# Data-Centric Infrastructure Functional Architecture

Classification: APPROVED REFERENCE DOCUMENT

Confidentiality: PUBLIC

Version 1.0

1/27/2022

[DCI]

# Legal

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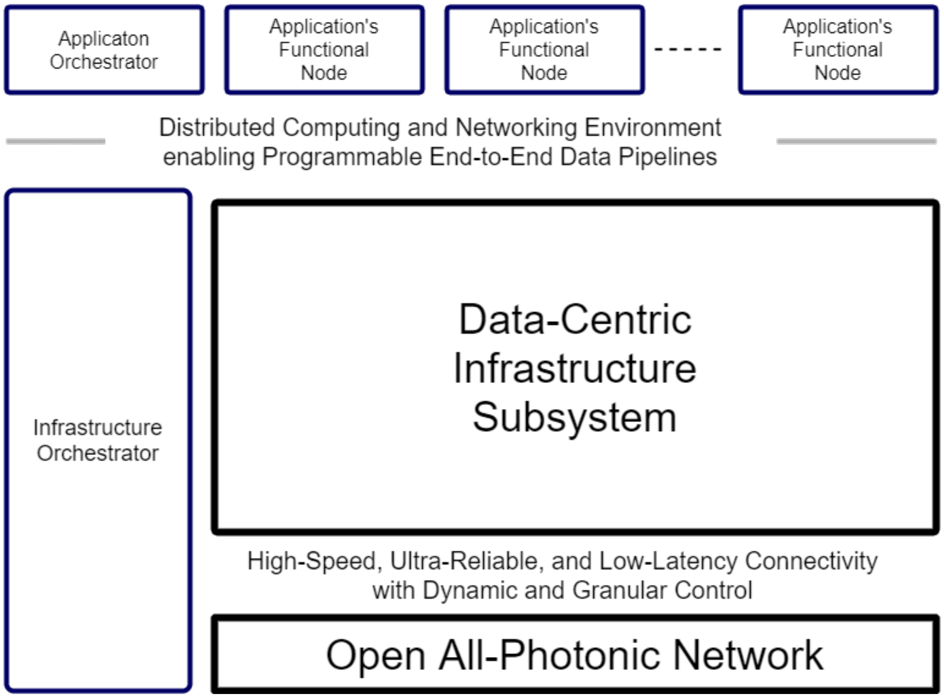
# 1. Introduction

## 1.1. Overview of the IOWN Global Forum Architecture

The Innovative Optical and Wireless Network Global Forum (IOWN GF) aims to establish an end-to-end architecture for computing and networking that can support various data flows and workloads, as shown in Figure 1.1-1.




The Open All-Photonic Network (APN) is a network that connects endpoints directly with optical paths. It provides high-speed, ultra-reliable, and low-latency connections. In today's networks, optical paths are disjointed and operated on a segment-by-segment basis, i.e., local area network (LAN), access network, and inter-data-center network. By contrast, the IOWN Global Forum Open APN will enable one optical path to span multiple segments. This will enable end-to-end communication with deterministic quality. However, this approach will require more dynamic and granular control for end-to-end optical path management.

Furthermore, as optical paths are dynamically created (making their performance demands impossible to predict until they are provisioned), we need a real-time performance measurement and monitoring mechanism that enables the infrastructure to set up new optical paths based on the projected achievable transmission speed. The IOWN GF aims to establish an open architecture for photonic networking so that service providers can integrate photonic network functions with their entire computing and networking infrastructure with more granularity. The open architecture should also enable service providers to build an intelligent operations support system.

The Data-Centric Infrastructure (DCI) subsystem is intended to provide applications with a distributed and heterogeneous computing and networking environment that spans end-to-end, i.e., across clouds, edges, and customer premises. This end-to-end, heterogeneous, and distributed computing/networking will enable service providers to build end-to-end data pipelines, placing data processing and storage functions in desired places. Data processing functions include filtering, aggregation, and event brokerage. Data storage functions provide shared storage, such as object storage and database, for data pipelines with multiple data sources and sinks.

DCI's support of heterogeneous networking will allow service providers to select data transfer and network protocols on a path-by-path basis. For example, protocols supporting deterministic quality may be used for network paths connecting real-time sensors in a manufacturing setting, while traditional IP networks would be used for networking paths connecting external data consumers. In this way, service providers will be able to accelerate data flow without isolating their systems from today's Internet ecosystems.

DCI's support of function-dedicated computing (FDC) will enable service providers to add various types of computing resources for performing dedicated computing tasks such as image artificial intelligence (AI) inference, time-sensitive data processing, network function virtualization (NFV), and database acceleration. In this way, service providers will benefit from the ongoing evolution of computing acceleration technologies.

The DCI subsystem exposes service interfaces to the Application's Functional Nodes for applications such as cyber-physical systems (CPS) and AI-integrated communication (AIC). Application developers can then build applications leveraging the functions and features provided by DCI and the Open APN. The features for high quality-of-service (QoS) are provided by the Function Dedicated Network (FDN) layer and may be realized by underlying networks, including an Open APN network.

The Infrastructure Orchestrator is the infrastructure's central management function that controls various infrastructure resources and exposes the single management interface. It is logically a single component, but it may be implemented with multiple nodes.

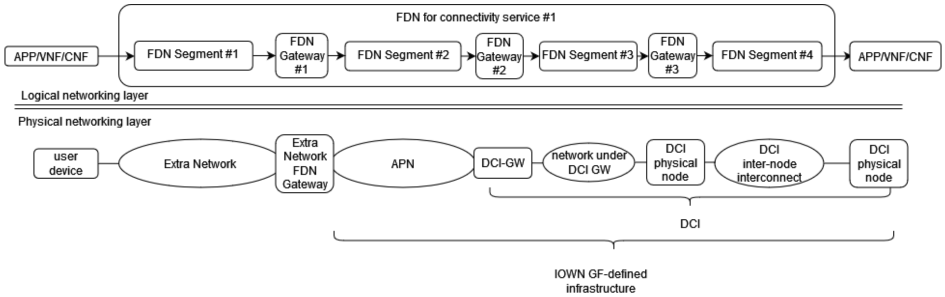
The Application Orchestrator is the central manager of an application system, which controls multiple application processes, i.e., microservices, for the application. When it deploys an application process on an IOWN Global Forum System, it should call the application programming interface (API) of the infrastructure orchestrator to create a runtime environment, e.g., a logical node.

Open APN, DCI, and Function Dedicated Network (FDN) are the main components of the IOWN GF System. Details of the Open APN are presented in the Open APN technical reports [IOWNGF-APN]. Details of DCI are presented in this DCI technical report.

## 1.2. FDN (Function Dedicated Network)

The FDN is a logical network created over DCI, Open APN, and Extra Networks and provides network connectivity with the quality required for IOWN GF services.

Note: The details of the FDN layer and its components will be further discussed and addressed in the future release. Only the overall concept is described in this document. Figure 1.2-1 shows an example of how FDN is configured.




The following components are defined to illustrate FDN.

- **Function Dedicated Network (FDN)**: A logical network that provides connectivity between application data transport endpoints, designed to guarantee the QoS requirements of the application. FDN is created for specific classes/functions defined by supported network protocols and management/control APIs. FDN class examples include Ethernet Virtual Connection (EVC), Converged Enhanced Ethernet (CEE), Time-Sensitive Network (TSN), Serial Digital Interface (SDI), Multi-Protocol Label Switching (MPLS), and the Internet Protocol (IP).

- **FDN Segment:** A logical subdivision of an FDN (e.g., an IP subnet, an L2 segment, and an L1 optical path). An FDN Segment is created within a single network infrastructure, for instance, an FDN Segment within Open APN or DCI intra-node interconnect. Multiple FDN Segments may be created within a single network infrastructure. FDN Segments may be interconnected by FDN Gateway functions that perform packet forwarding, protocol translations, etc., to form an FDN. However, the details of how an FDN Segment is created are left for the implementation.
- **Extra Network:** A physical network that is controlled, managed, and operated outside of the DCI cluster and the Open APN. An Extra Network connects with the Open APN through Extra Network FDN Gateway. Typical examples are local networks deployed in/near the customer premises and aggregate traffic from end nodes. FDN Segments can be instantiated on top of the Extra Network.
- **FDN Gateway**: A logical entity that connects one or more FDN segments with each other or their surroundings; FDN Gateway instances may provide functionality for the network infrastructure, such as routing and firewalling.

As the Open APN will provide optical paths that are more granular than those used for inter-data center communication, many end nodes, e.g., mobile radio units and user devices, will be connected directly to the Open APN. However, in some cases, users may choose to have an Extra Network between the Open APN and end nodes for several reasons. One reason may be because the Extra Network already exists and has been connected with end nodes. Another reason may be because the user wants to reduce cost of the optical transceiver by multiplexing the traffic of multiple nodes over one fiber. In such deployment scenarios, the Extra Network should support QoS-aware network protocols to avoid spoiling the benefits of optical communication.

In Figure 1.2-1, the FDN for connectivity service #1 is decomposed into several individual FDN Segments. These FDN Segments are interconnected by FDN Gateways that provide connectivity between different types of FDN Segments (in the figure, FDN Gateway #1 provides interconnectivity between FDN Segment #1 and FDN Segment #2).

## 1.3. Reference architecture

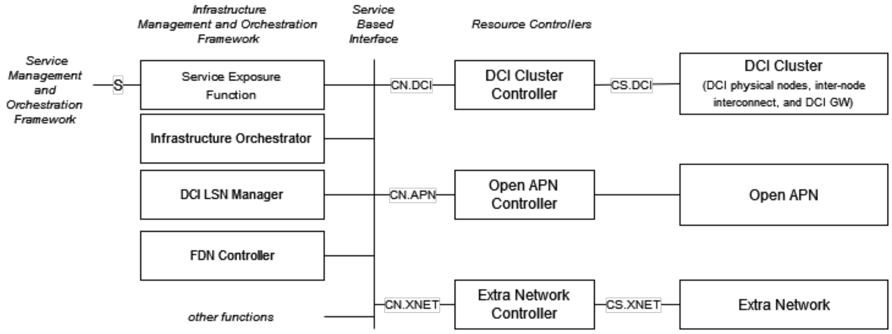



*Figure 1.3-1: IOWN Global Forum Reference Architecture*

Figure 1.3-1 shows the reference architecture defined by the IOWN Global Forum. This architecture is intended to realize elastic and scalable assignment of heterogeneous computing and networking resources to achieve data forwarding and processing under extreme QoS requirements.

The following functional blocks are defined as an initial reference. Other functional blocks may provide advanced features, but the details are deferred to IOWN GF service implementers.

- **DCI Cluster:** A computing infrastructure that comprises multiple DCI physical nodes/devices, an Inter-node Interconnect, and a DCI Gateway.
- **DCI Cluster Controller:** A logical function that dynamically reconfigures DCI physical nodes, the inter-node interconnect, and the DCI Gateway to create and maintain logical service nodes (LSNs) as defined below. The DCI Cluster Controller should also provide telemetry collection services. In addition, the DCI Cluster Controller manages and controls FDN Segments inside the cluster. One DCI Cluster Controller may control multiple DCI clusters.
- **Open APN Controller**: A logical function that controls the Open APN to create and maintain Open APN optical paths. The details should be defined in the Open APN Functional Architecture document.
- **Extra Network Controller**: A logical function that controls Extra Networks to create and maintain FDN Segments with enhanced elasticity, scalability, availability, and security. It should also provide a telemetry interface to collect the status data of FDN Segments. The supported set of APIs for management and control should be defined for each class of FDN.
- **Logical Service Node (LSN)**: A logical node made of the physical computing and networking resources of a DCI Cluster. In the current phase of DCI, LSNs are composed of parts of exactly one physical node. In future DCI phases, LSN may be composed of parts of multiple physical nodes.
- **DCI LSN Manager:** A logical instance of a function that manages LSNs. The function includes installing software and configuring low-level parameters such as management network address and admin credentials. When a service provider has a service node manager for further configuration, the configuration by the DCI LSN Manager would be limited to the minimum installation and configuration necessary for the service provider's service node manager to access the LSN. While DCI LSN Manager may be implemented as a cluster of multiple nodes, it should expose a single point of the northbound interface and maintain single coherent storage of the managed data.
- **FDN Manager:** A logical instance of a function that creates and maintains instances of FDN with the desired QoS. FDN Manager calls resource controllers (i.e. DCI Cluster Controller, Open APN Controller, and Extra Network Controller) to create and manage FDN Segments and instances of FDN Gateways within each physical infrastructure.
- **Infrastructure Orchestrator:** A logical instance of a function that creates and maintains overall logical resources within the IOWN GF architecture, such as composites of LSNs interconnected with necessary network resources based on user requests. It calls the LSN Managers, Open APN Controllers, Extra Network Controllers, DCI Cluster Controllers, and FDN Managers to orchestrate logical resources.
- **Service-based interface**: A logical concept of connectivity among management and control plane functions. Functions interface with each other through service function calls.
- **Service Exposure Function**: A logical function that exposes IOWN GF system operation services to external users. Details of IOWN GF system operation services are deferred to DCI implementers.

This technical report provides more details of the DCI part of the IOWN GF reference architecture and the data plane acceleration.

# 2. Issues and gaps

The following issues are identified in today's communication and computing infrastructure.

- Scalability issue
    - Intra data center scalability issue: diverse compute workload imposes different computing, memory, and input/output (I/O) requirements. This requires that different components can be scaled differently. However, today's monolithic model is inflexible and inefficient in supporting flexible scaling of the computing, memory, and I/O resources.
    - Device, edge, and inter-data center scalability issue: Today's computing is centralized in the central cloud and regional edge clouds. Today’s centralized computing model is no longer sufficient for use cases with large data volume or high performance requirements. We expect a scalable solution to enable widely distributed computing across devices, far edges, regional edges and central cloud infrastructure.
- Performance issue:
    - Latency and jitter: some applications have stringent requirements on latency and jitter. Today's data transport schemes have high tail latency and jitter. There is a need to have data transport acceleration schemes to achieve controlled latency and jitter.
- Resource utilization and energy efficiency
    - Due to inefficiency in scalability, I/O bandwidth and memory size often becomes the bottleneck in resource provision, i.e., computing resources are often under-utilized due to the bottlenecks in I/O and memory. There is a need to research new schemes that can improve resource utilization and energy efficiency.

# 3. System architecture and services

## 3.1. Overview

Foreseeing the technology gaps described in Section 2, the data-centric infrastructure (DCI) provides the data, communication, and computing infrastructure for realizing the performance quantum leap and the advanced services that the IOWN GF envisioned. DCI aims to achieve the following design goals:

- **Inherent support for computing scaling out**: DCI shall have inherent support on scaling out computing across cloud center, cloud edge, network edge, and device
- **Heterogeneous Computing**: DCI shall support energy-efficient data-intensive computing that leverages a variety of computing accelerators
- **In-Network Computing**: DCI shall enable wire-speed data pipelines that receive and process data at the speed of the underlying transport network
- **Data Copy Reduction with Shared Memory/Storage**: DCI shall support computing with a shared storage/memory, enabling multiple data processing functions to access the same data in the shared storage/memory and thus reducing data transfer workload.
- **Heterogeneous Networking**: DCI shall support data flows of various QoS demands, including demands for reserved bandwidth, spike bandwidth for instant data transfer, very low latency, bound jitter, and time-sensitive networking.
- **Hub for Multiple Networks:** DCI shall enable data flows across multiple networks, e.g., IP and non-IP networks.

As shown in Figure 3.1-1, the DCI is built with computer clusters, called the DCI Cluster, that are interconnected with an Open APN. DCI Clusters form logical service nodes (LSNs), as defined in Section 3.2. For a workload requiring highly efficient data processing, LSN is enhanced with hardware accelerators that fit the type of the workload. The Open APN provides DCI clusters with optical paths for high-speed & ultra-low latency data transfer. DCI's infrastructure management & orchestration functions orchestrate the creation of LSNs and optical paths. In this way, DCI achieves streamlined data transferring and processing at the speed of optical communication.

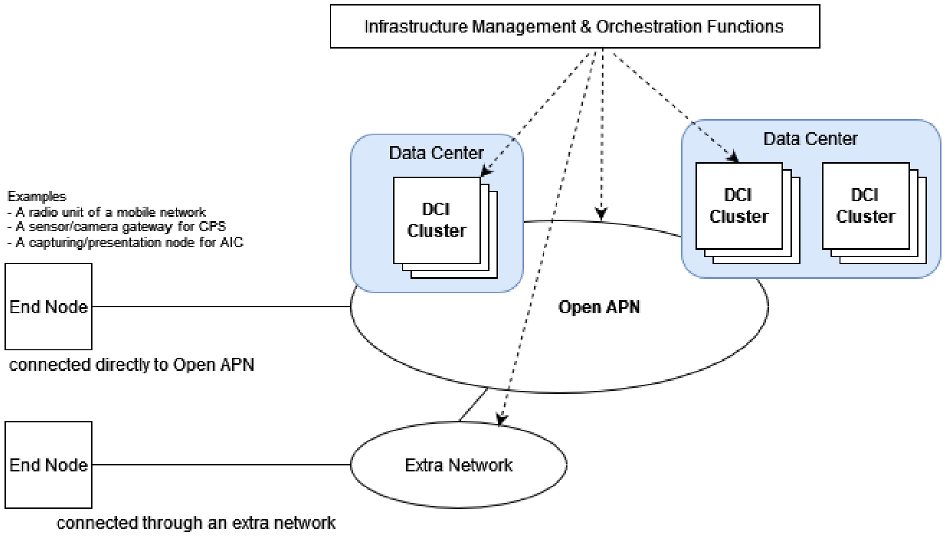



*Figure 3.1-1: Overview of DCI Clusters and Open APN*

DCI computing resource management is done in two layers:

- The DCI Cluster Controller should create and maintain logical service nodes (LSNs) at the hardware layer. Ideally, a cluster's physical elements, e.g., physical nodes and interconnects, are only visible to DCI Cluster Controller and do not need to be exposed to external users. The DCI cluster controller can hide all resource details in the DCI cluster from external users. When needed, DCI Cluster Controller can announce information such as the total number of resources of each resource type and the number of free resources of each resource type. The Cluster Controller API would eventually support features like placement policy enforcement, as infrastructure users often demand these features.
- At the logical infrastructure layer, the DCI LSN Manager should configure LSNs. The logical node configuration by the LSN Manager means setting the parameters of logical resources of logical service nodes, e.g., hostname, network address, key certificate, software stack, Kubernetes node parameters, etc.

Note that the LSN Manager does not create, modify or delete LSNs. Instead, the DCI Cluster Controller creates, modifies and deletes LSNs, as this requires physical resource management.

# 3.2. DCI cluster

A DCI cluster is comprised of DCI physical computing nodes, Inter-node Interconnect, and DCI Gateway. An example of DCI cluster architecture is shown in Figure 3.2-1.

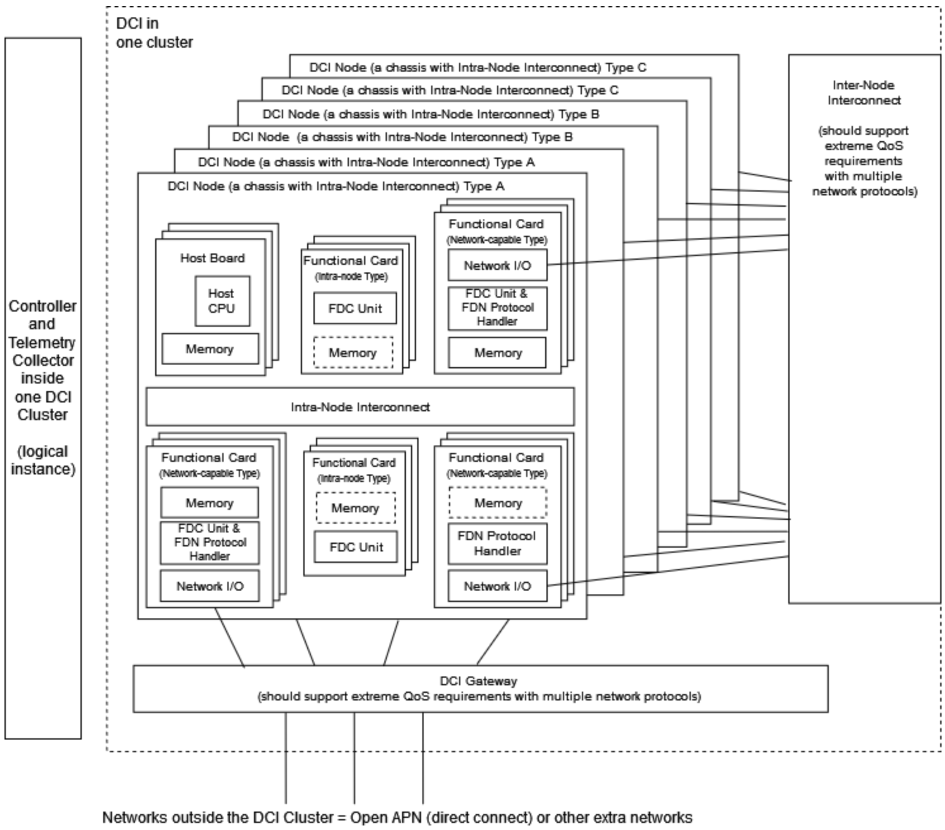



*Figure 3.2-1: Example of DCI cluster architecture*

## 3.2.1. Physical Node, Intra-node Interconnect, and Functional Cards

A **DCI Physical Node** is a physical subsystem made of computing modules connected on an interconnect., which is referred to as **an Intra-node Interconnect.** Each DCI physical node should expose a management and control interface to the DCI Cluster Controller.

Computing modules include host boards and functional cards as defined below.

A host board is basically a physical computing module that has one or multiple host central processing units (CPUs) and memory.

A **Functional Card** is a physical module that performs some processing, be it data processing or network protocol unit processing, and is connectable to the intra-node Interconnect. Examples of the functional units are vector processing units (VPUs), graphics processing units (GPUs), reconfigurable processors, and network protocol handlers.

Traditionally, computing modules, e.g., CPU and GPU, and network interface modules, i.e., network interface cards (NICs), used to be separate. However, the demand for the efficient processing of large volumes of real-time data has led to the emergence of computing modules equipped with network interface modules. Smart NICs, Data Processing Units (DPUs), and Infrastructure Processing Units (IPUs) are examples of such functional cards. This enables us to offload large data copy traffic from the electronic-based internal interconnect to the optical-based inter-node interconnect. DCI is intended to take advantage of this trend. We express a functional card that has a network I/O as **Network-capable type**. By contrast, a card with no network I/O is expressed as **Intra-node type**.

An **Intra-Node Interconnect** is a module that connects one or multiple host boards with functional cards. The range of this Intra-Node Interconnect is confined within the range of the DCI Physical Node.

One choice of the intra-node interconnect is Peripheral Component Interconnect Express (PCIe). However, while PCIe has long been successfully adopted by many computing products, some of the features desired for disaggregated and heterogeneous computing are not provided. For example, it is not designed to accommodate multiple hosts. (This might be possible. But, at least, the multi-root configuration is not a common practice). In addition, PCIe does not natively support cache-coherency.

On the other hand, the computing industry has recently developed a new cache-coherent type of interconnect, which enables the connected modules to share one coherent memory space. One promising example of cache-coherent interconnect is Compute Express Link (CXL). In particular, CXL 2.0 supports the multi-host configuration. These features will be advantageous in building a heterogeneous and disaggregated computing infrastructure.

That said, IOWN GF DCI should support two choices for intra-node interconnect, PCIe, and CXL. Table 3.2-1 below compares PCIe and CXL.

*Table 3.2-1: Comparison of PCIe and CXL*

| | DMA | MULTI-HOST | CACHE COHERENCY | AVAILABILITY OF COMPLIANT PRODUCTS |
|---|---|---|---|---|
| **PCIe** | YES | Need to be checked<br>(at least, not common) | NO | Many products are available |
| **CXL** | YES | YES<br>(supported by CXL 2.0) | YES | Yet very few products are available |

Today's PCIe-based functional cards have local memory near functional units. But, a cache-coherent interconnect, such as CXL, enables functional cards to cache data from other modules directly. As a result, such functional cards may not have local memory. We expect this to reduce the total amount of memory in the computer, reducing energy consumption.

Figure 3.2-2 illustrates various types of functional cards.

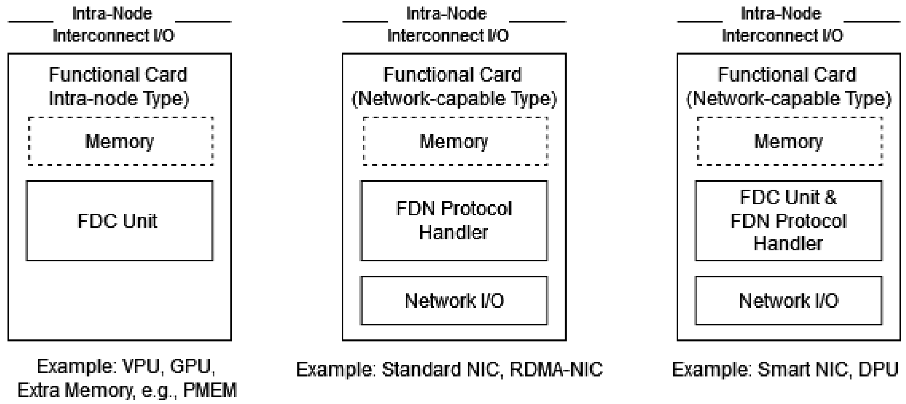



*Figure 3.2-2: Types of functional cards*

### 3.2.2. DCI Gateway

The **DCI Gateway** is a network module that relays data between DCI physical nodes in a DCI cluster and networks outside the DCI Cluster. It should provide data forwarding services that can achieve extreme QoS, e.g., guaranteed bandwidth of tens/hundreds of Gbps, forwarding latency less than a few microseconds for time-sensitive networking, required by IOWN GF use cases. It should also support point-to-multipoint forwarding.

It should expose a dynamic management/control interface to the DCI Cluster Controller to realize high availability and load balancing features.

A DCI Gateway as a logical instance should belong to a single DCI Cluster. For data transfer between DCI clusters, the DCI Gateways of the clusters should be inter-connected with an Open APN or an Extra Network. However, this may be implemented with one DCI Gateway product that can be separated into multiple logical gateways.

IOWN GF will develop the reference implementation models (RIM) and specifications of the DCI Gateway and the Inter-node Interconnect during the technical specification phase. A short-term approach to implement a DCI Gateway and an Inter-node Interconnect would be to use a large-scale converged ethernet infrastructure. However, there is room for innovations for quantum leaps in capacity, low-latency support, scalability, and energy efficiency. In the long term, IOWN GF should drive these innovations leveraging optical communication and optoelectronics integration technologies. Therefore, the RIM will be defined with multiple classes.

### 3.2.3. Inter-node Interconnect

The **Inter-node Interconnect** is a network module that connects multiple DCI physical nodes to form a DC-scale computing infrastructure. The Inter-node Interconnect should provide data forwarding services that can achieve extreme QoS, e.g., guaranteed bandwidth of tens of Gbps, forwarding latency less than a few microseconds for time-sensitive networking, required by IOWN GF use cases. It should also support point-to-multipoint forwarding.

It should expose a dynamic management/control interface to the DCI Cluster Controller to realize high availability and load balancing features.

IOWN GF will develop the reference implementation models (RIM) and specifications of the DCI Gateway and the Inter-node Interconnect during the technical specification phase.

## 3.3. DCI Cluster Controller

The DCI Cluster Controller is a logical function that dynamically reconfigures DCI physical nodes, the inter-node interconnect, and the DCI Gateway to create and maintain **Logical Service Nodes (LSN)**. It exposes an API to DCI's

Infrastructure Management and Orchestration functions. In addition, as is common to DCI resource controllers, the DCI Cluster Controller should also provide telemetry collection services.

A DCI Cluster Controller may control multiple DCI Clusters.

# 4. DCI Infrastructure as a Service

## 4.1. Overview

DCI manages infrastructure resources dynamically to provide users with virtually private computing and networking infrastructures on an as-a-Service (aaS) model. The basic unit for networking service is an FDN Segment, and the basic unit for computing service is a logical service node (LSN).

This section defines DCI Infrastructure as a Service with its object model, APIs, and user personas.

## 4.2. Object Model

The figure below shows an object model for DCI IaaS, which shows logical instances of provided infrastructure resources as objects. We call them DCI objects. DCI objects are associated with others, as shown in Figure 4.2-1.

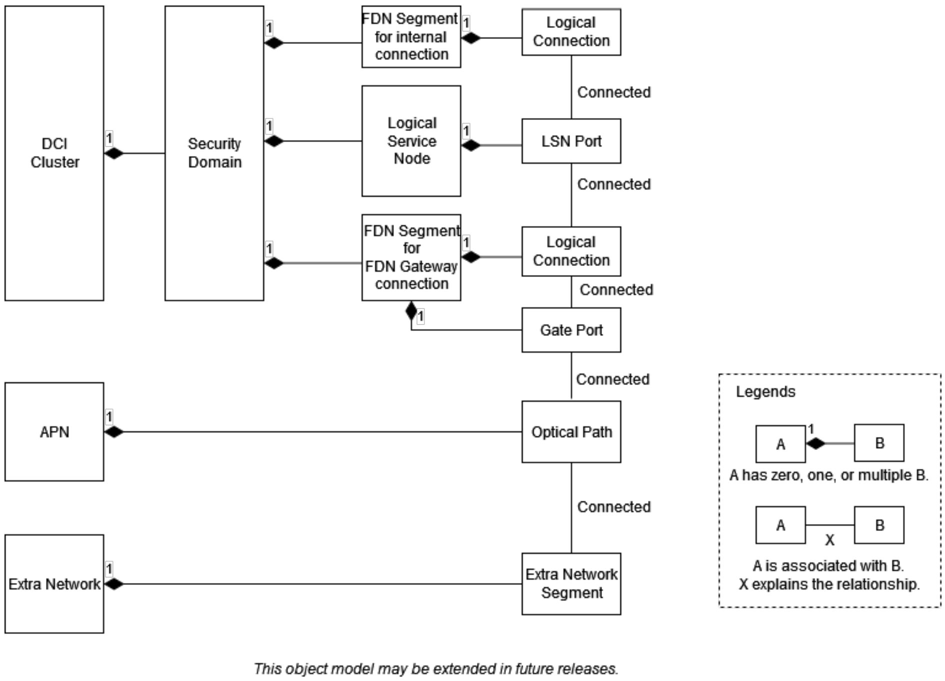



*Figure 4.2-1: Types of functional cards*

The definitions of DCI objects are given below.

- **DCI Cluster:** See Section 1
- **Security Domain:** A logical subspace of the computing space of a DCI Cluster, which a user can own as their private space. It is protected as an independent domain in access management. In other words, without explicit "allow" configurations on logical ports, access from external entities should be prohibited by default.
- **Logical Service Node (LSN):** See Section 1.
- **LSN port:** logical port of LSN.
- **Gate port:** logical port of DCI Gateway.

- **FDN Segment:** See Section 1. Examples of FDN Segment would be a connection internal to a DCI Cluster, a connection that is created on an Extra Network, and other connections that bridge between DCI LSNs and networks outside the DCI Cluster.
- **Logical Connection:** A logical connection between/among FDN Gateways. It may be point-to-point or point-to-multipoint. When the FDN Segment is of a connectionless type, a set of forwarding configurations to enable data traffic between/among the connected logical ports is regarded as a logical connection. Logical connections achieve QoS-aware data forwarding.
- **Extra Network:** See Section 1.
- **Extra Network Segment:** An FDN Segment that is instantiated on top of an Extra Network.

Each DCI object has attributes. IOWN GF will clarify the attributes of DCI objects during the technical specification phase. However, some of the important attributes are noted in Table 4.2-1 below:

*Table 4.2-1: DCI object attributes*

| DCI OBJECT | ATTRIBUTES (NOT EXHAUSTIVE) |
|---|---|
| DCI infrastructure owner | • user with usage time scale |
| Security Domain | • the owner |
| Logical Service Node | • the node flavor/type<br>• the node recipe (See Section 4.4)<br>• the resource allocation parameters<br>• the telemetry parameters (Read-Only) |
| FDN Segment | • the FDN class/type<br>• the telemetry parameters (Read-Only) |
| FDN Gateway | • the gateway type<br>• the network protocol parameters<br>• the telemetry parameters (Read-Only) |
| Logical Connection | • the connection/forwarding parameters<br>• quality of transport service parameters (latency, data rate, packet drop rate, level of synchronization, availability, downtime, etc.)<br>• the security policies<br>• the telemetry parameters (Read-Only) |
| Optical Path | • the optical communication parameters<br>• the MAC layer parameters<br>• the telemetry parameters (Read-Only) |

By setting the attributes of DCI objects, a DCI user can chain up DCI objects to form a DCI object composite (DCIOC) that can transfer and process data, accommodating extreme QoS requirements. Examples of DCI object composites are shown below in Figure 4.2-2.

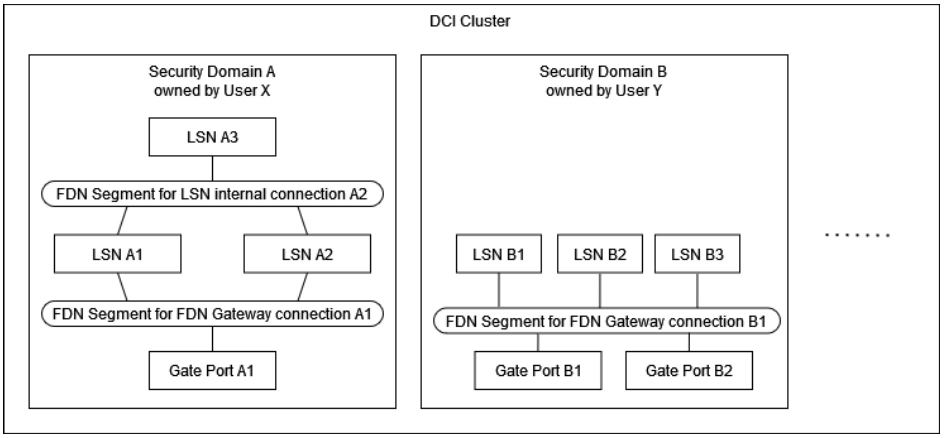



*Figure 4.2-2: Examples of DCI object composite in a DCI cluster*

## 4.3. Service APIs

Like today's cloud computing services, DCI IaaS (infrastructure as a service) enables users to create/delete DCI objects and set/get DCI object attributes. In other words, DCI IaaS should enable the basic Create, Read, Update, and Delete (CRUD) operations of DCI objects.

While IOWN GF will define DCI IaaS API during the technical specification phase, some of the important primitives are described below:

- DCI LSN creation. This service enables a DCI service consumer (e.g., tenant platform provider) to request the creation of DCI logical nodes. The DCI service consumer provides logical node specifications (e.g., required computing types/resources, required FDN type/capacity, etc.). Functions in the DCI infrastructure orchestration and management framework can then identify the necessary resources and create the DCI logical nodes.
- DCI LSN configuration. This service enables a DCI service consumer to update DCI LSN configurations, such as adding or releasing computing resources, adding or removing FDN resources, update computing resource settings, updating FDN settings, etc.
- DCI LSN release. This service enables a DCI service consumer to release DCI LSNs.
- DCI LSN reserved. This service enables a DCI service consumer to release to reserve an LSN.
- DCI LSN chaining and pipelining. This service enables a DCI service consumer to request the creation of a service pipeline with a chain of LSNs. Data flow can be flowed in the DCI infrastructure layer among the chain of LSNs according to the service pipeline with minimal upper layer software intervention. The chain of LSNs can belong to multiple DCI clusters across multiple physical sites (e.g., edge site, regional site, national site, etc.).
- DCI LSN status monitoring. This service enables a DCI service consumer to monitor and obtain LSN operation status such as ready for testing, ready for operation, in error/erred.

# 4.4. DCI IaaS User Personas

## 4.4.1. Tenant Platform Service Providers

With its heterogeneous architecture, DCI will become an ideal infrastructure for many services such as mobile network service, CPS area management service, and AIC streaming service. These services are called **DCI Tenant Platform Services** because, in most cases, the infrastructures of these services are designed to be a platform that can accommodate various applications.

Providers of DCI Tenant Platform Services are referred to as **DCI Tenant Platform Service Providers.**

DCI Infrastructures as a Service should support critical requirements from DCI Tenant Platform Service Providers. For example, we should assume the following requirements:

- Requirement 1: As a tenant platform service provider, I would like to control, manage and operate a group of DCI logical service nodes by my service management and orchestration system to have **control over the service quality**.
- Requirement 2: As a tenant platform service provider or an enhanced LSN provider, I would like to enable some protective measures, such as storage encryption, on DCI logical service nodes to **protect my intellectual property** from leakage.

Requirement 1 implies that the consumers of DCI IaaS APIs are service management and orchestration systems owned by tenant platform service providers. Figure 4.4-1 below shows the stack of systems for typical DCI use cases.

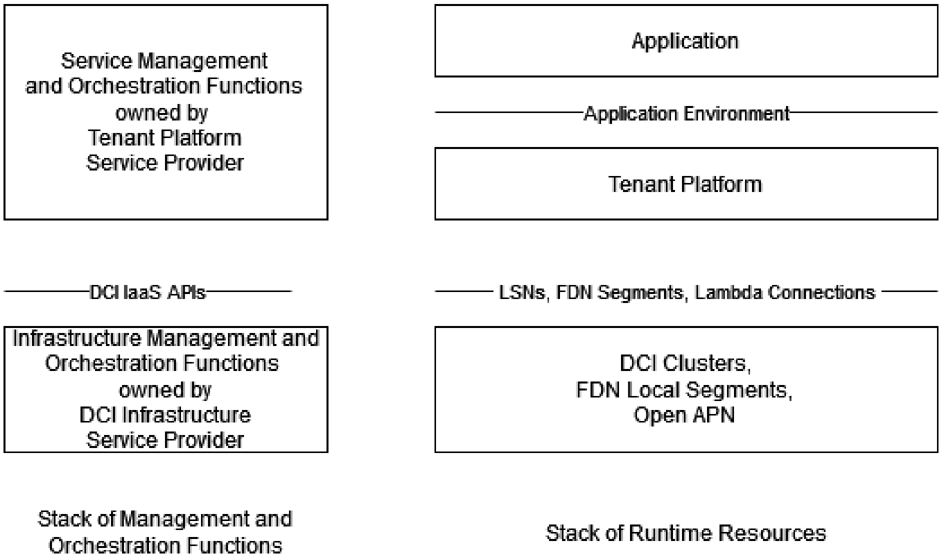



*Figure 4.4-1: Tenant platform service provider stacks*

Management and orchestration functions need to be selective to be provided under DCI IaaS API to **avoid building layers of duplicative management and orchestration functions**. Therefore, the main functional scope of DCI's infrastructure management and orchestration functions should be the following:

- The resource allocation and configuration/re-configuration of physical infrastructure resources to create DCI objects defined in Section 4.2
- The configuration of the management port of the created DCI objects
- The installation and configuration/reconfiguration of the base software, e.g., OS and a minimum set of complementary software, for the created DCI objects

- The telemetry of physical infrastructure resources and DCI objects

For example, suppose a mobile network operator builds a virtual radio access network (vRAN) and cloud-native network function (CNF)/virtualized network function (VNF) platform on top of DCI as a tenant platform service provider. In this case, the mobile network operator's (MNO's) service management and orchestration (SMO) function would create LSNs invoking the DCI IaaS API and add the created LSNs to its node list. IOWN GF will clarify the detailed procedure for this scenario during the technical specification phase. However, the following as a blueprint is assumed at this moment:

1. DCI LSN Manager allows tenant platform service providers to create their "node recipes," which specifies the flavor of LSNs, installed base software, and initial parameter configurations.
2. MNO's SMO requests the creation of new LSNs, specifying the applied node recipe. This request would be sent to the DCI Infrastructure Orchestrator through the Service Exposure Function.
3. The DCI Infrastructure Orchestrator somehow resolves a DCI Cluster Controller and calls the cluster controller to create LSNs. Then, the DCI Cluster Controller creates LSNs, configures their management ports, and returns their management addresses.
4. The DCI Infrastructure Orchestrator calls the LSN Manager to install the base software into the created LSNs, and apply the initial parameter configurations. This request should include the management addresses of the LSN and the ID of the applied node recipe.
5. Upon a completion response from the LSN Manager, the DCI Infrastructure Orchestrator sends to the MNO SMO a response including the LSN's management addresses.

## 4.4.2. Enhanced LSN Providers

While DCI Tenant Platform Service Providers would typically be regional businesses, they would seek the best-in-class technologies to handle a large amount of real-time data. This would create opportunities for product and equipment suppliers to develop logical service nodes (LSNs) specialized for specific purposes and sell them to the service providers in the global market. For example, a radio access network (RAN) vendor may allow its proprietary SDK and radio processing accelerator hardware to be added to LSNs and sell them to mobile service providers. We refer to these specialized LSNs as **enhanced LSNs** and refer to their suppliers as **enhanced LSN providers**.

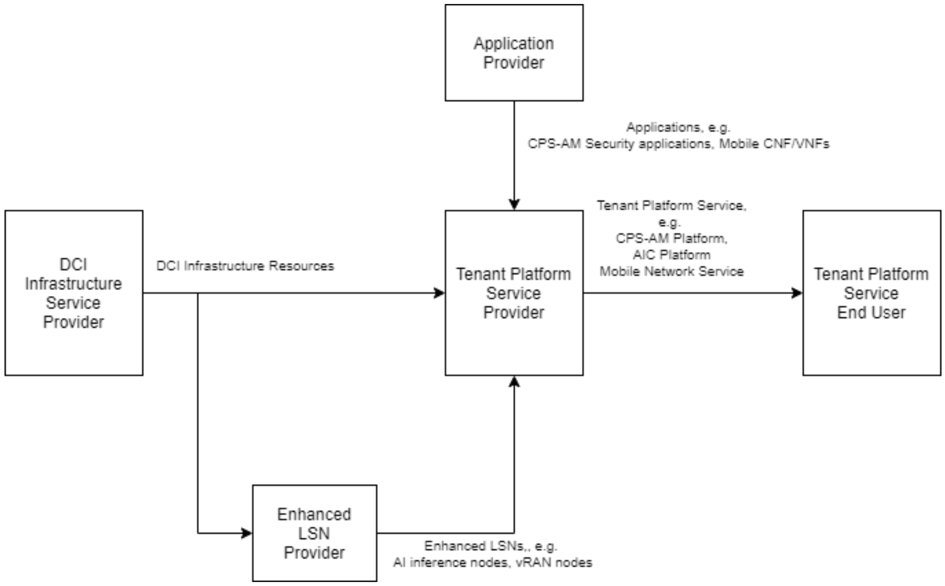



*Figure 4.4-2: Relationships among the infrastructure service provider, tenant platform service providers, and enhanced LSN providers*

Figure 4.4-2 illustrates the relationships among the infrastructure service provider, tenant platform service providers, and enhanced LSN providers.

IOWN GF will clarify the detailed procedures for the creation of enhanced LSNs during the technical specification case. However, we assume the following as a blueprint at this moment:

- An enhanced LSN provider registers its “node recipes” on the DCI LSN Manager.
- A tenant platform service provider selects the node recipe of an enhanced LSN provider in an LSN creation request to DCI.

# 5. Example deployment scenarios

## 5.1. Intra data center deployment scenario example:

Figure 5.1-1 shows an intra-data center deployment example with PCIe for intra-node interconnect. Each DCI physical node comprises various functional cards that include computing devices (CPUs, GPUs, field-programmable gate arrays (FPGAs), or other types of accelerators), memory, NICs (including smart NICs and IPUs). The functional cards are interconnected via intra-node interconnect (such as PCIe, CXL, etc.). The DCI physical nodes in a DCI cluster are interconnected through inter-node interconnect. This Inter-Node Interconnect should be able to cater to extreme service requirements such as ultra-high throughput and ultra-low latency. A DCI cluster connects with networks outside the DCI Cluster via a DCI Gateway. Figure 5.1-2 shows an intra-data center deployment example with CXL for intra-node interconnect.

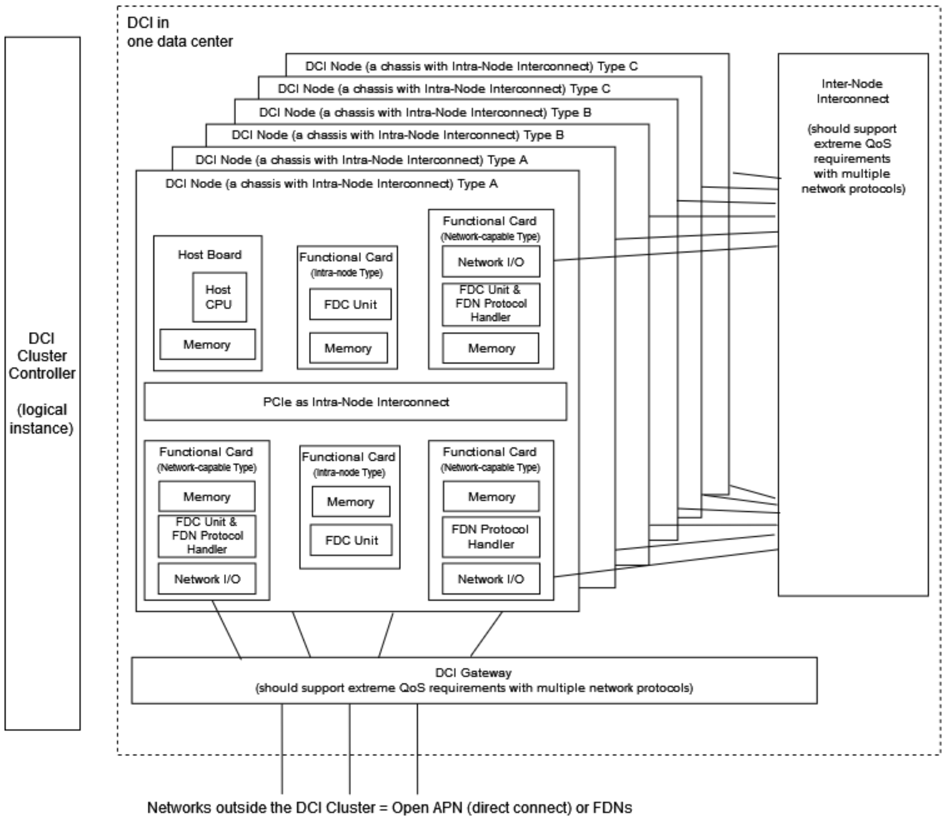



*Figure 5.1-1: Intra data center deployment example with PCIe for intra-node interconnect*

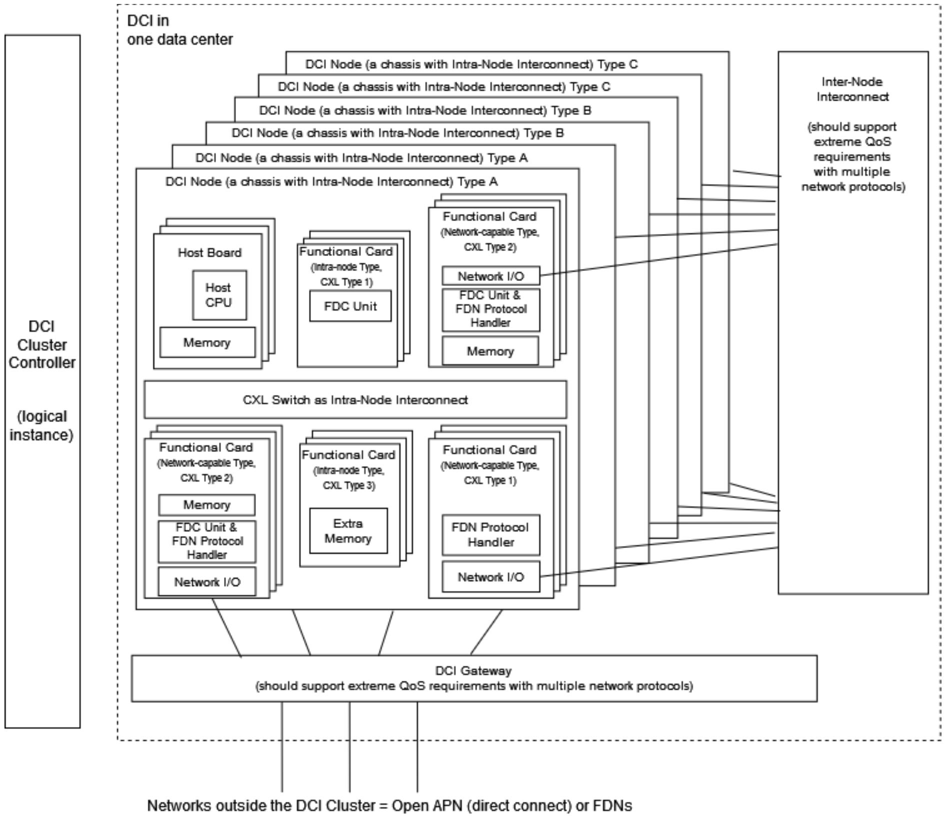



*Figure 5.1-2: Intra data center deployment example with CXL for intra-node interconnect*

Note that the difference between Figure 5.1-1 and Figure 5.1-2 is:

- PCIe will only allow one mainboard per physical node.
- Some versions of CXL will allow multiple mainboards per physical node; the actual transfer mechanism to be used is considered an item for further study.

# 5.2. CPS Area Management Security example

Figure 5.2-1 depicts an example of CPS Area Management with IOWN GF Open APN and DCI.

CPS Area Management builds data pipelines consisting of two levels of data aggregation and processing nodes called a local aggregation (LA) node and an ingestion (IN) node. The role of Infrastructure Management is to create DCI logical service nodes to host LA and IN and provision necessary connections. By contrast, the role of Service Management is to manage these LA and IN according to service demands. For example, a new demand may require adding a data processing function to some LA or IN. In this case, the service management system should deploy the data processing functions to the desired points.

We define Service Node Manager as a function of managing enhanced LSNs to host local aggregation (LA) and ingestion (IN) functions of the CPS area management (AM) use-case. The CPS-AM service provider may choose to build LA and IN as Linux container runtimes and deploy data processing functions in the form of Linux containers. In this case, the Service Node Manager would install the software stack for the Linux container runtime environment, e.g., Kubernetes software, into the DCI logical service nodes. Before this step, the DCI LSN Manager would only do minimal software installation and parameter configuration necessary for the CPS-AM node manager to access the logical service nodes.

We place an Extra Network to aggregate traffic from multiple LAs into an Open APN optical path. There would be many options for the data transfer protocol between LA and IN. If remote direct memory access (RDMA) is used, the Extra Network should be capable of congestion avoidance and low latency. An example of such an FDN is Converged Enhanced Ethernet (CEE).

We assume that IN may be built with multiple LSNs in tiers because some use cases require one captured data to be analyzed by multiple AI inference applications.

A detailed CPS deployment model can be found in Section 5 of the Reference Implementation Model technical report [IOWNGF-RIM].

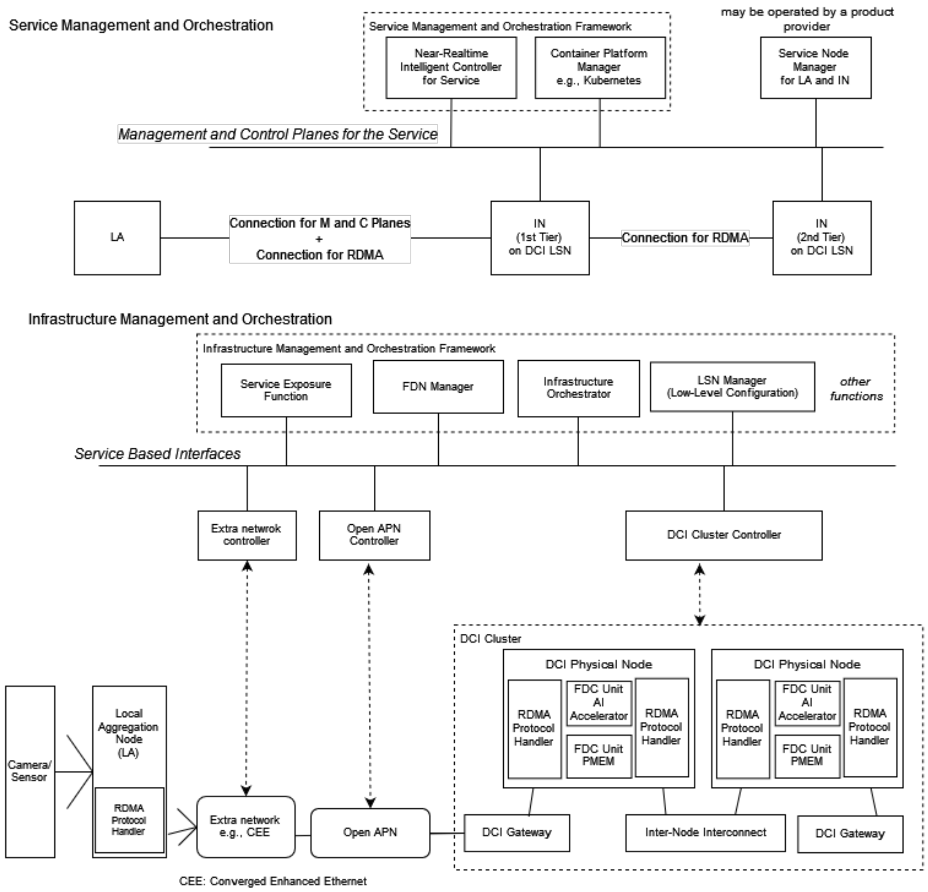



*Figure 5.2-1: DCI for CPS Area Management Security*

## 5.2.1. Operation Procedures

The deployment of a new IN should go through the following three stages:

- Stage 1 (Physical Resource Assignment)
  - DCI Cluster Controller creates DCI logical service nodes and connections inside the DCI Cluster.
- Stage 2 (Low-level Node Configuration)
  - DCI LSN Controller does minimum software installation and parameter configuration necessary for the Service Node Manager to access the created logical service nodes.
- Stage 3 (High-level Node Configuration)

  - The Service Node Manager does additional software installation and parameter configuration to make the created logical service nodes IN nodes.

The deployment of a new LA should go through the following two stages:

- Stage-1 (Physical Resource Assignment)
  - FDN Manager calls Open APN Controller, Extra Network Controller, and DCI Cluster Controller to create connections between the new LA and its IN:
    - DCI Cluster Controller creates connections between the DCI Gateway and the IN
    - Extra Network Controller reserves a port of the Extra Network for the new LA and creates connections between the reserved port and the Open APN port, i.e., the wide area network (WAN) port.
    - Open APN Controller creates or updates an Open APN optical path if necessary
- Stage-2 (Node Configuration through ZTP)
  - Once the new LA is connected to the port configured in Stage 1, some Zero-Touch Provisioning (ZTP) protocol should activate the new LA.

## 5.3. Mobile network deployment scenario example:

Figure 5.3-1 depicts an example of disaggregated RAN with IOWN GF Open APN and DCI.

In this case, the role of Infrastructure Management is to create logical service nodes to host RAN functions and provisions necessary connections. By contrast, the role of Service Management is to deploy RAN functions to the created nodes and control the deployed RAN functions.

We define RAN nodes as enhanced LSNs to host radio unit (RU), distributed unit (DU), and central unit (CU) functions and RAN Node Manager as a function of managing RAN nodes, i.e., RU, DU, and CU. This management includes the high-level configuration of DCI logical service nodes, such as installing executable codes and setting RAN function parameters.

If a RAN product provider wants to provide its products via an as-a-service model without disclosing its intellectual property, we may choose to have the **RAN product provider operate the RAN node manager**. In this case, the DCI LSN Controller would only do minimal software installation and parameter configuration necessary for the RAN node manager to access the logical service nodes.

We place an FDN, called Mobile Fronthaul FDN, to aggregate multiple RUs into an Open APN optical path. This FDN should achieve strict mobile front haul transport requirements, such as latency and packet delay variation. An example of such an FDN is Ethernet Virtual Connection (EVC).

Detailed mobile network deployment model can be found in the Technical Outlook for Mobile Network Using IOWN Technology [IOWNGF-IMN].

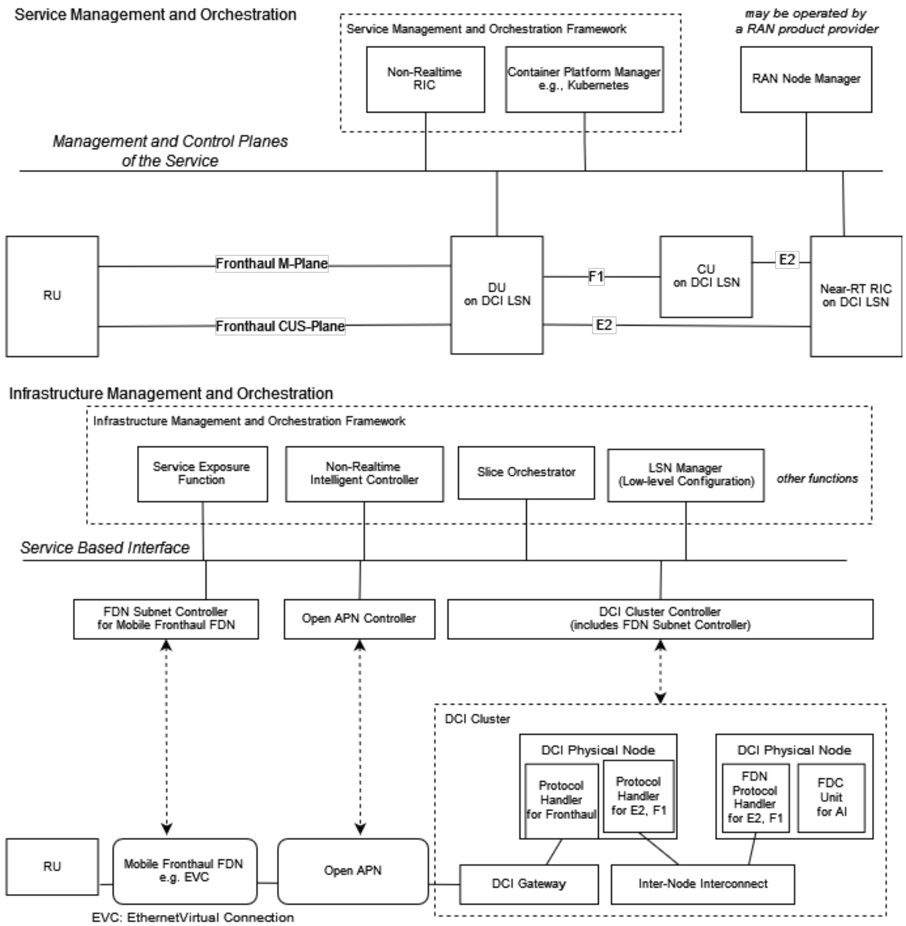



*Figure 5.3-1: IOWN GF technologies for mobile network*

## 5.3.1. Operation Procedures

The deployment of a new CU or DU should go through the following three stages:

- Stage 1 (Physical Resource Assignment)
  - DCI Cluster Controller creates DCI logical service nodes and connections inside the DCI Cluster.
- Stage 2 (Low-Level Node Configuration)
  - DCI LSN Controller does minimum software installation and parameter configuration that are necessary for the RAN Node Manager to access the created logical service nodes
- Stage 3 (High-Level Node Configuration)
  - The RAN Node Manager does additional software installation and parameter configuration.

The deployment of a new RU should go through the following two stages:

- Stage 1 (Physical Resource Assignment)
  - Infrastructure Orchestrator calls Open APN Controller, Extra Network Controller, and DCI Cluster Controller to create connections between the new RU and its DU:
    - DCI Cluster Controller creates connections between the DCI Gateway and the DU

        - Extra Network Controller reserves a port of the Extra Network for Mobile Fronthaul for the new RU and creates connections between the reserved port and the Open APN port, i.e., WAN.
        - Open APN Controller creates or updates an Open APN optical path if necessary
- Stage 2 (Node Configuration through ZTP)
    - Once the new RU is connected to the port configured in Stage 1, some Zero-Touch Provisioning (ZTP) protocol should activate the new RU.

The Okinawa Open Laboratory and NTT Group developed a proof concept system of the slice orchestration among RAN, Carrier Ethernet, and Optical Transport. Details are presented in [MEF3PoC].

# 6. DCI system control and management

This section provide high-level DCI system control and management procedures. These procedures could be updated in future releases.

## 6.1. Logical node management

### 6.1.1. Logical node creation

Figure 6.1-1 shows a procedure for LSN creation. In the procedure, the DCI service consumer requests LSN creation via the DCI service exposure function. The DCI service exposure function then forwards the creation request to the DCI infrastructure orchestrator. The DCI infrastructure orchestrator identifies a DCI cluster controller that can handle the request and sends the request to the selected DCI cluster controller. The DCI cluster controller then identifies the DCI cluster that can hold the LSN and sends an LSN creation request. Once the LSN is created, the completion message is sent back to the DCI service consumer. The DCI controller will also register the created LSN to the LSN manager. The completion message could contain the specifications of the created LSN, the LSN address information, and the LSN manager information.

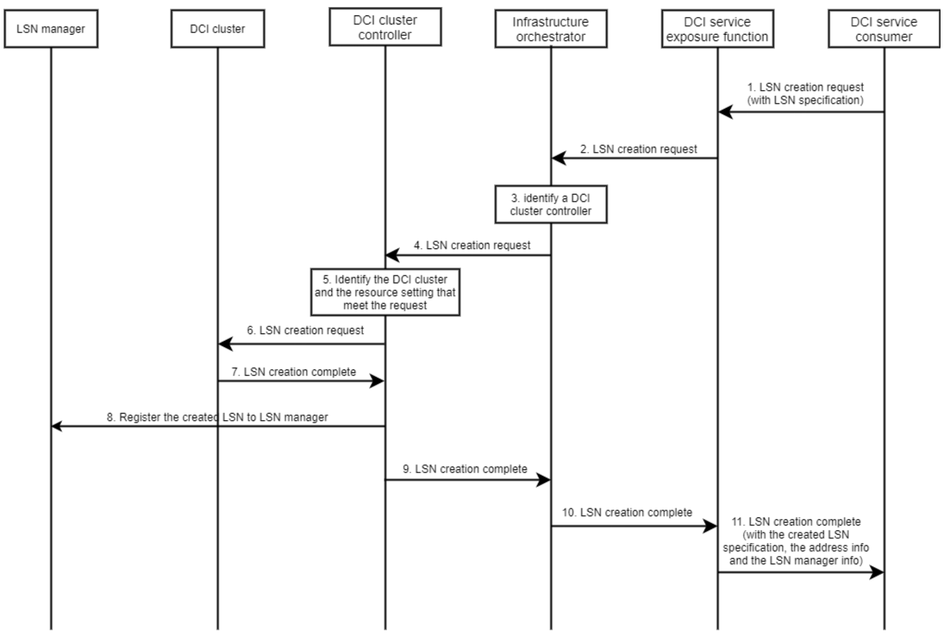



*Figure 6.1-1: LSN creation procedure*

### 6.1.2. LSN reconfiguration and update

Figure 6.1-2 shows a procedure for LSN configuration update. In the procedure, the DCI service consumer sends the LSN configuration request to the DCI service exposure function, which then forwards the request to the corresponding LSN manager. The LSN manger then updates the configurations of the LSN and updates the DCI cluster controller about the changes. Once the configuration is complete, the completion message is sent back to the DCI service consumer.

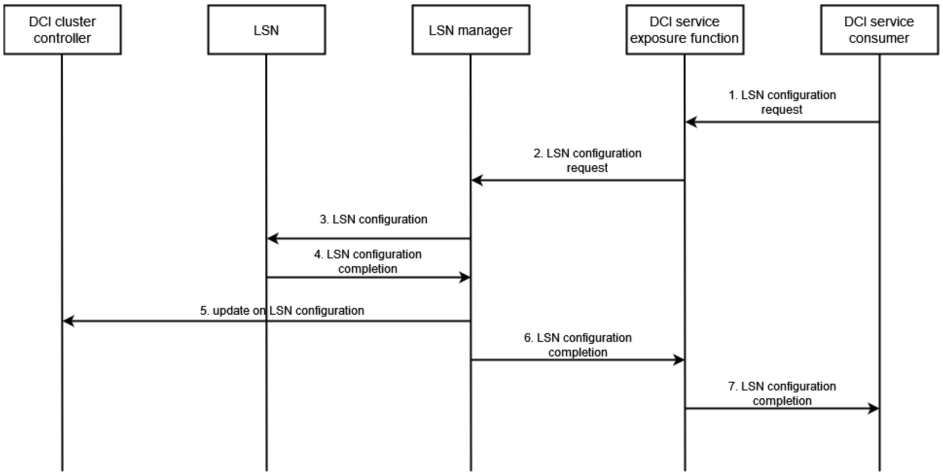



*Figure 6.1-2: Procedure for LSN configuration update without physical resource addition/release in the LSN*

The procedure shown in Figure 6.1-2 does not involve physical resource (compute/memory/FDN) addition/removal from the LSN. When there is a need to update the physical resource in an LSN, the DCI cluster controller needs to be called to handle the physical resource update. Figure 6.1-3 shows such a procedure. Steps 3-6 are the steps for physical resource update by the DCI cluster controller.

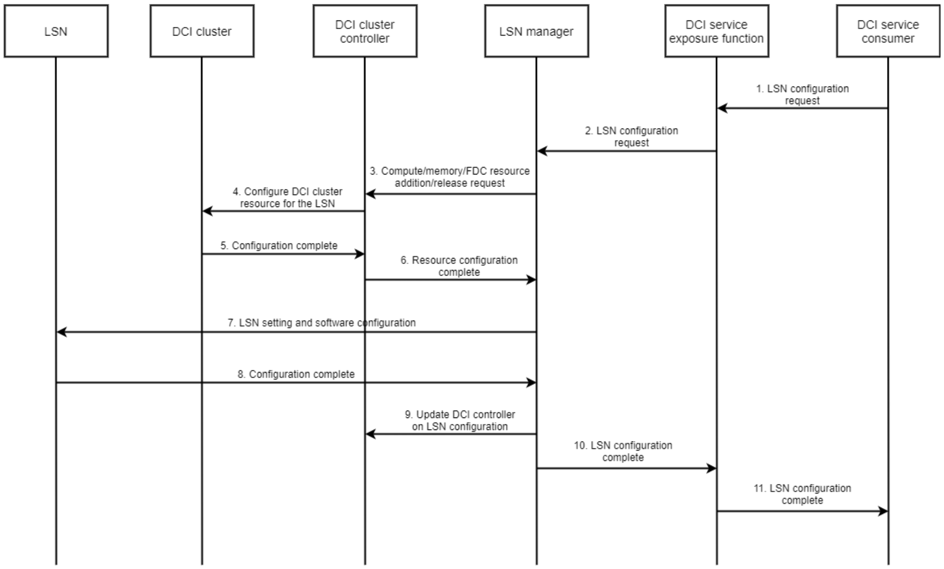



*Figure 6.1-3: Procedure for LSN configuration update with physical resource addition/release in the LSN*

## 6.1.3. LSN release

Figure 6.1-4 shows a procedure for LSN release. In the procedure, the DCI service consumer sends the LSN release request to the DCI service exposure function, which then forwards the LSN release request to the corresponding DCI cluster controller. The DCI cluster controller then deregisters the LSN from its LSN manager and releases the computing/memory and FDN resources assigned for the LSN. Once the LSN release is complete, the completion message is sent to the DCI service consumer.

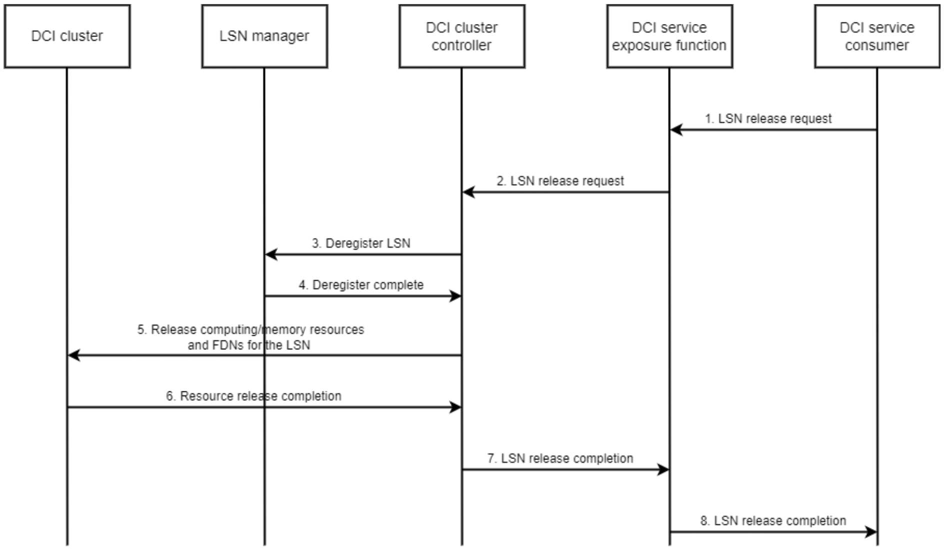



*Figure 6.1-4: LSN release procedure*

## 6.2. Hierarchical control and management

The DCI system's control and management hierarchy is comprised of the DCI infrastructure orchestrator, the DCI cluster controller, FDN/Open APN infrastructure controllers, and the LSN manager. The functionalities and responsibilities of those functions are described as follows:

- The DCI infrastructure orchestrator is the top-level control and management entity. It has the overall view of DCI resources and DCI controllers. Given an LSN create request, the infrastructure orchestrator will identify the DCI cluster that can hold the LSN and select the corresponding DCI cluster controller.
- The DCI cluster controller is responsible for the control and managing one or multiple DCI clusters. It has an overall view on the computing, memory, and FDN resources within those DCI clusters.
- The FDN/Open APN infrastructure controller is responsible for control and manages FDNs that interconnect DCI clusters.
- The LSN manager is responsible for boot up and configuring the LSNs. It does not directly manage the physical resources of the LSN. When there is a need to add or release some of the physical resources in the LSN, the DCI cluster controller will be called to conduct those tasks.

## 6.3. Orchestration and service chaining to generate the E2E data pipeline

Figure 6.3-1 shows a procedure for service orchestration and chaining. In the procedure, the DCI service consumer sends a service request to the DCI service exposure function, then parses the request and forwards it to the infrastructure orchestrator. The infrastructure orchestrator identifies and chains up the DCI clusters and the inter-cluster FDN for the service. The infrastructure orchestrator then sends corresponding configuration information to the DCI cluster controllers and the FDN controllers. The DCI cluster controllers and FDN controller then configure the DCI clusters and FDNs respectively to prepare the physical resources and connections for the service chain. Once the physical resource of the service chain is prepared, the infrastructure orchestrator can then send the service chain information to the LSN manger to prepare LSNs along the service chain. Once the LSNs along the service chain are configured, the service chain generation is completed. The DCI service consumer is then informed of the service chain completion.

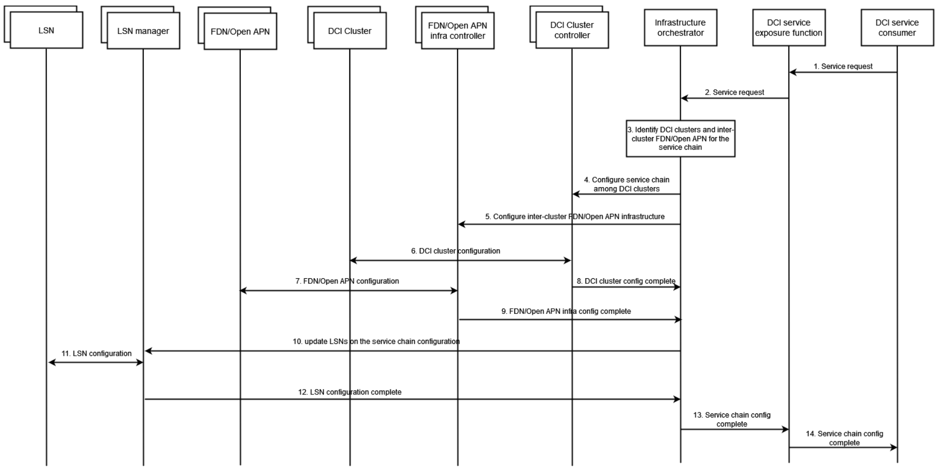



*Figure 6.3-1: Procedure for service orchestration and chaining*

# 7. Data Plane Acceleration

Due to the increase of network bandwidth, applications running on current server systems consume large amounts of CPU processing power not only for application specific tasks, but also for network protocol processing. To simultaneously provide enough bandwidth for the extreme use cases of the IOWN Global Forum and reduce the (system) power consumption, it is essential to create a data plane acceleration framework that provides mechanisms including offloading the task of network processing into hardware accelerators.

## 7.1. Overview of IOWN Global Forum Data Plane Acceleration Framework

### 7.1.1. Introduction

The IOWN GF use cases require to support various types of data processing and data flow, implemented on different data planes. The existing data plane framework may be able to be applied to some data flows. A new data plane framework may be needed for other data flows. In this section, the data plane acceleration (DPA) framework aims to apply to such latter data flows in combination of different data plane types. For this purpose, first, we analyze data flows of the CPS AM use case described in the RIM document [IOWNGF-RIM] and IDH document [IOWNGF-IDH]. Then, we define data plane types in terms of communication range from internal communications within a DCI physical node to inter-cluster communications between different DCI Clusters. After that, we deeply analyze internal data flows between processes in a DCI physical node again. Finally, we categorize the classes of data plane acceleration frameworks.

### 7.1.2. Data pipeline analysis for CPS AM

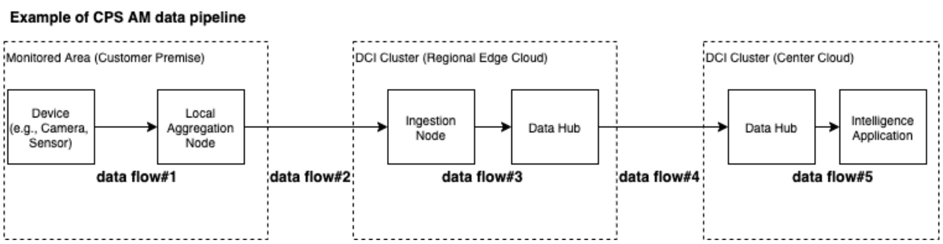



*Figure 7.1-1: Example of CPS AM data pipeline*

Figure 7.1-1 shows a typical data pipeline defined in Section 3 of the RIM document [IOWNGF-RIM]. In this standard pipeline, a camera device produces video streaming data continuously and uploads it to the nearest Local Aggregation node (**data flow#1**). After receiving such data from multiple cameras, the Local Aggregation node aggregates them. Then, the Local Aggregation node forwards such data to the Ingestion node (**data flow#2**). The Ingestion node receives it from multiple Local Aggregation nodes simultaneously. After receiving it from multiple Local Aggregation nodes, the Ingestion node executes processes such as conversion, decoding and resizing of the video image data, and object detection. Many applications may commonly utilize the inference results of object detection. After this process, the Ingestion node posts the output data (i.e., the inference results, and video image data) to the Data Hub for further usage (**data flow#3**). The Data Hub preserves the received data, then sends notifications to the listening nodes. In the case of maintaining the video image data, the Data Hub may store them internally. However, in the case of the inference results, they are transferred from the Data Hub in the regional edge cloud to that of the central cloud (**data flow#4**). In this case, the Intelligence Application node is supposed to subscribe to inference results, so, notifications are sent from the Data Hub to the Intelligence Application node to trigger further analysis (**data flow#5**).

#### data flow#1

- **Analysis**

    - As defined in the RIM document [IOWNGF-RIM], the data rate of uncompressed video image is 90MB (=6 MB x 15fps) per second per camera. In the case of Motion JPEG compression scheme, the video image data rate is from 45 to 60Mbps.

- **Requirements**
    - Compatibility
        - The data flow#1 is realized on the Best Available network written in Section 5.2 of the RIM document [IOWNGF-RIM]. Therefore, some processes which directly receive video image data from a camera in the Local Aggregation node should provide the first termination point of conventional network stack such as TCP/IP.

### data flow#2

- **Analysis**
    - As defined in the RIM document [IOWNGF-RIM], the captured video image data in the Local Aggregation node of each Monitored Area has to be transferred to processes running in the Ingestion node located in the regional edge cloud. The bandwidth of such data transferred between the Local Aggregation node and the Ingestion node will constantly be large. For instance, when thousands of camera devices simultaneously send video images to the Local Aggregation node and the data rate of uncompressed video image is 90MB(=6 MB x 15fps) per second per camera, some processes of the Local Aggregation node have to transfer about 720Gbps of data to the Ingestion node constantly. Even if the Motion JPEG compression scheme is applied to the video data, the bandwidth will achieve 60Gbps.
    - The communication range between a Monitored Area and a regional edge cloud is assumed to be up to 337km [IOWNGF-RIM].
- **Requirements**
    - Network bandwidth
        - Likely, this data flow may require network bandwidths beyond 100Gbps.
        - Hardware-accelerated network processing is also needed, since current host CPU-based network processing is likely to become a limiting factor for achievable bandwidth. For example, research indicates 42Gbps as the maximum possible bandwidth with CPUs, along with significant energy consumption [Cai2021].
    - Message size
        - Message size of data should be configured carefully keeping three effects in mind:
            - One is that if packets per second become larger, it is well-known that performance degrades.
            - The 2nd effect is that if a mechanism to check for data transfer completion is applied over the network layer, it may lead to performance degradation especially in a long-range network. In this case, message size has significant impact to performance.
            - The last effect is that in general, using large-size messages leads to longer latency.
    - Long-range communication
        - This data flow is implemented over a long-range data plane beyond 100km.

### data flow#3

- **Analysis**

- There are two types of data flow#3. One is for structured data representing the inference results (data flow#3-1). The other is related to chunked data of video images (data flow#3-2).
- Assuming that N is the number of Monitored Areas to be connected to the regional edge cloud,
  - The data flow#3-1 is estimated to be 3.6Gbits x N/second [IOWNGF-RIM].
  - The data flow#3-2 is estimated to be 60Gbits x N/second [IOWNGF-RIM].
- According to the IDH service types defined in Section 2 of the IDH document [IOWNGF-IDH],
  - “Relational Distributed Database” service type can be applied to the data flow#3-1.
  - “Object Storage” service type can be applied to data flow#3-2.

- **Requirements**
  - The requirements of these data flow#3-1 and #3-2 are almost the same as the data flow #2 except for the length of communication range.

## data flow#4

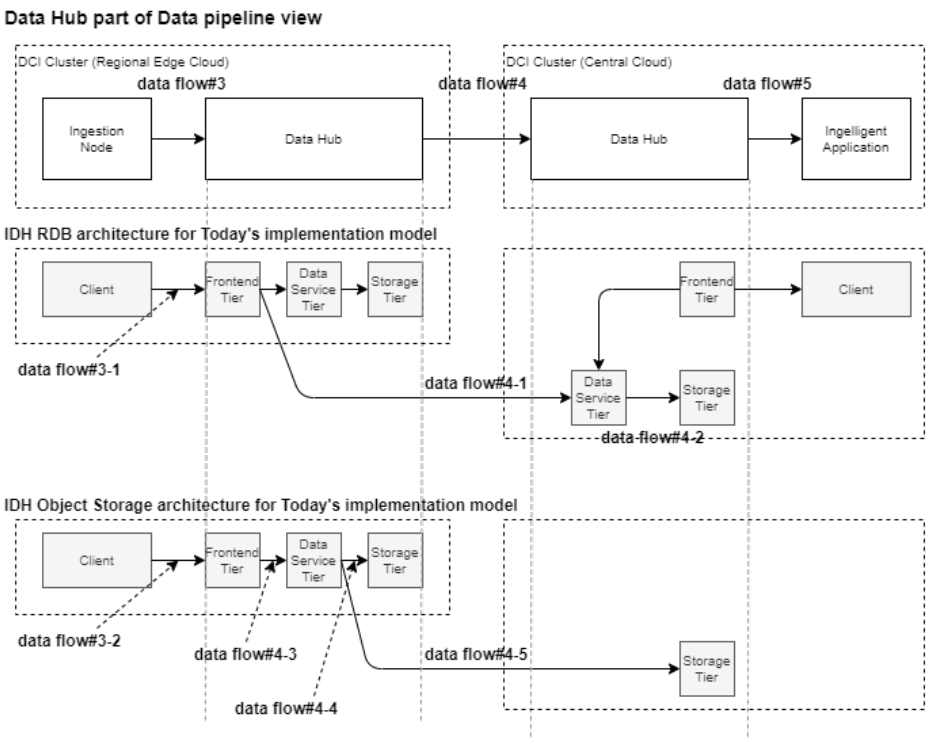



*Figure 7.1-2: Example of IDH deployment for CPS AM use case*

- **Analysis**
  - The data flow#4 has two types of data flow. One is relevant to the data flow#3-1 for structured data representing the result of the inference results (data flow#4-1, #4-2). The other is related to the data flow#3-2 for storing video image data(data flow#4-3, #4-4, #4-5).
  - For the structured data representing the inference results, when the Ingestion node posts it to the Data Hub placed in the regional edge cloud, it is stored in the Data Hub located in the Central Cloud (CC) depicted in Figure 7.1-2. Since the Intelligence Application node retrieves it, the Data Hub nearest to the Intelligence Application node is better to be utilized for fast access and efficient network bandwidth utilization.

        - In this case, the data flow#4-1 is implemented over the long-range data plane between the regional edge cloud and the central cloud. On the other hand, the data flow#2 is between the monitored area and the edge cloud. They are different segments and the data flow#4-1 would be longer than the data flow#2. The data flow#4-2 is propagated between Data Service Tier and Storage Tier in the same DCI Cluster. The data flow#4-1 is the mid connection, and data flow#4-2 is the backend connection defined in Section 5.1 of the IDH document [IOWNGF-IDH].
    - For storing the video image data, the Ingestion node posts it to the Data Hub of the regional edge cloud. The Data Hub distributes it to the different Data Hubs via three tiers: Frontend Tier, Data Service Tier, and Storage Tier.
        - As described in Figure 7.1-2, data flow#4-3 is between Frontend Tier and Data Service Tier in the same DCI Cluster in the regional edge cloud. But there are two types of the data flow between Data Service Tier and Storage Tier (data flow#4-4, #4-5). A choice of the data flow is dependent on the use case scenario.
        - In data flow#4-3 #4-4, and #4-5, the same amount of volume as the data flow#3-2 may be required at the worst. However, when we apply load balancing algorithms for distributing data into several different IDHs, the data flow bandwidth requirement is dependent on such a scheme.
- **Requirements**
    - We assume that the number of the regional edge clouds which converge into the CC (Central Cloud) is M.
    - Network bandwidth
        - For data flow#4-1, the network bandwidth requirement is estimated to be 3.6Gbits x N x M /second.
        - For data flow#4-2, the network bandwidth requirement is also estimated to be 3.6Gbits x N x M/second. However, as Storage Tier exists in the data flow#4-2, the other requirements such as redundancy may be considered. If it has to realize the redundancy of Storage Tier, the data flow#4-2 needs to be low-latency communication in addition to high-performance throughput for storage access.
        - For data flow#4-3 and #4-4, the network bandwidth requirement is estimated to be 60Gbits x N/second at the worst. However, since this usage is for preserving the video image data, the requirements for latency and throughput can be relaxed.
        - For data flow#4-5, the network bandwidth requirement is estimated to be 60Gbits x N x M/second at the worst. However, since this usage is for preserving the video image data, the requirements for latency and throughput can be relaxed.
    - High-performance storage access
        - For the storage access in the data flow#4-2 and #4-5, its throughput should be accelerated because generally, Storage Tier is assumed to be a possible bottleneck described in Section 5.2 of the IDH document [IOWNGF-IDH].
        - Backend connections between Data Service Tier and Storage Tier are expected to take place internally to the DCI Cluster. The reasons are that generally, the Data Service Tier may have to cache data of the Storage Tier and frequently write/update data that has already been stored in the Storage Tier. Further, critical messages such as for cluster heartbeat and transaction commit between these two Tiers have to be low latency [Exadata].
        - Additionally, inside the Storage Tier, new memory classes for storage, such as persistent memory, are placed in front of classical hard disk drives or flash-based drives to improve

the performance of databases and storage services. When the Storage Tier is accelerated with memory-based storage, the bottleneck point is moved to the network layer from the storage layer. Therefore, we should consider the data plane acceleration framework on Backend connections.

- From a Message Size perspective, when we look at database traffic types, these can be classified into two types of messages. One type is low latency and short-sized messages for control and management, such as cluster heartbeats or transaction commits. The other kind of message is a larger-sized message for backups and batch messages [Exadata]. Generally, control messages range from several kB to tens of kB [Exadata]**.** On the other hand, messages for large data should be configured to be more significant to avoid frequent ack-message exchanges.

- The communication range for each data flow is as follows:
  - The data flow#4-1 and #4-5 show long-range communication between different DCI clusters.
  - The data flow#4-2, #4-3, and #4-4 show the length between different DCI physical nodes.

### data flow#5

- **Analysis**
  - The Intelligence Application node analyzes the labeled data gathered in the Data Hub nearest to the CC. The labeled data include a considerable amount of data produced by M x N x 1000 cameras. They are propagated over the data flow#5 between the Data Hub and the Intelligence Application node.
- **Requirements**
  - The requirement of data flow#5 is almost the same as the data flow#4-1 or #4-2 especially in terms of network bandwidth.

### Common data flow features and requirements

- **Analysis**
  - In the CPS-AM use case scenario, the maximum turn-around time from the start of sensor data capture to the reception of the analysis results will be defined, e.g., 100 milliseconds ideally [IOWNGF-RIM]. This means that all of the data flows require a data plane that provides both high-bandwidth and low-latency. Furthermore, in some circumstances, data flow from the Local Aggregation node has to be duplicated to multiple destinations in the Ingestion node [IOWNGF-RIM].
- **Requirements**
  - Low-latency and low-energy consumption
    - When data is transferred between two functions or applications, a conventional network processing approach requires that the data to be transferred is copied multiple times between network and application layers. In terms of throughput and latency, this can lead to performance degradation and longer latency. Therefore, application memory areas should directly be transferred between functions or applications with low latency and high energy efficiency in a zero-copy manner [Balla2017], [Géhberger2018], [Lenkiewicz2018], [SIGCOMM2018].

## 7.1.3. Data plane types

Since how a data flow is implemented is dependent on data plane types, we define the three following data plane types written in Figure 7.1-3 :

- Intra-Node communication
    - Intra-Node communication is a data plane between components inside the same physical node. This communication is conducted over an internal bus such as the PCI Express (PCIe) bus, which is a popular choice for server systems.
    - This data plane between processes inside a physical node is standard practice.
    - It is assumed that the communication range is from a few to a few tens of centimeters.
- Inter-Node communication (Intra-Cluster communication)
    - Inter-Node communication is a data plane between physical nodes located in the same data central. Data is propagated via Network I/O such as network interface cards, which are installed inside physical nodes.
    - It is assumed that the communication range is from one to a few tens of meters.
- Inter-Cluster communication
    - Inter-Cluster communication is a data plane between different DCI Clusters, which are geographically located in other places. Data is also propagated via Network I/O such as network interface cards, which are installed inside physical nodes in the same manner as Inter-Node communication.
    - It is assumed that the communication range is from a few to hundreds of kilometers.

Among these three types of the data planes, there is a natural implementation candidate technology only for Intra-Node Communication, i.e., the PCI Express, the de-facto standard of the interconnect. In contrast, there are no such candidates for Inter-Node and Inter-Cluster communication.

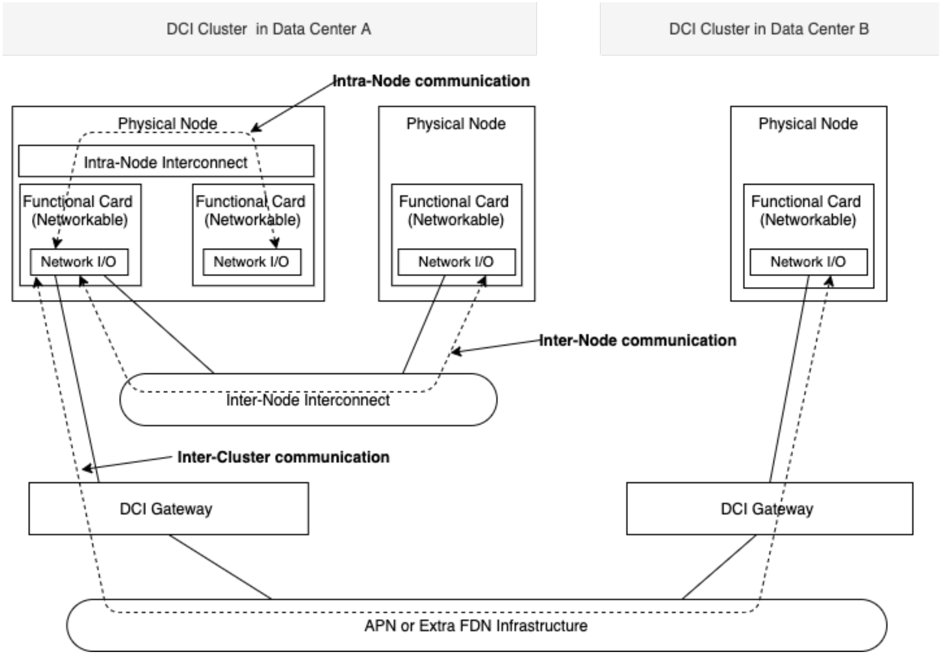
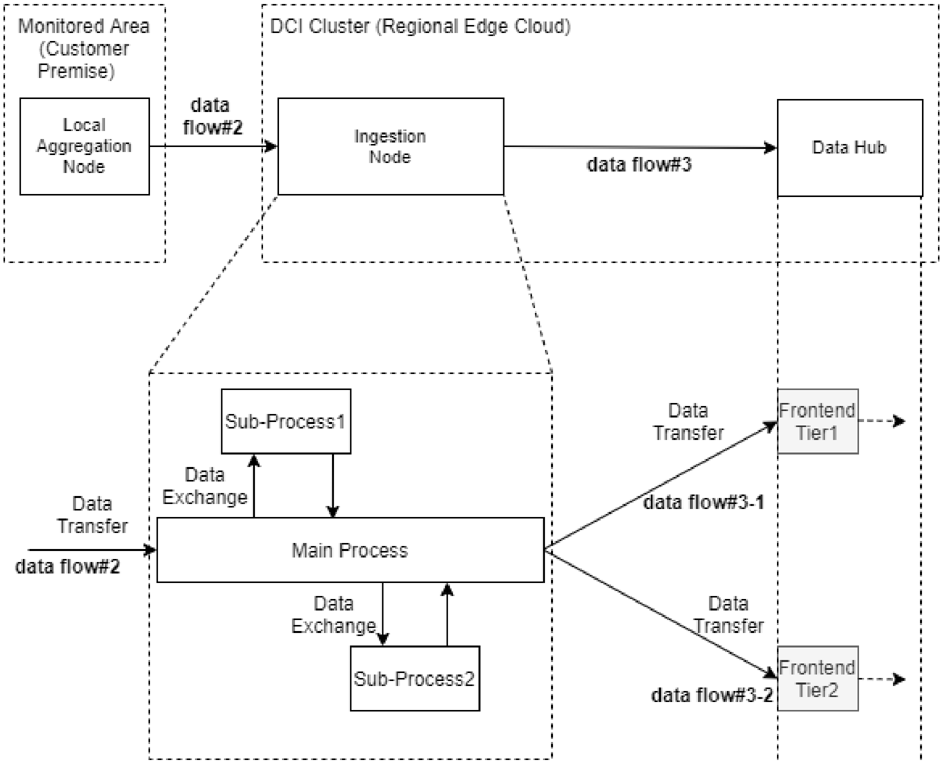



*Figure 7.1-3: Intra-Node Interconnect/Inter-Node Interconnect/Inter-Cluster Interconnect*

## Intra-Node communication




Data Transfer : uni-directional data flow from a Producer to a Consumer in the Data Pipeline
Data Exchange : bi-directional data flows between the Main Process and a Sub-Process within a single process stage in the Data Pipeline.

*Figure 7.1-4: typical data pipeline of CPS*

When we deeply analyze the data pipeline in Figure 7.1-1, we can illustrate data processing function and data flow depicted in Figure 7.1-4.

- **Main Process:** receives video image data from the camera, and then executes an inference process to detect objects via video image data after Sub-Process 1 and 2.
  - **Sub-Process 1:** Before executing the inference process, video images are decoded. The results are returned to the parent Main Process.
  - **Sub-Process 2:** Before the inference process, image resizing is executed after Sub-Process b1. The results are returned to the parent Main Process.
- **Frontend Tier1:** receives the inference results from the Main Process. This is related to the data flow#3-1 depicted in Figure 7.1-2.
- **Frontend Tier2:** receives the video image data from the Main Process for storing it. This is related to the data flow#3-2 depicted in Figure 7.1-2.

From these analyses described above, data flows can be classified into *Data Transfers and Data Exchanges*: In the case of a Data Exchange, the Main Process tends to communicate with Sub-Processes frequently with small amounts of data. Therefore, Data Exchange should be low-latency. Generally, it is implemented over Intra-Node communication. On the other hand, in the case of a Data Transfer, a single process often sends and/or receives significant amounts of bulk data.

### 7.1.4. Classification of data plane acceleration framework

Table 7.1-1: Class of data plane acceleration framework shows the classes for the data plane acceleration frameworks according to data plane types and data flow types. In the two classes of Intra-Node Data Transfer and Intra-Node Data Exchange, existing data plane frameworks such as DMA (Direct Memory Access) over PCIe or shared memory over PCIe are appropriate because PCIe is the most popular standard. The rest of the classes are discussed in the next section.

Section 7.2 describes the data plane acceleration framework focused on the data flow#2, #4-1 except for #4-2 which is related to storage access. On the other hand, Section 7.3 explains the data plane acceleration with storage access. A storage access part of this framework in Section 7.3 can be applied to the framework in Section 7.2.

*Table 7.1-1: Class of data plane acceleration framework*

| DATA PLANE TYPE | COMMUNICATION RANGE | DATA FLOW TYPES | CPS-AM DATA FLOW | FRAMEWORK |
|---|---|---|---|---|
| **Inter-Cluster** | a few to hundreds of kilometer | - | #2, #4-1, #4-5 | Section 7.2 |
| **Inter-Node** | one to a few tens of meter | - | #3-1, #3-2, #4-2, #4-3, #4-4 | Section 7.3 |
| **Intra-Node** | a few to a few tens of centimeter | Data Transfer | internal process communication | existing framework, such as DMA over PCIe<br><br>(Example of use case : common) |
| | | Data Exchange | internal process communication | existing framework, such as shared memory over PCIe<br><br>(Example of use case : common) |
| **Best Available Network** | - | - | #1 | existing framework based on TCP/IP |

## 7.2. Inter-Cluster Data Plane Acceleration Framework

### 7.2.1. Framework: RDMA over the Open APN

According to the above requirements, we propose to apply a remote direct memory access (RDMA) scheme even for long-range data flow over the All-Photonic Networks (APN) [IOWNGF-APN]. Because RDMA is generally implemented in hardware accelerated network interface cards (NIC), we expect that such NICs provide high-performance and low-latency communication by offloading kernel protocol processing and by reducing the number of memory copies (ideally in a zero-copy manner), resulting in lower CPU load. Furthermore we also expect that by providing RDMA-capable infrastructure as a default data transfer method all through end-to-end optical path in inter-node/inter-cluster communication, seamless integration of widely-distributed computing resources could be achieved without API translation between socket-based API and RDMA-based API.

## 7.2.2. Overview of end-to-end data plane architecture

RDMA endpoints connected by Inter-cluster interconnect over the Open APN, Extra network, and DCI are shown in Figure 7.2-1. The inter-cluster interconnect is between DCI-GW and ExtraNetwork gateway, built on top of the optical path set up by the Open APN in the diagram. The left side RDMA endpoints are inside the Extra Network in the chart, but also can exist inside the network under other DCI-GWs. Inside the ExtraNetwork and the DCI-GW, there would be communication channel provided by FlexBridge forwarding services, and such channels are chosen to be type D2 (bandwidth reserved) or D3 (bandwidth shared with congestion avoidance) depending on the use cases, referring to the Annex “IOWN Global Forum Flexible Bridge Services” [IOWNGF-APN].

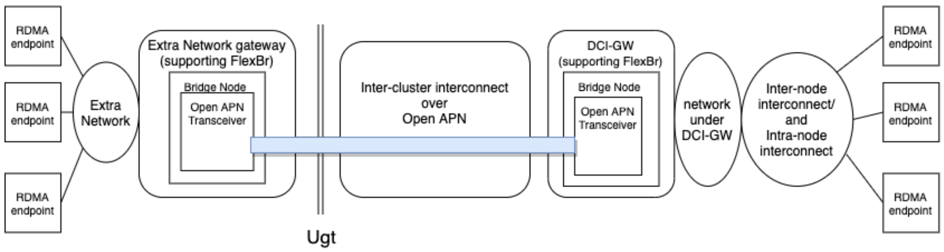



*Figure 7.2-1: Inter-cluster interconnect over the Open APN*

## 7.2.3. DPA network stack

DPA inter-cluster interconnect network stack is shown in Figure 7.2-2. The both sides inside ExtraNetwork and DCI-GW are similar, and under-layer protocols are chosen and provided by FlexBridge forwarding services. The diagram shows the RoCEv2 over Converged Enhanced Ethernet stacks to take advantage of existing stacks and existing products in the reference implementation model. Furthermore, a data flow is transferred via QoS-guaranteed layer-1 protocols with congestion-free and non-packet-multiplexed network as such Optical Transport Network (OTN) for example.

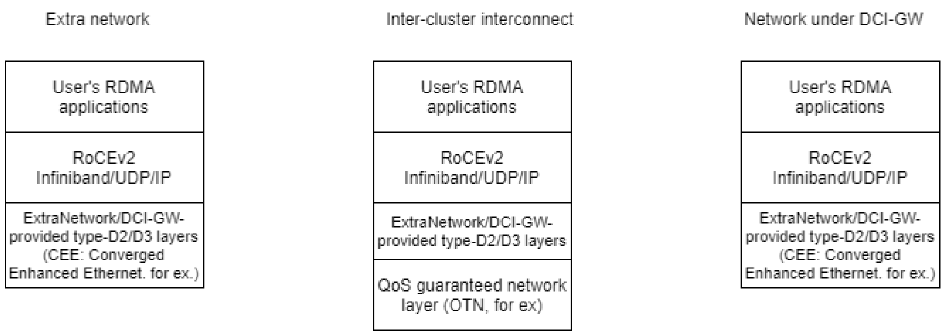



*Figure 7.2-2: Inter-cluster interconnect network stack*

## 7.2.4. Consideration

Providing RDMA functionality as an infrastructure requires consideration because RDMA is generally only applied to short-range communication, such as communication confined within a single data center. Achieving both long- and short-range RDMA transmission requires Open APN and FDN controllers to collaborate and negotiate their optimizing parameters to fulfill user’s requirements such as throughput, latency, jitter, loss rate, and so on.

### Throughput degradation: Queue Depth optimization

RDMA basic operations and the issue are described in Appendix when applying it to WAN. Ack-based ping-pong control in RDMA RC (Reliable Connection) protocols may cause performance degradation in a long-range communication.

Especially a Queue Depth parameter needs to be carefully configured. The required SQ depth can be derived using the following equation, which is the same root cause as the well-known long-fat-pipe network (LFN) problems.

(RTT * LineSpeed) / MessageSize = Required QueueDepth

Because the queue depth depends on implementing different RDMA NICs, we should carefully choose proper products with enough queue depth to support the maximum distance of optical path built by the Open APN.

### Efficient data transfer between RDMA NICs and FDN interface cards (HW Accelerators)

To take advantage of a zero-copy feature, RDMA NICs are better to support capabilities that enable direct data transfer between RDMA NICs and FDN interface cards in the same manner as GPU Direct [GPUD] and P2P DMA [PCI-P2P]. Or we can achieve such inter-device efficient data transfer via LSN's memories in the same manner as DMAbuf [KERNEL].

### Reliability: retransmission scheme

IOWN GF use cases require very reliable underlay networks. Even though we can expect the underlying optical path provided by the Open APN to be a high-quality path with an almost zero-packet-loss feature, to guarantee the data integrity between RDMA endpoints, it should support reliable behavior such as data retransmission as defined in RDMA reliable connection (RC) scheme.

The retransmission implemented in RDMA is usually an inefficient go-back-N scheme [GBN-Wiki]**, w**hich leads to performance degradation, especially in lossy long-distance networks. As a result, an Open APN controller should set up high-quality underlying optical networks to keep the number of retransmissions to a minimum and to have a flexible RDMA implementation capable of better retransmission algorithms.

### Controlling interfaces to communicate with the infrastructure orchestrator, an Open APN controller.

Collaboration with the Open APN: To optimize the queue depth described above, it is required to know the RTT between RDMA endpoints. Because the route distance of the optical path dynamically set up by the Open APN varies depending on the use cases and environment, collaboration interfaces to know the distance or RTT is required. And other than the number of RTTs, interfaces to know the characteristics of dynamically setup path includes ones for packet-loss rate, jitter, and so on. In addition, requesting interfaces for the Open APN's new optical path in a certain quality is required for the characteristics information acquisition.

### QoS mapping with cooperation to the control and management plane in DCI infrastructure

DCI infrastructure functions for control, management are defined in Section 6 of this document. To achieve QoS aware data pipelines for IOWN GF use case, network and computing resources have to be managed in DCI's control and management plane to avoid resource contention. When the service is deployed, the relevant data flow specs are declared to DCI's control and management plane. Once the network and computing resources required for each data flow are calculated for efficient resource allocation, the control and management plane should communicate with Inter-node interconnects and DCI-GWs over the data pipeline to reserve the necessary network and computing resources. At this time, the QoS of each data flow, e.g. D2, D3, is mapped to each resource of a network interface card, physical network wired-line, Inter-node interconnects, and DCI-GWs.

# 7.3. Inter-Node Data Plane Acceleration Framework

## 7.3.1. Framework: RDMA in DCI

New storage class memory such as persistent memory is being introduced into the Storage Tier to accelerate storage access. This new storage class itself is accessed directly using memory semantics; therefore, the underlay transport network should also provide the same semantics as the new storage class to access directly. Since RDMA scheme can give this feature to network, the underlay transport network should be applied by an RDMA scheme to increase the number of achievable IOPS without any translation such as data format.

## 7.3.2. Overview of end-to-end data plane architecture

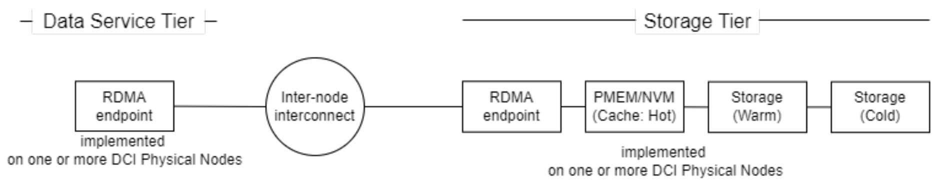



*Figure 7.3-1: Example of IDH Backend connection architecture over Inter-node communication*

From Inter-Node communication between Data Service Tier and Storage Tier, two RDMA endpoints read and send/write the data each other via Inter-node Interconnect defined in DCI architecture. In many cases, there are three storage tiers in the Storage Tier, Hot, Warm, and Cold storage depicted in Figure 7.3-1. The data which is accessed frequently is located in the Hot storage. Therefore, Hot storage is generally implemented in very low-latency and high-throughput storage stage. The new storage class memory is often placed in the Hot storage to act as a storage cache.

## 7.3.3. DPA network stack

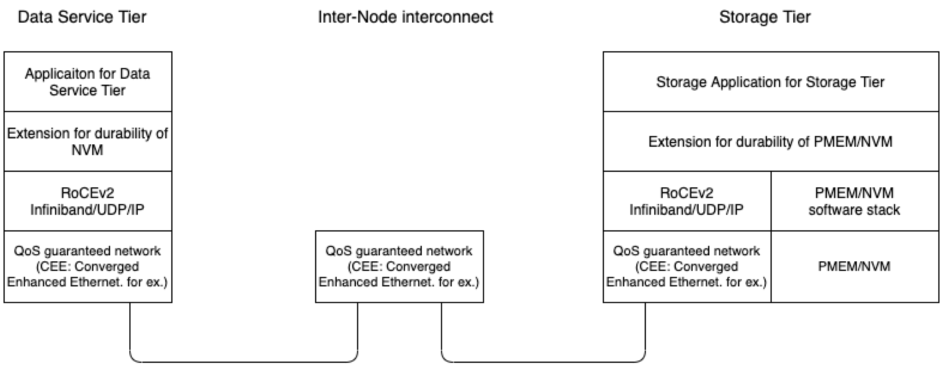



*Figure 7.3-2: DPA network stack for IDH Backend connection on Inter-node communication*

As mentioned before, the RDMA endpoint in the Data Service Tier is connected to that of the Storage Tier via Inter-node interconnect. Inter-Node communication between DCI Physical nodes is implemented in DCI Cluster. RoCEv2 is a possible candidate for the underlay transport network between RDMA endpoints via the Inter-node interconnect. As multi-tenancy feature is supported in DCI Cluster, such underlay transport network is shared with multiple-types of data flows. In this sense, the technologies defined in Converged Enhanced Ethernet (CEE) specification should be applied in the underlay transport network. Inter-node interconnect should be aware of the QoS of each data flow.

### 7.3.4. Consideration

#### Data durability

Conventional RDMA cannot support data durability that is important for storage application. Even if, with the RDMA method, a memory region is directly copied into a remote memory region, this doesn't lead to immediate data durability for persistent memory. A user for the RDMA method has to execute an additional action for guaranteeing remote data persistence. Therefore, extension for conventional RDMA stack is needed. For example, after RDMA write, confirmation of whether moved memory is persistent or not needs to be executed.

#### Queue Depth

This should be considered in the same manner as the framework of RDMA over the Open APN as described above.

#### Message Size

Based on requirements, the Message Size on the RDMA layer should be configured to be small or large: we can configure up to 1GB in the case of RDMA-RC. For failure detection message of Storage Tier, low-latency message transfer is a crucial feature. In this case, the RDMA message size should be small. However, when high-performance data throughput is needed, Message size should be configured higher to avoid protocol header overhead.

#### Lossless network

An internal data center network is an example of an Inter-Node interconnect network. In this case, multiple different data flows produced by multiple tenants are propagated in the same network, and they have other QoS classes. Congestion control mechanism should be applied to this kind of network, e.g., Converged Enhanced Ethernet. However, there is nothing for the most appropriate mechanism. Suitable congestion control mechanisms for this are dependent on the specification of the use case.

#### Network Interface cache influence

Some latest network interface cards and motherboards can support incoming packet data into directly CPU cache memory without storing main memory. These technologies can provide low-latency and high-performance data throughput. However, the new storage class memory, such as non-volatile memory, requires placing the data into memory, not cache. As soon as the RDMA endpoint of the Storage Tier receives the data from that of the Data Service Tier, it should be ensured that the data is written into the new storage-class memory.

#### QoS mapping with cooperation to the control and management plane in DCI infrastructure

This should be considered in the same manner as the framework of RDMA over the Open APN as described above.

# 8. Conclusion

In this technical report, we described the DCI system architecture and its functional components, along with the DCI service model, the system procedures, and the concept for data plane acceleration. The use cases of IOWN GF for mobile networks and cyber-physical systems are used as examples to illustrate the DCI deployment model. To understand why the data plane acceleration framework is essential for the IOWN GF use cases, the data pipeline derived by the use case's scenario of area management in the cyber-physical systems is analyzed.

DCI, Open APN, and FDN together form the communication and computing infrastructure of the IOWN GF System. The primary function of the DCI subsystem described in this report is to provide the IOWN GF infrastructure as a service: LSNs can be launched on DCI clusters on demand. This enables highly flexible, scalable, and efficient computing for the various use cases and deployment scenarios that the IOWN GF envisions. The framework of "RDMA over the Open APN" accelerates data transfer for the long-range data flow over the APN. On the other hand, the framework of "RDMA in DCI" provides high-performance data transfer in the DCI Cluster.

Moving forward, as IOWN GF continues to refine its services and requirements, more details on the DCI are to be defined. IOWN GF DCI work will co-develop with other IOWN GF working areas to refine the DCI architecture and enable additional features and services.

# Abbreviations and acronyms

For the purposes of this Reference Document, the following abbreviations and acronyms apply:

| ABBREVIATION | DESCRIPTION |
|---|---|
| AI | Artificial Intelligence |
| AIC | AI-Integrated Communication |
| AM | Area Management |
| API | Application Programming Interface |
| APN | All-Photonic Network |
| CC | Central Cloud |
| CEE | Converged Enhanced Ethernet |
| CNF | Cloud-native Network Function |
| CPS | Cyber-Physical System |
| CPS-AM | CPS Area Management |
| CPU | Central Processing Unit |
| CRUD | Create, Read, Update, and Delete |
| CU | Central Unit |
| CXL | Compute Express Link |
| DCI | Data-Centric Infrastructure |
| DCIOC | DCI Object Composite |
| DCI-GW | Data-Centric Infrastructure - Gateway |
| DPA | Data Plane Acceleration |
| DPU | Data Processing Unit |
| DU | Distributed Unit |
| EVC | Ethernet Virtual Connection |
| FDC | Function-Dedicated Computing |
| FDN | Function-Dedicated Network |
| FPGA | Field Programmable Gate Array |
| GF | Global Forum |
| GPU | Graphics Processing Unit |
| IaaS | Infrastructure-as-a-Service |
| IDH | IOWN Data Hub |

| | |
|---|---|
| **IN** | Ingestion |
| **IOWN** | Innovative Optical and Wireless Network |
| **IP** | Internet Protocol |
| **IPU** | Infrastructure Processing Unit |
| **I/O** | Input/Output |
| **LA** | Local Aggregation |
| **LAN** | Local Area Network |
| **LSN** | Logical Service Node |
| **MNO** | Mobile Network Operator |
| **MPLS** | Multi-Protocol Label Switching |
| **NIC** | Network Interface Card |
| **PCIe** | Peripheral Component Interconnect Express |
| **QoS** | Quality of Service |
| **RAN** | Radio Access Network |
| **RDMA** | Remote Direct Memory Access |
| **RIM** | Reference Implementation Model |
| **RoCEv2** | RDMA over Converged Ethernet version 2 |
| **RTT** | Round Trip Time |
| **RU** | Radio Unit |
| **SDI** | Serial Digital Interface |
| **SDK** | Software Development Kit |
| **SMO** | Service Management and Orchestration |
| **SQ** | Send Queue |
| **TSN** | Time-Sensitive Networking |
| **VNF** | Virtualized Network Function |
| **VPU** | Vector Processing Unit |
| **vRAN** | Virtual Radio Access Network |
| **WAN** | Wide Area Network |
| **WI** | Work Item |
| **ZTP** | Zero-Touch Provisioning |

# References


| REFERENCE | DESCRIPTION |
|---|---|
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| | |
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| **[KERNEL]** | “Buffer Sharing and Synchronization,” The Linux Kernel documentation, https://www.kernel.org/doc/html/latest/driver-api/dma-buf.html |
| **[GBN-Wiki]** | “Go-Back-N ARQ,” Wikipedia, https://en.wikipedia.org/wiki/Go-Back-N_ARQ |


 

# Appendix A: RDMA operation and performance considerations

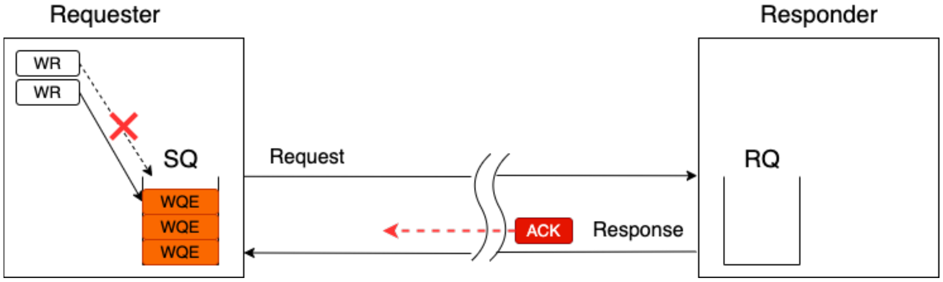


*Figure A-1: Queue Pair operation for basic RDMA scheme*

RDMA operation is managed by using Work Queue Entry (WQE), which includes information of memory address and data length to be sent to the RDMA memory region of the transfer destination host. RDMA provides several types of communication models, e.g., reliable connection (RC), unreliable datagram (UD), etc.

In the reliable connection mode, RDMA protocols implement retransmission and flow control mechanisms to guarantee loss-less communication. Loss-less communication is typically implemented by a ping-pong acknowledgement messages-based control protocol, similar to the TCP protocol. To clarify why performance optimization is required, the overall data transmission behavior of the RDMA Reliable Connection mode is illustrated in Figure A-1 and is described below;

- First, at the sender side (requester), a WQE is enqueued into the Send Queue (SQ) implemented within the hardware of an RDMA NIC. This enqueue operation triggers and therefore starts the data transmission from the requester to the responder.
- After that, at the receiver side (responder), right after the completion of data reception, an acknowledgement (ACK) message is sent back to the sender side to notify the completion of data reception.
- Finally, at the sender side (requester), receiving the ACK triggers to complete the already sent data by dequeuing the WQE from the SQ.

Therefore, considering the above, when using the RDMA Reliable Connection mode in a WAN environment, longer RTT will lead to long delays until ACK messages are received at the sender (requester) side. In turn, this reception delay results in long delays until WQEs that are enqueued in the SQ can be dequeued. The SQ size and the number of WQEs that can be stored within is limited: therefore, if SQ is full with remaining WQEs, it can no longer enqueue new WQEs until more ACK messages are received. To summarize, this effect impacts data transmission throughput for high data rates under long link transmission delays.

The RDMA unreliable datagram (UD) mode does not have such an ACK-based mechanism and just sends and receives data without acknowledgment in the same manner as the UDP protocol. Therefore, the RDMA UD mode does not suffer performance penalties over links with high transmission delay in the same way as described above; however, the use-case for the RDMA unreliable datagram mode is very limited.

 

# History

| Revision | Release Date | Summary of Changes |
|---|---|---|
| 1.0 | January 27, 2022 | Initial Release |