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SERIES G: Transmission systems and media, digital systems and networks

Supplements to ITU-T G-series Recommendations

Optical line termination capabilities for supporting cooperative dynamic bandwidth assignment

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Supplement 71 to ITU-T G-series Recommendations

Optical line termination capabilities for supporting cooperative dynamic bandwidth assignment

Summary

Supplement 71 to ITU-T G-series Recommendations describes the passive optical network optical line termination or passive optical network (PON) OLT capabilities needed for applying cooperative dynamic bandwidth assignment (CO DBA) both in a generic sense and for specific use cases. It explains the interactions of the optical line termination (OLT) with the external entity sending information for CO DBA, the way to interpret such information, and the needs for coordination on choosing values for configurable parameters. The specific use case described in this version of the Supplement is mobile fronthaul (MFH) over PON by using O-RAN's cooperative transport interface (CTI) for the interaction between the PON OLT and mobile distributed units (DUs).

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Optical line termination capabilities for supporting cooperative dynamic bandwidth assignment

1 Scope

This Supplement considers the use of cooperative dynamic bandwidth assignment (CO DBA) in a passive optical network (PON) optical line termination (OLT). The expected OLT capabilities are identified, and their functional role explained. This Supplement considers generic and use case related capabilities. The use case described in this first version of the Supplement is the support of mobile fronthaul (MFH) using the O-RAN cooperative transport interface (CTI) as the interface between the OLT and mobile distributed units (O-DU); see clause 8. Other use cases can be part of future revisions of this Supplement.

2 References

None.

3 Definitions

3.1 Terms defined elsewhere

This Supplement uses the following terms defined elsewhere:

3.1.1 CTI client [b-O-RAN CTI TC]: A process in the O-DU that exchanges CTI messages to one or multiple CTI servers, e.g., to request a given transport capacity.

3.1.2 CTI server [b-O-RAN CTI TC]: A process in the transport node that exchanges CTI messages with one or multiple CTI clients, e.g., to receive capacity requests.

3.1.3 dynamic bandwidth assignment (DBA) [b-ITU-T G.987]: A process by which the OLT distributes upstream PON capacity between the traffic-bearing entities within ONUs, based on dynamic indication of their traffic activity and their configured traffic contracts.

3.1.4 mobile slot [b-O-RAN CTI TC]: A subframe in 3GPP LTE or a slot in 3GPP NR.

3.1.5 optical distribution network (ODN) [b-ITU-T G.987]: A point-to-multipoint optical fibre infrastructure. A simple ODN is entirely passive and is represented by a single-rooted point-to-multipoint tree of optical fibres with splitters, combiners, filters, and possibly other passive optical components. A composite ODN consists of two or more passive segments interconnected by active devices, each of the segments being either an optical trunk line segment or an optical distribution segment. A Passive optical distribution segment is a simple ODN itself. Two ODNs with distinct roots can share a common subtree.

3.1.6 optical network unit (ONU) [b-ITU-T G.987]: A network element in an ODN-based optical access network that terminates a leaf of the ODN and provides an OAN UNI.

3.1.7 passive optical network (PON) system [b-ITU-T G.9804.1]: A combination of network elements in an ODN-based optical access network that includes an optical trunk line (OLT) and one or more optical network unions (ONUs) and implements a particular coordinated suite of physical medium dependent layer, transmission convergence layer, and management protocols.

3.1.8 quiet window [b-ITU-T G.987]: A time interval during which the OLT suppresses all bandwidth allocations to in-service ONUs in order to avoid collisions between their upstream transmissions and the transmissions from ONUs whose burst arrival time is uncertain. The OLT opens a quiet window to allow new ONUs to join the PON and to perform ranging of specific ONUs.

3.1.9 ranging [b-ITU-T G.9807.1]: A procedure of measuring the round-trip delay between the optical line terminal (OLT) and any of its subtending optical network units (ONUs) with the objective to determine and assign the appropriate equalization delay, which is necessary to align the ONU's upstream transmissions on a common OLT based upstream frame reference. Ranging is performed during ONU activation and may be performed while the ONU is in service.

3.1.10 service node interface (SNI) [b-ITU-T G.902]: The Service Node Interface is an interface which provides access to a service node.

3.1.11 traffic-monitoring DBA (TM-DBA) [b-ITU-T G.987]: A method of dynamic bandwidth assignment that infers the dynamic activity status of the traffic-bearing entities within ONUs based on observation of idle XGEM frame transmissions during upstream bursts.

3.2.12 transmission container (T-CONT) [b-ITU-T G.987]: A traffic-bearing object within an ONU that represents a group of logical connections, is managed via the ONU management and control channel (OMCC), and, through its TC layer Alloc-ID, is treated as a single entity for the purpose of upstream bandwidth assignment on the PON.

3.2 Terms defined in this Supplement

This Supplement defines the following terms:

3.2.1 channel termination (CT): A logical function that resides at the OLT network element and that terminates a single time and wavelength division multiplexing (TWDM) channel in TWDM PON systems.

NOTE – By extension, in this Supplement it is also used for time division multiplexing PON or TDM PON systems, referring to a logical function that resides at the OLT network element and that terminates a single physical PON port.

3.2.2 optical network terminal: Historically used to denote an ONU supporting a single subscriber.

3.2.3 cooperative dynamic bandwidth assignment: A method of dynamic bandwidth assignment based on the transport- or application-level upstream scheduling information provided by the OLT-side external equipment, such as in a mobile network.

4 Abbreviations and acronyms

This Supplement uses the following abbreviations and acronyms:

CO DBA Cooperative Dynamic Bandwidth Assignment

CoS Class-of-Service

CT Channel Termination

CTI Cooperative Transport Interface

DBA Dynamic Bandwidth Assignment

DU Distributed Unit

FTTH Fibre To The Home

GNSS Global Navigation Satellite System

HARQ Hybrid Automatic Repeat request

IP Internet Protocol

LAA Licensed-Assisted Access

LBT Listen Before Talk

LTE	Long-Term Evolution
MFH	Mobile Fronthaul
NR	New Radio
O-CU	Open Central Unit
ODN	Optical Distribution Network
O-DU	Open Distributed Unit
OLT	Optical Line Termination
OMCI	Optical Network Terminal Management and Control Interface
ONT	Optical Network Terminal
ONU	Optical Network Unit
O-RU	Open Radio Unit
OSS	Operations Support System
PLOAM	Physical Layer Operation, Administration and Maintenance
PON	Passive Optical Network
PRC	Primary Reference Clock
PRTC	Primary Reference Telecom Clock
PTP	Precision Time Protocol
RAN	Radio Access Network
SCS	Sub-Channel Spacing
SFI	Slot Format Indicator
SNI	Service Node Interface
SR-DBA	Status Reporting DBA
T-CONT	Transmission Container
TDM	Time Division Multiplexing
T-GM	Telecom Grand Master
TLV	Type Length Value
TM-DBA	Traffic Monitoring DBA
TN	Transport Node
ToD	Time of Day
TU	Transport Unit
TWDM	Time and Wavelength Division Multiplexing
UDP	User Datagram Protocol
UE	User Equipment
UNI	User Network Interface

5 Conventions

None.

6 Introduction

Cooperative DBA (CO DBA) is a method to reduce the upstream latency in a PON when applying variable bandwidth allocations to follow a variable bitrate traffic pattern. It is based on the notification of information about this traffic from a different entity (e.g., a distributed unit (DU) in case of mobile fronthaul) to the OLT. With this information the OLT can apply targeted bandwidth allocations aimed to address the corresponding traffic volumes in corresponding time intervals as notified in the information.

This cooperation between the OLT and the other entity requires exchange of messages across a logical interface. For the use case of transport of mobile fronthaul over a PON, the O-RAN Alliance has defined the CTI protocol. Other use cases for CO DBA could appear in the future.

CO DBA relies on several capabilities of the PON OLT: support of a signalling interface, interpretation and processing of the exchanged notifications into CO DBA, availability of a common time reference and possibly other features. The purpose of this Supplement is to document such functional expectations on the PON access node, both in generic terms and per specific use case. This Supplement provides a guide to operators and implementers on how to use CO DBA.

Clause 7 identifies OLT capabilities that are expected in general for every instance of CO DBA.

Clause 8 describes OLT capabilities and interactions with station equipment for the specific case of mobile fronthaul (MFH) using the O-RAN CTI interface.

Further use cases can be the subject of revisions of this Supplement.

7 Generic OLT capabilities

The purpose of CO DBA compared with traditional PON bandwidth allocation techniques is to give the ability to strike a trade-off between bandwidth efficiency and latency for transport of upstream traffic over the PON.

With traditional dynamic bandwidth assignment (DBA), both with or without status reporting, the bandwidth is allocated dynamically based on the perceived needs, allowing for statistical multiplexing between multiple traffic sources on the same PON. Traditional DBA works in a reactive way and cannot immediately follow fast changes in traffic. This means there can be undershoots and overshoots of allocated bandwidth, leading to latency and jitter due to buffering of the upstream traffic in the optical network units (ONUs).

With fixed bandwidth allocation, the latency can be minimal as there is always bandwidth being granted. However, as the bandwidth is static the minimal delay is only achieved when the bandwidth is dimensioned to the peak value that could appear in the traffic. This is fine for constant rate traffic, but for variable rate traffic it means that unused parts of the granted allocations cannot be re-used by any other traffic, impeding statistical multiplexing.

With CO DBA there is extra and possibly forward-looking information available about the traffic to be transported, so the bandwidth allocations can more closely match the actual traffic (both in terms of volume and timing). This allows better exploitation of statistical multiplexing while keeping the latency low.

At high level, CO DBA is based on the interaction between a "client system" and the PON transport system which acts as a "server system". The client system can consist of station equipment that in turn control or have visibility over multiple child equipment. The station equipment sends bandwidth reports about the traffic of its child equipment. The client system can also consist of integrated equipment that report about their own traffic needs.

When the station equipment containing the client is northbound of the OLT, it connects to the OLT through the service node interface (SNI) and reports about traffic needs of its child equipment being aggregated by the PON itself (see Figure 7-1).

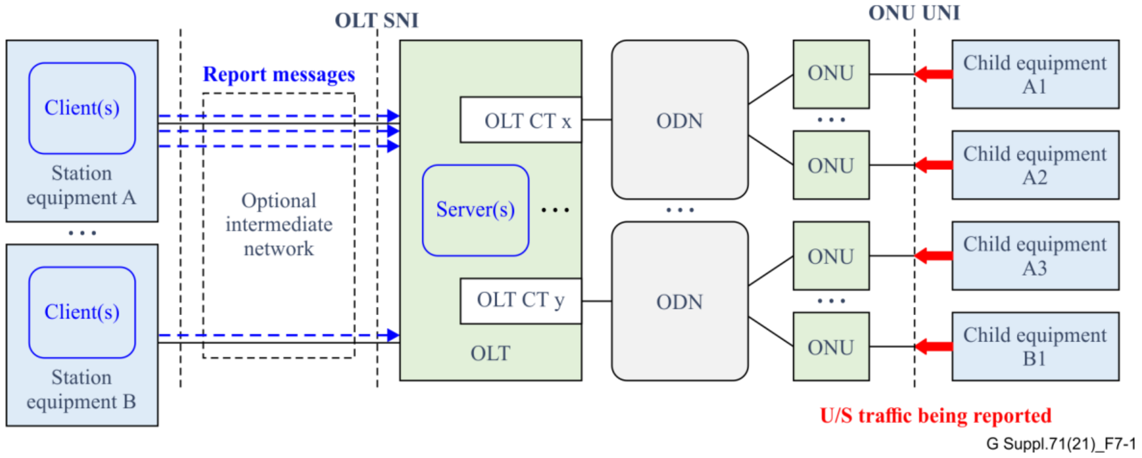


Figure 7-1 – CO DBA by exchanging information with external entity north of OLT

When the station equipment containing the client is also aggregated by the PON network itself, it connects to the OLT through a user network interface (UNI) on an ONU, and reports about its own traffic needs (see Figure 7-2). Note that in that case there must be connectivity from ONU to OLT both for the traffic itself and for the report information being sent by the station equipment.

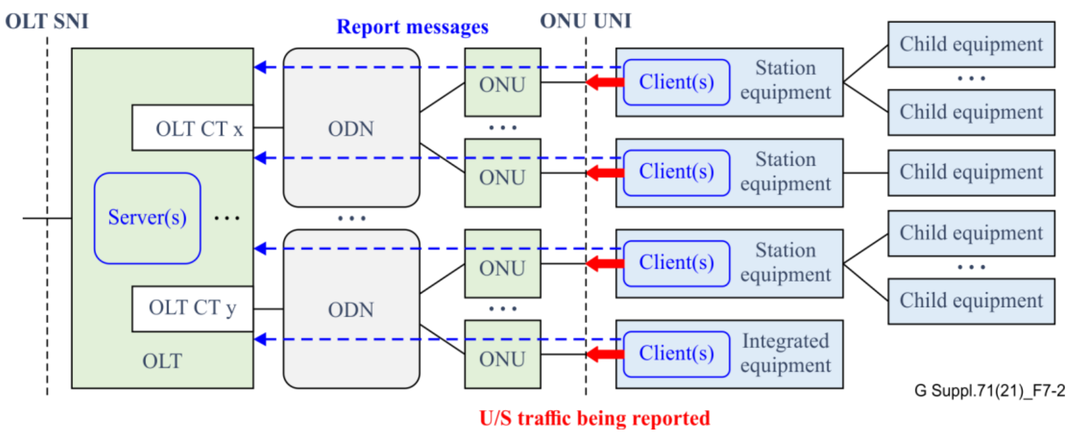


Figure 7-2 – CO DBA by exchanging information with external entity subtended by ONU

Basically, CO DBA needs three capabilities at the OLT:

a) Receiving and interpreting information about expected bandwidth, in terms of volume and timing indication. CO DBA needs to take this information into account for assigning bandwidth allocations at the appropriate time for the appropriate transmission containers (T-CONTs).

b) Supporting a protocol to convey this information from the client system (harbouring a protocol client) to the OLT (harbouring a protocol server). The protocol defines the messages, their formats and a state diagram if applicable.

c) Supporting a method to share a common time reference with the client system (the station equipment or its related network).

Different use cases can be considered for CO DBA. Each use case can be specified by its requirements and by the way it interacts with CO DBA (location of the external entity, protocol used, etc.).

Hereafter, each of the clauses in this Supplement describes the OLT capabilities for a specific use case.

8 Use case 1 – Transport of mobile fronthaul using O-RAN CTI

As described conceptually in clause 9.3.1.2 of [b-ITU-T G.Sup66], CO DBA can be used for the transport of mobile fronthaul traffic between distributed units (DUs) and radio units (RUs) over a PON. In this case the DU acts as station equipment reporting about the bandwidth needs of its corresponding RUs (child equipment). Note that the RU traffic needs are aggregated over all the user equipment (UEs) under the RU, as the OLT does not have the per-UE visibility or scalability to do so.

This use case is the subject of O-RAN's CTI specification consisting of [b-O-RAN CTI TC] and [b-O-RAN CTI TM].

NOTE – The O-RAN terminology O-DU (open distributed unit) and O-RU (open radio unit) is used in the rest of the clause. The O-DU can be standalone or be combined with an O-CU (open central unit). The OLT acts as the transport node (TN) and the ONU acts as the transport unit (TU) in the O-RAN terminology.

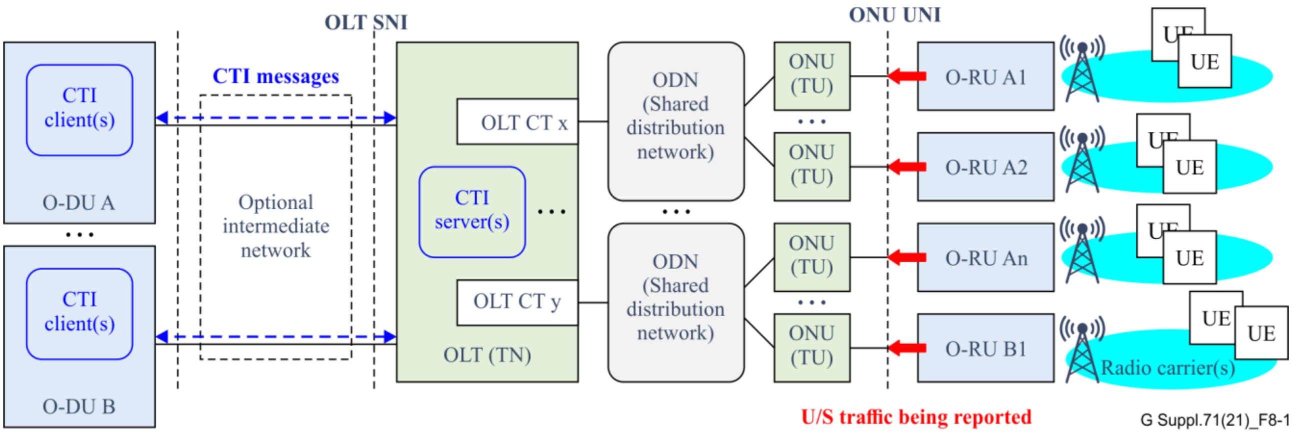


Figure 8-1 – Transport of mobile fronthaul with CTI

The interaction with CTI works as follows (see Figure 8-1):

a) The O-DU allocates air resources to the UE of its linked O-RUs in each mobile slot. The allocation is done based on requests from the UEs for a future time interval. The O-DU infers the corresponding fronthaul traffic per O-RU in advance and reports these future bandwidth needs to the OLT. The reports are sent regularly to follow changes in the traffic.

b) The protocol used to convey the reports from O-DU to OLT is CTI. The protocol is bidirectional (the OLT regularly receives messages from O-DUs and can send certain CTI messages to the O-DUs as well).

c) The mobile network is synchronized in time and frequency. The OLT needs access to the same time of day (ToD) reference to interpret the timestamps in the CTI reports.

Note that the O-RUs and ONUs do not participate in the CTI messaging and have no extra requirements.

The OLT needs several actions and capabilities for using CO DBA with CTI.

8.1 Types of MFH traffic and related connectivities

The MFH traffic between O-RU and O-DU consists of S-plane (synchronization), M-plane (management), C-plane (control) and U-plane (user) traffic; see [b-O-RAN CUS].

8.1.1 S-plane

The S-plane consists of precision time protocol (PTP) packets and physical layer frequency signals such as SyncE, but it is not carried over the PON as medium-specific mechanisms are needed for conveying frequency and phase/time synchronization from OLT to ONU; see clause 8.2. The S-plane is terminated from the network at the OLT and generated back at the ONU towards the O-RU without a need for transport of S-plane traffic over the PON itself, hence without impact on CTI or CO DBA.

8.1.2 M-plane

Independently from the use of CTI, the O-RU will require a bidirectional management connectivity to its subtending O-DU at start-up and during operation. Such management messages (called M-plane in O-RAN) are transparent for the PON but it is the responsibility of the intermediate transport network to foresee a connectivity. The M-plane traffic being exchanged between O-DU and O-RU is encapsulated in IPv4 over Ethernet or IPv6 over Ethernet. Such traffic is tolerant to latency; hence, it is not part of the traffic controlled by CO DBA with CTI. It runs on the same physical interface as the mobile user and control traffic (called U- and C-plane in O-RAN) and can be differentiated by means of Layer 2 or Layer 3 classifiers. The upstream M-plane traffic can be mapped to a specific management T-CONT at the ONU UNI, and handled with traditional DBA. Note that the M-plane messages do not carry any CTI related information or any O-DU scheduler bandwidth assignments to UEs, and are always present even without any CTI functionality.

8.1.3 U-plane

The MFH U-plane traffic carries the actual data exchanges over the air interface with all the UEs (both their application data and their control messages). It is bidirectional and its upstream bandwidth needs can be predicted by the O-DU scheduler and communicated to the OLT by CTI. The latency requirements are influenced by the hybrid automatic repeat request (HARQ) process and the implementation in O-RU and O-DU. The MFH U-plane traffic is mapped to a T-CONT that is handled by CO DBA.

8.1.4 C-plane

The C-plane traffic (not to be confused with control messages between the UEs and the mobile network which are carried inside the MFH U-plane traffic) is originating from or terminated by the O-RU and consists of control messages for the O-RU operation (e.g., scheduling and beamforming commands). It is always present in the downstream direction. The only case for upstream C-plane traffic is when licensed-assisted access (LAA) is used. LAA works on a listen before talk (LBT) principle where there is regular readout of channel activity by the O-DU to determine when and how much data can be used by the UEs. Such channel monitoring uses upstream C-plane LBT messages.

The C-plane is also latency-sensitive, but its traffic characteristics and latency requirements are different from the U-plane traffic. Upstream LBT messages do not represent a high load (in the order of several Mbit/s per O-RU). Their burstiness and actual time of occurrence (in a mobile subframe) depends on the implementation, and the number of messages and their repetition depends on the utilization of the monitored bands. Such LBT-related traffic is therefore not predictable, but worst-case assumptions can be taken. Its latency requirements are influenced by implementation and real-time operation of LAA.

Two methods can be used for providing bandwidth to the uplink C-plane traffic in case of LAA.

Option 1) Including uplink C-plane load in a CTI-controlled T-CONT

In this method the O-DU takes sufficiently conservative assumptions to estimate the load of uplink C-plane traffic, and continuously adds a corresponding extra load when determining the values for its CTI reports. Only one report per O-RU needs to contain this extra term. The value must allow to cover the bandwidth and the maximum buffering duration of such packets. The CO DBA then does not need any awareness about C-plane traffic, it just uses CTI as usual.

In general, the acceptable latency for LAA C-plane messages is larger than for U-plane packets. In case of shared ONU buffer for C-plane and U-plane traffic, C-plane traffic could increase the latency of U-plane packets. This can be controlled by overprovisioning the extra term computed for the CTI reports. Quantifying this overprovisioning depends on the latency requirements and how they are followed by the PON system, and could need an upfront analysis by the transport and the mobile systems to preconfigure the CTI client in the O-DU with an appropriate value for the extra load. On the other hand, the CTI server in the OLT does not need any extra configuration.

More details will be found in version 2 of [b-O-RAN CTI TM].

Option 2) Handling of uplink C-plane traffic in a separate T-CONT

By having a different marking of C- and U-plane packets by the O-RU, the C-plane traffic can be transported in a separate dedicated T-CONT. As this traffic is low-bandwidth, its T-CONT can be served by DBA with a fixed or assured bandwidth allocation, without control by CTI.

In order to define appropriate bandwidth parameters for this T-CONT, the transport operations support system (OSS) needs information about the C-plane traffic latency and peak throughput from the mobile network. This information is static and only needs to be updated when O-RUs activate or deactivate LAA. During operation, CO DBA does not need any awareness about C-plane traffic.

8.1.5 Prerequisite for start-up of O-RU

From a PON perspective appropriate T-CONTs and traffic profiles must be configured to the ONUs that subtend O-RUs for handling the M-plane traffic prior to the start-up of the O-RUs.

Also, a connectivity at some initial rate is needed for user and control plane traffic for the start-up of the UE traffic via the O-RU.

The ONU must be synchronized and generate synchronization signals towards the O-RU.

8.2 Sharing a common time of day reference with O-DU

Traffic is notified in given time intervals referenced at the air interface of the O-RUs. Each time interval is indicated by a start and end ToD. The shortest possible time interval is a mobile slot, but several slots can be grouped together in the reporting. Interpretation of the time intervals requires a common time reference between the OLT and the O-DU.

Note that the CTI protocol itself does not need to be synchronous, as it carries timestamps inside its payload. Messages must arrive sufficiently on time at the OLT, but the actual time of arrival of the messages at the OLT does not need to be aligned with precision.

The OLT can get the common time reference by supporting IEEE PTPv2 [b-IEEE 1588] at the SNI side, either via an O-DU or independently of the O-DUs. The OLT can also get the time reference by supporting global navigation satellite system (GNSS) input.

Note that the OLT also needs this time reference for providing synchronization via the ONUs to the O-RUs. Synchronization of O-RUs over a PON is out of scope of this Supplement.

The distribution of a common time between the RAN domain and transport domain can be done in different ways. Figures 8-2 and 8-3 illustrate two different approaches. Note that the location of primary reference clock (PRC), primary reference telecom clock (PRTC) and telecom grand master (T-GM) clock in a network can vary; the variations are not indicated in the figures.

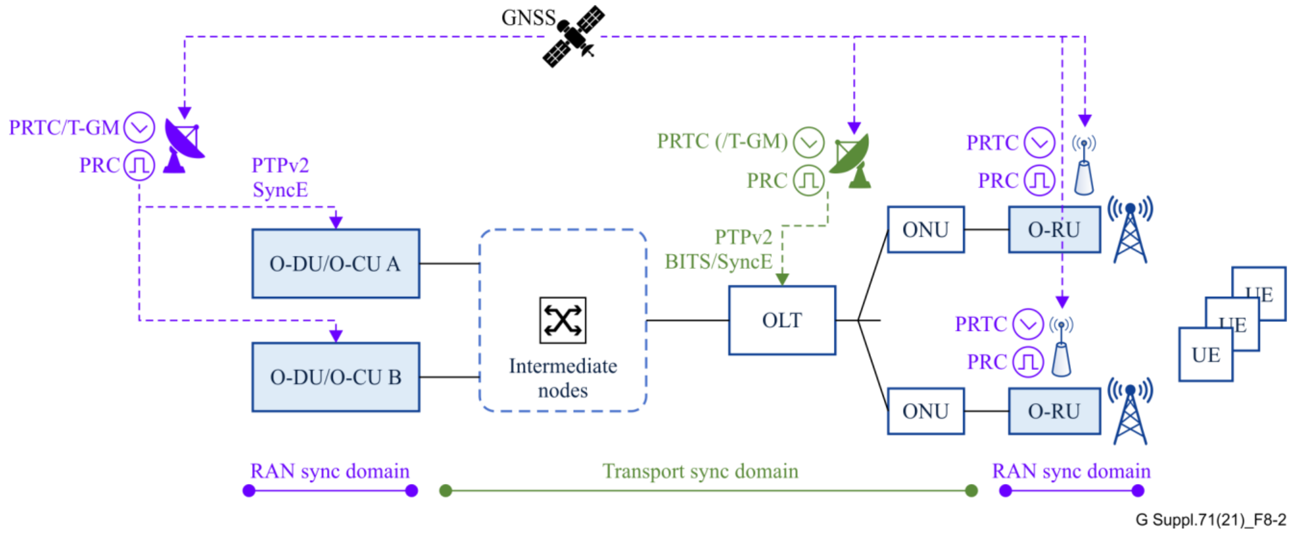


Figure 8-2 – Access to common time of day by separate GNSS inputs (no explicit synchronization between RAN and transport domains)

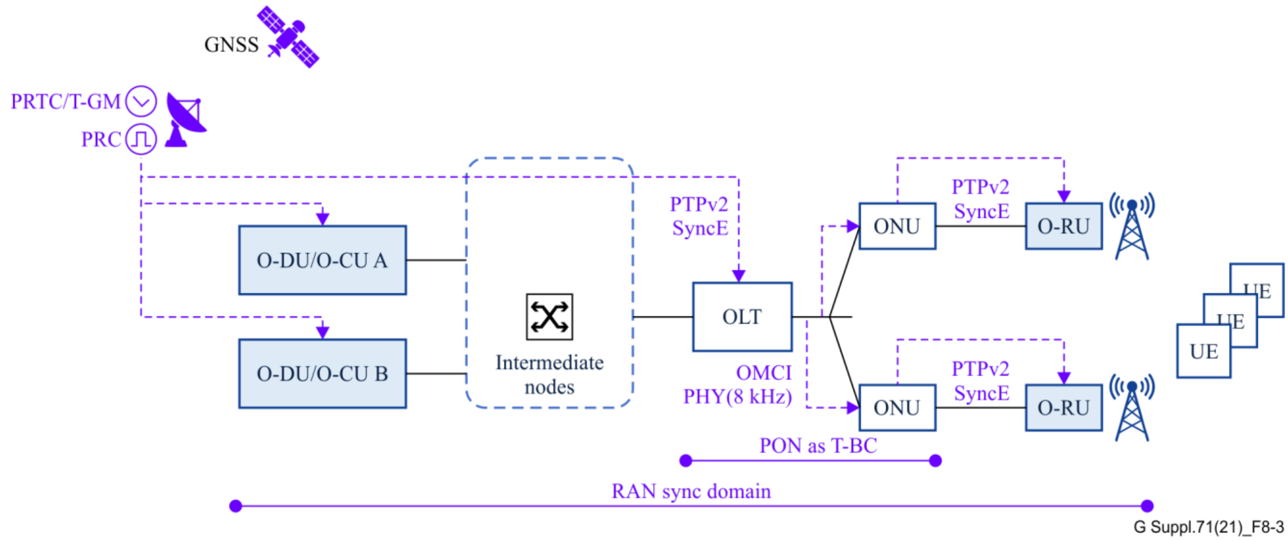


Figure 8-3 – Access to common time of day by synchronizing transport domain to the RAN domain

8.3 Support of CTI message exchange with O-DUs

The OLT sends and receives CTI messages from multiple O-DUs (the interface is bidirectional):

– The messages are transported over Ethernet and can optionally use UDP/IP.

– The timing and rate of the CTI messages are subject to rules as specified in [b-O-RAN CTI TC].

The PON access node supports transport of CTI messages over Ethernet (untagged, single-tagged, dual-tagged). Optionally the OLT may support the transport of CTI messages over UDP/IP (IPv4 or IPv6) over Ethernet.

The OLT and O-DU avoid fragmentation of a single CTI message over multiple Ethernet frames. If a message is too large for a frame, the message content is split over multiple messages, each using one frame.

CTI has built-in messages that allow starting and monitoring the connectivity status between server and client. For this purpose, each CTI interaction between a CTI server in the OLT and a CTI client in a O-DU follows a state diagram for exchanging messages, to establish a start-up (by exchanging beacon/beacon acknowledgement messages), to keep the connectivity up and running (by exchanging keep-alive messages), and to monitor the break of connectivity (monitoring absence of keep-alive messages). The OLT applies time-out and keep-alive timers for this process.

For allowing an operator to plan a network and determine how to configure CTI messaging on a given OLT – O-DU combination, the OLT needs to be characterized by:

– A CTI message rate performance (maximum rate at which it can accept CTI messages). Note that the OLT also supports rates lower than its maximal rate.
– A CTI message timing performance (minimum time needed between reception of a CTI message and start of the corresponding reported time interval); see Figure 8-4 and definition in [b-O-RAN CTI TC].

The OLT supports a configurable nominal CTI rate (which will be equal or lower than the OLT's supported maximal rate) based on the traffic latency needs and on the capabilities of the O-DU.

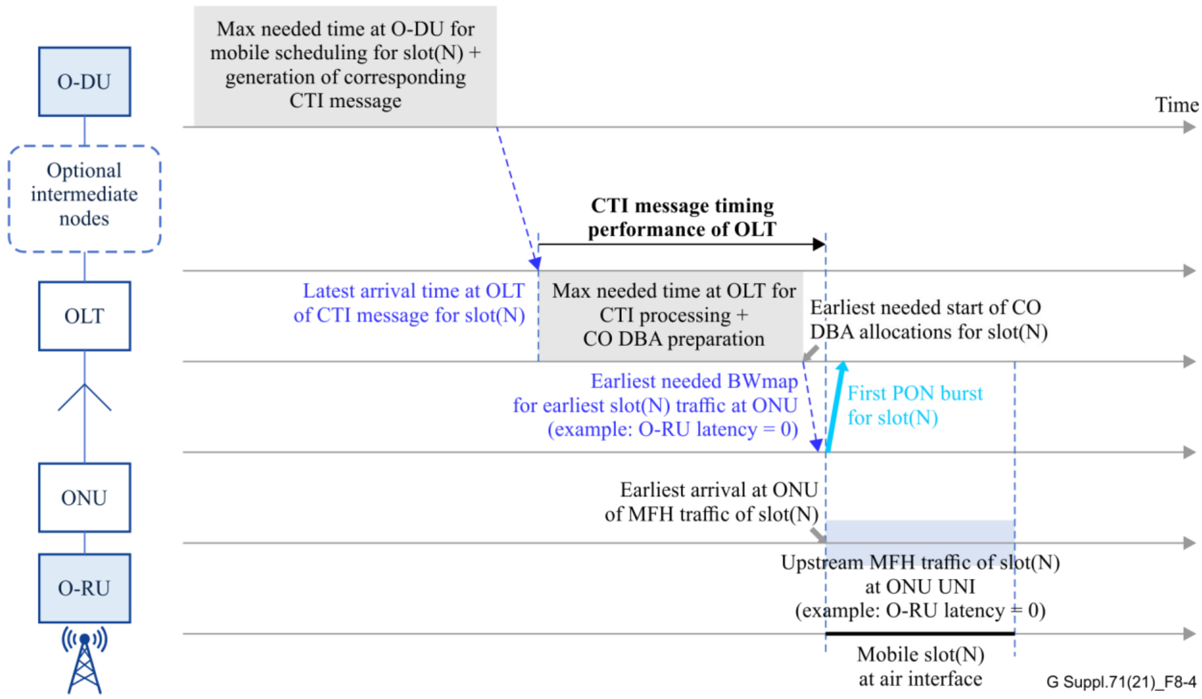


Figure 8-4 – OLT message timing performance

Depending on the aggregation of O-RUs over ONUs, PONs and OLTs, the interconnections between CTI clients and CTI servers can form a full N:M mesh:

• There can be one or multiple CTI servers in each OLT (e.g., for modularity). Each server can communicate with multiple CTI clients.
• There can be one or multiple CTI clients in each O-DU (e.g., for modularity). Each client can communicate (e.g., send reports) to multiple CTI servers.

Figure 8-5 shows interconnection between CTI clients and CTI servers.

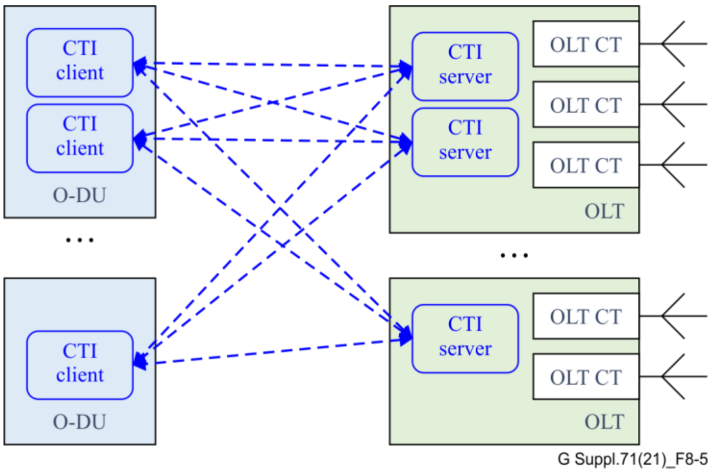


Figure 8-5 – Interconnection between CTI clients and CTI servers

8.4 Interpretation of CTI messages by OLT

The messages follow a given predefined format; the OLT interprets received CTI messages according to [b-O-RAN CTI TC].

There are two types of messages: one for exchanging signalling type of information (CTI signalling messages) and one for sending reports about the upstream traffic (CTI report message).

8.4.1 CTI signalling messages

Signalling messages are used for start-up (beacon and beacon-ack messages are sent at the start of a CTI interaction between a CTI client and CTI server) and connectivity check (keep-alive messages are exchanged in both directions at reduced rate between CTI client and CTI server) of the CTI communication between a CTI client and a CTI server, and for conveying information other than traffic reports (PON ranging notification message from the CTI server to the CTI clients).

The key contents of a CTI signalling message are:

- A correlation ID (see clause 8.4.2 for its meaning) set to null value.
- Message type.
- Message payload in type length value (TLV) format.

8.4.2 CTI report messages

Report messages are used to inform the OLT about upstream MFH traffic needs (for U-plane or for U-plane and C-plane; see clause 8.1).

The key contents of a CTI report message are:

- A correlation ID (called CTI session ID) to associate the traffic report with the O-RU (interface) from which the traffic is generated. It is used to correlate to the corresponding ONU (UNI).
- Optionally an additional flow ID to associate the traffic report of a given correlation ID with a class-of-service (CoS) flow.
- A time interval (absolute ToD).
- An indication of the traffic volume in the given time interval.
- Optionally, details about the traffic pattern inside that time interval (via a CTI pattern ID), allowing a description of the repartition of bytes within the mobile slot.

The rules and scope for a CTI report message are:

– Each message refers to a single CTI session ID, hence to a single ONU UNI. This ID is unique per message but can be different between messages, so different messages between the same CTI client and CTI server can point to different ONU UNIs on different OLT channel terminations.
– Each message can contain multiple traffic reports.
– Each report refers to a given time interval and optionally to a given flow. A flow ID represents filter settings at L2/L3/L4 and can be re-used with different CTI session IDs.

Note about uniqueness of IDs and support of multiple instances (see Figure 8-6):

- Each ONU can have one or multiple UNIs.
- Each ONU UNI can carry fronthaul traffic (possibly with different CoS flows).
- Each CTI session ID corresponds to an ONU (or ONU UNI) and its value is unique.
- Each ONU UNI can carry different CoS and each CoS has its own flow ID (but flow IDs are not unique, they can be re-used between different CTI session IDs).
- There can be multiple reports pointing to same CTI session ID inside one message (see clause 8.5.1).

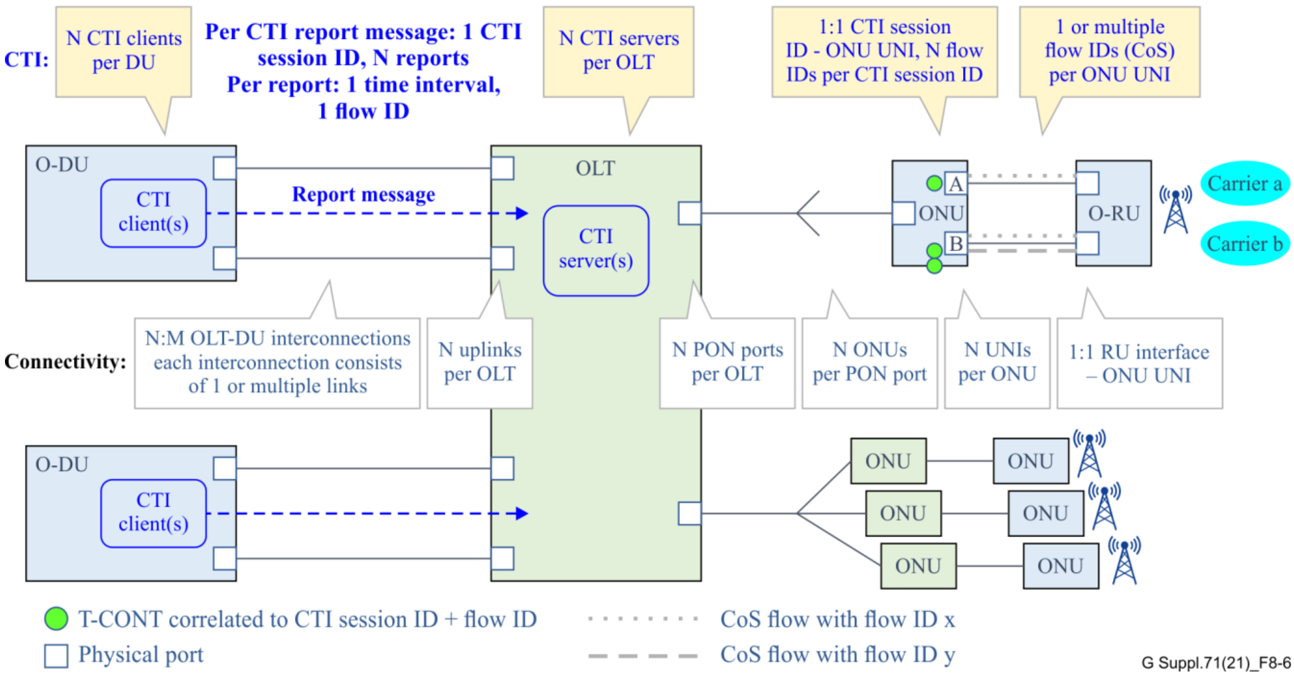


Figure 8-6 – Interconnections, CTI clients and CTI servers, identifiers (every instance of "N" and "M" represents an independent number larger or equal to one)

8.4.3 Uplink latency

For each given traffic flow (in other words, per CTI session ID or optionally per CTI session ID + flow ID combination) the mobile traffic will have a latency limit between the corresponding O-DU and O-RU; the value of this limit is dictated by the buffering and timing capabilities of the O-RU and O-DU nodes. This latency value must be known by the OLT by pre-configuration (note that this latency is a fixed value and is not conveyed in the CTI messages). In case of intermediate nodes between O-DU and OLT, these extra nodes will also generate delays and consume part of the latency limit. The value to be configured in the OLT must then reflect the remaining latency budget for the PON system (between ONU UNI and OLT SNI), namely the latency limit (called T34max in O-RAN) minus the delays by the intermediate nodes. Figure 8-7 shows uplink latency.

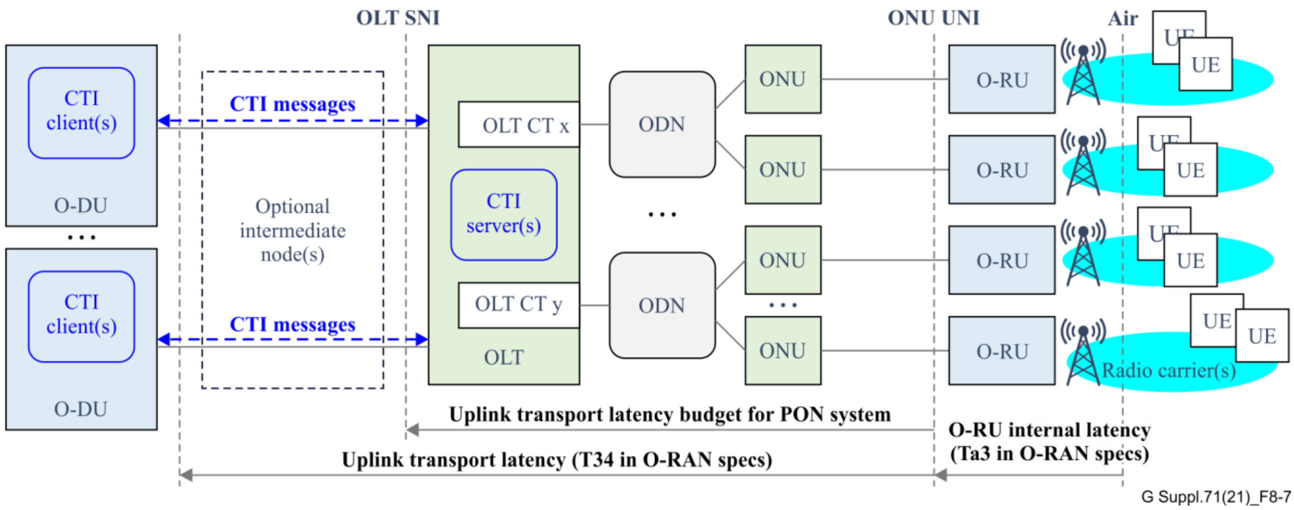


Figure 8-7 – Uplink latency

The latency value is taken as information by CO DBA to determine how to choose a sufficient bandwidth allocation scheme per T-CONT.

8.5 Interpretation for CO DBA

When using CO DBA, the OLT generates its bandwidth allocations (BWmaps) in function of the absolute ToD, in order to:

a) Take into account the CTI report information for the corresponding T-CONTs;

b) Provide sufficient bandwidth to the T-CONTs;

c) Time these bandwidth allocations in function of the time intervals as reported by the CTI.

The operation of CO DBA requires several correlations to be performed.

8.5.1 Correlation of message report(s) to T-CONT(s)

A CTI report message contains one or multiple reports. The OLT interprets each message and the report(s) in each message, by correlating each report to the corresponding T-CONT and to the corresponding time interval.

CO DBA can either map each report to a separate T-CONT or aggregate the values from multiple reports pertaining to the same ONU to a single T-CONT for applying a single bandwidth allocation. In other words, there is a N:1 relationship between the CTI report and corresponding T-CONT.

Reports per CTI message

The correlation per report is based on the combination of CTI session ID and flow ID:

– Each CTI message contains a single CTI session ID.

– Each report in the CTI message contains one flow ID. Note that a flow ID with null value indicates there is no flow differentiation.

In case of multiple reports in a CTI message, they can have:

– The same flow ID: There could be multiple reports about the same T-CONT in the same message. The OLT takes aggregated bandwidth decisions for such T-CONT from these individual reports. Note, a flow ID with null value indicates there is no flow differentiation.

– Different flow IDs: There could be multiple reports about multiple T-CONTs in the same message. The OLT infers the corresponding T-CONT from the combination of CTI session ID + flow ID.

In case of multiple reports in a CTI message, they can refer to:

– The same time interval (start/stop time): There could be multiple reports about the same time interval in the same message (namely for different flow IDs).

– Or different time intervals: There could be multiple reports about multiple time intervals in the same message. CO DBA maps each report to these different time intervals.

This leads to the possibilities as listed in Tables 8-1 and 8-2.

Table 8-1 – Possible number of CTI session IDs per ONU

CTI session IDs per ONU	Single CTI session ID	Multiple CTI session IDs
Single UNI used	1 CTI session ID	N.A.
N UNIs used	If O-DU aggregates reports per O-RU: 1 CTI session ID	If O-DU aggregates reports per O-RU interface: N CTI session IDs (see B,C,D,E in Figure 8-8)

Table 8-2 – Possible number of reports inside a single CTI message

Report fields per CTI message (1 CTI session ID)	Single flow ID (see Figure 8-8)	Multiple flow IDs (see Figure 8-9)
Same time interval	Only one report Single T-CONT	Multiple reports, for different T-CONTs
Different time intervals	Multiple reports, for same T-CONT	Multiple reports, for different T-CONTs

If there is no flow differentiation, a single T-CONT is sufficient (see Figure 8-8). It is also possible to support multiple CTI session IDs pertaining to the same O-RU connected to the ONU by using separate T-CONTs (see T-CONTs 2 and 3 in Figure 8-8) or by grouping them into a single T-CONT by aggregating their reports in CO DBA (see T-CONT 4 in Figure 8-8). The latter is more likely as the traffic latency requirements on two O-RU interfaces are likely to be the same, and then both flows do not need to be carried over separate T-CONTs.

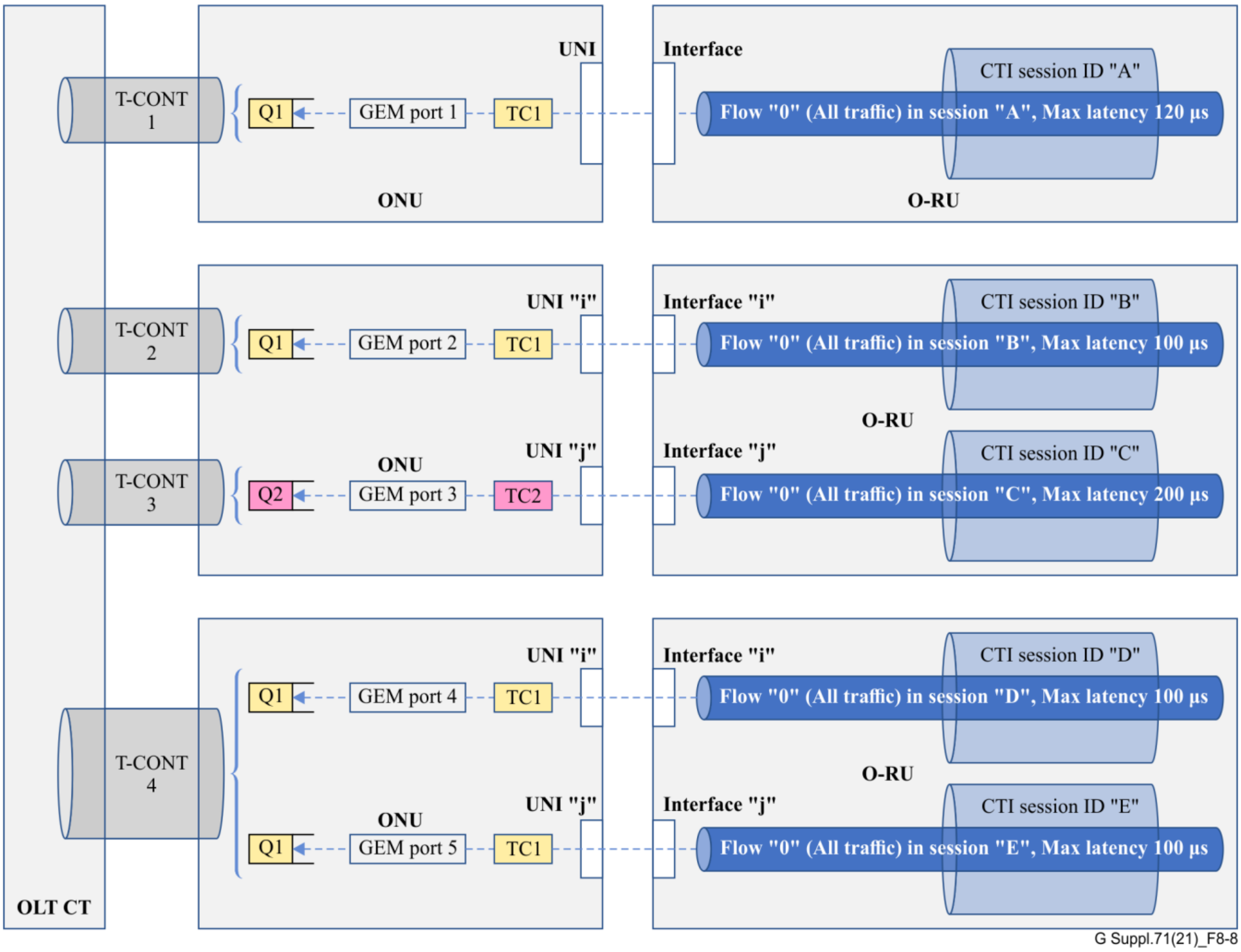


Figure 8-8 – Example of correlations to T-CONTs: single flow per CTI session ID

When multiple flows are present for a single CTI session ID, CO DBA can either use a separate T-CONT per report (see T-CONTs 5, 6, 8 in Figure 8-9), or group traffic from different reports into a T-CONT when they have similar requirements (see T-CONT 7 in Figure 8-9).

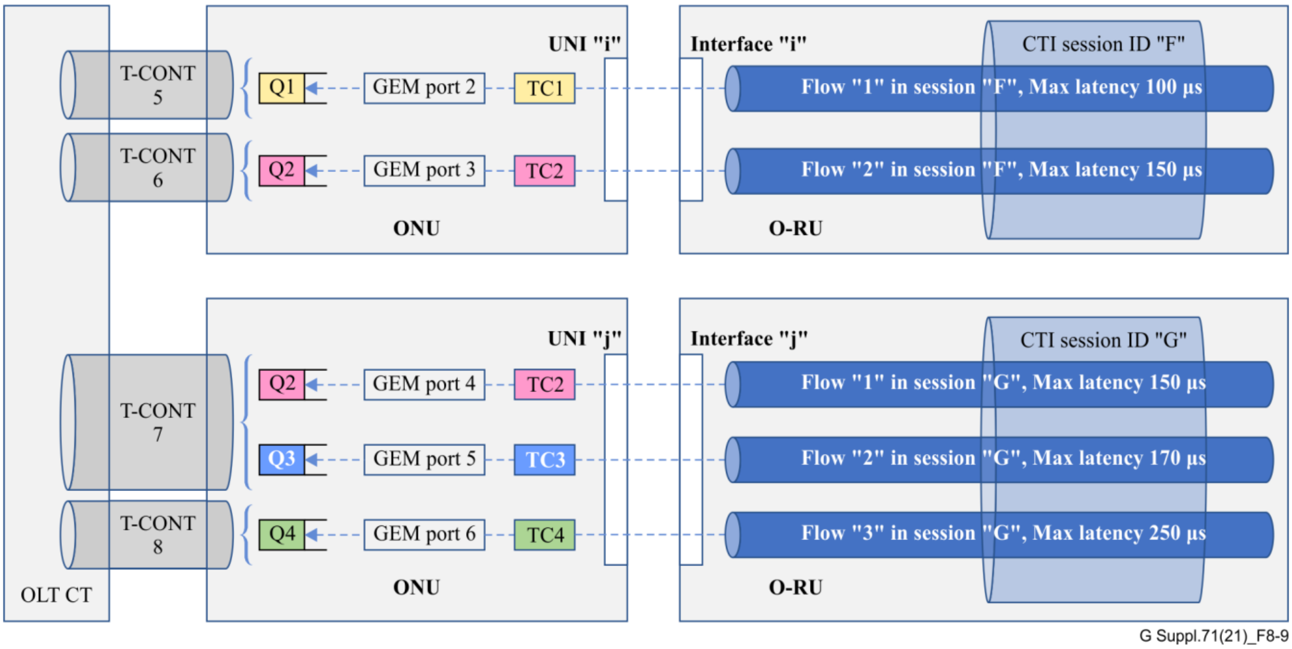


Figure 8-9 – Example of correlations to T-CONTs: multiple flows per CTI session ID

Configuration of correlations

The OLT must be preconfigured with the correlations of the CTI session ID and Flow ID to T-CONTs for each channel termination. This cannot be deduced by the OLT on its own and must be done by the OLT's element management system, which has a view on all T-CONTs in service. It also requires coordination at management level with the mobile network; see clause 8.9.2.

8.5.2 Correlation of CTI session IDs to CTI clients

An OLT can be in communication with multiple CTI clients in multiple O-DUs. As explained in [b-O-RAN CTI TC], the CTI connectivity to each CTI client is monitored by exchange of keep-alive messages. When connectivity with a given CTI client would be interrupted, it is useful for the OLT to know which T-CONTs are associated to flows managed by that CTI client. The OLT could then take actions such as generating an alarm or take a temporary bandwidth assignment for these T-CONTs (e.g., some minimal fixed bandwidth as back-up) until CTI connectivity is restored.

8.5.3 Bandwidth allocation: grants and timing of the grants

For each traffic flow (CTI session ID, or optionally combination of CTI session ID + flow ID) the OLT receives reports by CTI. For each traffic flow the OLT also knows (by configuration) the latency limit for the PON transport (from ONU UNI to OLT SNI).

Thus, for each traffic flow (CTI session ID, or optionally a combination of CTI session ID + flow ID) CO DBA can use this information to choose how to translate the bandwidth reports into specific PON bandwidth allocations (bursts). The OLT can additionally use traffic monitoring and/or DBRu reporting for making its decisions. The allocated bandwidth follows the variations in reported traffic.

In the simplest way, the CO DBA would assign bandwidth equal to the received CTI requests. However, it is beneficial to allow CO DBA to include margins and boundaries on top of the CTI requests. Such margins and boundaries can be expressed in terms of parameters of a traffic descriptor for T-CONTs that are subject to CO DBA. CO DBA then takes the traffic descriptor values together with the CTI requests to assign a corresponding bandwidth.

The traffic descriptor for CO DBA T-CONTs is

$$D = \langle R_{\mathrm{F}}, R_{\mathrm{T}}, R_{\mathrm{M}}, m, T_{\mathrm{JT}} \rangle$$

Where:

R_F is fixed rate per existing PON recommendations. It establishes a lower boundary and guarantees a minimal rate even when the CTI demand is lower than R_F. This guarantees connectivity between RU and DU even before CTI is operational, in order to allow the booting of the RU during which it needs to connect to the DU. The appropriate value can depend on the needs of the mobile RU & DU equipment.

R_T is a rate to be added as an extra term on top of the CTI demand. It can be used to take into account traffic that is not explicitly reported in CTI demands (e.g., management traffic between RU and DU, if it is transported over same T-CONT as the eCPRI traffic itself). The appropriate value can depend on the needs of the mobile RU & DU equipment.

R_M is the max rate per existing PON recommendations. It can be used to clamp the bandwidth of the T-CONT to an upper boundary in case the CTI demand would become "excessive" (e.g., above expectations due to misconfigurations), in order to preserve other T-CONTs from starvation. A straightforward choice would be to set R_M to the resulting BW when the considered RU is sending its peak upstream traffic, if that value is known.

m is a multiplication factor to be applied to the requested CTI demand. It can be used to take into account PON-specific proportional overheads such as XGEM overheads on the Ethernet frames (the DU is not aware of such overheads and does not include them in its CTI demands).

T_{JT} is jitter tolerance per existing PON recommendations. It can be used to influence the upstream latency (a lower value gives less latency but more burst mode overhead).

The BW assigned by the Co DBA then becomes (see Figure 8-10):

$$R(t) = min(max(R_F, R_T + R_{CTI}(t) * m), R_M)$$

(Note that CTI messages report are expressed in #Bytes, and $R_{CTI}(t)$ in the formula includes the conversion to the corresponding bandwidth). All rate values are constrained between 0 and the effective PON uplink capacity C. Every parameter in $R(t)$ can be set individually to a value that disables its effect ($R_F = 0$, $R_T = 0$, $R_M = C$, $m = 1$).

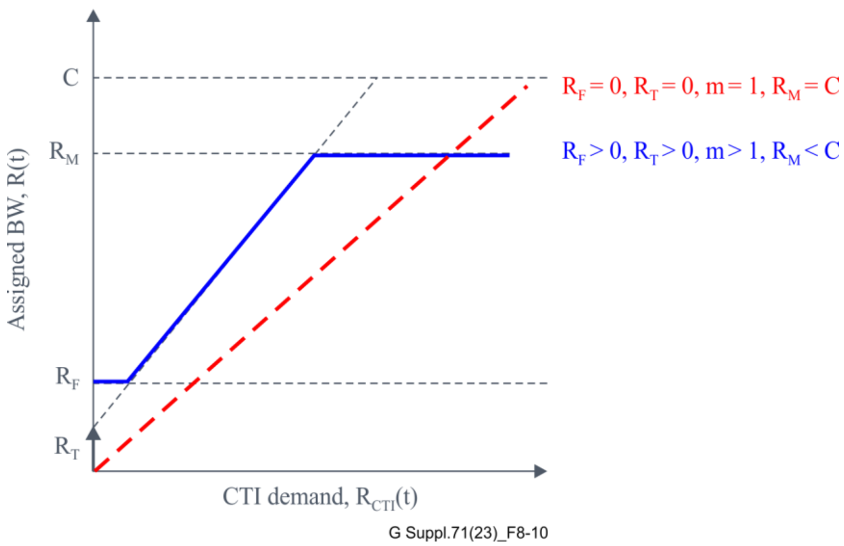


Figure 8-10 – Effect of Co DBA traffic descriptor parameters

The algorithm to translate the assigned BW into actual burst allocations (burst sizes and timings) is implementation specific and out of scope of this Supplement.

Note that there could be a mix of different types of traffic on the same PON: fronthaul traffic being handled by CO DBA, and non-fronthaul traffic without CO DBA handling.

The resulting uplink latency (from ONU UNI to OLT SNI) of the traffic reflects the CO DBA performance. The target of CO DBA should be to ensure that the uplink latency remains below the latency limit for the corresponding traffic flow. If that is not possible for all transported frames, the ratio of frames conforming to the latency limit should be maximized.

8.6 PON ranging notification

When the OLT performs ranging on a given PON channel termination (CT), the upstream traffic will be interrupted during the quiet windows. The CTI interface can be used by the OLT to notify the O-DU about upcoming ranging events. This allows the O-DU to foresee degradation due to the transport domain and act accordingly.

A PON ranging event is composed of one or several quiet windows and can be regularly repeated or executed on demand (see Figure 8-11).

The OLT generates PON ranging notification messages by:

- Estimating the start and max duration of a ranging event as experienced by the source (the O-RU), and the maximum duration of a quiet window;
- Building a list of impacted CTI session IDs to be reported, per corresponding CTI client;
- Sending a ranging notification message to each CTI client that manages CTI session IDs on impacted ONUs, including the corresponding list of CTI session IDs;
- Repeating the process for each ranging event.

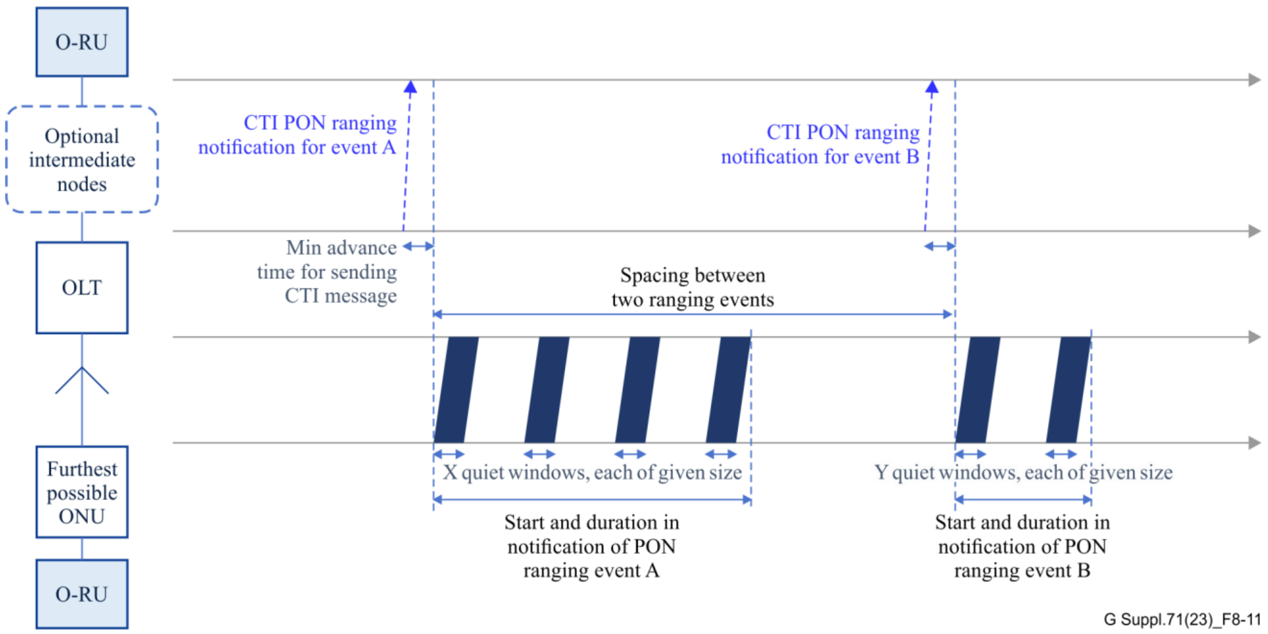


Figure 8-11 – PON ranging notification

The OLT sends a PON ranging notification in a dedicated CTI signalling message. The message must be sent at least some (configurable) advance time before the start of the ranging event itself, to take into account the reaction time of the O-DU to this notification.

The OLT needs the correlation of channel termination experiencing the ranging to the impacted CTI session IDs and the corresponding CTI client(s) to send the message to. The deployment topology (which O-RUs are connected on which ONUs) is not visible inside the OLT, hence the OLT must be preconfigured with the relationship (ONU, CTI session ID(s), CTI client) by the OLT element management system. This allows the deduction of the list of CTI session IDs and CTI client per CT. Note that a single CT could connect O-RUs from different O-DUs, so for each ranging event on a CT the OLT could need to send multiple CTI PON ranging notification messages (to reach multiple CTI clients).

8.7 Time alignment between RAN and PON

8.7.1 RAN time structures

Uplink and downlink transmission in the RAN is cadenced by the frames, subframes and mobile slots on the air interface. The number of mobile slots per subframe depends on the radio subcarrier spacing (SCS), as shown in Figure 8-12. When considering a slot of 14 symbols with 15 kHz SCS, one subframe will accommodate one slot. For 30 kHz, 60 kHz, and 120 kHz SCS, one subframe will contain two, four and eight slots, respectively [b-NGMN Alliance]. Unlike the subframe basis scheduling in LTE, a 5G NR scheduler assigns resources in a unit of slot, one mini-slot or multiple slots, taking account the radio conditions. A mini-slot consists of two, four or seven symbols instead of 14. In a mini-slot structure, mobile traffic does not wait for the start of a slot boundary.

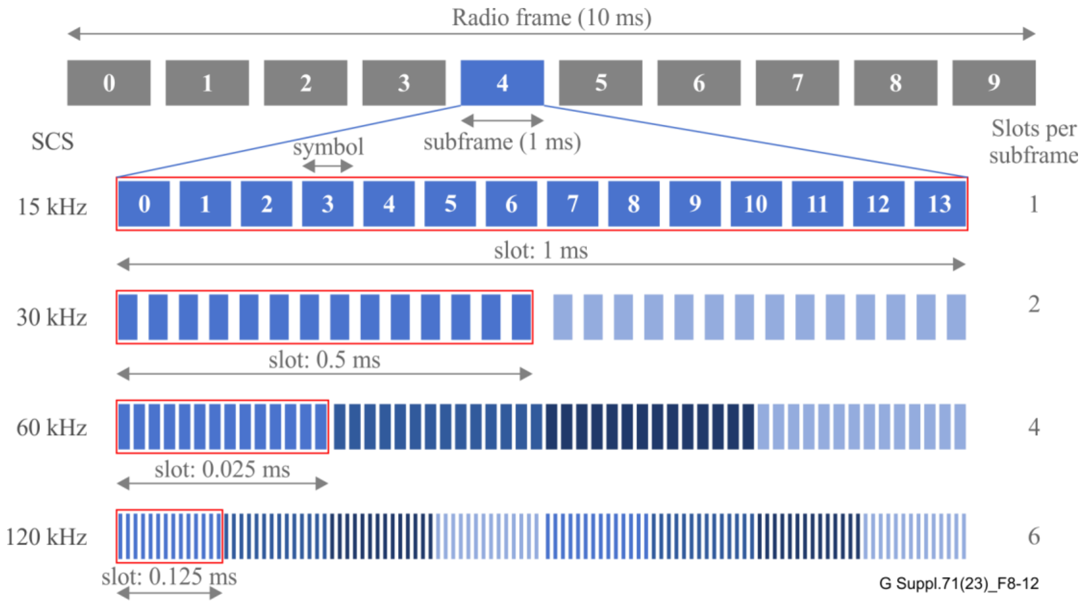


Figure 8-12 – Time structures in RAN (sub-6 GHz) [b-NGMN Alliance]

Each slot can be flexibly and independently configured, as shown in Figure 8-13. The slot format indicator (SFI) carries an index to the SFI table which contains 57 possible traffic configurations, going from either all symbols in downlink or in uplink, to a mix of DL/UL/X symbols with up to two switching points [b-3GPP TS 38.213] and [b-3GPP TS 38.211]. A reference to a given traffic pattern can be exchanged from O-DU to OLT in the CTI messages (using the CTI pattern ID).

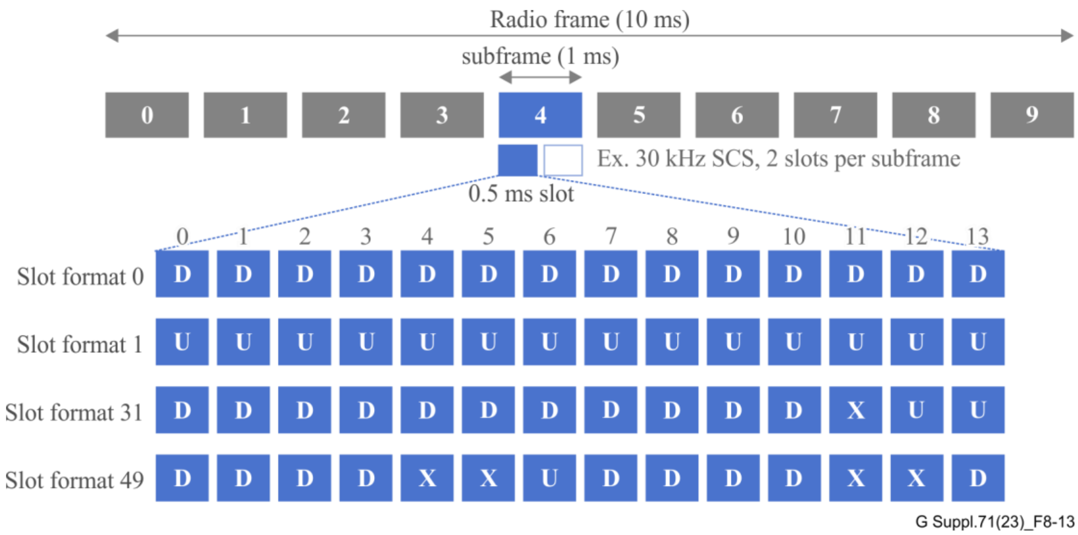


Figure 8-13 – Dynamic slot configurations in 5G TDD: D – downstream symbol; U – upstream symbol; X – Flexible symbol: U, D or guard period

These time slot boundaries are aligned over the whole RAN network. This means that every O-RU will generate these time structures on its air interface and will process data for the same mobile slot at the same time. However, there can be processing time differences between O-RUs, so that the timing of their upstream fronthaul traffic differ. For O-RUs of the same category (see [b-O-RAN CUS]), this difference will be small (order of 10 µs).

The scheduler in the O-DU will generate CTI reports pertaining to a given time interval for a given O-RU, by including the start and end time of the interval. Such time interval either corresponds to a mobile slot, or to a multiple of mobile slots. A single CTI message can also contain multiple reports pertaining to different mobile slots (each mobile slot being reported as a different time interval, and one message containing multiple such reports).

8.7.2 Accuracy of time reference

The PON upstream scheduling should be as aligned as possible to these time intervals in order to reduce buffering (and hence latency) in the ONU. As mentioned in clause 8.2, the OLT and RAN share a common ToD reference. The accuracy of this ToD is already very high for the purpose of the phase synchronization of the O-RUs over the PON (this is out of scope of this Supplement). The required accuracy for CO DBA however can be orders of magnitude more relaxed (order of multiple µs), so the accuracy for synchronization at the OLT offered by any usual method (GNSS, IEEE-1588 and SyncE) will be largely sufficient.

The accuracy of the start/end timestamps carried in CTI messages is 1 µs.

8.7.3 Impact of time alignment of CO DBA update cycles to time interval boundaries

The CO DBA translates a required load spread over a time interval into a series of bursts. The resulting PON transmission latency will depend on the choice of the bursts (timing, size and number).

A reported time interval is interpreted by CO DBA to generate an update of the content of the BWmaps to coincide with the time interval. The period of each update can be called a CO DBA cycle. This means that the boundaries of a CO DBA cycle should be aligned to the expected mobile slot boundaries reflected in the fronthaul traffic. The better this time alignment, the lower the latency. Note that the slot boundaries on the O-RU interface compared with the slot boundaries on the air interface are delayed by the internal processing time in the O-RU (called Ta3 in [b-O-RAN CUS]). The upstream "transport latency" is denoted by T34 in [b-O-RAN CUS]. Ta3 is not part of T34.

Figure 8-14 shows the alignment of CO DBA cycles with mobile slot boundaries at O-RU uplink.

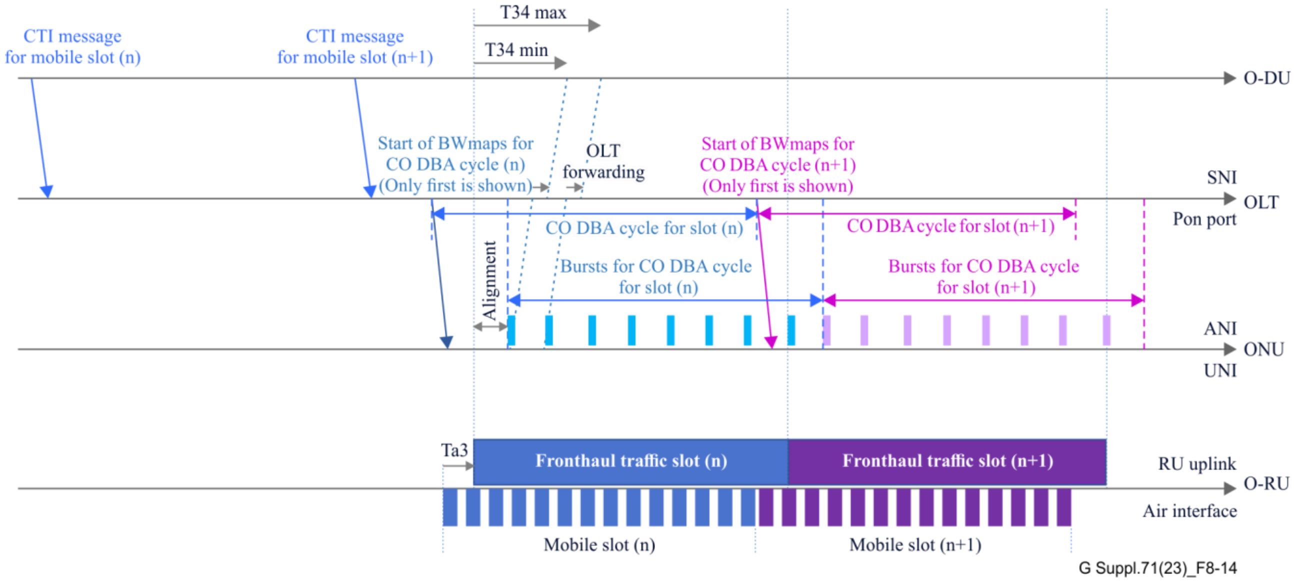


Figure 8-14 – Alignment of CO DBA cycles with mobile slot boundaries at O-RU uplink

8.7.4 Frequency of updates

CO DBA determines the size and repetition of bursts in each cycle. In the ideal case, each variation in fronthaul traffic is captured by a reported time interval and a corresponding CO DBA cycle (see Figure 8-15). When the variations are too fast for this (when the CO DBA cycle time is larger than the reported time interval, i.e., when short slots or minislots are used in the RAN), it is possible for the O-DU to group multiple time intervals in a single CTI message. The OLT then updates every CO DBA cycle to accommodate for the sum of the traffic in these multiple intervals (see Figure 8-16).

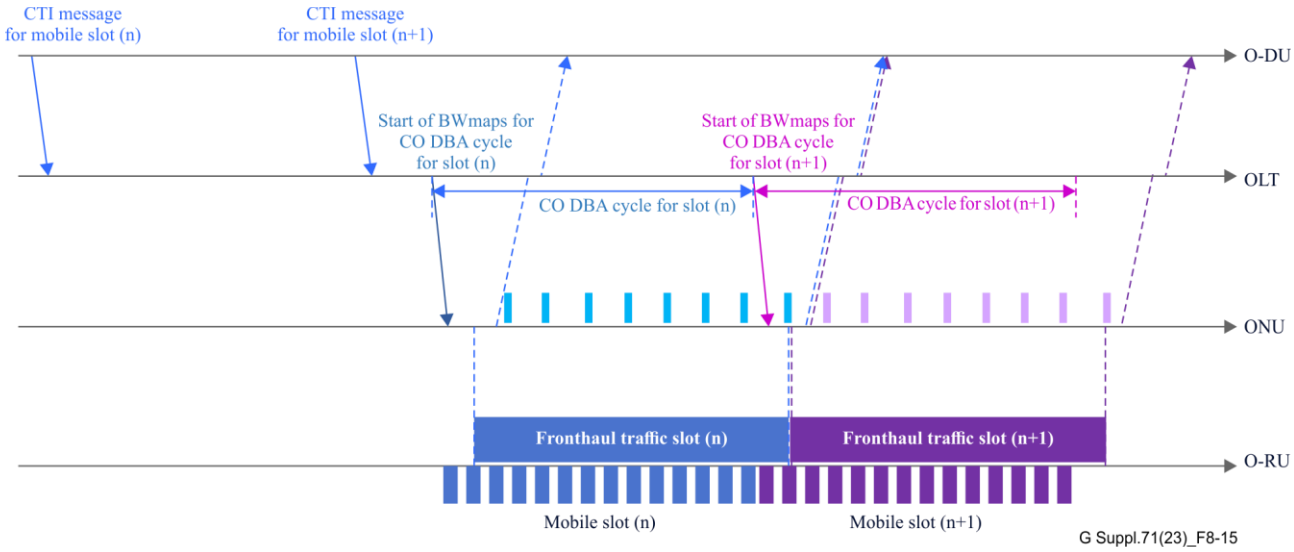


Figure 8-15 – 1 CO DBA cycle per reported time interval

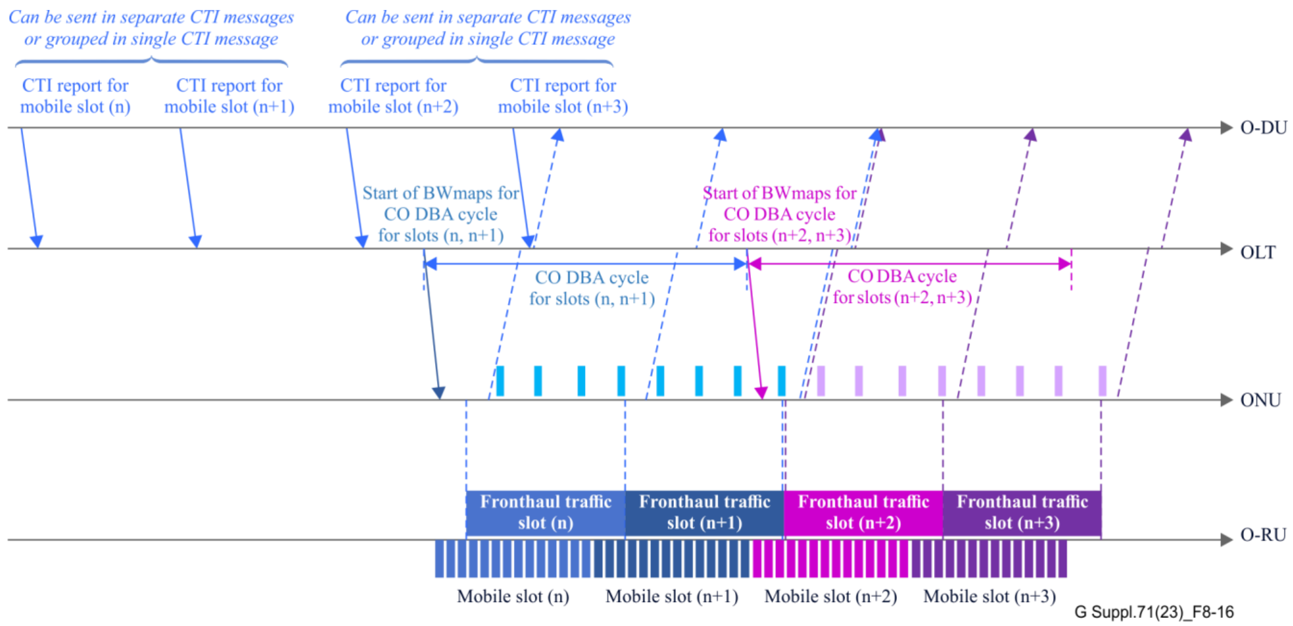


Figure 8-16 – Multiple reported time intervals per CO DBA cycle

8.7.5 Summary

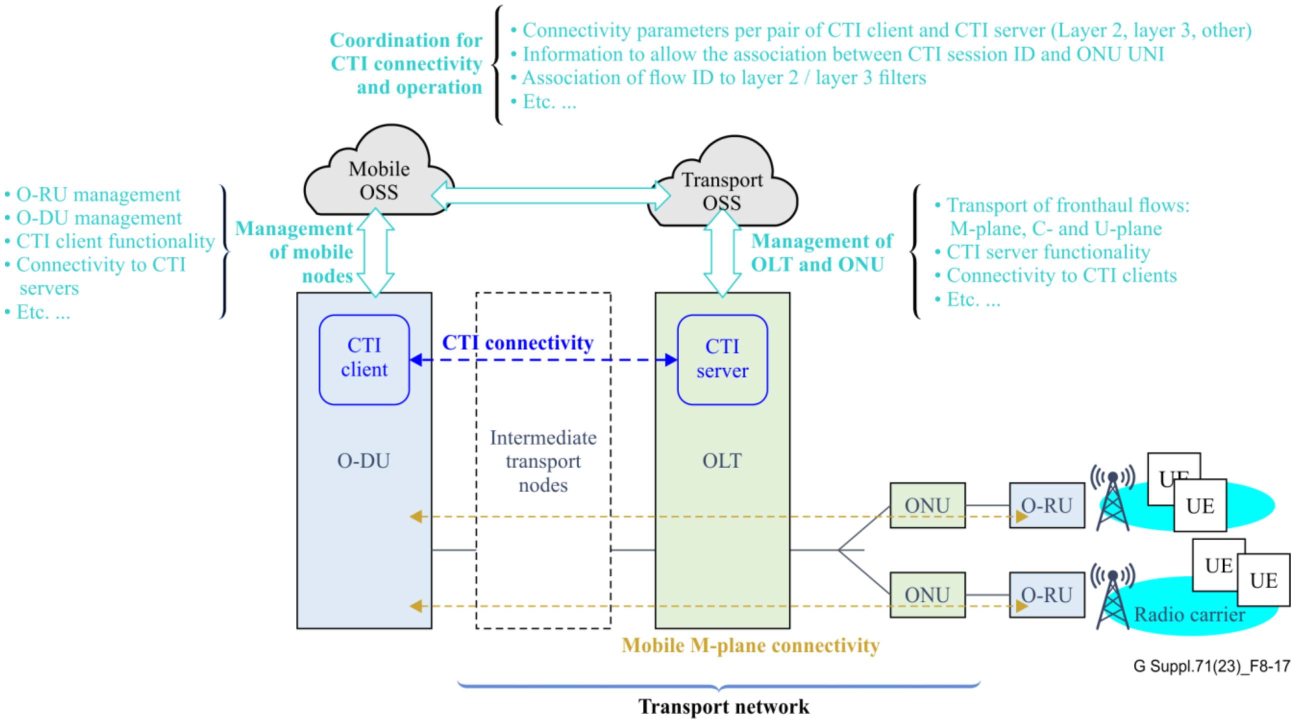
CO DBA strives to follow the variations of fronthaul traffic as accurately as possible. There will always be factors that generate inaccuracy on the alignment of the PON to the RAN (fronthaul traffic) time structures, such as variations in O-RU processing times, and cases of very high traffic variation rate (minislots). It is up to the CO DBA algorithm to choose an appropriate burst grant structure in order to meet the required latency while keeping bandwidth efficiency (each burst causing a bandwidth overhead penalty).

8.8 Handling of mix of latency-sensitive and latency-tolerant applications on the same PON

CO DBA with CTI is used for latency-sensitive fronthaul traffic, but other types of traffic could be present on the same PON, e.g., mobile backhaul or regular fibre to the home (FTTH) traffic. Latency-tolerant traffic does not use CTI and can rely on the regular DBA mechanisms (SR and TM-DBA). Both types of traffic can be supported simultaneously on the same PON. As the latency-tolerant applications do not need the same refresh rate of bandwidth assignments, the regular DBA can be updated at a slower pace than the CTI-driven CO DBA. The distinction between CO DBA and regular DBA is to be done on a per-T-CONT basis. Note that nothing prevents CO DBA to also take status reports into account for its T-CONTs.

8.9 Management of CTI functionality

8.9.1 Connectivity for exchanging CTI messages between an OLT and O-DUs



NOTE – M-plane connectivity between O-DU and O-RU is also depicted but is fully separate from CTI and does not replace the CTI connectivity between O-DU and OLT

Figure 8-17 – Mobile and transport OSS for management of CTI connectivity and CTI functionality

The CTI messages are encapsulated as IPv4 or IPv6 over Ethernet, or directly over Ethernet. The connectivity between the OLT and O-DUs (one OLT can subtend O-RUs from multiple O-DUs) can be based on Layer 2 switching or Layer 3 routing or other technologies which are outside the scope of this Supplement. The connectivity must be configured for each pair of CTI server – CTI client (one CTI server in the OLT can need connectivity to multiple CTI clients in potentially different O-DU nodes). This may require coordination between the transport OSS and mobile OSS. The functional steps of such coordination are explained in [b-O-RAN CTI TM] for a Layer 2 connectivity and for a Layer 3 connectivity. The management interactions themselves (e.g., management protocols and OSS architecture) are out of scope of this Supplement. Figure 8-17 shows mobile and transport OSS for management of CTI connectivity and CTI functionality.

8.9.2 Configuration parameters for CTI server in OLT

The reader is referred to [b-O-RAN CTI TM] for the full list of parameters and their format. The management interactions themselves (e.g., management protocols and OSS architecture) are out of scope of this Supplement.

Parameters depending on deployment topology and requiring coordination between mobile OSS and transport OSS

On the one hand, the CO DBA functionality at the OLT needs to keep track of the following associations:

– The mobile OSS determines the CTI session ID to be used for a particular O-RU interface. In turn, the OLT must associate each CTI session ID (or each combination of CTI session ID and CTI flow ID if flow IDs are used) with a specific T-CONT.

– Each CTI session ID (or each combination of CTI session ID and CTI flow ID if flow IDs are used) is associated with a total latency budget T34max. The value depends on the combined capabilities of the O-RU and O-DU and is determined by the mobile system, but the transport OSS is responsible for determining which portion of that budget can be consumed by the PON part in the transport network.
– The CTI server in the OLT must associate each CTI session ID with the corresponding CTI client, in order to know the destination when sending CTI messages related to that CTI session ID.
– As described in clause 8.6, for issuing PON ranging notifications the OLT needs to know which CTI session IDs are impacted per physical PON.

On the other hand, the CTI clients in the O-DUs must acquire the association of which CTI server to be contacted for each CTI session ID. As the philosophy of CTI is to avoid the mobile OSS having to be preconfigured with the physical topology inside the transport network (in other words, which O-RU is being connected to which ONU on which PON on which OLT), the transport OSS will have to provide this information to the mobile OSS.

Such associations require correlation between the transport and mobile management systems. The correlation can optionally be automated as described in [b-O-RAN CTI TM].

Common parameters

Both transport management system and mobile management system must be aligned to have coherent configured values for common parameters at CTI servers and CTI clients, such as the Layer 2/Layer 3 filters for the flow IDs, CTI timers, CTI UDP listening port, CTI pattern IDs and their corresponding pattern descriptors, etc.

Operational parameters to be chosen based on the capabilities of CTI client and CTI server

An agreement between mobile and transport systems must be made on the value of the following parameters:

- CTI version (1 value per CTI client to be configured in the CTI server). A common version is chosen based on supported versions on both sides.
- Nominal report message time interval (1 value per CTI session ID to be configured in the CTI server). The minimal time interval between CTI messages is determined by the reaction speed of CO DBA and the needs at mobile fronthaul level. See clause 8.7.4 of this Supplement and chapter 4.2 of [b-O-RAN CTI TC] for more details.
- Use of PON ranging notification (1 value per CTI client to be configured in the CTI server): Per CTI client, the CTI server keeps track of whether it should send such notifications and with what minimal notification advance time that the CTI client requires. O-Dus that do not interpret such messages do not need to receive them.
- Use of Type 1 extension field in CTI messages, see [b-O-RAN CTI TC] (1 value per CTI session ID to be configured in the CTI client). The transport system decides whether the extra information in the Type 1 extension field is required for the required CO DBA performance or not. For most cases it is expected to be required (to obtain the start time per report). Note that the pattern information can be kept optional even with the Type 1 extension field present (by using a default pattern ID value).
- Use of Type 2 field in CTI messages (see [b-O-RAN CTI TC]) (1 value per CTI server to be configured in the CTI client). The transport system decides whether the extra information in the Type 2 extension field is to be used or not. For most cases it is expected only to be useful for troubleshooting purposes.

8.9.3 Configuration and operation of ONUs

The ONUs do not participate to the exchange of CTI messages and there is no need for additional configuration on the ONU for using CO DBA. Their T-CONTs which are to be controlled by CO DBA are configured with the usual ONT Management and Control Interface (OMCI) procedures. T-CONTs for the mobile M-plane (controlled by classic DBA) are also configured as usual. There is no need for additional OMCI messages for CO DBA.

The start-up and operation of the ONUs follow the usual methods described in the ITU PON standards. There is no need for additional physical layer operation, administration and maintenance (PLOAM) messages for CO DBA.

9 Other use cases

For further study.

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