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Future networks

Enhanced software-defined networking data plane for IMT-2020

Recommendation ITU-T Y.3155

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Recommendation ITU-T Y.3155

Enhanced software-defined networking data plane for IMT-2020

Summary

Recommendation ITU-T Y.3155 provides the requirements and high-level architecture of enhanced SDN data plane (ESDP) for IMT-2020 which aims to provide improved support for relevant requirements of the network. Based on the high-level architecture, it specifies functional blocks, reference points, and the workflow of ESDP.

History

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Keywords

Autonomous functions, enhanced SDN data plane, IMT-2020, network programmability.

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Enhanced software-defined networking data plane for IMT-2020

1 Scope

This Recommendation describes the requirements and architecture of an enhanced SDN data plane (ESDP) for IMT-2020 which aims to provide improved support for the relevant requirements of the network.

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 Y.3101] Recommendation ITU-T Y.3101 (2018), *Requirements of the IMT-2020 network.*

[ITU-T Y.3104] Recommendation ITU-T Y.3104 (2018), *Architecture of the IMT-2020 network.*

[ITU-T Y.3152] Recommendation ITU-T Y.3152 (2019), *Advanced data plane programmability for IMT-2020.*

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

[ITU-T Y.3302] Recommendation ITU-T Y.3302 (2017), *Functional architecture of software-defined networking.*

[ITU-R M.2083-0] Recommendation ITU-R M.2083-0 (2015), *IMT Vision – Framework and overall objectives of the future development of IMT for 2020 and beyond.*

3 Definitions

3.1 Terms defined elsewhere

This Recommendation uses the following terms defined elsewhere:

3.1.1 control plane [b-ITU-T Y.2011]: The set of functions that controls the operation of entities in the stratum or layer under consideration, plus the functions required to support this control.

3.1.2 data plane [b-ITU-T Y.2011]: The set of functions used to transfer data in the stratum or layer under consideration.

3.1.3 IMT-2020 [b-ITU-T Y.3100]: Systems, system components, and related technologies that provide far more enhanced capabilities than those described in [b-ITU-R M.1645].

3.1.4 network function [b-ITU-T Y.3100]: In the context of IMT-2020, a processing function in a network.

3.1.5 network slice [b-ITU-T Y.3100]: A logical network that provides specific network capabilities and network characteristics.

3.1.6 protocol independent instruction set [ITU-T Y.3152]: A set of protocol-independent instructions supported by data plane elements required for implementing a wide range of network functionalities.

3.1.7 software-defined networking (SDN) [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.

3.1.8 user plane [b-ITU-T Y.2011]: A synonym for data plane.

3.2 Terms defined in this Recommendation

None.

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

App	Application
AF	Application Function
API	Application Programming Interface
ASF	Authentication Server Function
CEF	Capability Exposure Function
CP	Control Plane
E2E	End to End
ESDP	Enhanced SDN Data Plane
ID	Identifier
IMT-2020	International Mobile Telecommunication 2020
IPv4/6	Internet Protocol version 4/6
MAT	Match+Action Table
mMTC	massive Machine Type Communications
NACF	Network Access Control Function
NF	Network Function
NFR	Network Function Repository
NSSF	Network Slice Selection Function
PCF	Policy Control Function
PDU	Protocol Data Unit
QoS	Quality of Service
RAN	Radio Access Network
RP	Reference Point
SDN	Software-Defined Networking
SIMA	State Information Memory Area
SMF	Session Management Function
UE	User Equipment

UP	User Plane
UPF	User Plane Function
URLLC	Ultra Reliable Low Latency Communications
USM	Unified Subscription Management
WAP	Wireless Access Point

5 Conventions

In this Recommendation:

The keywords "is required to" indicate a requirement which must be strictly followed and from which no deviation is permitted if conformance to this Recommendation is to be claimed.

The keywords "is prohibited from" indicate a requirement which must be strictly followed and from which no deviation is permitted if conformance to this Recommendation is to be claimed.

The keywords "is recommended" indicate a requirement which is recommended but which is not absolutely required. Thus, this requirement need not be present to claim conformance.

The keywords "is not recommended" indicate a requirement which is not recommended but which is not specifically prohibited. Thus, conformance with this specification can still be claimed even if this requirement is present.

The keywords "can optionally" indicate an optional requirement which is permissible, without implying any sense of being recommended. This term is not intended to imply that the vendor's implementation must provide the option, and the feature can be optionally enabled by the network operator/service provider. Rather, it means the vendor may optionally provide the feature and still claim conformance with this Recommendation.

"Data plane event packet" and "event packet" are used interchangeably in this Recommendation.

6 Introduction

IMT-2020 is anticipated to meet the challenging requirements of network traffic, which are characterized by super high transmission rate, low transmission delay, high energy efficiency and large connection scale. Software-defined networking (SDN) is one of key enablers of IMT-2020. However, there still exist gaps between SDN capabilities [ITU-T Y.3302] and the requirements of IMT-2020 [ITU-T Y.3101]. The data plane of SDN has no capabilities to handle network events before querying the SDN controller. During application operations, the interaction between the SDN controller and data plane nodes will, for example, affect the user satisfaction in delay sensitive scenarios (URLLC [ITU-R M.2083-0]) and increase the network signalling burden in massive connection scenarios (mMTC [ITU-R M.2083-0]). Therefore, the data path nodes in SDN are required not only to define the data plane on how to process a received data packet but also to describe a network event and specify actions triggered by the event.

SDN is under continuous development, and it is an important evolving target to realize more flexible network function (NF) programming and protocol independent forwarding. [ITU-T Y.3152] describes an advanced data plane programming framework for IMT-2020, which can help to achieve a "top-down" design process of NFs. Enabled by more flexible and powerful network programmability, an enhanced SDN data plane (ESDP) model is introduced to enable the IMT-2020 with data plane response capability for network events. ESDP enables the delegation of a variety of control processes to the data plane while maintaining the SDN principle of separation between control and forwarding. With the specified mechanisms offered by ESDP, the SDN data plane is enhanced by the processing of network events in the data plane nodes. The delegation of various control plane (CP) functions along the data path can enable the real-time network event processing without the interaction with the SDN controller. The ESDP minimizes the interaction of CP and underlying network elements, thus can improve the delay performance, and reduces the signalling overhead to address relevant requirements of the IMT-2020 network.

7 Requirements of enhanced SDN data plane

This clause first specifies the general requirements to be supported by the IMT-2020 network in order to provide a more flexible and protocol independent network programming environment, and then clarifies the specific functional requirements of ESDP.

7.1 General requirements

To meet the stringent and diverse requirements of applications, the IMT-2020 is required to support a "top-down" design process of NFs. The IMT-2020 CP should be able to instruct the underlying network how to operate itself.

NOTE – Existing networks are designed primarily with hardware constrained functions. For example, a legacy switch can only recognize predetermined packet formats (e.g., Ethernet, IPv4/6, etc.) and process packets using predefined actions. This reflects a "bottom-up" design process in which the NFs are constrained by hardware capabilities.

To realize the on-demand NF design, IMT-2020 network is required to support a more flexible and programmable SDN data plane, to address the definition and control of data plane behaviour as a programming problem, instead of having network behaviour embedded into devices. Thus, the following requirements apply:

– The packet header field definitions and parsing rules are required to be explicit. A mechanism to formally describe packet header structure and how to process the fields in the header is required.

– A data plane node is required to be able to support flexible configuration of packet flows, including the execution order, chaining of flow tables, etc.

– A protocol independent programming model is required to support new protocols and functions in SDN data plane, including:

  1) a series of protocol-agnostic application programming interfaces (APIs) to allow programmers to create, modify, or delete the packet forwarding and processing functions on demand, and

  2) a protocol independent instruction set containing a series of low-level instructions which allows programming of a wide variety of data plane functions not assuming any pre-configured protocol behaviour in the data plane nodes.

7.2 Functional requirements

In the IMT-2020 network, an extended and more flexible flow table model is required not only to specify how to process a received data packet in data plane, but also to define a network event and specify actions triggered by the event. The table model is able to allow programmers to arbitrarily create, modify, and delete table entries at both pre-configuration and run-time stage.

IMT-2020 network is required to define an explicit and comprehensive network event processing framework to support the designing and implementation of data plane functions.

– The definition of network events is required to be supported.

NOTE – A basic set of network events is required to be defined. The network events of this basic set are those which can be identified directly (without programming by SDN controller) by the detection capabilities of the data plane (which depend on the data plane hardware implementation). Typical examples of the basic network event set include timer expiration and port operational status change. Other network events may be defined by combining different network events of the basic set or based on network event information carried by some specific network packets ("event packets" as described in clause 8.2.1). Examples of these network events include user equipment (UE) movement and session interruption.

– Propagation of a network event among data plane nodes is required.

IMT-2020 network is required to support stateful data plane forwarding/processing, and therefore, a state information storage and sharing mechanism within the data plane is required.

– A generic data area is required in data plane nodes to store state information pertaining to one specific packet, a flow, or a network event.

– During run-time, the state information should be arbitrarily used by the SDN controller or by data plane node, to share information between packets, flow tables, even applications or users.

8 Architecture of enhanced SDN data plane

8.1 Overview

The IMT-2020 network is assumed to support the advanced data plane programmability [ITU-T Y.3152]. The ESDP is introduced to enhance SDN data plane in IMT-2020 network; various data plane functions can be defined and delegated along the data path in ESDP so that the data plane functions can operate without run-time instructions from the SDN controller.

Note that the ESDP is not intended to overturn the control-forwarding separation principle of the SDN. In ESDP enabled network, the SDN controller still has the absolute control over all network devices and processes. Data plane functions in ESDP must be pre-configured and delegated by the SDN controller and can be arbitrarily interrupted or changed at any time by the SDN controller.

Based on the architecture of IMT-2020 network [ITU-T Y.3104] and the framework of SDN [ITU-T Y.3300], the high-level architecture of ESDP for IMT-2020 is shown in Figure 8-1.

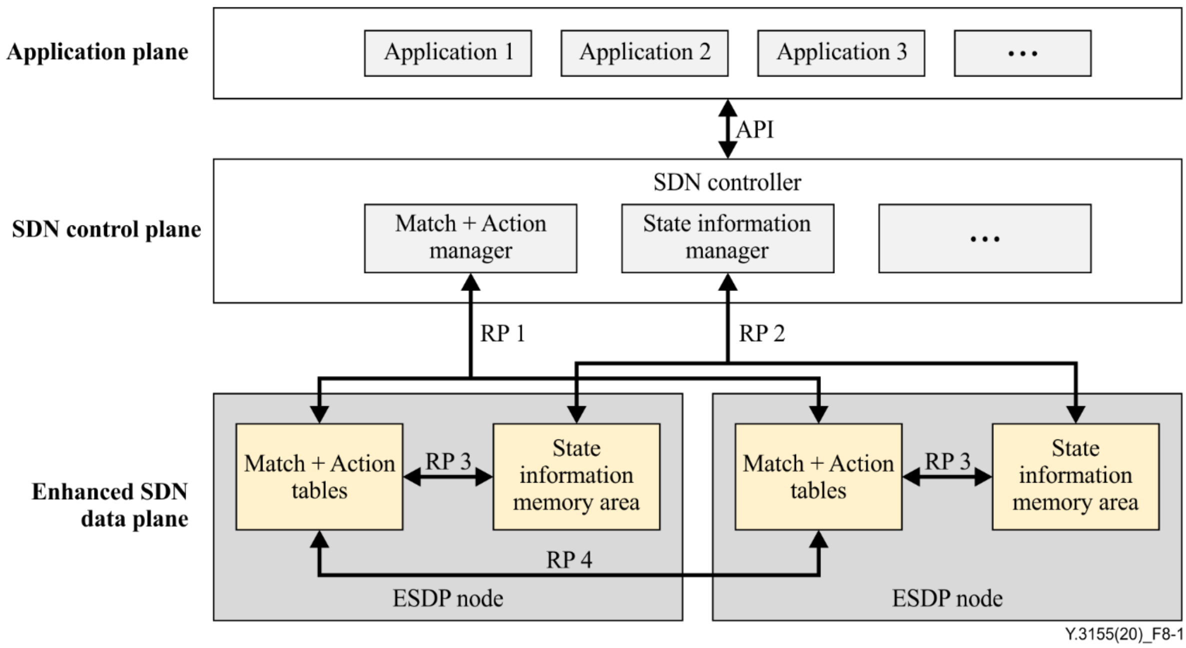


Figure 8-1 – High-level architecture of enhanced SDN data plane

ESDP supports an enhanced forwarding model based on two core functional components: Match+Action tables (MATs) and state information memory area (SIMA).

MATs and SIMA are the key enablers of ESDP which can satisfy the requirements specified in clause 7-2. A MAT is an extension of the flow table defined in Openflow [b-ONF TS-025], which can process both data packets and network events. The SIMA is a block of memory in each ESDP node enabling flexible information sharing within the data plane. The detailed functions of MATs and SIMA are described in clause 8.2.

NOTE – In addition to MATs and SIMA, the ESDP forwarding model contains other components, e.g., parser, queueing and scheduling module, etc. However, these other components, which are not relevant for the enhanced functions of the data plane, are outside the scope of this Recommendation.

As far as the SDN controller is concerned, there are two corresponding functional components in the SDN controller, the Match+Action manager and the state information manager, which manage MATs and SIMA, respectively.

The ESDP contains four reference points to define the interfaces between ESDP components. RP 1 represents the reference point between the SDN controller and MATs, RP 2 represents the reference point between the SDN controller and SIMA, RP 3 represents the reference point between MATs and SIMA within the same ESDP node and RP 4 represents the reference point between MATs in different ESDP nodes. The detailed description of the reference points is provided in clause 8-3.

8.2 Functional components

Figure 8-2 shows the two core functional components in each ESDP node: MATs and SIMA.

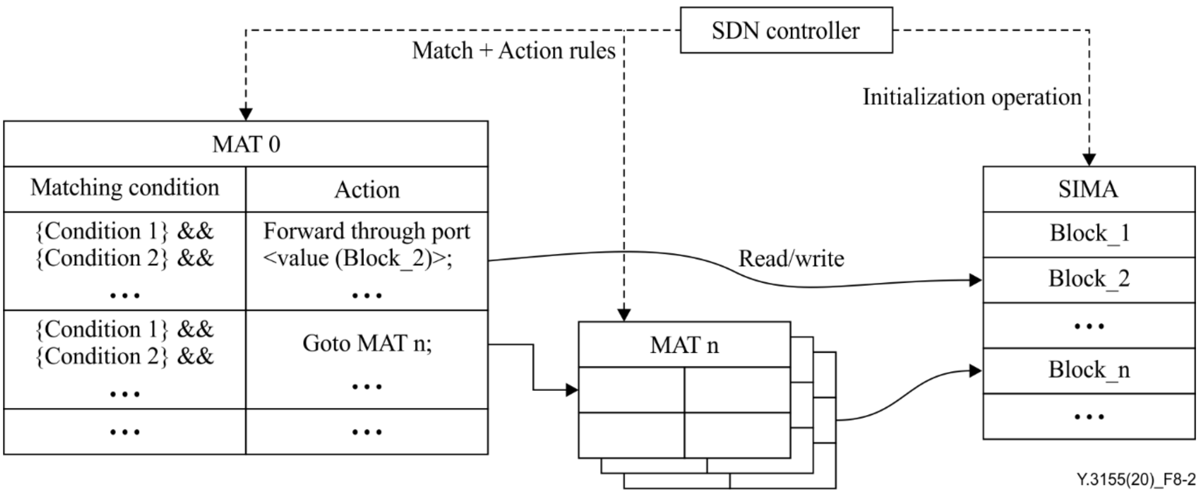


Figure 8-2 – Core functional components in ESDP

8.2.1 Match+Action table

The MATs are the key enabler to allow SDN controller to delegate data plane functions to ESDP. Each ESDP node has a series of MATs (and each MAT entry specifies a "rule" to process a network packet, including 1) matching conditions of a network packet and 2) instructions executed for this packet. A "network packet" includes two kinds of packets: data packet and "data plane event packet (event packet)" – the latter is essential to enable a MAT to handle network events.

The event packet is a kind of network packet generated by an ESDP node carrying type and attributes of a network event. By packaging network event information into event packets which can be identified by ESDP nodes, a MAT provides a unified method to deal with data forwarding and network event handling.

ESDP supports a protocol independent instruction set containing more flexible and powerful actions for packet processing, including arbitrarily adding, modifying and deleting packet header fields. This enables MAT to construct an event packet based on event information. The event information needed for constructing an event packet may be acquired from received packets (data packet or another event packet) or from messages sent by ESDP node's data plane detection capabilities.

Figure 8-3 illustrates the generation and propagation process of the event packet. The MAT can construct an event packet by directly modifying a received packet (e.g., adding an event parameter field), or by encapsulating and modifying a message from ESDP node's detection capabilities. When a network event occurs (e.g., a port is down), which can be detected by link monitoring, a message containing the event information (e.g., port ID) is sent to MAT through an internal logical port. The MAT can process the message locally if the event can be handled by this ESDP node, or construct and propagate an event packet to notify other ESDP nodes to process this event (in some cases, a network event needs to be processed by more than one ESDP node).

NOTE 1 – The message generated by ESDP node's detection capabilities is a special kind of event packet which can trigger local pre-defined actions. The format of the message varies depending on the implementation of the ESDP node.

NOTE 2 – An event packet may contain state information stored in SIMA (as described in clause 8.2.2).

The event definition and response logic are programmed and issued to MATs of ESDP nodes by the SDN controller, the detail process is described in clause 8.4. As shown in Figure 8-2, MATs can be pre-configured or programmed at run-time by SDN controller. To react to a network event as soon as possible, the programming of MATs is recommended to be accomplished in the pre-configuration stage.

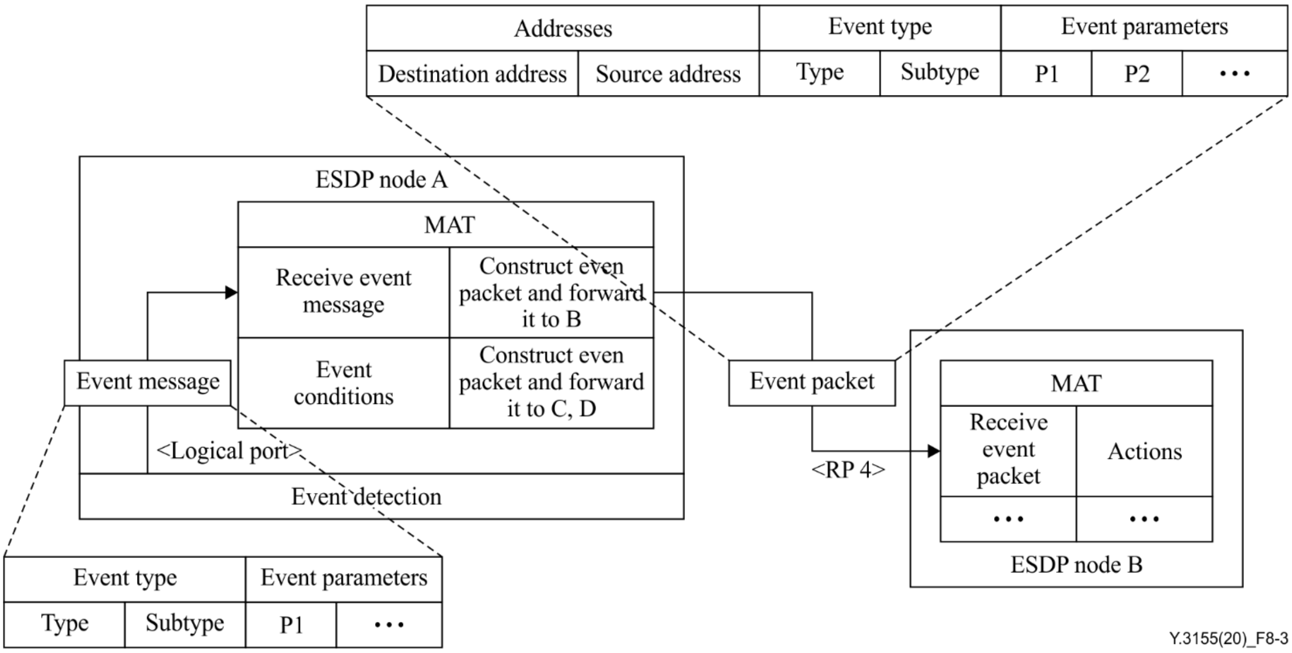


Figure 8-3 – Event packet generation and propagation among ESDP nodes

NOTE 3 – ESDP node can modify or add new information to the received event packet and continue to forward it through RP 4. Therefore, the event packets describing the same event along the propagation path may be different.

A packet may be processed through a series of linked MATs, a MAT "pipeline". The pipeline processing defines how the packet interacts with those MATs.

8.2.2 State information memory area

SIMA is the key component to enable stateful forwarding and processing in ESDP. The SIMA in the ESDP node is a set of memory blocks which provide an information storage and sharing mechanism during network procedures. Data stored in SIMA can be persistent during certain network procedures and be read/written by MAT entries or SDN controller arbitrarily.

The SIMA can be viewed as the extension or supplement to the "packet metadata" defined in existing SDN protocols (e.g., OpenFlow), which is a scratch pad data area along with each packet in the pipeline [b-ONF TS-025]. Packet metadata has a life span of a packet and is used by the controller to temporally store the data pertaining to one specific packet such as its input port, assigned queue ID, etc. However, the SIMA is a persistent, fixed memory area which can be used to keep any information pertaining to a network event (even application information), e.g., the location ID of a certain UE, connectivity status of a certain link, etc. SIMA can be used to share information between packets, flow entities, applications, even between users.

8.3 Reference points

The following reference points are identified.

– RP 1 represents the reference point between the SDN controller and MATs, which supports the following functions:

  1) At the pre-configuration stage, the SDN controller can delegate functions to the ESDP by acting on MATs through RP 1 (i.e., creating, modifying and deleting MATs' entries).

  2) At run-time, MATs will inform the SDN controller through RP 1 when undefined events occur for which the MATs cannot perform a matched action. The SDN controller returns new rules to the MATs to specify how to react for these events.

– RP 2 represents the reference point between SDN controller and SIMA. RP 2 is used in the pre-configuration stage for some initialization operations, e.g., SDN controller can assign initial values to SIMA through RP 2.

– RP 3 represents the reference point between MATs and SIMA within the same ESDP node. RP 3 is used by MATs at run-time to realize the stateful forwarding and processing.

  1) When a MAT processes a packet, some relevant information needs to be recorded in the SIMA through RP 3 to assist the subsequent processing of other MATs in the MAT pipeline.

  2) Each MAT in a MAT pipeline may need to access information related to some network events (e.g., UE state) when processing an event packet, accompanying read and write operations on the SIMA through RP 3.

– RP 4 represents the reference point between MATs in different ESDP nodes. The event packets are propagated through RP 4, then the RP 4 provides an interface for ESDP nodes to share the information of network events.

8.4 Workflow

Figure 8-4 illustrates the workflow of ESDP.

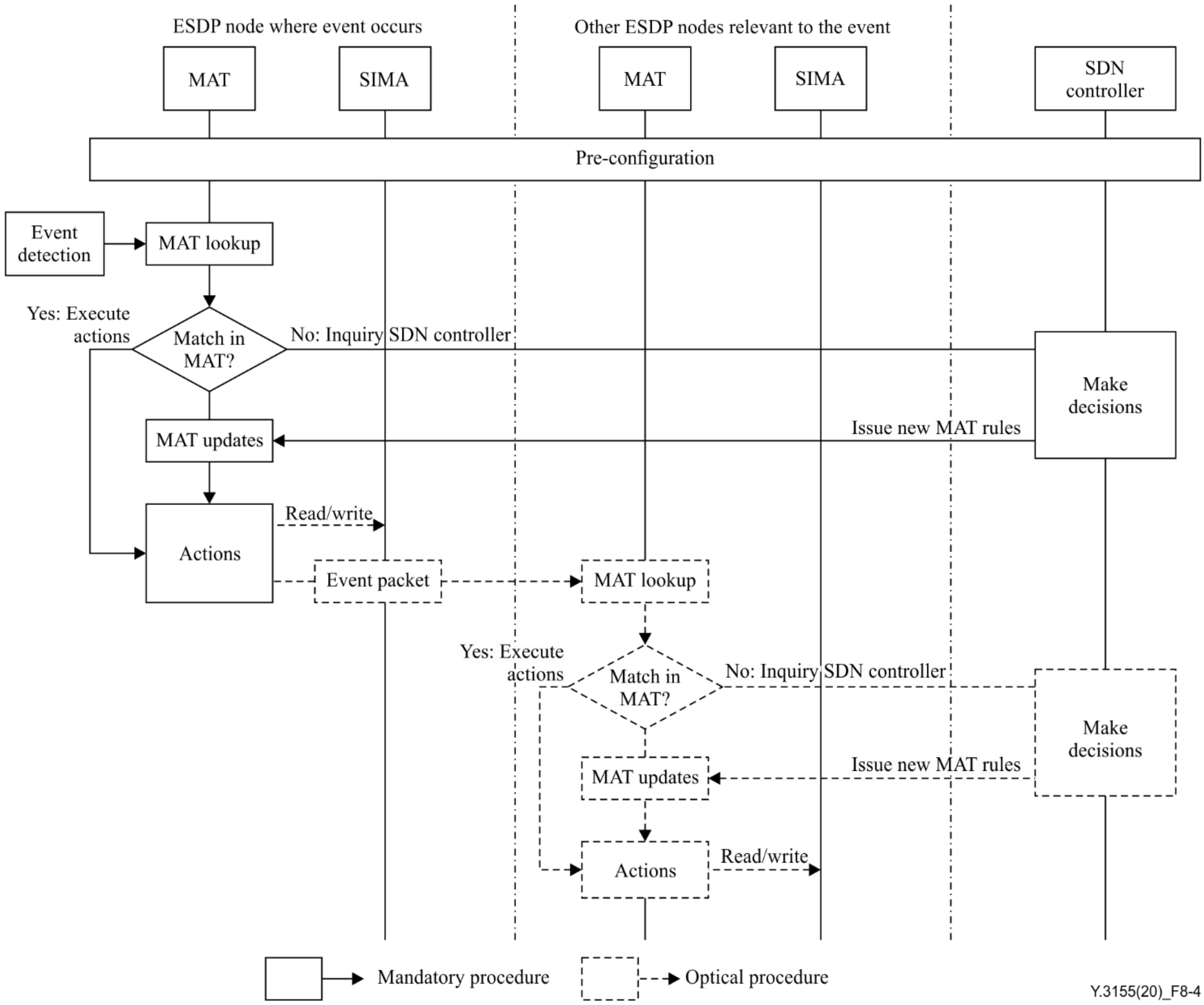


Figure 8-4 – Workflow of enhanced SDN data plane

The workflow includes the following steps, which can be grouped into two stages: pre-configuration and run-time.

Pre-configuration stage

In the pre-configuration stage, the SDN controller does the following for each ESDP node:

1) It defines a set of network events which may happen in the ESDP node. For each network event, it specifies:

   a) the matching conditions of the event,

   b) the impact scope of the network event, i.e., a collection of ESDP nodes (maybe only one) which need to process the network event,

   c) the actions invoked by the event, including local actions and whether it is needed to construct and send an event packet to other nodes in the impact scope (if so, the event packet format needs to be determined too).

2) It determines the response actions for each event packet the ESDP node may receive.

NOTE 1 – Receiving an event packet is also a kind of network event for an ESDP node.

3) It translates the above logic into MAT rules, and issues them to the ESDP node.

4) It configures initial values to SIMA.

NOTE 2 – Due to network topology and control policy, different ESDP nodes may receive different configuration messages. When the user requirements or network policy changes, the ESDP nodes can be re-configured.

Run-time stage

After the pre-configuration stage, all the actions of ESDP nodes can be triggered by event packets or event messages. At run time, if an ESDP node receives a data packet or event packet from other nodes, or an event message from an internal logical port within the same node, it will look up its MATs. If one or more MAT entries are matched, corresponding actions will be executed. If there are no matching entries, which means an undefined network event occurs, ESDP node will make an inquiry to the SDN controller for instructions.

An action invoked by a MAT entry may involve operations (mainly read and write) for the SIMA. State information related to network events can be stored in SIMA and be read on demand to assist the event handling.

9 Security considerations

This Recommendation describes the requirements and architecture of ESDP for future networks including IMT-2020. Therefore, general network security requirements and mechanisms in SDN-based networks should be applied [ITU-T Y.3101] and [ITU-T Y.3300].

It is required to prevent unauthorized access to and data leak from the CP, whether or not there is a malicious intention, with the implementation of mechanisms regarding authentication, authorization, external attack protection, etc. Moreover, the event packet mechanism can be a target of malicious attacks, thus special protection is required to make the sensitive event packet flow to be identified and transferred in a more secure manner, e.g., with security protocols.

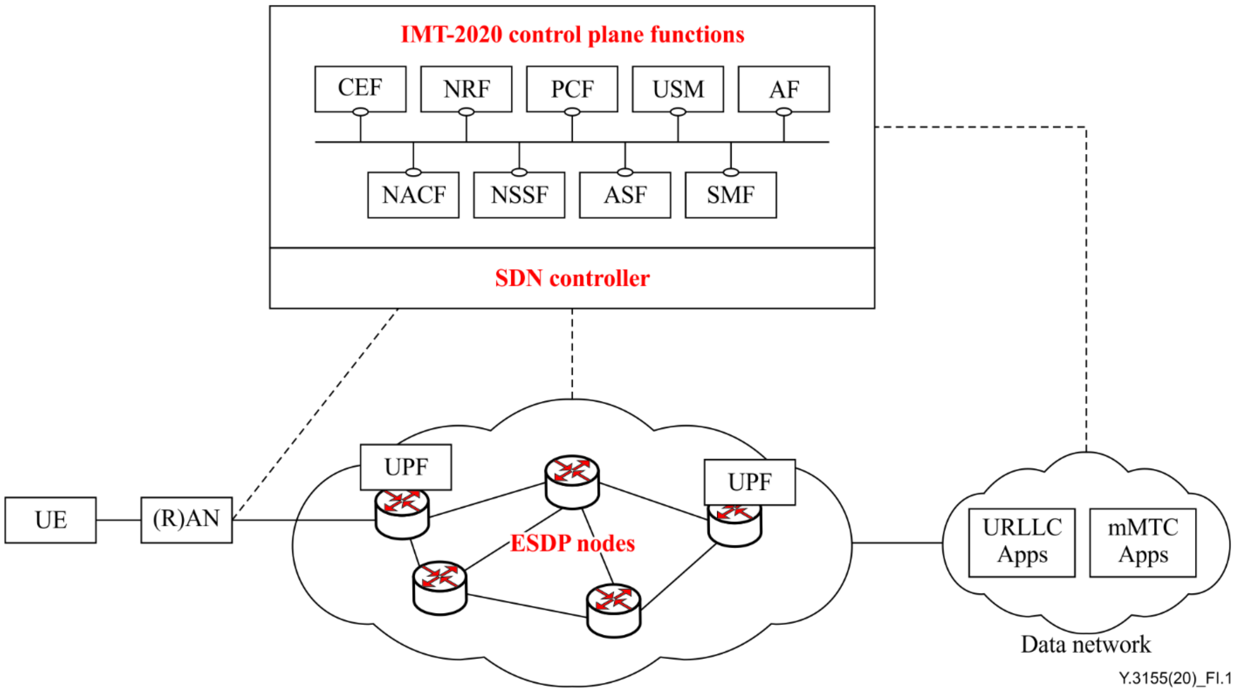
Appendix I

Application of enhanced SDN data plane in the IMT-2020

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

This appendix explores a possible way to apply ESDP to the IMT-2020 network and discusses how the typical IMT-2020 applications can benefit from the ESDP. Figure I.1 illustrates the process of ESDP integration in the IMT-2020 network.

I.1 ESDP integration in IMT-2020



(AF: Application Function; Apps: Applications; CEF: Capability Exposure Function; NFR: Network Function Repository; NSSF: Network Slice Selection Function; PCF: Policy Control Function; (R)AN: (Radio) Access Network; UPF: User Plane Function; USM: Unified Subscription Management)

Figure I.1 – ESDP integration in the IMT-2020 network

IMT-2020 network supports the complete separation between CP (which takes care of the user connection management, as well as defining the quality of service (QoS) policies, performing user authentication, etc.) and user plane (UP) (which deals with data traffic forwarding). By introducing a SDN controller in the middle, the CP and UP separated architecture of IMT-2020 and SDN can be integrated naturally.

Benefiting from the fully network programmability, some ESDP nodes can be selected and treated for particular roles (e.g., a data plane gateway, a regular transit router or switch) to perform forwarding, encapsulation, traffic steering or any needed operations, therefore the UP functions of IMT-2020 network can be easily supported by the ESDP nodes.

When considering a narrowly defined SDN controller, which is only responsible for networking functionalities such as underlying physical network monitoring, topology discovery, data plane elements configuration, etc., the IMT-2020 network CP NFs, e.g., ASF, NACF , etc., can be mapped to the application plane in SDN. In an IMT-2020 network adopting a service-based architecture, each CP NF service instance can be resolved into a series of network procedures, which can impact Match+Action rules to be programmed in the ESDP.

The IMT-2020 CP NF instances can be deployed in cloud servers (core or edge) and communicate with SDN controller through APIs or can be integrated and co-deployed with an SDN controller. In the latter deployment scenario, the translation between NF service procedures and ESDP instructions is done inside the CP. In both deployment scenarios, applications (mMTC, URLLC applications, etc.) can provide their requirements with IMT-2020 network, and can then influence ESDP behaviours such as traffic routing.

NOTE – IMT-2020 provides dedicated function modules and interfaces for the interaction between applications and the network, via which the network can expose its capabilities to the applications and the applications can request and access network resources. Relevant functions, interfaces and procedures are defined in [ITU-T Y.3104], [b-3GPP TS 23.501] and [b-3GPP TS 23.502].

I.2 IMT-2020 applications benefiting from ESDP

The ESDP can be introduced in IMT-2020 networks to provide the SDN data plane with capabilities to be aware of and process real-time network state information, and thus the applications can arbitrarily define functions and delegate them along the IMT-2020 datapath. Therefore, the ESDP can instantly react to defined network events automatically, without the necessity of querying the SDN controller. This mechanism can benefit the IMT-2020 applications mainly in two aspects: delay minimization and signalling reduction.

– Delay minimization:

  During application operations, the ESDP can reduce the interaction between SDN data plane and SDN controller, thus the delay introduced by this interaction can be reduced. Therefore, the ESDP can benefit the applications with extremely delay-sensitive scenarios such as URLLC, some of which require 1~10 ms end to end (E2E) delay [b-3GPP TR 22.891].

  NOTE 1 – The use case 1 in Appendix II shows how the ESDP can support user mobility and session continuity without the help of IMT-2020 CP functions. This can apply in URLLC scenarios in order to meet the requirements of ultra-low latency.

– Signalling reduction:

  In mMTC scenarios, a huge number of devices (even with low data rate) result in flooded signalling messages when establishing, managing and releasing connections. Therefore, mMTC applications require the IMT-2020 networks to avoid frequent signalling exchanges [b-3GPP TR 23.724]. Via reasonable pre-configuration, the ESDP can significantly reduce signalling overheads of the IMT-2020 networks by: 1) reducing control messages between SDN data plane and SDN controller 2) delegating some of the IMT-2020 CP functions to underlying UP nodes (ESDP-enabled nodes), which can avoid establishing and releasing session connections frequently.

  NOTE 2 – The use case 2 in Appendix II shows how ESDP can realize a connectionless data transmission in mMTC scenarios to reduce signalling exchange introduced by session establishing, managing, and releasing.

The IMT-2020 networks can offer network slices [b-ITU-T Y.3112] with different capabilities to support various applications. Network operators and users can define and install different data plane functions along the datapath in different network slices. For example, slices for URLLC applications may install some functions in the data plane nodes to ensure the "extremely high reliability" and "extremely low latency". Slices for mMTC applications mostly concentrate on "massive device management" and "signalling load minimization" and may install related data plane functions to ensure them.

NOTE 3 – Beside the IMT-2020 networks, the ESDP can be applied in general in SDN enabled networks to enhance the network flexibility and efficiency. In Appendix II, the use case 3 shows the advantage of ESDP in terms of quick network failure handling.

Appendix II

Potential use cases supported by ESDP

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

This appendix provides three typical use cases of ESDP. Use case 1 shows how the ESDP can support user mobility and session continuity without the help of IMT-2020 CP functions. Use case 2 shows how ESDP can realize a connectionless data transmission in mMTC scenarios to reduce signalling exchange. Use case 3 shows the advantage of ESDP in terms of quick network failure handling in general SDN networks.

II.1 Use case 1: Mobility support with ESDP

Figure II.1 shows a configuration of network topology where A, B, C and D are ESDP nodes. Wireless access points (WAP) 1 and 3 are connected to B. WAP 2 and WAP 4 are connected to C. WAP 5 is connected to D. A moving UE may experience handovers between WAPs while enjoying on-line gaming or other real-time services that have stringent delay requirement. In this use case, the ESDP detects the UE movement and backs up the application data to the WAP that the UE is about to attach to after the handover. Thus, the data loss and retransmission due to UP tunnel switching can be avoided and the service continuity can be guaranteed. The main procedures are as follows:

1) Before data transmission begins, the application server sends a notification message containing UE ID to relevant ESDP nodes. After receiving the message, ESDP nodes record the UE ID in SIMA and start the tracking mechanism for the UE.

2) By detecting the Non-Access-Stratum messages between WAPs (authorization from network operator is required), ESDP node B, C and D can learn which WAP the UE will be handed over to, and send an event packet containing the target WAP address to branching ESDP node A.

3) Based on event packets from B, C and D, node A uses two SIMA blocks to record values of parameters *Cur_WAP* and *Tar_WAP*, indicating the IDs of WAP that the UE is currently attached to and the WAP that the UE is moving towards, respectively. When receiving application data packet destined to this UE, node A will read the values of these two parameters and forward two copies of the packet to both WAPs that the parameters refer to.

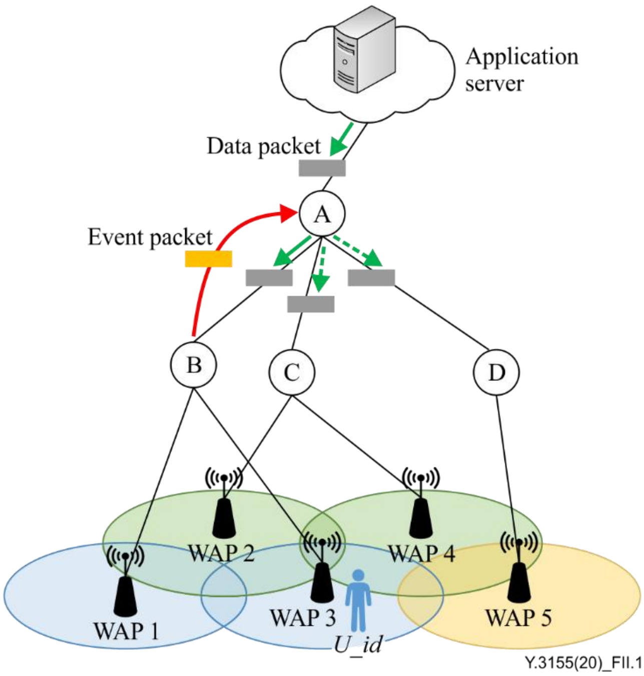


Figure II.1 – Use case of mobility support with ESDP

The examples of MAT and SIMA in node A are given below:

MAT	
Receive data packet destined to *UE_ID* && *Tar_WAP* is not 0	Forward packet to *Cur_WAP* and *Tar_WAP*
Receive event packet from B, C, D	Modify *Cur_WAP* and *Tar_WAP*
...	...

SIMA
UE_ID = *U_id*
Cur_WAP = 3
Tar_WAP = 4
...

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Figure II.2 – Examples of MAT and SIMA in ESDP node A

II.2 Use case 2: Connectionless data transmission with ESDP

Figure II.3 depicts a group of mMTC UEs (e.g., thermometers, electric meters, etc.) that transmits sporadic (frequent or infrequent, potentially small amount) data. As shown in the figure, data generated by the UEs will be transmitted and stored in a remote data centre. In the IMT-2020 networks, the normal practice to transmit an application data packet is based on a connection. This involves the setup and management of a protocol data unit (PDU) session for transmission (including radio bearer and a tunnel in the UP), which introduces dozens of signalling messages each time in the network [b-3GPP TS 23.502].

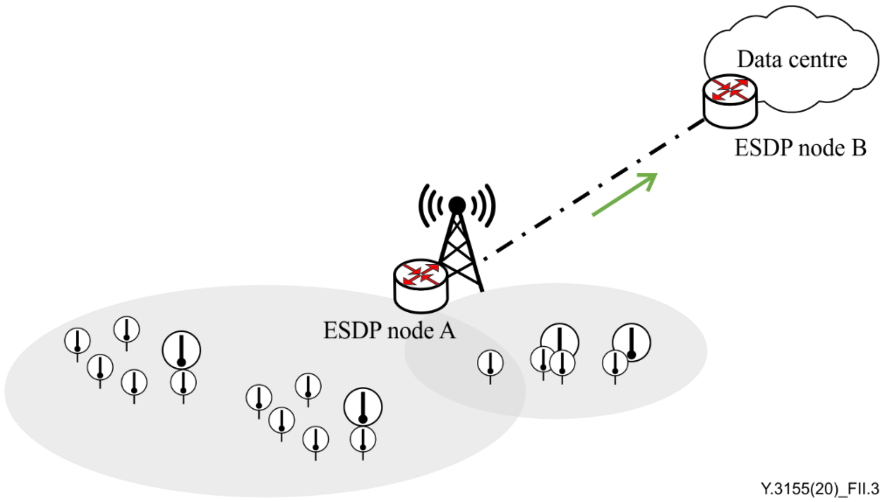

Figure II.3 – Use case of connectionless data transmission with ESDP

ESDP can realize a connectionless data transmission which can avoid the signalling exchanges in setting-up, managing and releasing a PDU session. The key points are as follows:

1) When a UE (both mMTC and other ordinary UEs) needs to send data, a PDU session establishment request will be sent to the network CP via the (R)AN. For mMTC UEs, the data is directly attached in the request packet (data volume generated by an mMTC UE at one time is usually small, e.g., a temperature value) as payload, and two fields are added to the packet header to indicate: a) this packet is an mMTC packet; b) the destination address (address of the data centre) of this packet.

2) By pre-configuration, the ESDP nodes attached to the (R)AN (e.g., nodes A in Figure II.2) can identify the attribute field and stop the general procedures of PDU session establishment, then start the predefined process flow for mMTC packets as in 3).

3) Edge ESDP node reconstructs the mMTC packet into a normal data packet, deleting the irrelevant fields and keeping the data payload, then forwards it directly to the destination nodes based on the address in the packet header.

II.3 Use case 3: Failure handling with ESDP

When a link fails in the network, ESDP can detect the failure and then automatically quickly switch the traffic to an alternate path. In the network topology depicted in Figure II.4, the default forwarding path from A to C is set as A-B-C (①). If the link between B and C crashes, ESDP will lead the traffic to an alternative path A-E-D-C (②) as soon as the failure is detected, without any path updating instruction from the SDN controller. The procedures are described below:

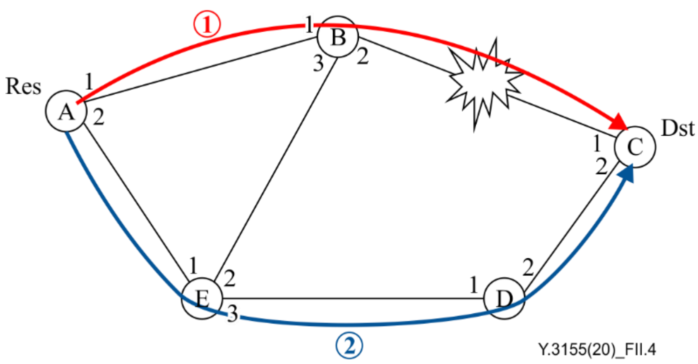

Figure II.4 – Use case of failure handling with ESDP

1) Each ESDP node in the network monitors the connectivity of direct connected links periodically. When B is aware of the failure of the link between itself and C, an event packet will be constructed and sent to relevant branching nodes, node A in this use case.

2) In SIMA of node A, certain blocks are reserved to keep parameters indicating the connectivity of relevant links, e.g., parameter *CC_BC* with initial value 1 indicates the connectivity of the link between node B and C. When A receives the event packet from B, the value of parameter *CC_BC* will be modified to 0.

3) When node A receives packets destined to C, it will look up the MAT (shown in Figure II.4) and execute the corresponding action, i.e., forwarding the packet through port 2.

MAT	
Destination == C && *CC_AB* == 1 && *CC_BC* == 1	Forward → 1
Destination == C && (*CC_AB* == 1 && *CC_BC* == 1) == false && (*CC_AE* == 1 && *CC_ED* == 1 && *CC_DC* = 1) == true	Forward → 2
...	...

SIMA
CC_AB = 1
CC_BC = 0
CC_AE = 1
CC_ED = 1
CC_DC = 1
...

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Figure II.5 – Examples of MAT and SIMA in ESDP node A

In traditional SDN networks, switching nodes cannot learn the information of non-directly connected links without the controller. That is, node A cannot know the link failure between B and C and will forward the received packets through port 1 as before, so the failure recovery mechanism cannot be activated until the packets reaches node B. ESDP can redirect the packets in advance of failure point to plan better alternate paths.

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