Draft Recommendation ITU-T Y.IMT2020-fa-lg-lsn

Functional Architecture for latency guarantee in large scale networks including IMT-2020 and beyond

Summary

Latency sensitive applications across multi-domain large scale network emerge, such as autonomous driving, augmented reality, virtual reality, tactile internet, and smart industry. ITU-T Y.3113 describes the requirements and framework for latency guarantee in large scale networks. ITU-T Y.3113 combines the FA-based queuing and scheduling architecture and the regulators at the aggregation domain (AD) boundaries. Because of its novel framework, Y.3113 requires its own procedures, functional entities, interfaces, and overall architecture. At the network design phase, the boundaries of ADs should be decided. The size of an AD is a key network design parameter. It affects the number of FAs, number of flows in an FA, the number of regulators, and the end-to-end (E2E) latency bound itself. In the call setup phase, given the traffic specification of a flow, the E2E latency bound must be pre-calculated with the cooperation among ADs. An FA may have flows join/leave dynamically, therefore it is necessary to re-negotiate the E2E latency bounds with the sources of flows in the FA. This is called the dynamic QoS negotiation.

In the Internet or the IMT-2020 network there are inevitably multiple network domains, with possibly different QoS frameworks. For example, in the IMT-2020 networks access networks (ANs), core networks (CNs), and the network slices ranging across CNs have different QoS provisioning architecture. The fronthaul network of the IMT-2020 may have Ethernet based architecture with the IEEE 802.1 TSN profile that requires class-based strict priority scheduling, token bucket type flow metering, and frame pre-emption, while core networks may be based on MPLS and DiffServ architecture with metering functions at the edge and class-based schedulers. It is necessary to cope with such different types of edge networks.

Further, with network slicing technology emphasized in IMT-2020 and beyond, the link and buffer resource should be strictly and dynamically divided and allocated to virtual networks according to the slicing requests. Resource allocation negotiations among different networks should be plausible.

In this Recommendation it is described the architecture, the functional entities, the interfaces, and the procedures including the cooperation among heterogeneous QoS network domains.

Keywords

Latency guarantee, large scale network, flow aggregate, quality of service, regulator

Table of Contents

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1 Scope

This Recommendation specifies the architecture and procedures for latency guarantee in large scale networks, based on the requirements and framework specified in ITU-T Y.3113, as follows:

- Architecture
- Functional entities and their interfaces
- Procedures for the aggregation domain design, the call setup, the dynamic QoS negotiation, etc.

Detail protocols, routing and upper layer functions are out of scope of this Recommendation. If necessary, the document will, instead, reference the existing works appropriately.

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-R M.1645] Recommendation ITU-R M.1645 (06/2003), *Framework and overall objectives of the future development of IMT-2000 and systems beyond IMT-2000*.

[ITU-R M.2083] Recommendation ITU-R M.2083-0 (09/2015), *IMT Vision – Framework and overall objectives of the future development of IMT for 2020 and beyond*.

[ITU-T E.800] Recommendation ITU-T E.800 (09/2008), *Definitions of terms related to quality of service*.

[ITU-T Y.2111] Recommendation ITU-T Y.2111 (2006), *Resource and admission control functions in Next Generation Networks.*

[ITU-T Y.2121] Recommendation ITU-T Y.2121 (2008), *Requirements for the support of flow-state-aware transport technology in NGN*.

[ITU-T Y.2122] Recommendation ITU-T Y.2122 (2009), *Flow aggregate information exchange functions in NGN.*

[ITU-T Y.3102] Recommendation ITU-T Y.3102 (2018), *Framework of the IMT-2020 network.*

[ITU-T Y.3113] Recommendation ITU-T Y.3113 (2021), *Requirements and framework for latency guarantee in large scale networks including IMT-2020 network.*

3 Definitions

3.1 Terms defined elsewhere

This Recommendation uses the following terms defined elsewhere:

3.1.1 IMT-2020 [ITU-R M.2083]: Systems, system components, and related technologies that provide far more enhanced capabilities than those described in [ITU-R M.1645].

NOTE – [ITU-R M.1645] defines the framework and overall objectives of the future development of IMT-2000 and systems beyond IMT-2000 for the radio access network.

3.1.2 customer premises equipment [ITU-T E.800]**:** Telecommunications equipment located at the customer installation on the customer side of the network interface.

3.1.3 service provider [ITU-T E.800]**:** An organization that provides services to users and customers.

3.2 Terms defined in this Recommendation

This Recommendation defines the following terms:

3.2.1 aggregation domain: A maximal set of the interfaces of the consecutive relay nodes in the path, travelled by a flow, in which the 'flow membership' of the flow aggregate the flow belongs to is unaltered. An aggregation domain is defined per a flow.

3.2.2 domain: A set of relay nodes and end-hosts under a single administrative control or within a closed group of administrative control; these include campus wide networks, private WANs, and IMT-2020 networks.

NOTE – This definition references the description in Introduction clause of [b-IETF RFC 8655].

3.2.3 large scale network: A network or a set of networks, whose longest end-to-end path includes 16 or more relay nodes.

3.2.4 relay node: A node supporting relay functionality that acts as an intermediary node, through which other nodes can pass their traffic (e.g. router, switch, gateway, etc.).

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

5QI	5G QoS Identifier
AD	Aggregation Domain
AN	Access Network
ATS	Asynchronous Traffic Shaping
CN	Core Network
CPE	Customer Premises Equipment
DiffServ	Differentiated Services
DL	Downlink
DN	Data Network
E2E	End-To-End
FA	Flow Aggregate
GBR	Guaranteed Bit Rate

GFBR	Guaranteed Flow Bit Rate
IntServ	Integrated Services
IR	Interleaved Regulator
MDBV	Maximum Data Burst Value
MFBR	Maximum Flow Bit Rate
NGBR	Non-GBR
PDB	Packet Delay Budget
PDU	Protocol Data Unit
QFI	QoS Flow ID
QoS	Quality of Service
RSpec	Request Specification
SDF	Service Data Flow
SMF	Session Management Function
TDM	Time Division Multiplexing
TSN	Time Sensitive Network
TSpec	Traffic Specification
UE	User Equipment
UL	Uplink
UPF	User Plane Function
uRLLC	Ultra-Reliable Low Latency Communications

5 Conventions

None.

6. Introduction

[Editor's Note: any contributions to further improve or fill any missing gaps are invited.]

Latency sensitive applications across multi-domain large scale network emerge, such as autonomous driving, augmented reality, virtual reality, tactile internet, and smart industry. ITU-T Y.3113 describes the requirements and framework for latency guarantee in large scale networks.

ITU-T Y.3113 combines the FA-based queuing and scheduling architecture and the regulators at the aggregation domain (AD) boundaries. The framework requires its own procedures, functional entities, interfaces, and overall architecture to be specified. At the network design phase, the boundaries of ADs should be decided. The size of an AD is a key network design parameter. It affects the number of FAs, number of flows in an FA, the number of regulators, and the end-to-end (E2E) latency bound itself. FA granularity should be also decided. In the call setup phase, given the traffic specification of a flow, the E2E latency bound must be pre-calculated with the cooperation among ADs. An FA may have flows join/leave dynamically, therefore it is necessary to re-negotiate the E2E latency bounds with the sources of flows in the FA. This is called the dynamic QoS negotiation.

In the Internet or the IMT-2020 network there are inevitably multiple network domains, with possibly different QoS frameworks. For example, in the IMT-2020 networks access networks (ANs), core networks (CNs), and the network slices ranging across CNs have different QoS provisioning architecture.

Further, with network slicing technology emphasized in IMT-2020 and beyond, the link and buffer resource should be strictly and dynamically divided and allocated to virtual networks according to the slicing requests. Resource allocation negotiations among different networks should be plausible.

In this Recommendation it is also described the cooperation among heterogeneous QoS network domains in the framework.

7 High level functional architecture

7.1 Aggregation domain (AD)

An aggregation domain is defined per a flow. As it is defined in clause 3.2.1, an AD is a maximal set of the interfaces of the consecutive relay nodes in the path, travelled by a flow, in which the 'flow membership' of the flow aggregate the flow belongs to is unaltered. There should be one or more non-overlapping aggregation domains (ADs) in an end-to-end path of a flow. Based on the FA, the queuing, scheduling, and regulation are executed. An important consequence of such treatment based on FA is that the FIFO characteristic of the FA is maintained within an AD. Requirement 7 in ITU-T Y.3113 specifies that it is required that networks be able to handle FAs as control elements. This requirement mandates the network relay nodes should be able to queue and schedule a packet according to FA. However, in an extreme case in which flows are treated based on their class, such as in DiffServ, an AD is limited to a single interface of a node. In this case, the membership of an FA is unaltered only for a single hop. Note that this case still meets the requirement 7 in ITU-T Y.3113.

For example, flows with an identical path may have different ADs. An AD may have a regulation function at its segregation point. Figure 1 a scenario in which the flows with the same path (flow 1 and 2) are put into different FAs thus have different ADs.

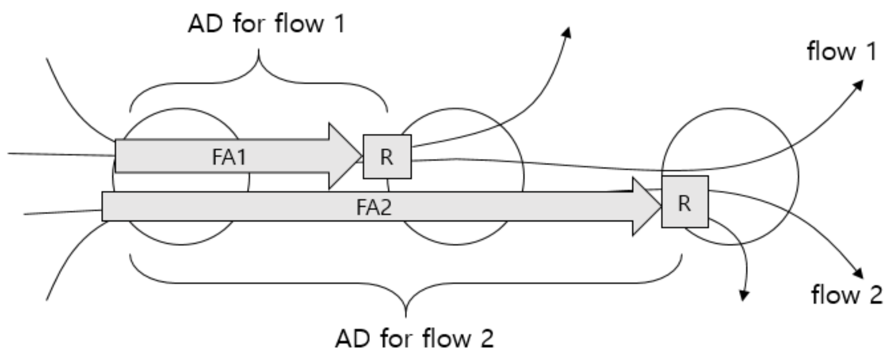

Figure 1 – Aggregation domain for each flow

In reality, the flows with the same path and similar traffic specifications are likely to belong to a single FA and have an identical AD.

7.2 Aggregation point of an AD

An aggregation point of an AD is defined to be a functional entity, at which the flow is aggregated into an FA. An aggregation point is defined per flow. An exemplary location of an aggregation point is an output port of a relay node. An aggregation point is part of an AD.

7.3 Segregation point of an AD

A segregation point of an AD is defined to be a functional entity, at which the FA is segregated. The flows are separated into different output path. A segregation point is defined per flow. An exemplary location for a segregation point is an input port (or a switch fabric) of a relay node. A segregation point is part of an AD.

7.3 Location of regulation functions

A regulation function is recommended to be collocated with the segregation point of an AD. By placing a regulation function with the FA segregation, the FIFO characteristic of the AD for the flows can be kept before the regulation. However, the regulation function may be omitted for an AD; or the regulation functions may be placed anywhere in an AD.

7.5 Relay node capability

The relay nodes may have incomplete transport functionality. For example, a legacy node does not have the FA based scheduling or the regulation function. The FA based scheduling function is required to guarantee both 1) the FIFO characteristic among the packets within an FA and 2) the isolation of an FA with a separated queue. A simple FIFO scheduler with a single queue, as well as a weighted fair queuing scheduler with separated queues, would guarantee the FIFO characteristic for any FA. However, a FIFO scheduler can accumulate the maximum burst of FAs sharing the queue. If a cycle is formed by relay nodes with such FIFO schedulers, one cannot guarantee a latency bound. As such, it is required the FA based scheduling support the FA isolation.

Based on the supporting functions, relay nodes are categorized as the following

- CAT 0: A relay node without the FA based scheduling or the regulation function.
- CAT 1: A relay node with the FA based scheduling but without the regulation function.
- CAT 2: A relay node with the regulation function but without the FA based scheduling
- CAT 2-1: A relay node dedicated for the regulation function. This type of relay nodes does not have the switching capability.
- CAT 3: A relay node with both the FA based scheduling and the regulation function.

7.6 Regulation function capability of a node

The regulation functions reside in relay nodes, or placed in separated physical devices. It may be available only in limited relay nodes. It is preferable that a regulation function is collocated with the segregation point of an AD. The location information of the regulation functions is preferable to be gathered prior to an AD design. This information is gathered through a dedicated interface with an automated procedure or manually. The regulation function, however, is independent of flow aggregation/segregation functions. The regulation functions may also be placed at the middle of an AD.

7.7 Regulation function taxonomy

A regulation function is categorized based on its queue and the regulation target. A per flow regulation function has queues per flow and regulates based on a flow-level regulation rule. An interleaved regulator (IR) has a single queue and is based on a flow-level regulation rule. An IR examines the packet at the head of queue, checks the flow it belongs, and determines when to transmit the packet. A per FA based regulator has a single queue for the FA, and the regulation rule is obtained from the sum of flows' arrival rates.

8 Mechanisms and operation procedures

[Editor's Note: This clause is currently a rough draft. Further refinement is necessary]

8.1 AD decision

The ADs have to be determined with considerations of many aspects. The size of an AD decides the number of the boundary ports of the AD, therefore the number of input-output ports pairs of the AD, and the number of FAs within the AD. Smaller the AD, fewer FAs, fewer queues necessary, thus simpler the network schedulers. On the other hand, smaller AD means more ADs in the path, larger the latency bound. The balanced point in between has to be determined in the network design phase. As the network state dynamically changes, AD merge and division should also be possible.

8.2 AD alteration

Aggregation domain may be merged or divided anytime. The ADs have to be determined with considerations of many aspects. The size of an AD decides the number of the boundary ports of the AD, therefore the number of input-output ports pairs of the AD, and the number of FAs within the AD. Simply put, smaller the AD, fewer FAs, fewer queues necessary, thus simpler the network schedulers. On the other hand, smaller AD means more ADs in the path, larger the latency bound. The balanced point in between has to be determined in the network design phase or during the runtime. As the network state dynamically changes, AD merge and division is recommended to be possible.

8.3 FA granularity decision

[Editor's Note: One of the requirements for the framework is that the flows with different in/out port pairs should belong to different FAs. Flows with the same in/out port pairs may or may not belong to a same FA. More criteria, such as latency bound requirements or maximum burst size may be considered for FA granularity. Finer granularity means better performance but more complexity.]

- FA granularity negotiation among AD should be possible.

8.4 Call setup

[Editor's Note: The call setup mechanism includes the admission control and resource reservation. They are covered in numerous standards such as IETF RSVP and ITU-T Y.2111 (RACF). RSVP has the path-coupled (in-band) control mechanism, while RACF has specific interfaces between control function entities (out of-band). It should be considered in the framework that the AD and the administrative domain may not identical.]

- Network may provide to the flow multiple latency bounds to choose. The flow may select one of them.

- The TSpec may include token bucket parameters (a burst size and an input rate), a peak rate (p), and a maximum datagram size (M). If a packet is larger than M, then it may not receive the same service with the conforming packets.
- Upon the flow admission request, the end-to-end path should be decided; and the guaranteed performance level should be calculated and notified to the flow.
- Existing best-effort service traffic should not affect the latency bound of the high priority flows. Network should aware of the best-effort service traffic and take it into consideration.

- For another example, the QoS provisioning is based on the network allowance. This means that an individual flow does not specify their latency bound requirement (RSpec in IntServ). Rather, as a flow specify traffic specification (for example the burst size and the input rate), then based on the best end-to-end path among those can be provided, the feasible latency bound is calculated and notified to the flow. The flow decides to accept or not.
- Interactions among supporting domains (or “Transport network” in the following figure) should be possible. There are two scenarios for passing the QoS information for a given service over an end-to-end path. [Y.2111 RACF]

1) In scenario 1, the QoS requirements and information for a given flow’s service can be passed over the end-to-end path through application layer signalling or through the Ri reference point between RACF.

2) In scenario 2, the QoS requirements for a given service can be passed over the end-to-end path through path-coupled QoS signalling (e.g., RSVP-like).

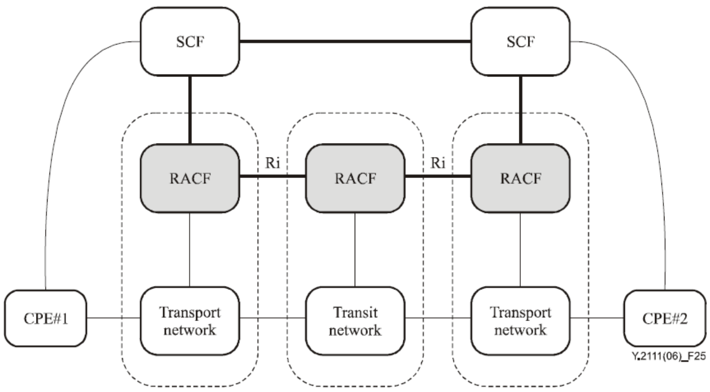

Figure 25/Y.2111 – Inter-operator RACF communications

8.5 Dynamic QoS negotiation

[Editor’s Note: The IntServ’s admission control is static. It guarantees a fixed service rate to a flow during its lifetime. It is simple but may under-utilize the network. It is required in the framework the dynamic QoS negotiation. The network or the end-host may initiate the re-negotiation. A single flow’s renegotiation may result in all the other flows renegotiation. As such this process must be executed with care.]

- The service level negotiation can be two-way handshake, or more complex process.

- The simplest negotiation is that of the IntServ. Flow specifies its Request-spec and Traffic-spec. Network decides whether it is met. If not denies the admission.
- Latency budget negotiation should be possible.
- Dynamic admission control information exchange should be possible. (Current flow's latency guarantee status)
- If first negotiation failed, the flow may restart with a new TSpec.

9 Architecture

[Editor's Note: This clause is currently a rough draft. Further refinement is necessary]

An example network for the description of the proposed framework is depicted in Figure 8.1, in which

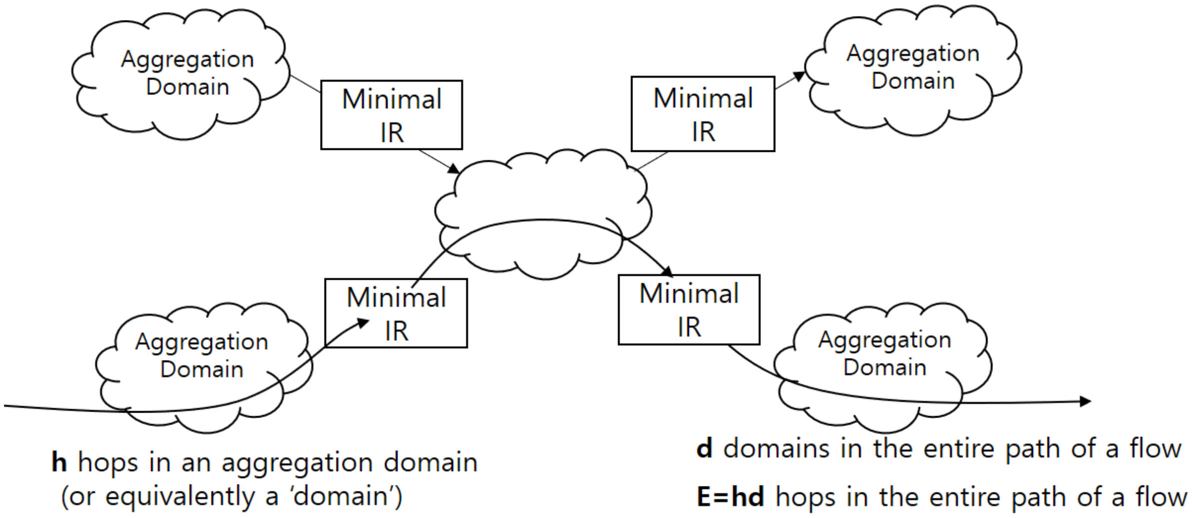

Figure 2 – An example network architecture of the framework.

minimal IRs are implemented between the aggregation domains (or equivalently 'domains' in this Recommendation). Note that other types of regulation functions are also allowed. Assume the internetwork in Figure 2 is perfectly symmetrical. A flow travels d domains, with identically h hops in a domain, which further makes the total number of hops the flow travels is $E=hd$. The critical design choice in this architecture would be the value of h (and thus d), given E.

10 Functional Entities

11 Reference points

12. Security Considerations

The QoS management of IMT-2020 network includes UE, ANs, and CN that are subject to security and privacy measures. Sensitive information should be protected as a high priority in order to avoid leaking and unauthorized access. Security and privacy concerns should be aligned with the requirements specified in [b-ITU-T Y.2701] and [b-ITU-T Y.3101].