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SERIES Y: GLOBAL INFORMATION INFRASTRUCTURE, INTERNET PROTOCOL ASPECTS, NEXT-GENERATION NETWORKS, INTERNET OF THINGS AND SMART CITIES

Future networks

Functional architecture of software-defined networking

Recommendation ITU-T Y.3302

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Recommendation ITU-T Y.3302

Functional architecture of software-defined networking

Summary

Recommendation ITU-T Y.3302 provides the functional architecture of software-defined networking (SDN) with descriptions of functional components and reference points. The described functional architecture is intended to be used as an enabler for further studies on other aspects such as protocols and security as well as being used to customize SDN in support of appropriate use cases (e.g., cloud computing, mobile networks).

This Recommendation is based on ITU-T Y.3300 and ITU-T Y.3301. Recommendation ITU-T Y.3300 describes the framework of SDN including definitions, objectives, high-level capabilities, requirements and the high-level architecture of SDN; Recommendation ITU-T Y.3301 describes more detailed requirements.

History

Edition	Recommendation	Approval	Study Group	Unique ID*
1.0	ITU-T Y.3302	2017-01-12	13	11.1002/1000/13017

Keywords

Abstraction, functional component, multi-layer management, orchestration, programmability, software-defined networking.

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As of the date of approval of this Recommendation, ITU had received notice of intellectual property, protected by patents, which may be required to implement this Recommendation. However, implementers are cautioned that this may not represent the latest information and are therefore strongly urged to consult the TSB patent database at http://www.itu.int/ITU-T/ipr/.

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1 Scope

This Recommendation defines the functional architecture of software-defined networking (SDN) by describing a layered architecture, the functional components of the architecture and its reference points. Details of multi-layer management are provided in Annex A and the role of orchestration is addressed in Appendix I. The architecture is based on [ITU-T Y.3300] which defines the SDN framework and [ITU-T Y.3301] which describes the functional requirements of the SDN architecture which the present Recommendation has to fulfil.

2 References

The following ITU-T Recommendations and other references contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published. The reference to a document within this Recommendation does not give it, as a stand-alone document, the status of a Recommendation.

[ITU-T M.3400] Recommendation ITU-T M.3400 (2000), *TMN management functions*.

[ITU-T Y.3001] Recommendation ITU-T Y.3001 (2011), *Future networks: Objectives and design goals*.

[ITU-T Y.3300] Recommendation ITU-T Y.3300 (2014), *Framework of software-defined networking*.

[ITU-T Y.3301] Recommendation ITU-T Y.3301 (2016), *Functional requirements of software-defined networking*.

[ITU-T Y.3320] Recommendation ITU-T Y.3320 (2014), *Requirements for applying formal methods to software-defined networking*.

3 Definitions

3.1 Terms defined elsewhere

This Recommendation uses the following terms defined elsewhere:

3.1.1 functional component [b-ITU-T Y.3502]: A functional building block needed to engage in an activity, backed by an implementation.

3.1.2 network virtualization [b-ITU-T Y.3011]: A technology that enables the creation of logically isolated network partitions over shared physical networks so that heterogeneous collection of multiple virtual networks can simultaneously coexist over the shared networks. This includes the aggregation of multiple resources in a provider and appearing as a single resource.

3.1.3 software-defined networking [ITU-T Y.3300]: A set of techniques that enables to directly program, orchestrate, control and manage network resources, which facilitates the design, delivery and operation of network services in a dynamic and scalable manner.

3.2 Terms defined in this Recommendation

This Recommendation defines the following term:

3.2.1 SDN orchestration: A process that oversees and directs a set of software-defined networking activities and interactions with the objective of carrying out certain work in an automated manner.

NOTE – In SDN, orchestration can be used to arrange, configure and coordinate a set of operations in multi-domain, multi-layer or end-to-end heterogeneous networking environments in order to execute a specific task.

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

ACI	Application Control Interface
AL	Application Layer
ALM	Application Layer Management
AL-MSO	Application Layer Management Support and Orchestration
BSS	Business Support System
CL	Control Layer
CL-AS	Control Layer Application Support
CL-MSO	Control Layer Management Support and Orchestration
CL-RA	Control Layer Resource Abstraction
CLM	Control Layer Management
DevOps	Development Operations
ERM	External Relationship Management
FCAPS	Fault, Configuration, Accounting, Performance and Security
KPI	Key Performance Indicator
MMF	Multi-layer Management Functions
MMFA	Multi-layer Management Functions Application layer
MMFC	Multi-layer Management Functions Control layer
MMFO	Multi-layer Management Functions OSS/BSS
MMFR	Multi-layer Management Functions Resource layer
MMO	Multi-Layer Management Orchestration
OSS	Operations Support System
RCI	Resource Control Interfaces
RL	Resource Layer
RL-CS	Resource Layer Control Support
RL-DP	Resource Layer Data Processing
RL-DT	Resource Layer Data Transport
RL-MS	Resource Layer Management Support
RLM	Resource Layer Management
SDN	Software-Defined Networking
SDN-AL	SDN Application Layer
SDN-CL	SDN Control Layer
SDN-RL	SDN Resource Layer

5 Conventions

None.

6 Introduction

As described in [ITU-T Y.3300], key properties of SDN include:

1) logically centralized network control which allows for controlling and managing network resources by software;
2) support for network virtualization, and;
3) network customization, for efficient and effective network deployments and operations.

Requirements for SDN [ITU-T Y.3300] include:

1) separation of SDN control from network resources;
2) programmability of network resources;
3) abstraction of network resources, by means of standard information and data models, and;
4) support for orchestration of network resources and SDN applications.

More detailed requirements are provided in [ITU-T Y.3301].

This Recommendation provides a description of the SDN functional architecture with the aim of ensuring that the key properties and requirements of SDN are appropriately supported. The SDN functional architecture is based on the layering framework derived from clause 11 of [ITU-T Y.3300] and shown in Figure 6-1.

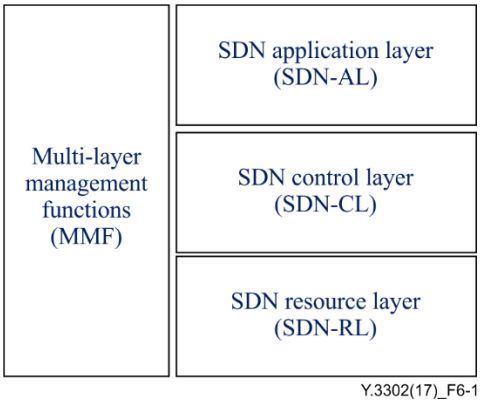

Figure 6-1 – SDN layering framework

Considering other efforts to design an SDN architecture [b-ONF-arch 1.0], [b-ONF-arch 1.1], [b-IETF RFC 7426], the SDN architecture described in this Recommendation takes into account factors that are important in large-scale public networks:

– Orchestration-based run-time lifecycle management of software-based SDN functions.

  Since public networks are becoming even more complex due to the emerging technologies, services and companion usage behaviors as well as the integration of fixed and mobile networks, SDN technologies need to contribute to the orchestration of operations and the resulting lifecycle management of network functions. SDN orchestration in this Recommendation is used to automate a set of operations;

  NOTE – The background, design principle and role of SDN orchestration is described in more details in Appendix I.

– Interaction with operators' legacy operations support system (OSS)/business support system (BSS).

The SDN architecture is designed to be capable to interact with the existing OSS/BSS;

– Scalability.

In order to cope with appropriate control and application layers (ALs) performance in SDN networks potentially involving a huge number of customers, providing various types of services and covering vast geographical areas, the SDN architecture provides independent control and management capabilities, which enables performance monitoring of available resources in all layers, and enables dynamic adaptation of resources, e.g., scaling up and scaling down. The SDN architecture also allows for implementation of functions in a distributed manner, and enables distribution of fault, configuration, accounting, performance and security (FCAPS) management in each of the SDN layers;

– Reliability.

The possibility of decomposition of the SDN architecture and their functionalities enabled by this Recommendation, with the important role of management, contribute to the increased overall SDN reliability. Some reliability-related mechanisms are implementation dependent;

– Covering multiple resource layer (RL) technologies.

The SDN architecture is designed to cover multiple resource layer technologies including basic data forwarding and more complex data processing, which makes it easier for future expansion towards software-defined infrastructure;

– Efficiency of resource usage.

The decomposition of the control and management architectures and their functionalities contributes to overall efficiency of SDN resource usage. It is realized by monitoring and analytics of all layers' resource usage together with dynamic resource provisioning in order to reach the required system performance but at the same time to maintain optimal resource usage, taking into account energy consumption reduction.

7 Functional architecture

Figure 7-1 presents an overview of the SDN functional architecture organized by means of the SDN layering framework shown in Figure 6-1.

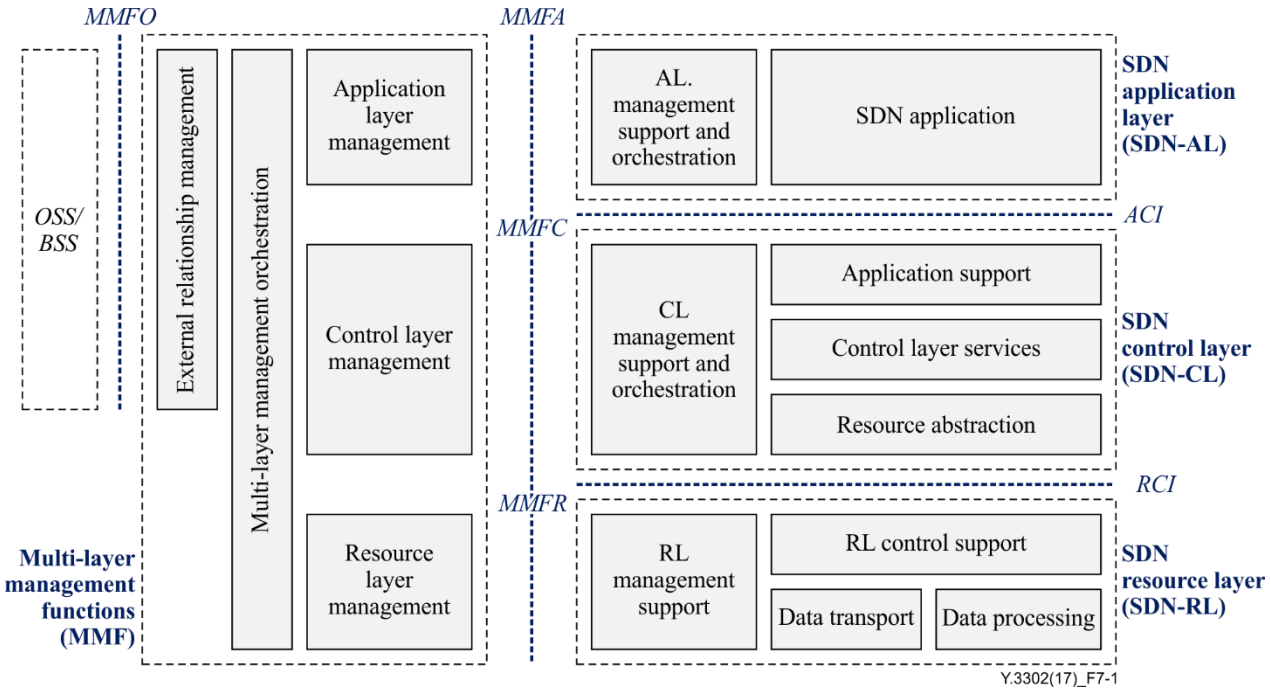

Figure 7-1 – SDN functional architecture

The functionalities that reside at the SDN application layer (SDN-AL), the SDN control layer (SDN-CL), the SDN resource layer (SDN-RL) and the multi-layer management functions (MMF) are described in subsequent clauses.

7.1 SDN application layer

The SDN-AL enables a service-aware behaviour of the underlying network in a programmatic manner. It is composed of the application layer management support and orchestration (AL-MSO) functional component and multiple SDN application functional components (see Figure 7-2).

The SDN-AL interacts with the SDN-CL via the application control interface (ACI) reference point, and interacts with the MMF via the MMF application layer (MMFA) reference point.

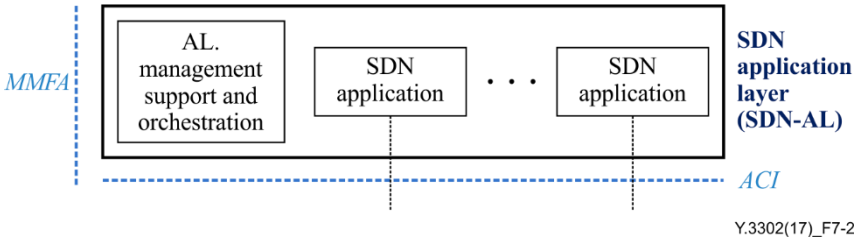

Figure 7-2 – SDN-AL functional components

7.1.1 SDN application functional component

SDN application functional components interact with the SDN-CL via the ACI reference point, in order for the SDN-CL to automatically customize the behaviour and the properties of network resources. An SDN application functional component uses the abstracted view and status of the network provided by the SDN-CL by means of information and data models exposed through the ACI reference point. Depending on the SDN use cases (e.g., intra- or inter-data centres, mobile networks, access networks), interfaces exposed by the SDN-CL at the ACI reference point can differ in nature.

NOTE – This Recommendation also uses the term "SDN application", an application that controls and manages network resources (e.g., for application specific routing purposes) by using capabilities provided through the ACI reference point. An SDN application functional component as described in this clause consists of the necessary software required to implement an SDN application.

7.1.2 AL management support and orchestration functional component

The AL-MSO functional component orchestrates SDN applications (including applications composed of multiple applications) with the support of MMF. The AL-MSO functional component may involve the SDN-CL and/or MMF orchestration for the deployment of appropriate SDN-CL and MMF functional components respectively.

The AL-MSO functional component includes the following:

– SDN applications code repository management;

– SDN applications' lifecycle management (creation, modification, and deletion);

– performance monitoring of SDN applications to meet SLA requirements;

– detection, isolation, and correction of SDN applications' faults, and;

– security related capabilities (including for authentication and identity management purposes) of SDN applications provided by network operators and/or third parties.

SDN applications code repository management provides optimal usage of the repository which stores various SDN application codes and ensures integrity and authenticity of SDN application codes. It also provides efficient search capability of the stored SDN application codes. AL-MSO security

management of 3rd party SDN applications protects from anomalous registration and usage of 3rd party SDN applications.

The AL-MSO functional component provides capabilities for provisioning SDN-AL resources, i.e., resources that are used to run SDN applications, based on the requests received from MMF. The AL-MSO functional component coordinates provisioning of SDN-AL resources and network resources in the SDN-RL in a cross-layer manner and also performs atomic transactions to ensure the integrity of the requested provisioning. The AL-MSO functional component provides capabilities for managing the capacity and performance related to each SDN application. The AL-MSO functional component obtains resource quality of service information in order to measure and record key performance indicators (KPIs) for the SDN applications. Computing and storage resources required for executing an SDN application are allocated or de-allocated based on these KPIs. In case virtual networks have been created, they are built with the support of the SDN-CL, and may use the same application layer, or attach an SDN-AL instance to each virtual network.

7.2 SDN control layer

The SDN-CL provides programmable means to control the behaviour of SDN-RL resources (such as data transport and processing), following requests received from the SDN-AL and according to MMF policies. The SDN-CL is operating on resources provided by the SDN-RL and exposes an abstracted view of the controlled network to the SDN-AL.

The SDN-CL interacts with the SDN-RL using the resource control interfaces (RCI) reference point, and with MMF using the MMF control layer (MMFC) reference point. It also interacts with the SDN-AL at the ACI reference point, as described in clause 7.1.

Figure 7-3 shows the SDN-CL functional components.

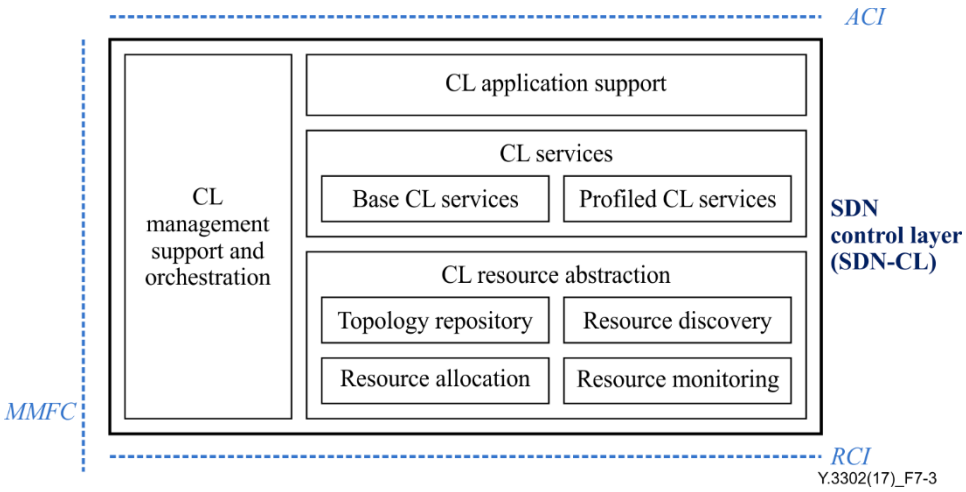

Figure 7-3 – SDN-CL functional components

7.2.1 CL application support functional component

The control layer application support (CL-AS) functional component provides an ACI reference point that is used by the SDN-AL to access network information and to request the SDN-CL to perform application-specific behaviour. The information exposed by the CL-AS functional component to the SDN-AL is abstracted by means of information and data models. In case of network virtualization, the CL-AS functional component may expose a subset of network resources which can be used for exclusive control by additional, external SDN control and application layers. Specification of such operations is out of scope of this Recommendation.

NOTE – The control layer resource abstraction (CL-RA) functional component of the SDN-CL hides the configuration and technology-specific details of potentially heterogeneous network elements whereas the CL-AS functional component hides details of the underlying network topology by providing a global and abstracted view of that network.

7.2.2 Control layer management support and orchestration functional component

The control layer (CL) management support and orchestration (CL-MSO) functional component provides management support and orchestration of functional components of the SDN-CL and, if delegated by the MMF, the management and orchestration of network resources based on the policies provided by the MMF.

The CL-MSO functional component provides capabilities for provisioning CL services, both in terms of the provisioning of CL services' implementations and of their access endpoints and the workflow required to ensure that CL services' components are provisioned in the correct sequence. A catalogue of CL services provides a list of all available CL services that can be provisioned by the CL-MSO functional component. This catalogue can contain/reference all relevant technical information (including relevant templates) required to deploy, provision and run a CL service and/or its components.

NOTE – The term "CL service" as used in this Recommendation refers to a service provided by either the base CL services functional component or a profiled CL services functional component (see clause 7.2.3). These two components consist of the necessary software required to implement CL services, either base CL services or profiled CL services.

The CL-MSO functional component also provides the capabilities for managing a particular CL service, it manages the scaling and performance related to a CL service: the CL-MSO functional component obtains monitoring information in order to measure and record KPIs of each CL service and the amount of resources allocated for a CL service based on these KPIs.

The orchestration of the SDN-CL by the CL-MSO functional component may involve relevant policies (e.g., a placement rule which aims to avoid a single point of failure).

The CL-MSO functional component also keeps track of the overall state of allocated and available resources in the SDN-CL. The comparison of allocated resources in the SDN-CL against CL service's performance KPIs can assist in the identification of current or potential bottlenecks.

The CL-MSO functional component provides capabilities for connecting different SDN domains in order to make inter-domain operations where an SDN domain is a collection of SDN-RL entities under logically one SDN-CL entity. In such cases, it is responsible for establishing the communication path(s) required, and for passing appropriate identity and credentials with requests made to other SDN domains. The details of these operations are beyond the scope of this Recommendation.

If delegated by MMF, some management tasks can be performed by the SDN-CL, in particular tasks that are tightly coupled with control operations and can be jointly optimized for resource usage, or for performance.

7.2.3 Control layer services functional component

The CL services functional component provides a set of programmable control and optionally management functions (if delegated by MMF) covering e.g., physical and virtual network topologies, network element configuration, and traffic forwarding management. The CL services functional component includes the following:

– base CL services functional component that is obligatory in all SDN instantiations, that is, connectivity. It includes common functions used in all SDN deployments e.g., topology discovery, monitoring of resources, and on-demand path computation and monitoring;

– profiled CL services functional component (shown in Figure 7-3 and representing use case specific CL services), which will be defined in separate Recommendations. In a given implementation it is allowed to combine many of such profile-dependent services, e.g., mobility management for mobile networks.

Base CL services and different profiled CL services functional components may be instantiated depending on the targeted SDN functional profile. More explanation on functional profiles is given in clause 8.

7.2.4 Control layer resource abstraction functional component

The main purpose of the CL-RA functional component is to support unified programmability of resources in the SDN-RL. Information and data models of underlying network resources are means to provide an abstracted and unified view of these resources to the SDN-CL, so that the developers of CL services and/or functions can simplify their program logics without the need for a detailed knowledge of the underlying network resource technologies. These models provide a detailed, abstracted view of both, physical or virtualized network resources. The CL-RA functional component provides capabilities to create multiple virtual resources by using a single physical resource or can create a composite virtual resource as an aggregation of several virtual or physical resources.

The CL-RA functional component includes, but is not limited to, the following functional components:

– resource discovery functional component. In cooperation with MMF this functional component provides discovery of SDN-RL resources. The MMF companion counterpart in the resource layer management (RLM) functional component (see Annex A.3.2) provides a functionality to handle and/or discover the network resources of different technologies for connectivity (also referred as technology-dependent resource discovery in this Recommendation), whereas the resource discovery functional component in the SDN-CL provides technology-agnostic mechanisms for resource discovery (also referred as technology-independent resource discovery in this Recommendation)

– topology repository functional component. This component keeps up-to-date topology of the network as well as topology of all virtual networks (if created);

– resource allocation functional component. It provides the allocation of abstracted resources for the creation of virtual networks by the SDN-CL. The virtual networks may use existing components of the SDN-CL or there is a possibility to activate virtual network related components, i.e., the CL services, CL-AS, and CL-MSO functional components.

- resource monitoring functional component. This component, in cooperation with the resource layer control support (RL-CS) functional component, monitors failures and performance of SDN-RL resources.

7.3 SDN resource layer

The SDN-RL is where the physical or virtual network elements perform transport and/or processing of data packets according to SDN-CL decisions. The policy-provisioning information (including configuration information) that result as decisions made by the SDN-CL as well as the information about network resources are exchanged via the RCI reference point. The SDN-RL also interacts with MMF using the MMF resource layer (MMFR) reference point.

Information exchanged through the RCI include control information provided by the SDN-CL to the SDN-RL (e.g., for configuring a network resource or providing policies) as well as the information that pertains to the (unsolicited) notifications sent by the SDN-RL whenever a network resource change is detected (if such information is available).

The RCI reference point provides high-level access to network resources regardless of their respective technology.

Network resources include:

– entities, virtual or physical ones, that support data forwarding functionalities, such as network switches with data forwarding rules, which are configured by the SDN-CL;

– entities, virtual or physical ones, that support route computation functionalities, such as IP routers with capabilities of distributed routing control, which are customized by the SDN-CL, as part of the dynamic enforcement of routing and traffic engineering policies, for example;

– entities, virtual or physical ones, which support data processing functionalities, such as modules for media transcoding and data compression.

Data forwarding and data routing functionalities are network resources located in the Data Transport functional component.

Figure 7-4 shows the SDN-RL functional components.

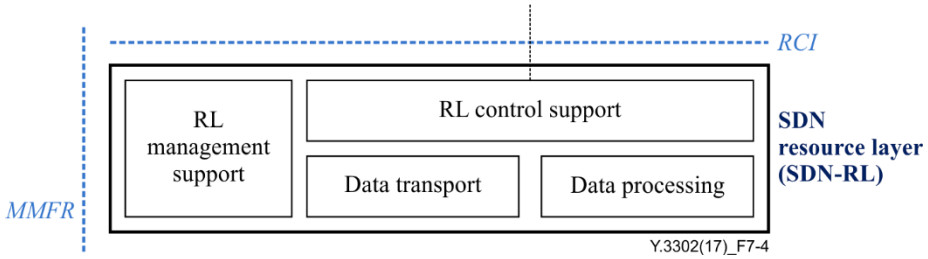

Figure 7-4 – SDN-RL functional components

7.3.1 Resource layer control support functional component

The RL-CS functional component interacts with the SDN-CL via the RCI reference point. It provides data models, or optionally information models, of the network resources, which are abstracted in the SDN-CL.

The RL-CS functional component may itself realize resource abstraction instead of the SDN-CL, in case resource abstraction is supported by the underlying resource technology.

The RL-CS functional component is programmable. The RL-CS functional component enables to update and/or modify the data transport and/or the data processing functional components. For example, a new protocol or a new set of interface specifications may be added for the purpose of enhancing functionalities of the data transport and/or the data processing functional components. The programmability of the RL-CS functional component is supported by the MMF.

7.3.2 Resource layer data transport functional component

The resource layer data transport (RL-DT) functional component provides data forwarding and data routing functionalities.

NOTE – Though mentioned as being an SDN-RL functionality, data routing functionality (including route computation, selection and establishment) can also be provided by the SDN-CL, e.g., in a scenario where data forwarding functionalities in the SDN-RL is performed according to the routes computed, selected and instructed by the SDN-CL.

The data forwarding functionality handles the incoming data flows to forward them along the data forwarding paths that have been computed and established according to the requirements defined by the SDN applications. The control of the data forwarding functionality is provided by the SDN-CL.

SDN-RL routing policies can be configured by the SDN-CL for SDN applications needs.

Data forwarding and data routing functionalities are extensible. Examples of functional extension include enhancing the existing data transport capabilities and incorporating new data transport capabilities, e.g., for the handling a new data frame format or a new data packet format.

7.3.3 Resource layer data processing functional component

The resource layer data processing (RL-DP) functional component provides functionalities to examine and manipulate data. Data processing functionalities enable to alter format and/or payload of data packets/frames and to adjust sending of data packets/frames as specified by SDN applications.

Data processing functionalities are extensible. Examples of functional extension include enhancing the existing data processing capabilities and incorporating new data processing capabilities, e.g., new transcoding algorithms.

7.3.4 Resource layer management support functional component

The resource layer management support (RL-MS) functional component provides resource description, i.e., vendor, software version, and their status (e.g., CPU load, used RAM memory or storage). It may include a management agent that performs some local management operations if delegated by MMF. This agent can be used to support technology-dependent resource discovery, for programmable, local monitoring of the SND-RL entity (in order to limit the amount of exchanged data between the SDN-CL and the SDN-RL or to focus on a specific issue) or to implement so-called autonomic behaviour [b-GANA-arch].

The RL-MS functional component also provides lifecycle management of all RL software-based components, including the RL-CS functional component.

7.4 Multi-layer management functions

The MMF provides functionalities for managing the functionalities of SDN layers, i.e., SDN-AL, SDN-CL and SDN-RL. MMF interacts with these layers using MMFA, MMFC, and MMFR reference points. MMF interoperates with 3rd party management systems, for example for billing, customer care, statistics collection or dynamic service provisioning, therefore a reference point to the operator management systems also exists (e.g., the MMF OSS/BSS (MMFO) reference point in Figure 7-1). MMF is also responsible for the orchestration of dynamically deployed MMF services and coordinated (orchestrated) reconfiguration of SDN-RL resources.

MMF includes functionalities for supporting FCAPS as described in [ITU-T M.3400]. Examples of such functionalities are equipment inventory, fault isolation, performance optimization, and initial configuration of the SDN-RL, SDN-CL and SDN-AL. MMF is also responsible for the lifecycle management of software-based components contained in the SDN layers. By considering energy and environmental constraints, MMF provides energy efficient operations of virtual and physical resources used for the implementation of all layers. The functionality can be realized by energy-aware algorithms supported by resource status monitoring and analytics.

MMF interacts with the developers' environment to support the development of the SDN software components by building a ready-to-deploy software package. The software package consists of both the service implementation software and also the configuration metadata and scripts. The test management produces reports of the executed tests and these can be communicated to the SDN operator.

As shown in Figure 7-5, MMF functions include RLM, control layer management (CLM), application layer management (ALM), multi-layer management orchestration (MMO) and external relationship management (ERM) functional components. The internal lines of the MMF block do not represent reference points. They simply show relationships among functional components.

MMF can delegate some management operations, specifically those which require intensive exchange of data with the SDN-CL to be performed directly by the SDN-CL (e.g., so-called autonomous management operations). Delegated operations are performed by the AL-MSO, CL-MSO and RL-MS functional components.

NOTE – Details of MMF functional components are provided in Annex A.

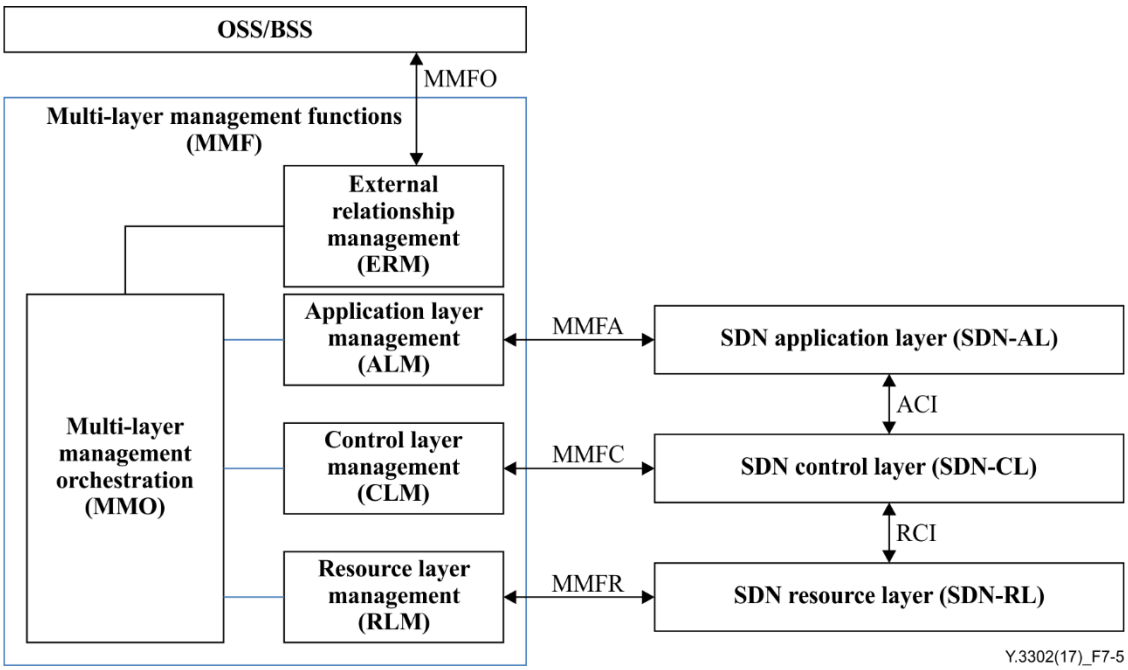

Figure 7-5 – MMF internal structure and reference points

7.4.1 Resource layer management functional component

The RLM functional component is responsible for the management of physical and/or virtual resources in the SDN-RL. The RLM functional component provides capabilities for discovering and activation of virtual and physical resources to make them ready for operation. The RLM functional component includes support for FCAPS and SDN-RL orchestration (e.g., coordinated resource reconfiguration) that is provided by the MMO functional component. The MMO functional component provides the capabilities for provisioning of SDN-RL resources and the RLM functional component keeps track of the overall state of allocated and available resources in the SDN-RL.

The RLM functional component is also responsible for managing the configuration relationship between virtual and physical resources (e.g., interface ID mapping between virtual and physical resources), performance correlation between virtual and physical resources, and faults by considering the relationship between virtual and physical resources, and finally isolation and control of any anomaly concerning SDN network resources, as well as authentication and authorization of the network resources.

By providing the overall resource status information monitored as an input to the RLM functional component, energy efficient resource management capability and other management capabilities can be realized by e.g., turning off of unused resources.

7.4.2 Control layer management functional component

The CLM functional component includes management of resources used to deploy SDN-CL functions (hardware, software platforms, links connecting control plane with other planes) in order to ensure high availability and scalability of the SDN-CL, performance, fault and security management of control traffic generated between SDN-CL entities and SDN-RL or SDN-AL entities. It can activate SDN-CL entities or their components, monitor performance of SDN-CL entities in terms of reliability, utilization, detection, root cause analysis, and correction of faults of the SDN-CL: detection, isolation, and control of SDN-CL related traffic and authentication and authorization management functionality of SDN-CL entities. Policy management can include business, technical, security, privacy and certification policies that apply to CL services and their usage by SDN applications.

The CLM functional component can also provide energy-aware CL resource management. Mechanisms used by the RL energy-aware resource management can be applied in the CL as well.

7.4.3 Application layer management functional component

The ALM functional component provides management functionality for managing SDN-AL resources covering FCAPS management for these SDN-AL resources. It is also involved in cross-layer orchestration driven by the SDN-AL.

The ALM functional component provides SDN applications' code repository management, SDN applications' lifecycle management (creation, modification, and deletion of SDN applications), performance monitoring of SDN applications to meet the SLA requirements, detection, isolation, recovery of SDN application faults and security management of 3rd party SDN applications (authentication, identity management).

7.4.4 Multi-layer management orchestration functional component

The MMO functional component supports functionalities for the lifecycle management of SDN application/network services across the entire SDN operator's domain and orchestrates multi-layer resource management. It coordinates management operations among the SDN-AL, SDN-CL, and SDN-RL, especially the relationship among virtualized and physical resources across these SDN layers.

7.4.5 External relationship management functional component

The ERM functional component provides management functionality to interwork with external management entities. The ERM functional component plays a role of the representative interface of SDN management toward the external management entities. Its main functionality includes abstraction of SDN management information, request and reply of management operations with external management entities, policy management, data analytics, accounting and development operations (DevOps) operations.

8 SDN functional profiles

SDN comes with the programmability of the SDN-CL, the SDN-AL and MMF. The already installed functionalities including appropriate APIs of all SDN layers and MMF that can be used to support different SDN use cases (e.g., mobile networks, optical transport, cloud environment, or network functions virtualization (NFV)) are called SDN functional profiles. These functional profiles can be merged if necessary. Moreover, SDN operators may add additional functions that are required for specific use cases. The definition of basic and use case-specific functionalities is not in the scope of this Recommendation and will be described in separate Recommendations. The base functional profile consists of common functions shall be included in all SDN use cases.

NOTE – The base functional profile for the SDN-CL includes, but is not limited to, the following functionalities:

– topology discovery and topology change monitoring (nodes, hosts, and links);
– monitoring of links (link statistics) and nodes;
– on-demand path computation, selection and monitoring (multiple paths between any source-destination pair);
– shortest-path forwarding using single or multiple paths;
– asynchronous and synchronous update of data forwarding rules (flow programming).

Lifecycle management of each functional profile is a target of MMF.

9 Environmental considerations

SDN provides a flexible and robust means to control underlying network resources including the capability of redirecting traffic from one link to another one, and/or from one switch to another. This influences traffic distribution in the network, and enables network operators to switch off equipment that is not in use, or reduce power consumption of the equipment by changing the mode of its operations.

Traditionally, control functionality of network resources resides in each network element. SDN relocates this functionality to a logically centralized SDN controller. This can simplify network elements and contribute to the reduction of their power consumption. The simplification can also contribute to switch network elements off more easily because the data forwarding function does not have to be in operation if there is no traffic. The simplification may also contribute to expand device lifetime. On the other hand, the functionality that is logically centralized may become complicated, and its power consumption may increase. This may be mitigated by virtualizing the function and applying energy management in cloud computing.

10 Security considerations

The introduction of a high level of automation in the overall service delivery procedure by means of SDN and orchestration techniques raises security challenges.

SDN provides new possibilities to combat security breaches. The affected resources may be easily and quickly isolated, malicious traffic may be safely terminated, sensitive flows can be identified and separately transferred in a more secure manner, e.g., with dedicated equipment and security protocols. All these processes may be automated due to SDN's improved robustness.

Moreover, a logically centralized SDN controller enables operators and/or entities that aim to make use of SDN capabilities to have a broader and/or global view of the current status of networks, which makes security operation easier and more efficient. SDN also raises new security issues. More functionalities traditionally implemented in hardware become software-based, and it becomes possible to modify their behavior through API, policy management, or lifecycle management functionalities. Therefore, it becomes critical to guarantee that legitimate person/function does appropriate operation with these functionalities through secure authentication and authorization.

Appropriateness of operation may be checked by the introduction of formal method, whose requirement is described in [ITU-T Y.3320]. It is also important to prevent or mitigate other kinds of security breaches, e.g., denial of service by e.g., filtering of packets to target functionality.

A logically centralized controller can be a single point of failure, and can be a target of malicious attacks. It is therefore important to pay special attention to redundancy designs.

The possibilities and challenges will be described in more detail in forthcoming ITU-T X-series Recommendations.

Annex A

Multi-layer management functional components details

(This annex forms an integral part of this Recommendation.)

This annex describes in more detail multi-layer management functional components identified in clause 7.4. Each of these functional components is decomposed into functional elements that represent a logical functionality provided by the functional component, independent of any implementation.

A.1 Application layer management functional component

Figure A.1 shows the functional elements of the ALM functional component.

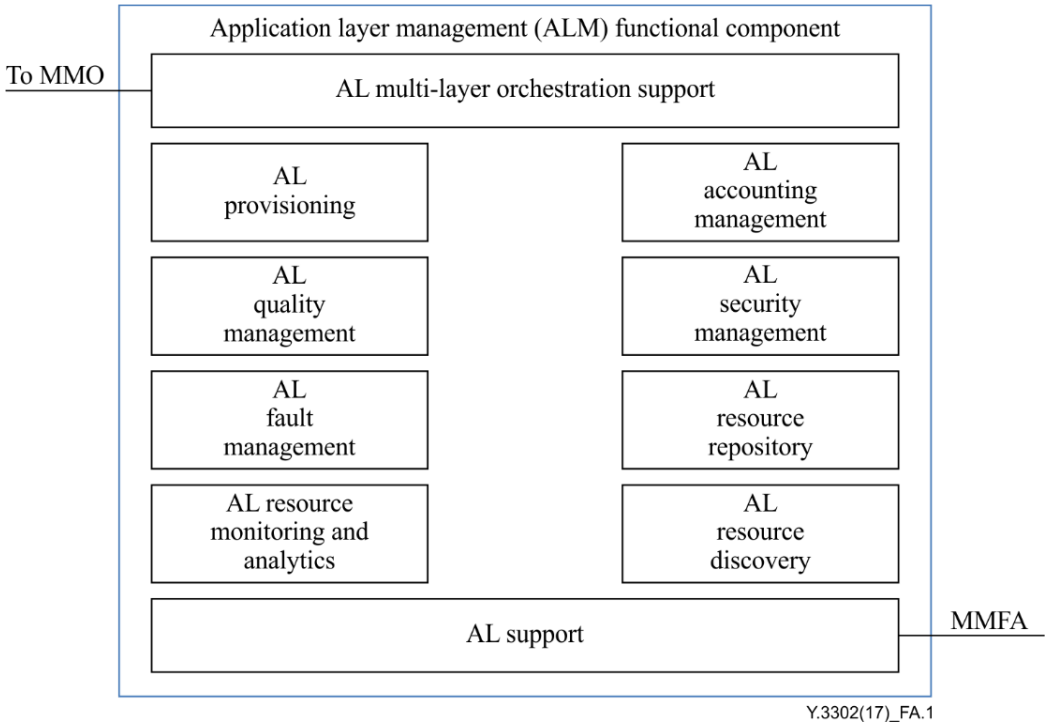

Figure A.1 – Functional elements of the ALM functional component

A.1.1 Application layer support functional element

The AL support functional element provides an MMFA reference point to the AL-MSO functional component (see clause 7.1.2) which is used for requesting and receiving management operations and associated information to/from the SDN-AL.

A.1.2 Application layer resource discovery functional element

The AL resource discovery functional element is responsible for discovering applications and relevant SDN-AL resources, such as application codes under execution, or functional components used in the SDN-AL, and provides capabilities for discovering application and the resources in the SDN-AL. The discovered resources are stored in the AL resource repository functional element.

A.1.3 Application layer resource monitoring and analytics functional element

The AL resource monitoring and analytics functional element is responsible for collecting the status and events of SDN-AL resources and analyzing them for the purpose of fault, quality, and security management. It provides capabilities for:

– monitoring the activities, status, anomalous events of the application and relevant SDN-AL resources;

– analyzing the monitored data and providing reports on the behaviour of the resources, which can take the form of alerts for abnormal behaviour which has a time-sensitive aspect (e.g., the occurrence of a fault, the completion of a task), or it can take the form of aggregated forms of historical data (e.g., resource usage data);

– storing and retrieving monitored data and analysis reports as logging records in the AL resource repository functional element.

A.1.4 Application layer resource repository functional element

The AL resource repository functional element is responsible for storing the contents discovered by the AL resource discovery functional element and managing the lifecycle of these contents in the repository. It provides capabilities for:

– storing and providing APIs for querying the contents discovered by the AL resource discovery functional element;

– storing and providing APIs for querying the contents generated by the AL resource monitoring and analytics functional element;

– ensuring lifecycle management of the contents in the repository (e.g., creation by storing, modification, deletion).

A.1.5 Application layer provisioning functional element

The AL provisioning functional element is responsible for provisioning applications and relevant SDN-AL resources. It provides capabilities for:

– provisioning applications and relevant SDN-AL resources. The application and resource provisioning will trigger the SDN-AL orchestration operation which will further trigger the SDN-CL orchestration and possibly allocate requested resources in the SDN-RL;

– mapping and translating customer's abstracted, high-level application/service provisioning profile into more detailed provisioning policies;

– managing lifecycle of provisioning policy.

A.1.6 Application layer fault management functional element

The AL fault management functional element is responsible for fault management of the SDN-AL. It provides capabilities for:

– detecting anomalous events which cause failure of the SDN-AL resources;

– analyzing a root cause of the failure of the SDN-AL resources;

– generating failure resolving policies and interact with control and provisioning functional components for the actual healing actions.

A.1.7 Application layer quality management functional element

The AL quality management functional element is responsible for ensuring performance of the SDN-AL resources. It provides capabilities for:

– monitoring and ensuring quality of the SDN-AL application and relevant resources based on the given KPIs.

A.1.8 Application layer security management functional element

The AL security management functional element is responsible for security management of the SDN-AL. It provides capabilities for:

– managing authentication and authorization capabilities of the SDN-AL;

– detecting and avoiding anomalous attacks of the SDN-AL.

NOTE – this functional element is optional.

A.1.9 Application layer accounting management functional element

The AL accounting management functional element is responsible for accounting management of the SDN-AL. It provides capabilities for metering and reporting SDN applications and relevant SDN-AL resource usage data for further accounting. Resource usage data can be metered per SDN application or per end-user/customer.

A.1.10 Application layer multi-layer orchestration support functional element

The AL multi-layer orchestration support functional element provides an internal interface to the multi-layer orchestration support functional element in the MMO functional component for requesting and receiving management operations and associated information for multi-layer orchestration specific to application layer management.

A.2 Control layer management functional component

Figure A.2 shows the functional elements of the CLM functional component.

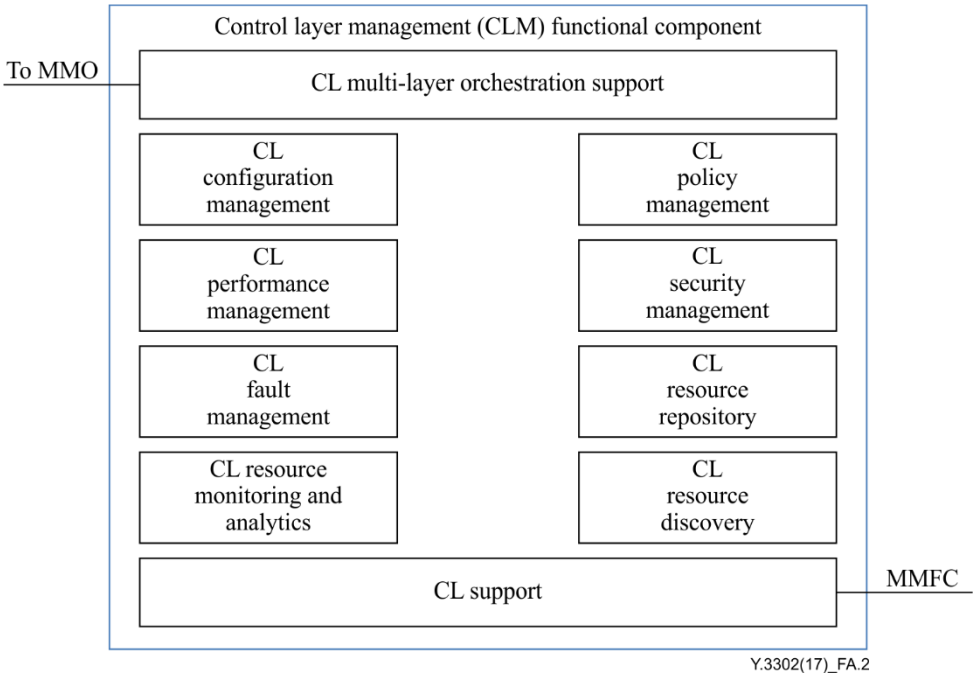

Figure A.2 – Functional elements of the CLM functional component

A.2.1 Control layer support functional element

The CL support functional element provides an MMC reference point to the CL-MSO functional component (see clause 7.2.2) which is used for requesting and receiving management operations and associated information to/from the SDN-CL.

A.2.2 Control layer resource discovery functional element

The CL resource discovery functional element is responsible for discovering control resources in the SDN-CL. It provides capabilities for:

– discovering control resources in the SDN-CL. The discovered resources are stored in the CL resource repository functional element.

A.2.3 Control layer resource repository functional element

The CL resource repository functional element is responsible for storing the contents discovered by the resource discovery and bootstrapping and managing the lifecycle of the contents in the repository. It provides capabilities for:

– storing and providing APIs for querying the contents discovered by the CL resource discovery functional element;

– storing and providing APIs for querying the contents generated by the CL resource monitoring and analytics functional element;

– ensuring lifecycle management of the contents in the repository (e.g., creation by storing, modification, deletion).

A.2.4 Control layer resource monitoring and analytics functional element

The CL resource monitoring and analytics functional element is responsible for collecting the status and events of SDN-CL resources and analyzing them for the purpose of performance, fault, and security management. It provides capabilities for:

– monitoring the activities, status, abnormal events of the control resources in the SDN-CL;

– analyzing the monitored data and providing reports on the behaviour of the resources, which can take the form of alerts for abnormal behaviour which has a time-sensitive aspect (e.g., the occurrence of a fault, the completion of a task), or it can take the form of aggregated forms of historical data (e.g., resource usage data);

– storing and retrieving monitored data and analysis reports as logging records in the CL resource repository.

A.2.5 Control layer configuration management functional element

The CL configuration management functional element is responsible for configuration management of the SDN-CL and provides capabilities for:

– provisioning control resources in the SDN-CL;

– scaling in/out of control resources based on the demand and availability.

A.2.6 Control layer fault management functional element

The CL fault management functional element is responsible for fault management of the SDN-CL. It provides capabilities for:

– detecting anomalous events which cause failure of the SDN-CL resources;

– analyzing a root cause regarding the failure of the SDN-CL resources;

– generating failure resolving policies and interact with control and provisioning functional components in the SDN-CL for the actual healing actions.

A.2.7 Control layer performance management functional element

The CL performance management functional element is responsible for ensuring performance of the SDN-CL resources. It provides capabilities for monitoring and ensuring performance of the SDN-CL resources based on the given KPIs.

A.2.8 Control layer security management functional element

The CL security management is an optional functional element responsible for security management of the SDN-CL. It provides capabilities for:

– managing authentication and authorization capabilities of the SDN-CL;

– detecting and avoiding anomalous attacks towards the SDN-CL;
– storing and providing APIs for querying the contents discovered by the CL resource discovery functional element;
– storing and providing APIs for querying the contents generated by the CL resource monitoring and analytics functional element;
– ensuring lifecycle management of the contents in the repository (e.g., creation by storing, modification, deletion)

A.2.9 Control layer policy management functional element

The CL policy management functional component provides capabilities to define, store and retrieve policies that apply to CL services. Policies can include business, technical, security, privacy and certification policies that apply to CL services and their usage by SDN applications.

Some policies can be general and apply to a CL service irrespective of the SDN application concerned. Other policies can be specific to a particular SDN application.

A.2.10 Control layer multi-layer orchestration support functional element

The CL multi-layer orchestration support functional element provides an internal interface to the multi-layer orchestration support functional element in the MMO functional component for requesting and receiving management operations and associated information for multi-layer orchestration specific to control layer management.

A.3 Resource layer management functional component

Figure A.3 shows the functional elements of the RLM functional component.

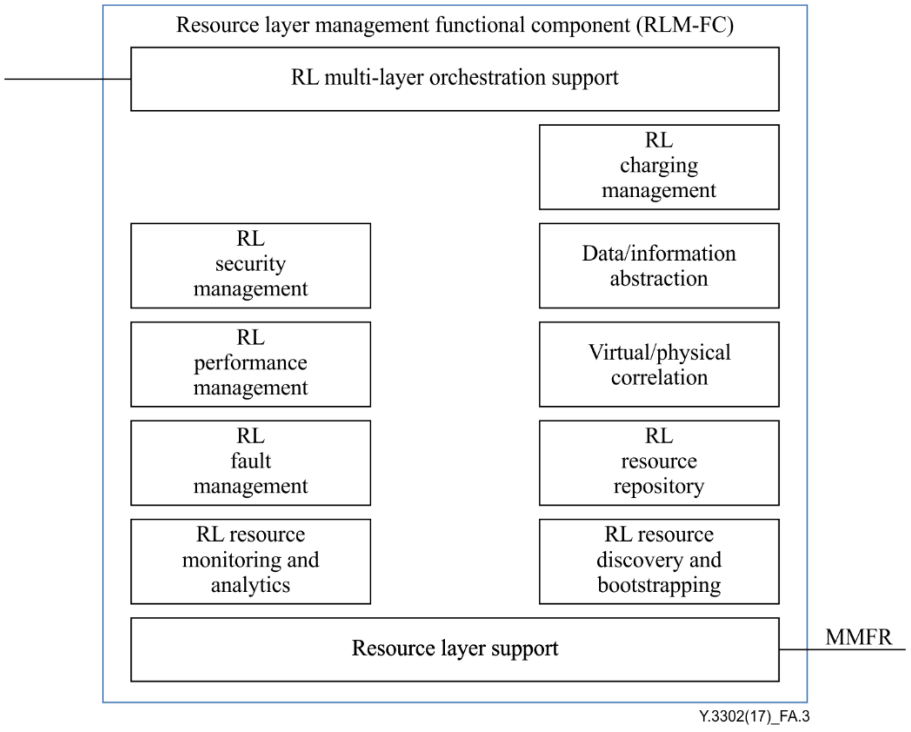

Figure A.3 – Functional elements of the RLM functional component

A.3.1 Resource layer support functional element

The RL support functional element provides a MMR reference point to the RL-MS functional component (see clause 7.3.4) which is used for requesting and receiving management operations and associated information from/to the SDN-AL.

A.3.2 Resource layer resource discovery and bootstrapping functional element

The RL resource discovery and bootstrapping functional element is responsible for discovering and bootstrapping physical and virtual resources in the SDN-RL. It provides capabilities for:

– discovering technology specific physical and virtual resources. The discovered resources are stored in the RL resource repository functional element. The SDN-CL is responsible for abstract resource discovery which is common across any underlying heterogeneous technology specific physical and virtual resources;

– bootstrapping of physical and virtual resources to make them ready for operation based on the bootstrapping policies.

A.3.3 Resource layer resource repository functional element

The RL resource repository functional element is responsible for storing the contents discovered by the resource discovery and bootstrapping and managing the lifecycle of the contents in the repository. It provides capabilities for:

– storing and providing APIs for querying the contents discovered by the RL resource discovery and bootstrapping functional element;

– storing and providing APIs for querying the contents generated by the RL resource monitoring and analytics functional element:

– ensuring lifecycle management of the contents in the repository (e.g., creation by storing, modification, deletion).

A.3.4 Data/information abstraction functional element

The data/information abstraction functional element is responsible for generating abstractions of technology specific physical and virtual resources in the SN-RL into technology independent common information. It provides capabilities for:

– converting device dependent resource data into independent abstracted information;

– storing abstracted information in RL resource repository functional element;

– providing APIs to other functional components which need abstraction information.

A.3.5 Virtual/physical correlation functional element

The virtual/physical correlation functional element is responsible for correlating the relationship between virtual and physical resources in RL and provides the following capabilities for:

– identifying correlation information among virtual and physical resources in the underlying SDN networks for efficient provisioning, performance monitoring and fault detection and root-cause analysis;

– identifying correlation information between virtual and physical flows for accounting purpose;

– storing correlation information in a common resource information repository and providing programming interfaces to other functional components which need correlation information.

A.3.6 Resource layer resource monitoring and analytics functional element

The RL resource monitoring and analytics functional element is responsible for collecting the status and events of SDN-RL resources and analyzing them for the purpose of FCAPS management. It provides capabilities for:

– monitoring the activities, status, anomalous events of the virtual and physical resources in the SDN-RL;

– analyzing the monitored data and providing reports on the behaviour of the resources, which can take the form of alerts for behaviour which has a time-sensitive aspect (e.g., the

occurrence of a fault, the completion of a task), or it can take the form of aggregated forms of historical data (e.g., resource usage data);

– storing and retrieving monitored data and analysis reports as logging records in the RL resource repository functional element.

A.3.7 Resource layer fault management functional element

The RL fault management functional element is responsible for fault management of the SDN-RL. It provides capabilities for:

– detecting anomalous events which cause failure of the underlying virtual and physical resources;

– analyzing a root cause of the failure including the correlated event among virtual and physical resources;

– generating failure resolving policies and interact with control and provisioning functional components for the actual healing actions.

A.3.8 Resource layer performance management functional element

The RL performance management functional element is responsible for ensuring performance of the SDN-RL resources including energy-aware resource management in the SDN-RL It provides capabilities for:

– monitoring and ensuring performance of SDN-RL physical and virtual resources based on the given KPIs;

– estimating total energy consumption costs of underlying resources (both virtual and physical nodes and links) with the monitored resource status information;

– calculating energy efficient optimal resource mapping based on the current estimated total energy consumption costs and the requested KPI.

A.3.9 Resource layer security management functional element

The RL security management is an optional functional element responsible for security management of the SDN-RL. It provides authentication and authorization capabilities of the SDN-RL and detects and avoids anomalous attacks of the SDN-RL.

A.3.10 Resource layer resource accounting management functional element

The RL accounting management functional element is responsible for accounting management of the SDN-RL. It provides capabilities for metering and reporting resource usage data (e.g., for charging purposes). Resource usage data can be metered per flow or aggregated flows of virtual or physical links. Identifying correlation information between virtual and physical flows can be performed by the virtual/physical correlation functional element.

A.3.11 Resource layer multi-layer orchestration support functional element

The RL multi-layer orchestration support functional element provides an internal interface to the multi-layer orchestration support functional element in the MMO functional component for requesting and receiving management operations and associated information for multi-layer orchestration specific to the RLM.

A.4 Multi-layer management orchestration functional component

Figure A.4 shows the functional elements of the MMO functional component.

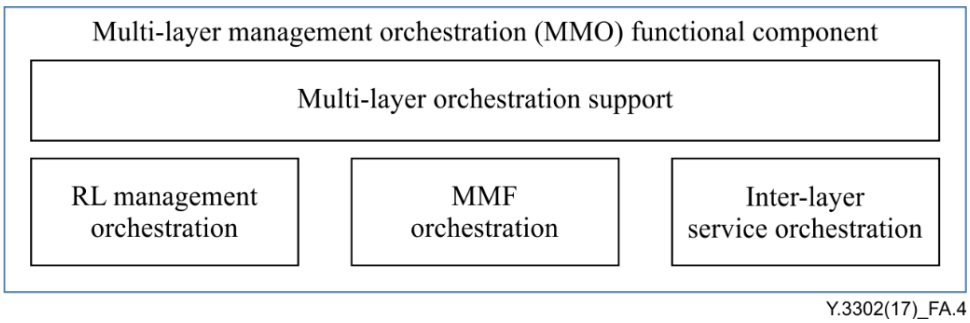

Figure A.4 – Functional elements of the MMO functional component

A.4.1 Multi-layer orchestration support functional element

The multi-layer orchestration support functional element provides an internal interface to the multi-layer orchestration support functional element in the ALM, CLM, RLM functional components for requesting and receiving management operations and associated information for multi-layer orchestration.

A.4.2 Resource layer management orchestration functional element

The RLM orchestration functional element provides orchestration of SDN-RL resources provisioning and configuration.

A.4.3 Multi-layer management functions orchestration functional element

The MMF orchestration functional element provides functionality for supporting the lifecycle management of SDN application/network services across the entire SDN operator's domain (e.g., multiple data centers interconnected by a WAN transport network).

A.4.4 Inter-layer service orchestration functional element

The inter-layer service orchestration functional element provides orchestration of multi-layer resource management. It coordinates management operations among the SDN-AL, SDN-CL, and SDN-RL, especially the relationships among virtualized and physical resources across the SDN layers. Some examples of orchestration realized by this functional element can be:

– orchestration for a multi-layer virtual to physical resource fault correlation;

– orchestration for scale-in and scale-out of control element (e.g., controller instances) depending on the traffic demand changes in the underlying resource layer, and;

– orchestration for an application layer service provisioning request to resource layer relevant resources.

A.5 External relationship management functional component

Figure A.5 shows the internal structure of the ERM functional component.

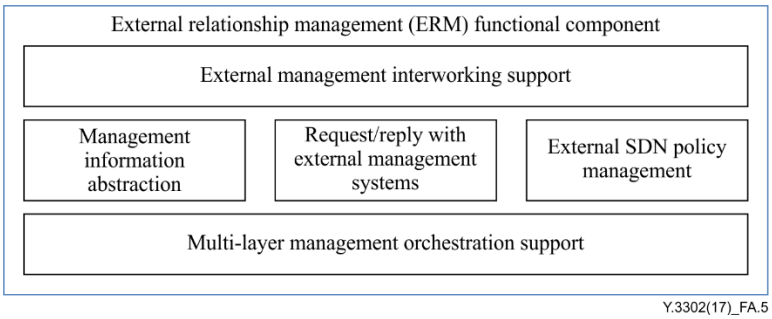

Figure A.5 – Functional elements of the ERM functional component

The ERM functional component provides management functionality to interwork with external management entities. External management entities can be a legacy OSS/BSS, management and orchestration entities [b-MANO], cloud management entities, or other management functionality which can be defined in the future. The ERM functional component plays a role of the representative interface of SDN management toward the external management entities. Its main functionality includes abstraction of SDN management information for the exchange and request/reply of management operations with external management entities. It can be used for policy management, data analytics, accounting, etc.

The ERM functional component is also responsible for MMF to interact with an external DevOps system to enable efficient development of SDN functionality by providing developer environment setup processes, build and test management, and deployment.

A.5.1 External management interworking support functional element

The external management interworking support functional element provides an MMFO reference point to OSS/BSS for requesting and receiving management operations and associated information to/from OSS/BSS.

A.5.2 Management information abstraction functional element

The management information abstraction functional element provides abstraction of SDN management information for the exchange with external management entities for inter-domain management information hiding purpose.

A.5.3 Request/reply with external management functional element

The request/reply with external management functional element provides functionality associated with request/reply management operations with external management entities.

A.5.4 External SDN policy management functional element

The external SDN policy management functional element provides external SDN policy exchanges involved between MMF and external management entities, data analytics, accounting, and interaction with an external DevOps system to enable efficient development of SDN functionality by providing developer environment setup processes, build and test management, and deployment.

A.5.5 Multi-layer management orchestration support functional element

The multi-layer management orchestration support functional element provides an internal interface to the multi-layer orchestration support functional element in the MMO functional component for the purpose of inter-domain orchestration between SDN MMF and OSS/BSS.

Appendix I

Orchestration in SDN

(This appendix does not form an integral part of this Recommendation.)

Network operations are becoming ever more complicated and their automation is required to cope with this complexity and to make networks' service agile and deployment of new services fast and simple (so-called 'one click' approach). The key mechanism to support this functionality is orchestration.

In general, the orchestration automates a set of operations for a specific purpose. It arranges, configures and coordinates everything that is necessary in: multi-domain, multi-layer, or end-to-end operations in heterogeneous network environments in order to execute the orchestrated task. An orchestrated task is a high-level task composed of many lower-level operations in a seamless manner. Orchestration provides the orchestrated task lifecycle management. The orchestrated task can be triggered externally (by human or application) or it can be triggered internally (inside a layer to which the orchestrated task belongs). The orchestrated task can be programmed or not. An orchestrated task may include orchestrated or non-orchestrated operations (lower-level tasks).

In order to achieve its goals, it uses the control and management systems in a cross-layer manner. An orchestration can be seen as a generic service deployment mechanism.

The main difference between the orchestration and prior service provisioning approaches lies in the higher level of automation that was not achievable in the past, synchronization of operations and cross-layer and cross-domain capabilities.

In the SDN architecture the orchestration deals with:

– Orchestrated control layer tasks.

  Such orchestration is provided by the CL-MSO functional component. CL-MSO operations are internal to the SDN-CL.

– Orchestrated application layer tasks.

  SDN-AL service deployment is orchestrated (if needed) by the MMO functional component. For this purpose, according to the service template, the SDN-CL and the MMF appropriate operations are executed in a synchronous manner. The CL-MSO functional component in this case is used as a slave to orchestrate SDN-CL tasks.

– Orchestrated multi-layer management function tasks.

  Orchestrated MMF tasks provide a set of management operations. Some of them can compose a high level of management services which can be triggered on demand. For the deployment of such orchestrated management tasks the MMO functional component is used.

– Orchestration of provisioning and configuration or reconfiguration resources within the SDN-RL.

Bibliography

[b-ITU-T Y.3011] Recommendation ITU-T Y.3011 (2012), *Framework of network virtualization for future networks*.

[b-ITU-T Y.3502] Recommendation ITU-T Y.3502 (2014), *Information technology – Cloud computing – Reference architecture*.

[b-IETF RFC 7426] IETF RFC 7426 (2015), *Software-Defined Networking (SDN): Layers and Architecture Terminology*.

[b-GANA-arch] ETSI GS AFI 002 V1.1.1 (2013), *Autonomic network engineering for the self-managing Future Internet (AFI); Generic Autonomic Network Architecture*.

[b-MANO] ETSI GS NFV-MAN 001 V1.1.1 (2014), *Network Functions Virtualisation (NFV); Management and Orchestration*.

[b-ONF-arch 1.0] ONF TR-502 (2014), *SDN Architecture 1.0*.

[b-ONF-arch 1.1] ONF TR-521 (2016), *SDN Architecture 1.1*.

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