redundancy Summary

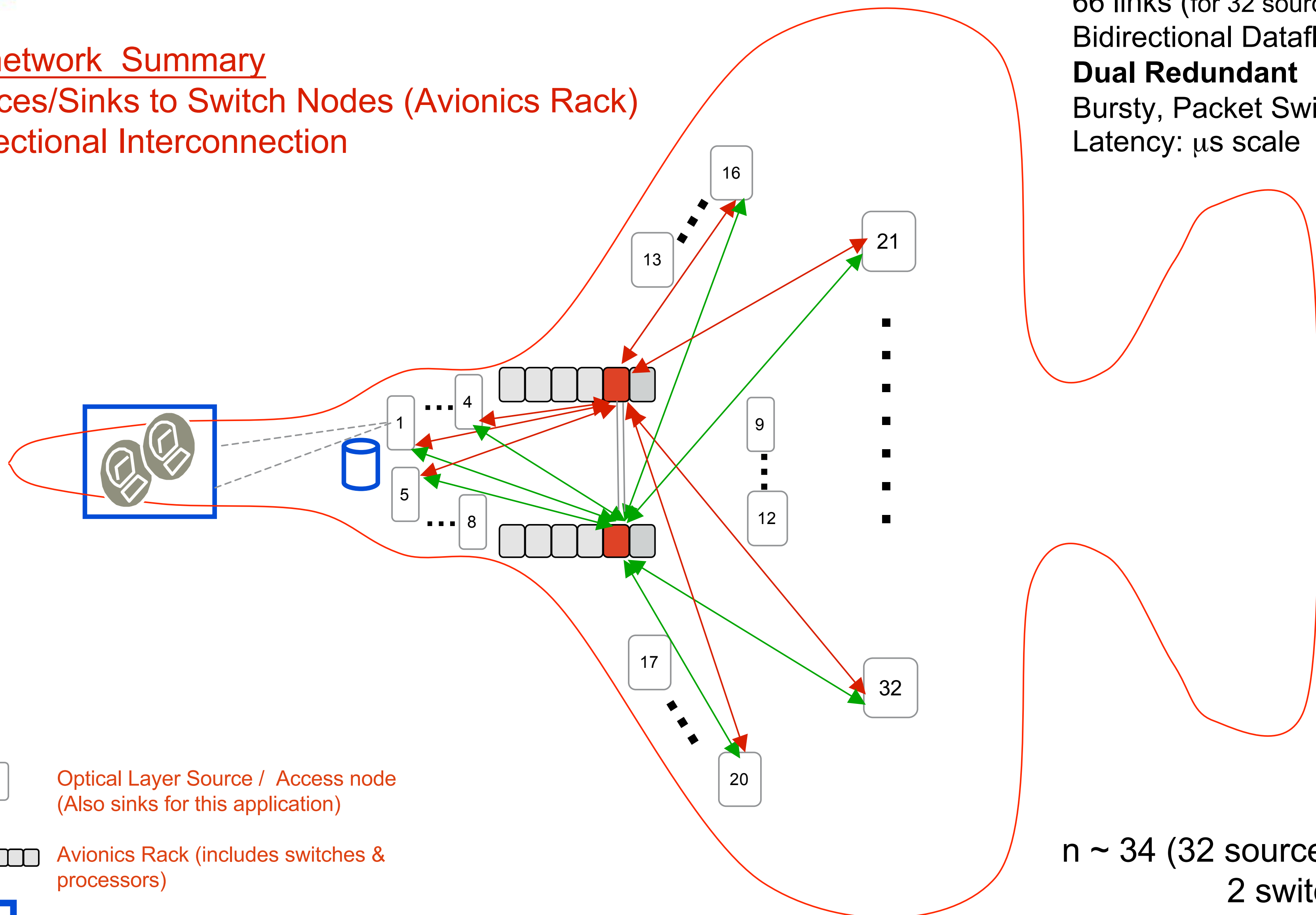
- Channel redundancy refers to the minimum number of separate paths available. For example, dual redundancy would require two separate data layer links.
- Tactical and widebody platform included a combination of non-redundant, dual redundant, and quad redundant subsystems.
- Many redundancy options can be supported within a common WDM infrastructure; can specify redundancy requirement per "SLA" (COS / QOS) to satisfy a reliability or availability objective of the avionics application
- WDM-based networks enable a logical circuit view vs physical link view of redundancy supported on the embedded optical infrastructure

Representative Network Example

Functional Architecture

66 links (for 32 sources & 2 switche
Bidirectional Dataflow
Dual Redundant
Bursty, Packet Switched
Latency: μs scale

Subnetwork Summary
Sources/Sinks to Switch Nodes (Avionics Rack)
Bidirectional Interconnection



Optical Layer Source / Access node
(Also sinks for this application)

Avionics Rack (includes switches & processors)

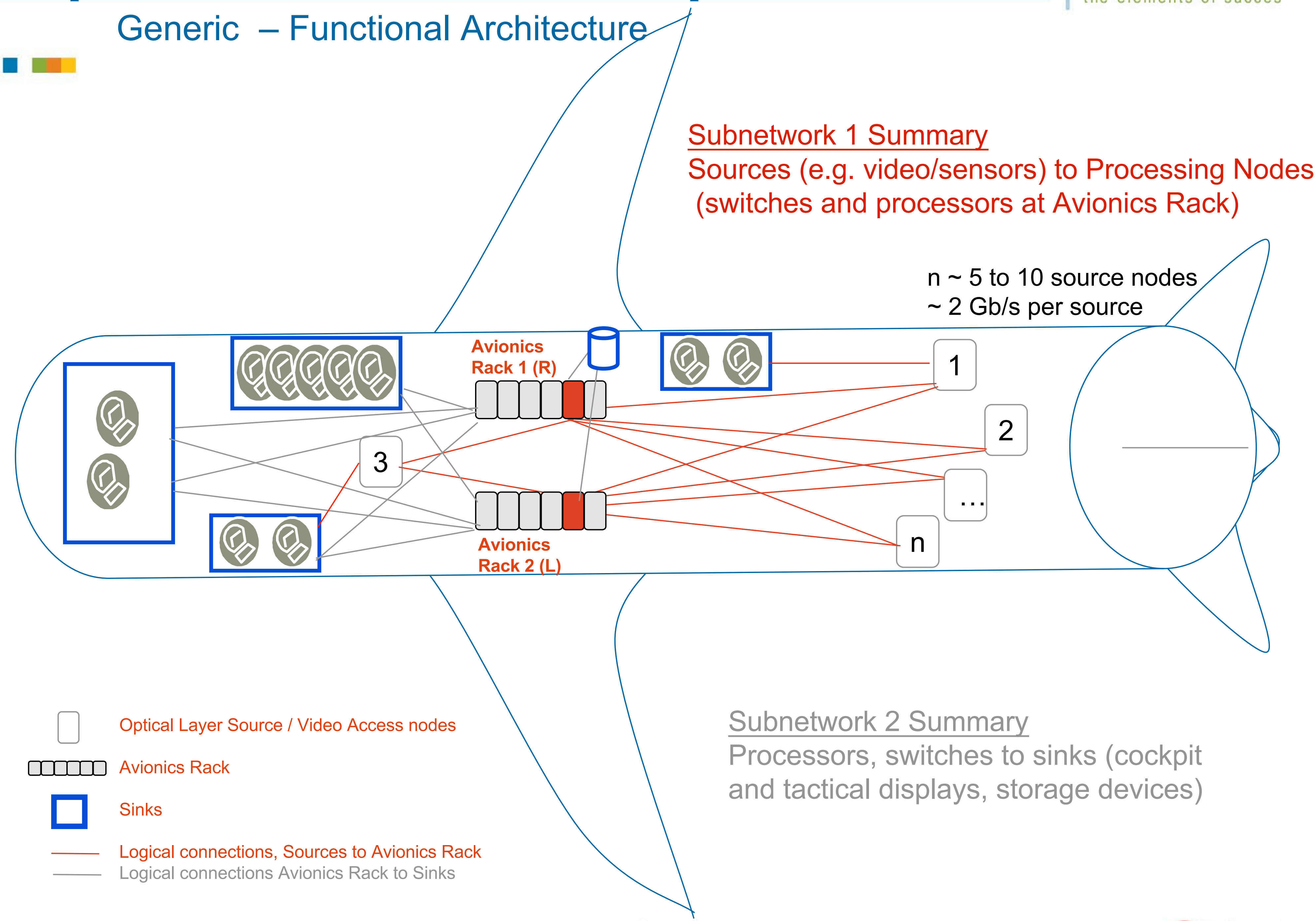
Sinks

n ~ 34 (32 source/sink nodes
2 switch nodes)

~ 2 Gb/s per source

Representative Network Example

Generic – Functional Architecture

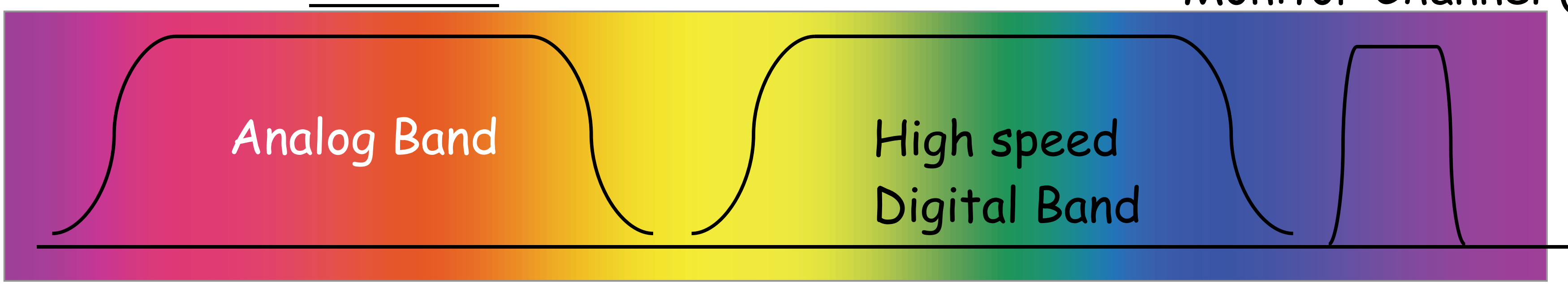


Subnetwork 2 Summary

Processors, switches to sinks (cockpit and tactical displays, storage devices)

▪ Other ways to use the wavelengths

1) Different data formats



2) Multiple Independent Levels of Security

Choice of wavelength bands depends on understanding details of

- Component behavior
- Interactions in the fiber

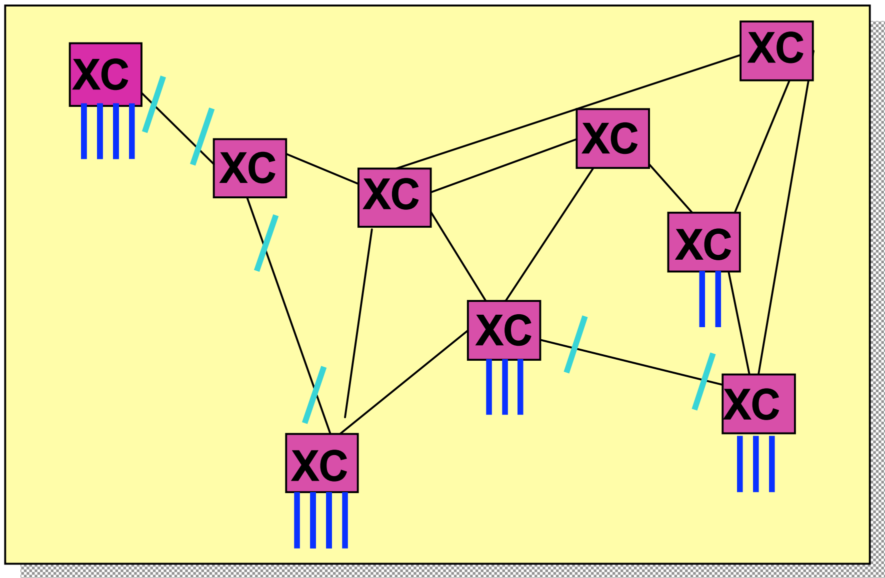
Reconfigurability

- Optical networks (single mode fiber, DWDM) can be changed or new ones set up, as needed, if the optical backbone nodes contain wavelength cross connects.
- Each overlay network can be operated independent of the others (using wavelength domain).
- Applications can be added without rebuilding the fiber infrastructure, if the right network is built for each application.
- Reconfigurability can also provide protection/redundancy/survivability.

WDM Networking – Access and Network Interfaces

WDM Networking enables definition of standard interfaces across multiple avionics system.

- Network Access Interfaces – NAI
- Backbone Network Interfaces - BNI.



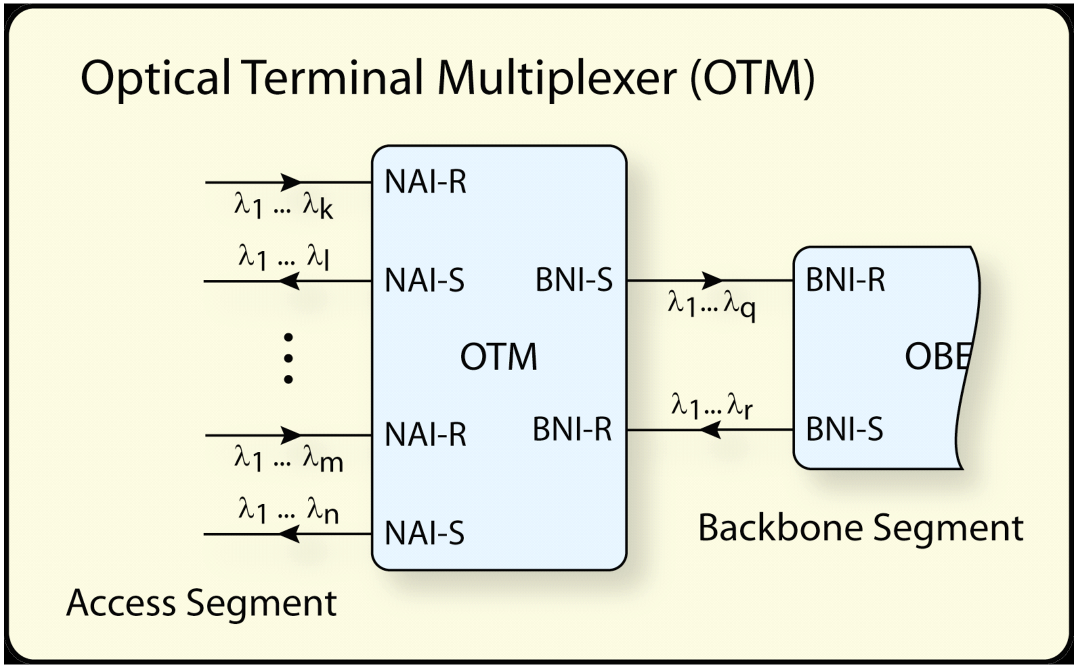
- SAE is standardizing BNI, NAI definition as well as performance requirements across any of the WDM LAN Optical Network Elements (ONEs); Telcordia is WDM LAN standards subcommittee chair.
- Cross-connects can be reconfigurable to allow updates, protection

Network Management and control Level Definitions

Level	Functionality
1	Locally configured, and monitored
2	Locally configured and monitored via a craft interface to a local craft terminal
3	Centralized management via NMS/EMS, unit connects to a NMDCN (Network Management Data Communication Network)
4	Centralized management via NMS/EMS plus distributed control plane protocols for discovery, routing and signaling to automate service establishment and recovery

Example ONE requirements: OTM

R: An OTM shall support at least one BNI_R or one BNI_S or one of each, and one or more NAIs.



Examples of Requirements & Objectives (R/CR/O)

- R: An OBN shall consist of an interconnected collection of OBEs, containing at least one NAE, together with a set of Interface Application Codes (IACs) defined at its NAIs.
- R: The optical signals crossing the specified ONE and OFI network interfaces, either BNI or NAI, shall conform to an Interface Application Codes (IACs) per the application code template defined in Table 5.4.
- R: Each of the OBE (OFI and ONE) latencies shall be specified. The overall OBN transport latency is the sum of the OBE latencies.
- R: The network shall be able to provide the required level of redundancy. The level of redundancy shall be specified.
- O: Where applicable, it is desirable to have a minimum 1:1 redundancy with an goal to provide 1:N redundancy where practical.