Serial Attached SCSI General Overview

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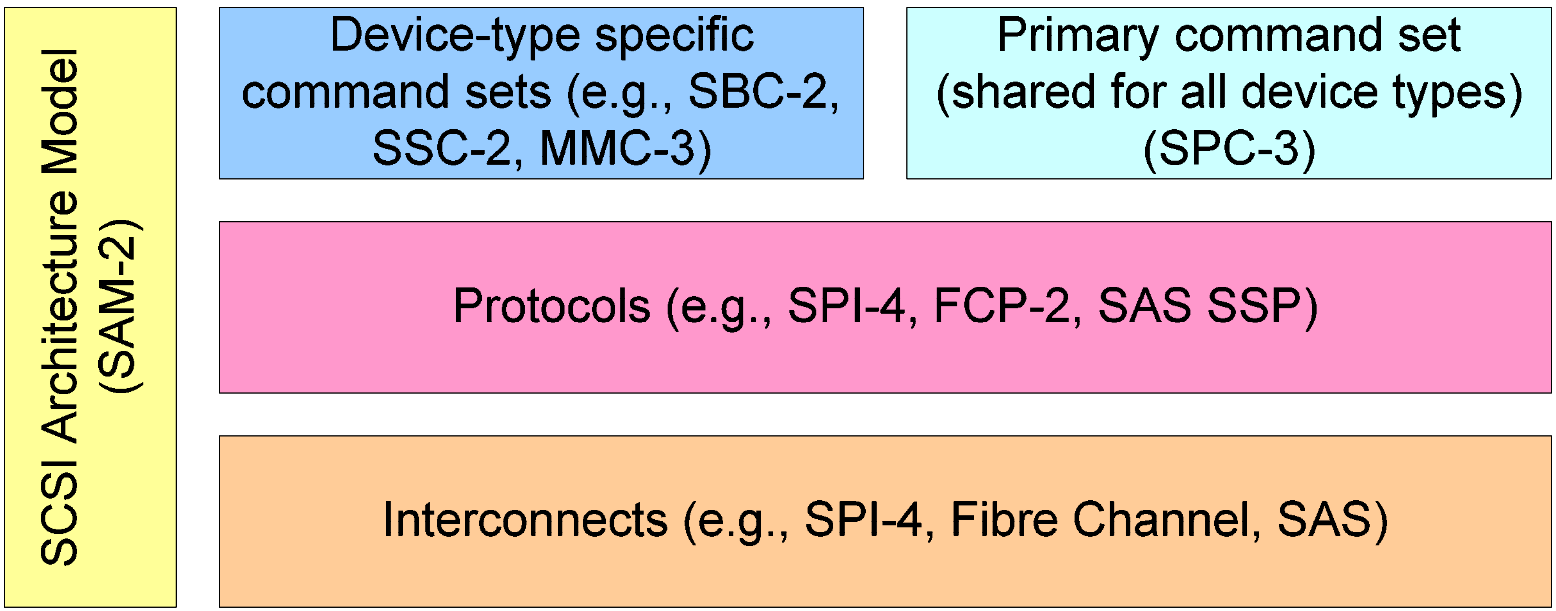
SCSI – Small Computer System Interface

History of parallel SCSI

Interconnect	Standard	Year	Speed	Key features
SASI		1979		Shugart Associates
SCSI-1	SCSI-1	1986	~ 2 MB/sec	Asynchronous, narrow
SCSI-2	SCSI-2	1989	10 MB/sec	Synchronous, wide
SCSI-3	Split command sets, transport protocols, and physical interfaces into separate standards			
Fast-Wide	SPI/SIP	1992	20 MB/sec	
Ultra	Fast-20 annex	1995	40 MB/sec	
Ultra 2	SPI-2	1997	80 MB/sec	LVD
Ultra 3	SPI-3	1999	160 MB/sec	DT, CRC
Ultra 320	SPI-4	2001	320 MB/sec	Paced, Packetized, QAS

SCSI standards structure

- With SCSI-3, SCSI has been broken into multiple standards (and has dropped the -3 moniker)
- Allows support for additional SCSI transport protocols

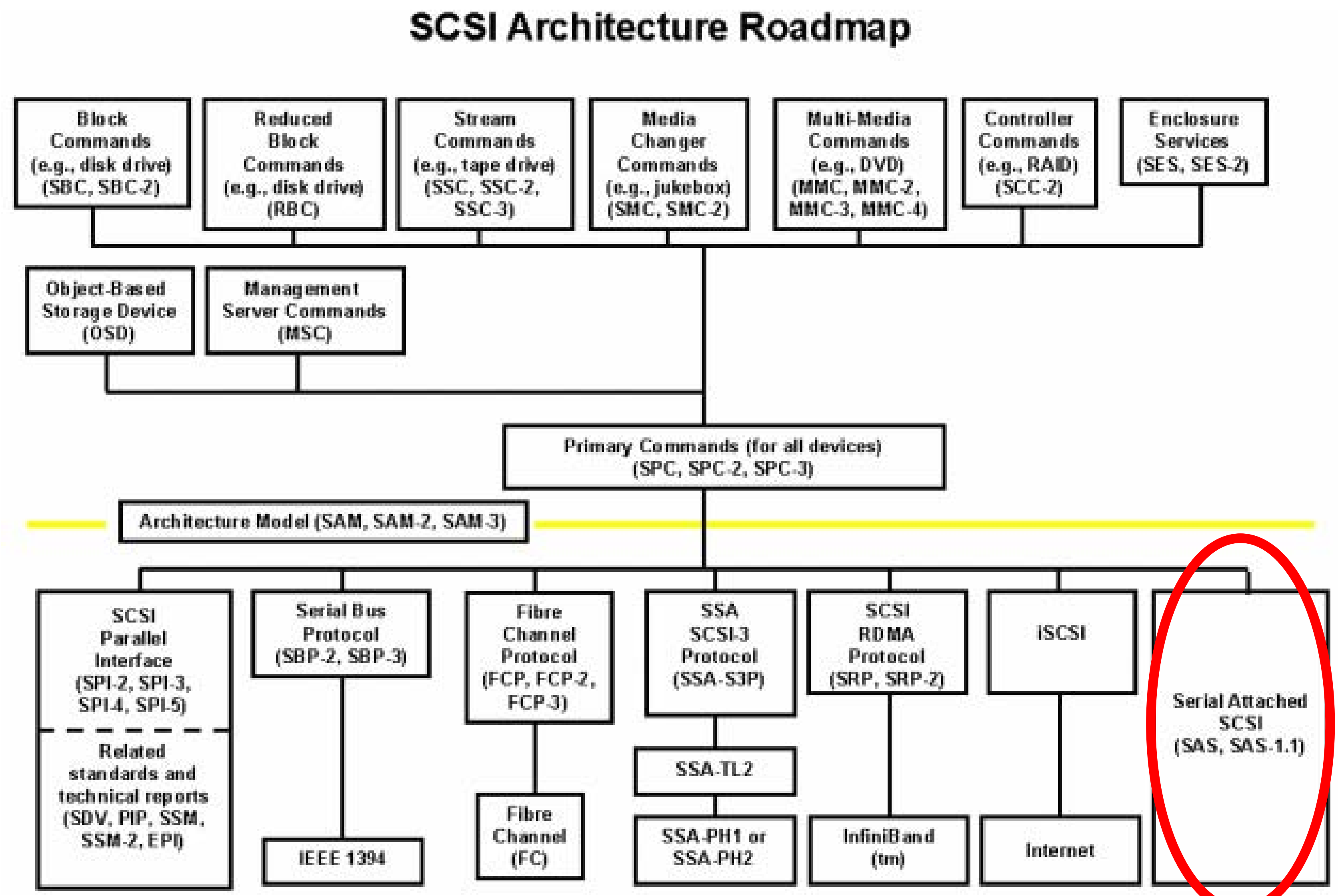


History of serial SCSI

- There have been many serial SCSI protocols

Interconnect	Standard	Year	Typical speed	Key features
Fibre Channel	FCP	1995	100 MB/sec	Optical
Serial Storage Architecture (SSA)	SSA-S2P, SSA-TL1, SSA-PL1	1996	20 MB/sec	IBM only vendor
Serial Storage Architecture (SSA)	SSA-S3P, SSA-TL2, SSA-PL2	1997	40 MB/sec	IBM only vendor
FireWire (IEEE 1394)	SBP-2	1998	50 MB/sec	
Fibre Channel	FCP-2	2002	200 MB/sec	
InfiniBand	SRP	2002	250 MB/sec	4x, 12x too
Ethernet	iSCSI	2003	~ 100 MB/sec	Gigabit Ethernet

SCSI architecture roadmap (comprehensive)



ATA – AT Attachment

History of parallel ATA

Generation	Standard	Year	Speed	Key features
IDE		1986		Pre-standard
	ATA	1994		PIO modes 0-2, multiword DMA 0
EIDE	ATA-2	1996	16 MB/sec	PIO modes 3-4, multiword DMA modes 1-2, LBAs
	ATA-3	1997	16 MB/sec	SMART
	ATA/ATAPI-4	1998	33 MB/sec	Ultra DMA modes 0-2, CRC, overlap, queuing, 80-wire
Ultra DMA 66	ATA/ATAPI-5	2000	66 MB/sec	Ultra DMA mode 3-4
Ultra DMA 100	ATA/ATAPI-6	2002	100 MB/sec	Ultra DMA mode 5, 48-bit LBA
Ultra DMA 133	ATA/ATAPI-7	2003	133 MB/sec	Ultra DMA mode 6

ATA standards architecture

ATA register-delivered command set (ATA/ATAPI-7 Volume 1)

Device-type specific command sets (e.g., MMC-3)

Primary command set (shared for all device types) (SPC-3)

ATAPI
(Packet delivered command set)
(ATA/ATAPI-7 Volume 1)

ATA/ATAPI register set (ATA/ATAPI-7 Volume 1)

Protocols (e.g., SAS STP, ATA/ATAPI-7 Volume 2 (parallel ATA), ATA/ATAPI-7 Volume 3 (Serial ATA))

Interconnects (e.g., SAS, ATA/ATAPI-7 Volume 2 (parallel ATA), ATA/ATAPI-7 Volume 3 (Serial ATA))

History of serial ATA

Generation	Standard	Year	Speed	Key features
Serial ATA	ATA/ATAPI-7	2002	150 MB/sec	
Serial ATA II	ATA/ATAPI-8?	2003?	300 MB/sec	Enhanced queuing
Serial ATA III	ATA/ATAPI-9?	?	600 MB/sec	

Distinct markets

- Different classes of disk drives

Characteristic	Mobile	Desktop	Enterprise
rpm	3600, 4200, 5400 rpm	5400, 7200 rpm	10K, 15K rpm
Seek time	12 – 14 ms	8.9 – 9.5 ms	3.2 – 7.4 ms
Performance as file server*	N/A	79 – 136	146 - 366
Write cache	2 MB	2 – 8 MB	2 – 8 MB
Capacity	10 – 80 GB	40 – 250 GB	18, 36, 72, 144, 180 GB
Reliability	300 K hr MTBF	500 K hr MTBF	1.2 M hr MTBF
Power	2.5 W	10 W	15 W
Cost	$73 – $160	$75 – $240	$160 – $1400
Interfaces	ATA/66, ATA/100	ATA/100, ATA/133	Ultra 160 SCSI, Ultra 320 SCSI, FC

* Benchmark of many drives on http://www.storagereview.com   Note: As of mid 2002

Bringing SCSI and ATA together…

Serial Attached SCSI (SAS)

- Serial Attached SCSI (SAS) supports both SCSI and ATA
- Three transport protocols
  - Serial SCSI Protocol (SSP)
    - Supports SAS (SCSI) disk drives, tape drives, etc.
  - Serial ATA Tunneling Protocol (STP)
    - Supports Serial ATA disk drives
  - Serial Management Protocol (SMP)
    - Supports SAS expanders

Positioning SATA, SAS, and FC

Desktop PC / Workstation

Mainstream Servers / Direct Attached Storage

Storage Area Network

PC Chipset

SAS HBA

Server chipset with SAS support, SAS HBA card, or SAS RAID card to drives or JBODs

FC HBA to external storage

Configuration Flexibility & Simplicity

One host design accommodates SATA for Low Cost Bulk Storage or SAS for Performance & Reliability in Mission Critical Apps

SATA

SAS

FC

Desktop-class disk drives (single port)

Enterprise-class disk drives (single or dual port)

Enterprise-class disk drives (dual port)

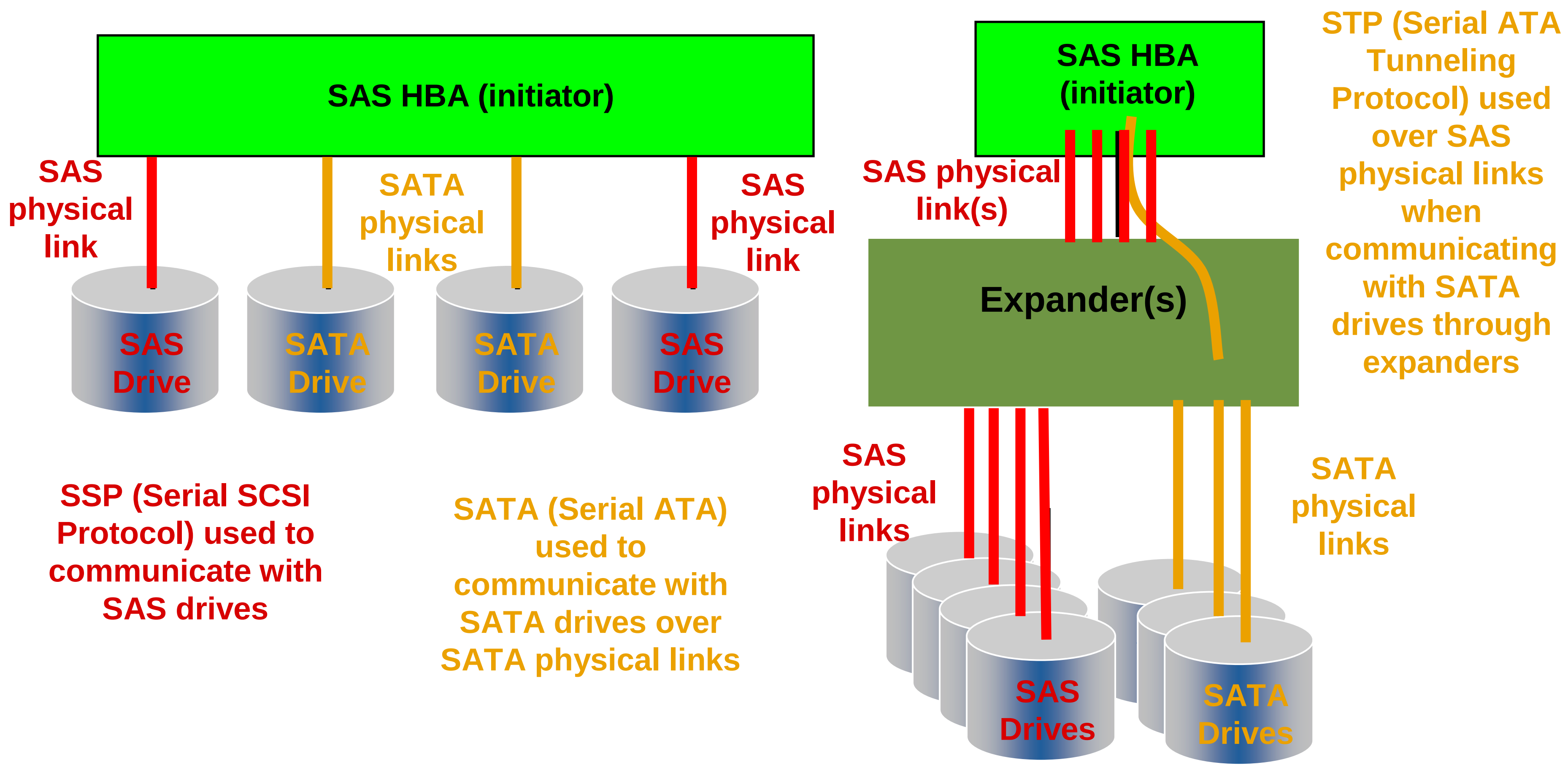
Compatible physical layer between SATA and SATA

Similar HDD ASIC and firmware design between SAS and FC

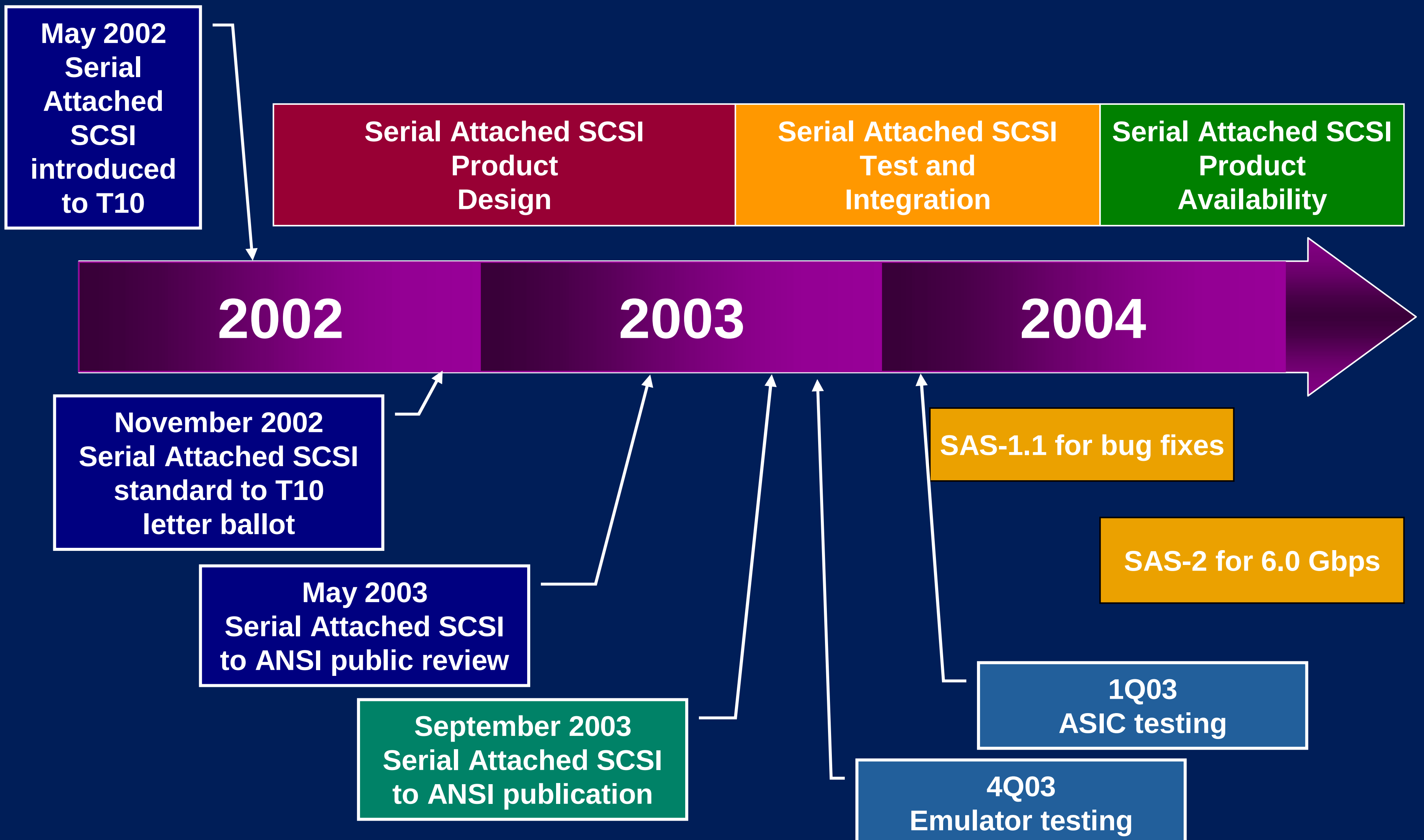
Direct attach and expander attach

Direct attach =
Number of drives limited to number of ports in the HBA

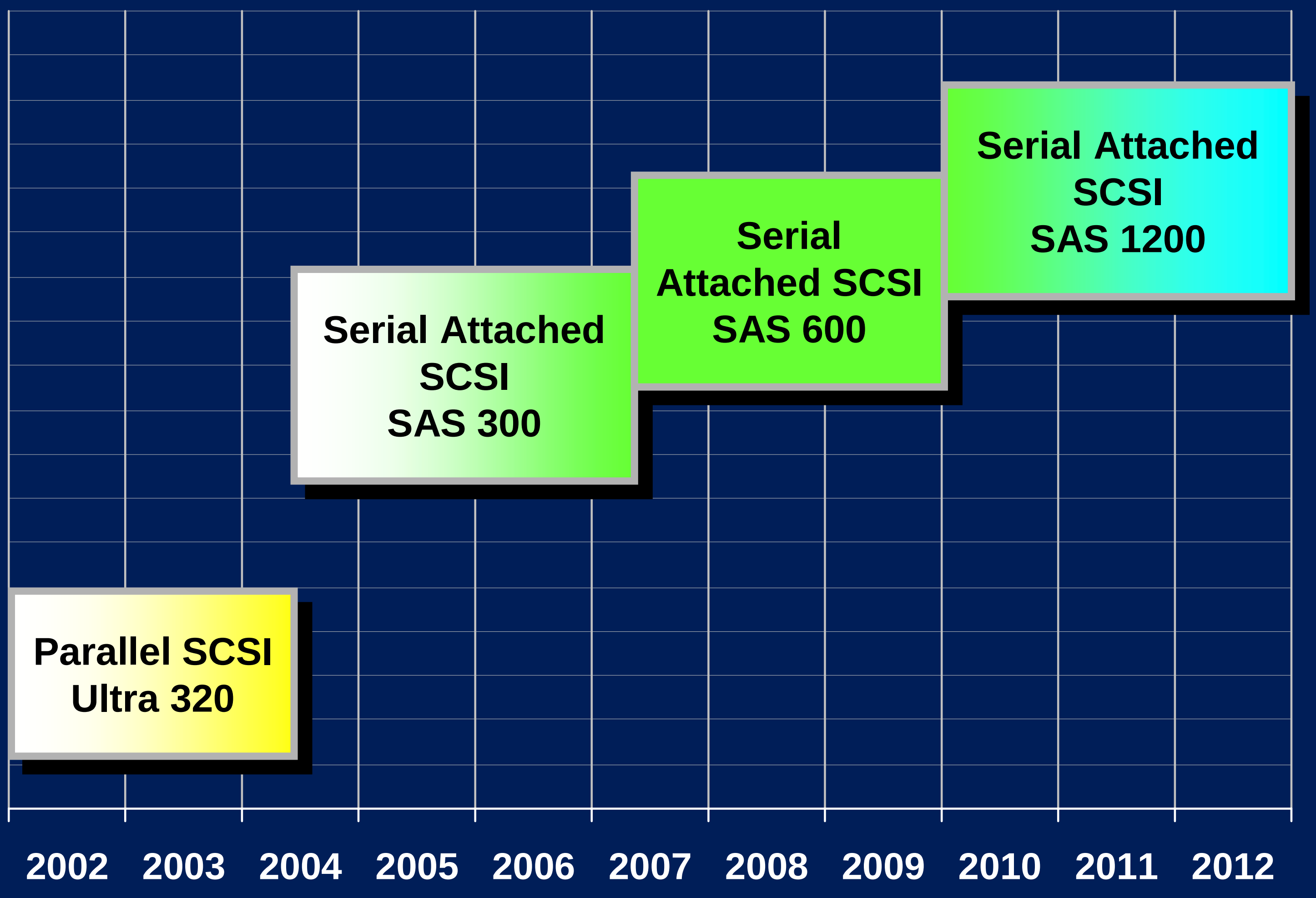
Expander attach =
More drives than HBA ports



Serial Attached SCSI timeline



SCSI Trade Association roadmap



SAS press releases (part 1)

- 11/26/2001 Compaq/IBM/LSI Logic/Maxtor/Seagate
  - Industry Leaders Team to Form Serial Attached SCSI Working Group to Address Next-Generation Interconnect Needs
- 2/4/2002 STA
  - SCSI Trade Association and Serial Attached SCSI Working Group Announce Agreement
- 5/6/2002 STA
  - INCITS Technical Committee T10 Accepts Proposal to Begin Work on Serial Attached SCSI Standard
- 6/12/2002 Dell/HP/Intel
  - Industry Leaders Collaborate on New Choices for Next-Generation Serial Architectures for Server Storage
- 1/9/2003 STA
  - Serial Attached SCSI Letter Ballot Released by T10
- 1/20/2003 STA
  - STA and SATA II Working Group Agree to Collaborate on Specification Alignment
- 1/20/2003 HP/Seagate
  - Seagate Demonstrates Industry's First Serial Attached SCSI Storage Solutions with HP
- 1/20/2003 LSI Logic
  - LSI Logic and Leading Hard Disk Drive Manufacturers Initiate Serial Attached SCSI Product Planning

SAS press releases (part 2)

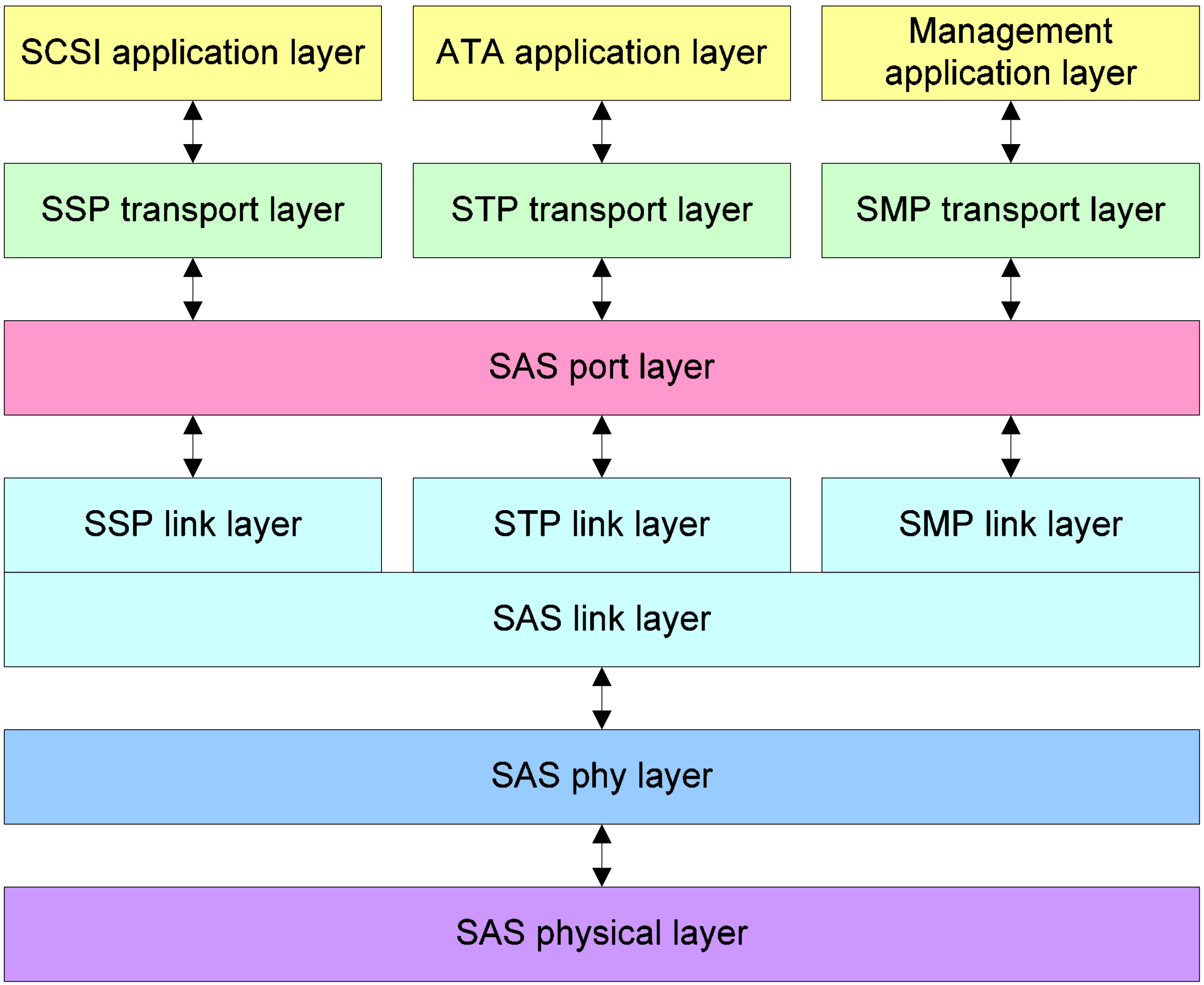
- 3/18/2003 Adaptec
  - Adaptec First Host Bus Adapter Provider to Transmit Serial Attached SCSI Protocol Packet
- 3/25/2003 Hitachi/LSI Logic
  - Hitachi and LSI Logic to Accelerate Delivery of Serial Attached SCSI
- 4/15/2003 Emulex/Intel
  - Emulex and Intel to Develop first Storage Processors for Serial ATA, SAS and Fibre Channel within a Single Architecture
- 4/21/2003 Adaptec/Fujitsu/Hitachi/Maxtor/Seagate
  - Adaptec Teams with Fujitsu, Hitachi, Maxtor and Seagate to Bring First Serial Attached SCSI Solutions to Market
- 4/29/2003 LSI Logic/Seagate/Tabernus
  - Tabernus, LSI Logic and Seagate Technology Work Together for Serial Attached SCSI
- 5/9/2003 LSI Logic
  - LSI Logic First To Demonstrate Serial Attached SCSI Initiator-to-Target Functionality with Full Read/Write Validation
- 6/11/2003 Adaptec/Maxtor/Tabernus
  - Tabernus, Adaptec, and Maxtor Work to Ensure Compatibility of Serial Attached SCSI Solutions, Speed Time to Market

SAS press releases (part 3)

- 6/16/2003 Adaptec/HP/Seagate
  - Adaptec, HP and Seagate Technology Team to Debut Compatibility of Serial Attached SCSI and Serial ATA at CeBIT America
- 6/24/2003 LSI Logic/Maxtor
  - LSI Logic and Maxtor Extend Testing of Serial Attached SCSI Prototypes
- 6/26/2003 LSI/Seagate
  - LSI Logic Teams With Seagate to Drive Serial Attached SCSI Interoperability
- 6/30/2003 Maxtor
  - Maxtor Demonstrates Early Success with Serial Attached SCSI Interface
- to be continued…

Serial Attached SCSI standard

SAS standard layering



SCSI: mode pages, log pages, spinup
Mgmt: SMP functions

Frame definitions

Wide port handling

Frame transmission

Connection management
Primitives

OOB, speed negotiation
8b10b encoding

Electrical specs
Cables and connectors

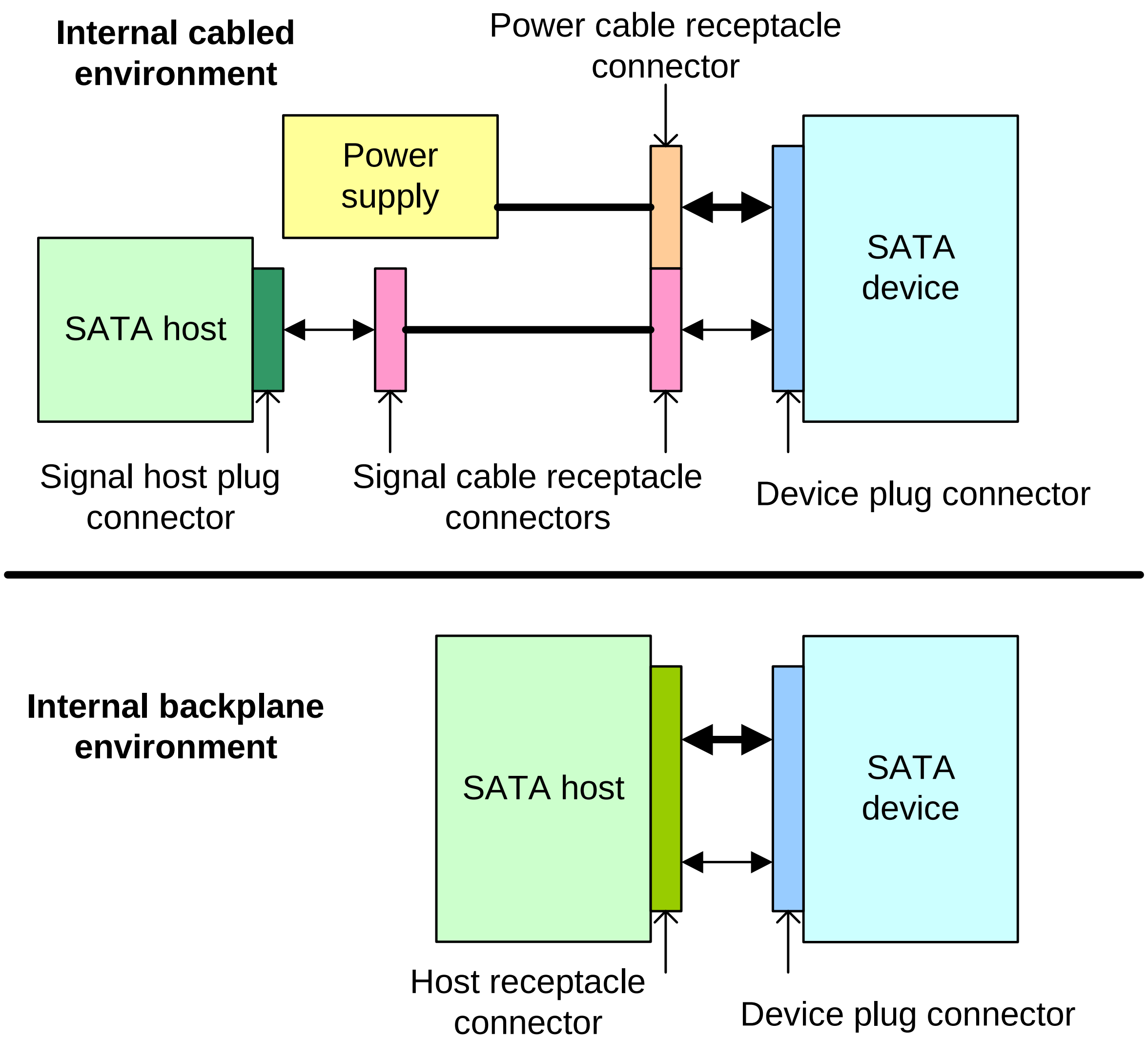
Key features of SAS by layer

- Physical layer – connectors
- Architecture - Expanders and topologies
- Phy layer – OOB and speed negotiation
- Link layer - connections
- Transport layer – frames
- Wrap Up

Physical layer

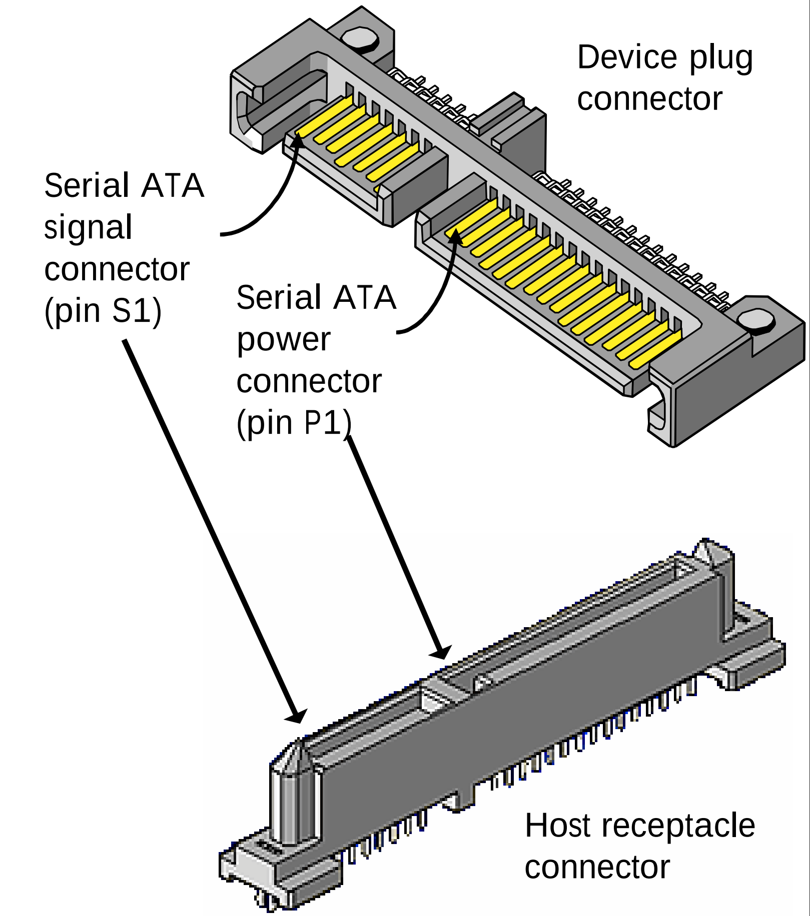
SATA cables and connectors

- SATA 1.0 was defined for internal use only (e.g. inside a PC)
- 1 m internal cable
- No external connectors/cables

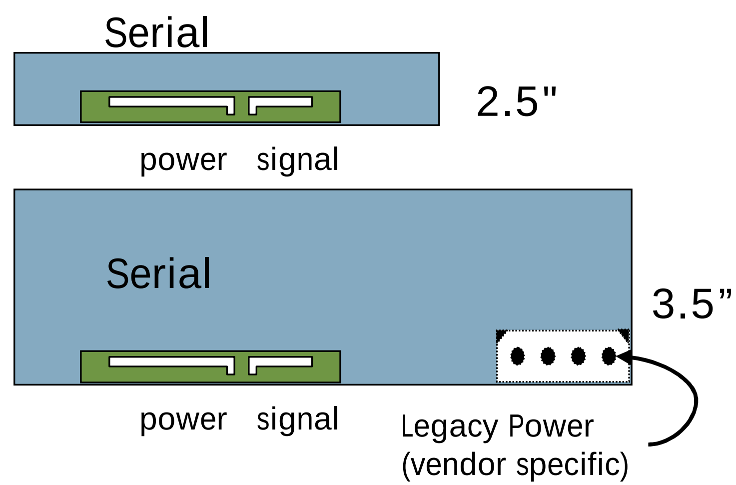


SATA device connector

Appearance of Serial ATA Connectors
(Drawing courtesy of Molex)

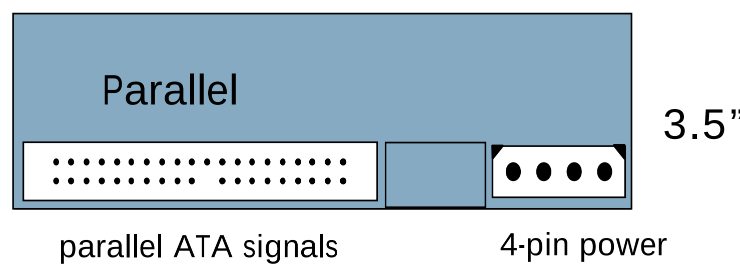


Device connector sizes and locations



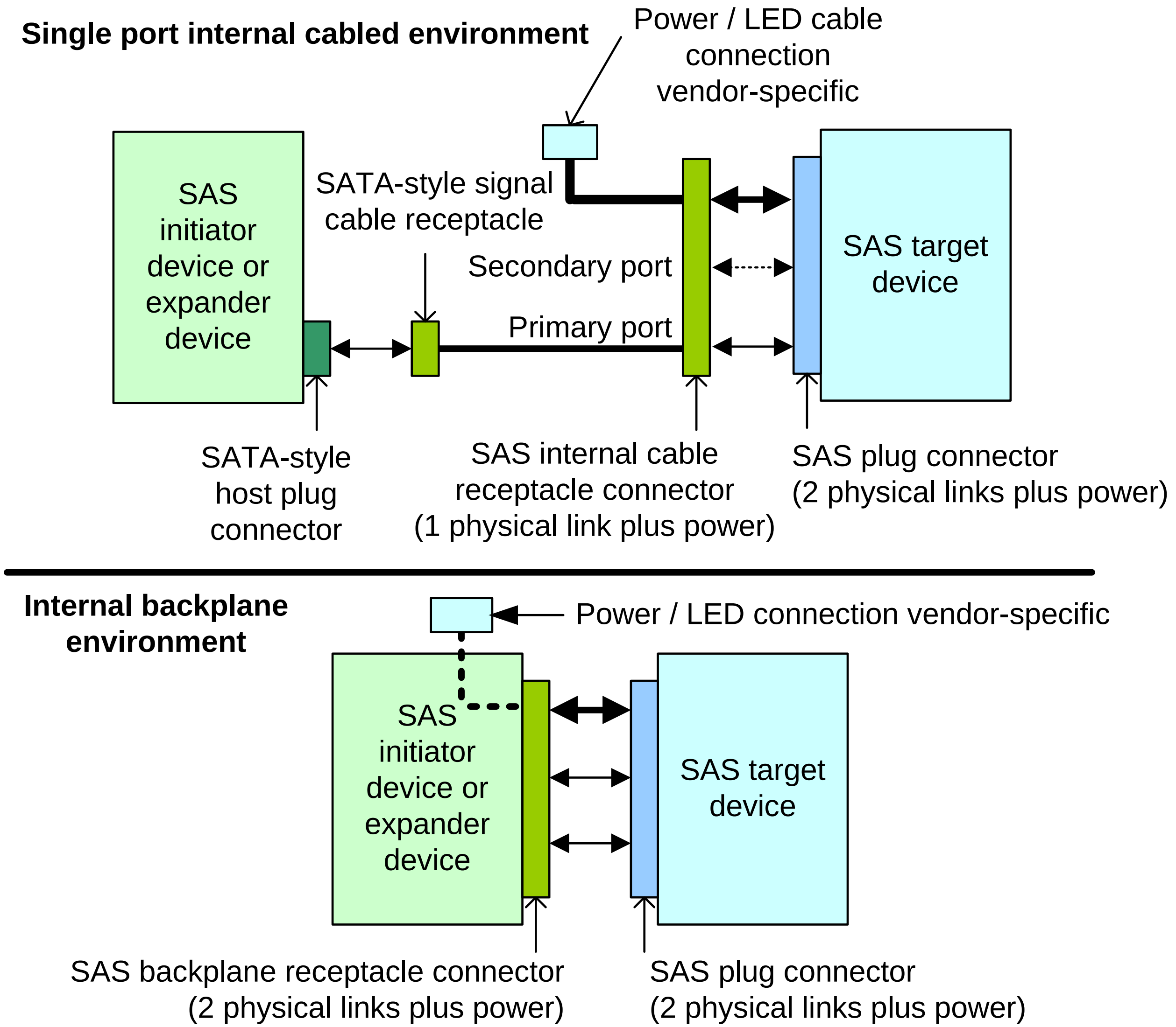
(5.25” form factor also defined for devices like tape drives and DVDs)

in comparison…

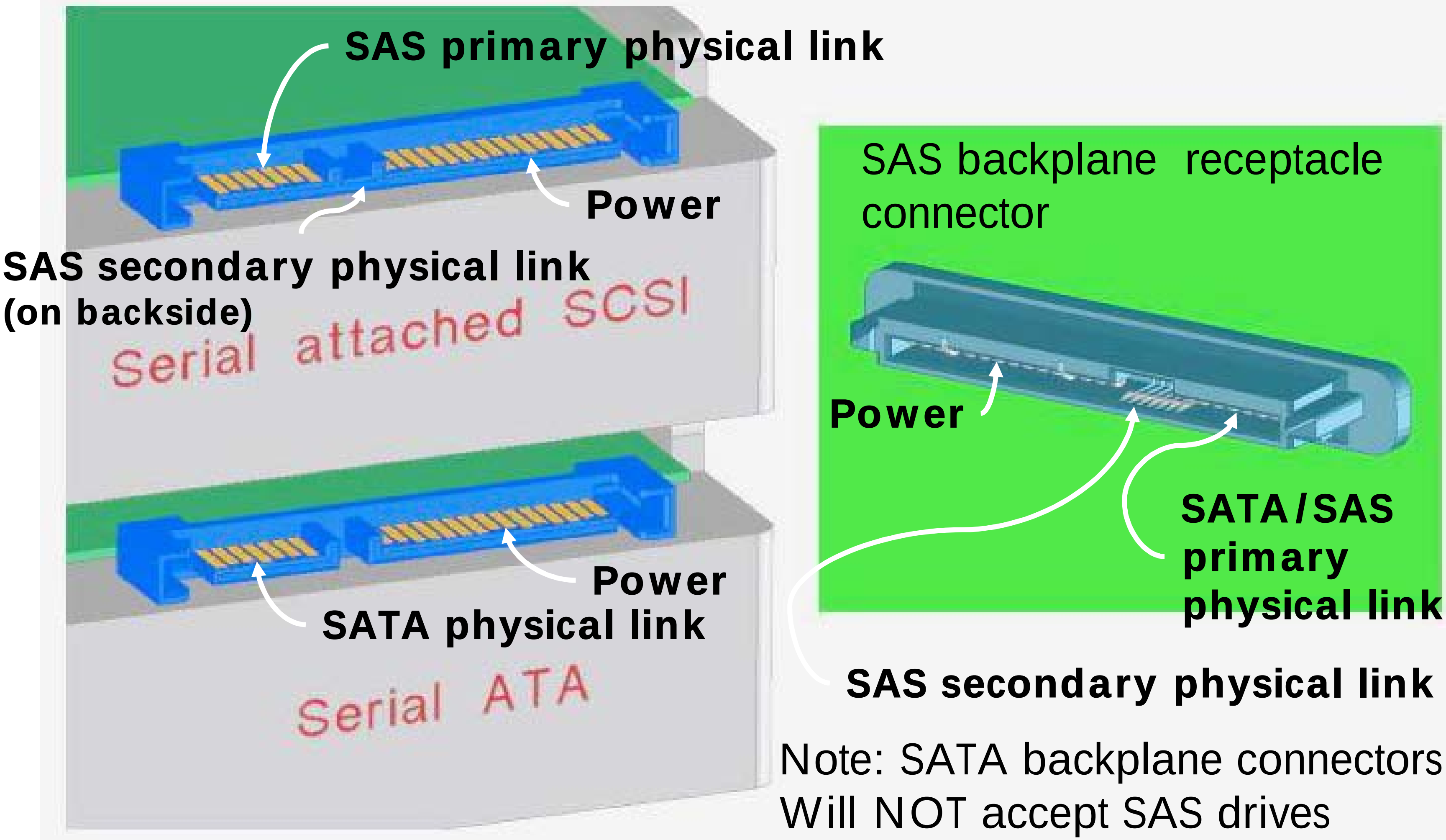


SAS cables and connectors - internal

- Similarly, SAS defines internal environments
- Backplanes support two physical links
- Cables mainly support one phy (for debug, two physical link cables might be useful)
- HP proposing 4x internal connector for SAS-1.1



SAS plug and backplane receptacle connectors

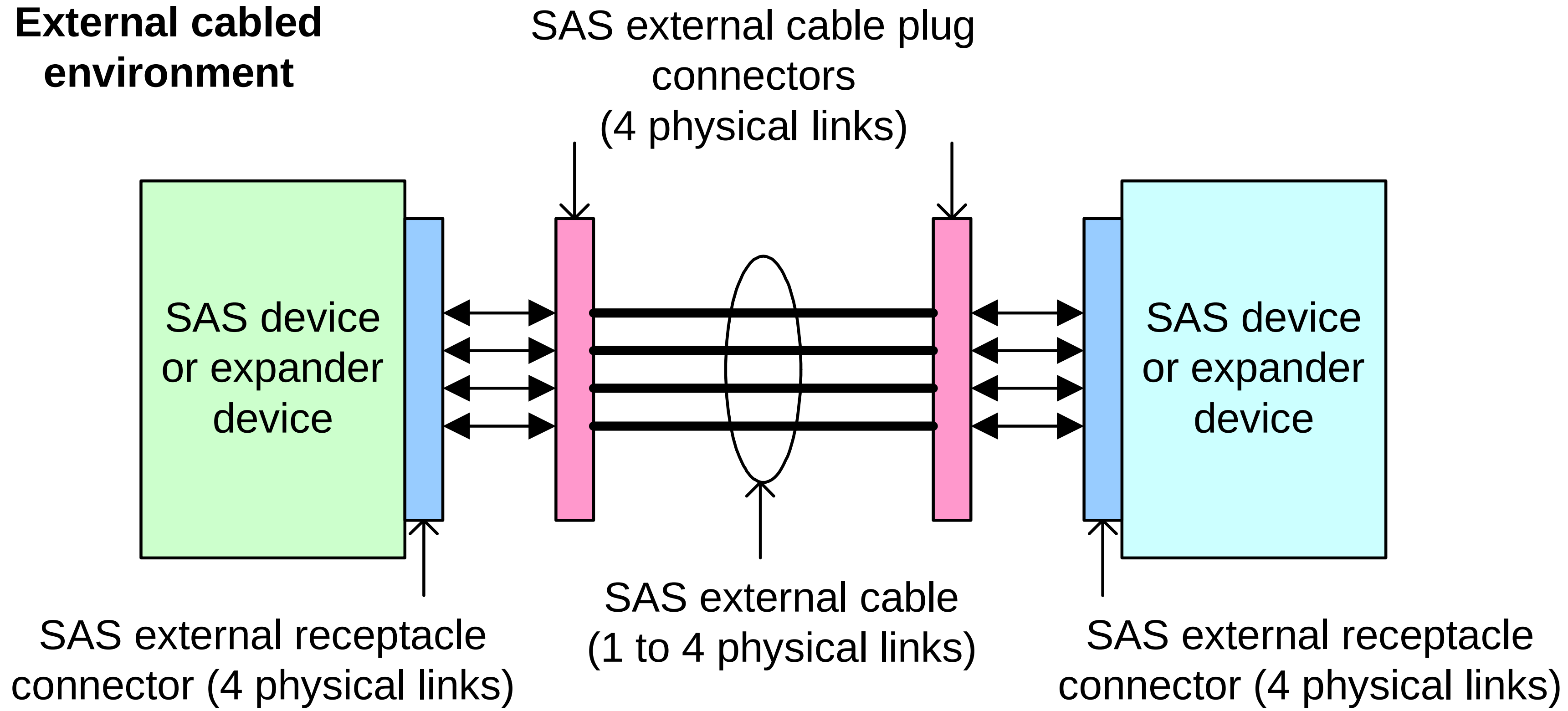


Note: SATA backplane connectors
Will NOT accept SAS drives

SAS cables and connectors - external

- SAS defines an external (box-to-box) environment using InfiniBand 4x connectors and cables

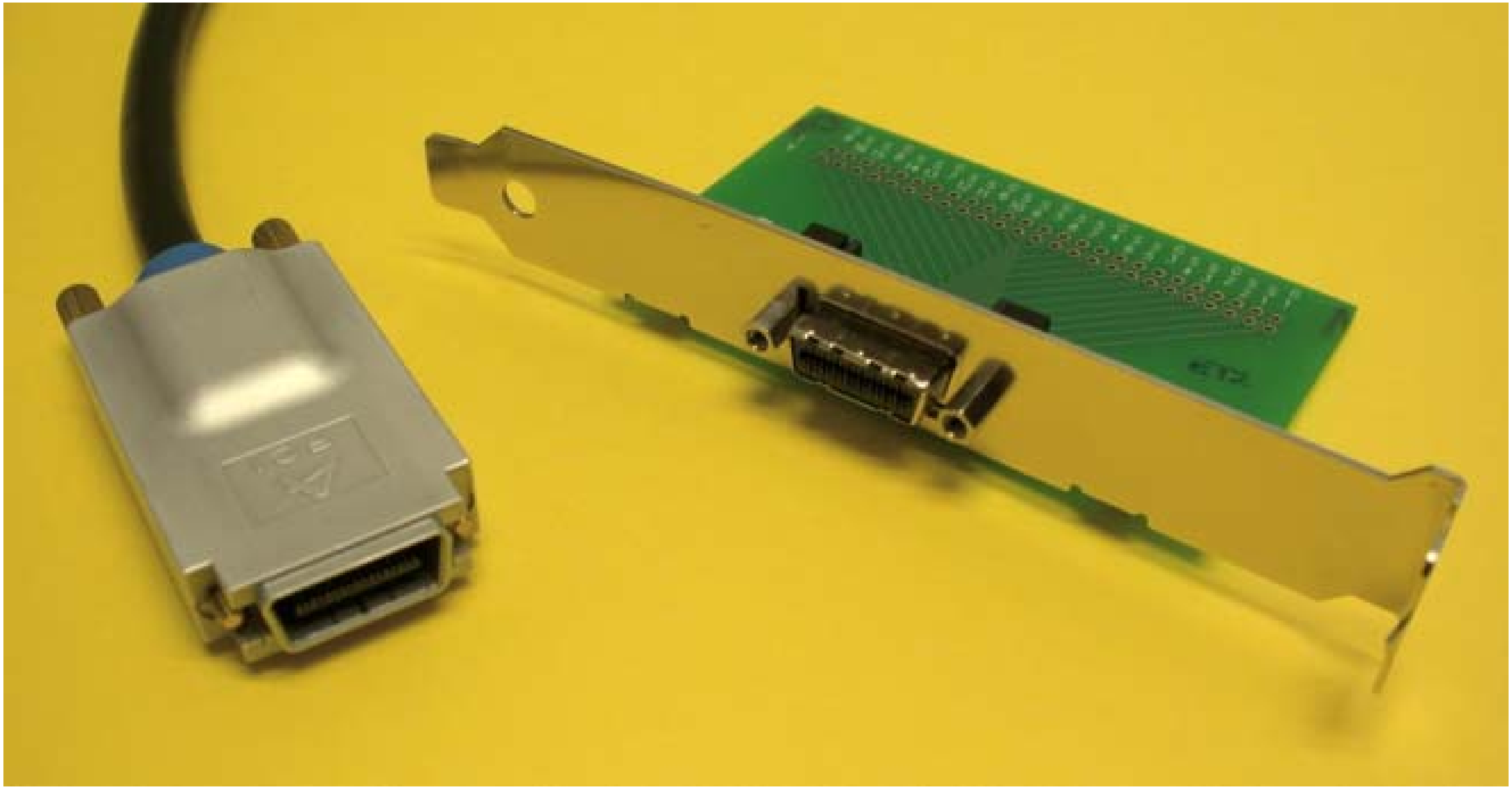
External cabled environment



(SAS external cable connects the Tx signal pins to the Rx signal pins on each physical link)

SAS external receptacle connector

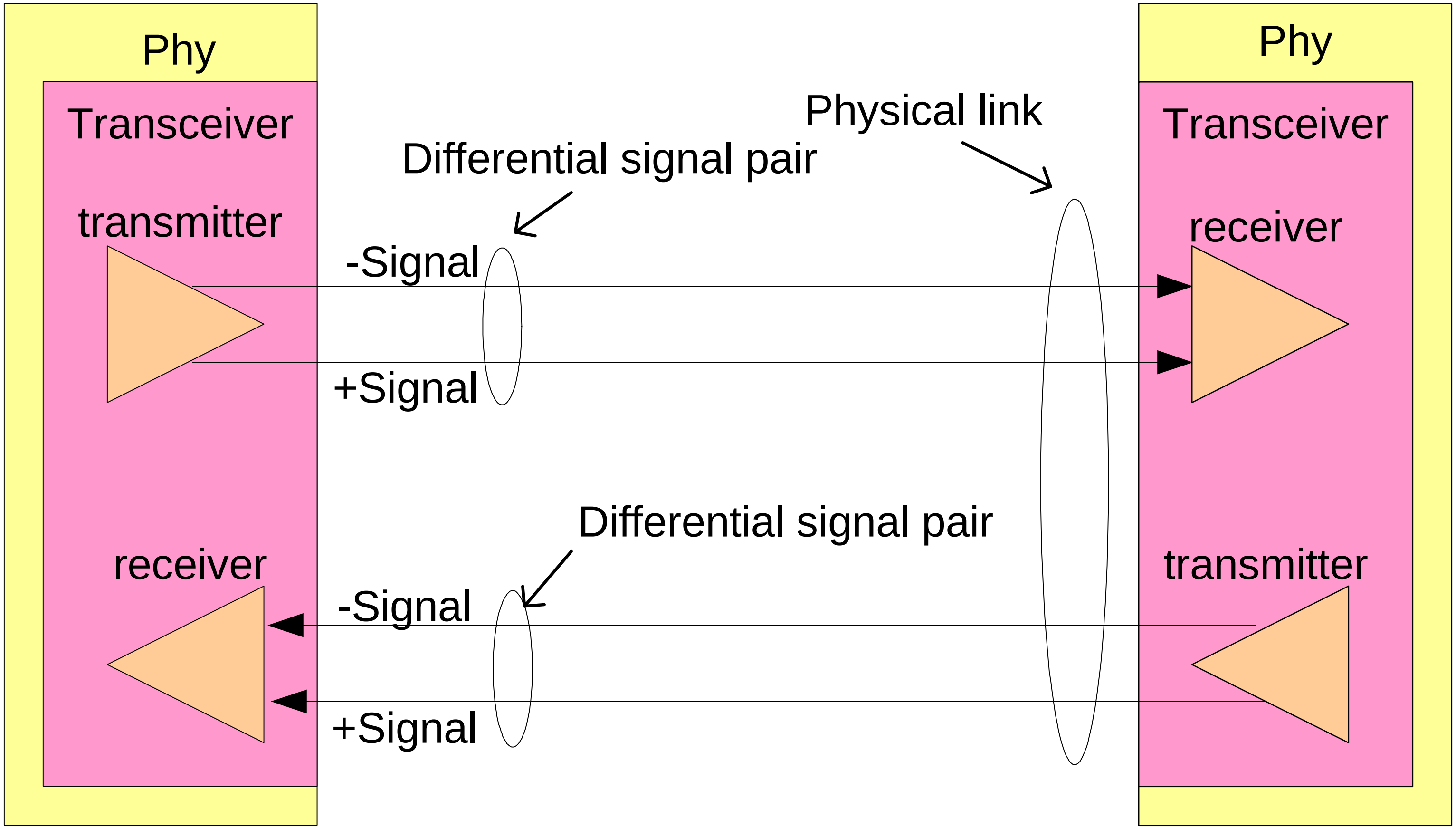
- (picture courtesy FCI / Berg)



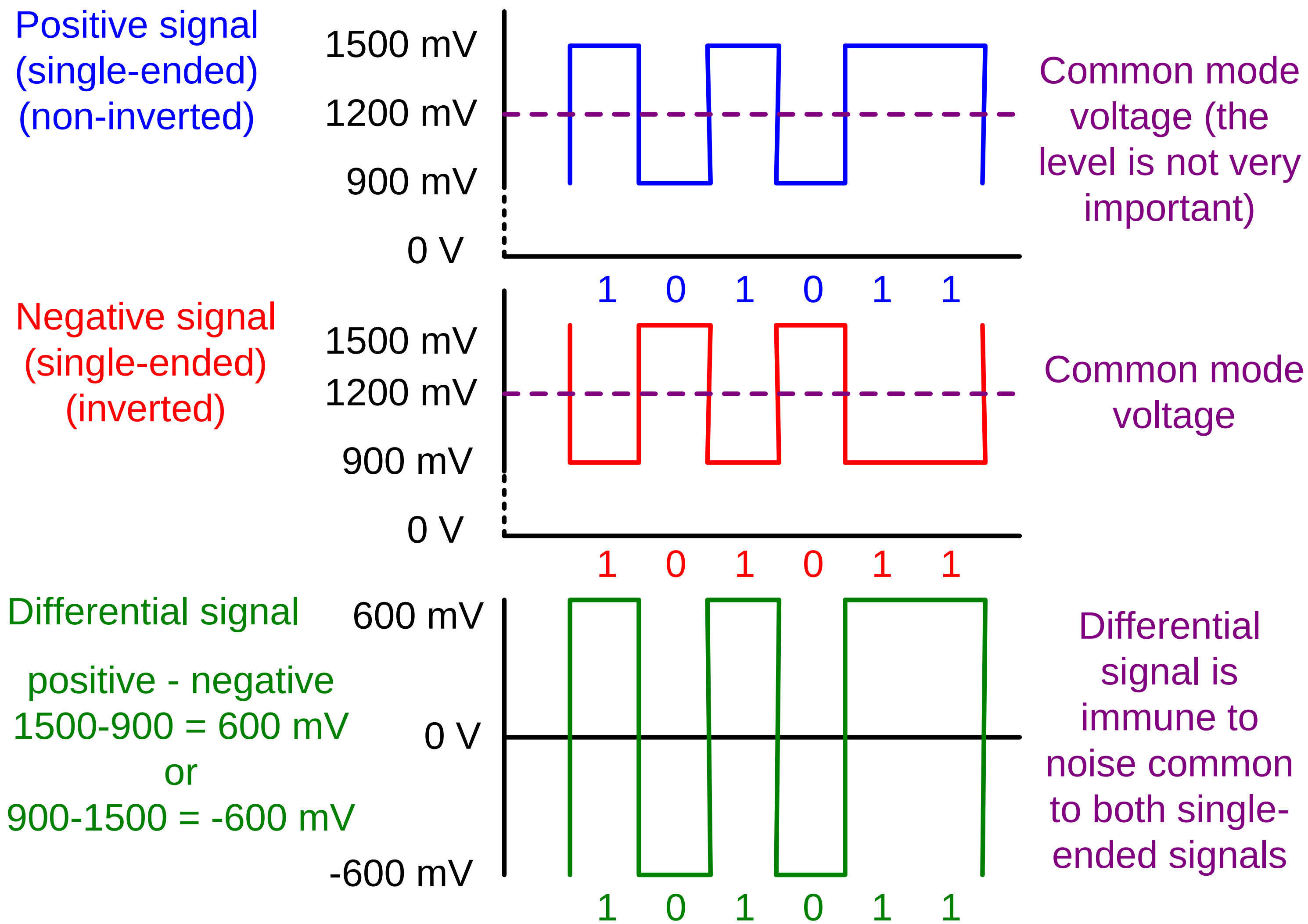
Architecture

Physical links and phys

- A phy contains one transceiver
- A physical link attaches two phys together



Differential signaling

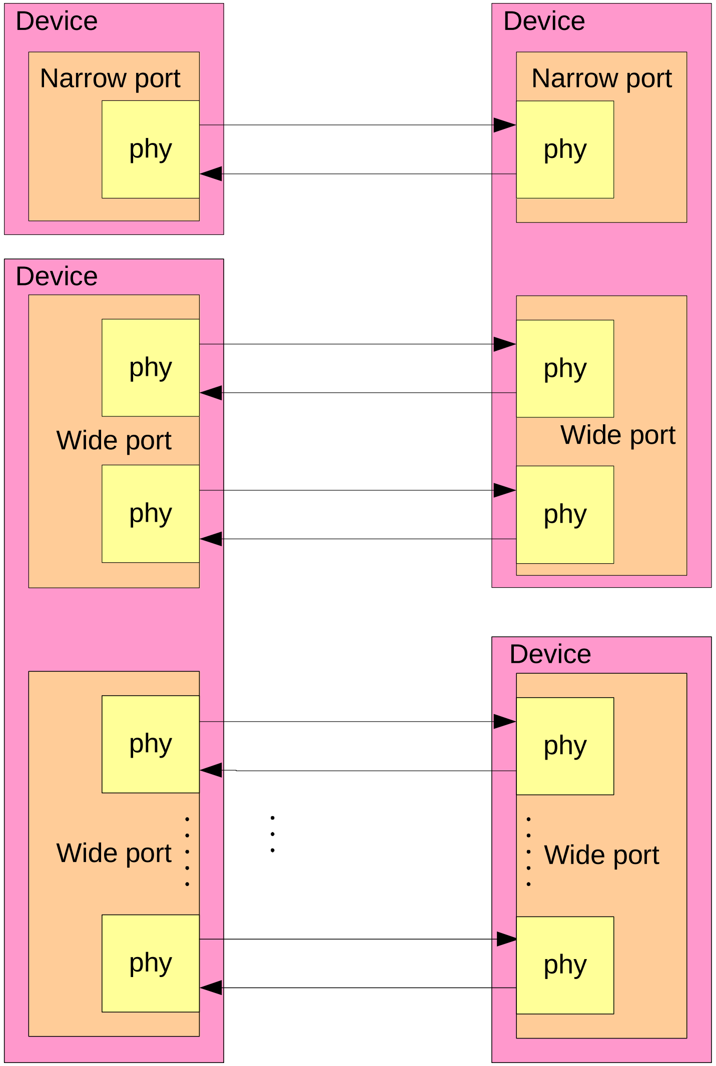


Physical link rate

- Each direction runs 1.5 Gbps or 3.0 Gbps (150 MB/sec or 300 MB/sec)
  - Both directions use the same physical link rate
- Dual simplex (full duplex) operation – 600 MB/sec total bandwidth
- Example: peak bandwidth needs of an HBA with 8 phys
  - 2400 MB/sec half duplex, 4800 MB/sec full duplex

SAS devices and ports

- SAS devices contain ports
- Ports contain phys
- Ports are virtual constructs
  - Groups of phy with the same SAS address, attached to another group of phys with the same SAS address



Each horizontal line represents a differential signal pair

SAS address

- Each SAS port and expander device has a worldwide unique 64-bit SAS address
- Same namespace as the Fibre Channel Port_Name

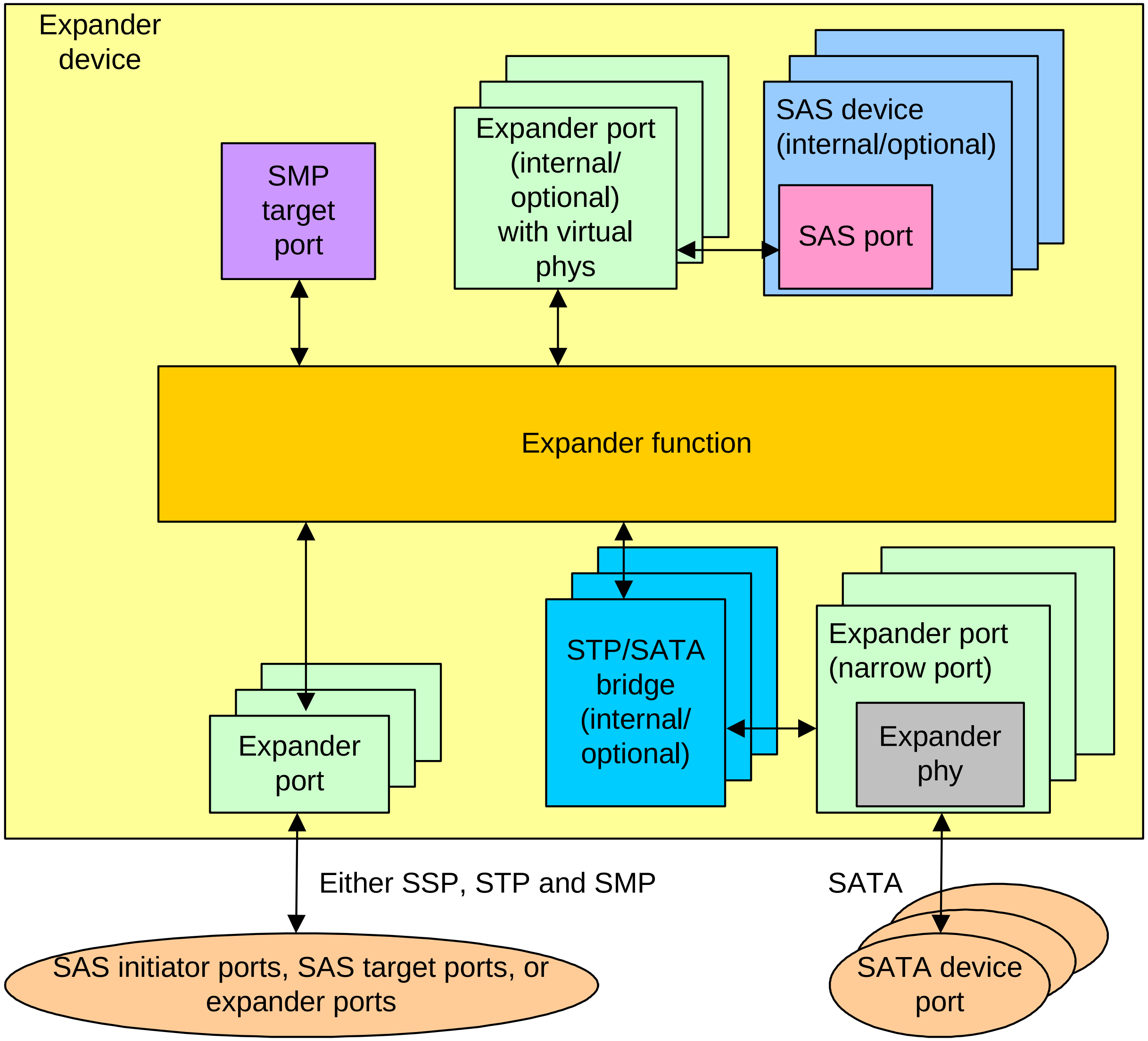
Byte\Bit	7	6	5	4	3	2	1	0
0	NAA (5h)							
1	IEEE Company ID (24 bits)							
2								
3								
4	Vendor-Specific Identifier (40 bits)							
5								
6								
7								

End devices

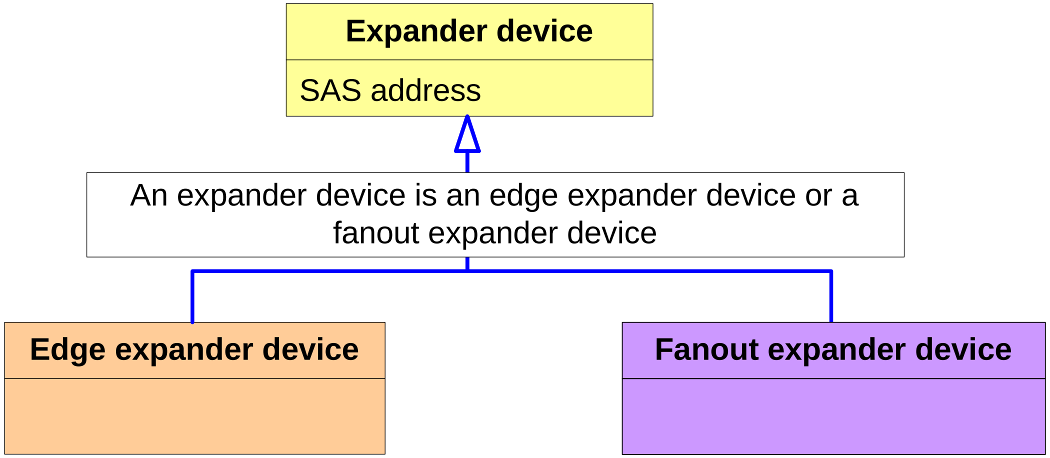
- End device is a SAS device that is not an expander device
- Sample end devices
  - HBA – 8 phys
    - One SAS address for all 8 phys
      - Potentially all one (very) wide port
    - One SAS address for 4 phys, another SAS address for 4 phys
      - Guarantees at least two ports
      - Good match for 4-wide connectors
    - Eight SAS addresses
  - Disk drive - 2 phys
    - Separate SAS address for each phy
      - Guarantees two ports
      - Never a wide port

Expander devices

- Expander device contains expander ports
- May contain SAS devices too (e.g. for enclosure management)
- Each expander device has a SAS address
- Each expander phy has a phy identifier unique within that expander device



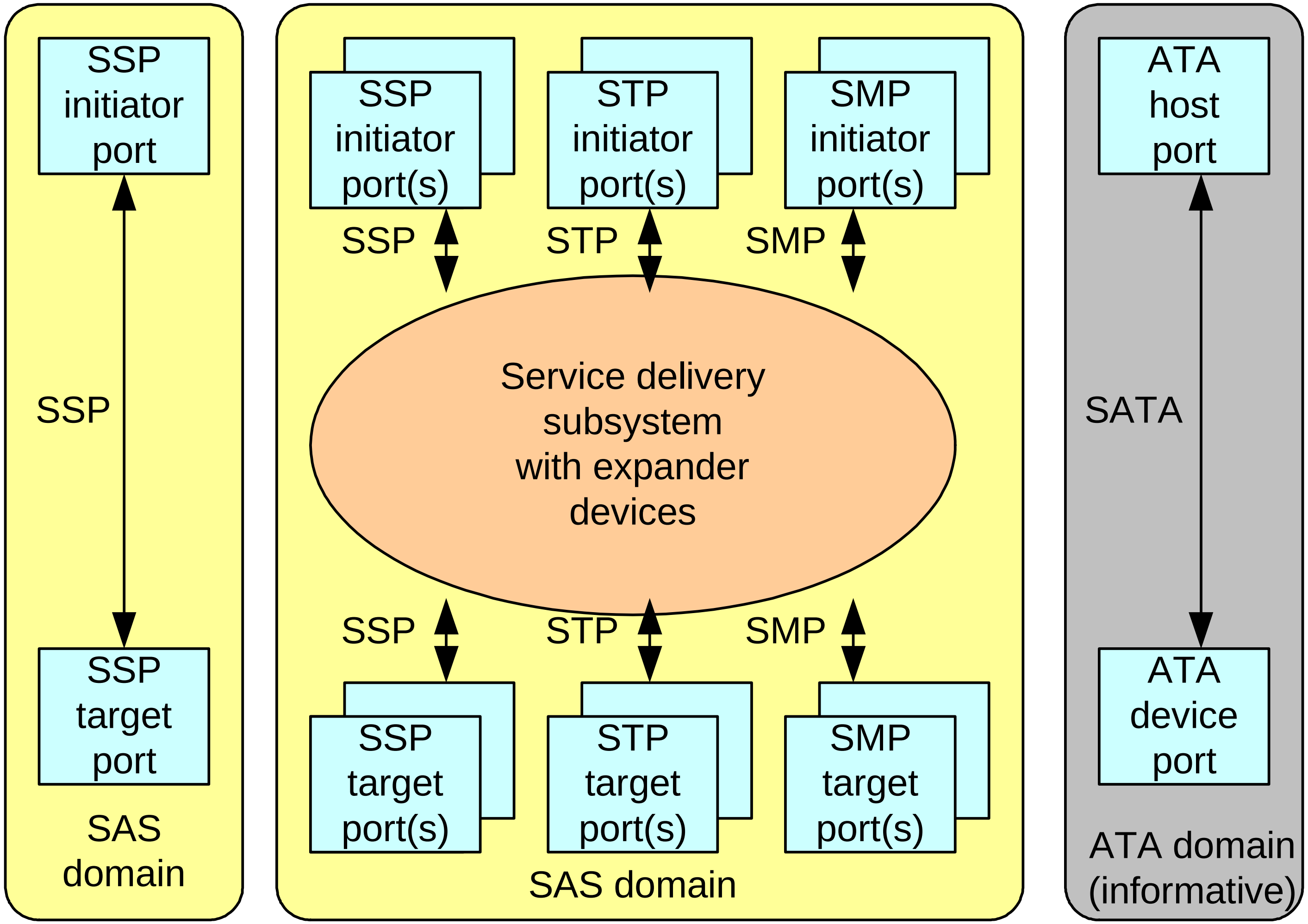
Expander device types – edge vs. fanout



- Edge expander device
  - Always part of an “edge expander device set”
  - May perform subtractive routing
- Fanout expander device
  - Never does subtractive routing
  - Usually supports larger tables for table routing
- Topologies described later

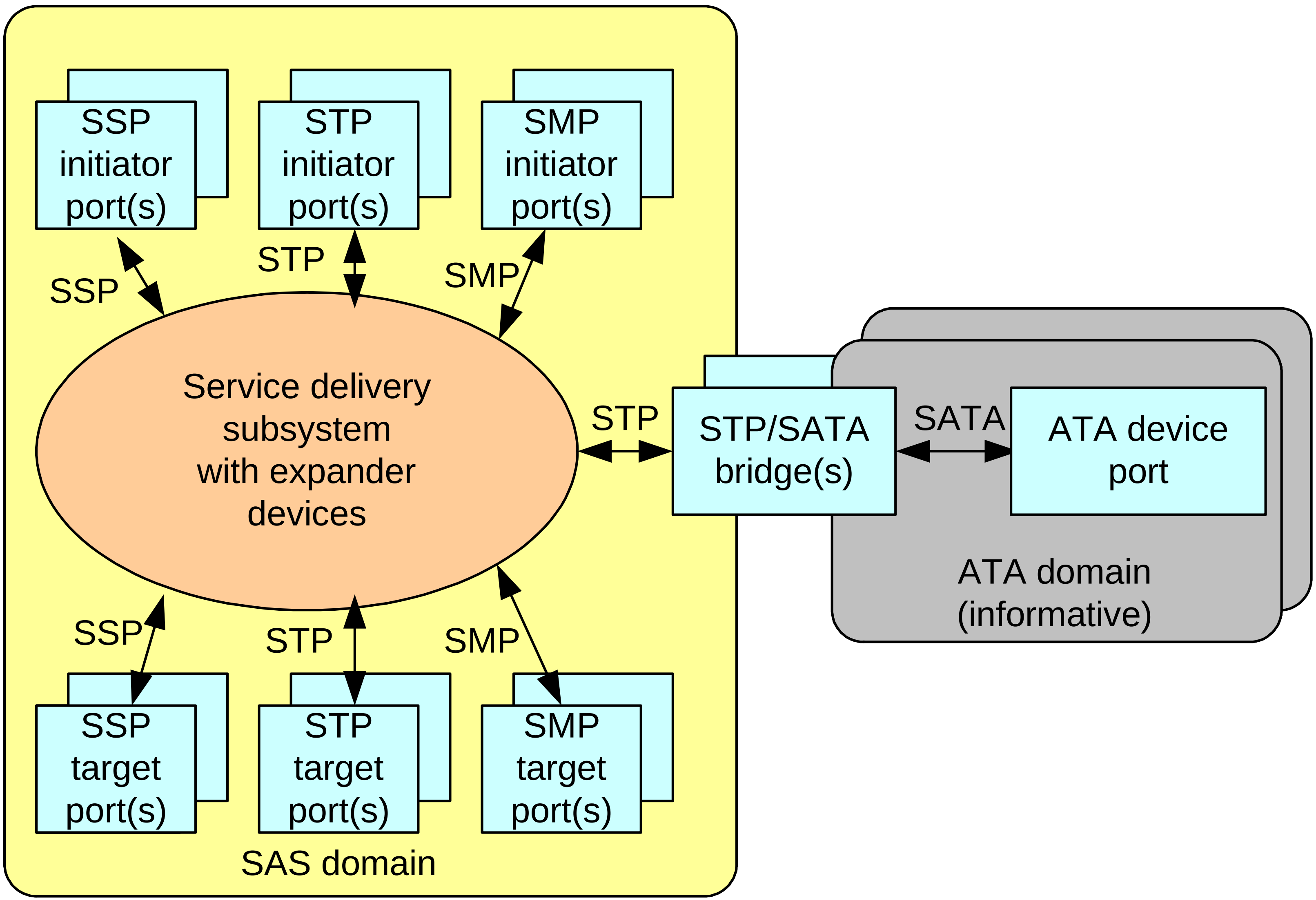
Domains

- A simple SAS domain contains SAS devices and expander devices
- An ATA domain contains a SATA host and a SATA device

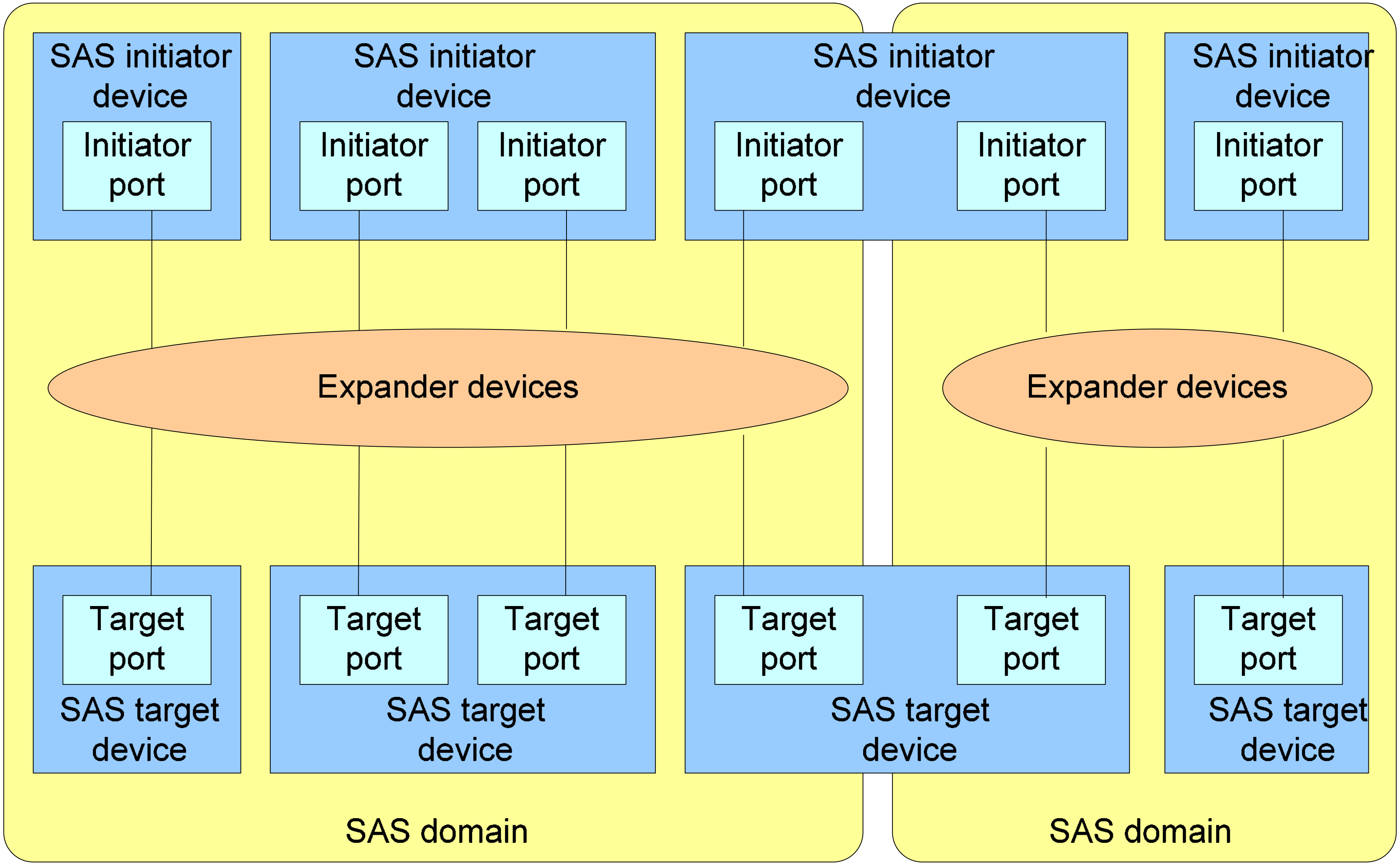


Note: When expander devices are present, SAS target ports may be located in SAS devices contained in expander devices.

SAS domain bridged to ATA domains



SAS devices in multiple SAS domains



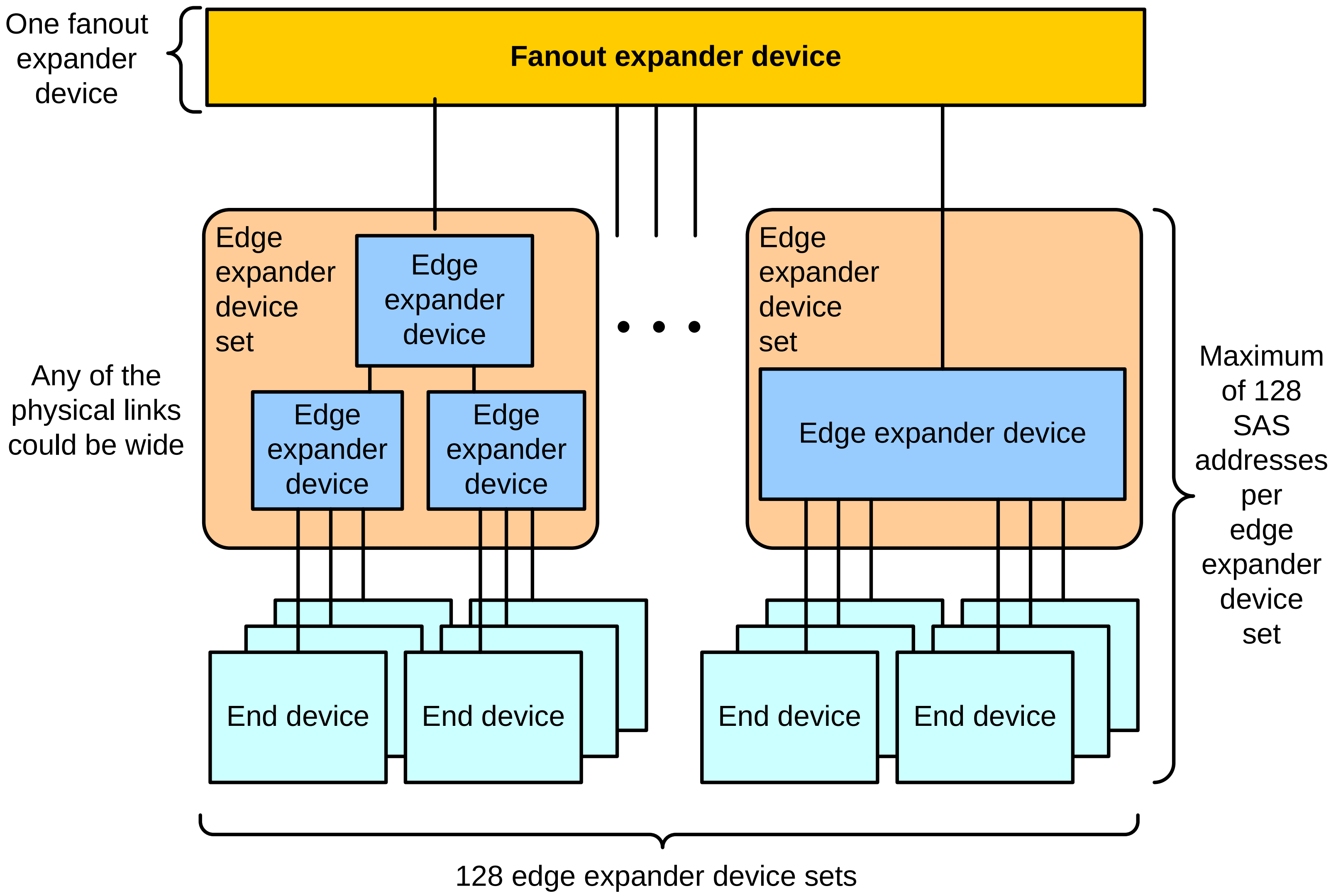
Edge expander device set

- Set of edge expander devices
- 128 SAS addresses per set
- Typically bounded by a subtractive port (to a fanout expander device, or to another edge expander device set)
- Edge expander devices uses table routing and direct routing “downstream” and subtractive routing “upstream”
- Wide links between expanders are allowed
- No loops

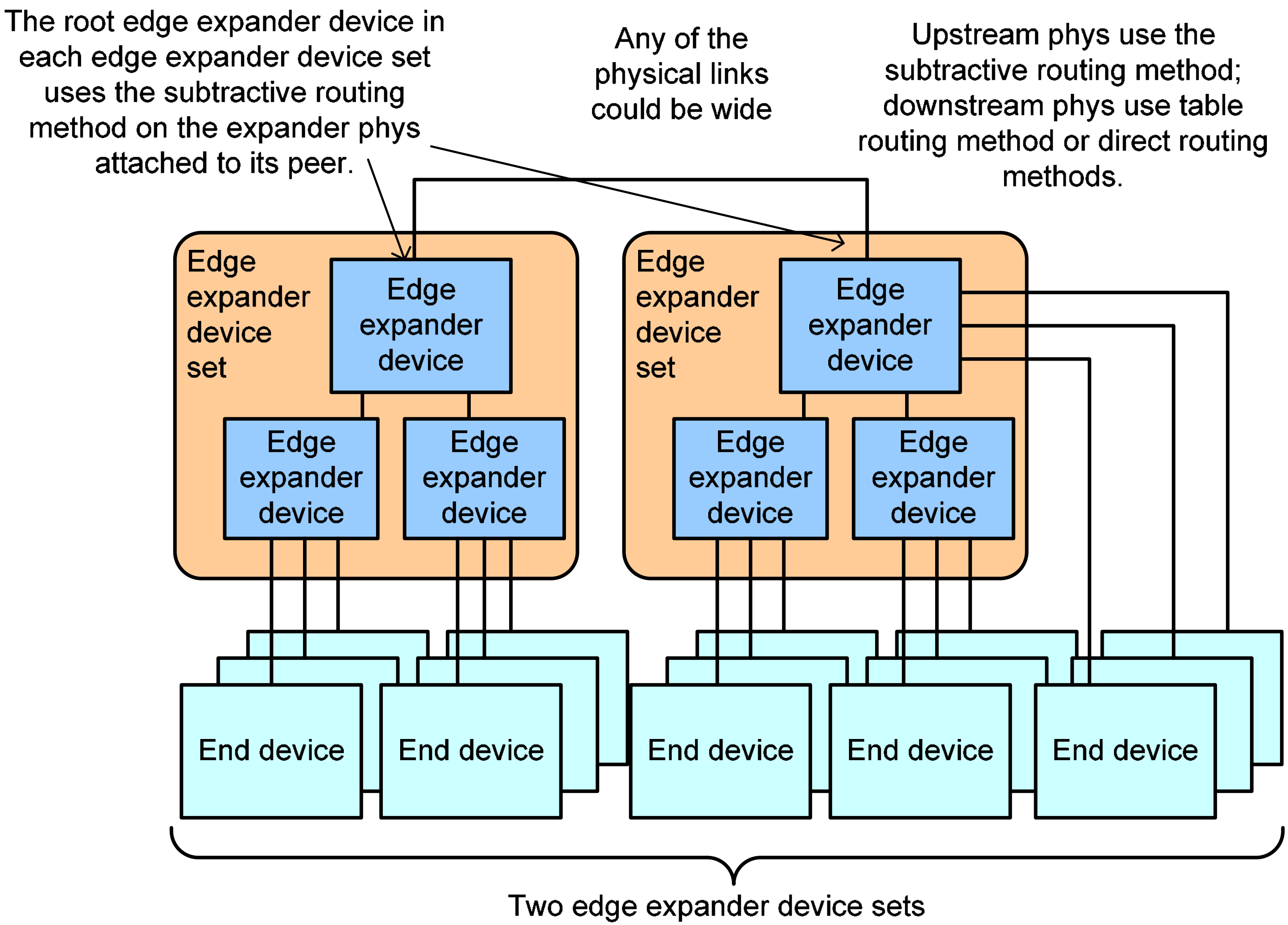
Expander topologies

- Maximum of one fanout expander device in a SAS domain
- If no fanout expander, maximum of two edge expander device sets (attached via subtractive decode ports)
- End devices may be attached at any level
  - Directly to fanout expander device
  - Any level edge expander device
- Wide links possible between any two devices
- No loops
- No multiple paths

Edge expander device set and fanout expander device



Two edge expander device sets



Expander routing attributes and methods

- Each expander phy has an expander routing attribute
- The attribute determines the routing methods the expander uses with each phy

Routing attribute	When attached to	Routing method used
Direct	End device	Direct
Table	Expander device	Table + Direct
	End device	Direct
Subtractive	Expander device	Subtractive (+ Direct)
	End device	Direct

- Direct = route requests to the attached SAS port through this phy
- Table = route requests that match in routing table through this phy
- Subtractive = route unresolved requests through this phy

Expander route table contents

Expander route table

	0	1	2	...	N
0					
1					
2					
...					
M					

Phy identifier

A phy identifier for each expander phy of the expander device.

N $\leq$ number of phys - 1

Expander route entry

Includes:

- Routed SAS address
- Enable/disable bit

Expander route index

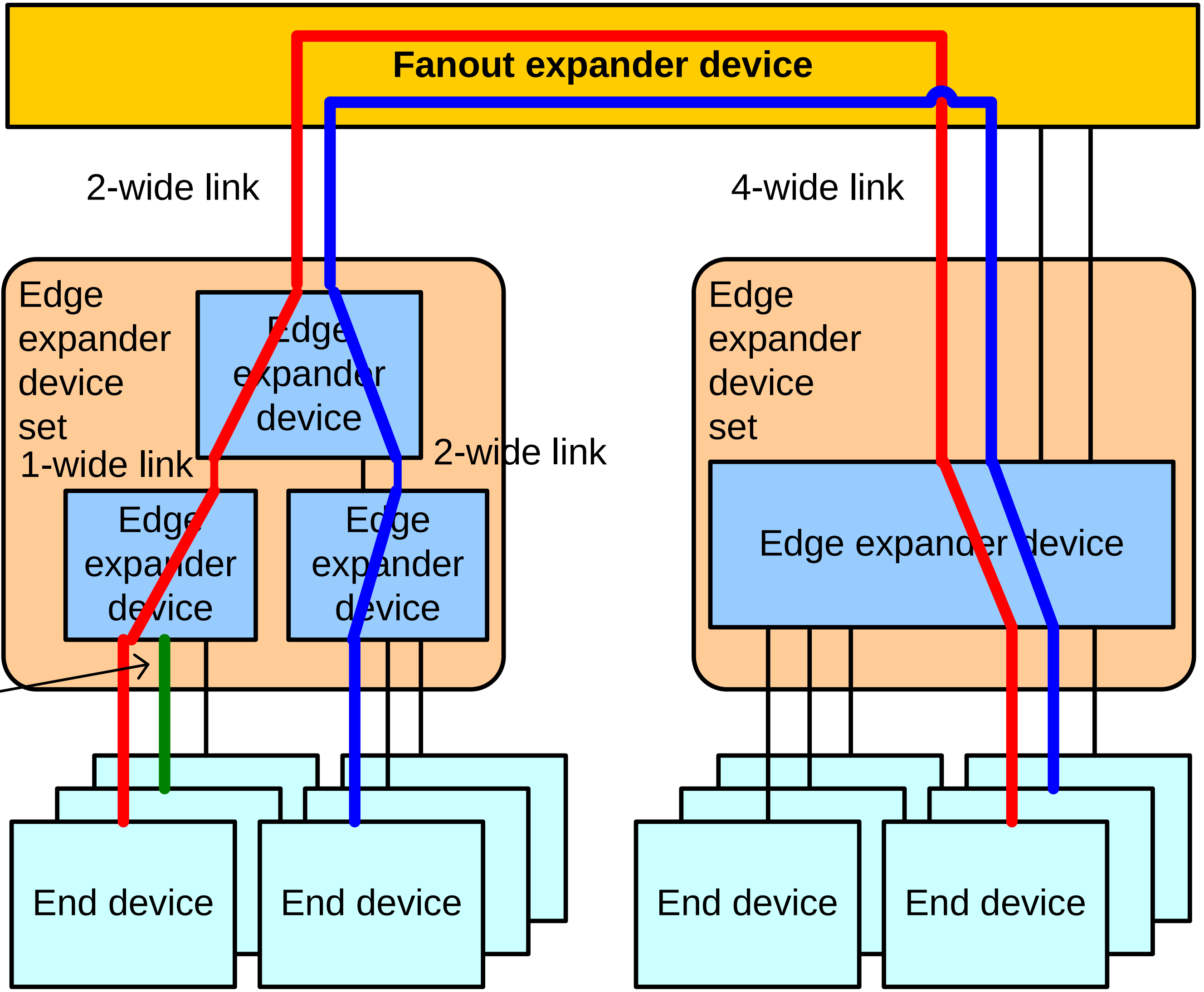
An expander route index for each expander route entry.

M = expander route indexes - 1

Connections

- Connection = temporary association between an initiator phy and a target phy
  - Source phy transmits an OPEN address frame
    - Contains a destination SAS address
  - Expanders route it to a matching destination phy
  - Destination phy replies with an OPEN_ACCEPT primitive
  - Connection is established
  - Both sides exchange CLOSE primitives to close
- Connections are addressed to ports but established phy-to-phy
- N-wide ports may establish N connections at a time (to up to N other ports)
- Wide ports may establish multiple connections to other wide ports simultaneously

Connection examples



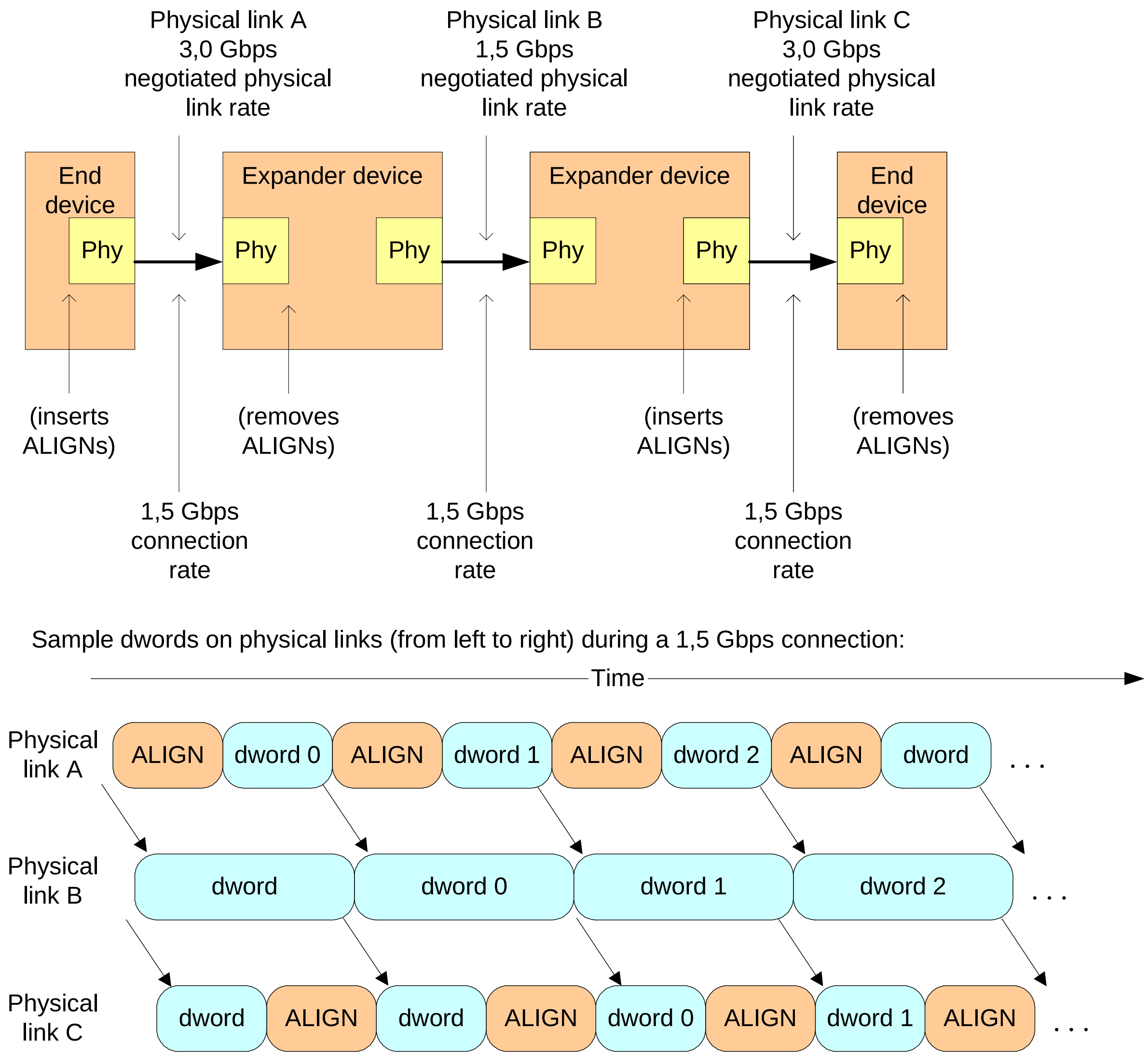
The green request is blocked until the red connection finishes

Connection rules

- Connections are addressed to SAS ports but are established from phy to phy
- Wide ports may establish multiple connections at a time (to up to one per phy) to different destinations
- Wide ports may establish multiple connections to other wide ports simultaneously (wide initiator port to wide target port)
  - SAS disk drives will offer two narrow ports
  - Only HBAs and RAID controllers will offer wide ports

Rate matching (connection rate)

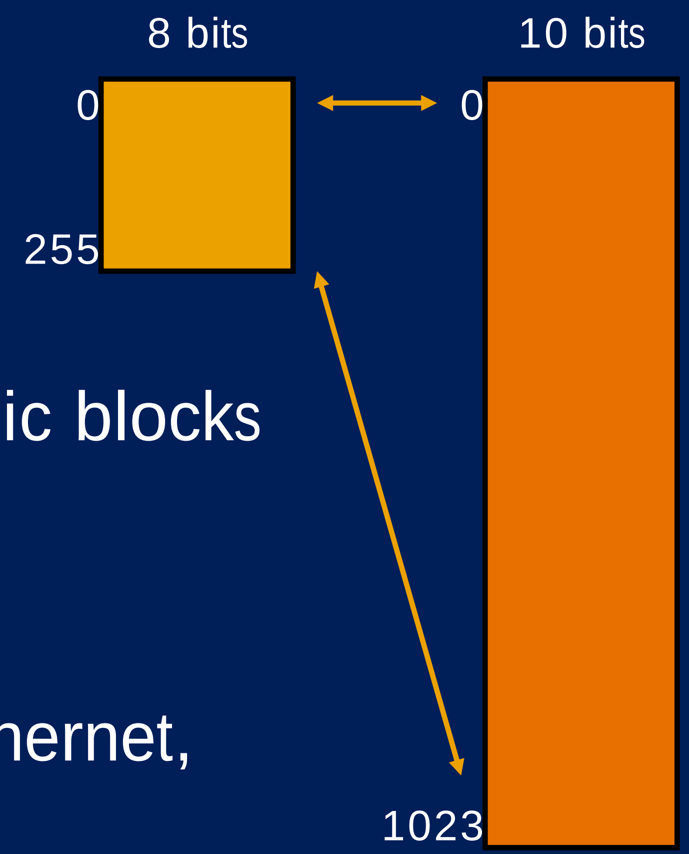
- Lets 1.5 Gbps and 3.0 Gbps SAS ports communicate
  - Especially 3.0 Gbps initiators and 1.5 Gbps SATA drives
- On faster physical links, insert ALIGN primitives to slow down the effective data rate to match the slowest physical link in the connection



Phy layer

Encoding

- 8b10b coding converts 8-bit bytes into 10-bit data characters for transmission on the wire
- Reasons
  - Clock recovery
  - DC balance
  - Special characters
  - Error detection
- Mapping done with two simple logic blocks
  - 5b6b and 3b4b
  - Full table in SAS and SATA
- Invented by IBM in 1983
- Used by Fibre Channel, Gigabit Ethernet, 1394b, and many other standards



Dwords

- Byte = 8 bits (xxh)
- Character = 10 bits (Dxx.y or Kxx.y)
- Dword = 4 characters (or 4 bytes, depending on context)
  - 40 bits on the wire
  - Usually represents 32 bits of data
  - A dword may flip disparity or leave it the same
  - A dword is either a data dword, a primitive, or an invalid dword

first	second	third	fourth
char	char	char	char

Primitives

- 1 control character and 3 data characters
  - First character is K28.5 (for SAS primitives), K28.3 (for SATA primitives), or K28.6 (special SATA error primitive)
    - K28.6 primitive serves as an invalid dword for SATA
  - Last three characters are data characters
  - Endianness does not matter
    - both SAS and SATA primitives always have the control character first on the wire

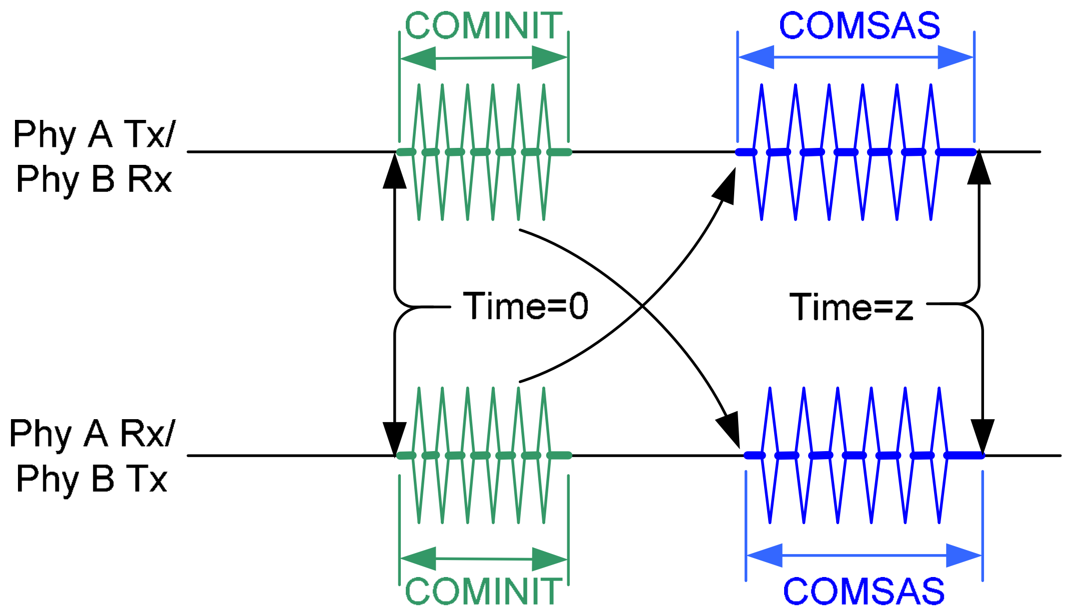
first	second	third	fourth
K28.5	Dxx.y	Dxx.y	Dxx.y
K28.3	Dxx.y	Dxx.y	Dxx.y
K28.6	Dxx.y	Dxx.y	Dxx.y

OOB signals

- OOB signal is a pattern of idle times and burst times
  - Idle time (and negation time)
    - Differential 0 V (Positive signal = negative signal)
    - No transitions (DC idle)
  - Burst time
    - Transmitted as a burst of ALIGN(0) primitives
    - Received as presence of edges (whether they are valid ALIGNs is irrelevant)
- Designed to be detectable by analog squelch detection logic
- Length of idle time distinguishes between OOB signals
  - COMINIT, COMWAKE, and COMSAS

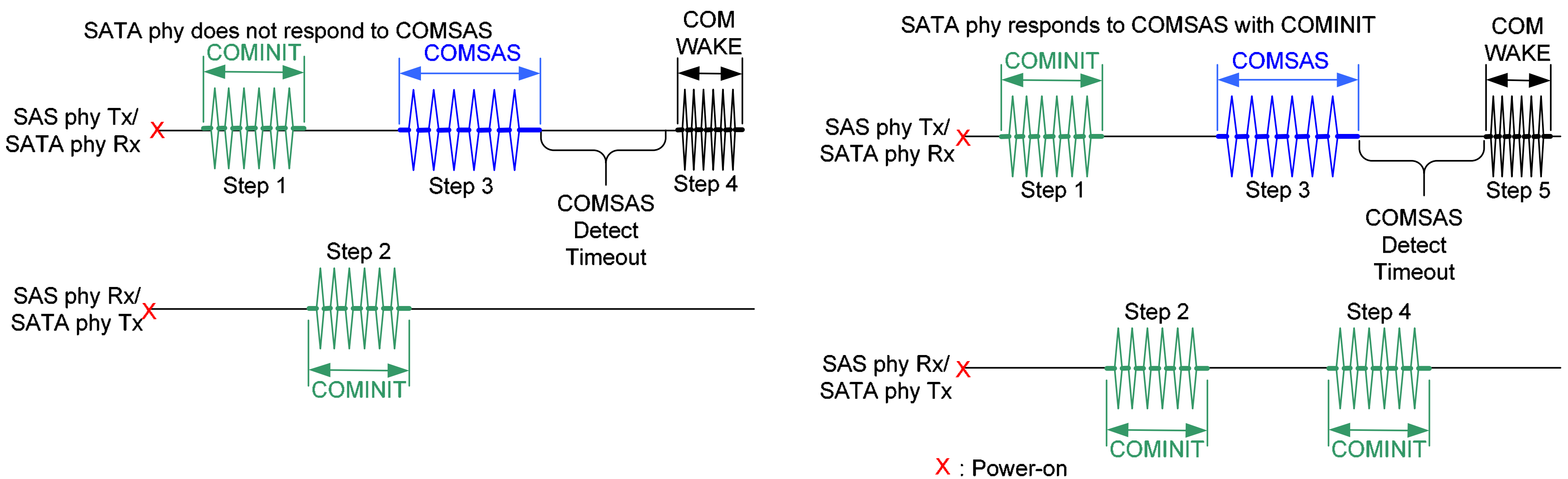
SAS OOB sequence

- Transmit and receive COMINIT
- Transmit COMSAS
  - If COMSAS received, physical link is SAS to SAS
  - If COMSAS is not received, physical link is SAS to SATA
- There are a few hot-plug situations where COMINIT leads directly to COMSAS; this is allowed



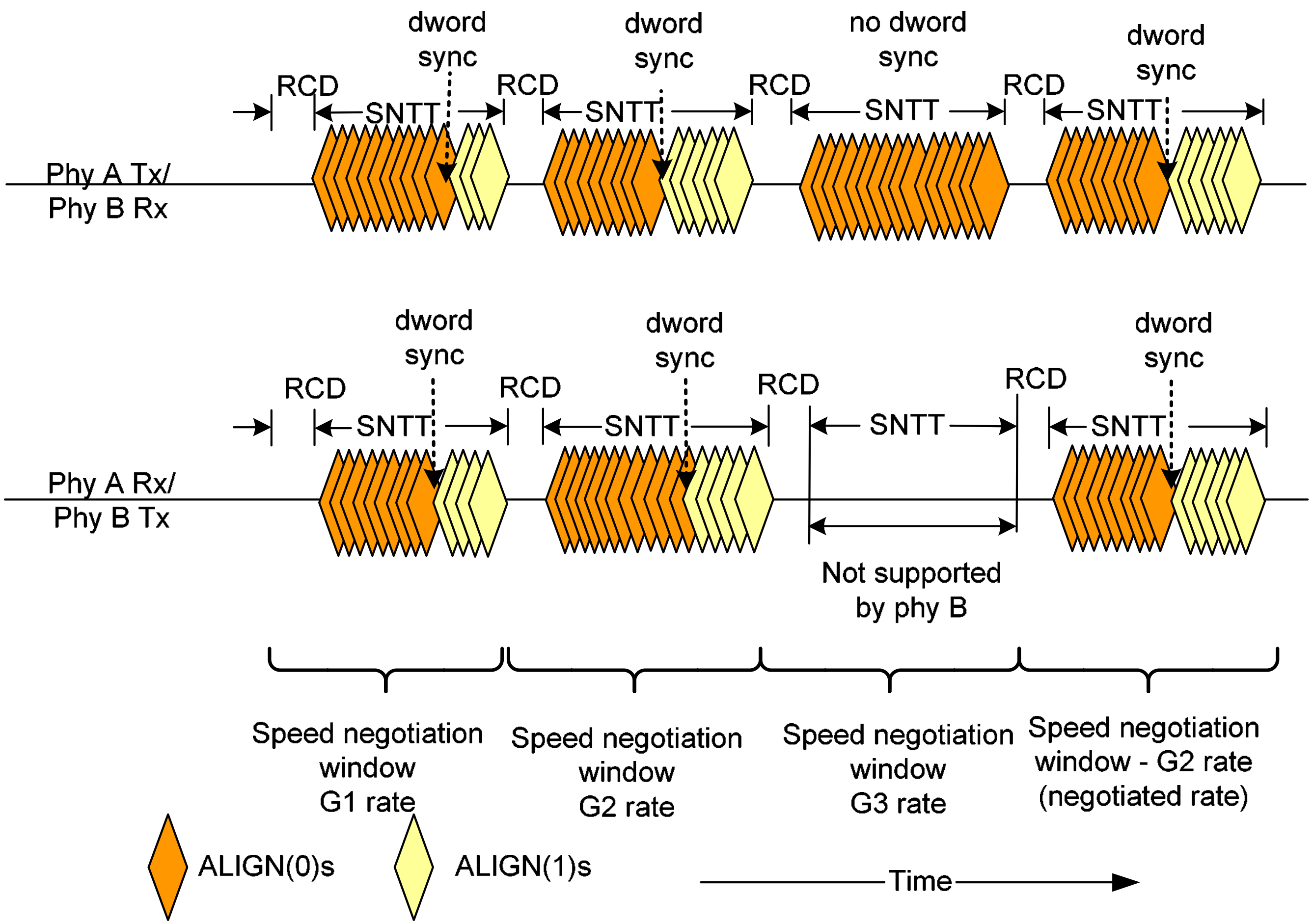
SAS to SATA OOB sequence

- If COMSAS is not received, physical link is SAS to SATA
- SAS OOB sequence morphs into the SATA OOB sequence
- Since the SAS device drives COMWAKE, it looks like a SATA host
- Only supports SATA device not SATA host



SAS speed negotiation sequence

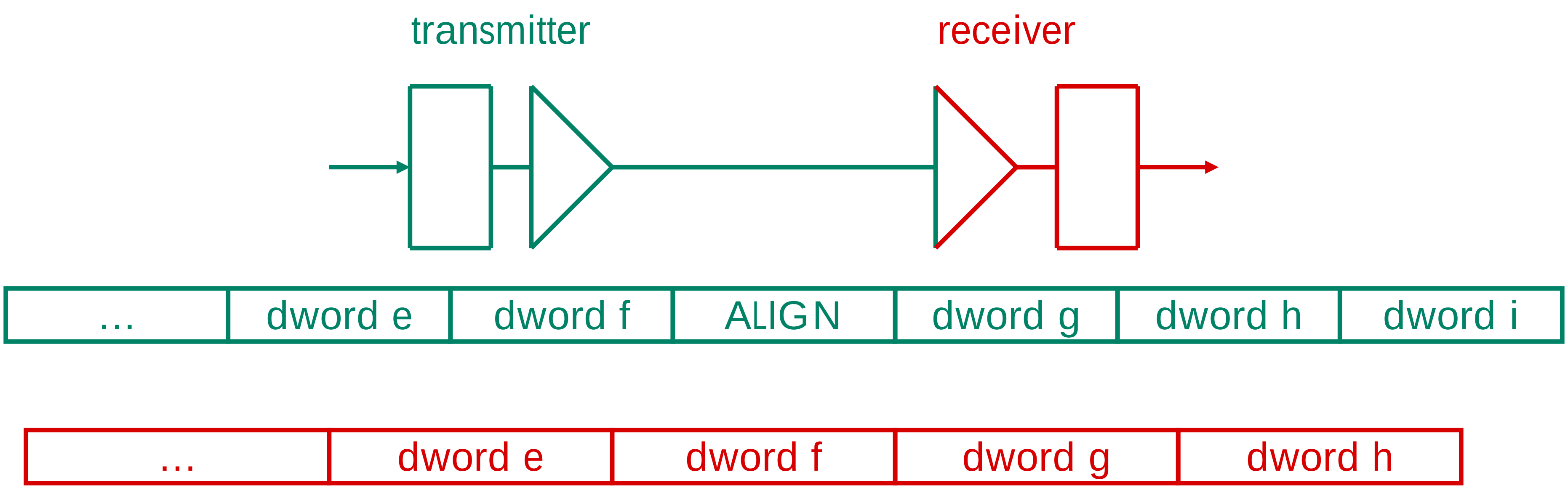
- Slow-to-fast
- Both phys run same set of speed negotiation windows
- 1.5, then 3.0, then 6.0 (if needed), etc. until they find:
  - a supported rate; then
  - a (faster) non-supported rate
- Last window returns to the highest supported rate detected



Link layer

Clock skew management

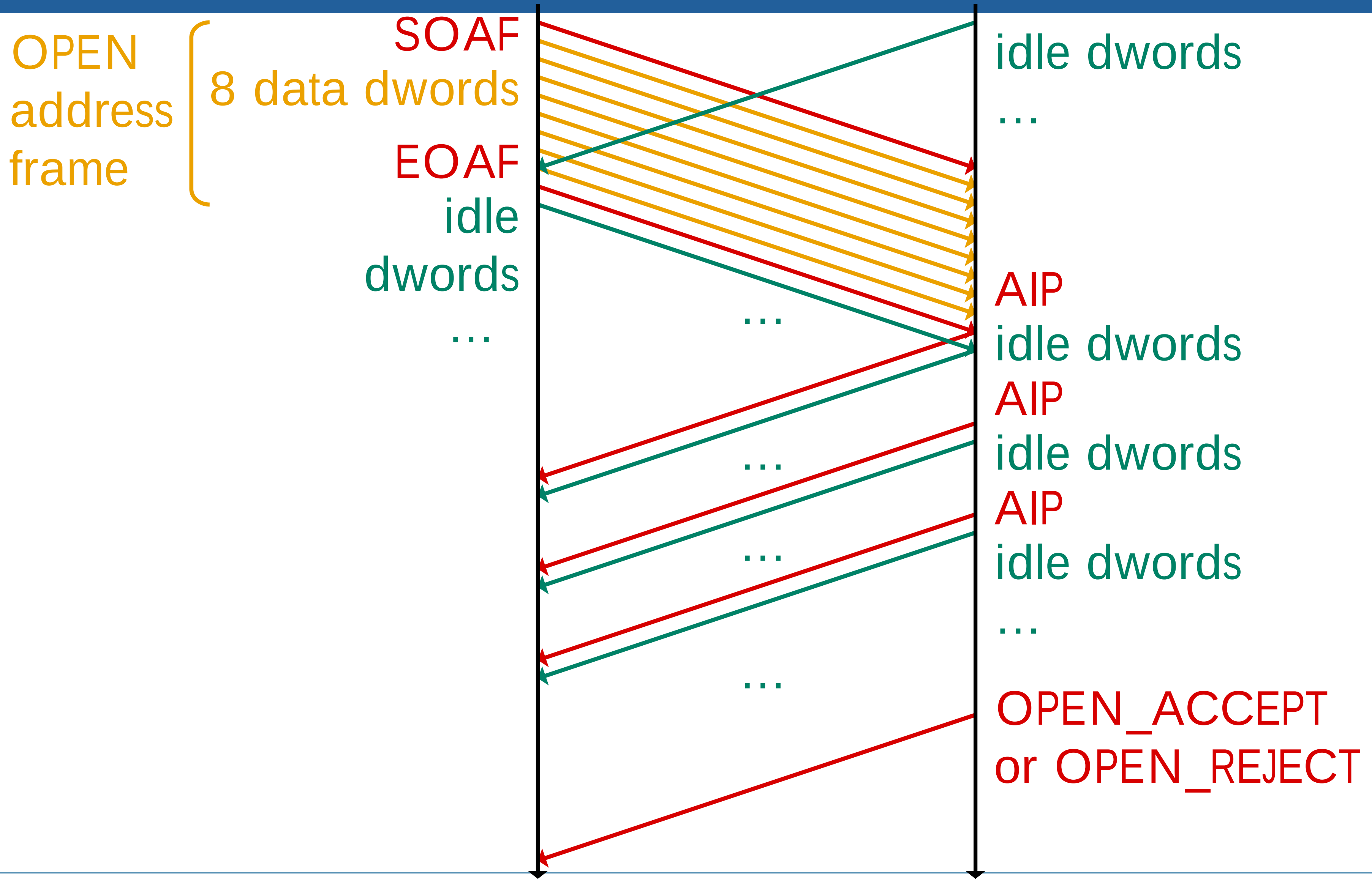
- Slow down the transmitter by including dwords that can be deleted
  - ALIGN (and NOTIFY for SAS) primitives stuck in
  - Throttles the transmitter to be slower than the slowest receiver
    - SATA (and SAS STP) requires 2 per 256 dwords (0.7812%)
      - Must always appear in pairs
    - SAS requires 1 per 2048 dwords (0.0488%)
  - Receiver throws away incoming ALIGNs (and NOTIFYs for SAS)



Connections

- Established between a SAS initiator phy and a SAS target phy
- Three types of connections
  - SSP (Serial SCSI protocol)
  - SMP (Serial management protocol)
  - STP (Serial ATA Tunneling protocol)
- Basic sequence
  - 1. Transmit OPEN address frame
  - 2. Receive AIP (arbitration in progress) primitives if expanders are involved
  - 3. Receive final result
    - OPEN_ACCEPT primitive – connection established
    - OPEN_REJECT primitive – rejected, go back to idle
- SATA has no concept of connections

Connection – basic sequence

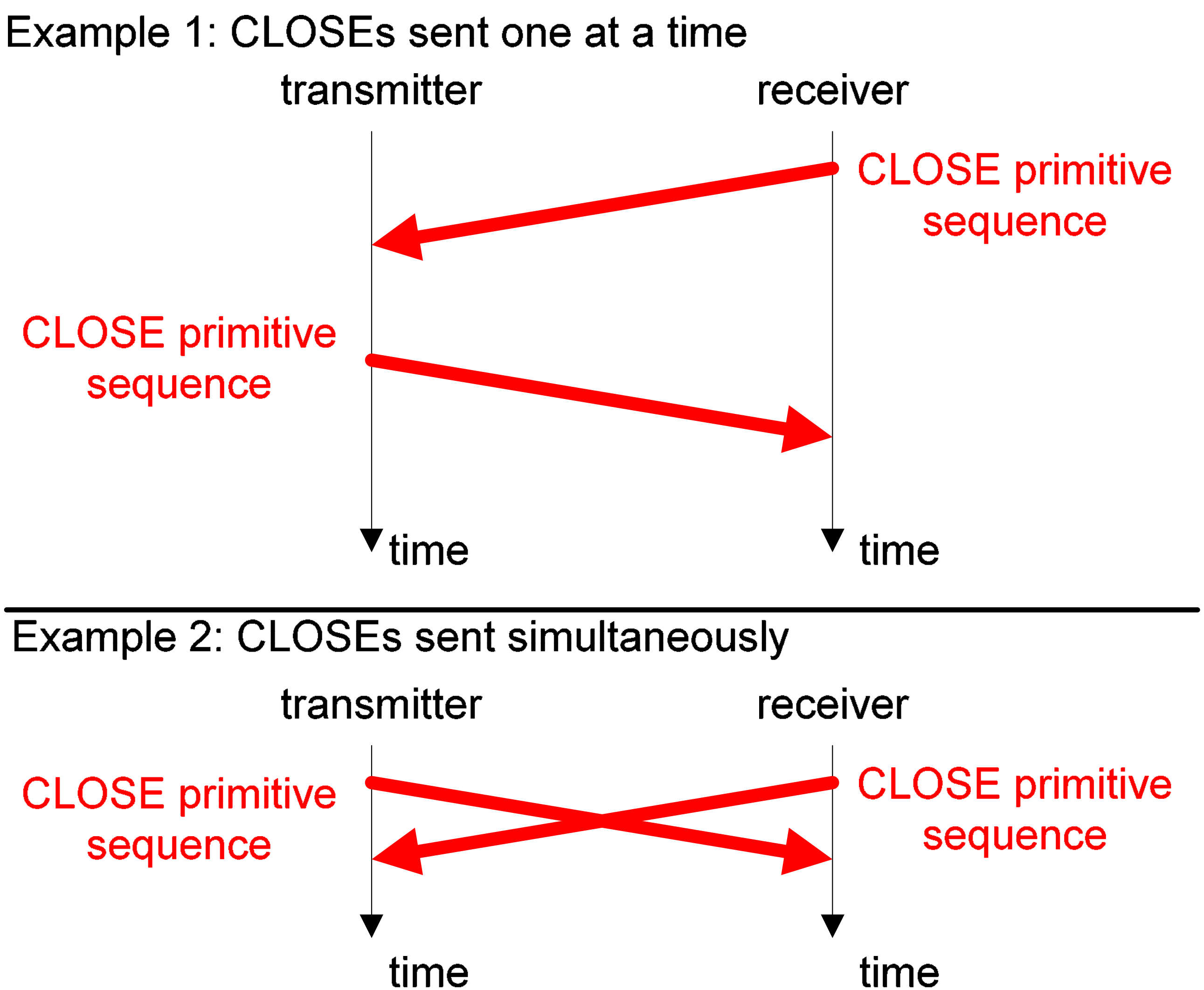


Arbitration fairness and deadlocks

- SAS implements a Least Recently Used (LRU) arbitration fairness scheme
  - Each OPEN address frame includes the age of a request
  - In case of ties, SAS addresses are used to pick the highest priority
- SAS implements deadlock detection and recovery using Partial Pathway timers
  - When expanders detect a hang, one request is backed off to break the likely deadlock
  - SAS addresses are eventually used to decide which request is the lowest priority and gets backed off

Closing a connection

- Exchange CLOSE primitive sequences end-to-end to close a connection
- SSP and SMP require traffic be stopped first
  - CLOSE ignored by SAS phy state machines if not at the correct time
- STP connection should be idle before closing
  - Not enforced by SL state machine
- Expanders always honor CLOSE regardless of connection state

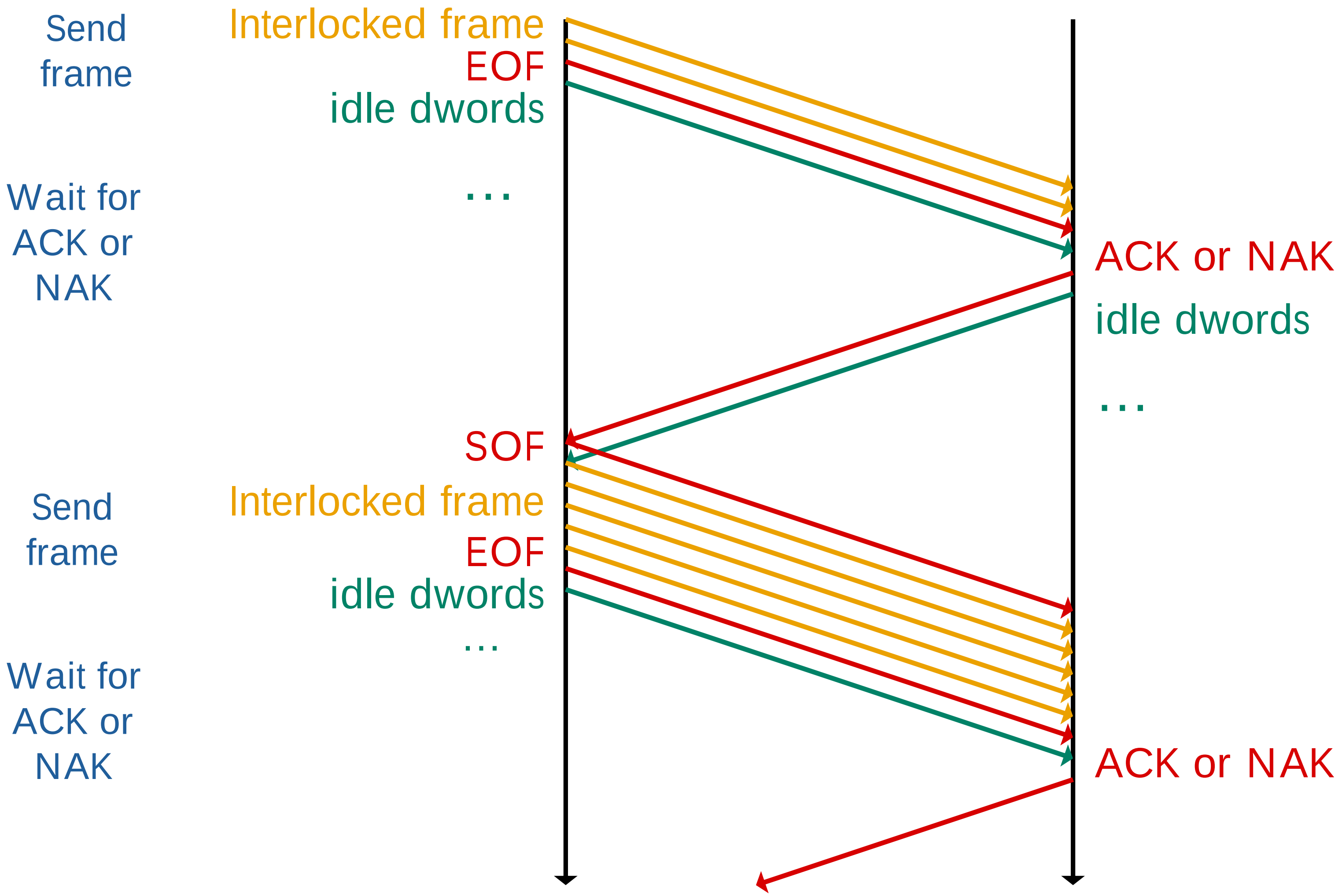


SSP overview

- Inside an SSP connection…
- Phys exchange SSP frames
  - SSP frame = SOF primitive, data dwords, EOF primitive
  - Each frame results in an ACK or NAK primitive
- Credit-based flow control
  - Permission to send a frame must be granted with RRDY primitives
- Full duplex
  - SSP frames can be sent in both directions simultaneously
  - Independent credit for each direction
- ACK, NAK, and RRDY primitives may be interjected among frame dwords
  - (so can ALIGNs and NOTIFYs)

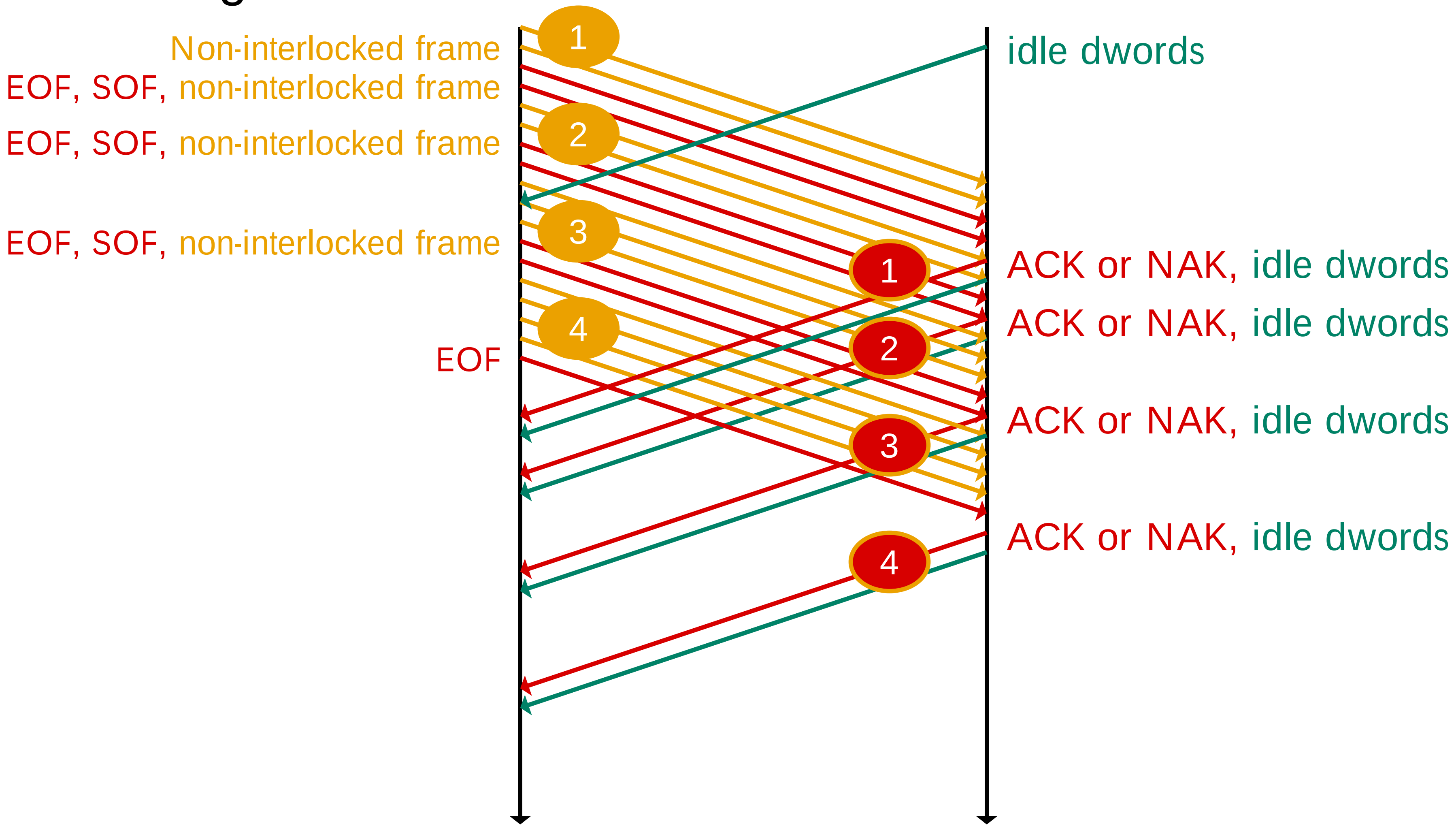
SSP interlocked frames example

- Showing frames only in one direction



SSP non-interlocked frames example

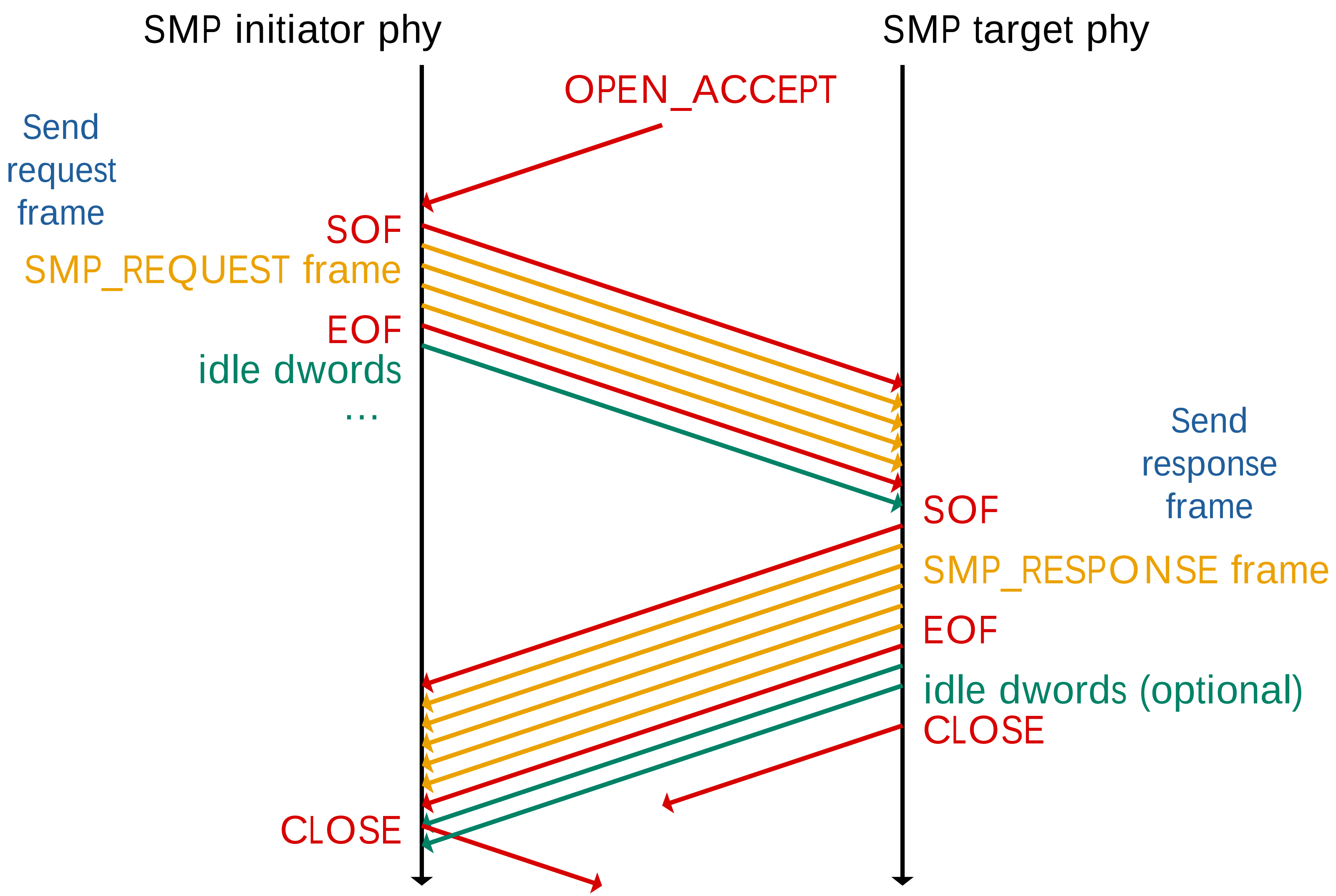
- Showing frames in one direction



SMP overview

- Only an initiator can open an SMP connection
  - Target not allowed to open an initiator
- Inside an SMP connection…
- Two SMP frames are transferred
  - SMP frame = SOF primitive, data dwords, EOF primitive
  - 1. Initiator transmits one SMP_REQUEST frame to target
  - 2. Target transmits one SMP_RESPONSE frame to initiator

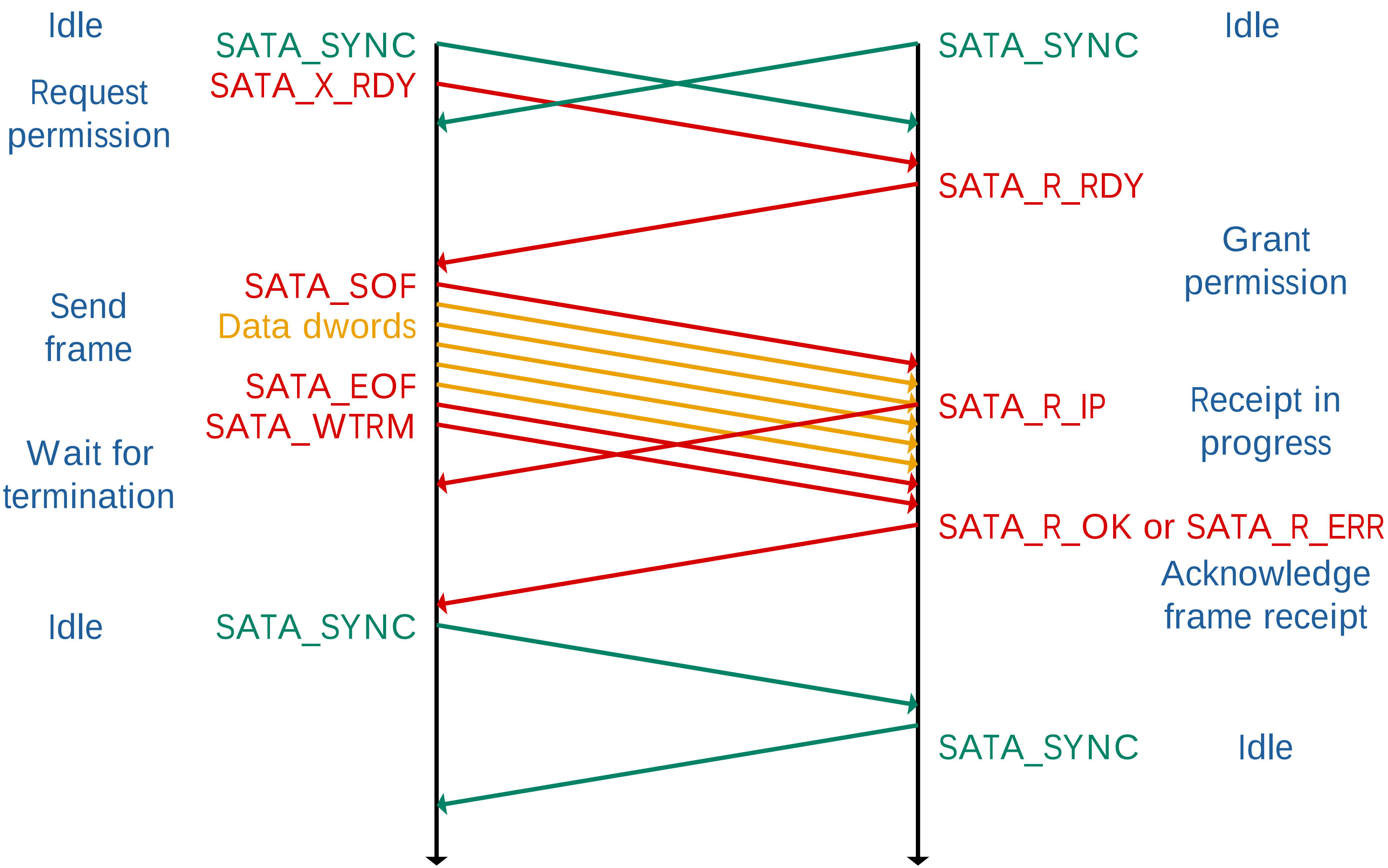
SMP example


SMP initiator phy
SMP target phy
OPEN_ACCEPT
Send request frame
SOF
SMP_REQUEST frame
EOF
idle dwords
...
Send response frame
SOF
SMP_RESPONSE frame
EOF
idle dwords (optional)
CLOSE
CLOSE

STP and SATA overview

- In SATA, SATA host and SATA device just communicate directly – no connections
- In SAS, once an STP connection is open, STP initiator and STP target communicate as if they were SATA host and SATA device directly attached on a physical link
  - Extra latency introduced as dwords flow through expanders
- Half duplex
  - SATA never transmit frames in both directions at one time
  - Usually the frame goes one way and R_IP primitives go the other way
- Note: SAS prefixes the SATA primitive names with “SATA_”
  - SATA_SOF (used in STP) is different than SOF (used in SSP)
  - In this presentation, prefix not always used

SATA basic frame transmission



Transport layer

SSP frames

- One common SSP frame format
  - Frame header: 24 bytes
  - Information Unit: 0 to 1024 bytes
  - Fill bytes: 0 to 2 bytes
  - CRC: 4 bytes
- Frame format is based on Fibre Channel

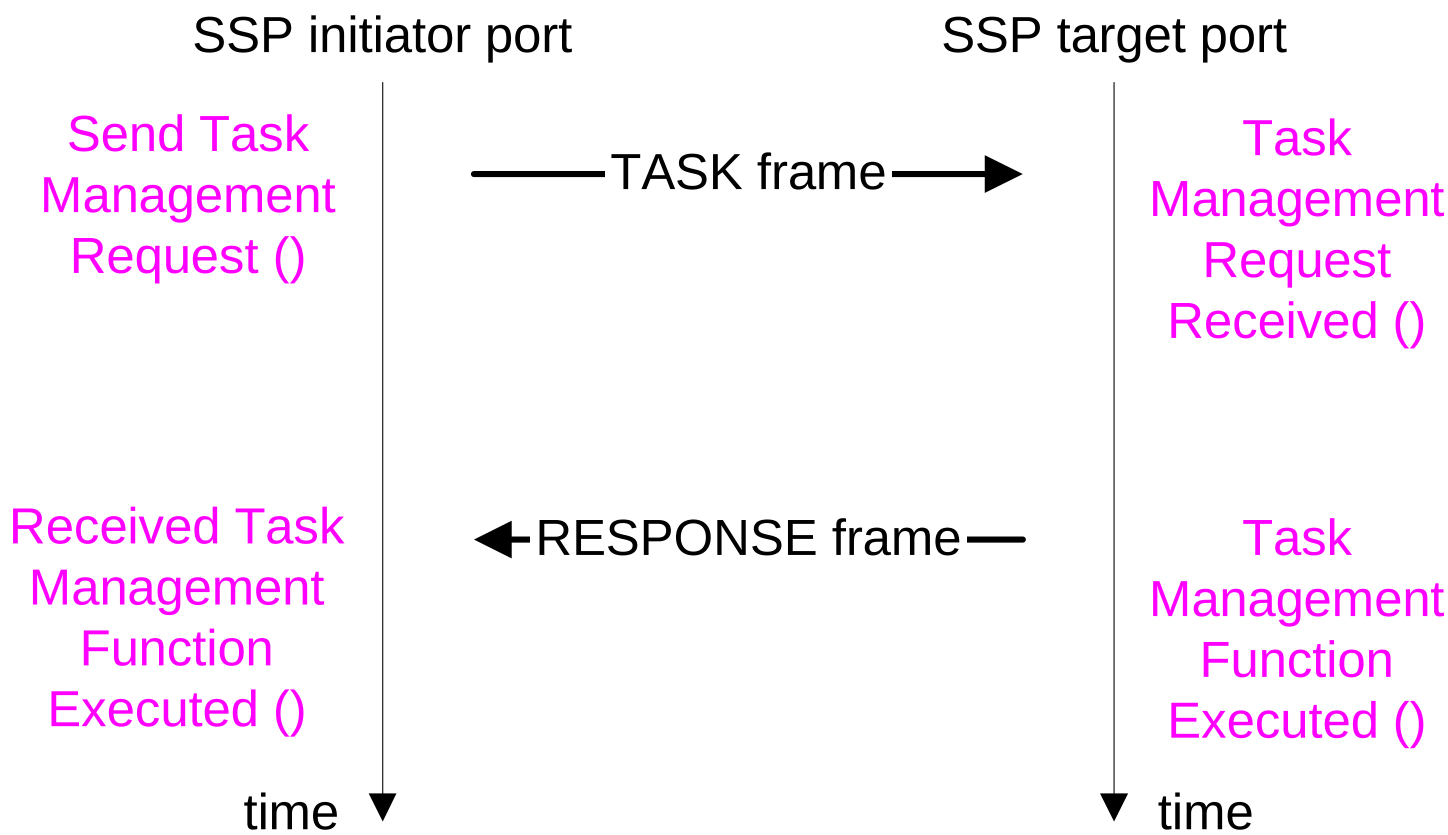
<table>
<tr><th>Byte</th><th colspan="3">Field(s)</th></tr>
<tr><td>0</td><td colspan="3">Frame Type</td></tr>
<tr><td>1 to 3</td><td colspan="3">Hashed Destination SAS address</td></tr>
<tr><td>4</td><td colspan="3">Reserved</td></tr>
<tr><td>5 to 7</td><td colspan="3">Hashed Source SAS address</td></tr>
<tr><td>8 to 9</td><td colspan="3">Reserved</td></tr>
<tr><td>10</td><td>Reserved</td><td>Retransmit</td><td>Rsvd</td></tr>
<tr><td>11</td><td>Reserved</td><td colspan="2">Number of Fill Bytes</td></tr>
<tr><td>12 to 15</td><td colspan="3">Reserved</td></tr>
<tr><td>16 to 17</td><td colspan="3">Tag</td></tr>
<tr><td>18 to19</td><td colspan="3">Target Port Transfer Tag</td></tr>
<tr><td>20 to 23</td><td colspan="3">Data Offset</td></tr>
<tr><td>24 to m</td><td colspan="3">Information Unit</td></tr>
<tr><td>m to (n-3)</td><td colspan="3">Fill bytes, if needed</td></tr>
<tr><td>(n-3) to n</td><td colspan="3">CRC</td></tr>
</table>

SSP frame types

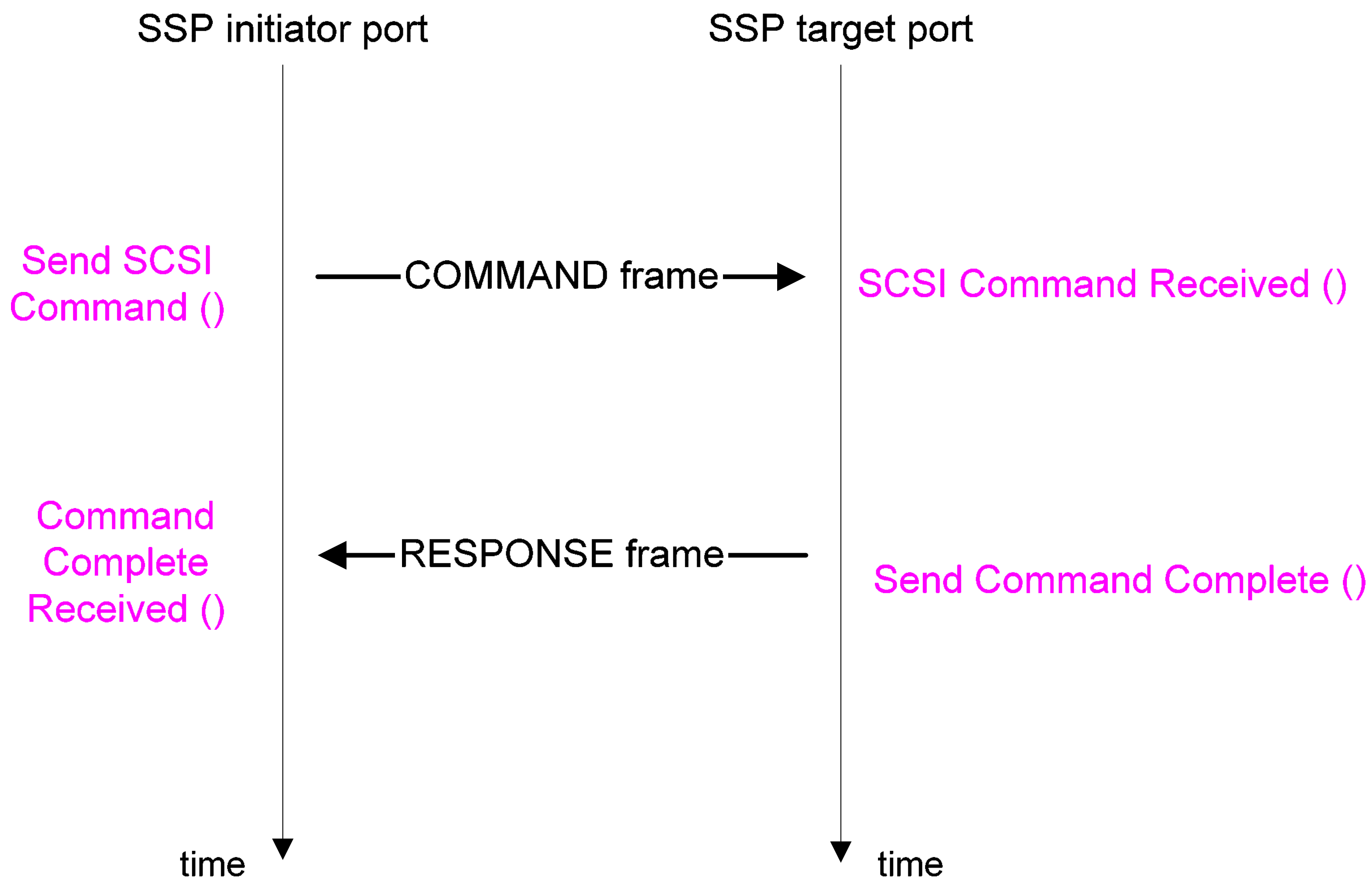
- Information Units are nearly identical to Fibre Channel Protocol (FCP)
  - Separate TASK frame is new to SAS

Command	Information Unit field size	Direction	Description
COMMAND	28 to 284	I to T	Send a command
TASK	28	I to T	Send a task management function
XFER_RDY	12	T to I	Request write data
DATA	1 to 1024	I to T or T to I	Write data (I to T) or read data (T to I)
RESPONSE	24 to 1024	T to I	Send SCSI status (for commands) or task management response (for task management functions)

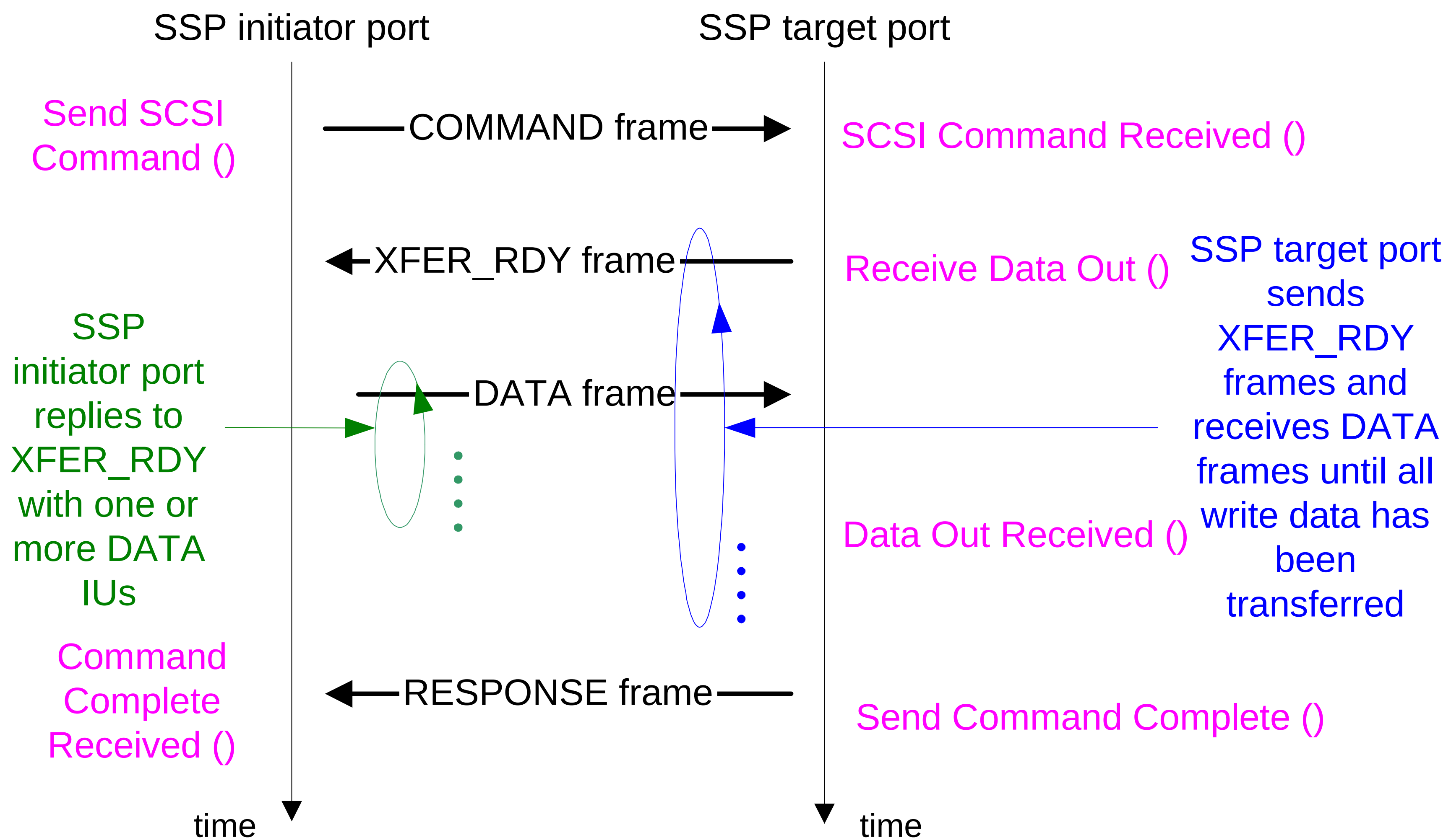
SSP task management frame sequence



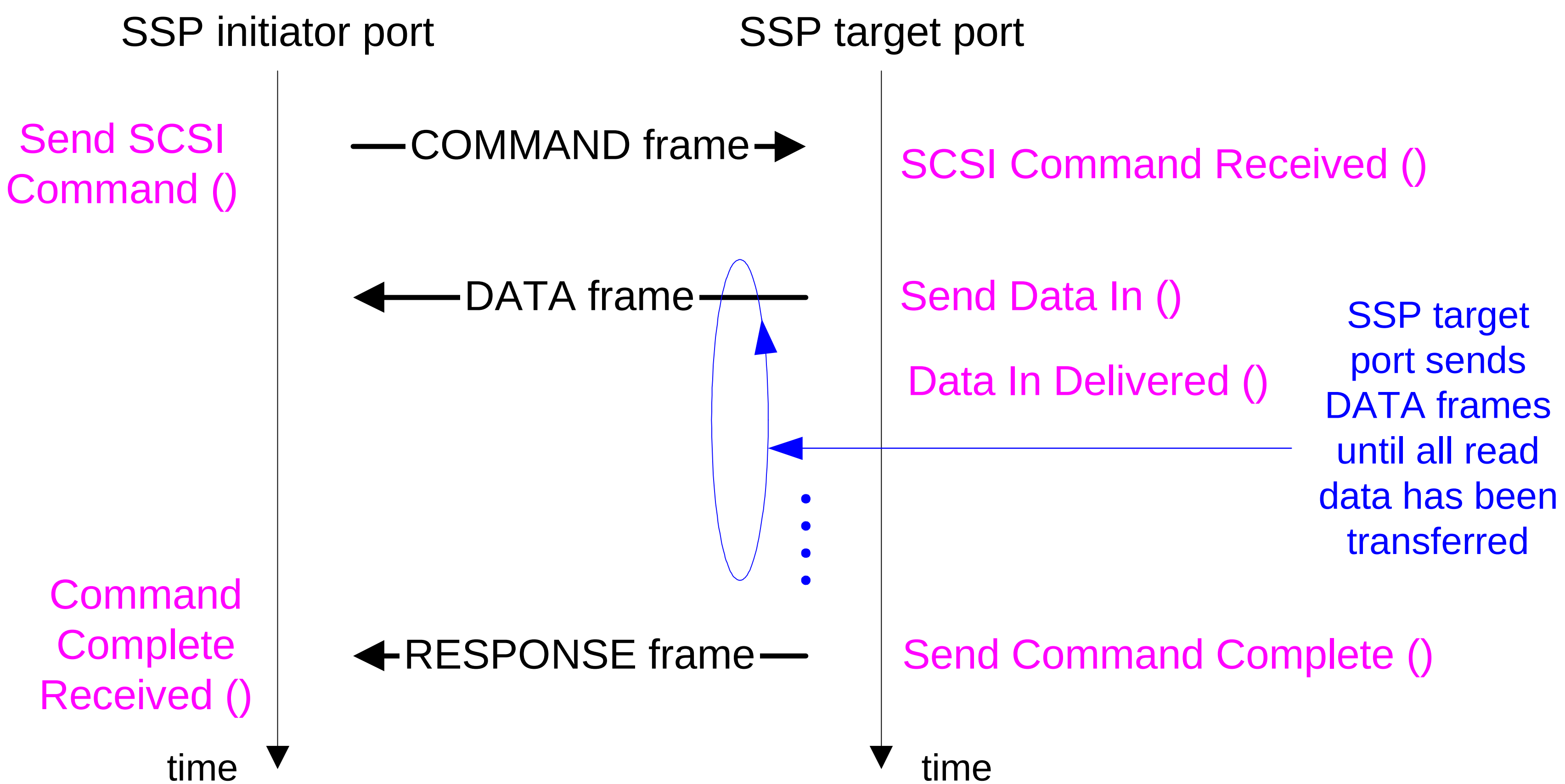
SSP non-data command sequence



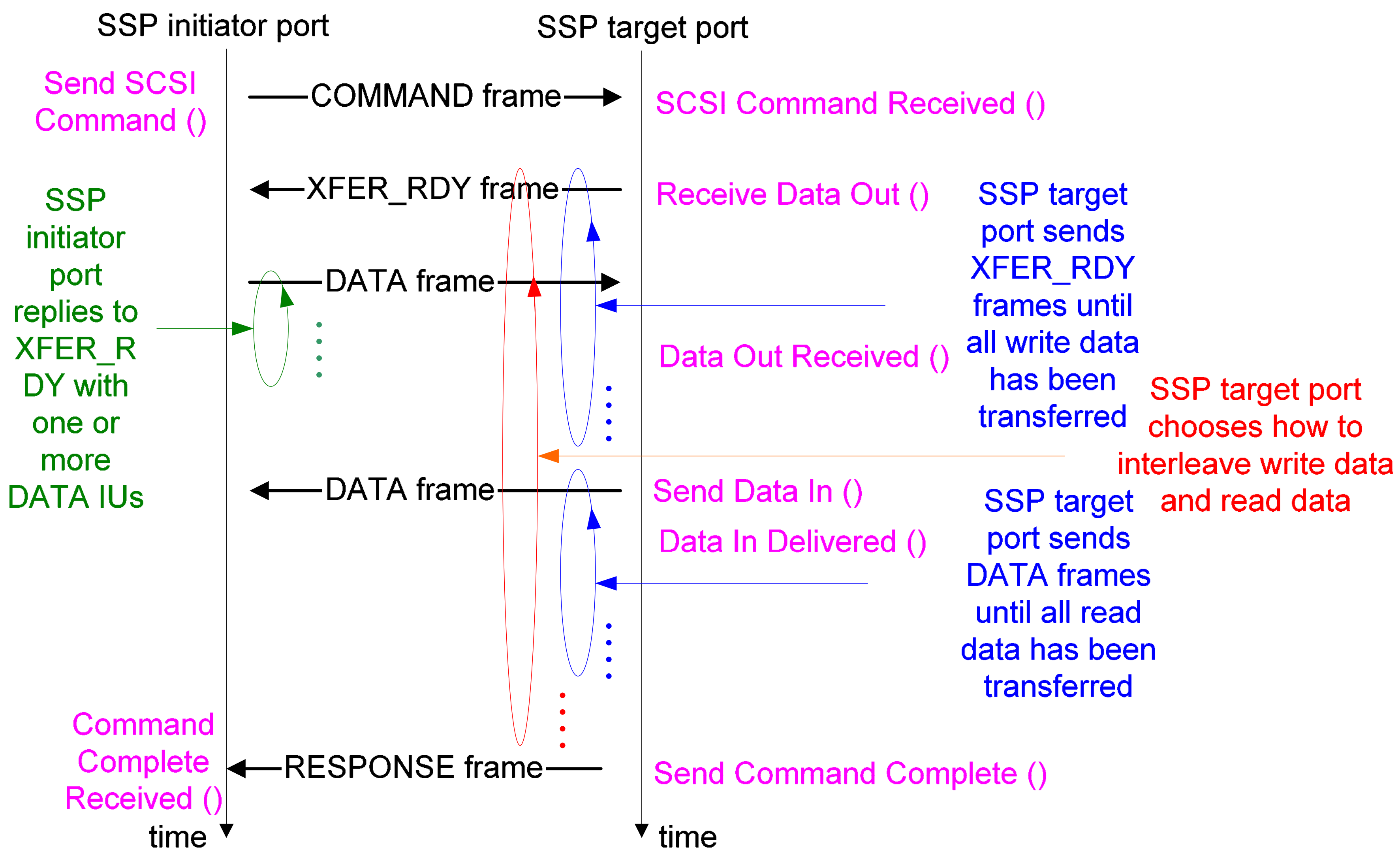
SSP write command sequence



SSP read command sequence



SSP bidirectional command sequence



Wrap Up

Additional tutorials

- General overview
- More detailed 7-part tutorial:
  - #1: General introduction and architectural overview
  - #2: Physical and phy layers
  - #3: Link layer
    - Part 1) Primitives, address frames, connections
    - Part 2) Arbitration fairness, deadlocks and livelocks, rate matching, SSP, STP, and SMP frame transmission
  - #4: Upper layers
    - Part 1) SCSI application and transport layers
    - Part 2) ATA application and transport layers
    - Part 3) Management application and transport layers, plus port layer

Key SCSI standards

- Working drafts of SCSI standards are available on http://www.t10.org
- Published through http://www.incits.org
  - Serial Attached SCSI
  - SCSI Architecture Model - 3
  - SCSI Primary Commands - 3
  - SCSI Block Commands - 2
  - SCSI Stream Commands - 2
  - SCSI Enclosure Services – 2
- SAS connector specifications are available on http://www.sffcommittee.org
  - SFF 8482 (internal)
  - SFF 8470 (external)
  - SFF 8223, 8224, 8225 (form factors)

Key ATA standards

- Working drafts of ATA standards are available on http://www.t13.org
  - Serial ATA 1.0a (private WG specification)
  - ATA/ATAPI-7 Volume 1 (architecture and commands)
  - ATA/ATAPI-7 Volume 3 (Serial ATA standard)
- Serial ATA II specifications are available on http://www.t10.org and http://www.serialata.org
  - Serial ATA II: Extensions to Serial ATA 1.0
  - Serial ATA II: Port Multiplier
  - Serial ATA II: Port Selector
  - Serial ATA II: Cables and Connectors Volume 1

For more information

- International Committee for Information Technology Standards
  - http://www.incits.org
- T10 (SCSI standards)
  - http://www.t10.org
  - Latest SAS working draft
  - T10 reflector for developers
- T13 (ATA standards)
  - http://www.t13.org
  - T13 reflector for developers
- T11 (Fibre Channel standards)
  - http://www.t11.org
- SFF (connectors)
  - http://www.sffcommittee.org
- SCSI Trade Association
  - http://www.scsita.org
- Serial ATA Working Group
  - http://www.serialata.org
- SNIA (Storage Networking Industry Association)
  - http://www.snia.org
- Industry news
  - http://www.infostor.com
  - http://www.byteandswitch.com
  - http://www.wwpi.com
  - http://searchstorage.com
- Training
  - http://www.knowledgetek.com

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