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EDUCATION

Fibre Channel Technologies

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Engenio Information Technologies Inc.

(formerly LSI Logic Storage Systems, Inc.)

Abstract

This tutorial will educate the user by providing foundational knowledge of the Fibre Channel protocol, an overview of the functionality of the numerous components that comprise a FC SAN, and material relative to the connectivity characteristics, architectural designs, and applications of Fibre Channel SANs.

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General Information: Fibre Channel Benefits

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- Supports, interconnects, and provides a common transport mechanism across multiple physical interface type
  - Traditional Channels: SCSI, IPI3, SBCCS, and HIPPI
  - Traditional Networks: IP, IEEE 802, and ATM
- Provide high-speed transfer of large amounts of information – 100/200/400/1200 MB/s
- Provides reliable data transmission – BER < 10^{-12}
- Provide a means to map many interfaces to a single transport protocol
- Provide scalability of performance and cost
- Encourage industry support through open standards
- Designed to fulfill the needs of SANs

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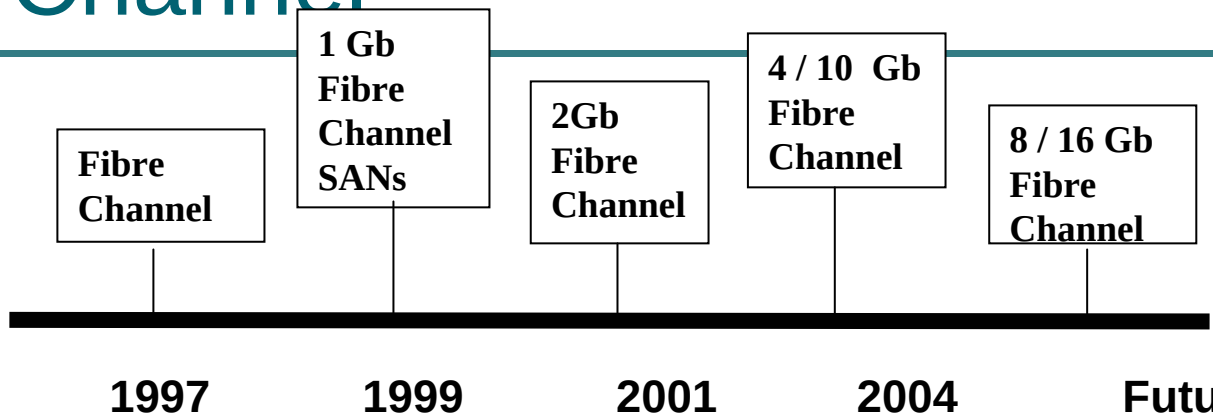
General Information: Fibre Channel



- Established in late 1980s, first standardized by ANSI T11 in 1994
- 4Gb this year & 10Gb on roadmap
- $1.5B Fibre Channel SAN Market in 2002 & growing to $6.5B by 2007 (37% CAGR)*
- 2Gb FC at the same price as 1Gb/s Ethernet
- 2Gb, 4Gb FC are plug-compatible with 1Gb FC (devices auto negotiate)
- Applications are driving higher data rates (i.e. Video)
- Read/Write Operations on 2Gb FC HBAs show dramatic improvements with 98.5% real utilization on saturated lines
- Serial SCSI; FCP protocol
- Minimal error rates for network technology
- Credit-based flow control

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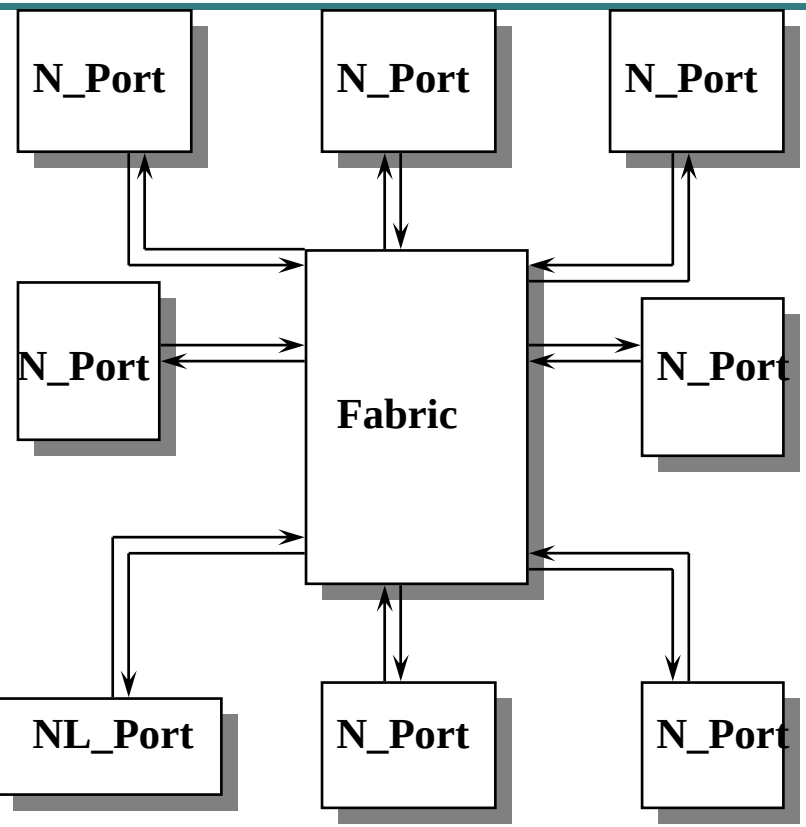
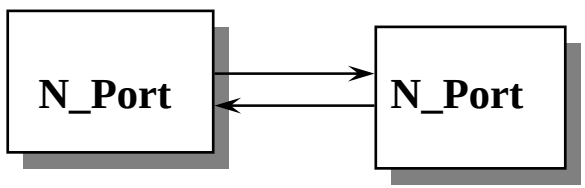
General Information: Fibre Channel Topologies

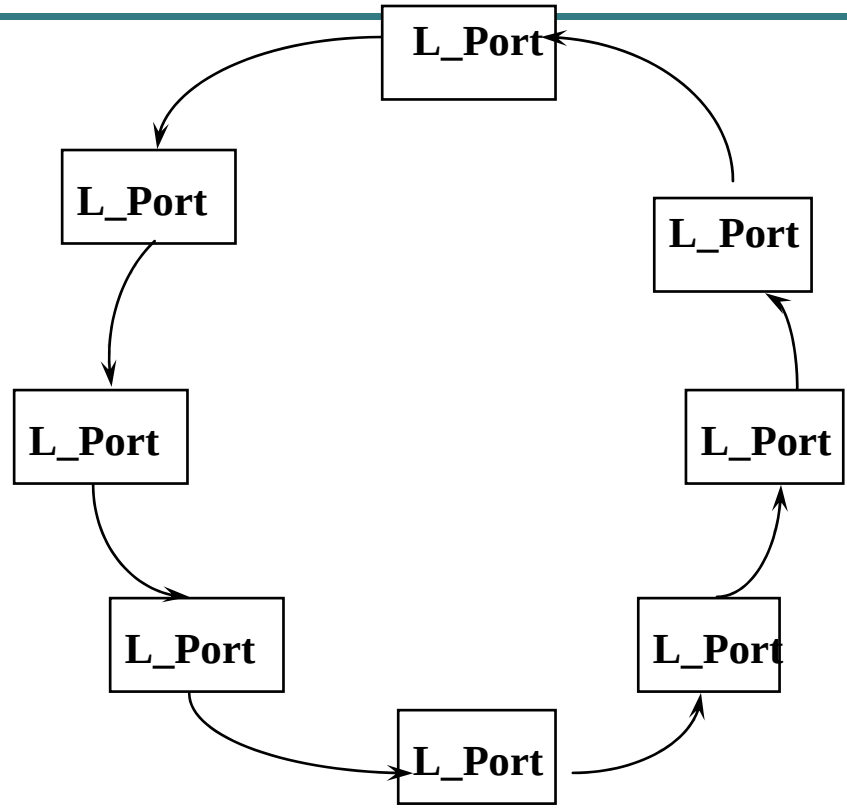


Fabric

Note: NL-port can be attached to a Fabric



Point_to_Point



Loop

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General Information: Fibre Channel Ports

Port Type	Location	Topology Associated With
N_Port	Node	Point-to-Point or Fabric
NL_Port	Node	In N_Port mode - Point to Point or Fabric In NL_Port mode - Arbitrated Loop
F_Port	Fabric	Fabric
FL_Port	Fabric	In FL_Port mode – Arbitrated Loop
E_Port	Fabric	Internal Fabric Expansion
G_Port	Fabric	In F_Port mode - Fabric In E_Port mode – Internal Fabric Expansion
GL_Port	Fabric	In F_Port mode – Fabric In FL_Port mode – Arbitrated Loop In E_Port mode – Internal Fabric Expansion
B_Port	Bridge	Fabric Expansion

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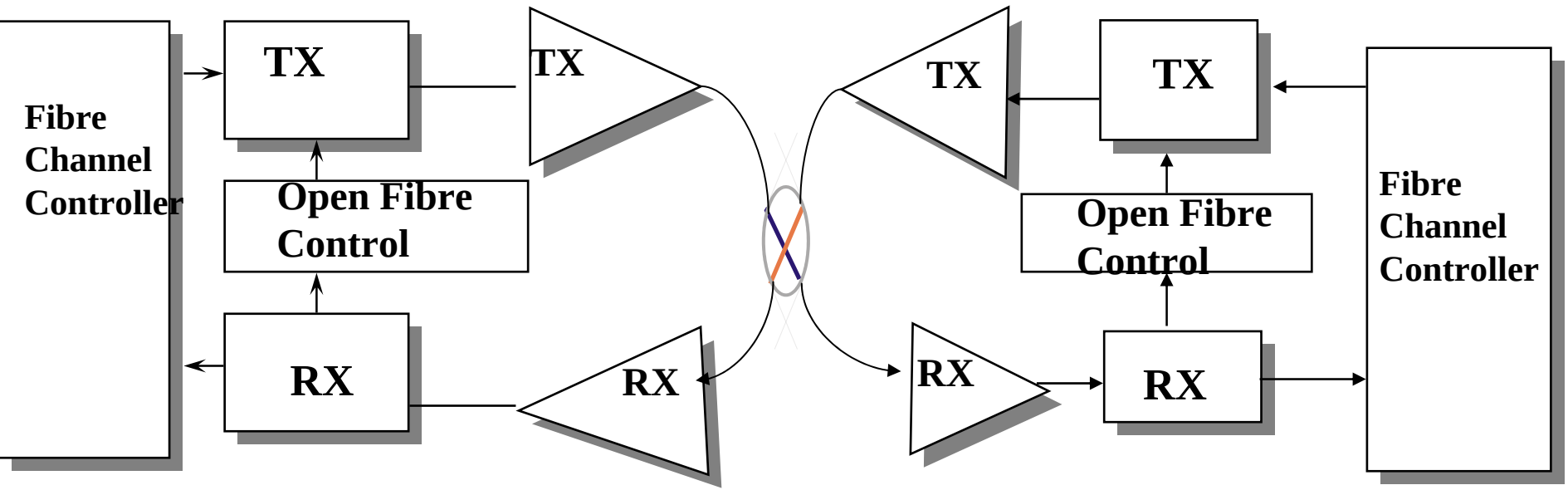
General Information:
FC Optical / Electrical link



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General Information: Fibre Channel Classes

- **FC2 supports several classes of service (these are not the same as classes in the IP sense ” Class in IP refers to addresses”):**
  - **Class-1**: reserves a path from the originator to the destination; each link on the path is entirely dedicated to that data flow. This is more or less like circuit reservation and is seldom used.
  - **Class-2**: Connectionless communications with end to end acknowledgements
  - **Class-3**: Connectionless communications with no end to end acknowledgements.
  - **Class-4**: Similar to class-1 except that only part of the bandwidth is reserved instead of the entire link.
  - **Class-5** is still being defined
  - **Class-6** is for multicast service
  - **Intermix class**, which allows class-2 or class-3 packets to backfill the unused bandwidth of class-1 or 4 traffic.

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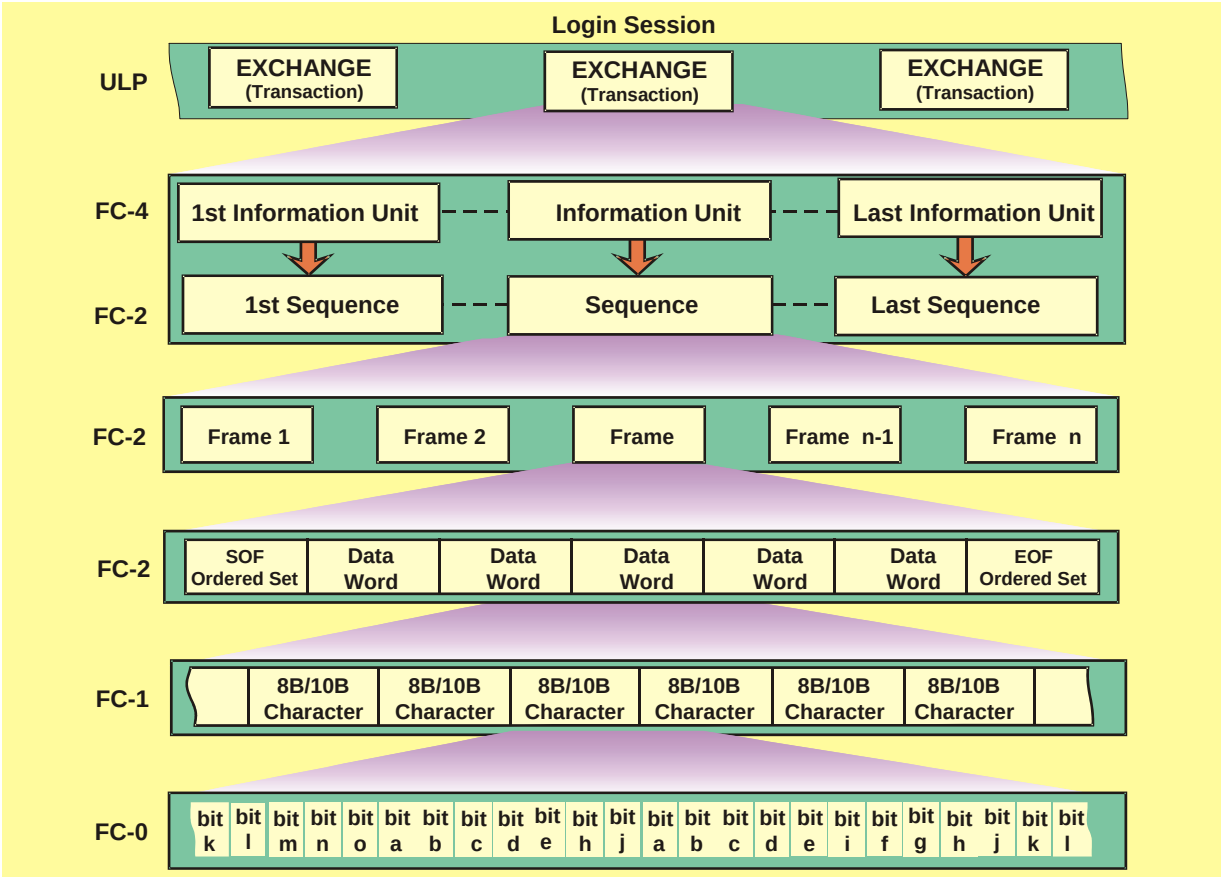
General Information: Fibre Channel Protocol Levels



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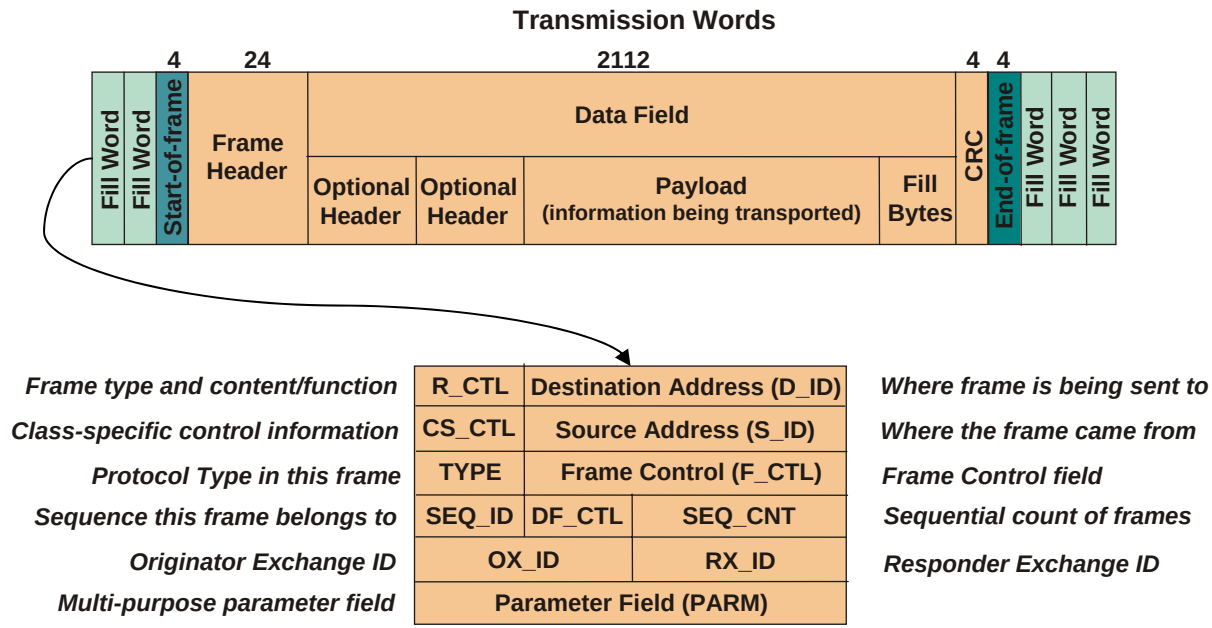
General Information: Fibre Channel Frames



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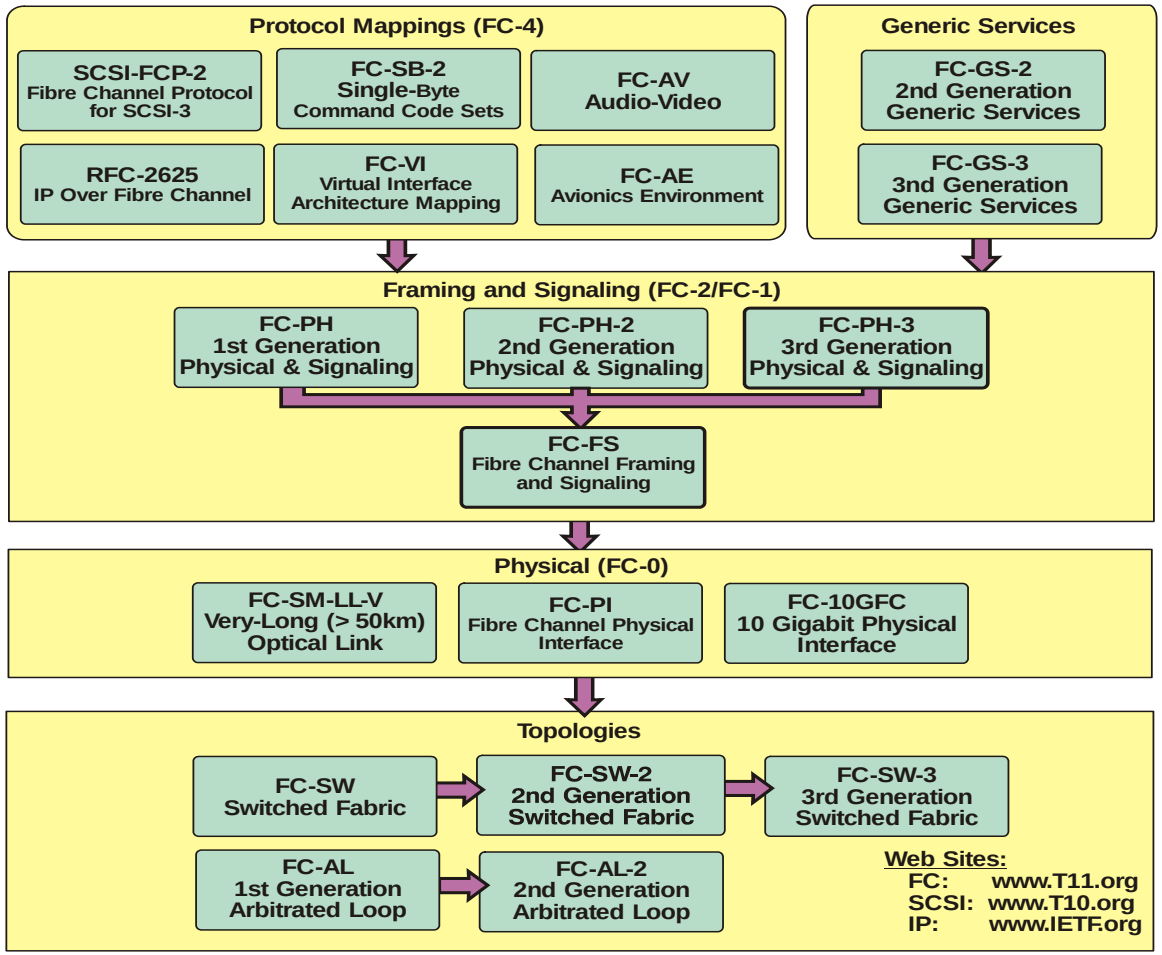
General Information:
Fibre Channel Documentation Structure



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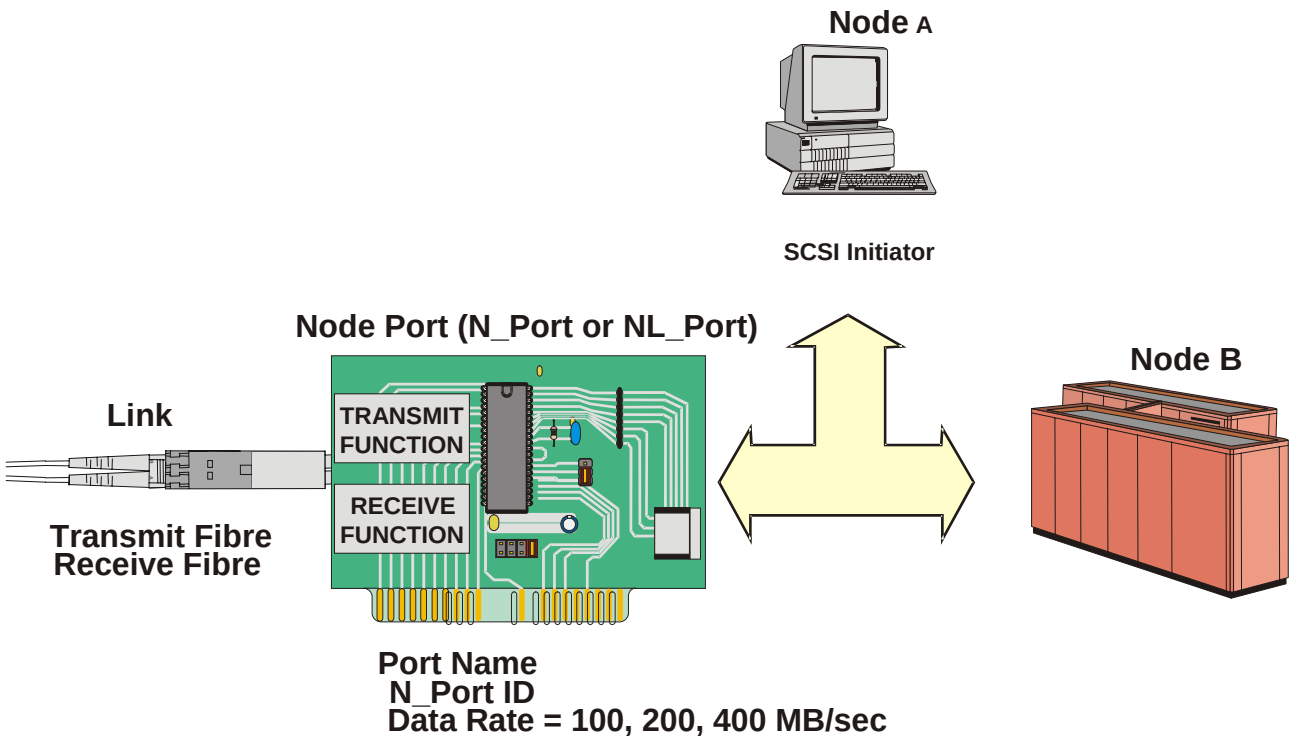
FC Components: Fibre Channel Node



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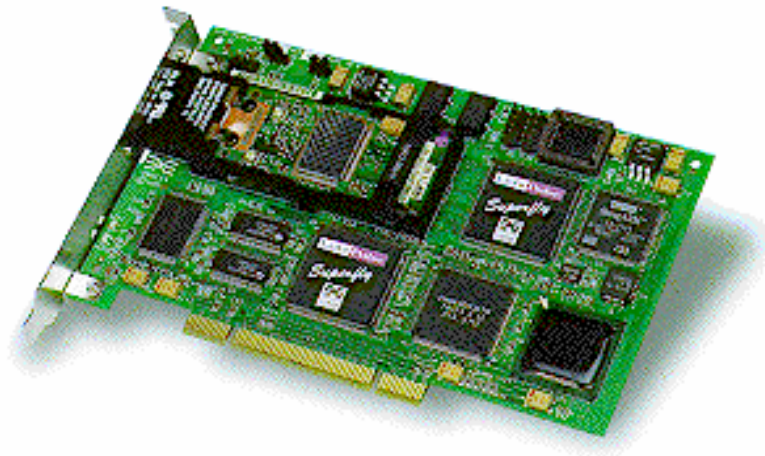
FC Components:

Sophisticated Fibre Channel PCI Host Adapter

- Support FC full speed 1, 2, or 4 Gb/s
- Support point-to-point, arbitrated loop, and switch fabric
- Class 1, 2, and 3
- Direct interface to optical or copper cables
- On board high speed RISC processor
- Up to 126 devices
- Up to 500 meters between devices
- Software support different OS



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FC Components: Physical characteristics

- Physical description
- Transmitter/Receiver
- Cable requirement
- Connector requirement

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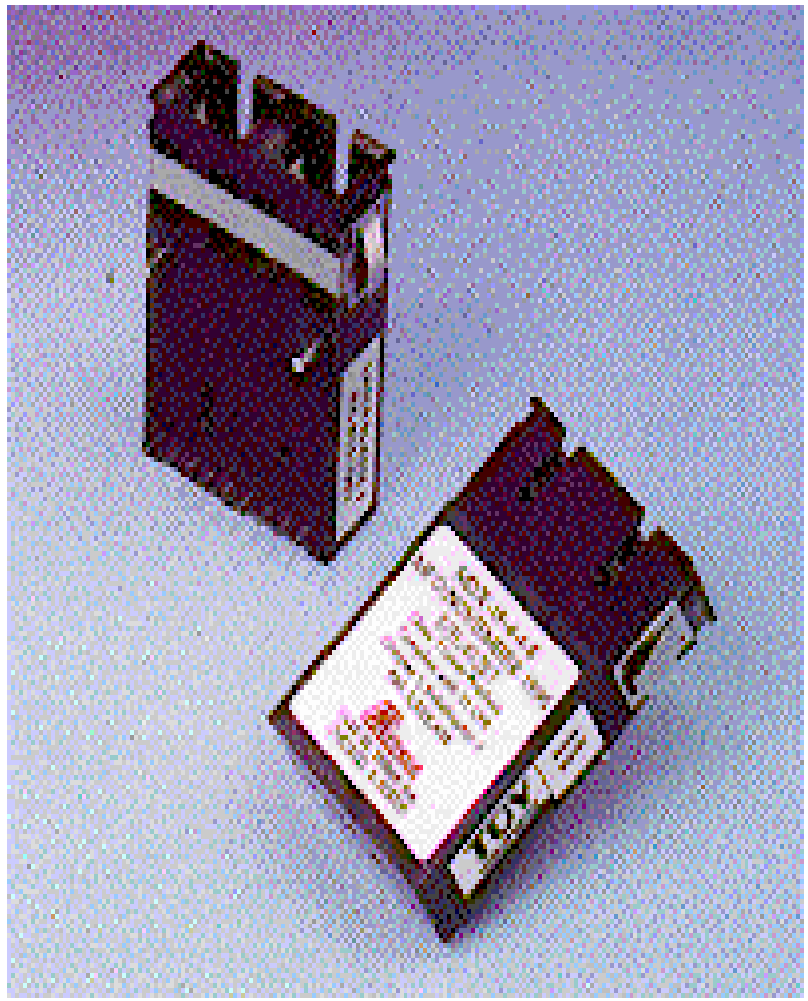
FC Components: Optical Transceiver (TX & RX)

- 1, 2, or 4 Gbps Performance
- Class 1 Laser Safety Compliance
- Wavelength
  - 850 nm (multimode)
  - 1300 nm (Single mode)
- Run length
  - 50 um : 500 m
  - 62.5 um : 300 m



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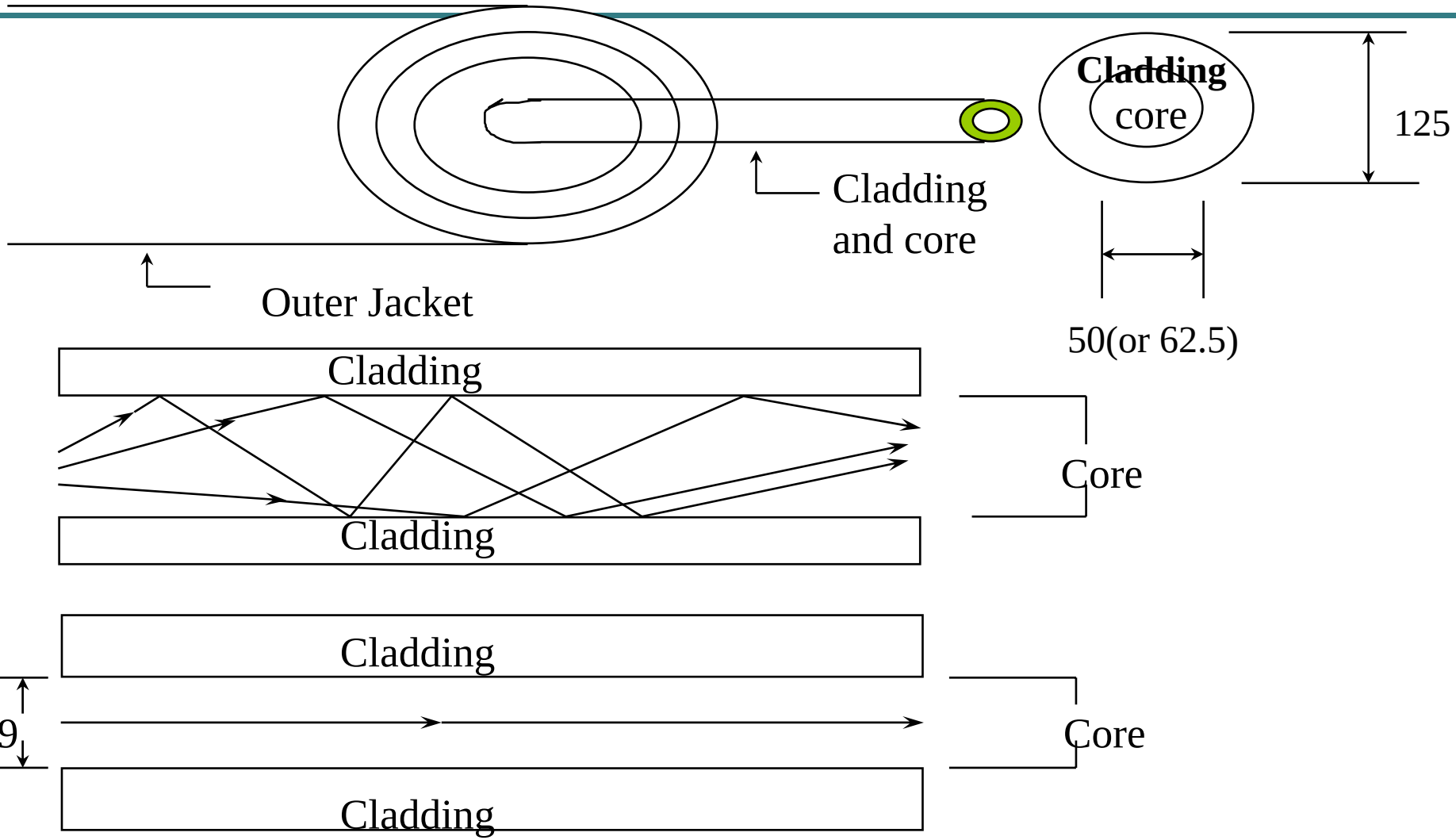
FC Components:

Fiber Optic Cable Construction & Total Internal Reflection With Multimode Fibre



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FC Components:
Fiber Cable Characteristics

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Media Type	Transmitter	Speed	Distance	Variant
Electrical (Differential)	ECL/PECL	200 MB/s	0m – 10m (typical)	200-DF-EL-S
		100 MB/s	0m – 30m (typical)	100-DF-EL-S
9 um. Single-Mode Fiber	1550 nm. Long wave Laser	200 MB/s	2m - >50km	200-SM-LL-V
		100 MB/s	2m - >50km	100-SM-LL-V
	1300 nm. Long wave Laser	400 MB/s	2m - 2km	400-SM-LL-I
		200 MB/s	2m - 2km	200-SM-LL-I
		100 MB/s	2m - 10km	100-SM-LL-L
			2m - 2km	100-SM-LL-VI
50 um. Multi-Mode Fiber	850 nm. Short-wave Laser	400 MB/s	0.5m - 175m	400-M5-SN-I
		200 MB/s	0.5m - 300m	200-M5-SN-I
		100 MB/s	0.5m - 500m	100-M5-SN-I
62.5 um. Multi-Mode Fiber		400 MB/s	0.5m - 70m	400-M6-SN-I
		200 MB/s	0.5m - 150m	200-M6-SN-I
		100 MB/s	0.5m - 300m	100-M6-SN-I

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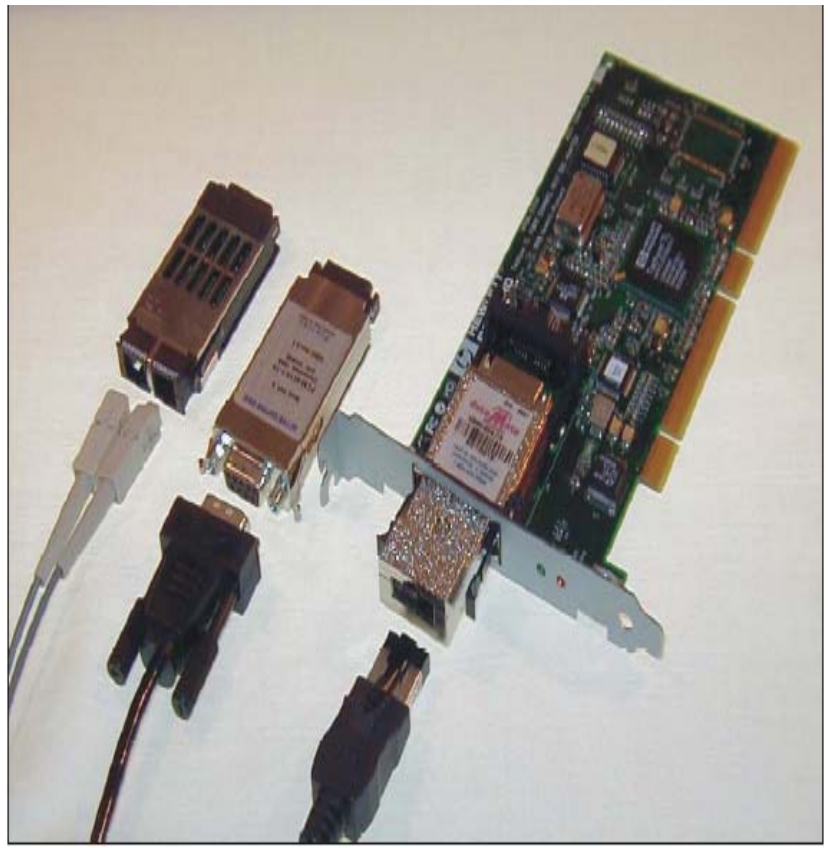
FC Components:
Fibre Channel Accessories

- GLM
- MIA
- GBIC
- Hubs (star connection)
- Fabric (MI - MT)



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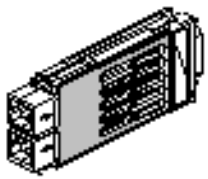
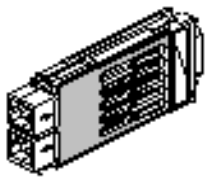
FC Components:
Installation - GBIC Types

Short Wave Laser



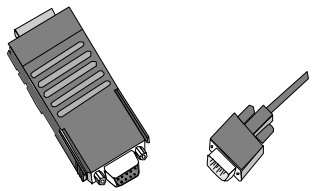
- To 500 meters
- Multimode Cable

Long Wave Laser

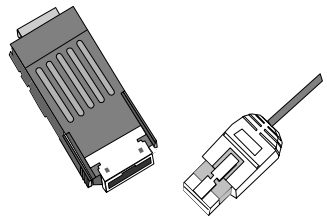


- To 10 kilometers
- Single Mode Cable

Copper DB9



Copper HSSDC



- 13 meters Passive
- 30 meters Active

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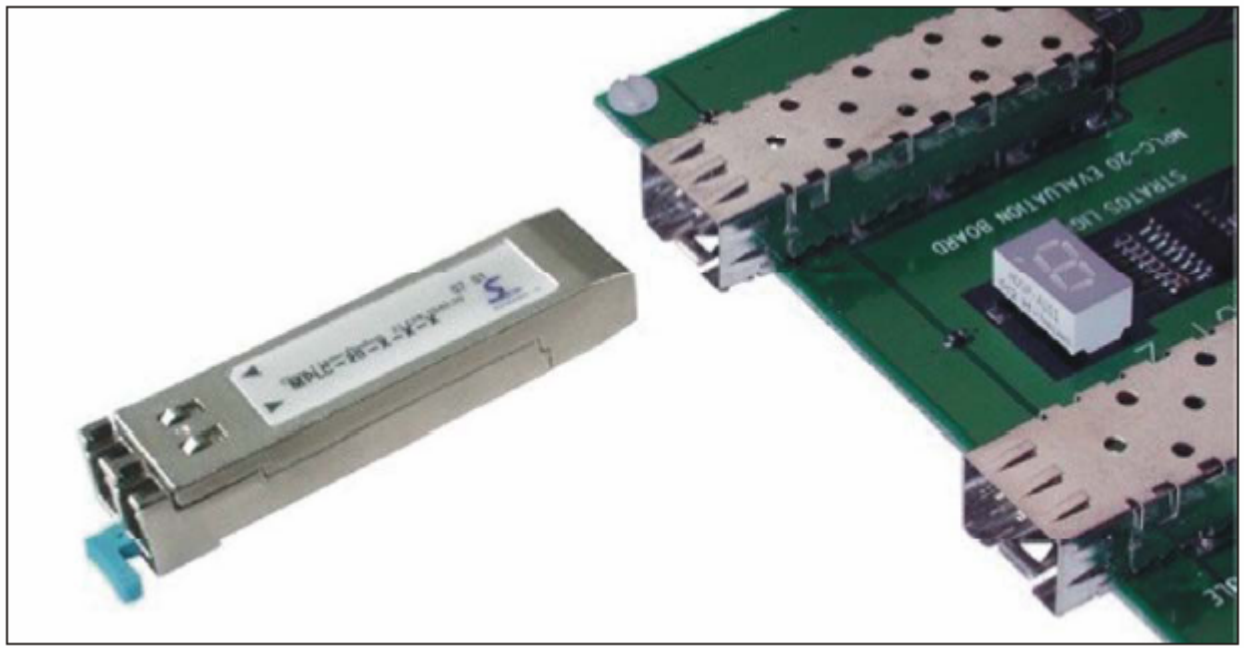
FC Components:
Small Form Factor Pluggable (SFP)



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FC Components: Integrated HUB

- Improve loop stability, reliability, and availability
- Eliminate signal jitter and automatic clock speed matching
- Bypass isolated faulty nodes
- Synchronous cut-in / cut-out
- provide LIP on hot port insertion
- Join cascaded hubs to sub-divide loop or join separate loops

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FC Components: Fabric Switch

- 1 , 2, or 4 Gb/s full duplex per port
- 16 Gb/s per switch (1 Gb/s)
- FC class 2 and 3 connectionless service
- under 2 usec latency
- scalability (2 to 16 ports)
- Fabric resiliency
  - auto configuration
  - Redundant data paths
  - up to 8 parallel links to others
- Fabric Management

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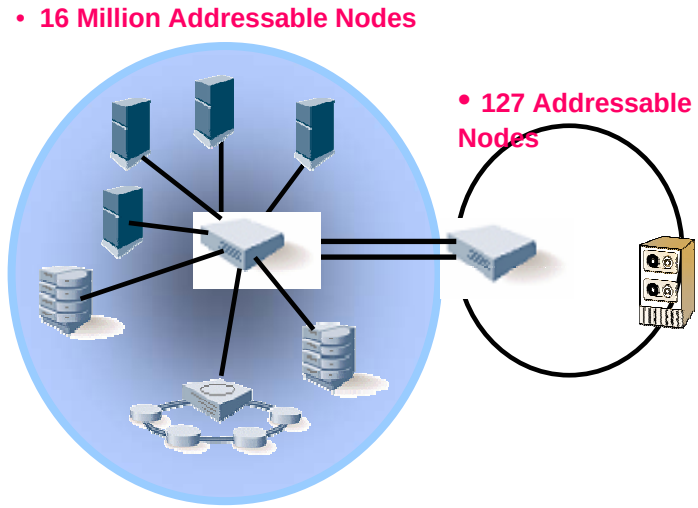
Protocol Specifics: Fibre Channel Addressing

- Fibre Channel supports a 24-bit address space
  - Provide over 16 million address
  - FC Routing is done based on NPort ID assigned on login (24-bit addressing consisting of Domain ID, Area ID, and Device ID)
- FC Device ports are uniquely identified by a MAC ID (World Wide Name)
- Address lookup is provided by the Fabric Switch using the Name Server portion of Directory Services
- Point-to-Point → Two ports on a dedicated link
- Arbitrated Loop → Up to 127 ports on a shared loop
- Switched Fabric
  - Up to 2 ^{24} ports in a switched interconnect
  - Multiple concurrent communications for high aggregate throughput



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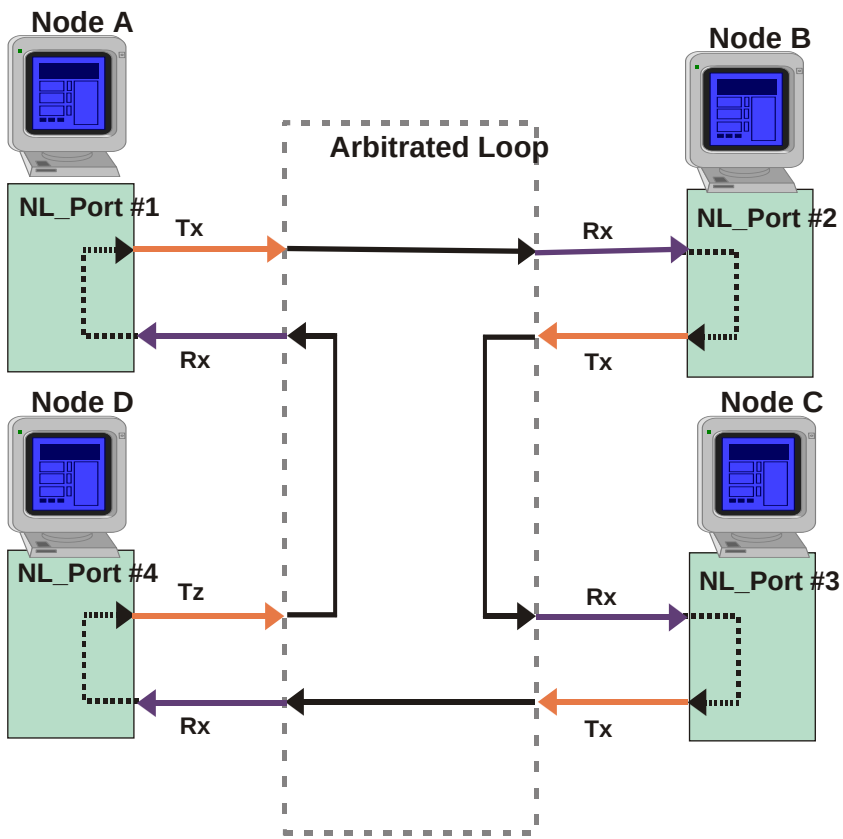
Protocol Specifics: Loop Protocols

- Arbitrated loop ports use a series of loop-specific protocols
  - Initialization
  - Arbitration
  - Opening circuit
  - Closing circuit
  - Access fairness



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Protocol Specifics:
FC Arbitrated Loop vs. Parallel SCSI

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Loop (LPSM)	SCSI
Exchange	I/O Operation
Sequence	REQ/Response primitive
Unsolicited CMD IU (FCP_CMND)	CMD Service request
Data Descriptor IU (FCP_XFER_RDY)	Data Delivery Request
Solicited Data IU (FCP_DATA)	Data Delivery action
Command Status IU (FCP_RSP)	Command Service Response
Arbitrate	Arbitrate
Arbitration Won	Arbitration Won
Open port	Selection
Close port	Disconnection
Relinquish loop	Bus Free

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Protocol Specifics: Ordered set

- Primitive signals are normally used to indicate events or actions
- Primitive sequences are used to indicate states or conditions and transmitted continuously until something causes the current state to change
- Loop protocols requires transmitting the primitive sequence around until it received by the sender

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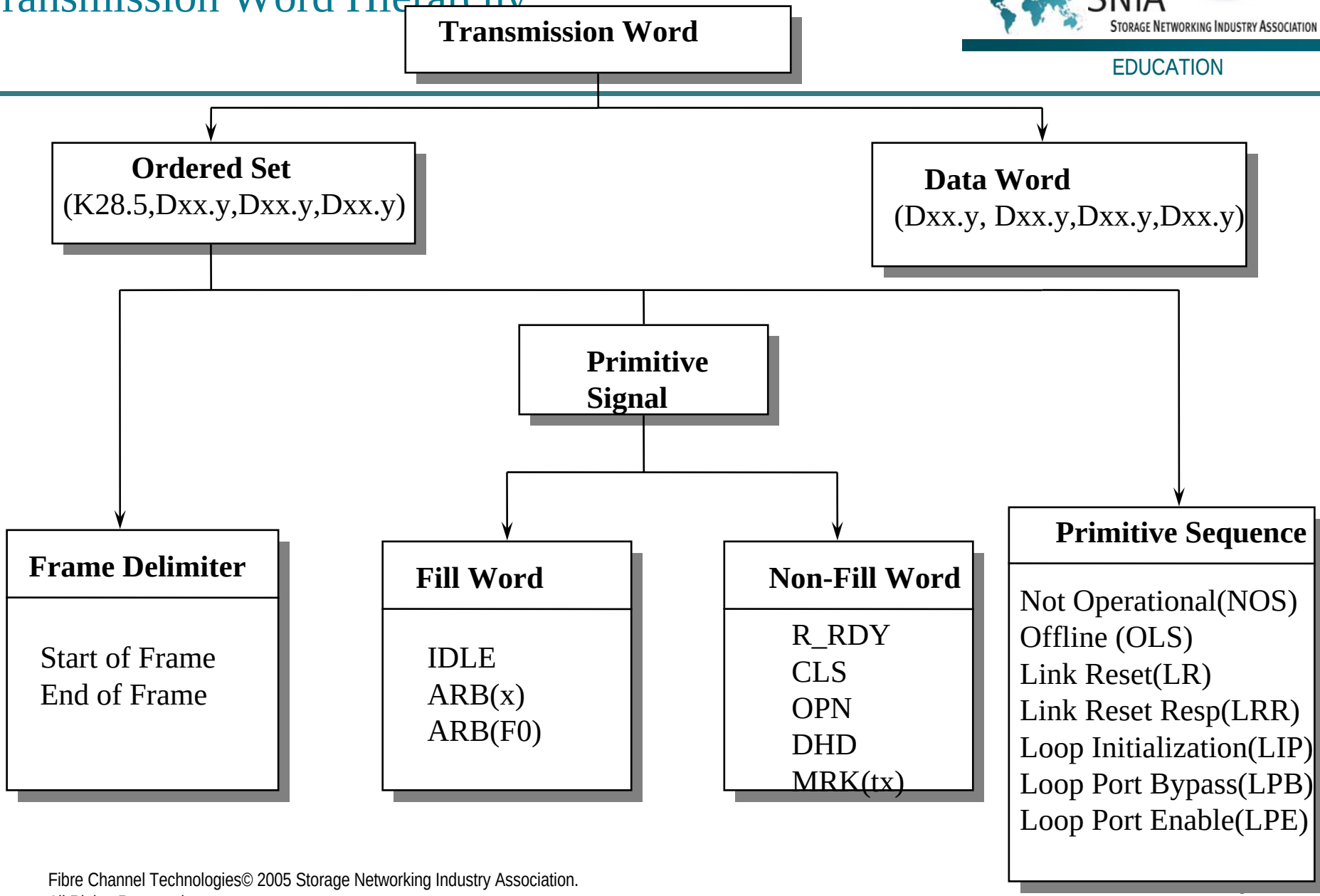
Protocol Specifics:

Transmission Word Hierarchy



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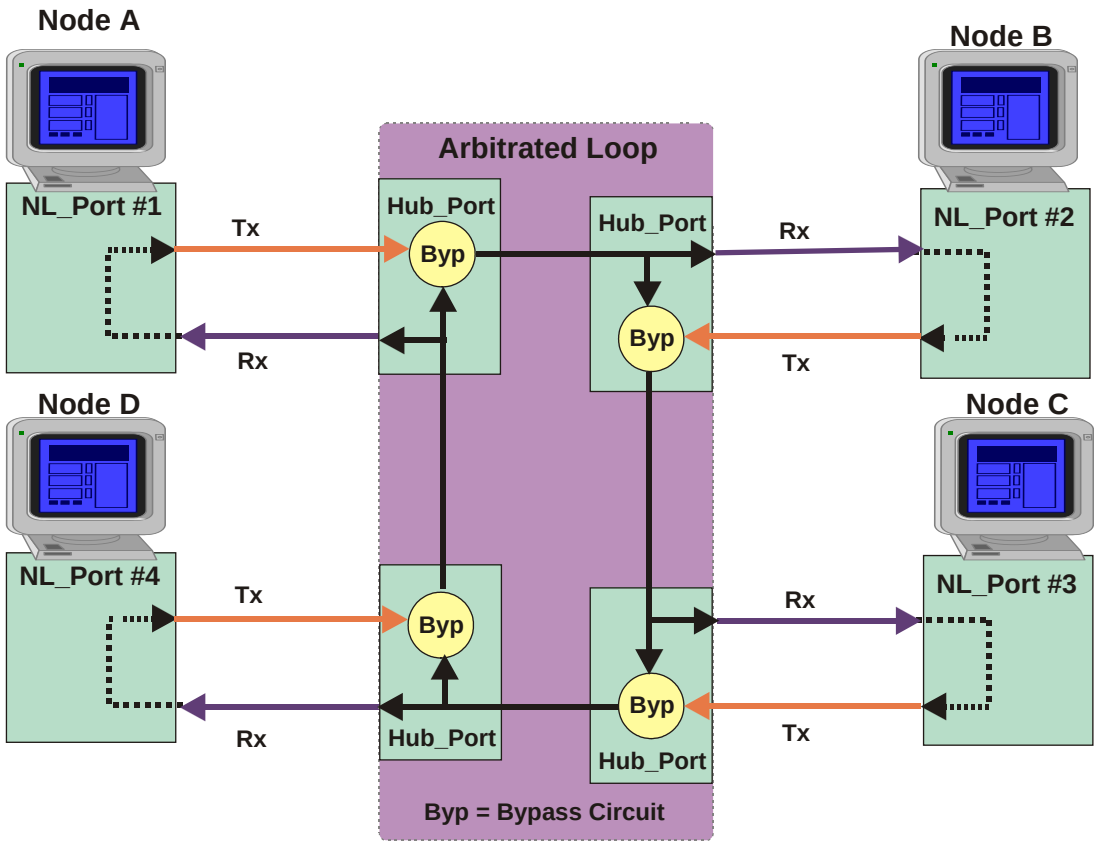
Protocol Specifics: Arbitrated Loop With a Hub



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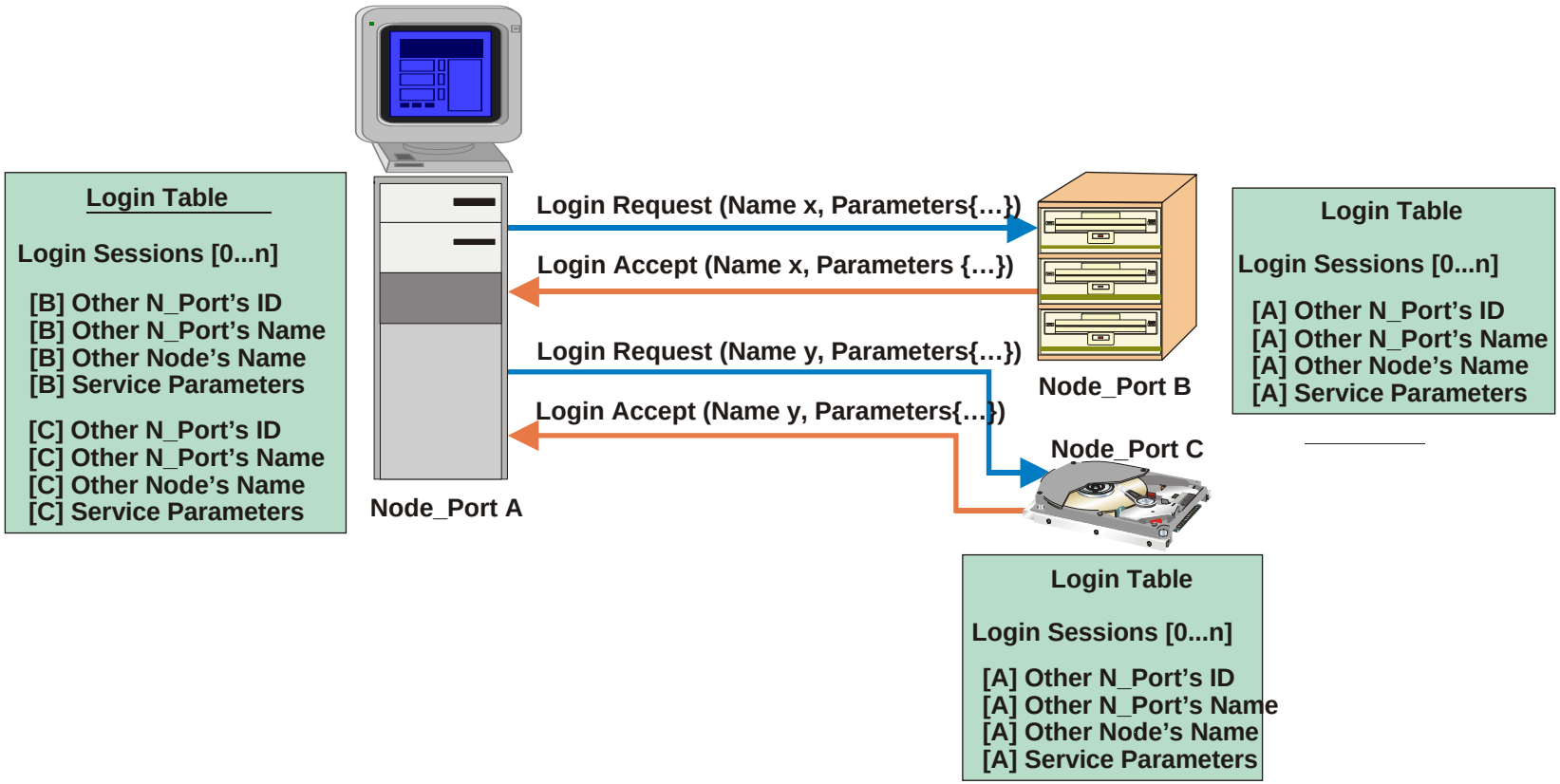
Protocol Specifics: Fibre Channel Login Sessions



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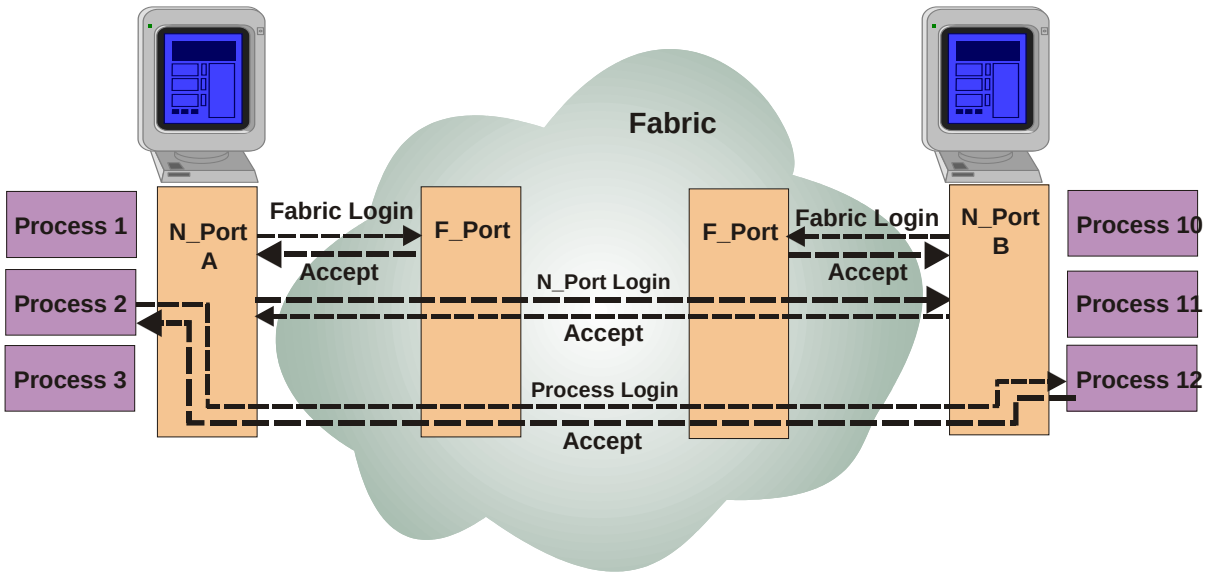
Protocol Specifics: Fibre Channel Logins



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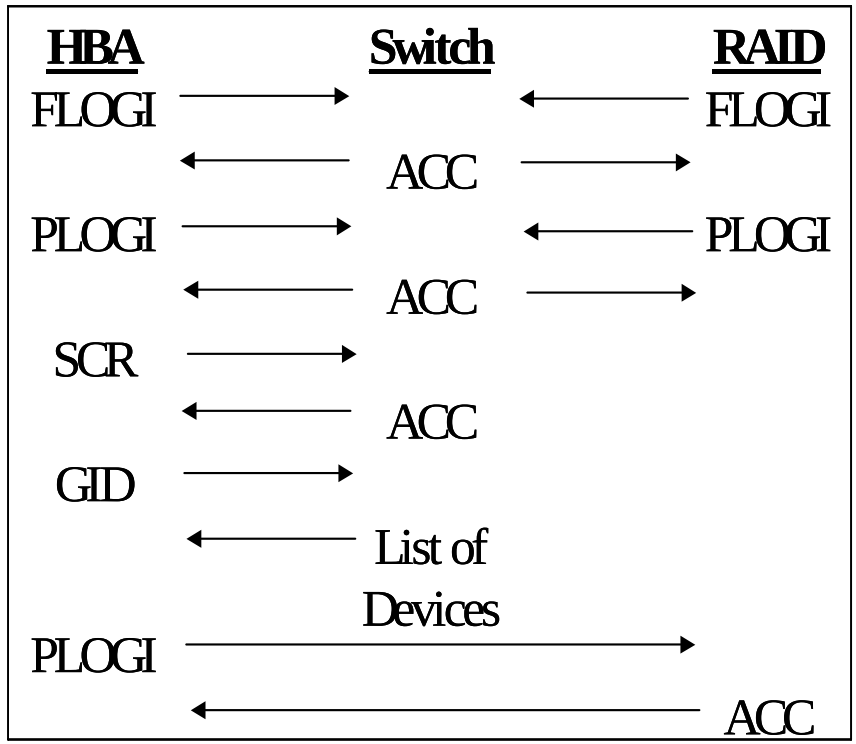
Protocol Specifics: Fabric Initialization

- Fabric Login (FLOGI):
  - FLOGI is issued by an N_Port to:
    - Determine if a fabric is present.
    - Establish a session with the fabric.
    - Exchange service parameters.
  - Mechanism for the fabric to assign an address to an N_Port.
  - Mandatory for N_Ports and optional for NL_Ports.
  - Performed after link initialization and before communication with other N_Ports.
  - N_Port uses a S_ID of 0x000000 (unidentified).
  - Issued to a well-known address (0xFFFFFE) assigned to the F_Port.



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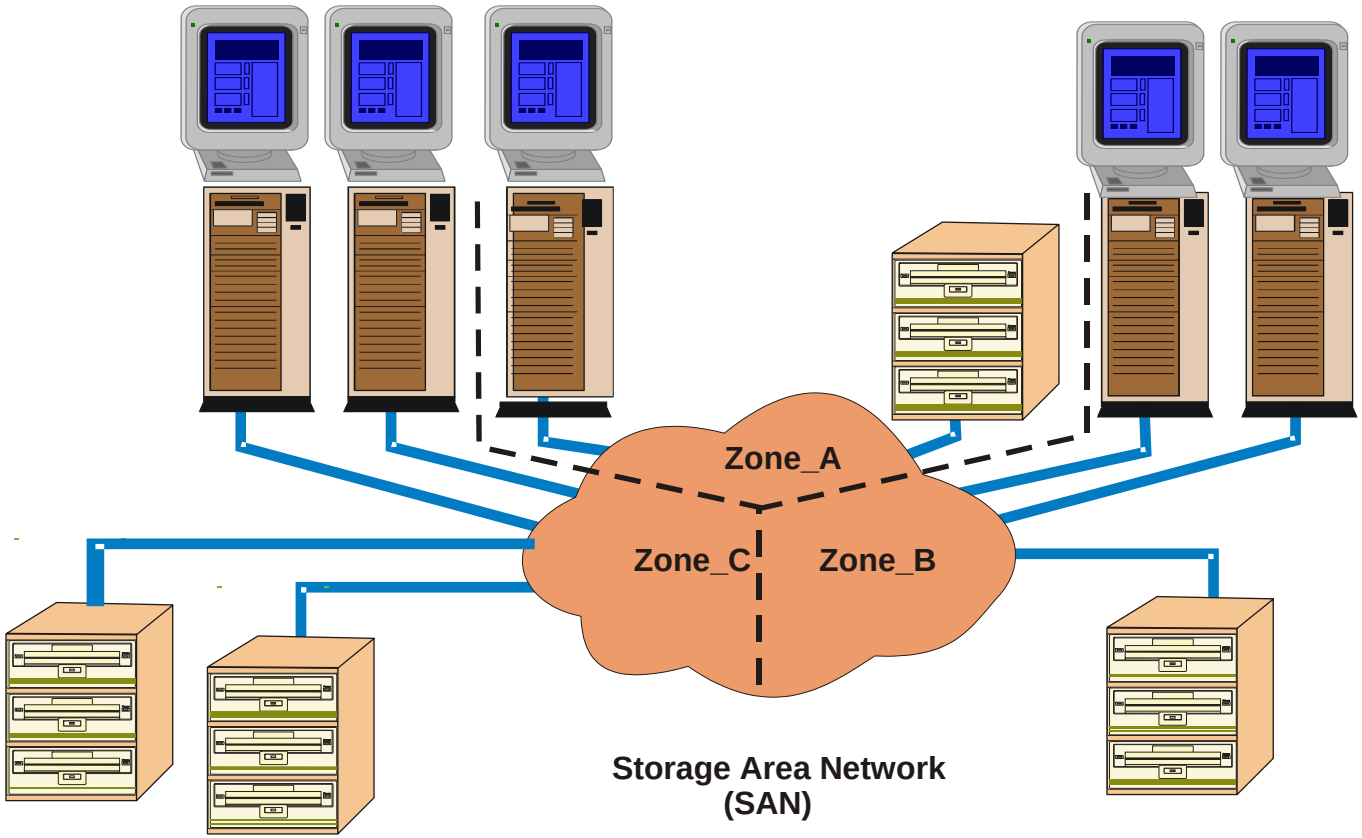
Protocol Specifics: Fibre Channel Zoning



Soft Zoning: Employs the nameserver to limit the information returned to an initiator in response to a query.

Hard Zoning:Specified by Domain/Port or WWN.

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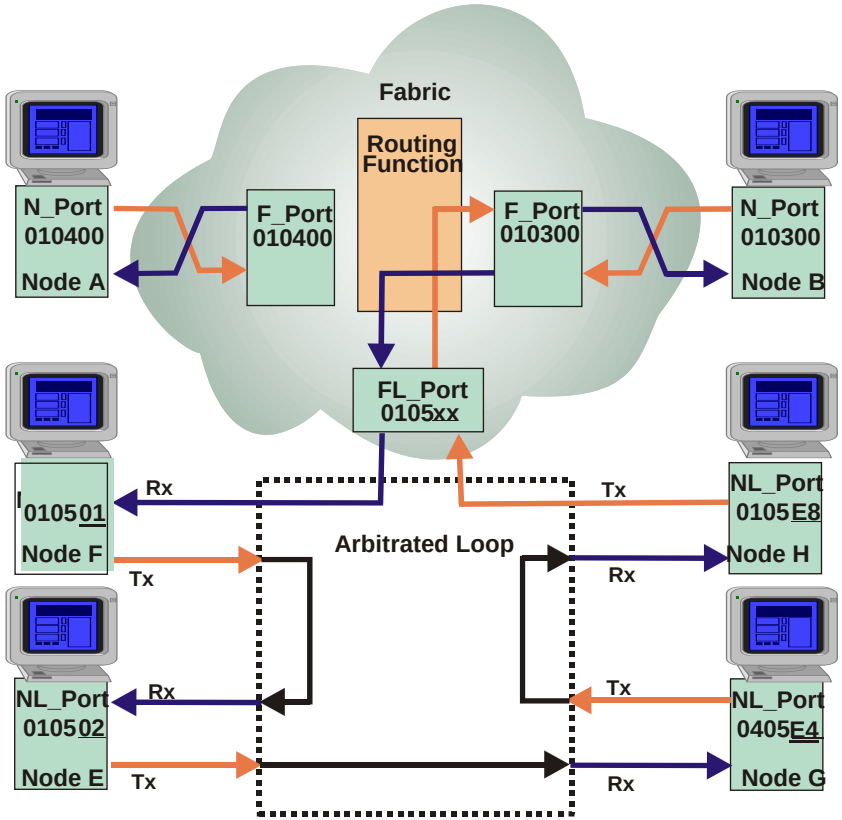
Protocol Specifics: Public Loop



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Protocol Specifics: Topology Comparison

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Attribute	Point-to-Point	Arbitrated Loop	Switched Fabric
Number of ports	2	2 to 127	Up to 2^{24}
Maximum bandwidth	Link rate times 2	Link rate times 2	Link rate times number of ports
Bandwidth allocation	Dedicated	Shared by all loop ports	Managed by fabric
Address assignment	N_Port Login	Loop initialization and Fabric Login	Fabric Login
Number of concurrent circuits	1	1	Number of port pairs (number of ports/2)
Effect of port failure	Point-to-point link fails	Loop fails (port bypass function required	Link between switch and port fails
Concurrent maintenance	Link is down	May be disruptive to entire loop	Link between switch and port is down
Expansion	Add additional point-to-point links	Attach loop to fabric	Expand fabric
Redundancy/High-Availability	Add redundant port and point-to-point links	Use dual loops and dual-ported devices	Use redundant switches
Link rates supported	All	All (all devices on loop must be same rate)	All (fabric may support mixed rates)
Media types supported	All	All	All
Classes of service supported	All	Class-1, -2, -3	All
Frame delivery order	In order	In order	Not guaranteed
Access to interconnect medium	Dedicated	Arbitration	Dedicated
Cost per port	Port cost	Port cost + loop function(+hub if used)	Port cost + fabric port

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Protocol Specifics: FC Buffer Credits

- Flow control mechanism that ensures congestion does not result in packet loss in the delivery of each frame placed on the Fabric.
- Used for end-to-end and for link-level flow control
  - When two devices are first connected to each other, they grant each other a certain number of buffer credits.
  - Each time the sender sends a packet it decrements its credits by one
  - When receiving end processes packet from buffer it sends an R_Rdy signal
  - The sender increments its credit count each time it receives an R_RDY signal from the receiver
- Typical rule of thumb is 1 buffer credit is required for each 2km at 1Gbps (1 buffer credit per km for FC200)

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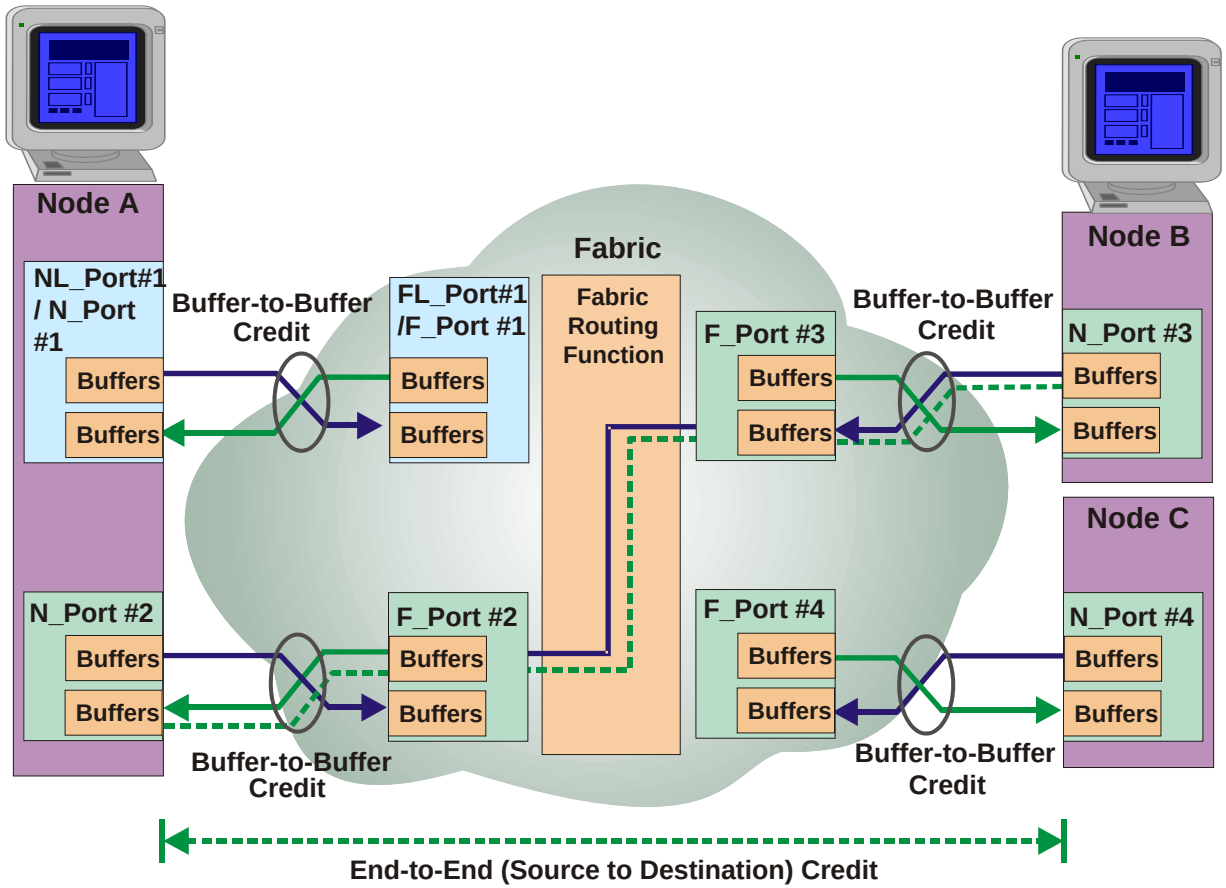
Protocol Specifics: BB-Credit v.s. EE-Credit



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Protocol Specifics: BB-Credit v.s. EE-Credit

- **Buffer-To-Buffer Credit**
  - Control pace of frame transmission
  - Each R_RDY received increments the available BB_Credit value
  - Each frame sent decrements the available BB_Credit
  - Used in Class 1 (SOFc1), 2, and 3
  - Ports signal the number of available buffer at OPN with R_RDYs
  - Zero login BB_Credit: RX controls transmission
  - Nonzero login BB_Credit: TX controls transmission

- **End-To-End Credit**
  - Provide confirmation of frame delivery or notification of no deliverability of frames in class 1, and class 2
  - EE_Credit does not apply to class 3
  - End-to-End <==> Source-to-Destination (N_ or NL_Ports)
  - Require respective available credit to be nonzero in order to transmit frames

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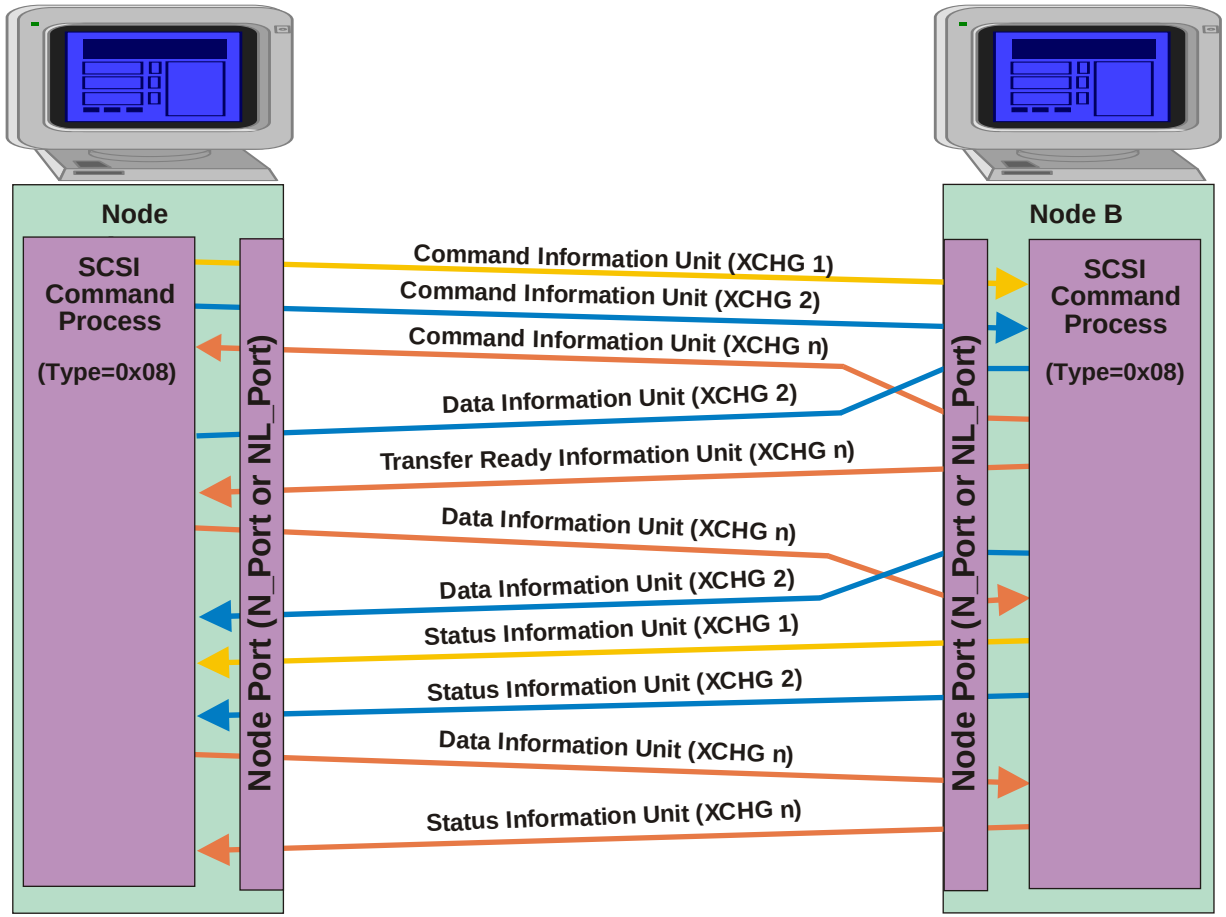
Protocol Specifics: Information Transfer



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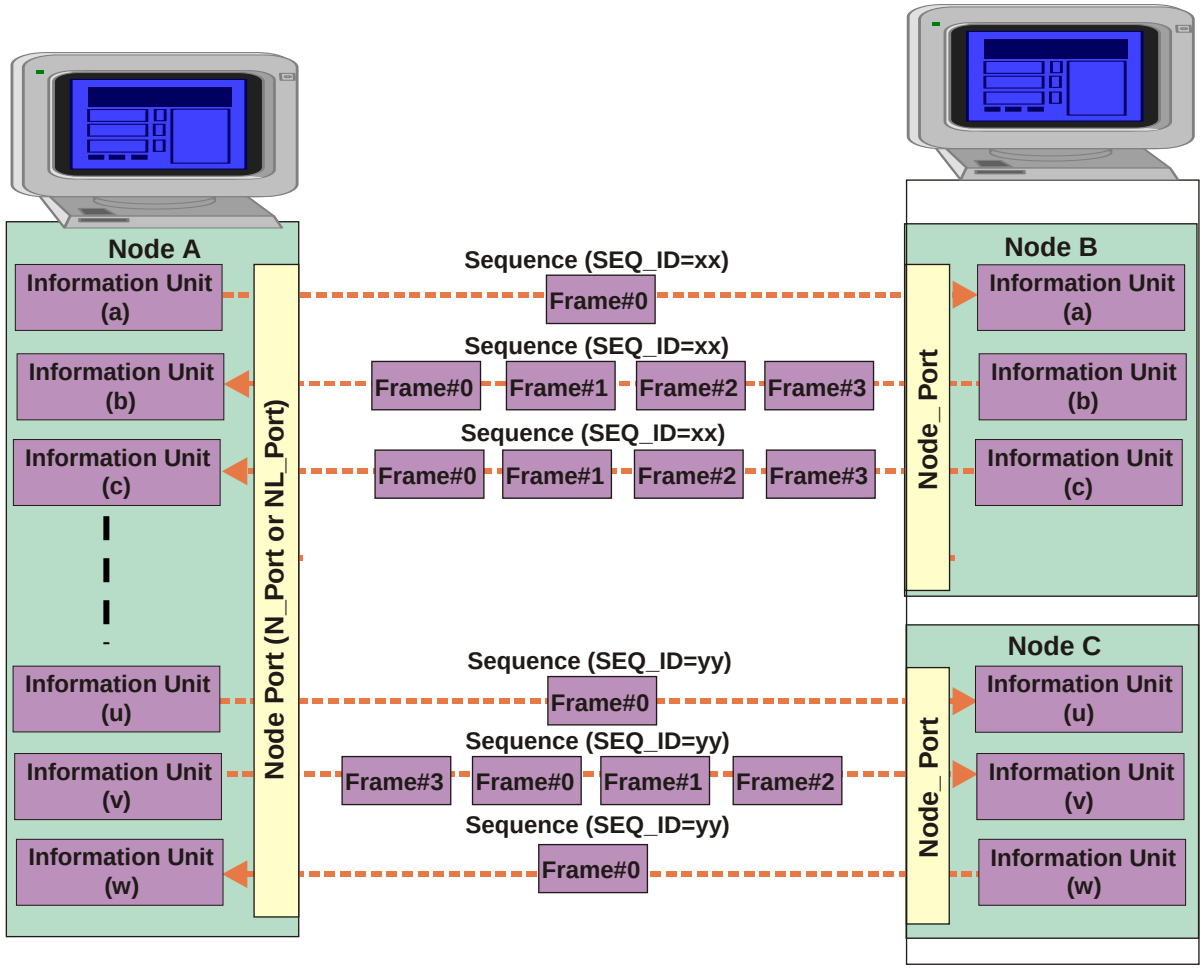
Protocol Specifics: Information Transfer



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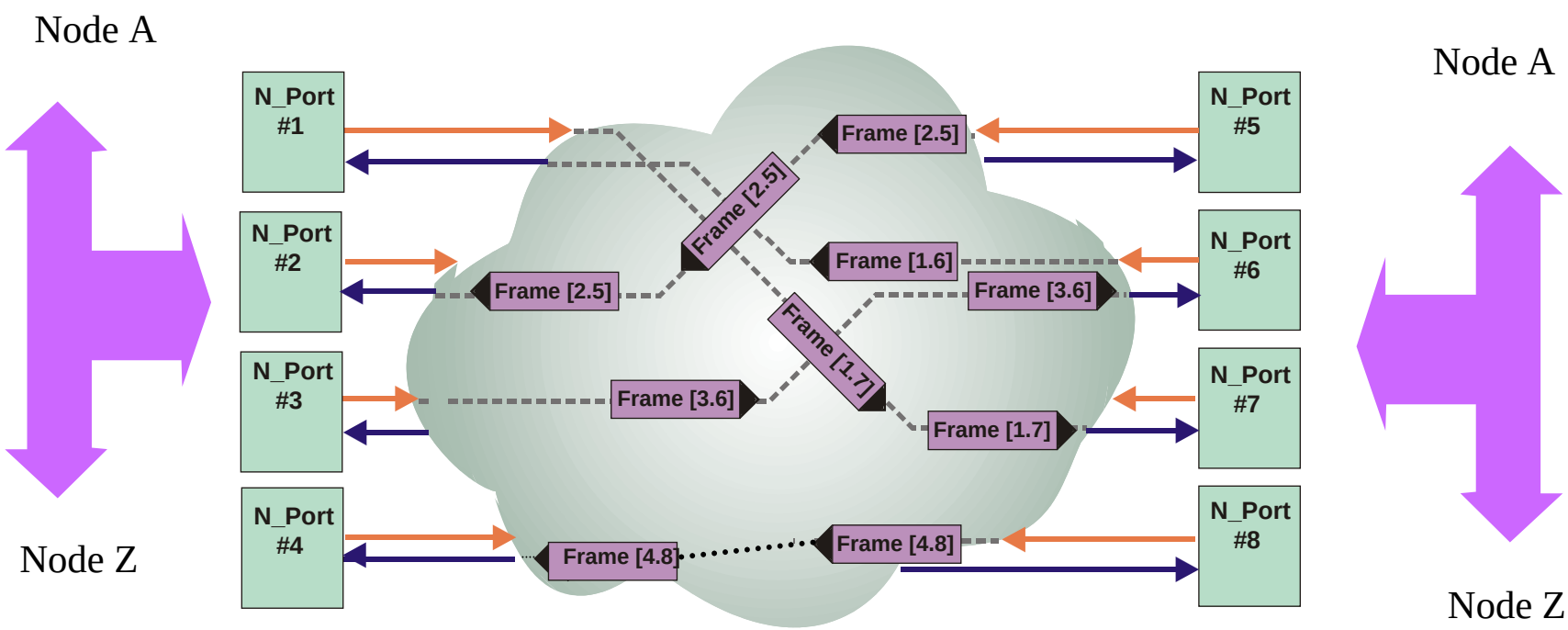
Protocol Specifics: Frame Routing



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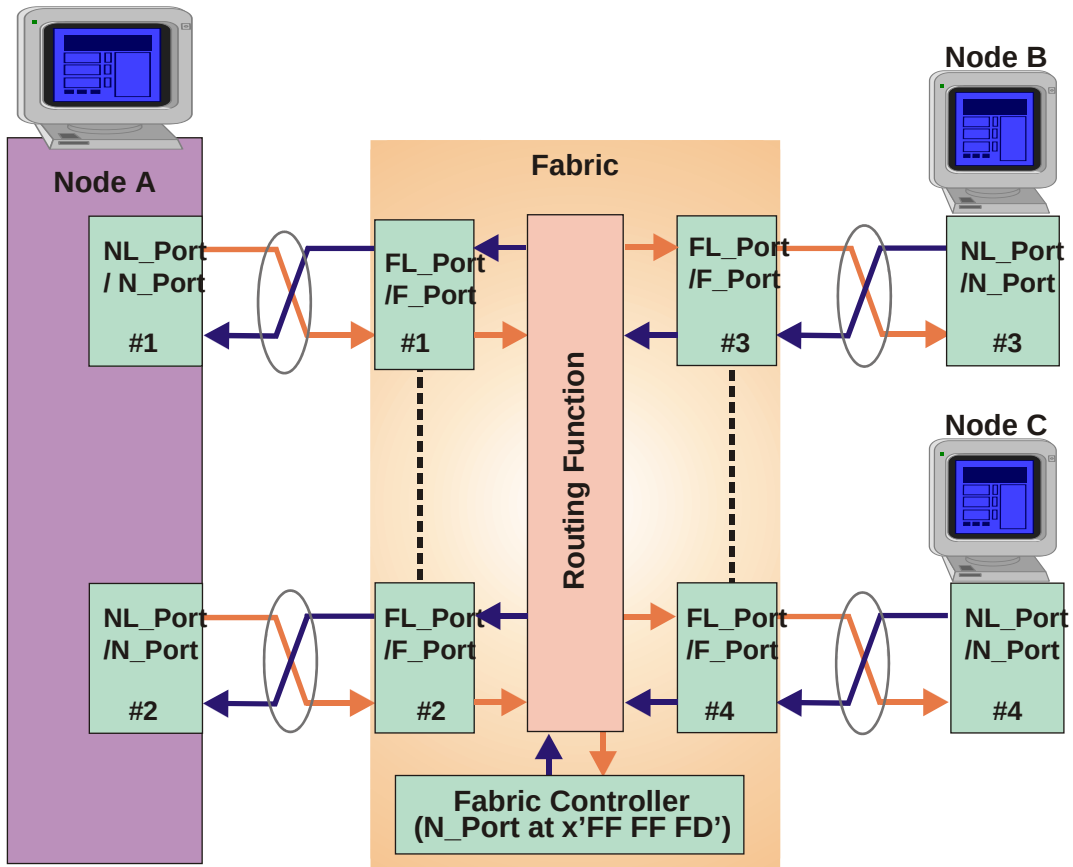
Protocol Specifics: Frame Routing



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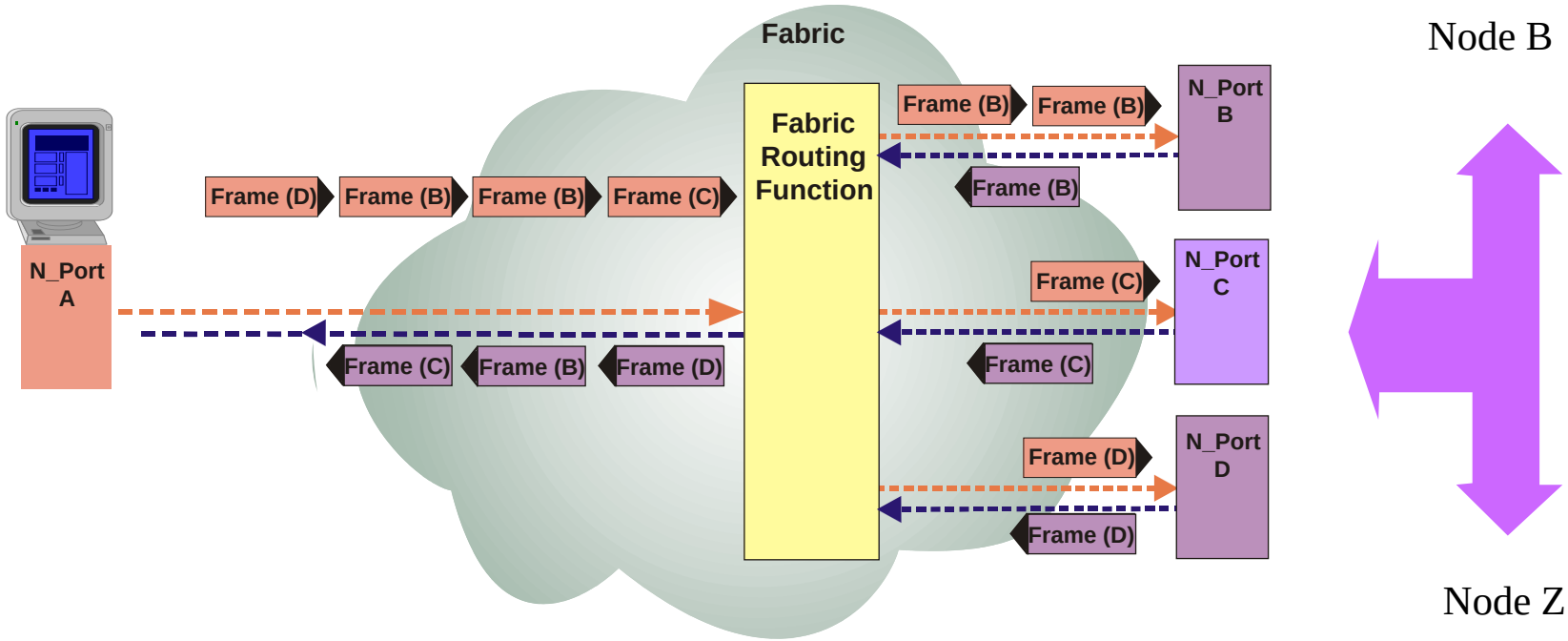
Protocol Specifics: Frame Multiplexing



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Error Handling: Link Level, Frame and Sequence

- Link Level error(Loss of Sync or Invalid characters)
  - Loop Failure → LIP & Update LESB (Link Error Status Block)
  - Timeout → Update LESB 'Link Failure Count'
- Frame Error (8B/10B, No SOF, No EOF, CRC..)
  - Discard frame
  - Update LESB
- Sequence Error (Frame Header, Delimiter, or Resource, error, Timeout, and Missing frame)
  - Reject frame (P_RJT)

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Fibre Channel Advantages over Parallel SCSI

- Fibre Channel retains the benefits of logical SCSI
  - Transparent to OS and application software
- Resolves physical limitations of SCSI
  - **Distance**
    - max 25 meters for SCSI *vs.* unlimited for FC with buffer credits
  - **Speed**
    - 40, 80, or 160 MB/s for SCSI *vs.* 100, 200 or 400 MB/s for FC (Note: newer SCSI at 320 MB/s is a counterpoint.)
  - **Number of Addressable Devices**
    - 8 or 16 for SCSI *vs.* 127 (FCAL) or 2^24 (FCSW)
  - **Cabling**
    - electrically-parallel cable (ribbon or thick round, with multiple differing connectors) for SCSI *vs.* serial cables (copper, multi-mode optical, single-mode optical) for FC

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Cost Comparison Table

Components	Before	1Gb	2 Gb	4 Gb
GBIC / SPF (Multi-mode)	$100 - 150	$ 65.00	$ 32.50	$31.22
Host Adapter “Dual Port”	2.5 – 3K	1.2K –1.5K	.9K – 1K	NA
FC Switch	30K	9K – 15K	4K – 9K	5K – 12K
FC Hub	3.5K	NA	NA	NA
FC Integrated Hub	NA	1.5K	1.5K	NA
2 m Fibre Cable	$ 50.00	$ 30.49	$ 23.50	$ 23.50
FC Router	5K	1.5K –3.5K	1.5K -3.5K	NA

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Primary Advantages of Fibre Channel

- High Bandwidth
  - Typically 2Gbps or 4Gbps vs. 1Gbps for Ethernet
- No packet loss due to congestion through FC Buffer Credits
  - No packet discard upon congestion
  - Better for low latency applications
- Widely deployed in SAN's globally
  - Defacto standard protocol for SAN
  - Likely to be dominant protocol for next 3-5 years minimum

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Q&A / Feedback

- Please send any questions or comments on this presentation to SNIA: track-networking@snia.org

Many thanks to the following individuals for their contributions to this tutorial.

SNIA Education Committee

Dr. M. K. Jibbe
Robert Kembel
Howard Goldstein
Dave Deming
SW Worth
Jack Hunt

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APPENDIX

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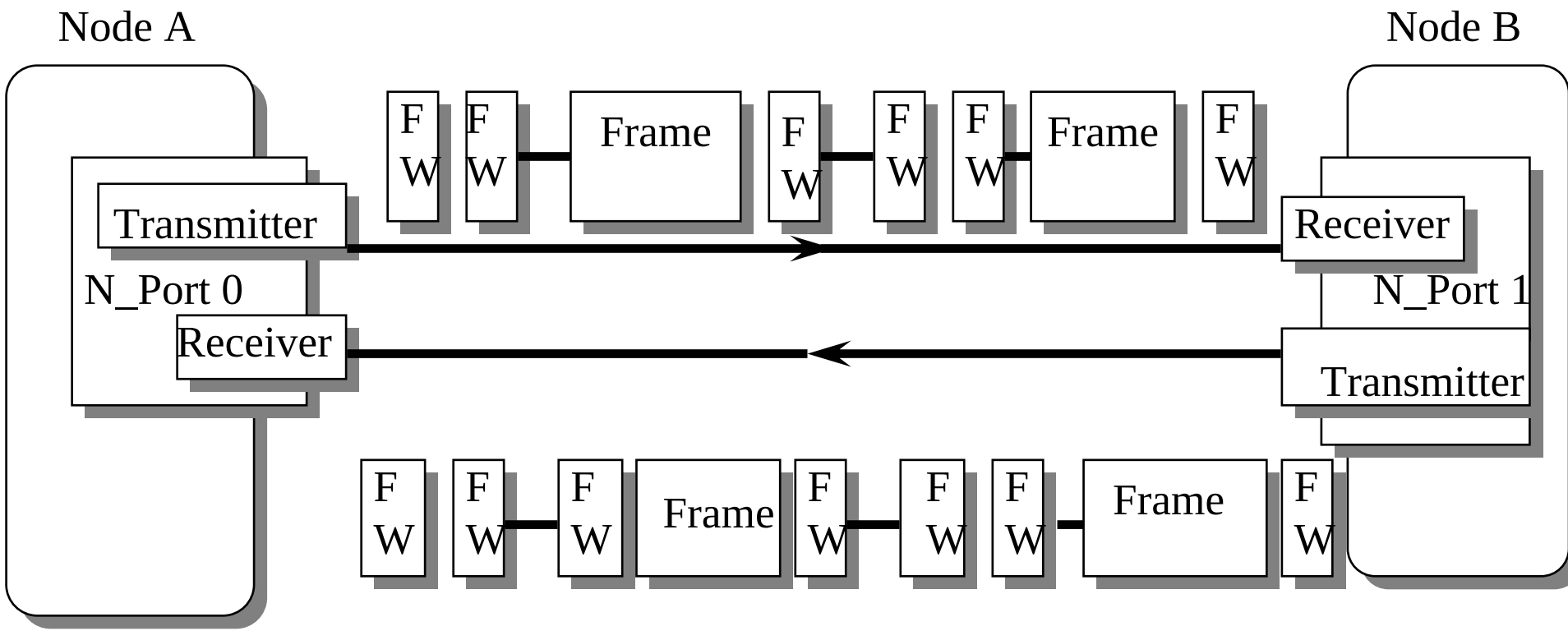
Protocol Specifics:
Fibre Channel Link X



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Protocol Specifics: Fabric Initialization – con't X

- Responses to Fabric Login:
  - If ACC with a S_ID of 0xFFFFFE and the OX_ID is the same as the OX_ID of the FLOGI command.
    - FLOGI is complete and the D_ID field of the ACC contains the N_Port address identifier.
  - If F_BSY or P_BSY with a D_ID of 0x000000 and S_ID of 0xFFFFFE.
    - The recipient is busy and the originator should retry.
  - If F_RJT or P_RJT with a D_ID of 0x000000 and S_ID of 0xFFFFFE.
    - The recipient has rejected the frame and the originator should examine the reason code and take appropriate action.
  - If no reply is received within E_D_TOV (Error Detection TimeOut Value), an error has occurred and ABTS should be performed.

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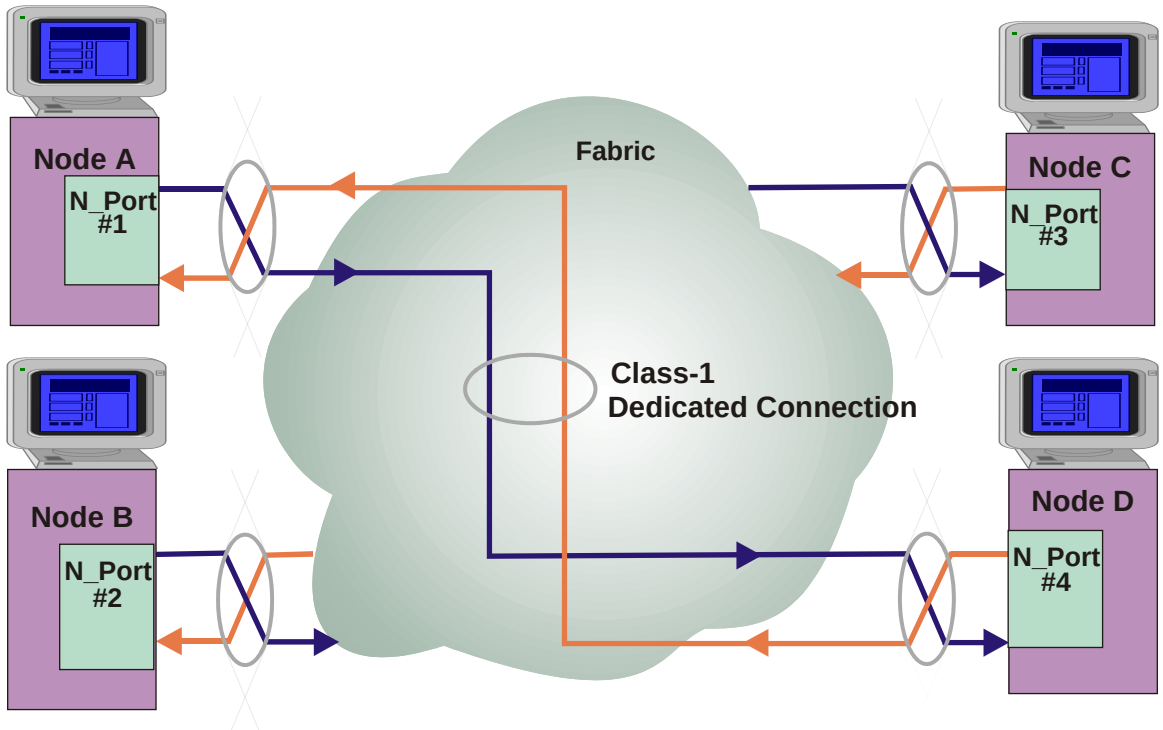
Class 1 Connection



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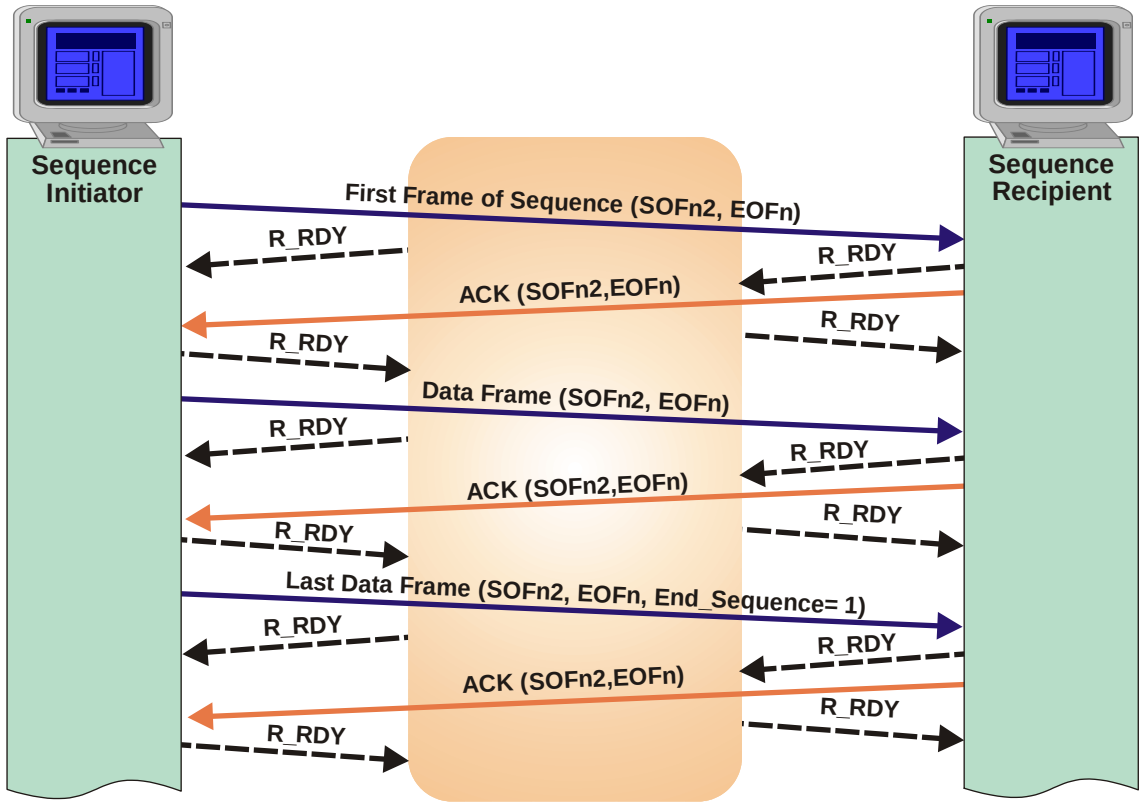
Class 2 Operation



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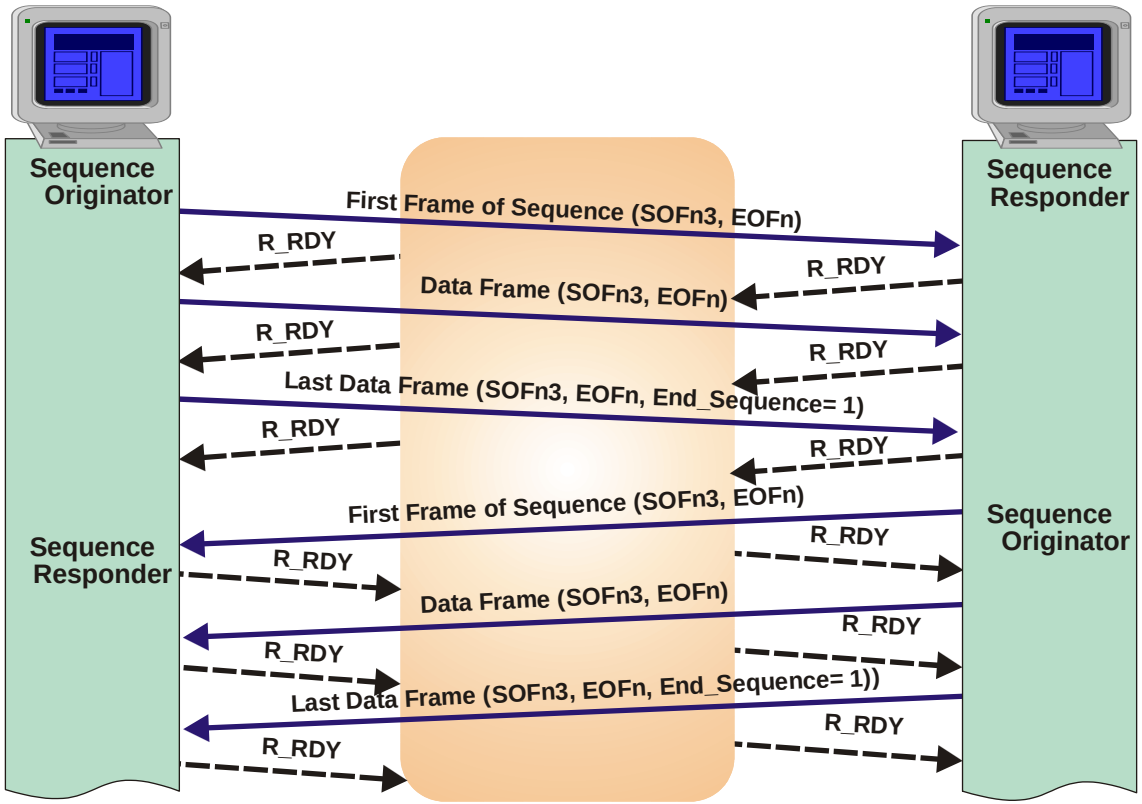
Class 3 Operations



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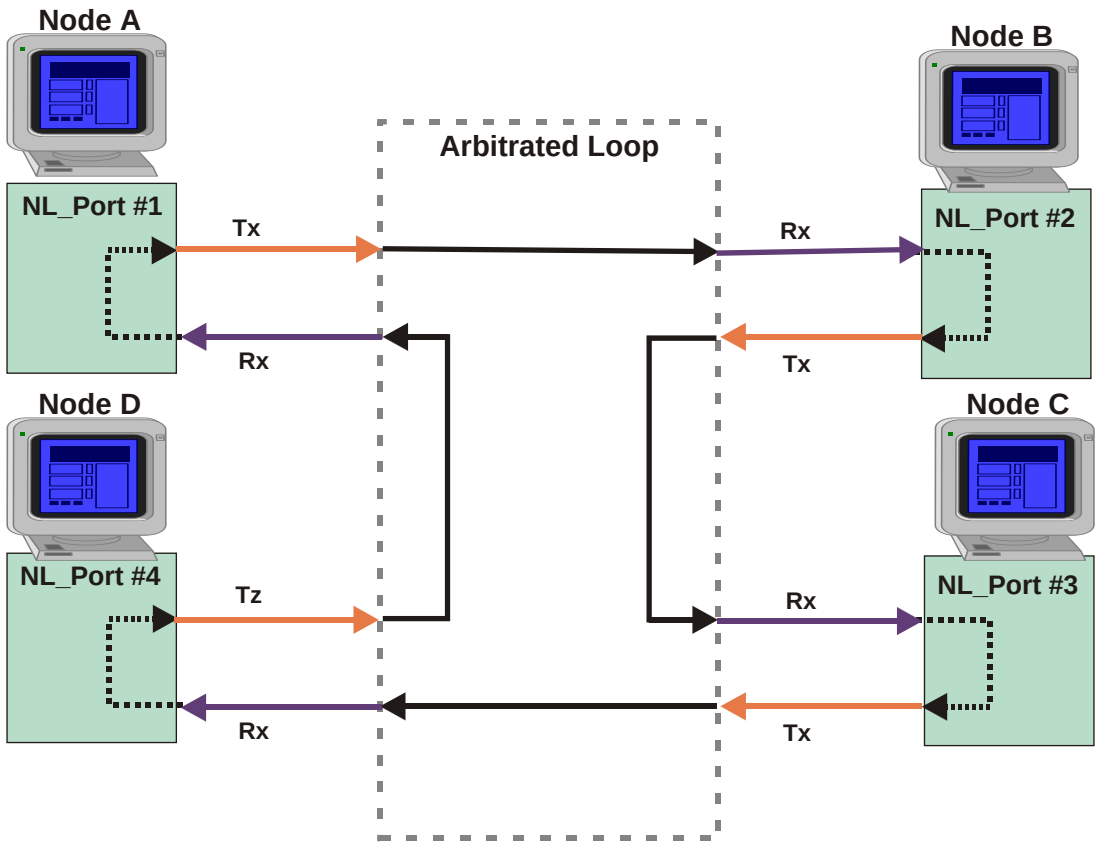
Arbitrated Loop Topology



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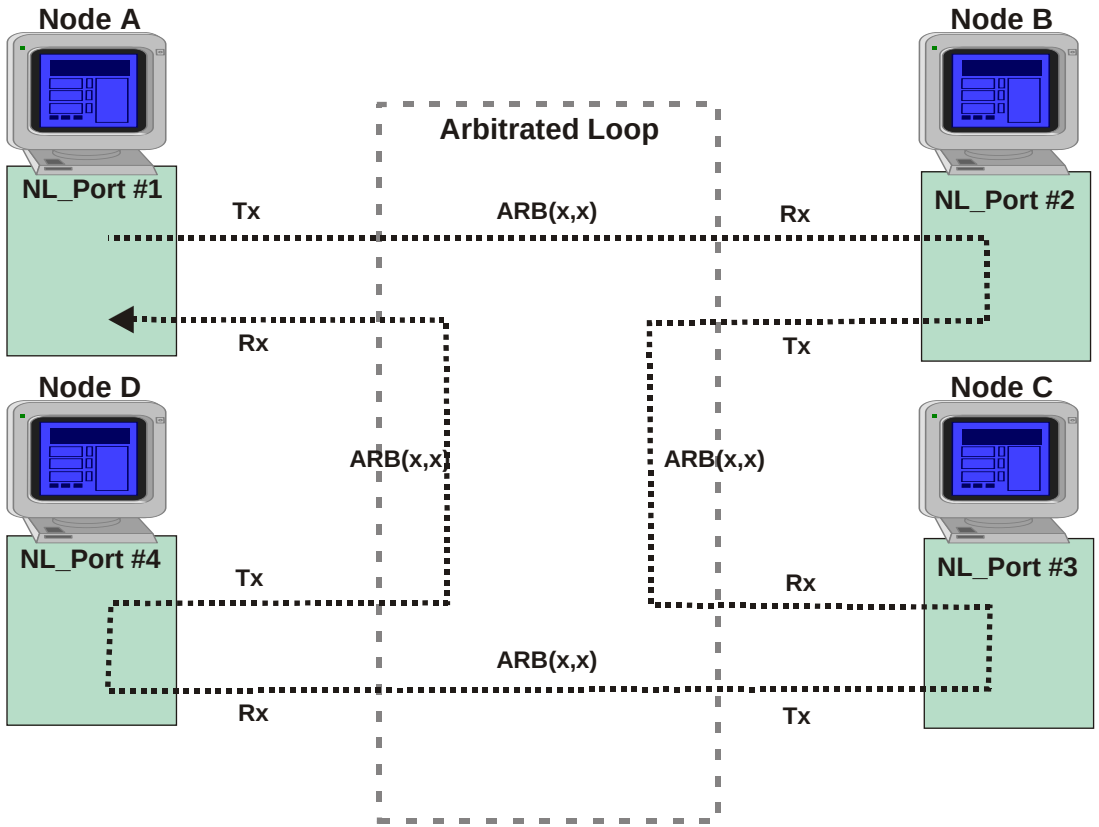
Arbitration



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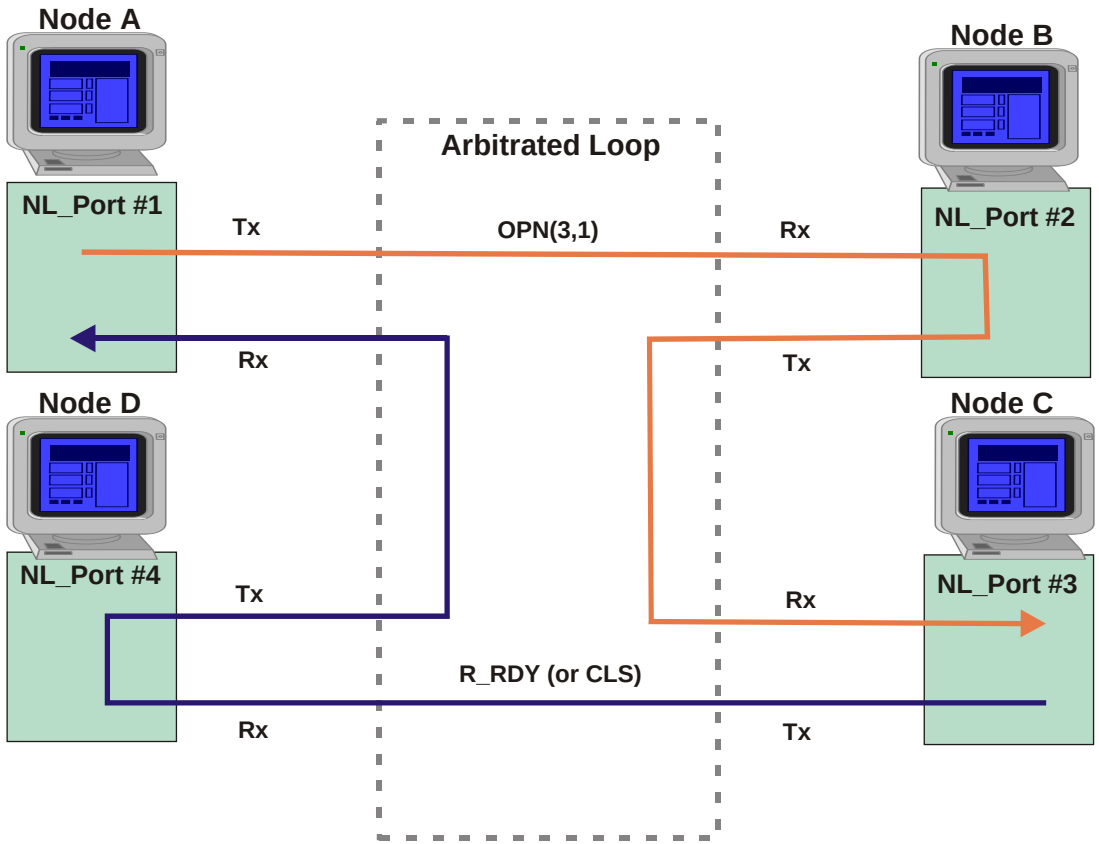
Opening a Loop Circuit



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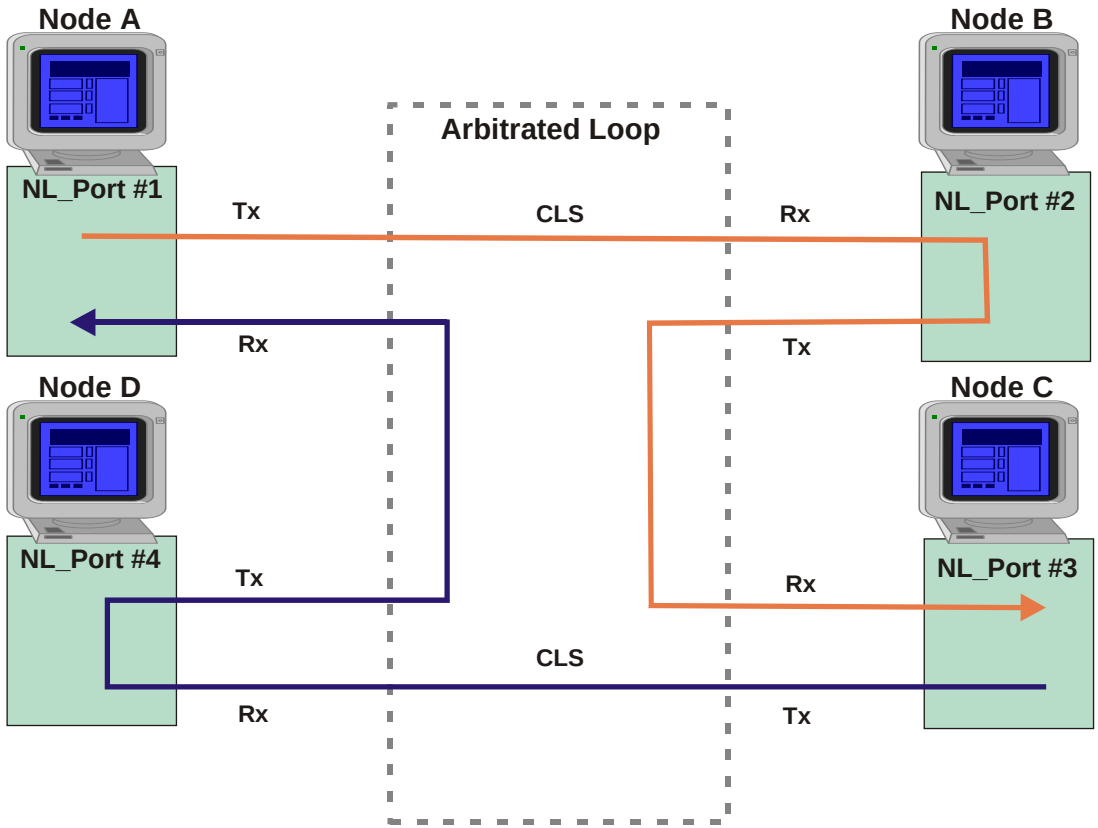
Closing Protocol



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IP Storage

- iSCSI
- FCIP
- iFCP

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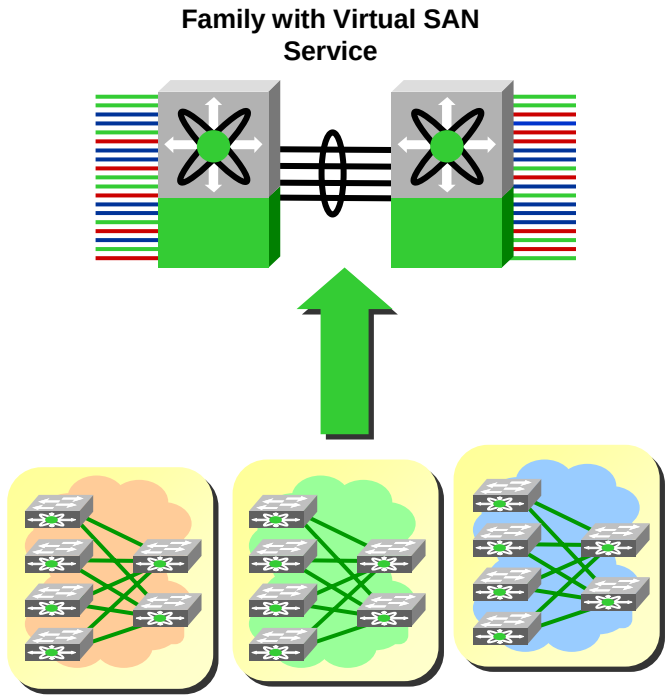
Virtual SAN

- A Virtual SAN provides a method to allocate ports within a physical fabric to create virtual fabrics
  - Analogous to Virtual LANs in Ethernet
  - Virtual fabrics created from larger cost-effective redundant physical fabric
  - Reduces wasted ports of island approach
  - Fabric events are isolated per Virtual SAN – maintains isolation for HA
  - Hardware-based isolation - traffic is explicitly tagged across inter-switch links with VSAN membership info
  - Statistics can be gathered per VSAN



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Fibre Channel Security

- Zoning defines which egress F-Ports are reachable from any ingress F-Port
  - Frames destined to F-Ports outside of the specified zone are not allowed onto the fabric (they are discarded if hard zoned)
  - All FC switches support zoning
- Authentication and access control at the end devices
- Soft zoning - restricted notification and partitioning of the WWN service offered by the fabric.
- New FC-SP security standard that include DH-CHAP and FCAP
- Most SAN's are closed and hence do not have the same security issues as IP networks linked to the public internet

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FC SAN

- Industries answer to massive growth in data storage and distributed computers
- Provides block level I/O over fiber channel
- Provides LAN free backup and restore
- Allows many to many connections from
  - Server to storage
  - Storage to storage

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