Framework and Elements for Edge/Fog Manageability and Orchestration

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1.   Architecture and Framework for Edge/Fog Manageability and Orchestration[2]

The technology of edge computing has evolved considerably in recent years with the support of emerging key enablers like Network Function Virtualization (NFV) and Software Defined Network (SDN). NFV and SDN can be used to consolidate and deliver the networking components needed to support a fully virtualized infrastructure, such as virtual servers, storage units, and even other networks. They are applicable to any data plane processing or control plane function in both wired and wireless network infrastructures.

Also, as a maturing solution for emerging applications and scenarios, many different variants of Edge/Fog systems have been created to handle various use cases and different deployment conditions. The most famous examples include the next generation mobile network, smart factory, and Industrial Internet of Things (IIoT). Even though the designs adapted to local conditions can result in a powerful standalone product, such a large number of variants may damage the connectivity and increase communication costs between systems. In this context, the need to standardize the relevant system architecture and operational processes become evident, and IEEE P1935 standard for Edge/Fog manageability and orchestration is created in response to it.

As a standard for management and orchestration of Edge/Fog systems, IEEE P1935 covers the system architecture, resource management, application lifecycle operations, and communication specification between multiple Edge/Fog systems. The unified management and orchestration, such as the regulation of the transmissions of messages, the controlling and allocation of the resources of the edge devices, and the monitoring and arrangement in the mobile application lifecycle, can satisfy the mentioned needs and ensure better availability, flexibility, reliability, scalability, stability, service mobility, and performance. It means that the system shall be easy for multiple types of users to operate and configure, be hard to down while facing different challenges, and be as efficient as possible.

In the Edge/Fog system described in the P1935 standard document, there are three levels - Orchestrator Level, Controller Level, and Computer Level - responsible for different functionality and various entities in each level. This document describes the overall Edge/Fog architecture and the responsibility of each entity and component, as well as the interfaces between each entity. The Orchestrator Level includes the Edge/Fog Orchestrator (EFO) as the main management and orchestration entity, and it is responsible for interacting with "users", that is, End Users, Edge Service Providers, and Edge Service Operators. The Controller Level may include one or more Edge/Fog control nodes, which oversee the Edge/Fog compute nodes and manage the related resources. The Edge Platform Manager and the (Virtualization) Infrastructure Manager are at this level. The Computer Level may include one or more Edge/Fog compute nodes as well, which is (are) responsible for the practical computing tasks. The Edge Platform, the Edge Application, and the (Virtual) Network Infrastructure are at this level. All these entities and components will be described in detail in the text.

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[2] This document was submitted as technical contribution to IEEE P1935 working group in 2021. Part of the technical contents have been included in the IEEE P1935 standard.

1.1   Edge/Fog Manageability and Orchestration Framework Overview

Figure 1 is the basic architecture of the Edge/Fog system framework. The term "framework" here refers to the full architecture of the system and the components and entities in it. The entities refer to the elements, either inside the system or outside the system (e.g. some 3rd party software), and may be composed of one or more components. The system can be classified into three levels: Orchestrator Level, Controller Level, and Computer Level, and the more detailed information of the components introduced here can be found in 1.2. The Orchestrator Level includes the Edge/Fog Orchestrator (EFO) as the main management and orchestration entity, and it is responsible for interacting with "users", that is, End Users, Edge Service Providers, and Edge Service Operators. The End Users can call all the users accessing the system via the End User App, which is another entity in the Edge/Fog system. The Edge Service Providers are the designers and onboarders of Edge Applications. The Edge Service Operators provide the Edge/Fog system functionalities and infrastructures and are responsible for managing and operating these applications properly. The Controller Level may include one or more Edge/Fog control nodes, which oversee the Edge/Fog compute nodes and manage the related resources. The Edge Platform Manager and the (Virtualization) Infrastructure Manager are at this level. The Computer Level may include one or more Edge/Fog compute nodes as well, which is (are) responsible for the practical computing tasks. The Edge Platform, the Edge Application, and the (Virtual) Network Infrastructure are at this level. The Edge/Fog compute nodes, as the most common and the most widely distributed entity in the system, can also be called "Edge nodes" as an abbreviation.[3] All these entities and components will be described in detail in the following clauses.

Table 1 gives some brief descriptions and the related clause to each entity mentioned in Figure 1, as well as the terms used in the document.

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[3] For ease of reading and description, we abbreviate the term "Edge/Fog" to "Edge" in the remaining sections of this standard. These terms refer to the completely same things. For example, an Edge/Fog control node can also be written as an Edge control node.
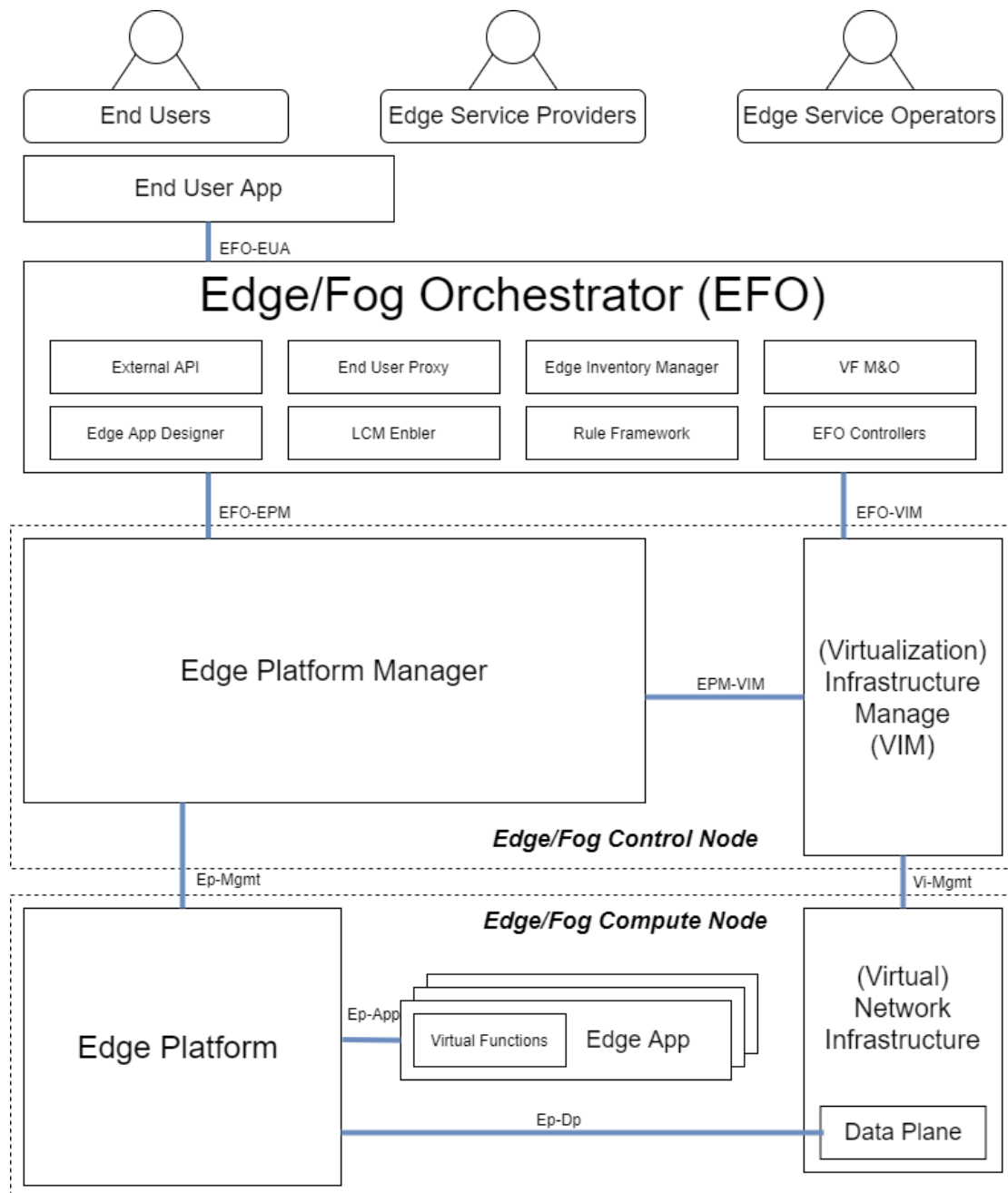
Figure 1—The basic architecture of the Edge/Fog system framework

Table 1—The brief description of the entities in the Figure 1 and Clause 1

Entity	Brief Description	Clause
(Virtual) Network Infrastructure	The virtualized and non-virtualized resources which enable network operations. Usually abbreviated as VNI.	1.4
(Virtualization) Infrastructure Manager	An entity managing the infrastructure resources named Virtual Network Infrastructure, which can be virtualized or non-virtualized.	1.3
Application Management Element	The entity managing and coordinating the operation of Edge Applications, such as Edge Platform.	1.3
Compute node	Compute node is one entity in the Computer Level that is able to handle the computing tasks on its own.	1.1
Computer Level	Computer Level is the bottom layer of the Edge system which is composed of one or more compute nodes, dealing with the computing tasks.	1.1
Control Level	Control Level is the middle layer of the Edge system which is composed of one or more control nodes, responsible for management and coordination of Computer Level.	1.1
Control node	Control node is one entity in the Control Level for management of the related compute nodes.	1.1
Data Plane	The functional entity that handles the traffic routes.	1.4
Edge App	The applications running on Edge system.	1.4
Edge App Designer	A component in the EFO handling the application design and onboarding.	1.2.1
Edge Inventory Manager	A component in the EFO for the management of the inventory in the Edge system.	1.2.1
Edge Platform	A platform which handles purposed computing tasks.	1.4
Edge Platform Manager	An entity managing the Edge Platform.	1.3
Edge Service Operator	The service operator dealing with the management and operation of Edge Applications.	1.1
Edge Service Provider	The designer and onboarder of Edge Applications.	1.1
Edge/Fog Orchestrator	An orchestrator of the whole Edge system. It can be abbreviated as Edge Orchestrator or just EFO.	1.2.1
EFO Controllers	The components in the EFO responsible for coordinating and configuration of virtual network functions (VNFs) and related resources.	1.2.1
End User App	An interface for all end users.	1.5
End User Proxy	A component in the EFO as an interface between the EFO and the End User App.	1.2.1
End Users	The users accessing the system via the End User Apps.	1.5
End Users	All users that access the EFO via the End User Apps.	1.1
External API	External API in the EFO is provided for the Edge Service Operators or other entities to access the functionalities of the EFO.	1.2.1
Inventory	Inventory are the network information, topology, and metadata that are about the Edge system environment and are stored in the Edge Inventory Manager component.	1.2.1
Lifecycle Manager Enabler (LCM Enabler)	A component in the EFO which is responsible for the management of the application lifecycle.	1.2.1
Orchestrator Level	The top layer of the Edge system for management and orchestration of the whole system, including Controller Level and Computer Level.	1.1
Resource Management Element	The entity managing the resources in the Edge system, such as IM/VIM.	1.3
Rule Framework	A component in the EFO dealing with all conditions, requirements, and reaction policies.	1.2.1

Virtual Function Management and Orchestration	A component in the EFO responsible for the start-up and operation of the application.	1.2.1

1.2 Edge Orchestrator Level Entities

The Edge/Fog orchestrator level can also be abbreviated as the Edge orchestrator level. The entities and components in this level are responsible for the management and control of the whole Edge system, in order to orchestrate and automate the network service running on the Edge system. The Edge Orchestrator (EFO) is the core functionality in orchestrator level management. There are multiple ways to access the EFO described in the following subclause in detail.

1.2.1 Edge Orchestrator

The Edge/Fog Orchestrator is designed to provide real-time and rule-driven service orchestration and automation, including the start-up and configuration of virtual/physical network functions. The Edge/Fog Orchestrator allows various providers and developers involved in the different fields such as network, software, and cloud service, to rapidly automate new service, and support complete lifecycle management. With a common architecture as the base, the platform will help promote the development of the service.

The Edge and Fog Orchestrator can be generally divided into three sections, the design time framework, the runtime framework and the user interface. Each section contains one or more components, which take different responsibilities.

- The design time framework will be a comprehensive development environment with related tools, techniques and repositories for defining and describing resources, services, and products.
- The Edge App Designer component in the platform will provide the functionality mentioned above to define/simulate/certify system assets as well as their associated processes and policies.
- Lifecycle Management Enabler (LCM Enabler) component, is responsible for designing and managing the application lifecycle.

The run time framework executes the rules and policies distributed by the design and creation environment, the Edge App Designer component in this case, and controllers which manage resources corresponding to their assigned controlled domain.

- Virtual Function Management and Orchestration (VF M&O) component will follow the BPMN (Business Process Model and Notation) flows which operate on the models distributed from Edge App Designer. VF M&O will use the models which describe the services and associated VNFs and other resources to automate the sequences of associated components needed for on-demand creation, modification or removal of network, application, or infrastructure services and resources. VF M&O is able to drive any cloud platform.
- Rule framework is responsible for dealing with all conditions, requirements, constraints, attributes, and needs that must be provided, maintained, and/or enforced.
- Edge Inventory Manager (EIM) component provides real-time view of a system's various inventory, including resources, services, products and their relationships with each other.
- End User Proxy (EUP) is responsible for interacting with end user applications. It receives requests from the end user applications. The EUP allows end user applications to request on-boarding, instantiation, termination of Edge application. The EUP authorizes requests from end user applications and CSP and interacts with the other components in the EFO for further processing.
- The EFO Controllers are responsible for network configuration for cloud computing resources and network, VNF configurations and lifecycle management operations, and the lifecycle management of VNFs and network services based on VNF using VNF Manager.

Finally, the user interface is for various platform users to design, operate and manage the services and applications on the platform. The platform users have different access and allowed operations according

to their assigned roles. Additionally, external API are also provided for the access to core network and from external user applications in order to execute specific operations and access the functionalities of the EFO.

1.3   Edge Controller Level Entities

These entities located in Edge/Fog controller level are responsible for the management and orchestration of the Edge compute nodes. The entities can be generally divided into two classes according to their management targets: Resource Management Elements (RME) and Application Management Element (AME). The function and responsibility of each class of entities is described in the following sub-sections.

1.3.1   Resource Management Elements

Resource management elements focus on management and storage of network infrastructure. They are able to control and schedule the usage of the resources in the Edge/Fog system.

The (Virtualization) Infrastructure Manager (VIM) is responsible for managing both the virtualized infrastructure and the non-virtualized infrastructure as well as its virtualized and non-virtualized resources, including resource allocation, infrastructure preparation, and system information report.

1.3.2   Application Management Elements

Application management elements focus on lifecycle management of the Edge Platform and the edge applications running on the platform.

The Edge Platform Manager manages the rules, requirements and lifecycle of applications, and provides element management functions to the Edge platform. The Edge platform manager receives virtualized resource fault reports and performance measurements from the VIM for further processing.

Edge Platform Manager also includes the functional blocks that are responsible for the management of the Edge platform and the Edge applications with standard LCM procedures. Edge application instances are considered as VNF instances. It is possible to deploy more than one Edge Application LCM instance.

1.4   Edge Computer Level Entities

The Edge/Fog computer entities are the functional elements that are involved in the computing tasks in an Edge host. includes the Edge platform and a virtualization infrastructure which provides compute, storage, and network resources for the Edge applications.

The Edge platform is responsible for the Edge functions which are necessary to run Edge applications. It serves as a platform where Edge applications are able to provide, discover, and consume certain mobile edge services. The Edge platform also instructs data plane and configures DNS proxy/server according to the traffic rules prescribed by the Edge platform manager.

Edge applications are executed as virtual machines on top of the virtualization infrastructure provided by the Edge host, and can interact with the Edge platform to consume and provide Edge services. An Edge Application is composed of single or multiple virtual function(s), which can be managed and orchestrated by the VF M&O component in EFO. It is possible either for an Edge App to provide several services, or for multiple Edge Apps to provide a single service.

The data plane in the Edge host is responsible for dealing with the traffic rules, including routing the traffic among entities, as well as task offloading and installation of applications from IM/VIM.

The (Virtual) Network Infrastructure (VNI) is the totality of all hardware and software that build up the entire environment where VNFs are deployed. The virtualization infrastructure is deployed as a VNI and is managed by an IM/VIM.

1.5   External Entities

This section describes the elements which connect the external environment. Explanations of how the Edge/Fog architecture communicates with other existing standards are presented.

End user applications are able to interact with the End User App LCM component in EFO in Orchestrator level via the standard API. The users, including end users, edge service operators, and edge service providers, can access the EFO services through the end user application.

1.6   Interfaces

This section lists and describes the interfaces and the reference points between entities inside and outside of Edge/Fog system. The interfaces can be classified based on the highest level of the connected entities. That is, an interface between Orchestrator Level and Control Level is classified as the Orchestrator Interfaces.

1.6.1   Orchestrator Interfaces

- The "EFO-EPM" reference point between the EFO and the Edge platform manager is used for the application management, including application lifecycle, rules and requirements, checking Edge service availability, and exchanging related notification between following entities.

- The "EFO-VIM" reference point between the EFO and the VIM is used for management of the virtualized and non-virtualized resources in the Edge system.

1.6.2   Controller Interfaces

- The "Ep-Mgmt" reference point between the Edge platform manager and the Edge platform is used for the configuration of Edge platform, including the rules, requirements and lifecycle support of applications.

- The "Vi-Mgmt" reference point between the VIM and the VNI is used for the management and coordination of the VNI and the data plane in the Edge/Fog system.

- The "EPM-VIM" reference point between the Edge platform manager and the VIM is responsible for the communication between these two entities.

1.6.3   Computer Interfaces

- The "Ep-App" reference point between the Edge platform and the Edge applications provides the registration, discovery and communication support of services.

- The "Ep-Dp" reference point between the Edge platform and the data plane of the (virtual) network infrastructure is used to set the data plane on how to route traffic among applications, network, service, etc.

1.7   Summary

The booming technology of edge computing can be used to solve many existing and emerging application problems. Numerous researches and use cases are proposed to demonstrate the feasibility. At the same time, however, most technology developers are developing their own scenario-specific systems, which can lead to serious efficiency problems of collaboration and communication. Therefore, there is a need to unify the architectural design of Edge/Fog systems and their communication processes.

This document depicts the architecture and framework of an Edge/Fog computing system specified by IEEE P1935 standard, including the entities, components, and interfaces. The Orchestrator Level includes the Edge/Fog Orchestrator (EFO) as the main management and orchestration entity, and it is responsible for interacting with the users. The Controller Level may include one or more Edge/Fog control nodes, which oversee the Edge/Fog compute nodes and manage the related resources. The

Computer Level may include one or more Edge/Fog compute nodes as well, which is (are) responsible for the practical computing tasks. Such the three-level design clarifies the responsibility of each entity and interface, ensuring the connectivity, communication, security, and operability. There is also a tablet placed at the beginning of the document which can be used to look up certain terms, and the detailed functionalities and responsibilities can be found in corresponding subclauses.

Thanks to the clearly-illustrated concept diagram, this document can help practitioners start relevant fieldwork and research investigations in a simpler approach. The unified specification introduced in the document should help the regulation and integration of Edge/Fog systems and further improve the development of the relevant industries.