



# PCI Express® Basics

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**LSI Corporation**



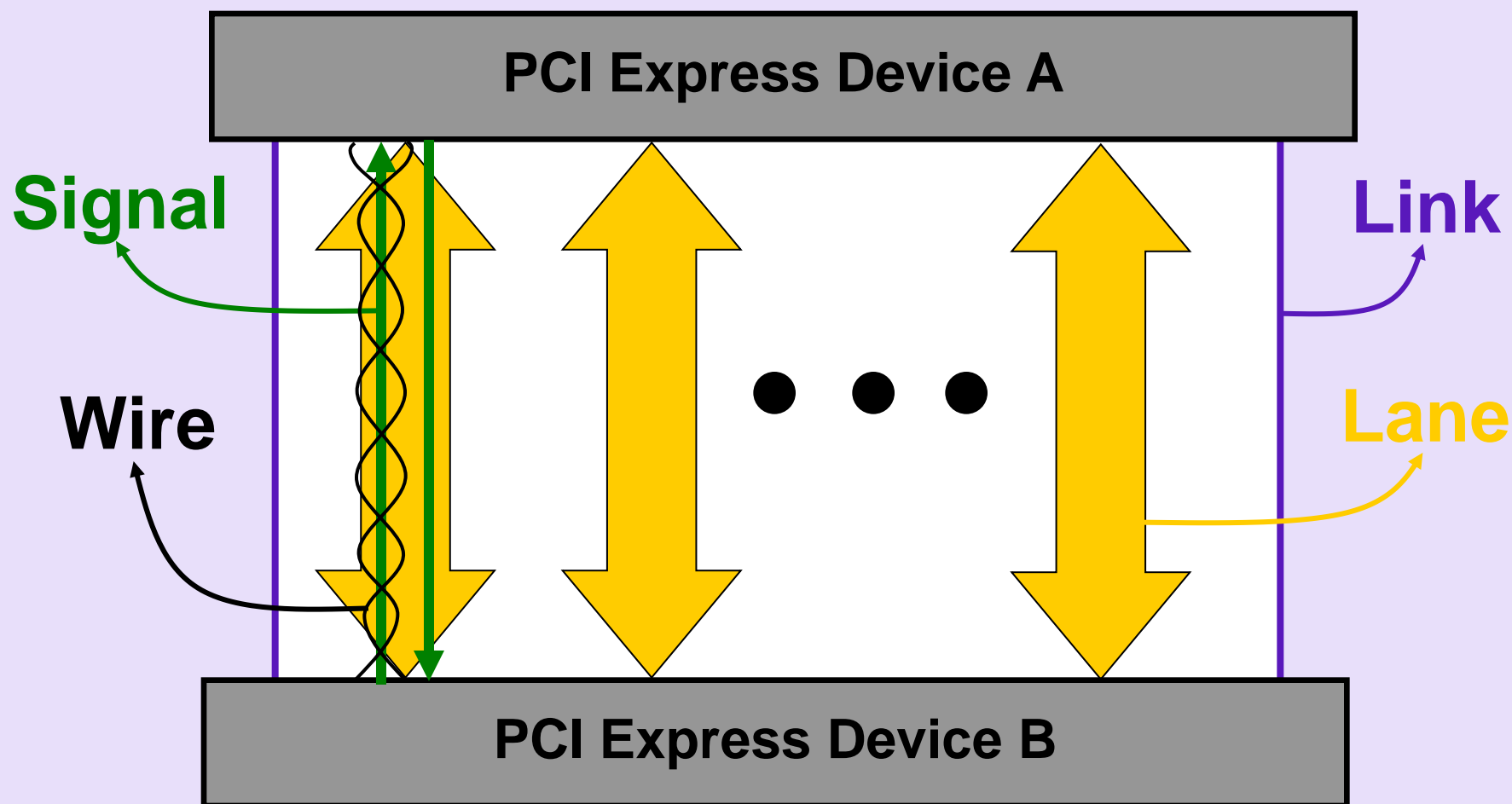
# Acknowledgements

- I would like to acknowledge the contributions of Ravi Budruk, Mindshare, Inc.

# PCI Express® Introduction

- PCI Express architecture is a high performance, IO interconnect for peripherals in computing/communication platforms
- Evolved from PCI™ and PCI-X™ architectures
  - ✓ Yet PCI Express architecture is significantly different from its predecessors PCI and PCI-X
- PCI Express is a serial point-to-point interconnect between two devices
- Implements packet based protocol for information transfer
- Scalable performance based on number of signal Lanes implemented on the PCI Express interconnect

# PCI Express Terminology



# PCI Express Throughput

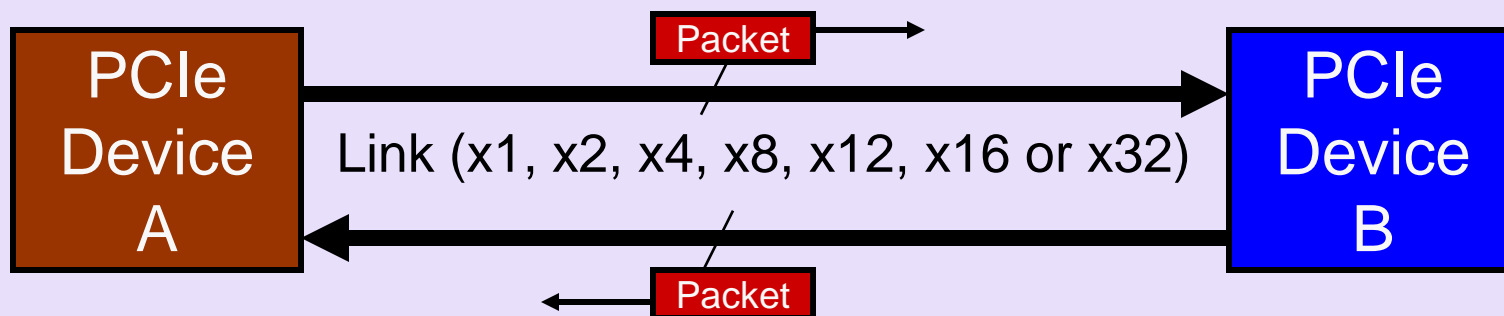
	Link Width						
	x1	x2	x4	x8	x12	x16	x32
<b>PCIe 1.x BW (GB/s)</b>	0.5	1	2	4	6	8	16
<b>PCIe 2.x BW (GB/s)</b>	1	2	4	8	12	16	32
<b>PCIe 3.0 BW (GB/s)</b>	2	4	8	16	24	32	64

## Derivation of these numbers:

- 2.5 GT/s (PCIe 1.x), 5.0 GT/s (PCIe 2.x), or 8GT/s (PCIe 3.0) signaling in each direction
- 20% overhead due to 8b/10b encoding in 1.x and 2.x
- “Aggregate bandwidth”, implying traffic in both directions

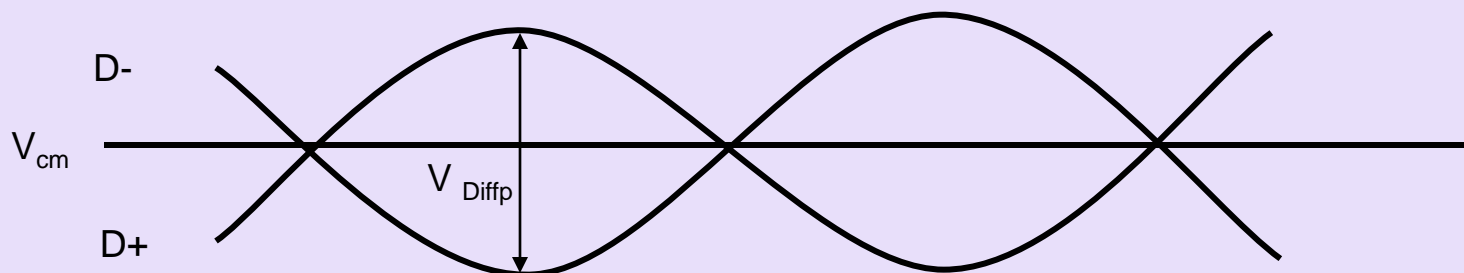
# PCI Express Features

- Point-to-point connection
- Serial bus means fewer pins
- Scalable: x1, x2, x4, x8, x12, x16, x32
- Dual Simplex connection
- 2.5, 5.0 and 8.0 GT/s transfer/direction/s
- Packet based transaction protocol



# Differential Signaling

- Electrical characteristics of PCI Express signal
  - ✓ Differential signaling
    - Transmitter Differential Peak voltage = 0.4 - 0.6 V
    - Transmitter Common mode voltage = 0 - 3.6 V



- Two devices at opposite ends of a Link may support different DC common mode voltages

# Additional Features

- Switches used to interconnect multiple devices
- Packet based protocol
- Bandwidth and clocking
- Same memory, IO and configuration address space as PCI
  - ✓ Similar transaction types as PCI with additional message transaction
- PCI Express Transactions include:
  - ✓ memory read/write, memory read lock, IO read/write, configuration read/write, message requests
- Split transaction model for non-posted



# Additional Features

- Data Integrity and Error Handling
  - ✓ RAS capable (Reliable, Available, Serviceable)
  - ✓ Data integrity at: 1) Link level, 2) end-to-end
- Virtual channels (VCs) and traffic classes (TCs) to support differentiated traffic or Quality of Service (QoS)
  - ✓ The ability to define levels of performance for packets of different TCs
  - ✓ 8 TC's and 8 VC's available

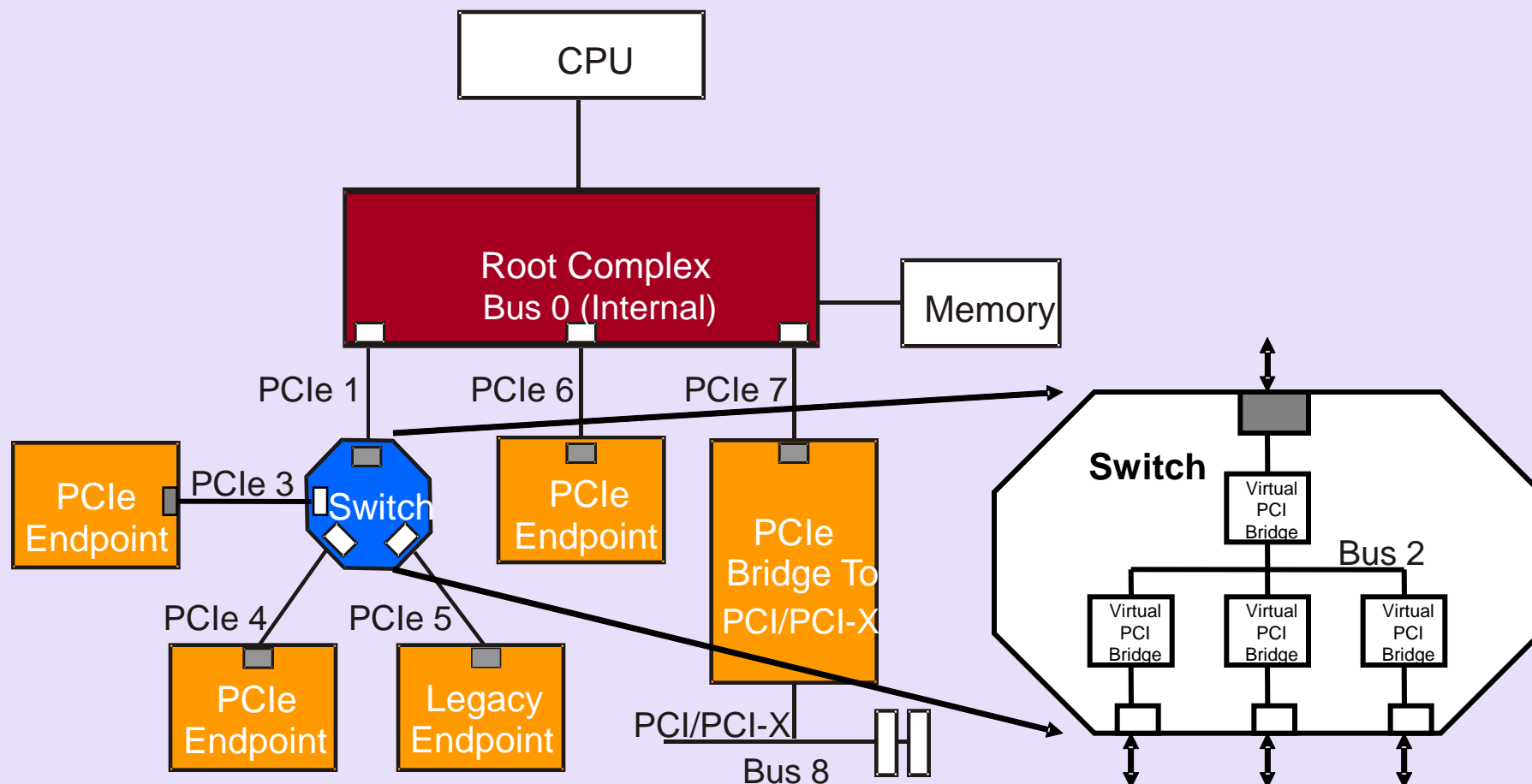
# Additional Features

- Flow Control
  - ✓ No retry as in PCI
- MSI style interrupt handling
  - ✓ Also supports legacy PCI interrupt handling in-band
- Advanced power management
  - ✓ Active State PM
  - ✓ PCI compatible PM

# Additional Features

- Hot Plug and Hot Swap support
  - ✓ Native
  - ✓ No sideband signals
- PCI compatible software model
  - ✓ PCI configuration and enumeration software can be used to enumerate PCI Express hardware
  - ✓ PCI Express system will boot existing OS
  - ✓ PCI Express supports existing device drivers
  - ✓ New additional configuration address space requires OS and driver update

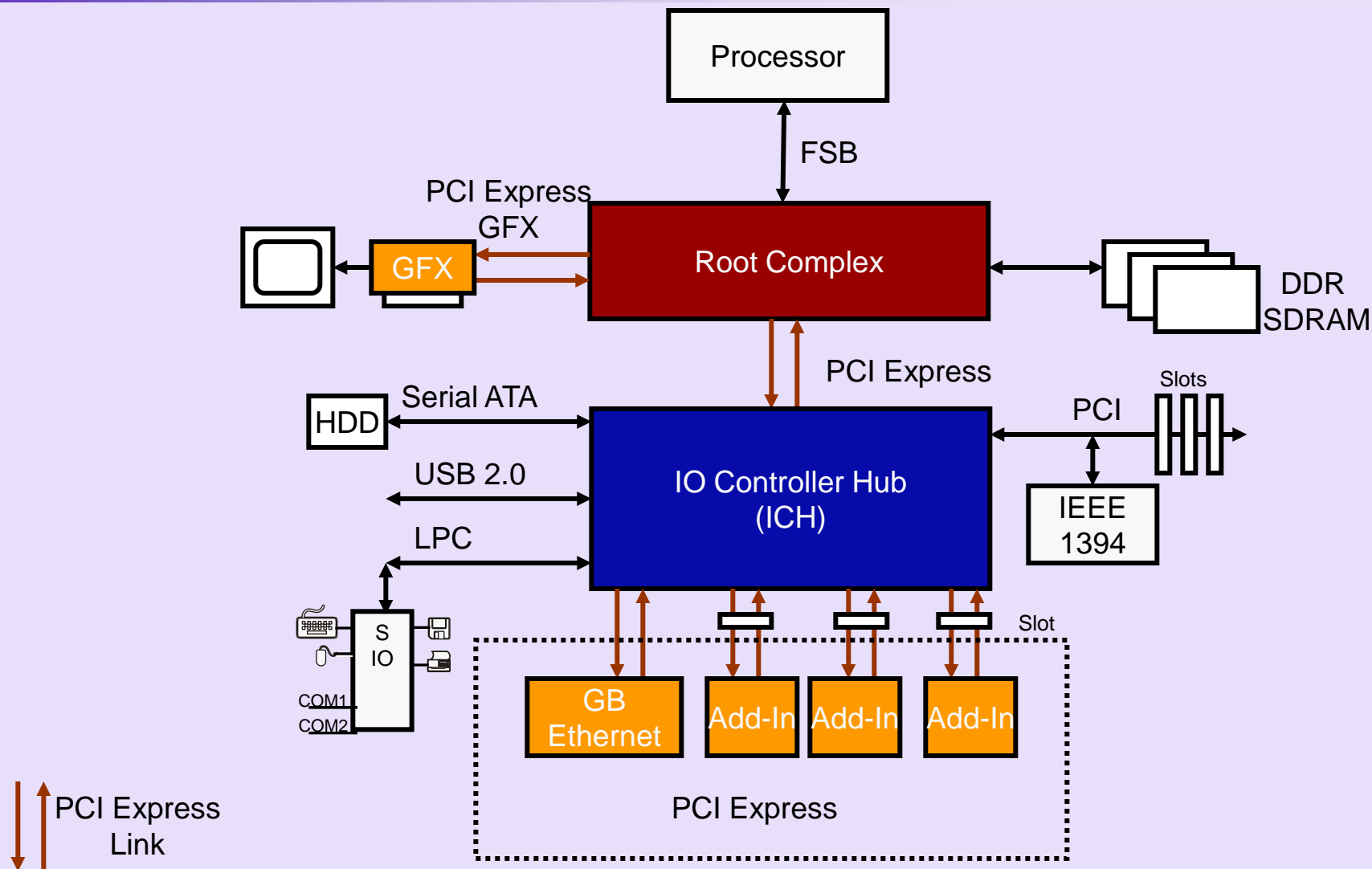
# PCI Express Topology



## Legend

-  PCI Express Device Downstream Port
-  PCI Express Device Upstream Port

# PCI Express System



# Transaction Types, Address Spaces

- Request are translated to one of four transaction types by the Transaction Layer:
  1. **Memory Read or Memory Write.** Used to transfer data from or to a memory mapped location
    - The protocol also supports a *locked memory read* transaction variant.
  2. **I/O Read or I/O Write.** Used to transfer data from or to an I/O location
    - These transactions are restricted to supporting legacy endpoint devices.
  3. **Configuration Read or Configuration Write.** Used to discover device capabilities, program features, and check status in the 4KB PCI Express configuration space.
  4. **Messages.** Handled like posted writes. Used for event signaling and general purpose messaging.

# PCI Express TLP Types

Description	Abbreviated Name
Memory Read Request	MRd
Memory Read Request – Locked Access	MRdLk
Memory Write Request	MWr
IO Read Request	IORd
IO Write Request	IOWr
Configuration Read Request Type 0 and Type 1	CfgRd0, CfgRd1
Configuration Write Request Type 0 and Type 1	CfgWr0, CfgWr1
Message Request without Data Payload	Msg
Message Request with Data Payload	MsgD
Completion without Data (used for IO, configuration write completions and read completion with error completion status)	Cpl
Completion with Data (used for memory, IO and configuration read completions)	CplD
Completion for Locked Memory Read without Data (used for error status)	CplLk
Completion for Locked Memory Read with Data	CplDLk

# Three Methods For Packet Routing

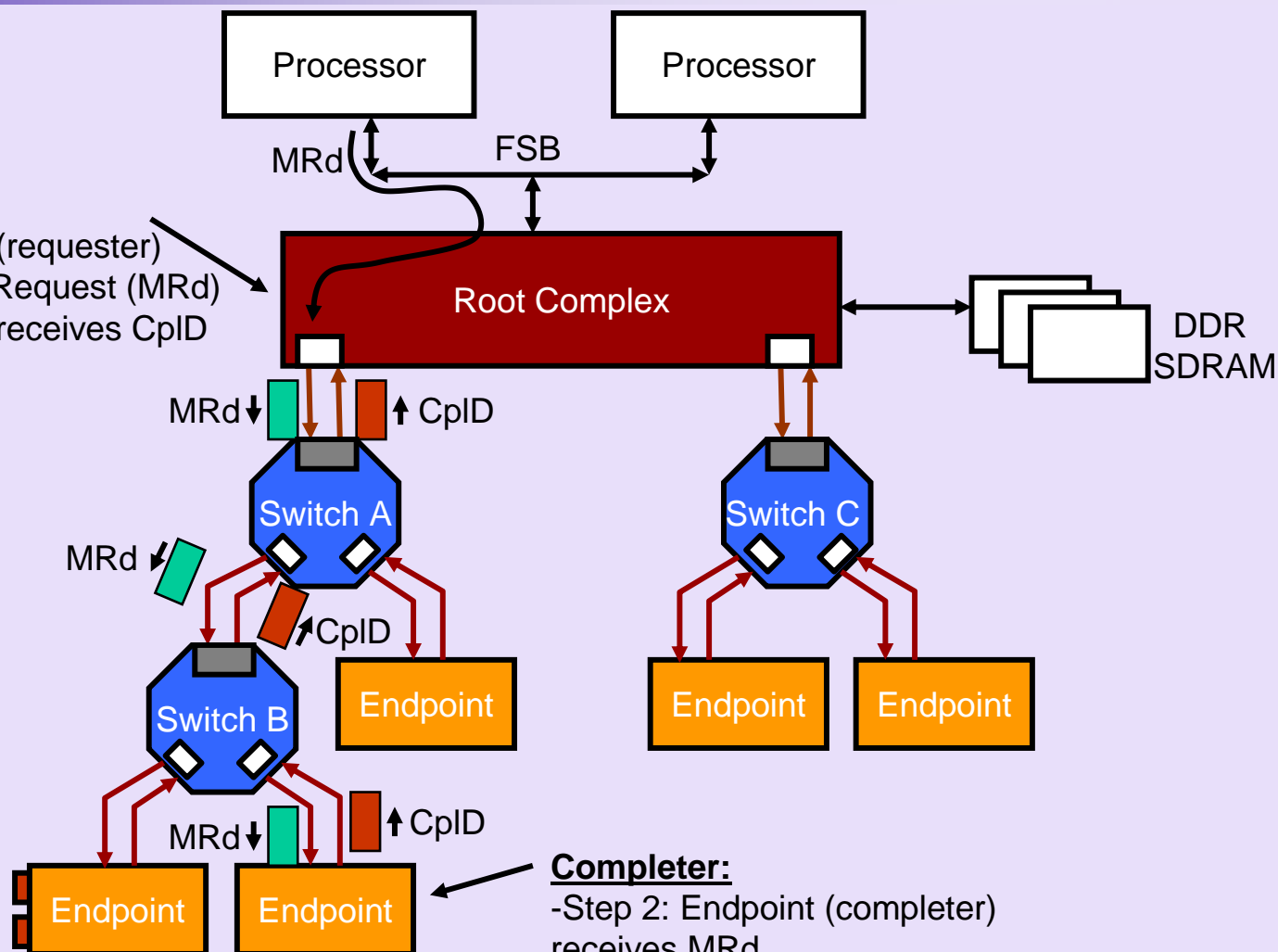
- Each request or completion header is tagged as to its *type*, and each of the packet types is routed based on one of three schemes:
  - ✓ Address Routing
  - ✓ ID Routing
  - ✓ Implicit Routing
- Memory and IO requests use address routing.
- Completions and Configuration cycles use ID routing.
- Message requests have selectable routing based on a 3-bit code in the message routing sub-field of the header type field.



# Programmed I/O Transaction

## Requester:

- Step 1: Root Complex (requester) initiates Memory Read Request (MRd)
- Step 4: Root Complex receives CplD



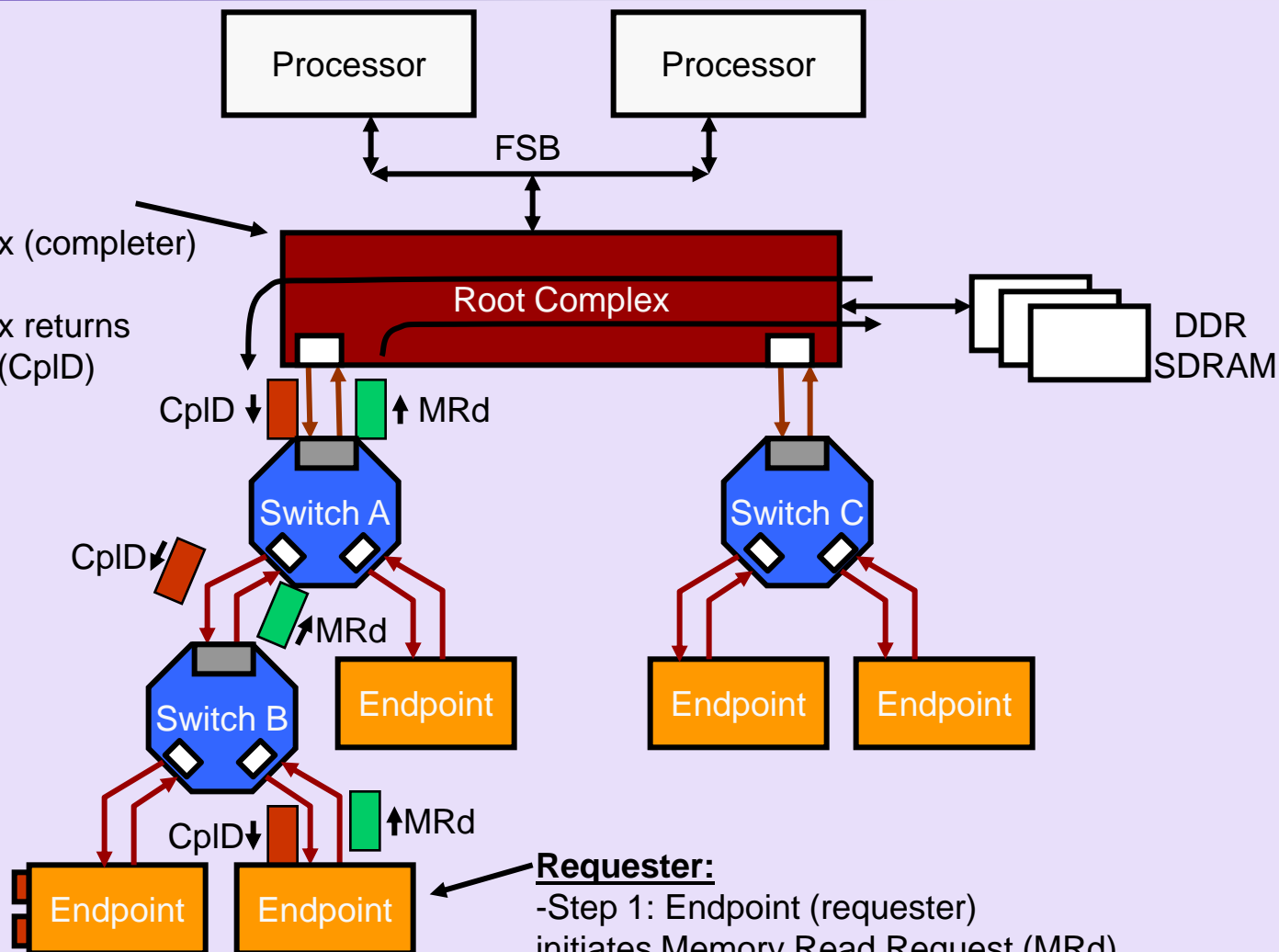
## Completer:

- Step 2: Endpoint (completer) receives MRd
- Step 3: Endpoint returns Completion with data (CplD)

# DMA Transaction

## Completer:

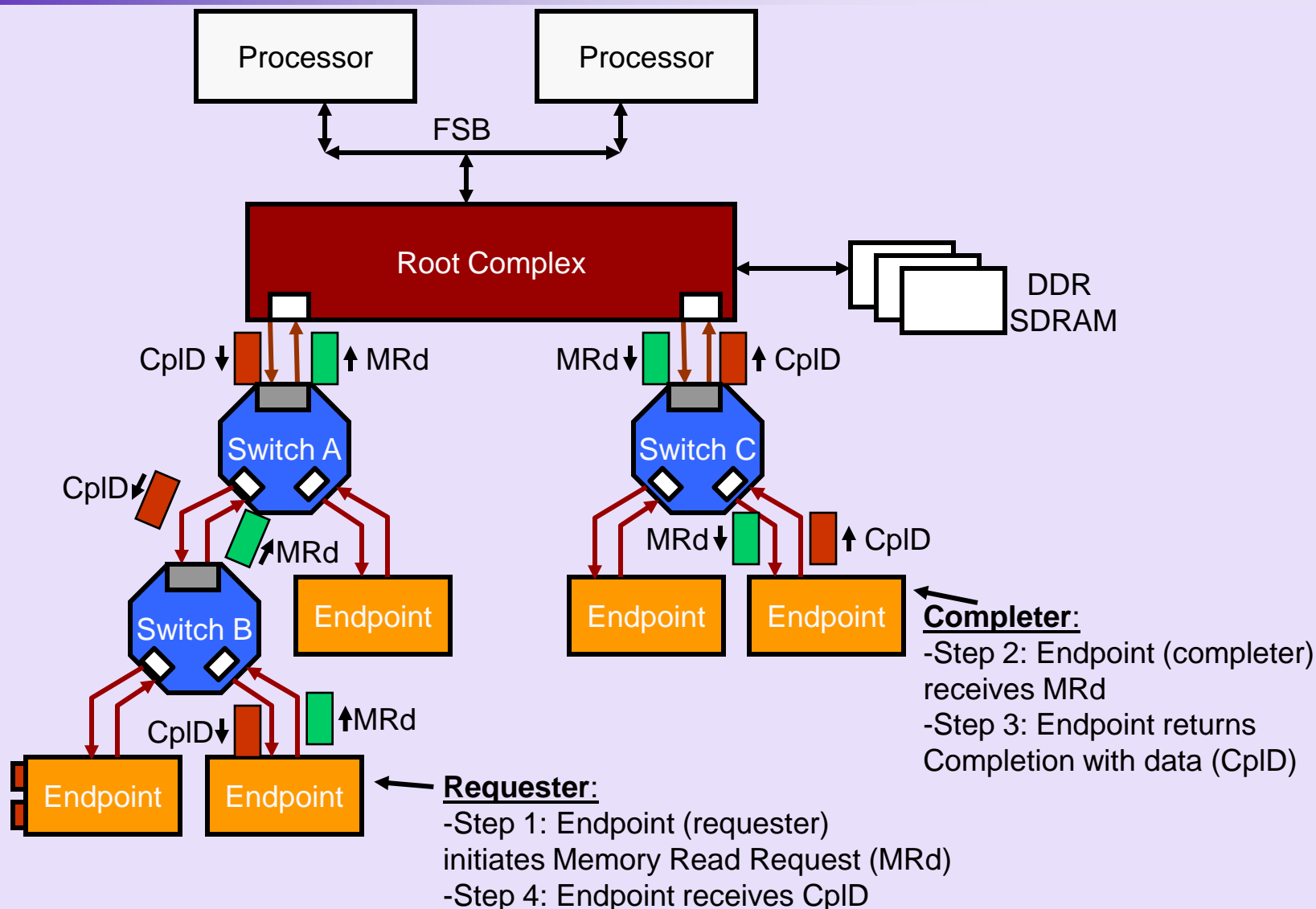
- Step 2: Root Complex (completer) receives MRd
- Step 3: Root Complex returns Completion with data (CpID)



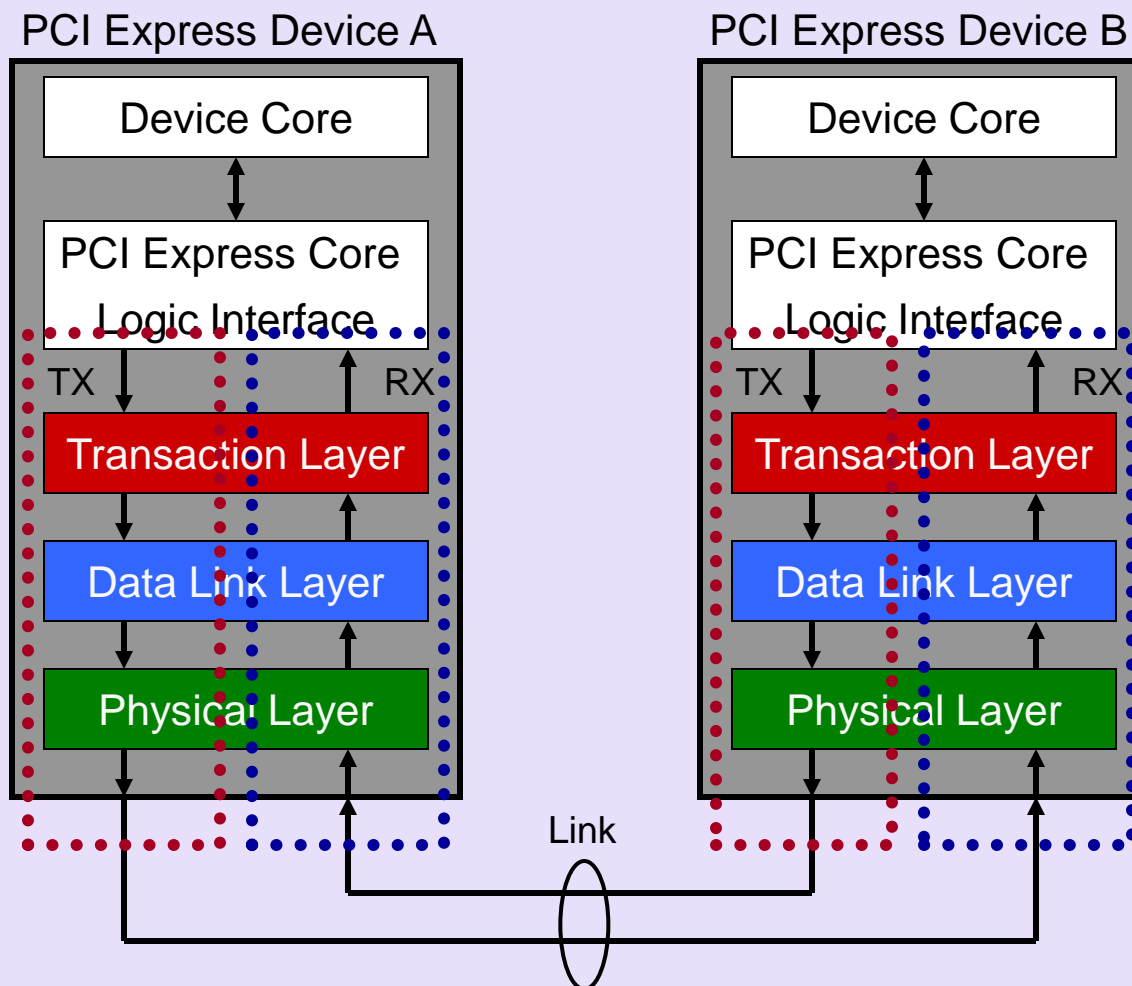
## Requester:

- Step 1: Endpoint (requester) initiates Memory Read Request (MRd)
- Step 4: Endpoint receives CpID

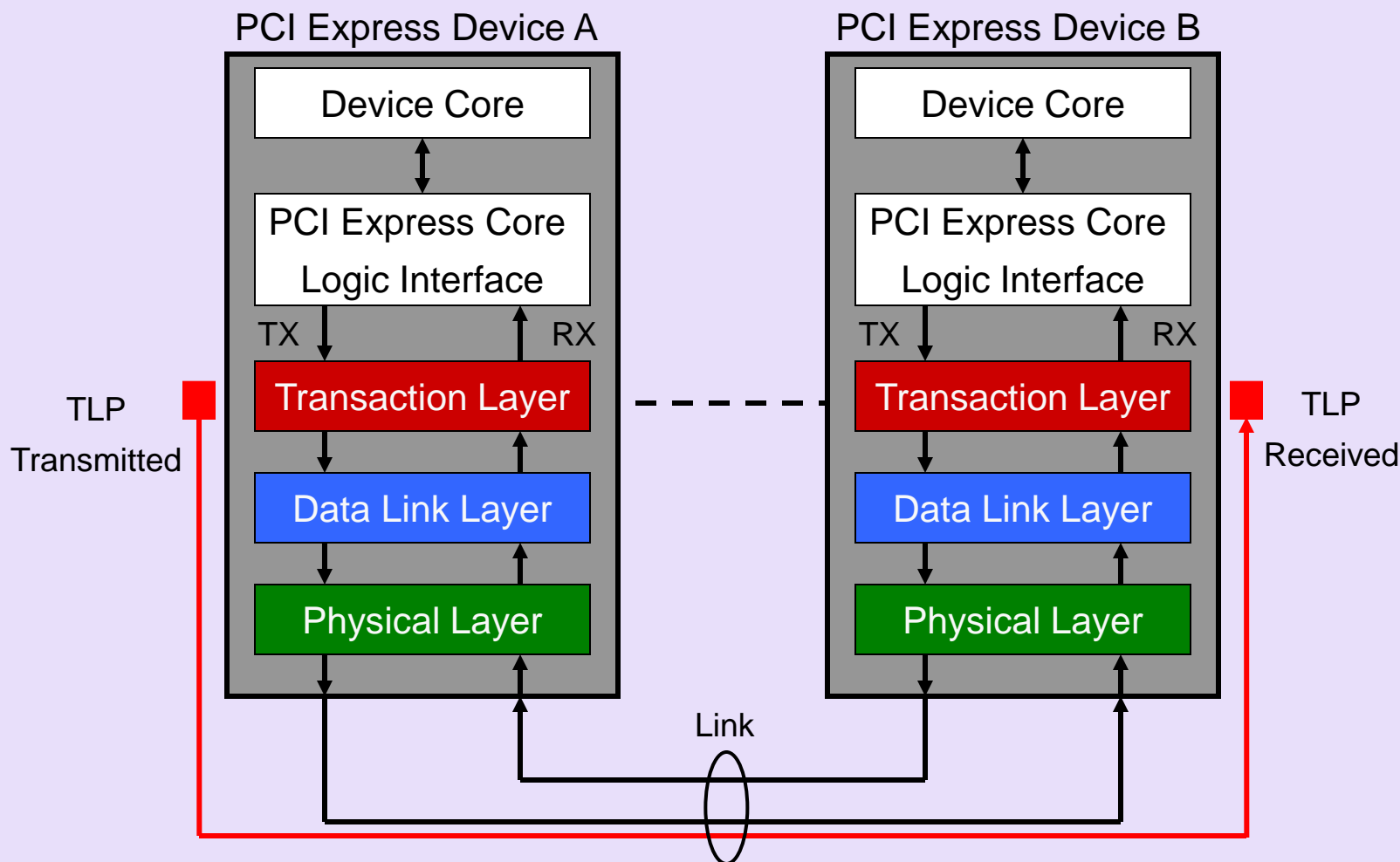
# Peer-to-Peer Transaction



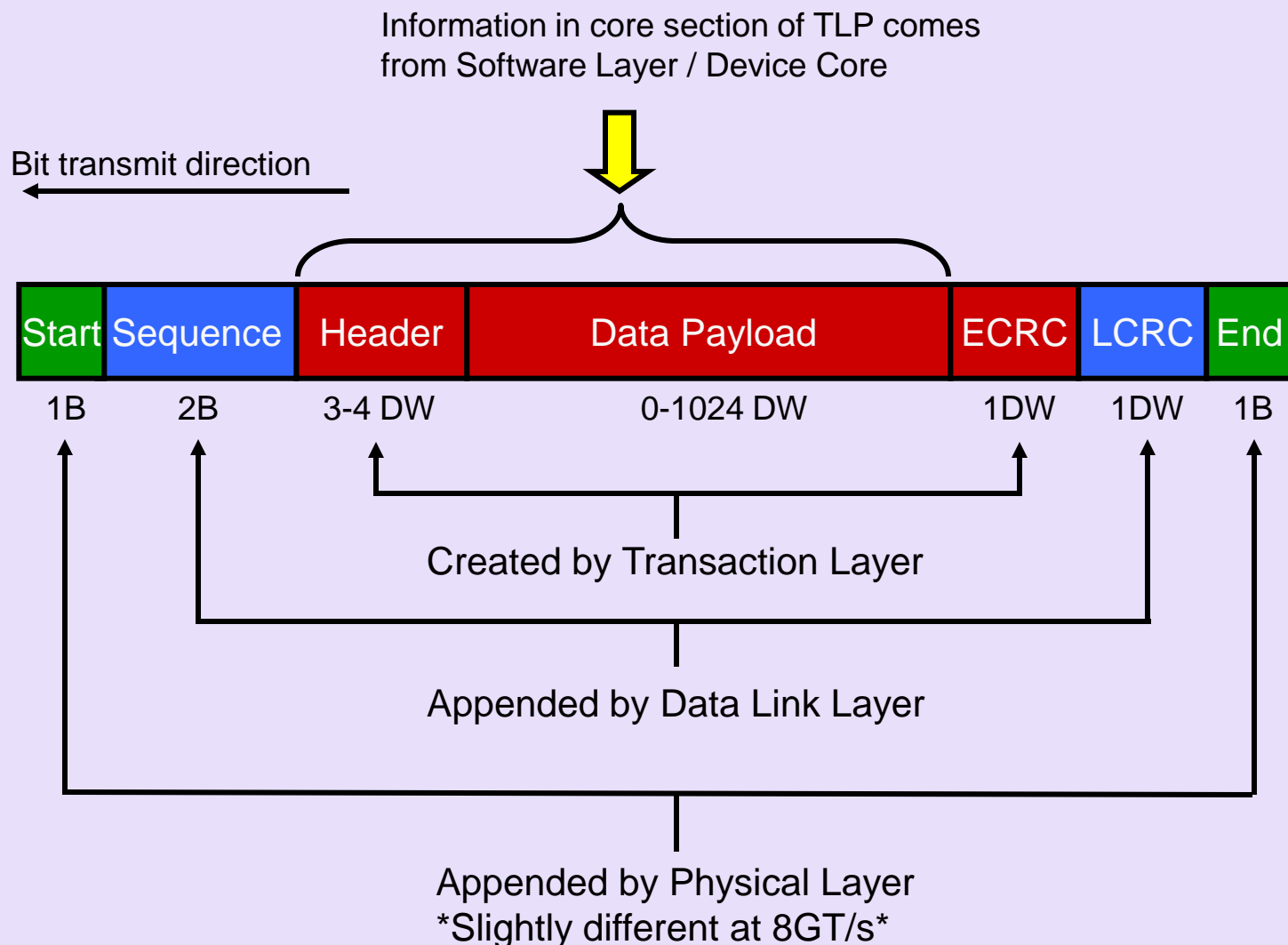
# PCI Express Device Layers



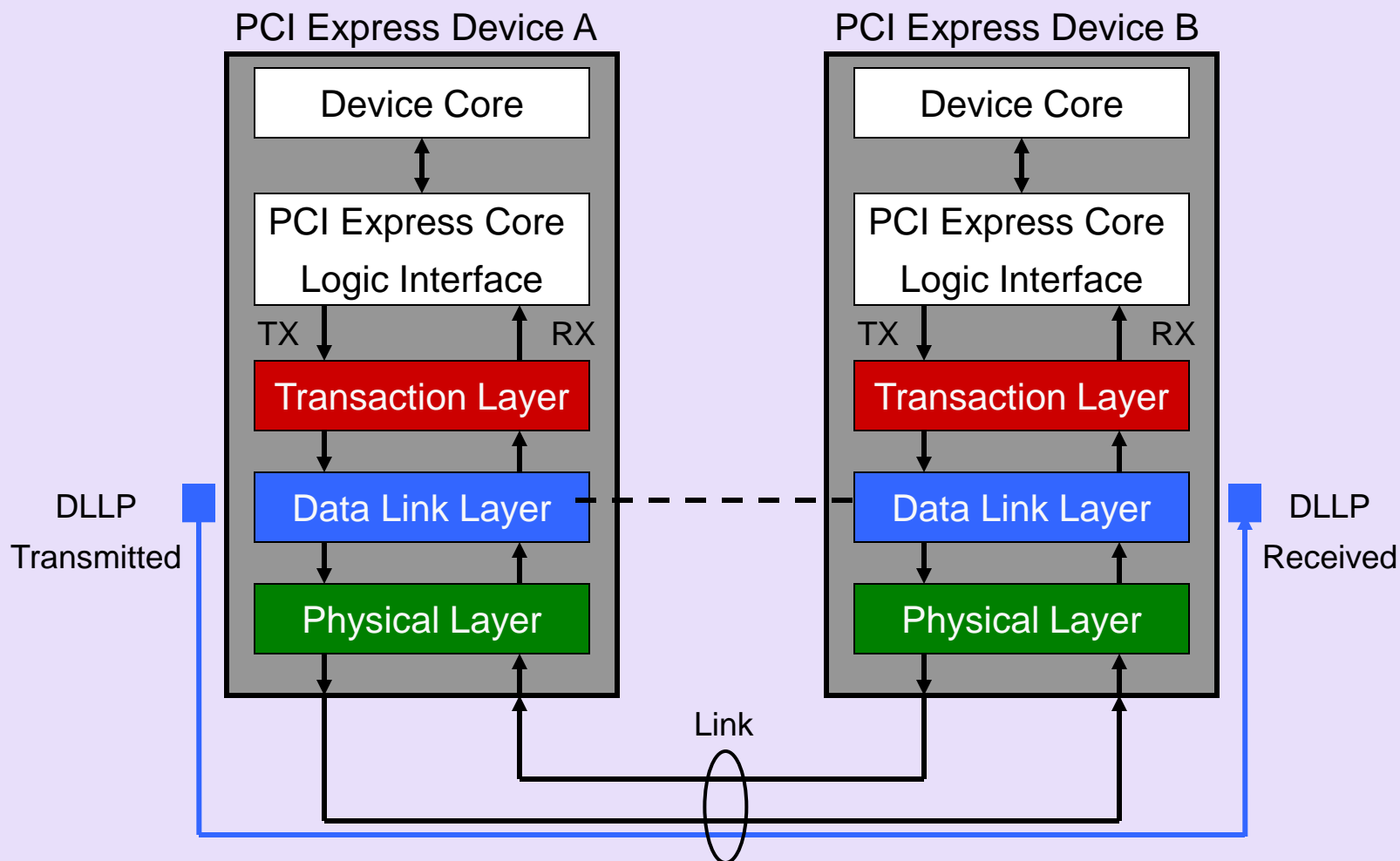
# TLP Origin and Destination



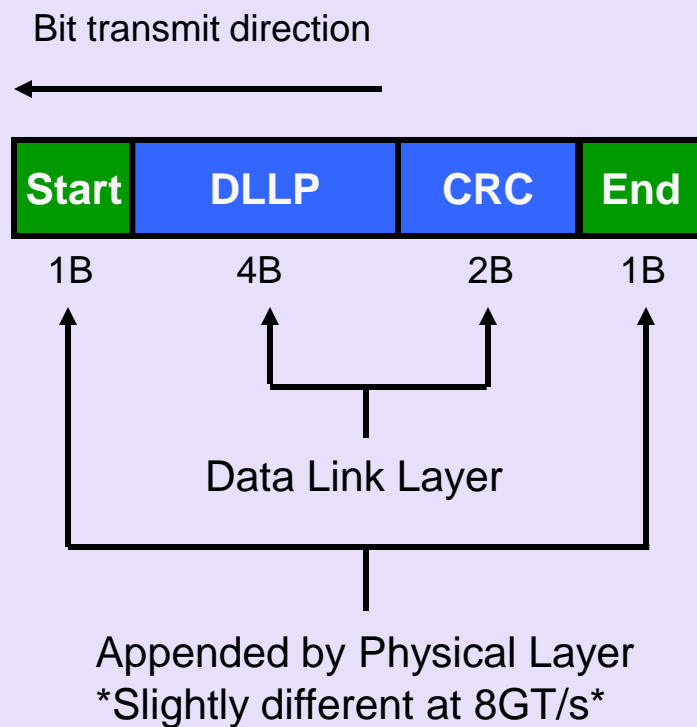
# TLP Structure



# DLLP Origin and Destination



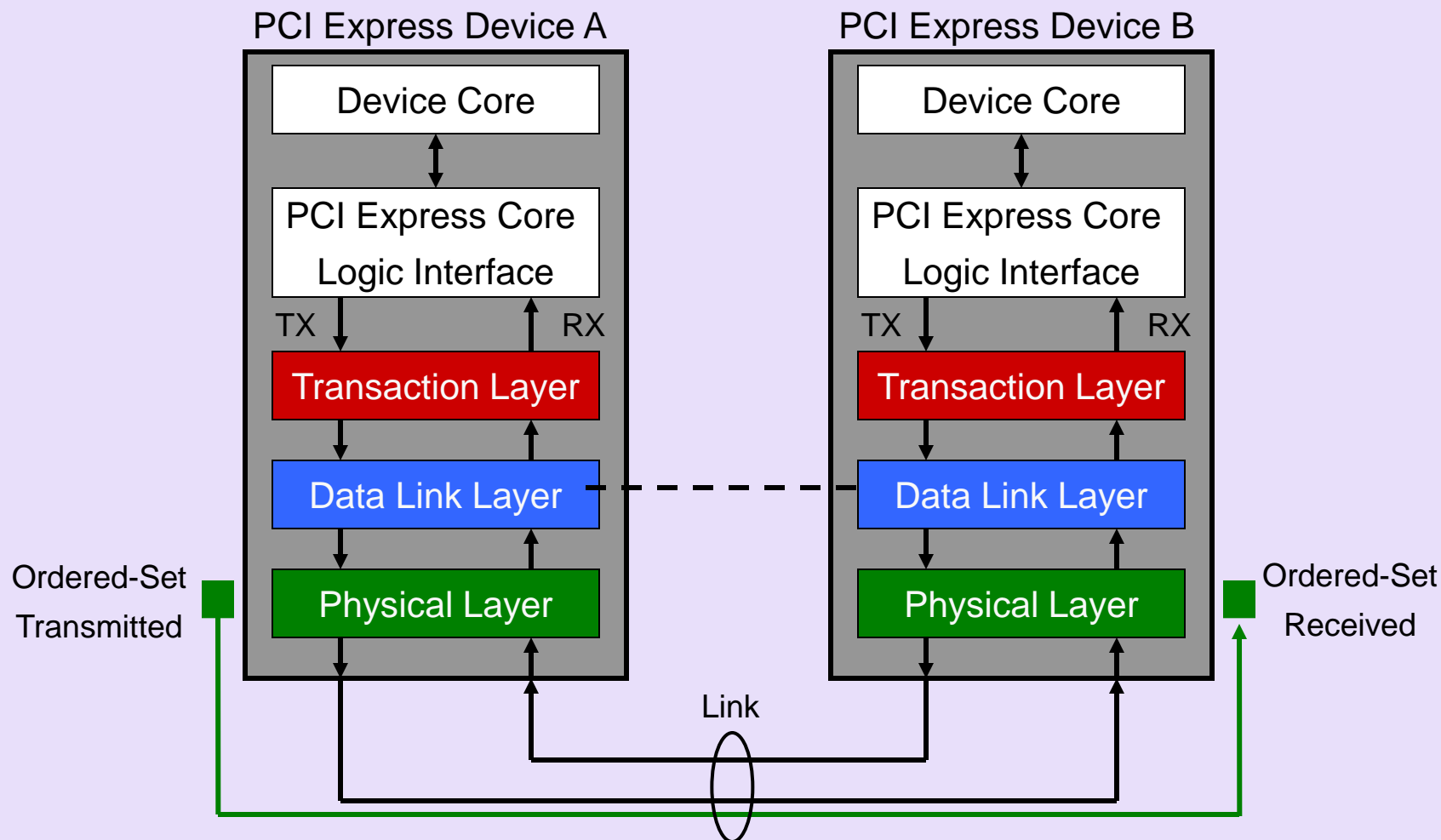
# DLLP Structure



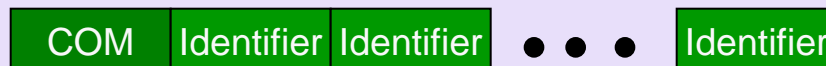
- ACK / NAK Packets
- Flow Control Packets
- Power Management Packets
- Vendor Defined Packets



# Ordered-Set Origin and Destination

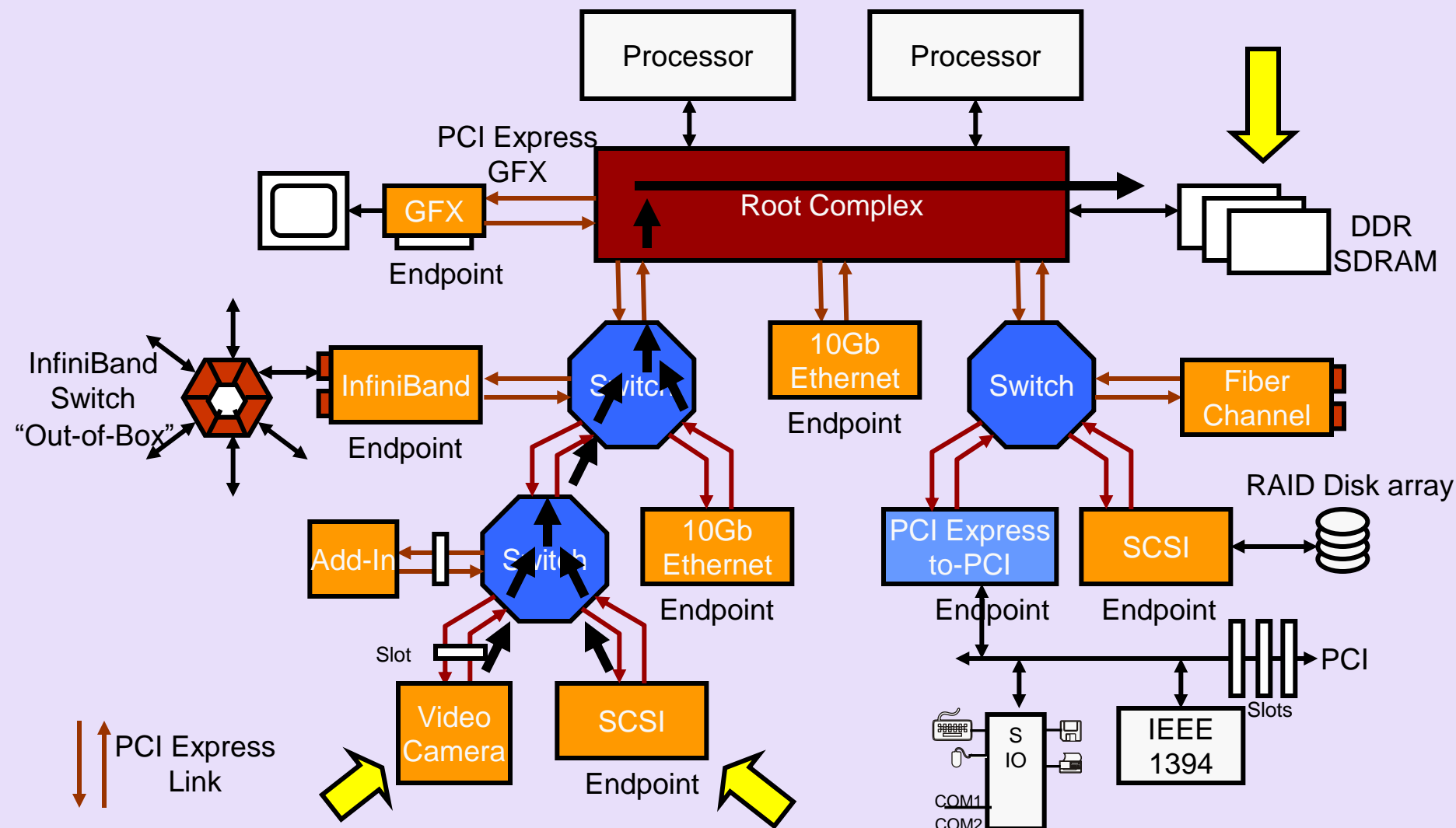


# Ordered-Set Structure in 2.5GT/s and 5GT/s modes



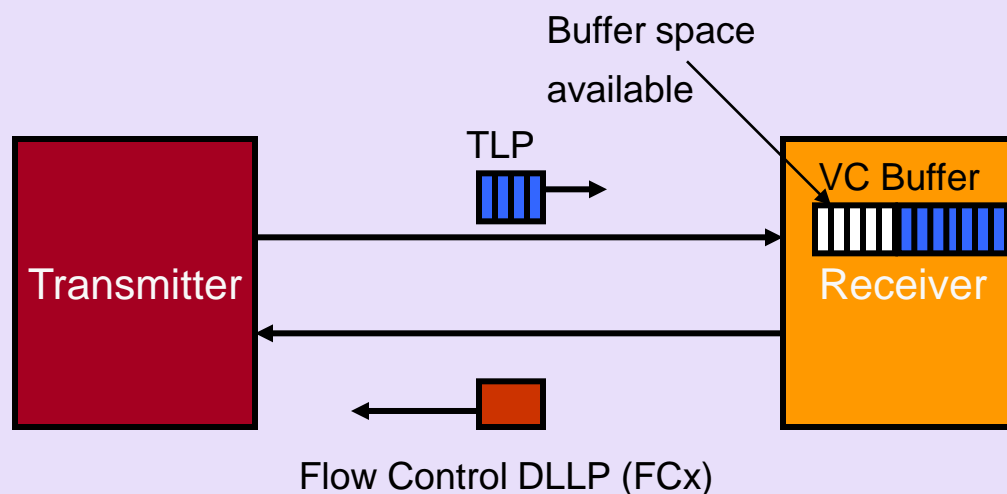
- Training Sequence One (TS1)
  - ✓ 16 character set: 1 COM, 15 TS1 data characters
- Training Sequence Two (TS2)
  - ✓ 16 character set: 1 COM, 15 TS2 data characters
- SKIP
  - ✓ 4 character set: 1 COM followed by 3 SKP identifiers
- Fast Training Sequence (FTS)
  - ✓ 4 characters: 1 COM followed by 3 FTS identifiers
- Electrical Idle (IDLE)
  - ✓ 4 characters: 1 COM followed by 3 IDL identifiers
- Electrical Idle Exit (EIEOS) (new to 2.0 spec)
  - ✓ 16 characters

# Quality of Service



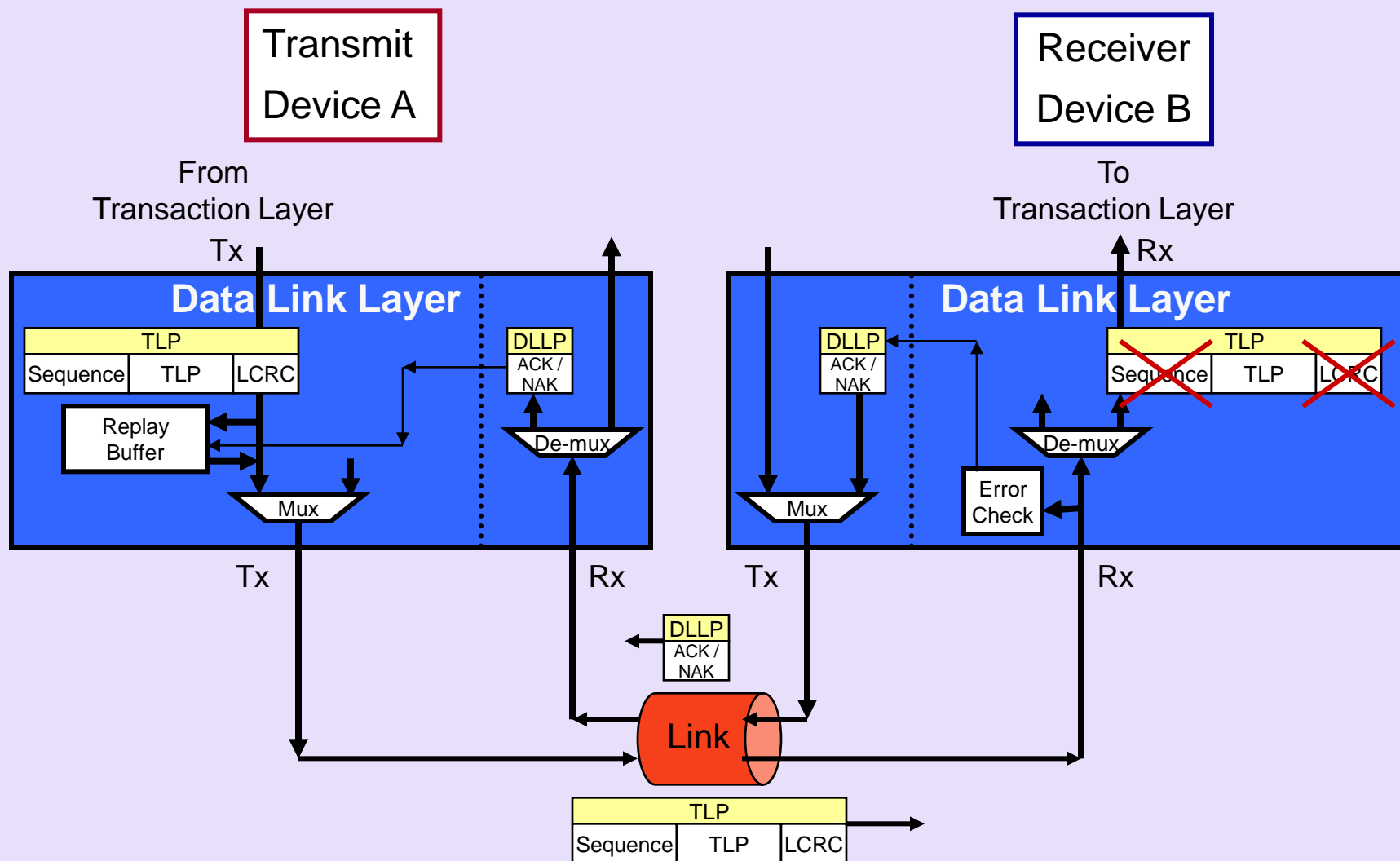
# PCI Express Flow Control

- Credit-based *flow control* is point-to-point based, not end-to-end

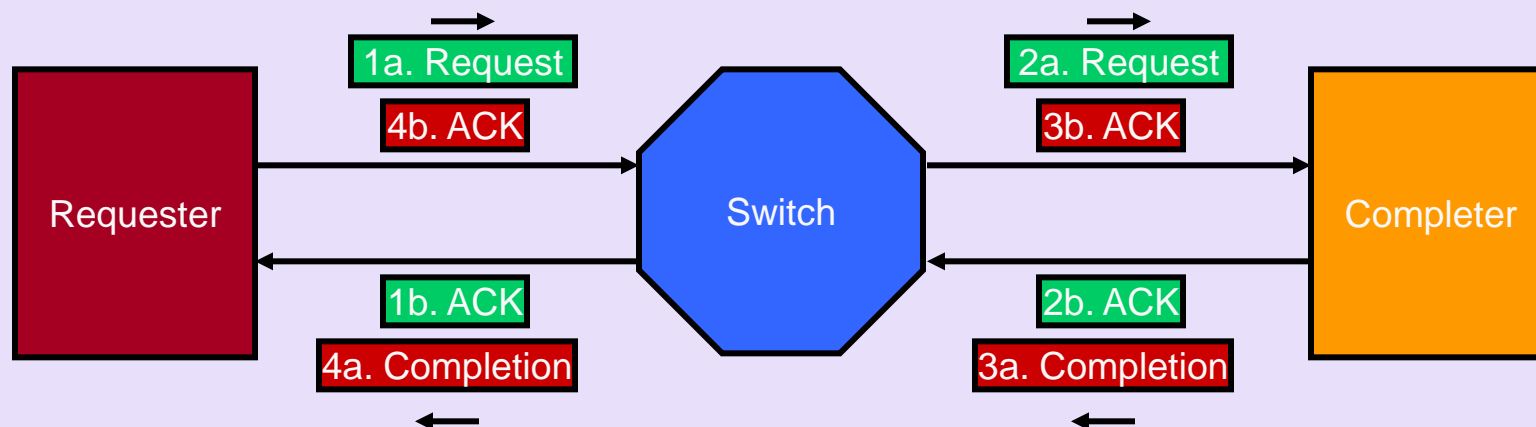


Receiver sends Flow Control Packets (FCP) which are a type of DLLP (Data Link Layer Packet) to provide the transmitter with credits so that it can transmit packets to the receiver

# ACK/NAK Protocol Overview



# ACK/NAK Protocol: Point-to-Point

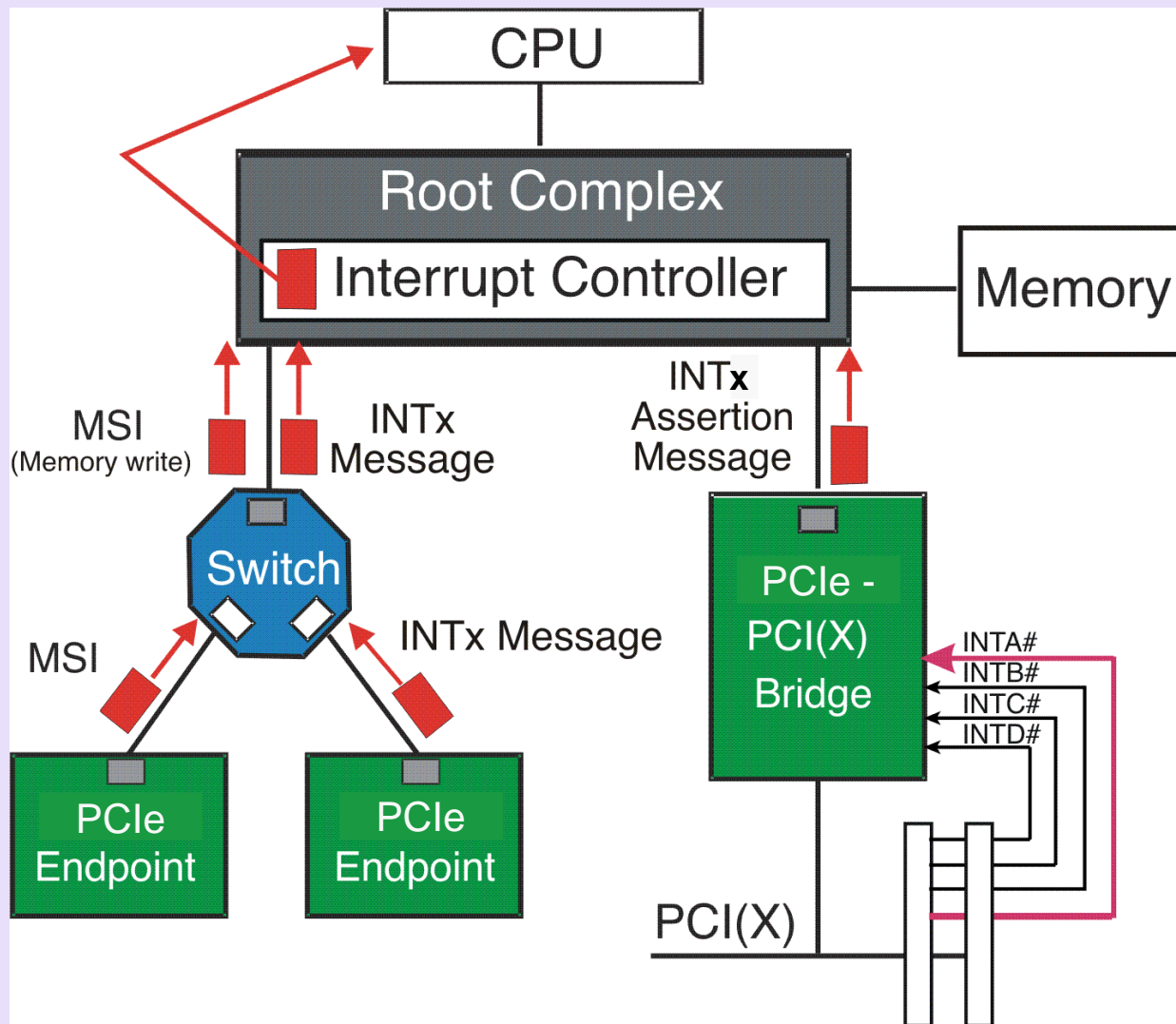


ACK returned for good reception of Request or Completion  
NAK returned for error reception of Request or Completion

# Interrupt Model: Three Methods

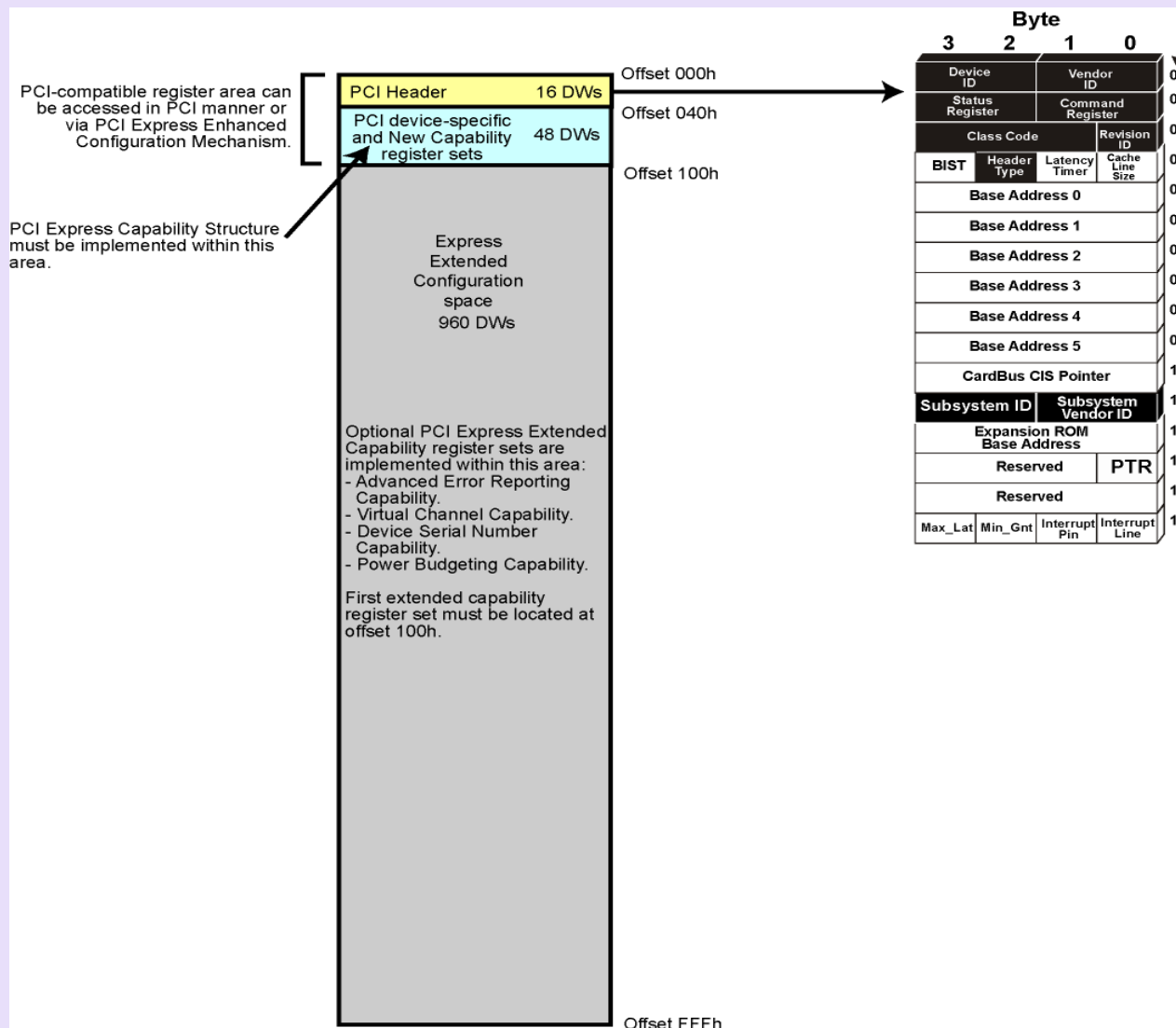
- PCI Express supports three interrupt reporting mechanisms:
  1. **Message Signaled Interrupts (MSI)**
    - Legacy endpoints are required to support MSI (or MSI-X) with 32- or 64-bit MSI capability register implementation
    - Native PCI Express endpoints are required to support MSI with 64-bit MSI capability register implementation
  2. **Message Signaled Interrupts - X (MSI-X)**
    - Legacy and native endpoints are required to support MSI-X (or MSI) and implement the associated MSI-X capability register
  3. **INTx Emulation.**
    - Native and Legacy endpoints are required to support Legacy INTx Emulation
    - PCI Express defines in-band messages which emulate the four physical interrupt signals (INTA-INTD) routed between PCI devices and the system interrupt controller
    - Forwarding support required by switches

# Native and Legacy Interrupts





# PCI Express Configuration Space



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