USB4™ System Overview

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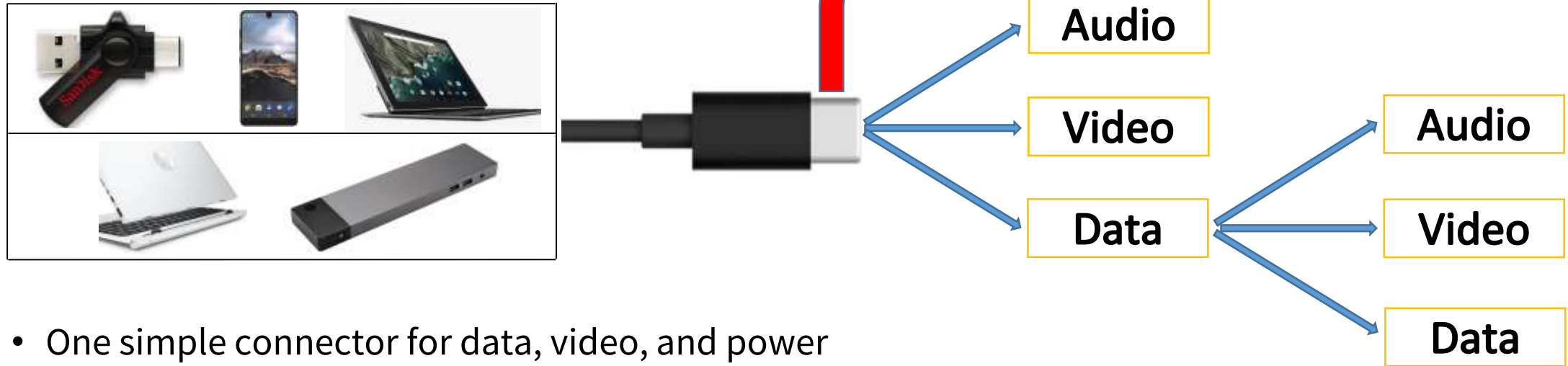
USB Developer Days 2019 – Taipei, Taiwan

November 19, 2019

Presentation Agenda

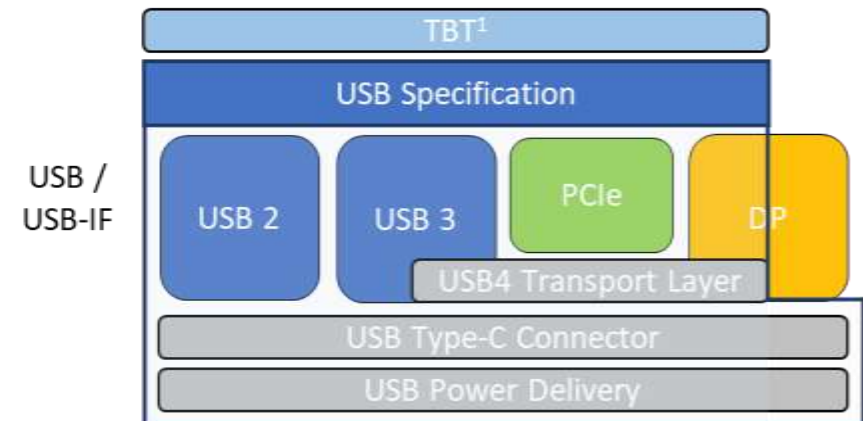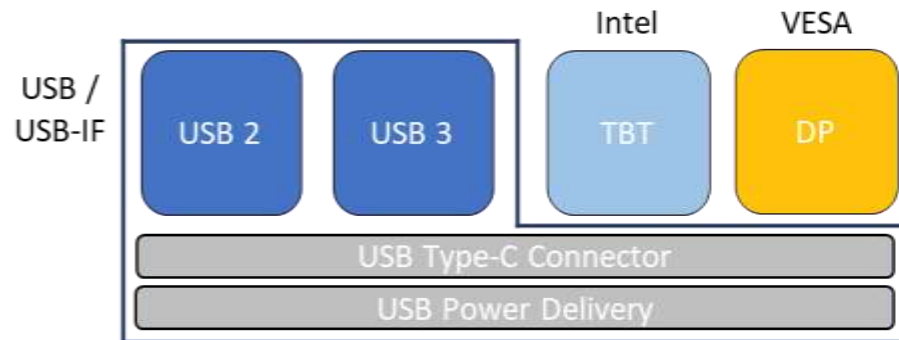- USB Type-C® Vision
- USB4™ Specification Overview

USB Type-C® Vision

- One simple connector for data, video, and power
  - Small, flippable connector with symmetrical cables
  - Compatible systems, cables, and devices at various performance levels
- Scalable
  - Across form factors (phone to workstation), and peripherals (displays, docks, storage)
  - Across usages (low power / performance, to 8k uncompressed video)
- USB and Thunderbolt™ architecture as the foundation

Delivering the USB Type-C® Vision

- USB4™ Specification Goals:
  - Help converge USB Type-C connector ecosystem to minimize end-user confusion
  - Drive broad adoption of USB4 architecture

- What the Specification Enables:
  - Standards-based ownership for specifications and certification
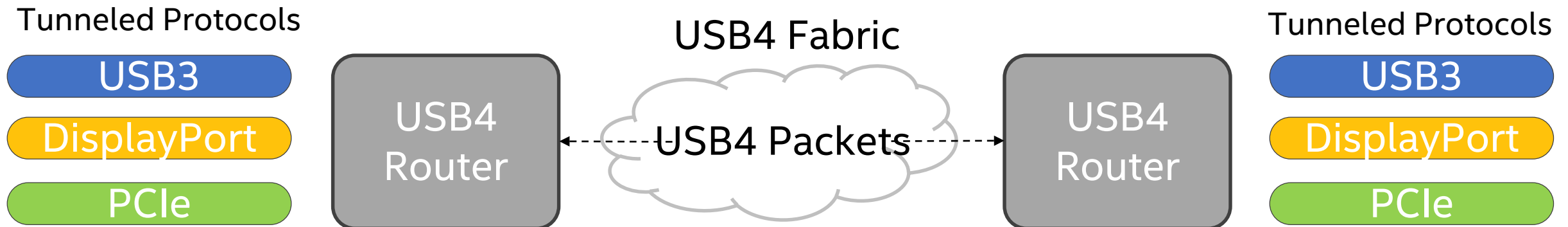 - Third party vendors can build Thunderbolt™ 3 compatible SOC or peripheral silicon

[1]Thunderbolt capabilities defined in USB4 specification

Presentation Agenda

- USB Type-C® Vision

- USB4™ Specification Overview

10,000 Foot View

- Runs over USB Type-C® interconnect
- Tunnels USB3, PCIe and DP protocols
- Signaling rates of 10 or 20 Gbps (10 to 40Gbps aggregated b/w)
- Utilizes passive and active cables (longer reach)
- Topologies with up to 6 routers
- Time sync accuracy support across USB4™ Fabric

Tunneled Protocols

USB3

DisplayPort

PCIe

USB4 Router

USB4 Fabric

USB4 Packets

USB4 Router

Tunneled Protocols

USB3

DisplayPort

PCIe

USB4™ System Description

- Routers are the fundamental building block of any USB4 Product
    - Host Router resides at the top of the tree
        - All other Routers are Device Routers
    - Connection Manager (CM) runs on the platform that includes the Host Router
- Domain
    - A collection of interconnected Routers managed by a single CM
    - Contains one USB4 Host
    - Contains zero or more USB4 Hubs
    - Contains zero or more USB4 Devices
   - Each USB4 Hub/Device is reachable by one or more USB4 Links
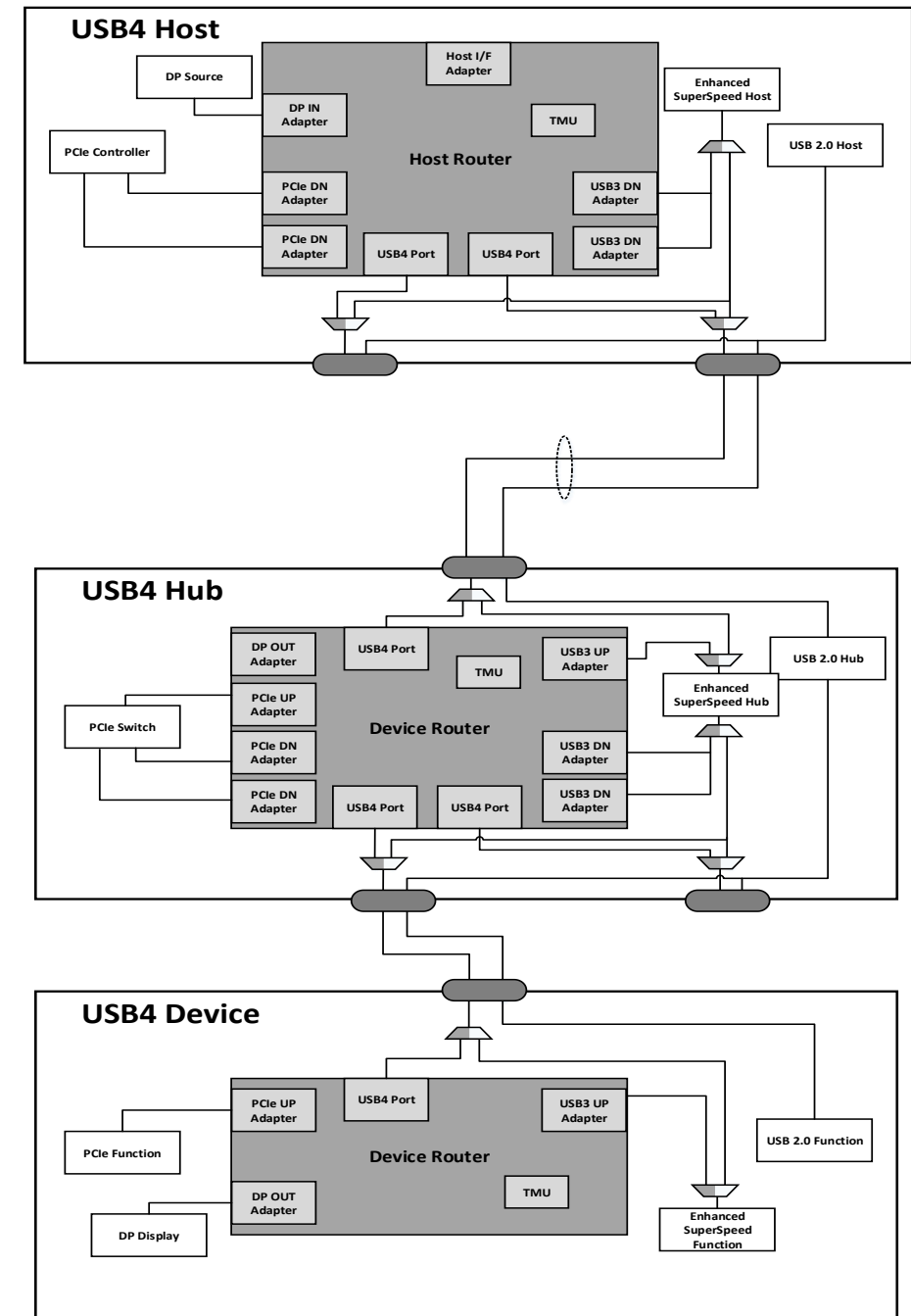
Elements of a Router

- A router core that interconnects between ports and provides router-wide services
- A Control Adapter
- USB4™ Ports, connected to USB4 Links
- Optional Protocol Adapters
- A Time Management Unit (TMU)

Router example
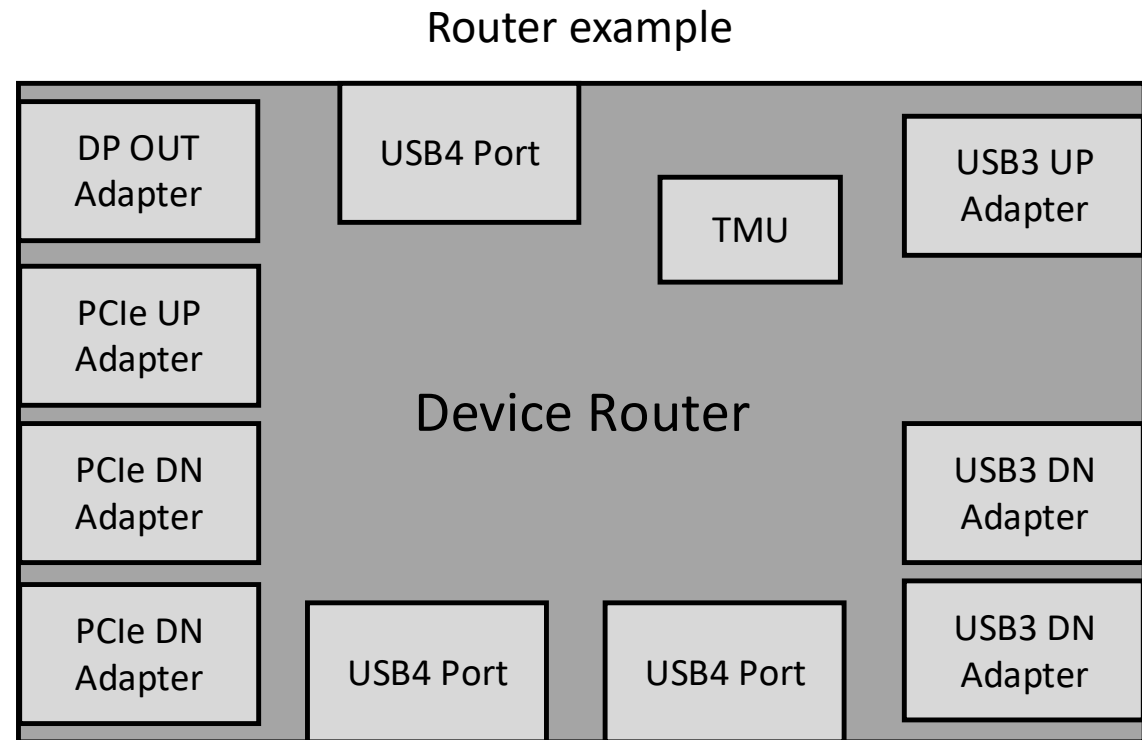
USB4™ Host

- A USB4 host contains:
  - A Host Router
  - An internal USB host controller
  - A DisplayPort Source
    - At least one DP IN Adapter
- Optionally support PCIe Tunneling
  - Supports a PCIe Controller
- A USB4 host supports 20 Gbps operation and optionally 40 Gbps operation
- A USB4 host is required to support DisplayPort™ Alt Mode on all of its DFP
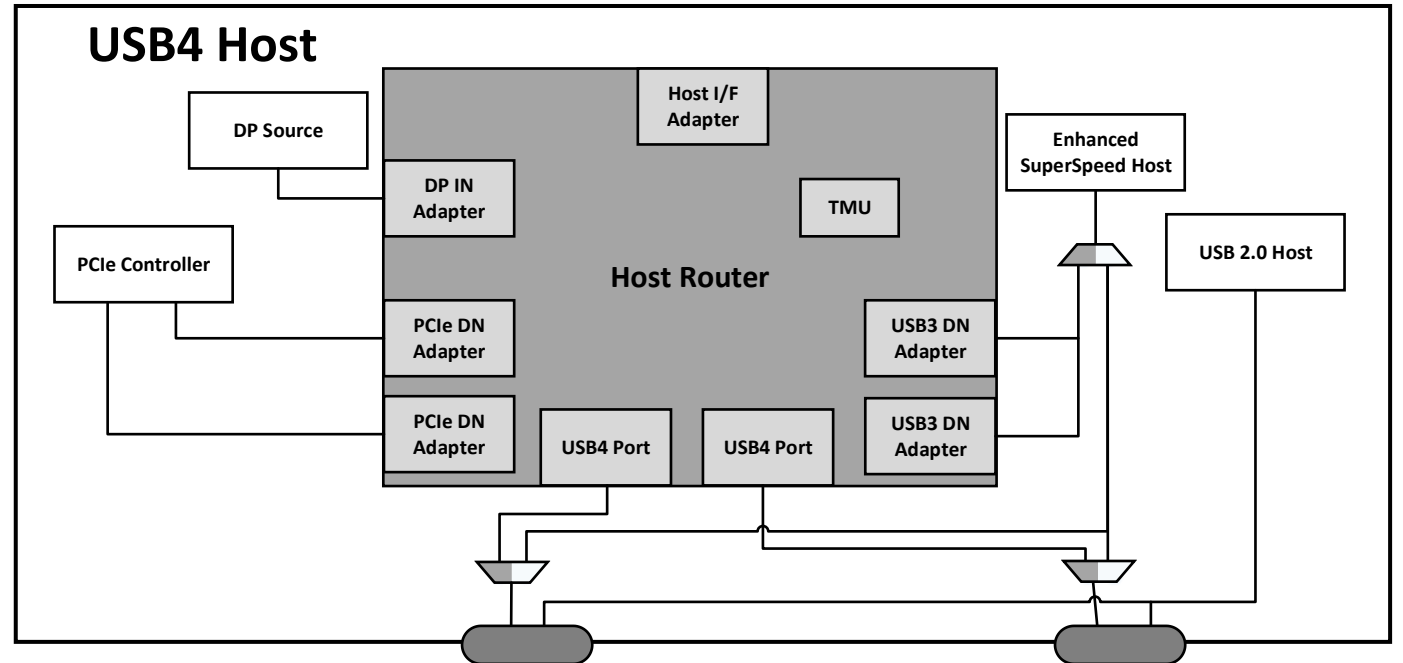
USB4™ Hub

- USB4 Hub
  - One Upstream Facing USB4 Port and one or more Downstream Facing USB4 Ports
  - Provides backward-compatibility
  - Contains:
    - A Device Router
    - A USB3 and a USB2 hub
    - A PCIe switch
  - Supports DP Tunneling
    - Requires at least one DP OUT Adapter to support DP Alt Mode on DFPs
  - Supports 40 Gbps operation
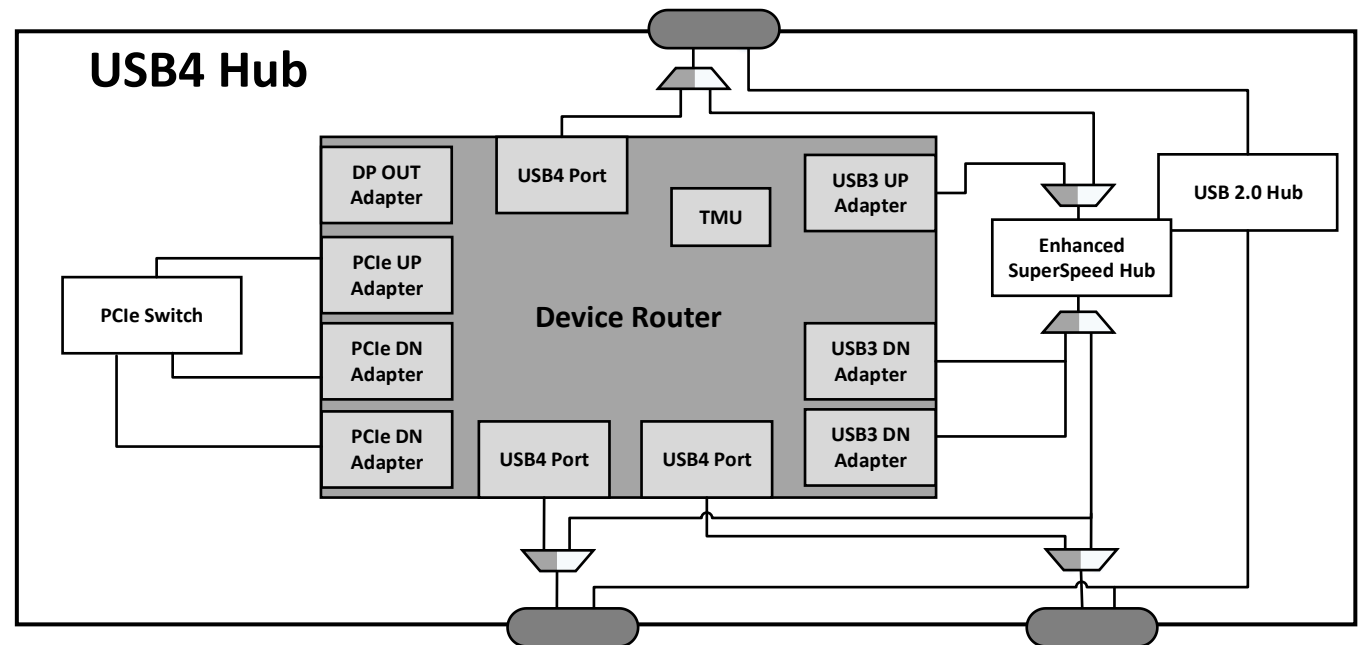
- USB4-Based Dock
  - Combines a USB4 Hub with additional capabilities to expose other connector types and/or include other user-visible functions

USB4™ Peripheral Device

- One Upstream Facing Port and zero Downstream Facing Ports

- Contains a Device Router and optionally contain one or more of the following:
  - An Enhanced SuperSpeed hub
  - An Enhanced Superspeed function
  - A PCIe switch or endpoint
  - A DisplayPort™ Source or Sink

- Supports 20 Gbps and optionally 40 Gbps operation

USB4™ Functional Stack

Maps an I/O protocol (PCIe, DP, USB, Host Interface) to USB4

Performs Router setup, configuration and management

Protocol Adapter Layer

Configuration Layer

Transport Layer

Handles packet multiplexing, routing, QoS, flow control and time synch

Physical Layer

Establishes a High-Speed Link between two routers, encodes/decodes byte streams, and performs Link PM services

Logical Layer

Electrical Layer

Defines Electrical signaling across High-Speed Lanes
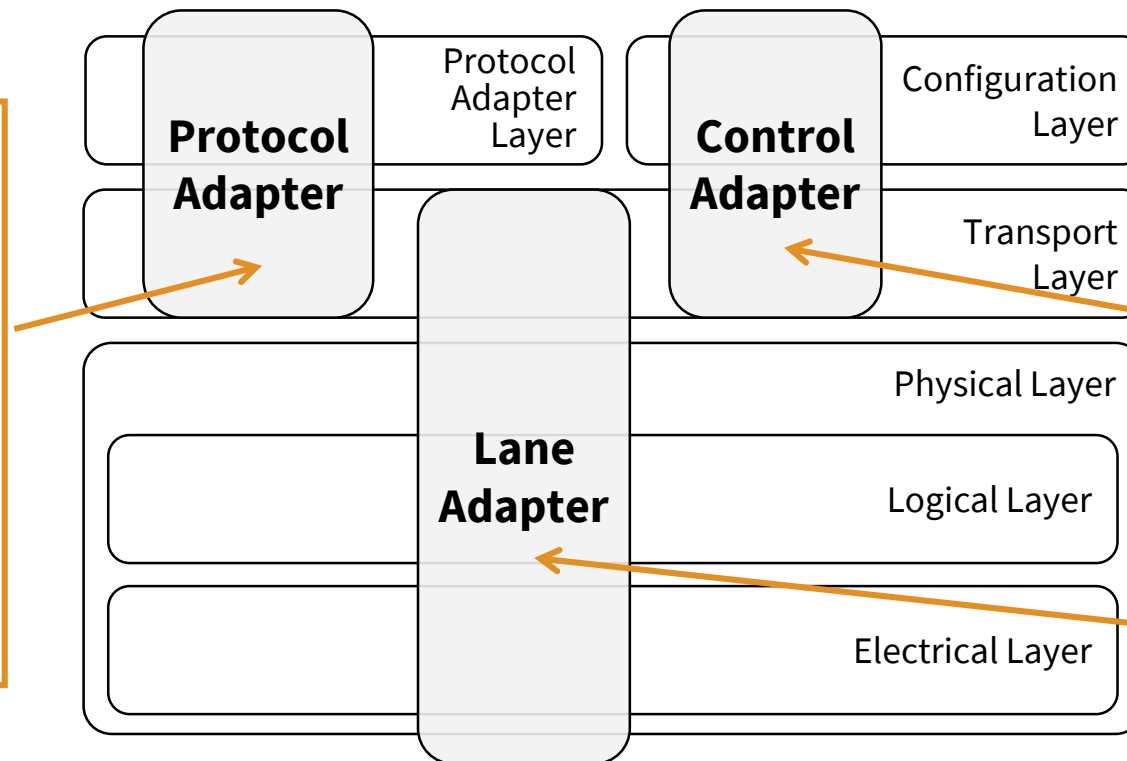
USB4™ Adapters

- A Router can contain up to 64 Adapters

- Provide an interface between a Router and an external entity

- Addressable using Adapter Number

- Maps a Tunneled Protocol to USB4™
- Four types of Protocol Adapters:
  - USB3 Adapters
  - DP Adapters
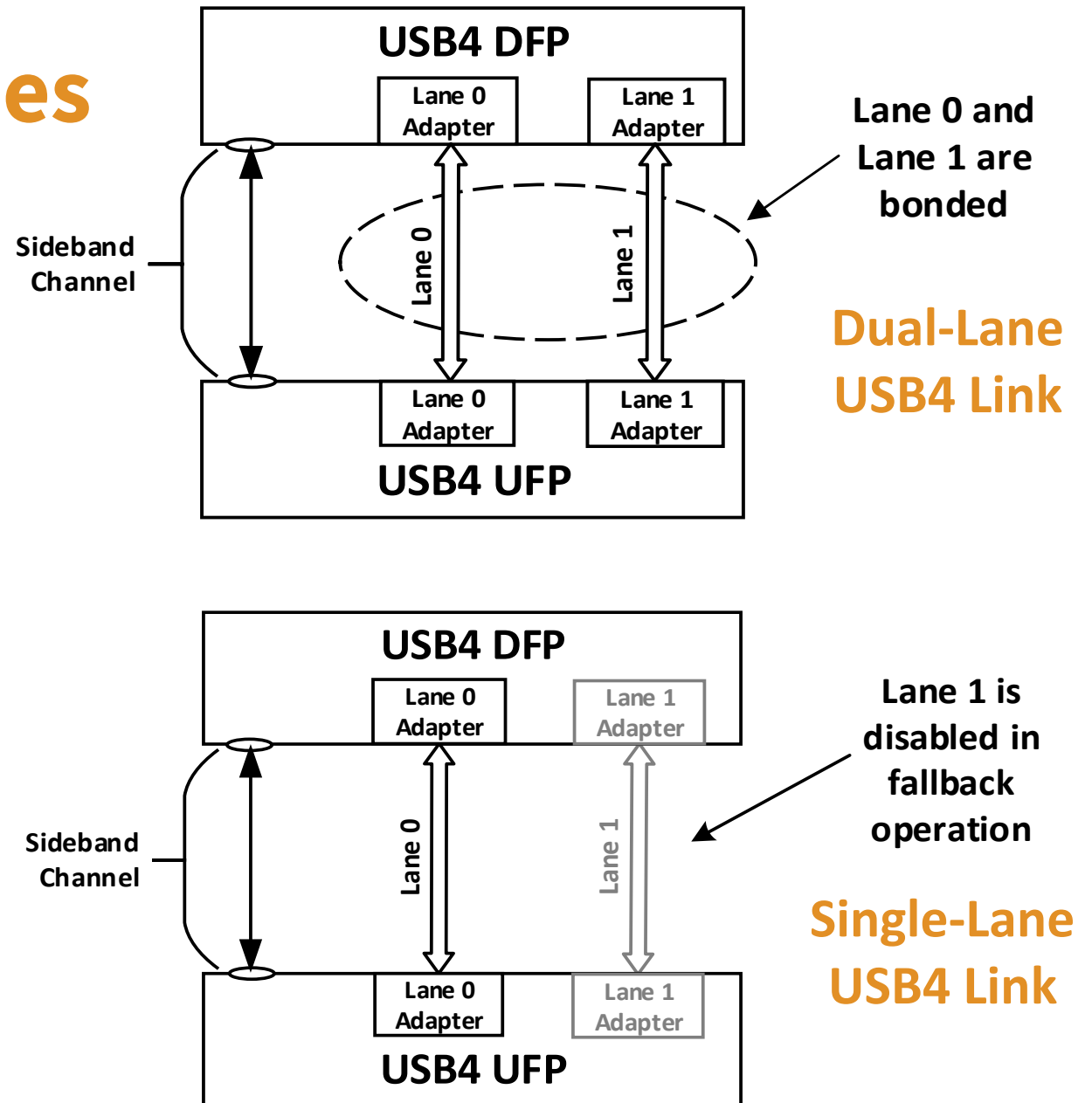 - PCIe Adapters
  - Host Interface Adapters

Protocol Adapter

Protocol Adapter Layer

Control Adapter

Configuration Layer

Transport Layer

Lane Adapter

Physical Layer

Logical Layer

Electrical Layer

- Configuration and management interface
- Logical Adapter

- Provides an interface for a Lane
- A USB4 Port has two Lane Adapters

USB4™ Links and Lanes

- USB4 Link = the logical connection between two USB4 ports
  - Transports USB4 packets between connected USB4 products
- USB4 Lane
  - Two differential signal pairs (Tx/Rx)
  - Operates at Gen2 (10 Gbps) or Gen3 (20 Gbps)
  - Used for tunneled protocol and control traffic
- Sideband (SB) Channel
  - Two-wire channel
  - Used for link initialization and management

Lane 0 and Lane 1 are bonded

Dual-Lane USB4 Link

Lane 1 is disabled in fallback operation

Single-Lane USB4 Link

Connection Manager

- Interfaces to a Domain via the USB4™ Host
  - Communicates to a Router through the Control Adapter
- Enumerates and configures all USB4 Routers
  - Hot Plug and Hot Unplug
  - Path setup and teardown
  - Path bandwidth allocation
  - Path Flow control setup
- Enables Host-to-Host Tunneling
- Implementation choices:
  - Device Driver for the Host Router in the OS or VMM
 - Part of system BIOS
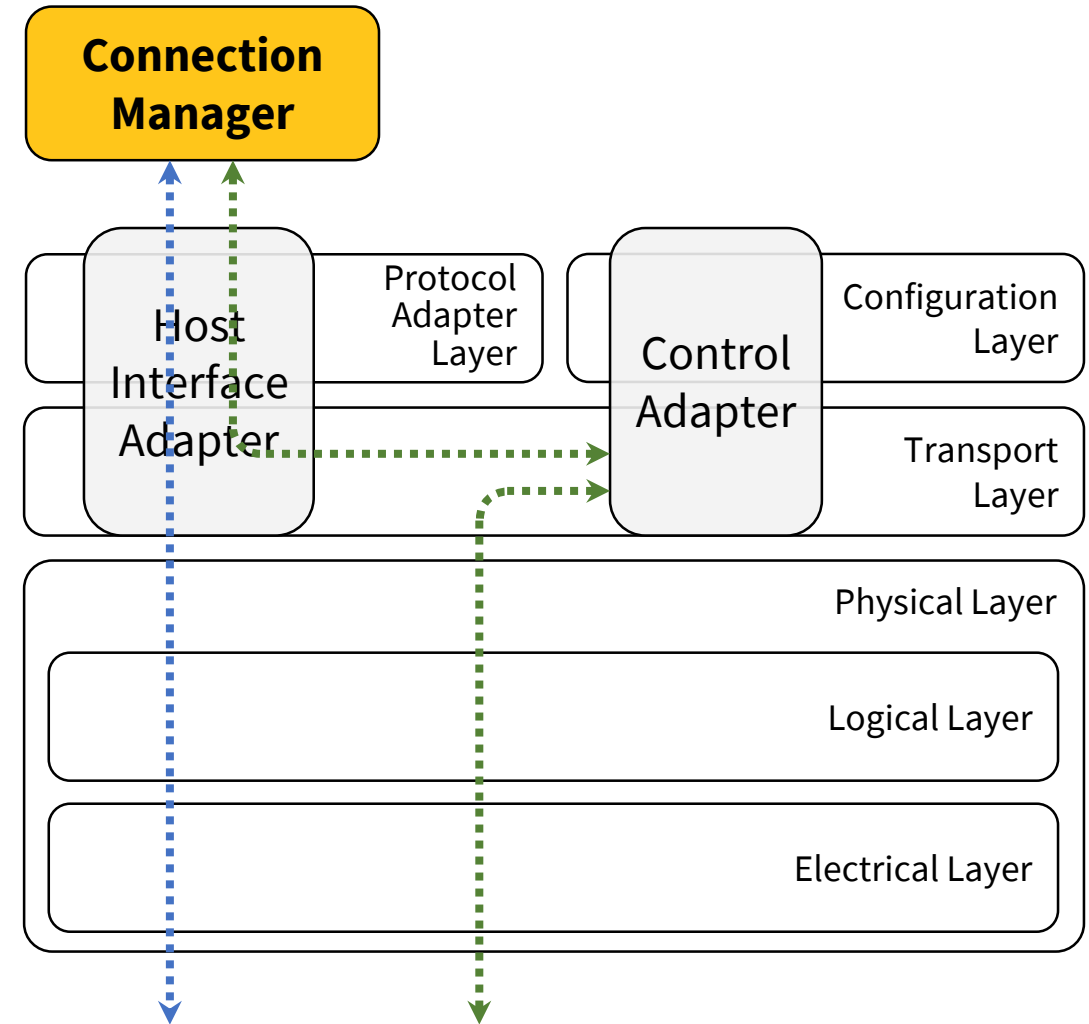
USB4™ Topology

- Typically a tree topology
  - Host Router at the top with device Routers connected downstream
    - CM runs on the Host Router platform
  - The CM creates a Spanning Tree to configure/manage the Domain
- Device Routers are downstream of Host Router
- CM detects loops in the physical topology
  - Invalid "DFP-DFP" connections made by users possible for hosts and hubs
  - Loops occur if there are multiple connections between two Routers
  - CM ignores them in the Spanning Tree

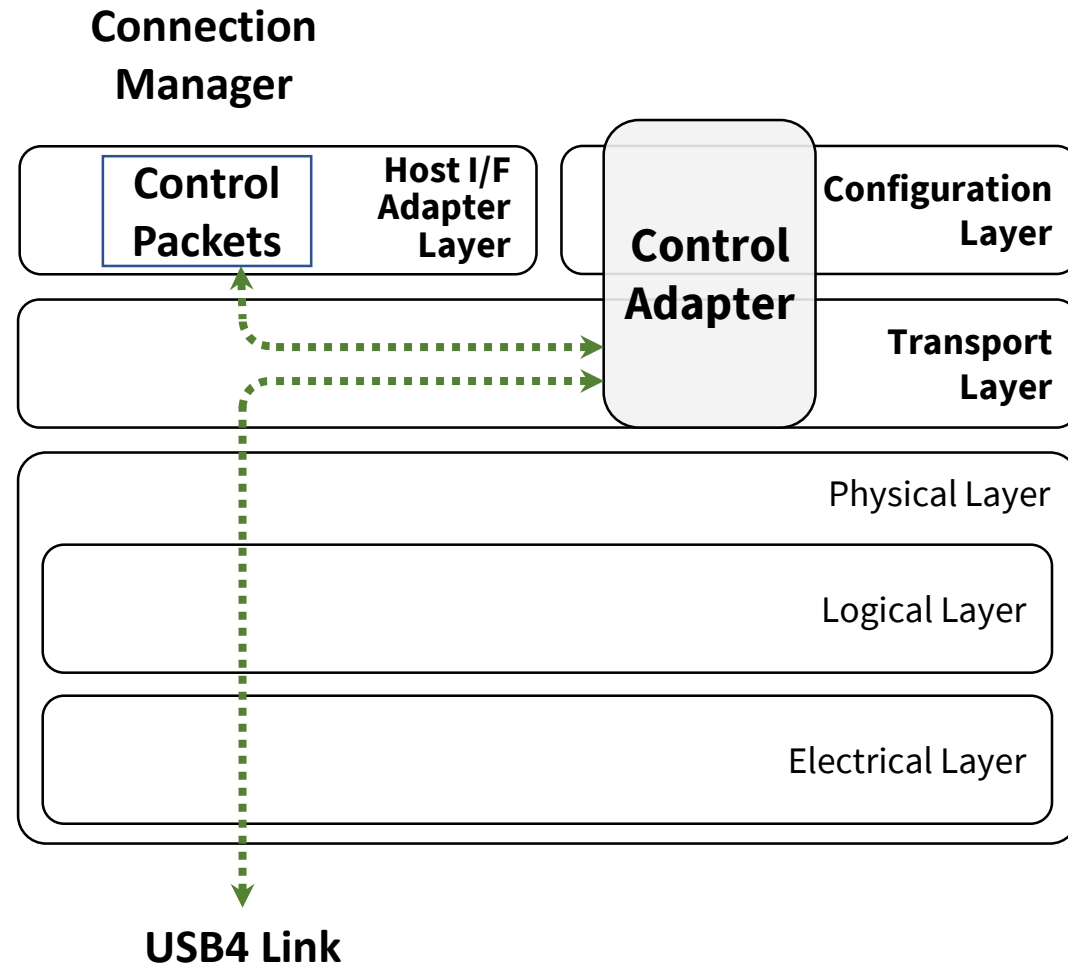**Physical Topology**

Spanning Tree
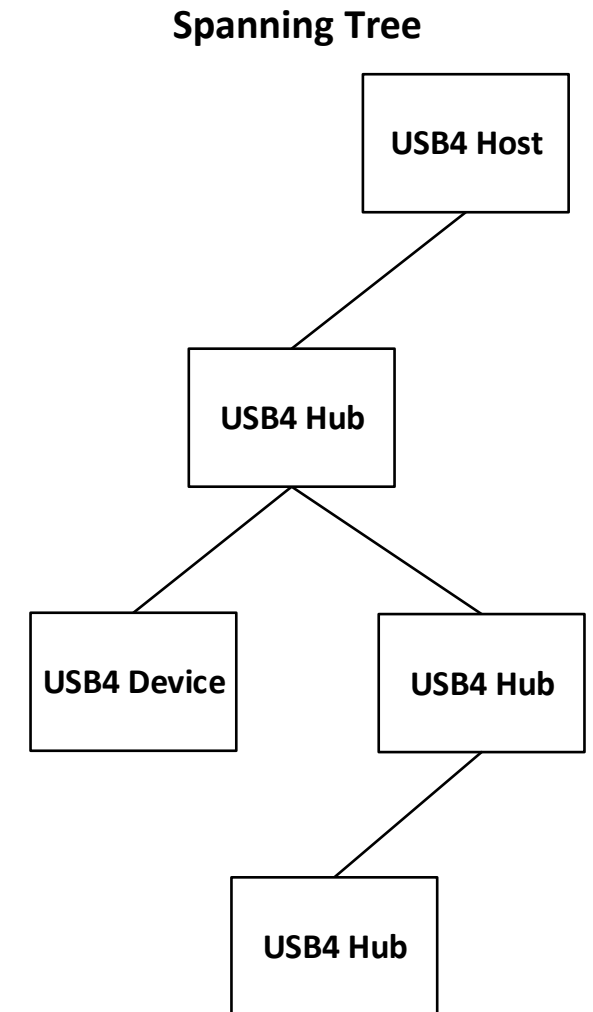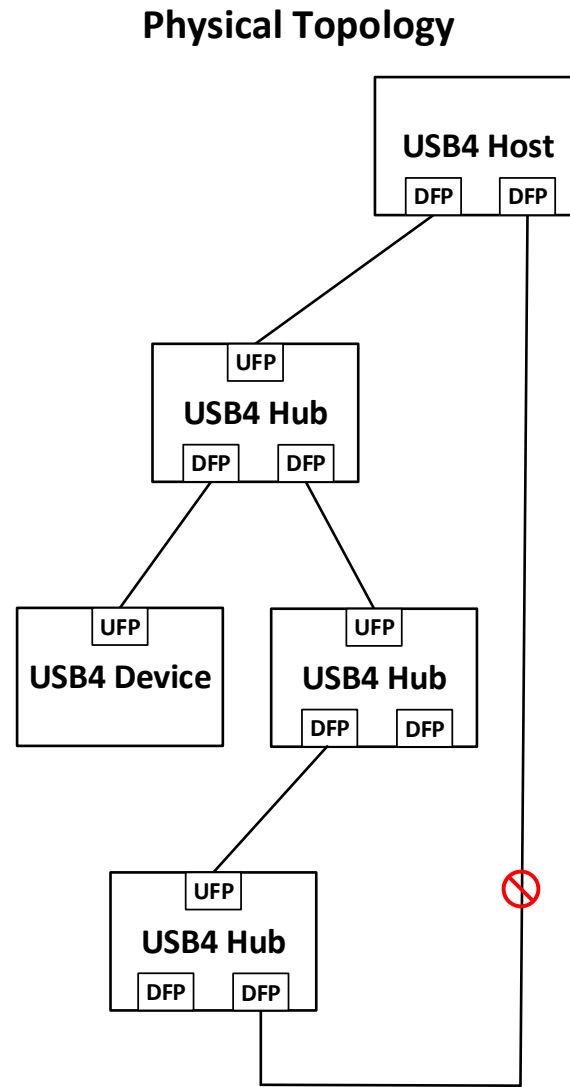
Paths and Tunnels

- Path is a one-way logical connection between two Adapters
  - Two types:
    - Protocol Adapter-to-Protocol Adapter
    - Connection Manager-to-Control Adapter
  - Represents a "virtual wire" for a Tunneled Protocol
  - Identified by a Link-specific HopID in packet headers
- Tunnel is a logical connection between two USB4™ products
  - For Display and Host-to-Host tunneling, tunnel is one end-to-end path
  - For USB3 and PCIe tunneling, tunnel is a series of paths
- USB4 is a connection-oriented architecture
  - One or more paths can be established after a Router is enumerated
  - Tunnel is configured end-to-end before data transfer can take place
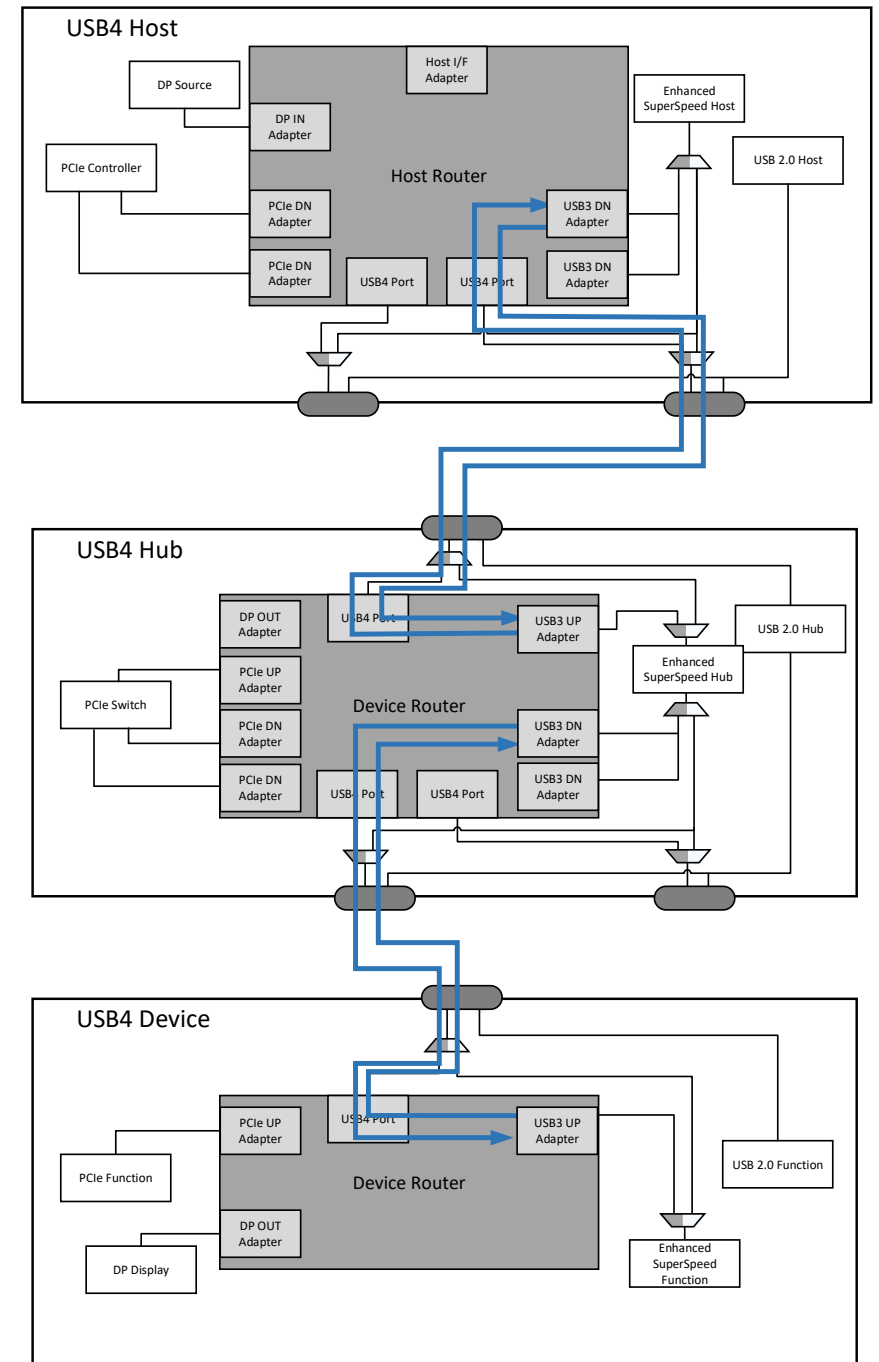
Adapter/Transport Layer Communication

- Control Packets
  - Used for Router configuration

Adapter/Transport Layer Communication

Native Protocol Traffic
(e.g USB3, DP, etc.)

| **Tunneled Packets** | **Protocol Adapter Layer** | Configuration Layer |

Transport Layer

Physical Layer

Logical Layer

Electrical Layer

USB4 Link

- Tunneled Packets
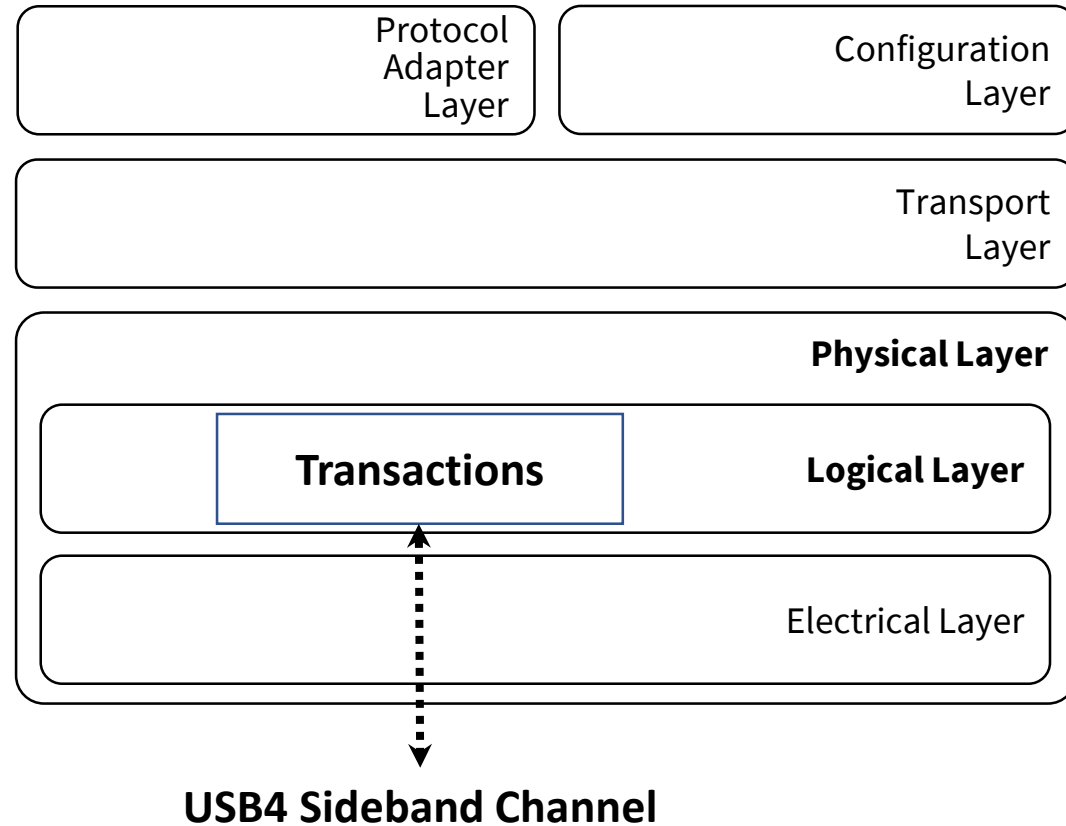 - Used for tunneling protocol data
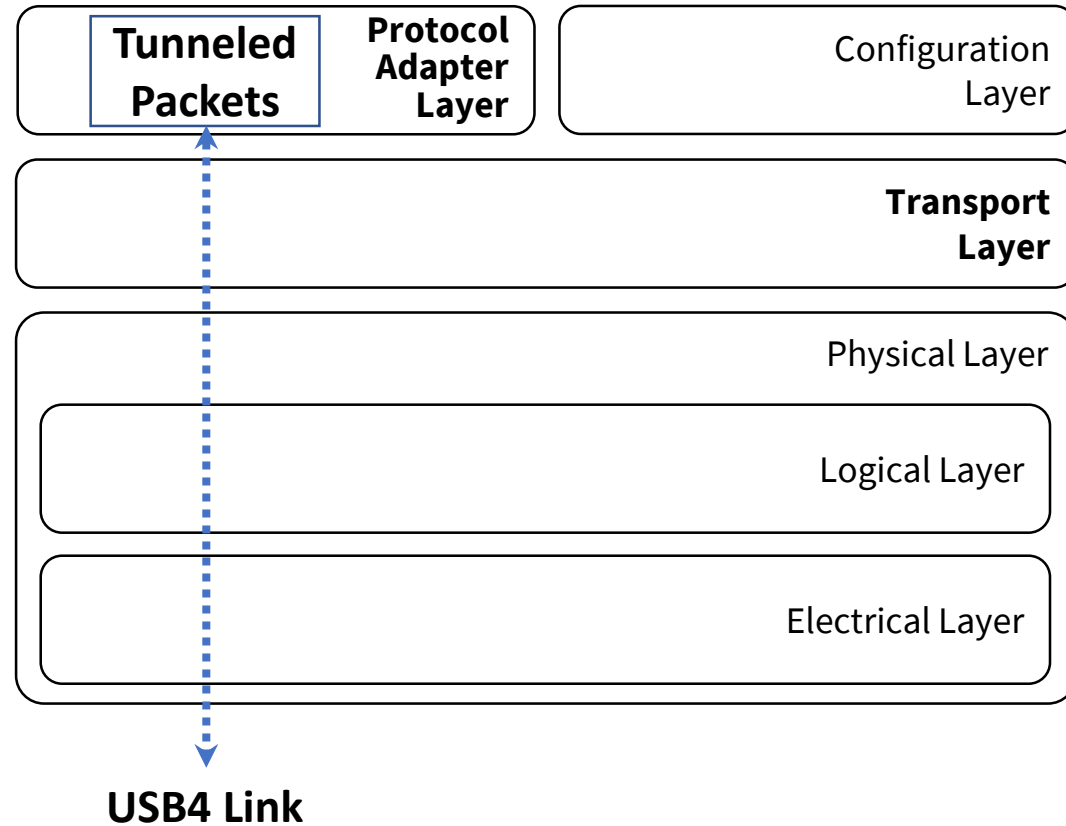
Adapter/Transport Layer Communication

- Link Management Packets
  - Used for flow control and time sync
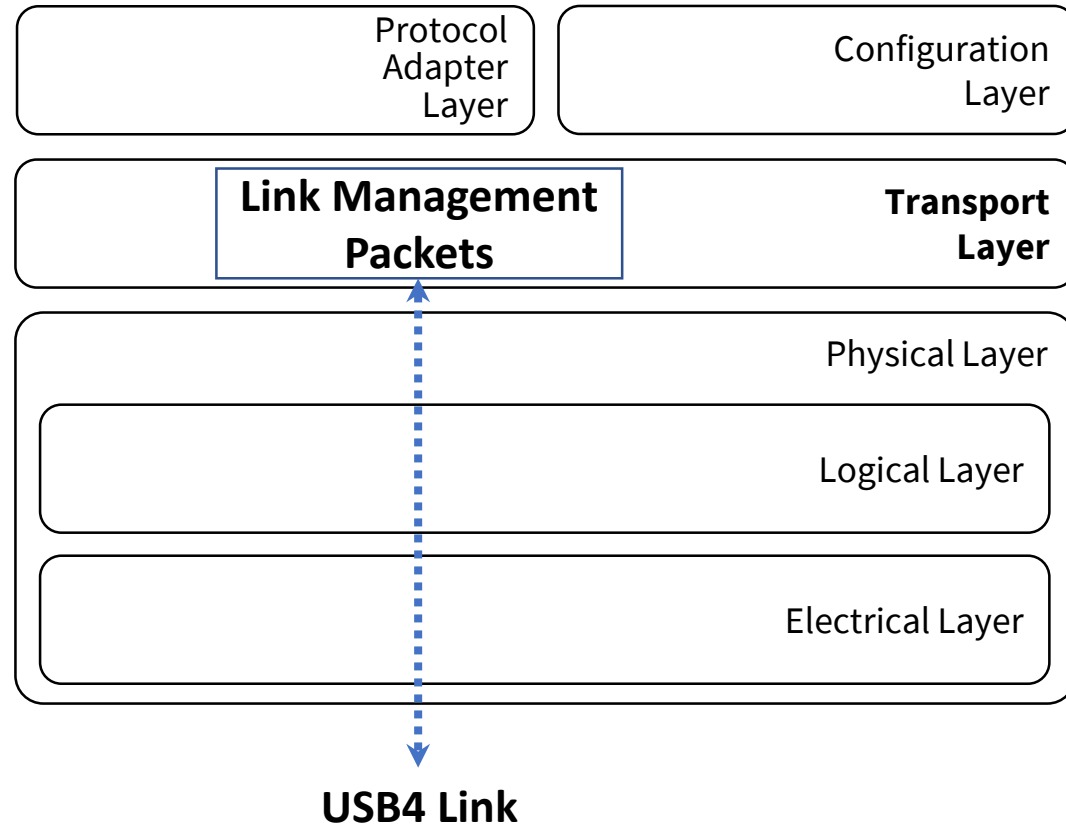
Logical Layer Communication

- Low-Speed Link Transactions
  - Used for link initialization

Logical Layer Communication

- LFPS*
  - Used for exiting low power state
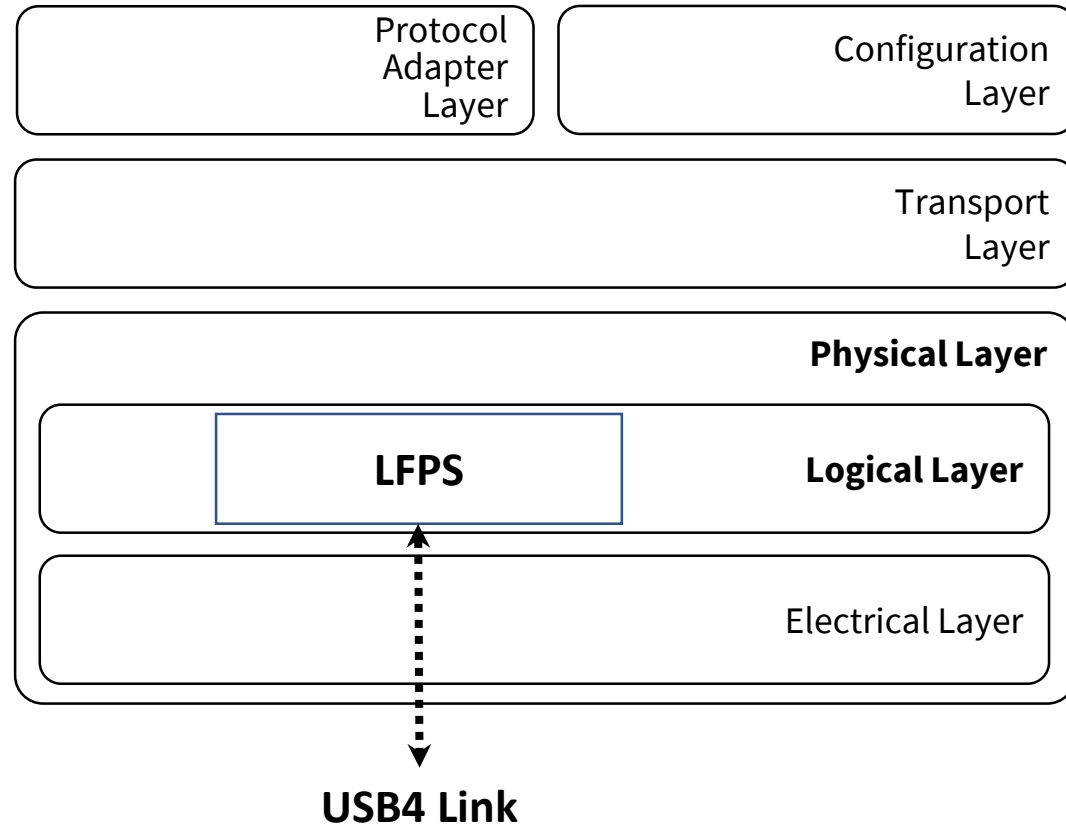
* Low Frequency Periodic Signaling

Logical Layer Communication

- Ordered Sets
  - Used for logical layer functions (e.g. symbol sync, de-skew)

Protocol Adapter Layer	Configuration Layer

Transport Layer

Physical Layer

Ordered Sets — **Logical Layer**

Electrical Layer

USB4 Link

Configuration Spaces

Router Configuration Space
- Router Capabilities

One instance per Router

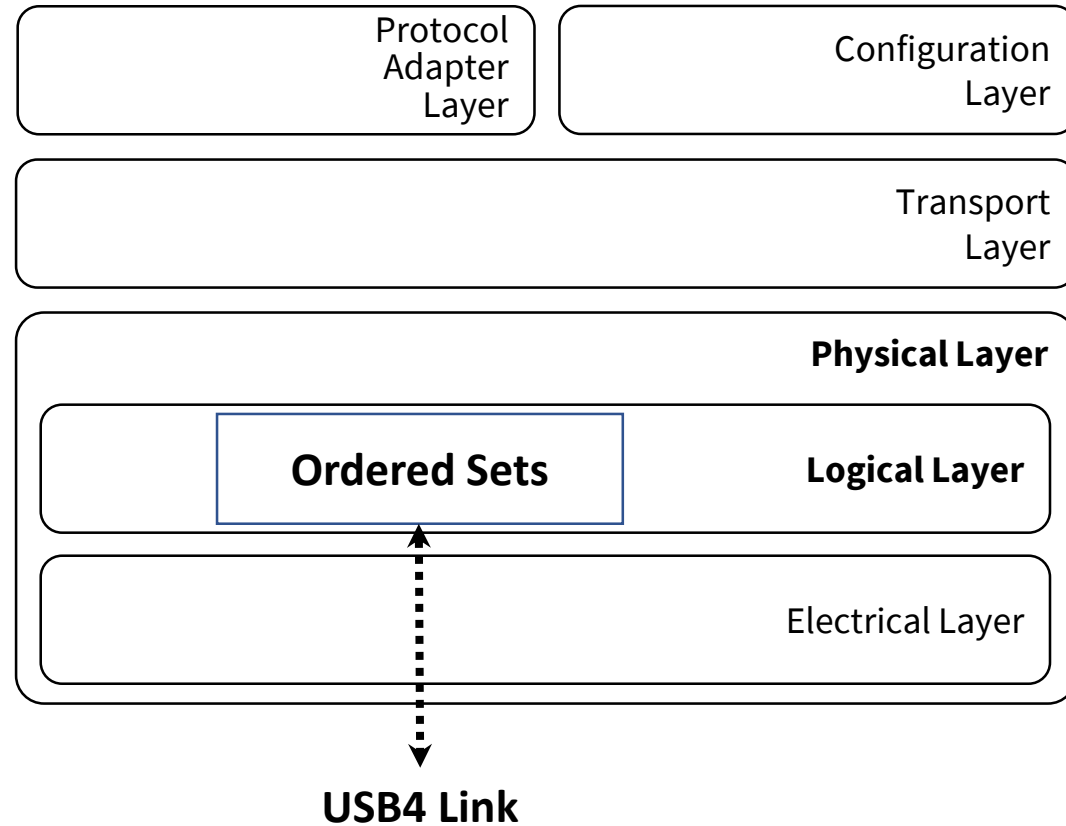**Adapter Configuration Space**
- Contains capabilities, configuration, and error statistics for an Adapter

Path Configuration Space
- Contains an entry for each supported Path

Counter Configuration Space (Optional)
- Contains performance statistics for a set of selected Paths

One instance of each per Protocol and Lane adapter in the Router

NOTE: Control Adapters do not have Configuration Space

Life of a Router

1. Router loads default values into the Configuration Space registers

2. When Router is hot-plugged, Link Initialization brings up the USB4™ Link

3. Router enables Control Packet routing and scheduling

4. Connection Manager (CM) enumerates and configures the Router
   - CM sets up any Paths in the Router

5. Router is ready to route and process Tunneled Protocol traffic

6. When a USB4 Device is plugged into a Router's Downstream Facing Port (DFP):
   - Link Initialization on the Router's DFP
   - After Link Initialization, Router sends a Hot Plug Event Packet to the CM

7. When the USB4 Device is unplugged from Router's DFP:
   - Router discards any packets that would otherwise be routed to the unplugged device
   - Router performs a DFP disconnect

8. If the Router is disconnected, it performs a UFP disconnect
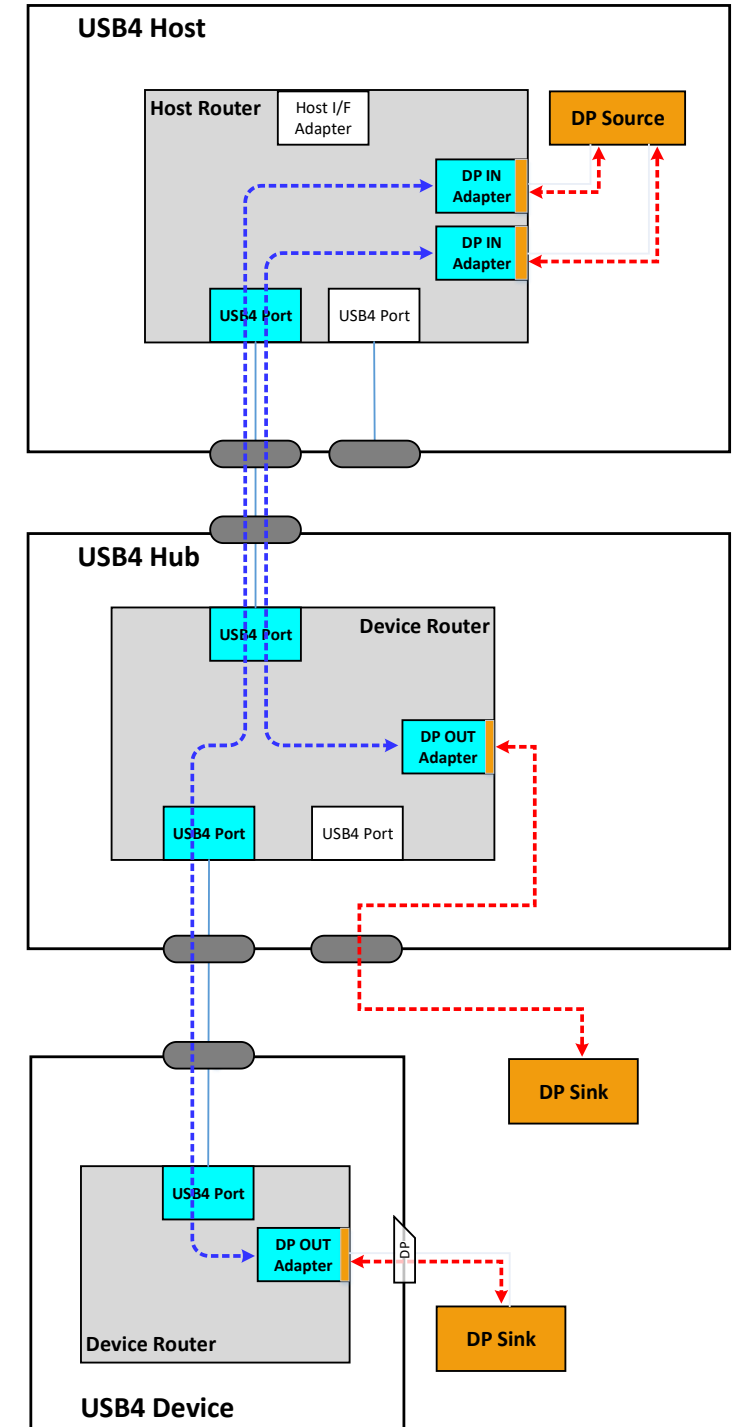
USB3 Tunneling

- USB 3.2 Enhanced SuperSpeed (ESS) protocol is tunneled over the USB4™ fabric
  - To USB3 software, the USB3 topology remains the same

- Internal ESS Host in USB4 Hosts

- Internal ESS Hub and/or ESS Function in USB4 Devices

- ESS Hub provides fan-out to:
  - Internal ESS Peripheral Devices
  - External USB4 Ports via USB3 DN Adapters

- USB3 Adapter Layer:
  - USB3 DN Adapter receives USB3 packets from internal USB3 hub/functions and encapsulates them in tunnel packets
  - USB3 UP Adapter receives tunnel packets from USB4 fabric and passes USB3 packets to internal USB3 hub/functions
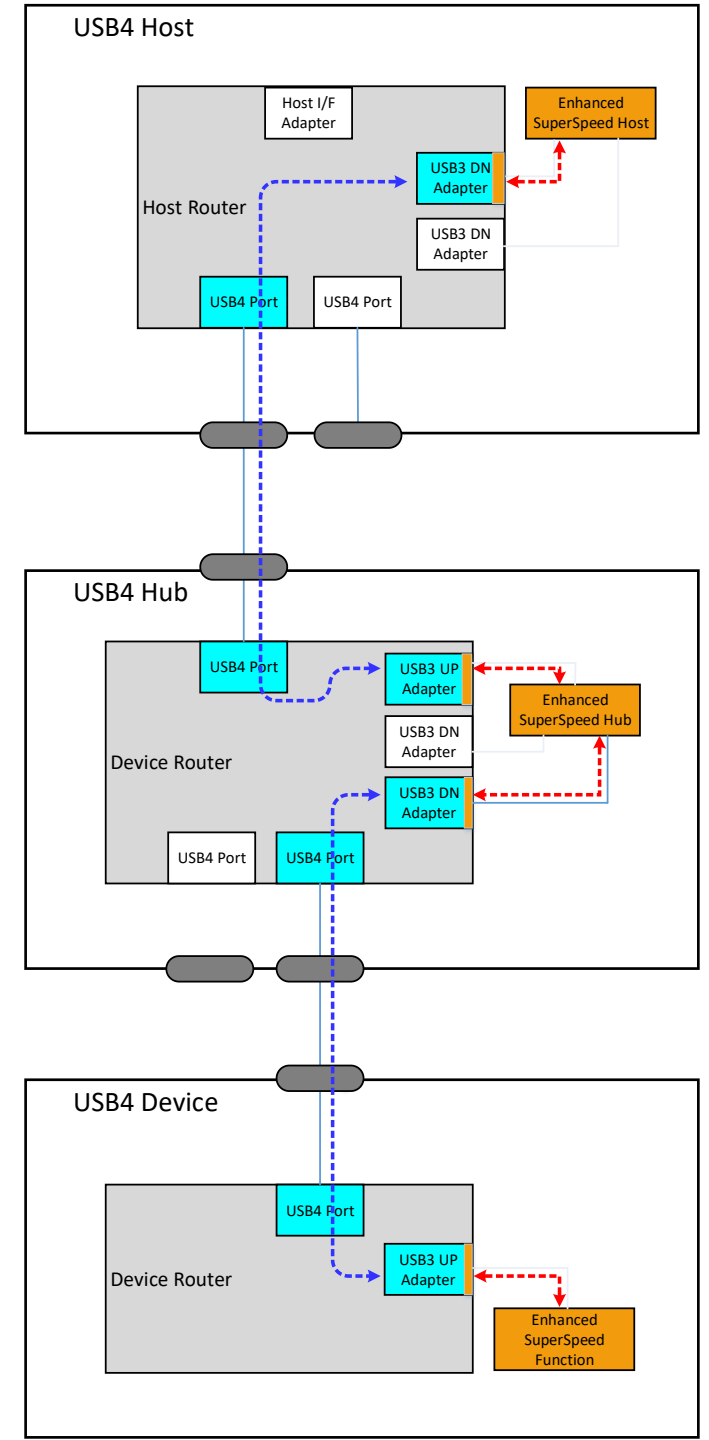
DP Tunneling

- DisplayPort™ protocol is tunneled over the USB4™ Fabric
  - To DP Source, the USB4 Fabric and the Adapters are either totally transparent or act as an LTTPR*
  - DP links at each end are identical down to the symbol level

- Supports: [SST & MST], [1,2 & 4] Lanes at [RBR, HBR, HBR2 & HBR3] Rates
  - Data sent in 8-bit representation, stuffing symbols not sent

- DP Adapter Layer:
  - DP IN Adapter packs the DisplayPort video stream into tunnel packets
  - DP OUT Adapter unpacks it and recreates the DP stream

* Link-Training Tunable PHY Repeater

PCIe Tunneling

- PCIe protocol is tunneled over the USB4™ Fabric
  - To PCIe software, the PCIe tree remains the same

- Internal PCIe Controller in USB4 Hosts

- Internal PCIe Switch and/or PCIe Endpoint in USB4 Hubs/Devices

- PCIe Switch provides fan-out to:
  - Internal PCIe Switches or Endpoints
  - External USB4 Ports via PCIe DN Adapters

- PCIe Adapter Layer:
  - PCIe DN Adapter receives PCIe packets from the internal Switch/Endpoint and encapsulates them in tunnel packets
  - PCIe UP Adapter receives tunnel packets from the USB4 fabric and passes PCIe packets to the internal Switch/Endpoint

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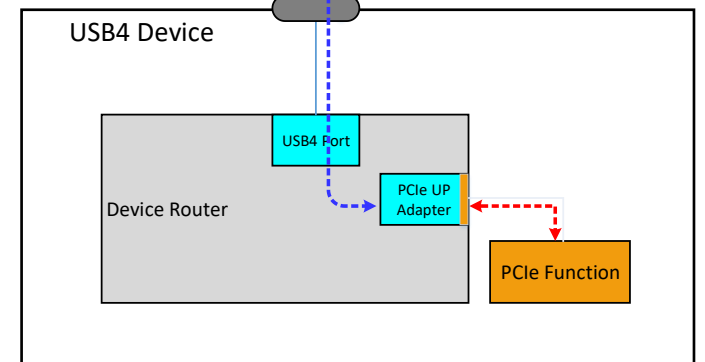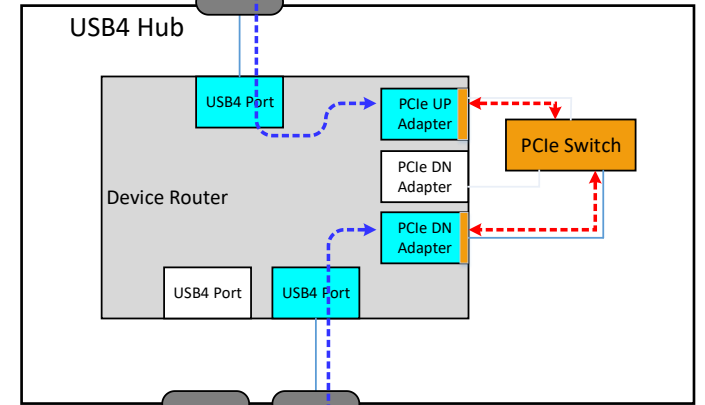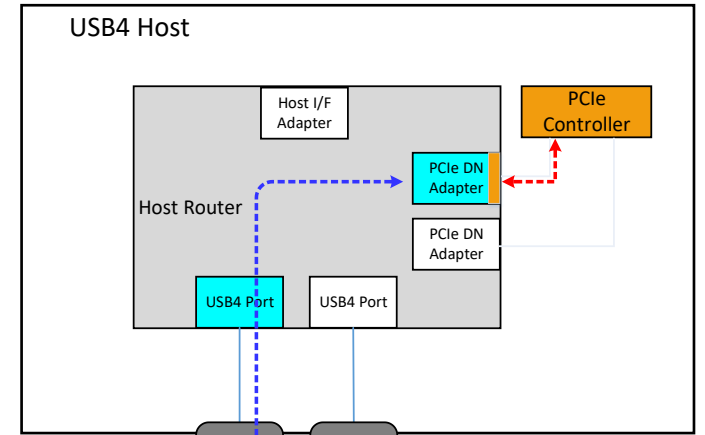
Time for Q&A

USB Developer Days – Technical Session Schedule

Tuesday – Day 1

Track One	Track Two		Track One	Track Two

Time	Tuesday – Day 1	Wednesday – Day 2

Tuesday – Day 1

	Track One	Track Two
	Registration	
9 AM	*Welcome Keynote*	
	Break	
	USB Type-C® System Overview	
11 AM	USB4™ System Overview	
Noon	Lunch / Showcase	
1 PM	USB4™ Electricals	*USB Branding Update*
2 PM		
	Break	
3 PM	USB4™ Logical Layer, Re-Timer and Transport	Microsoft/Intel: USB4™ on Windows
4 PM		Google: CTVPD, a new PD stack and Making USB-C® thingamajigs

Wednesday – Day 2

	Track One	Track Two
8 AM	USB4™ Configuration and Tunneling for USB3, DP and PCIe	USB Power Delivery: Overview and Charging Usages
9 AM		
		Break
10 AM	Break	USB Power Delivery: USB4™ Support and USB PD Certification
11 AM	USB4™ Compliance and Certification	
Noon	Lunch / Showcase	
1 PM	USB4™ Time Management Unit, Host Interface, Connection Manager and TBT3	USB4™ Cable Electricals and System Design
2 PM		
	Break	
3 PM	VESA: DisplayPort™ Alt Mode	USB Type-C® Active Cables
4 PM	*The Closing Hour: On the Horizon, Key Messages and Final Q&A*	