Overview of G.fast

Key functionalities and technical overview of draft Recommendations G.9700 and G.9701

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ITU-T G.fast summary overview and timeline presented by Frank Van der Putten in the main session

Presentation overview

- What is FTTdp? (see main session)
- FTTdp/G.fast "raison d'être" (see main session)
- Applications (see main session)
- Service provider requirements (see main session)
- FTTdp standards body eco-system (see main session)
- FTTdp deployment use cases (see main session)
- G.fast key functionalities
- *ITU-T G.9700 overview*
- *ITU-T G.9701 overview*
- Standards time-line (see main session)
- *Backup material*

- What is FTTdp?
- FTTdp/G.fast "raison d'être"
- Applications
- Service provider requirements
- FTTdp standards body eco-system
- FTTdp deployment use cases
- **G.fast key functionalities**
- ITU-T G.9700 overview
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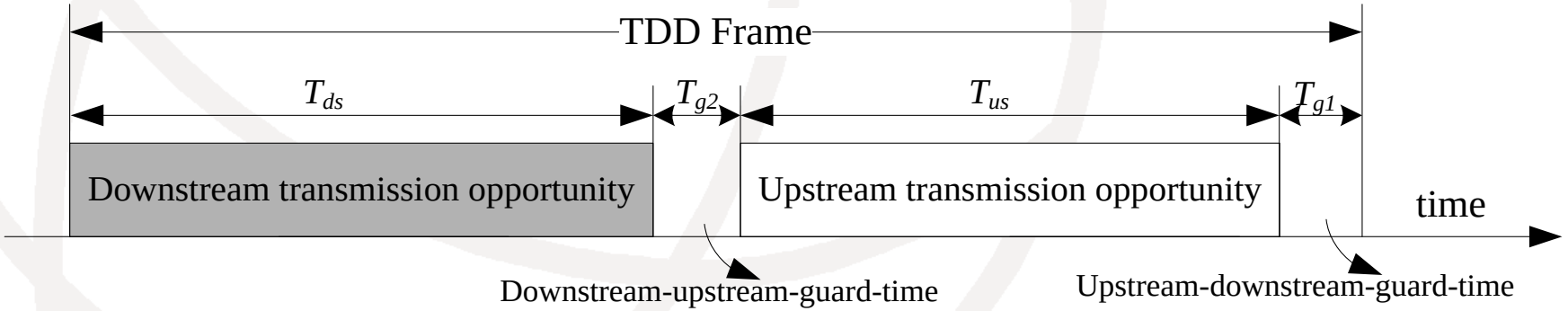
G.fast key functionalities (1/6)

- Duplexing method: TDD
  - Can easily vary DS/US asymmetry ratio
    - Independent of loop length
    - Varies from about 90/10 to 30/70
  - Easily supports low-power states
  - Discontinuous operation allows flexible trade-off of throughput vs. power consumption
  - Simplifies analogue front end



G.fast key functionalities (2/6)

- Bandwidth:
  - 106 MHz profile in the 1st version
    - 212 MHz profile in a future amendment
  - Configurable start and stop frequencies, PSD shaping and notching
    - Configurable start frequency allows for coexistence with VDSL2 and supports a migration path to G.fast only

G.fast key functionalities (3/6)

- Modulation:
  - Discrete multi-tone (DMT)
  - 2048 sub-carriers for 106 MHz, 4096 sub-carriers for 212 MHz
  - Sub-carrier spacing 51.75 kHz
  - Default symbol rate 48.00 kHz
    - The difference between sub-carrier spacing and symbol rate is due to the cyclic extension, which is used to remove ISI
  - Bit loading of ≤12 bits/sub-carrier
    - VDSL2 is ≤15 bits/sub-carrier

G.fast key functionalities (4/6)

- PHY layer retransmission
  - improved robustness against impulsive noise events (up to 10 ms duration) without loss of data while maintaining low latency
- Mandatory support for vectoring
  - Far-end self crosstalk (FEXT) cancellation
  - Linear precoding in the 1st version, non-linear precoding in a future amendment
- Forward error correction (FEC)
  - Trellis code + Reed Solomon of VDSL2 (G.993.2) with the retransmission block (DTU) interleaving defined in G.998.4

G.fast key functionalities (5/6)

- Fast rate adaptation (FRA)
  - To quickly adapt the data rate depending on changing channel or noise conditions
  - Uses a robust management channel (RMC) to make rapid changes (TDD frame rates, <1 ms)
- Expected reach/rate
  - Intended to operate over loops up to approximately 250 m of 24 AWG (0.5 mm) wire pair
    - VDSL2 is approximately 2500 metres of 26 AWG (0.4 mm)
  - Expected rate of 500 Mbit/s @ 100m, 150 Mbit/s @ 250 m

G.fast key functionalities (6/6)

- Provides transport of network timing (8 kHz NTR)
- Support for Time of Day (ToD) – IEEE 1588
  - in order to support services that require accurate ToD at both sides of the G.fast link to operate the higher layers of the protocol stack (e.g., cellular backhaul)
- Support for both TR-156 and TR-167 Broadband Forum architectures

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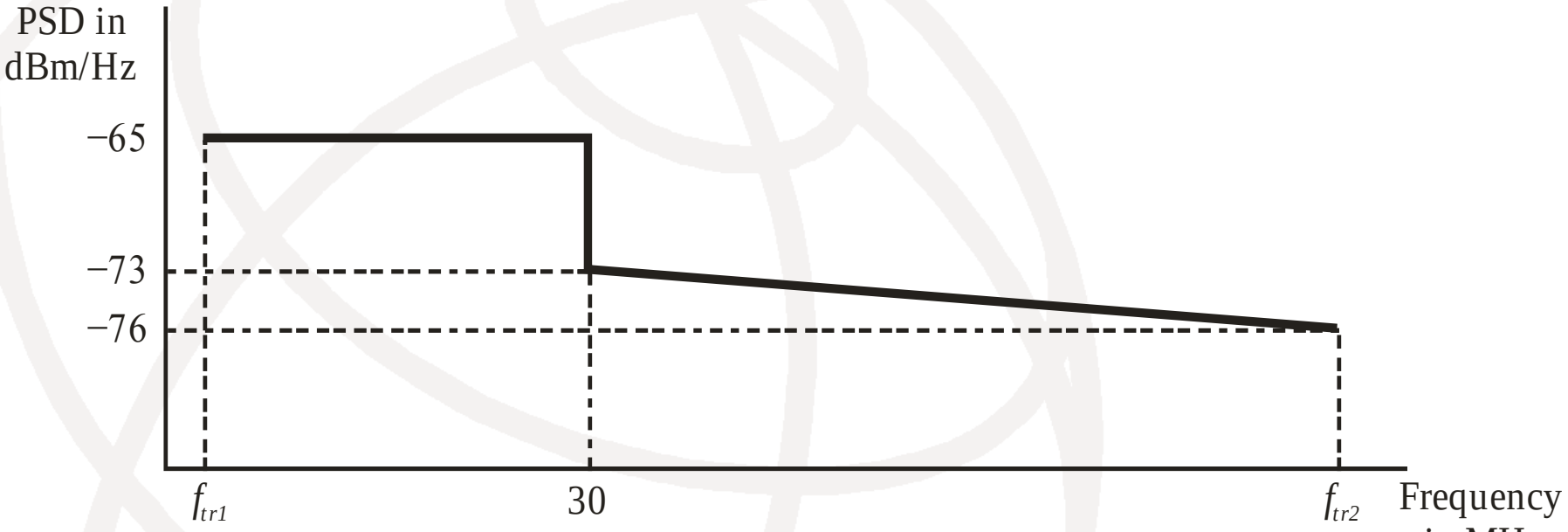
ITU-T G.9700 Overview

- This Recommendation complements the physical layer (PHY) specification in [ITU-T G.9701]. It specifies:
  - power spectral density (PSD) limit mask requirements
  - a set of tools to support reduction of the transmit PSD mask
  - profile control parameters that determine spectral content, including the allowable maximum aggregate transmit power into a specified termination impedance
  - a methodology for transmit PSD verification
- This ensures that the technology can address:
  - regional requirements
  - operator deployment requirements, for example, compatibility with other digital subscriber line (DSL) technologies
  - applicable electromagnetic compatibility (EMC) regulations or standards
  - local EMC issues

G.9700 PSD Tools

- The transmit PSD mask (TxPSDM) is constructed from the combination of the following masks:
  - Limit PSD mask (LPM)
    - Defines the absolute maximum PSD limit of the TxPSDM that shall never be exceeded
  - Sub-carrier mask (SM)
    - Used to eliminate transmission on one or more sub-carriers.
    - Not intended to protect radio services
  - PSD shaping mask (PSM)
    - Allows reduction of the TxPSDM in some parts of the spectrum, mainly for spectrum compatibility and coexistence with other access and home network technologies
  - Notching mask (NM)
    - Notch one or more specific frequency bands in order to protect radio services; for example, amateur radio bands or broadcast radio bands
  - Low-frequency edge stop-band mask (LESM)
    - Used to set the lower band edge for spectral compatibility with other DSL services (e.g., VDSL2)

106 MHz profile in-band LPM

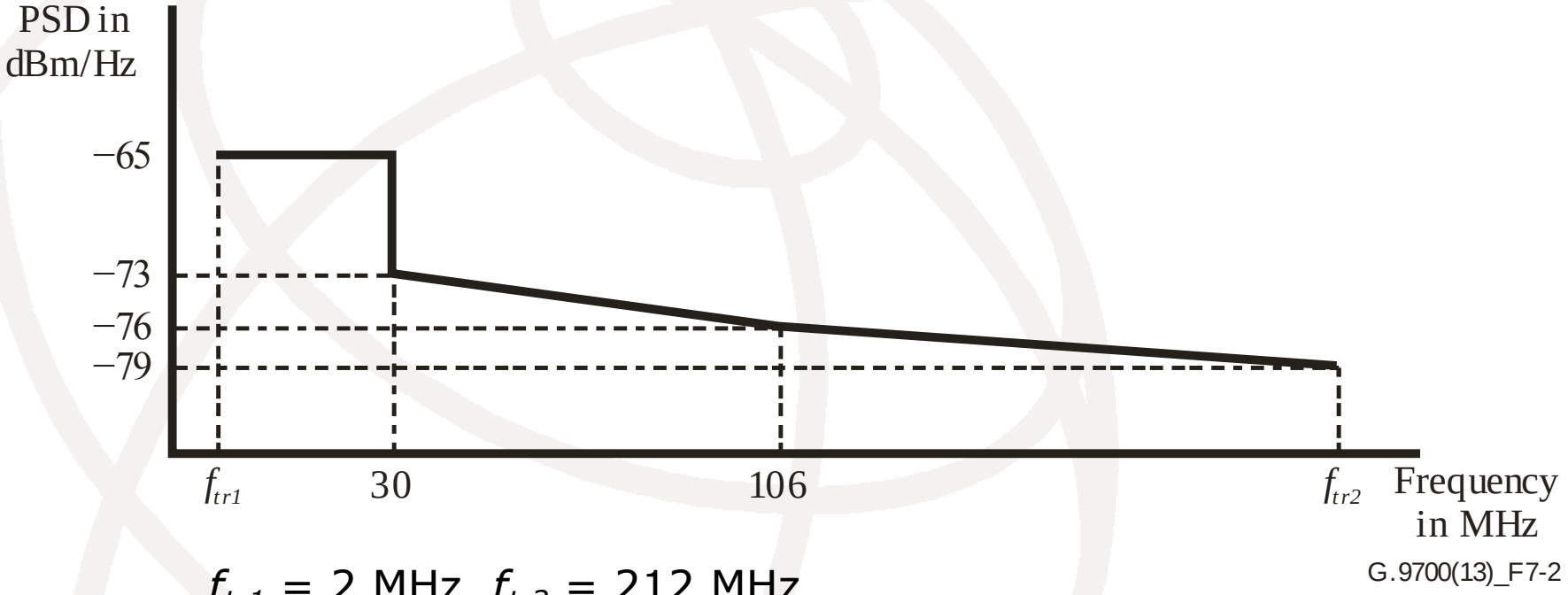


f_{tr1} = 2 MHz, f_{tr2} = 106 MHz

Maximum aggregate transmit power = +4 dBm

- VDSL2 17 & 30 MHz profiles are +14.5 dBm

212 MHz profile in-band LPM*

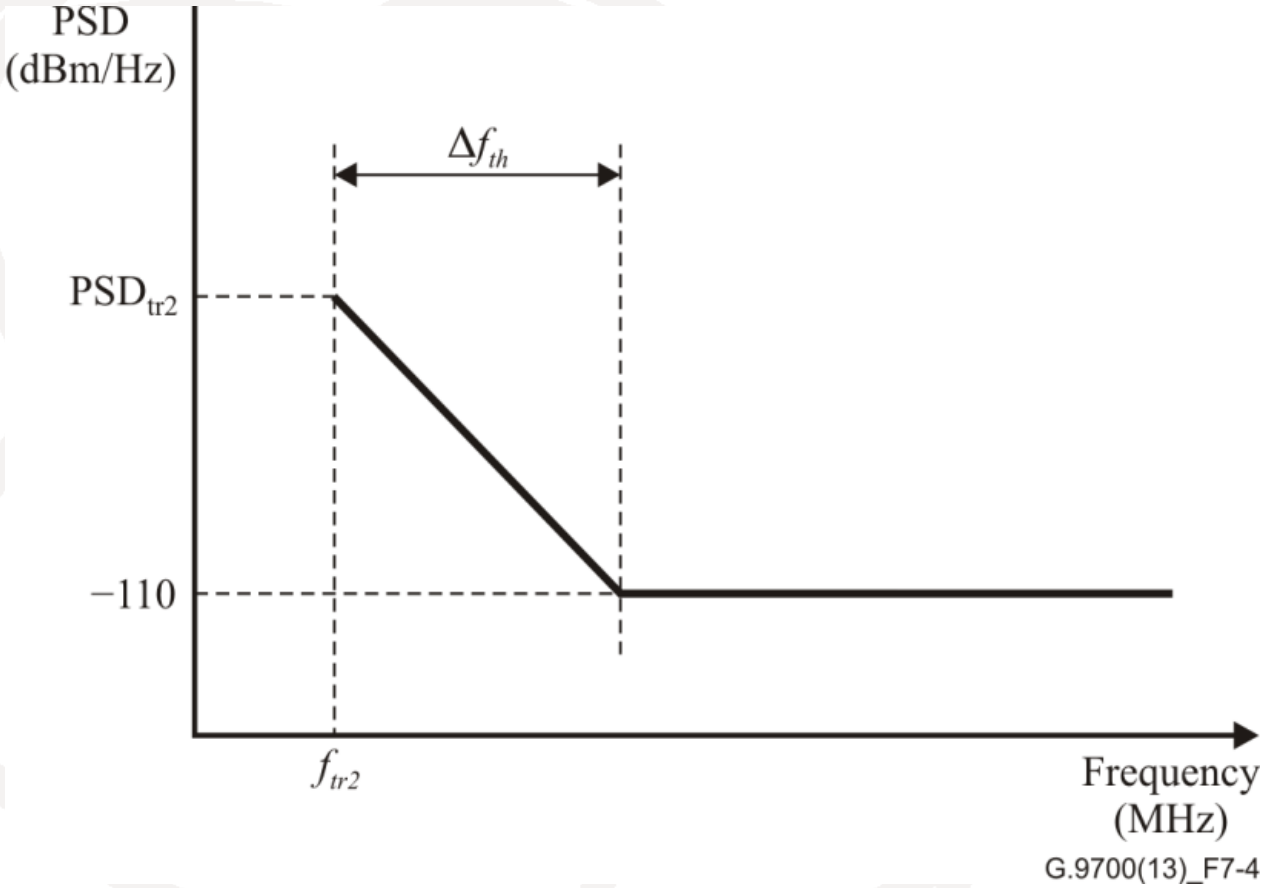


f_{tr1} = 2 MHz, f_{tr2} = 212 MHz

Maximum aggregate transmit power is for further study

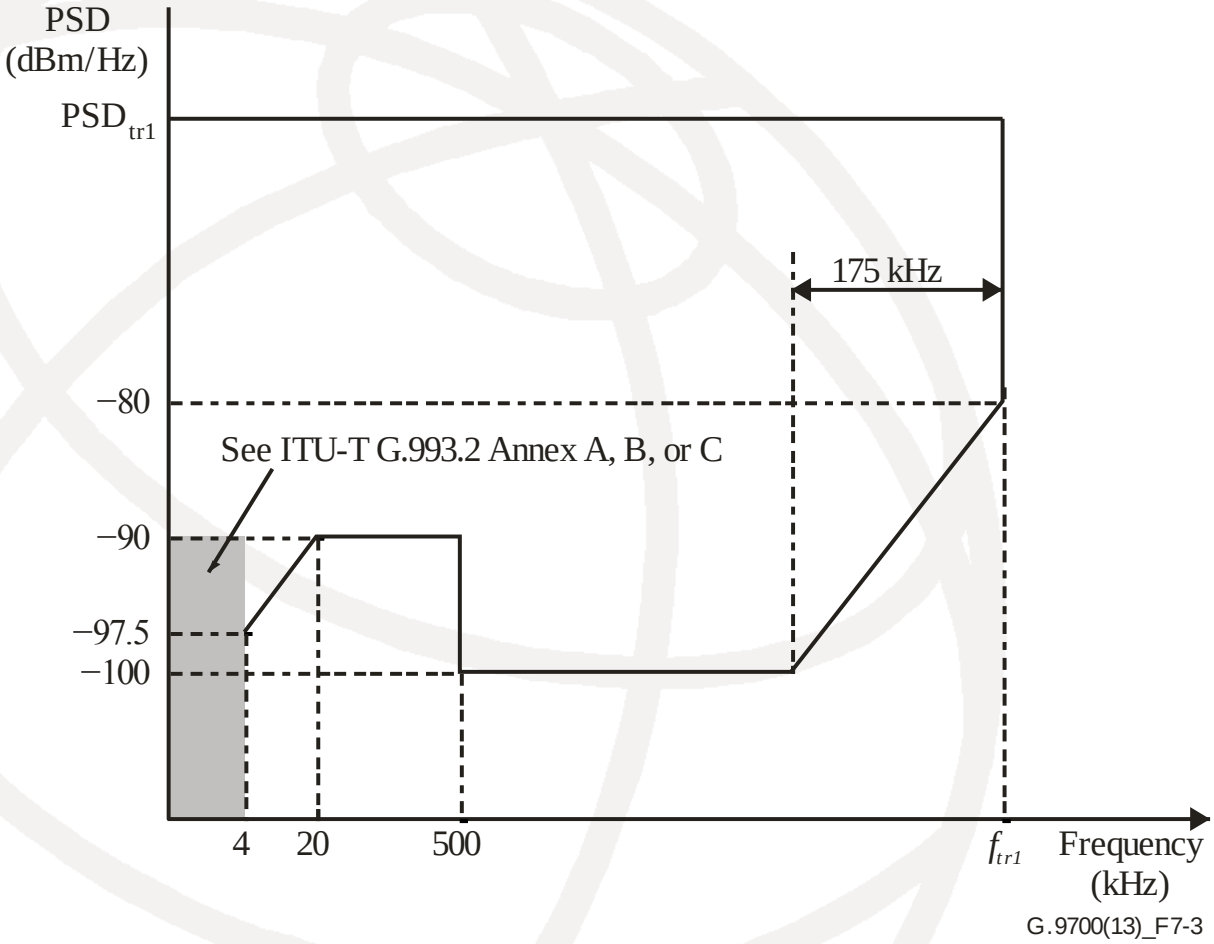
* The use of this mask is for further study in G.9701

High frequency out-of-band LPM



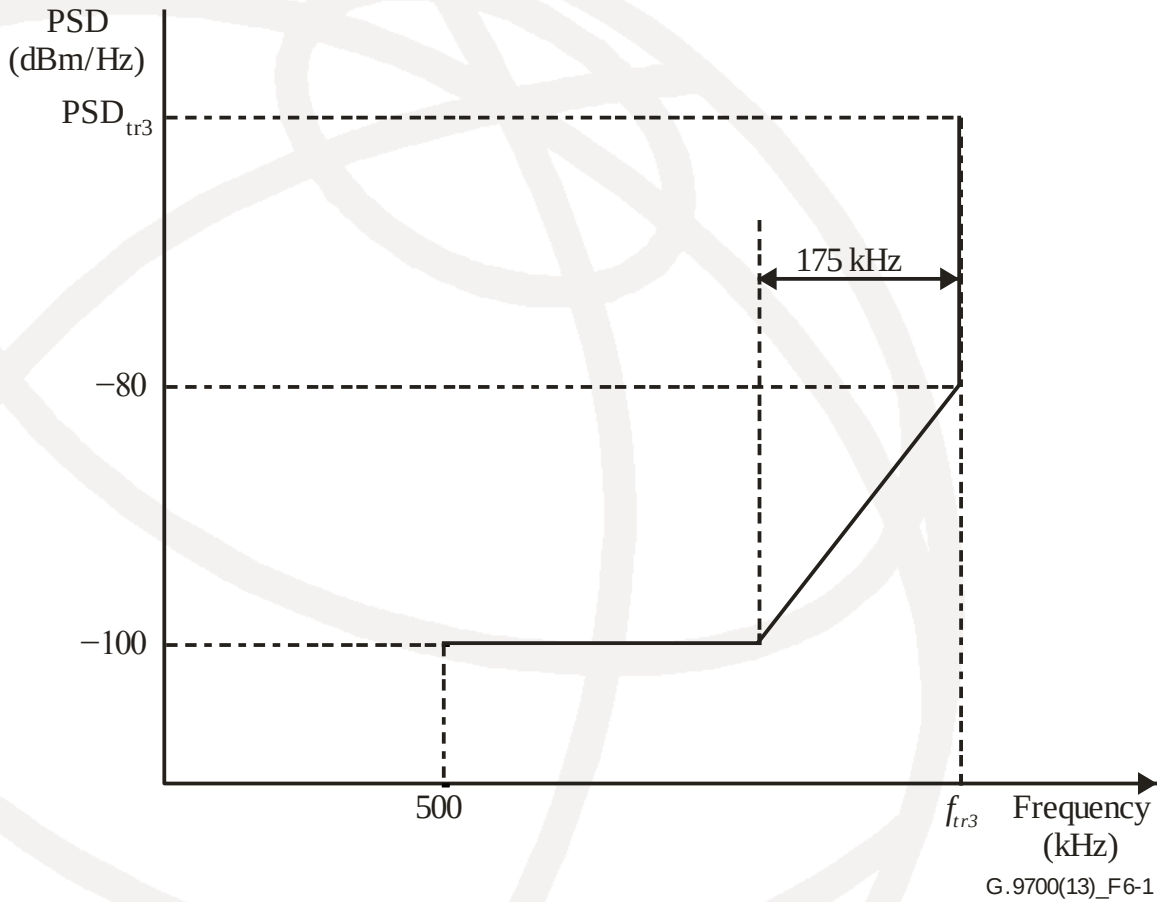
Δf_{th} = 20 MHz for 106 MHz profile
Δf_{th} = 40 MHz for 212 MHz profile

Low frequency out-of-band LPM



f_{tr1} = 2 MHz

Low-frequency Edge Stop-band LPM



$f_{tr1} \leq f_{tr3} \leq 30$ MHz

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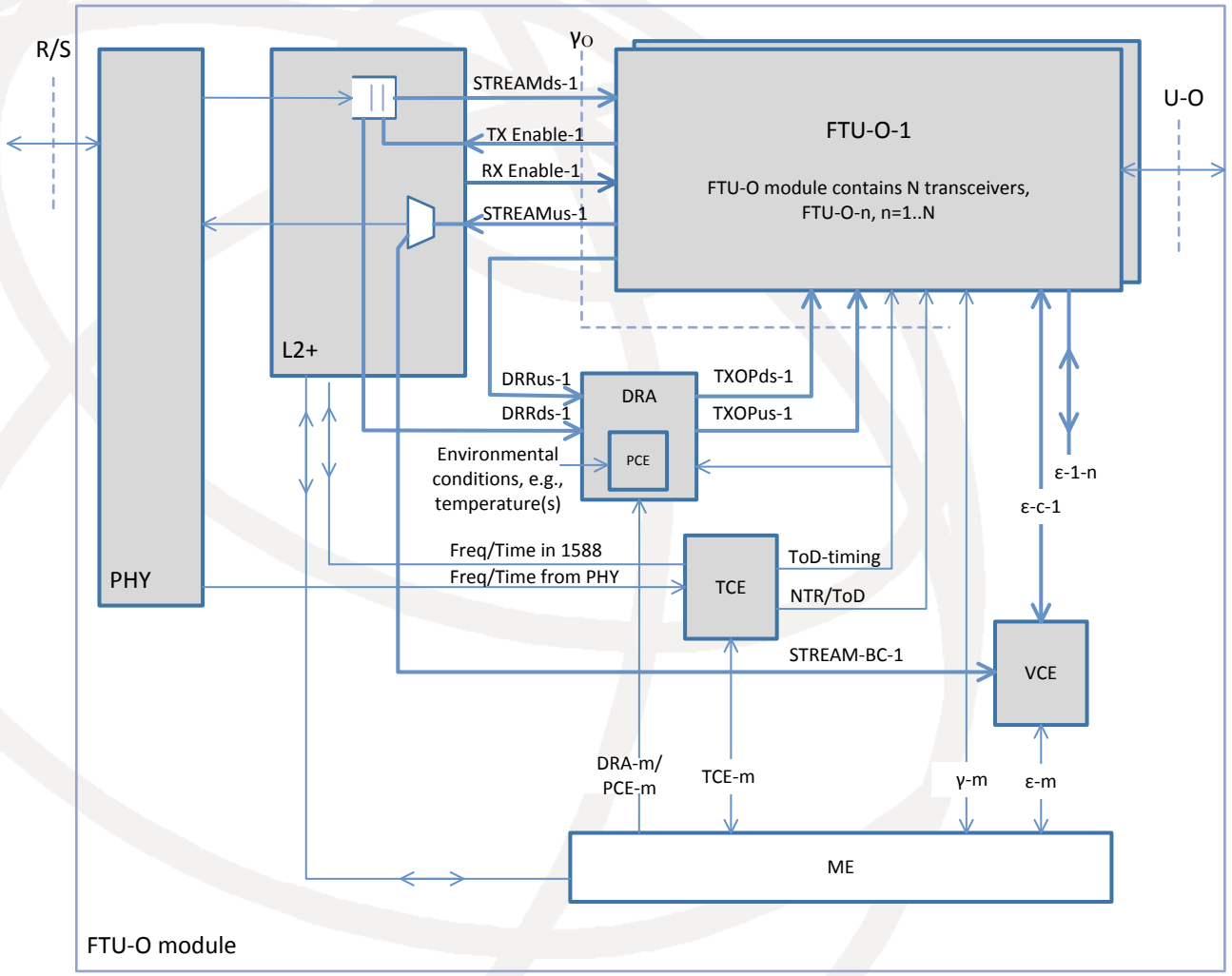
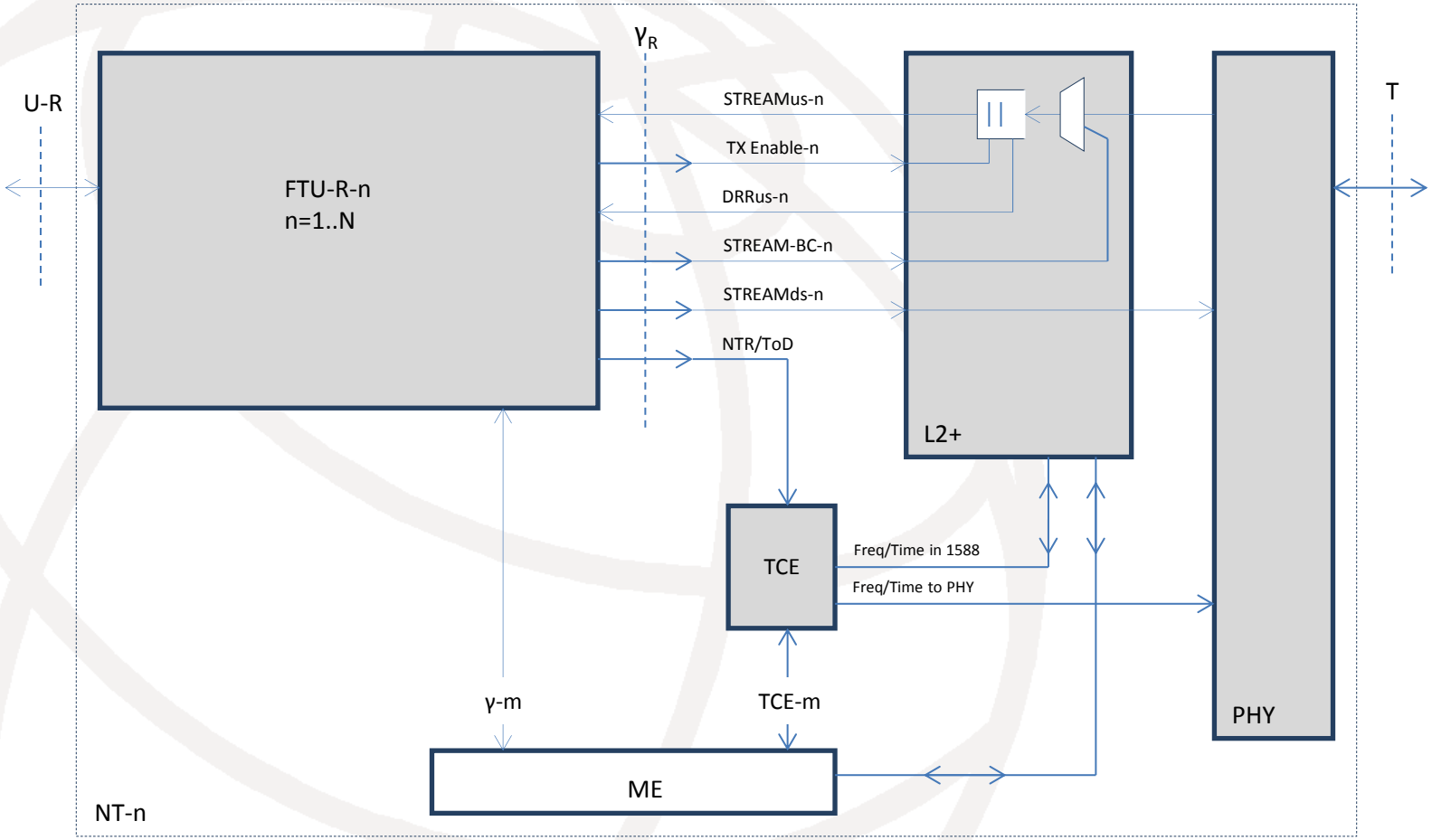
Reference model of the FTU-O module



Legend for FTU-O module

- DRA: dynamic resource allocation
- DRR: dynamic resource report
- FTU-O, FTU-R: Fast Transceiver Unit at network and remote ends
- γ_O, γ_R : reference point for upper edge of transceiver specification
- L2+: functionality at layer 2 and above
- ME: management entity
- NTR: network timing reference
- PCE: power control entity
- RX Enable: upstream flow control
- STREAMds, STREAMus: downstream/upstream data stream
- STREAM-BC: back channel information from FTU-R for vectoring
- TCE: timing control entity
- ToD: time-of-day
- TX Enable: downstream flow control
- U-O: physical line interface
- VCE: vectoring control entity
- ε-1-*n*: precoder data for vectoring exchanged between FTU-O_1 and FTU-O_n
- ε-c-*1*: precoder coefficients for FTU-O_1

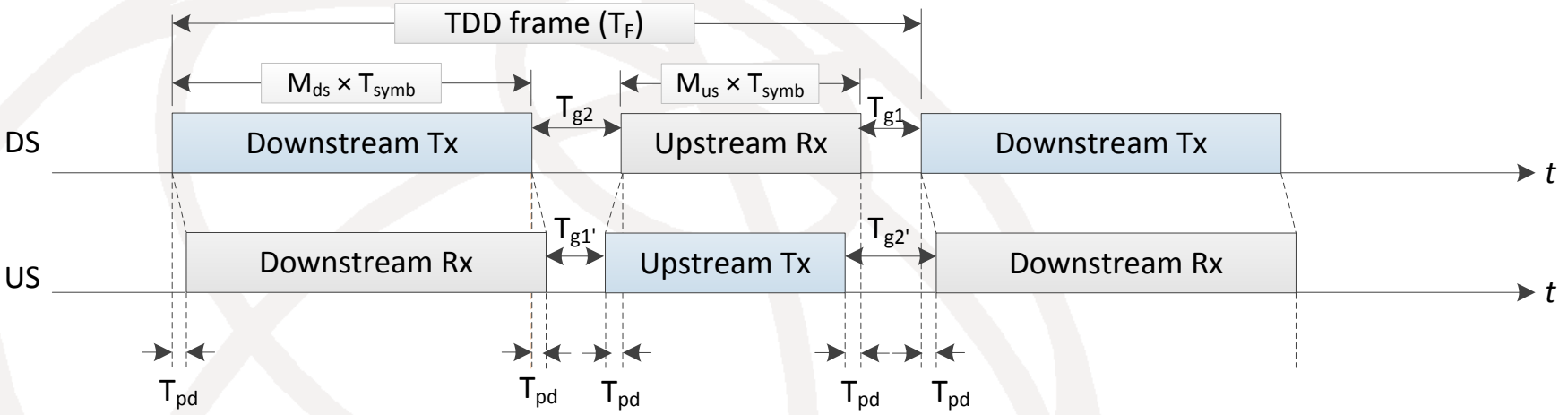
Reference model of an NT



Symbol types

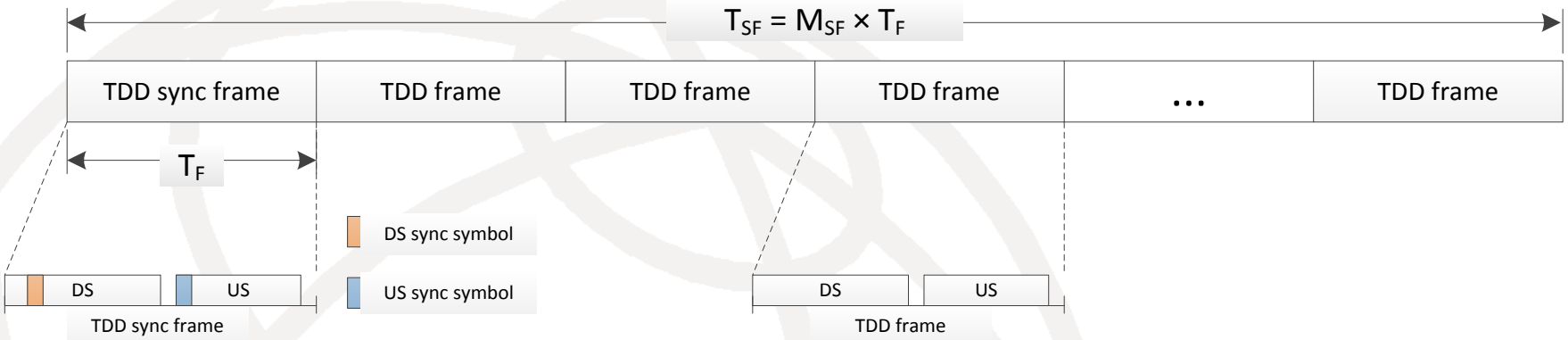
- There are 6 different types of symbols in showtime
  - Sync symbol (see slide 24)
  - Pilot symbol (see slide 33)
  - RMC symbol (see slides 31, 32, 36, 38, 39)
  - Data symbol (see slides 33, 34, 38, 39)
  - Idle symbol (see slides 38, 39)
  - Quiet symbol (see slides 38, 39)

TDD Frame structure



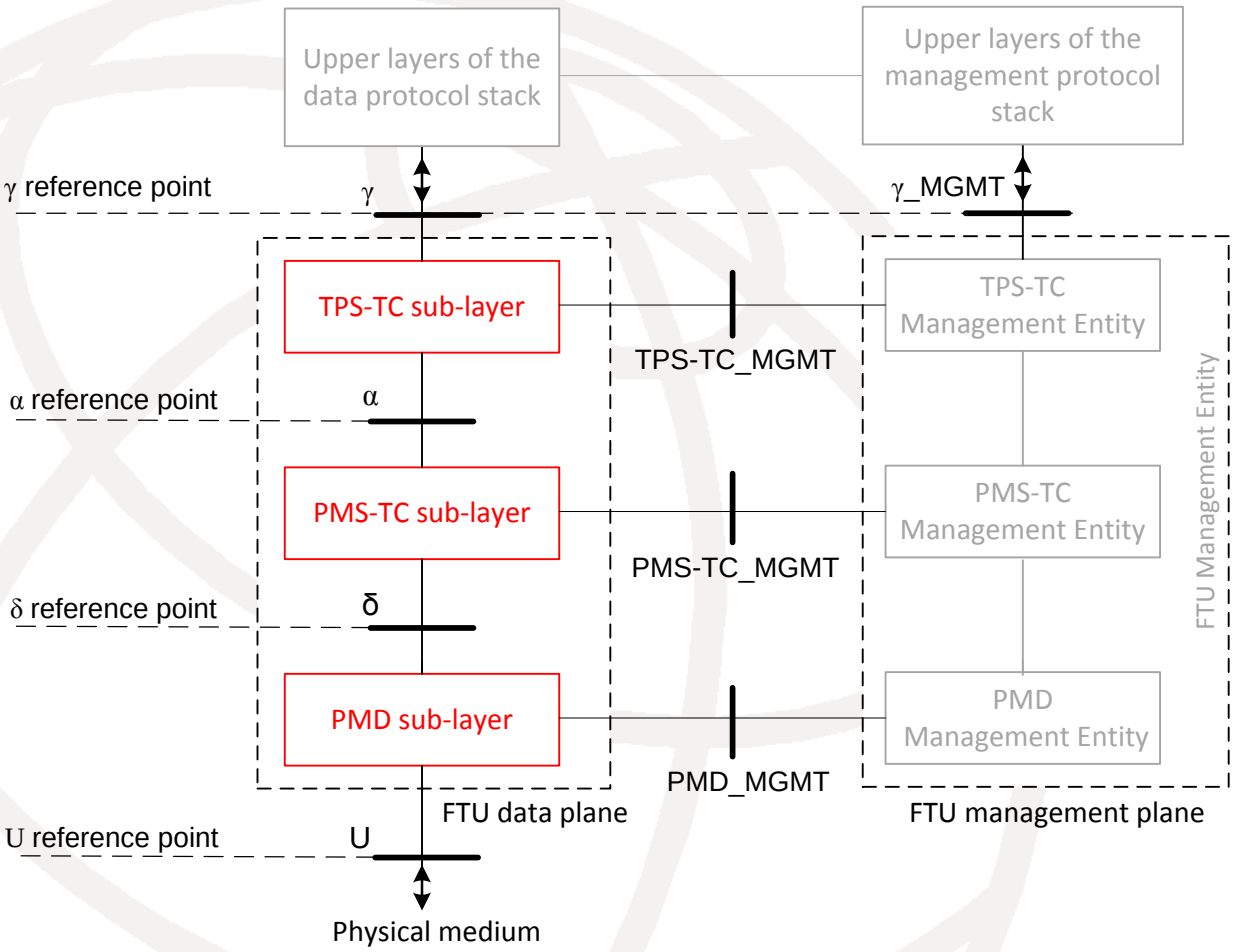
- TDD frame lengths (.145 to .875 ms, default .75 ms)
  - T_F = 36 and 23 symbols supported in the main body
  - T_F = 12 and 7 symbols support in an Annex for delay critical applications

Superframe structure



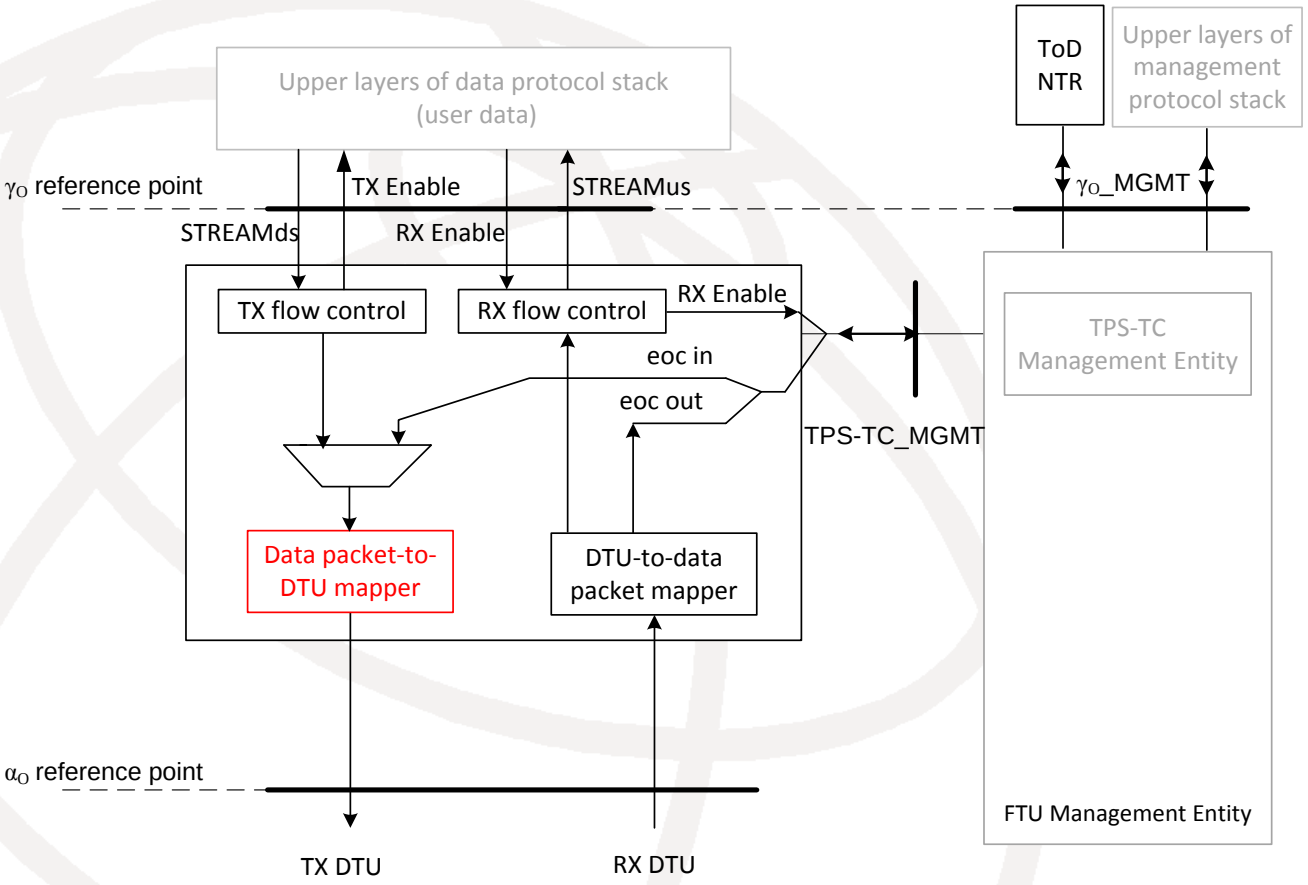
- Superframe lengths (5.75 to 7 ms, default 6 ms)
  - M_{SF} = 8 for T_F = 36 supported in the main body
  - M_{SF} = 12 for T_F = 23 supported in the main body
  - M_{SF} = 24 for T_F = 12 supported in the Annex
  - M_{SF} = 41 for T_F = 7 supported in the Annex
- Sync symbol: modulates probe sequences and is used for synchronization and channel estimation. ToD reference samples are also associated with the sync symbol.

FTU protocol reference model



Legend: TPS-TC = transport protocol specific transmission convergence
PMS-TC = physical medium specific transmission convergence
PMD = physical medium dependent

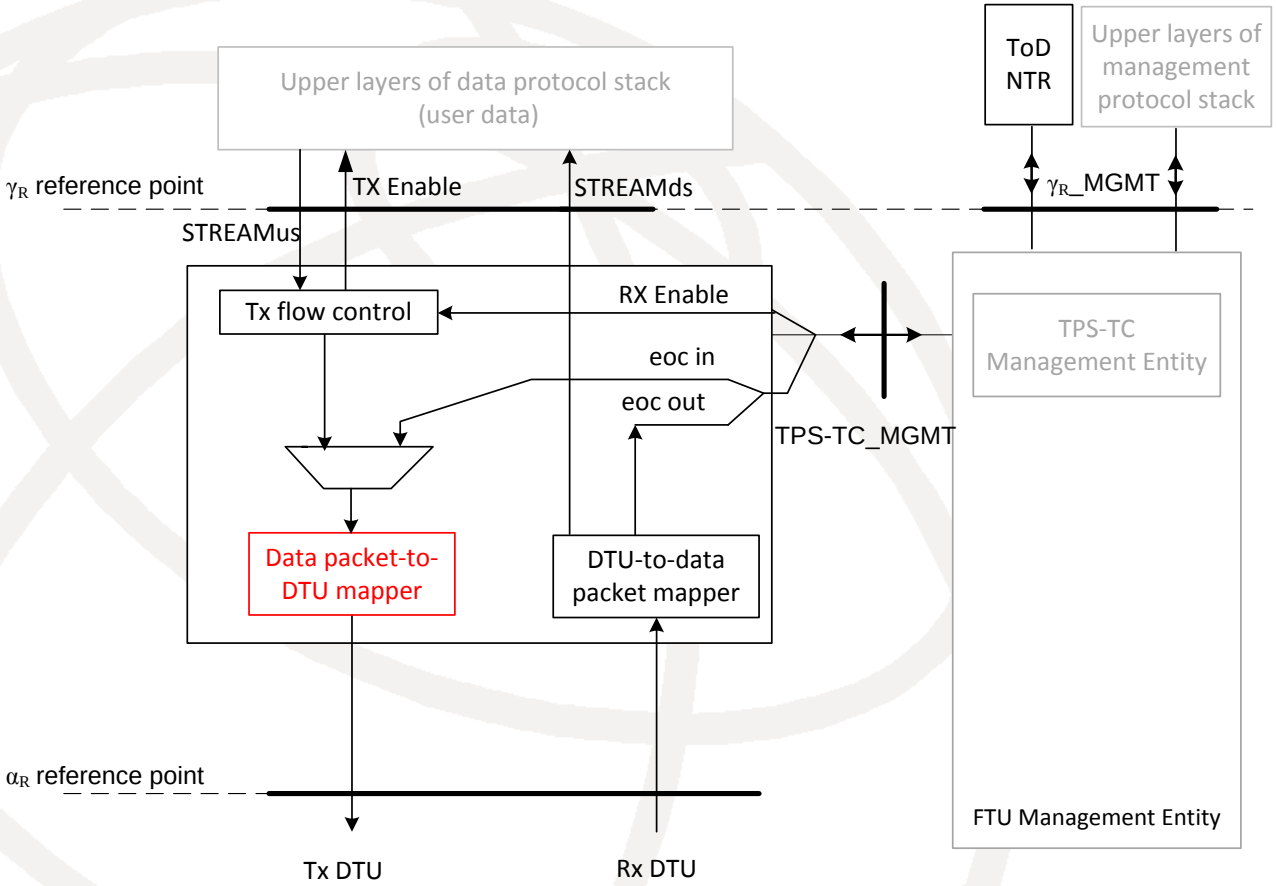
TPS-TC sub-layer (FTU-O)



Functional reference model of the TPS-TC (FTU-O)

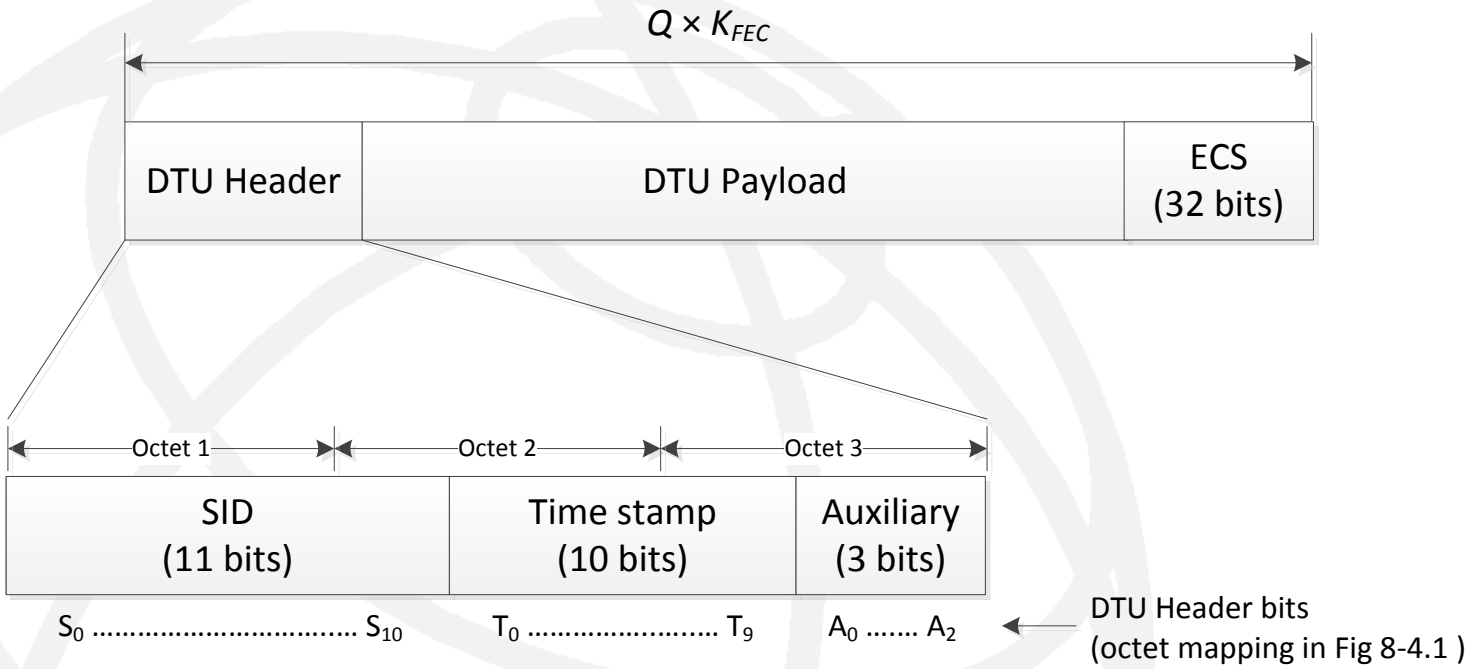
Legend: DTU = data transfer unit, eoc = embedded operations channel

TPS-TC sub-layer (FTU-R)



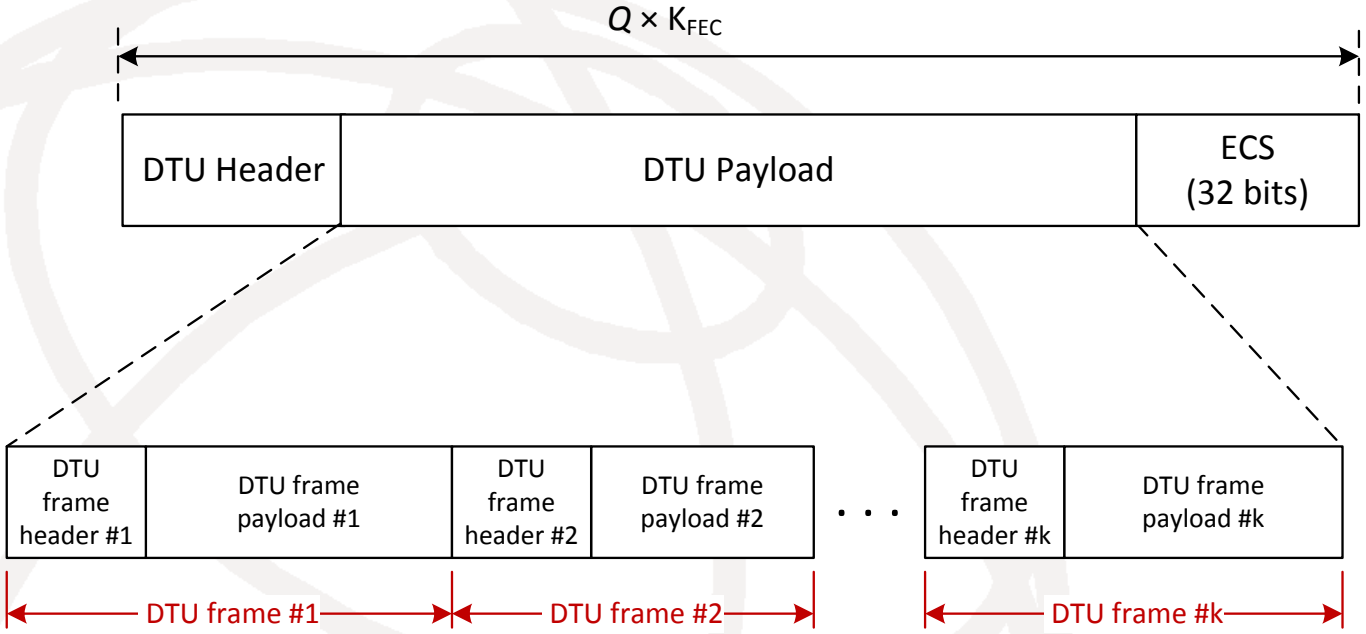
Functional reference model of the TPS-TC (FTU-R)

DTU mapper (1/3)



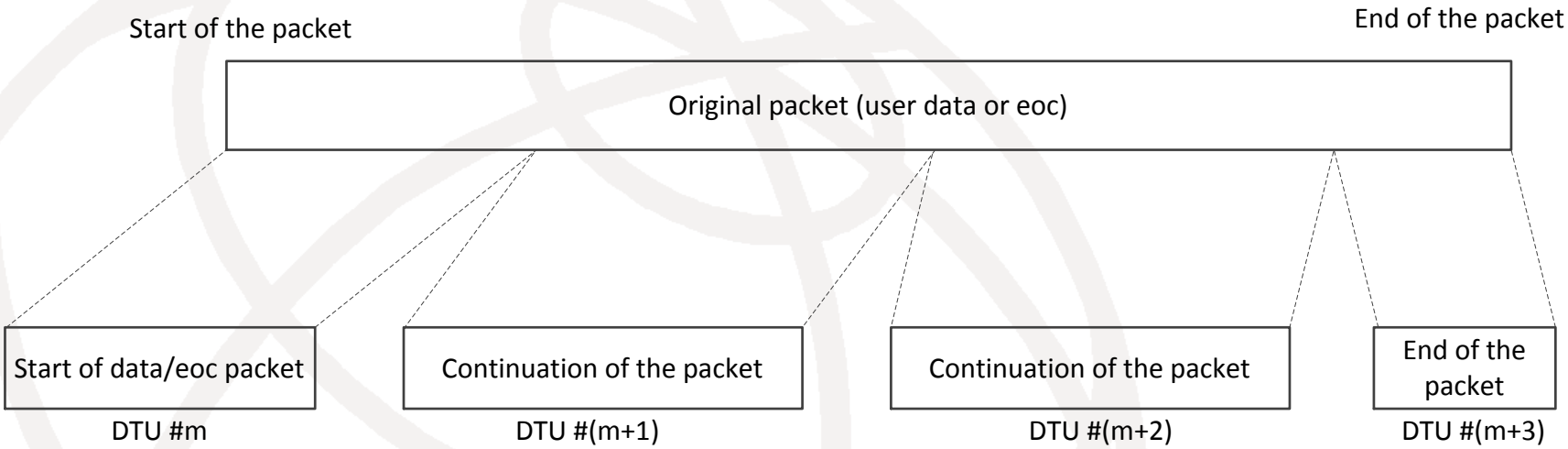
- DTU header:
  - SID – sequence identifier used to identify the particular DTU in the transmitted sequence of DTUs
  - Time Stamp (TS) – symbol count of the symbol at the U reference point containing bit S_0 of this header
  - Auxiliary field – DTU type (normal or dummy)

DTU mapper (2/3)



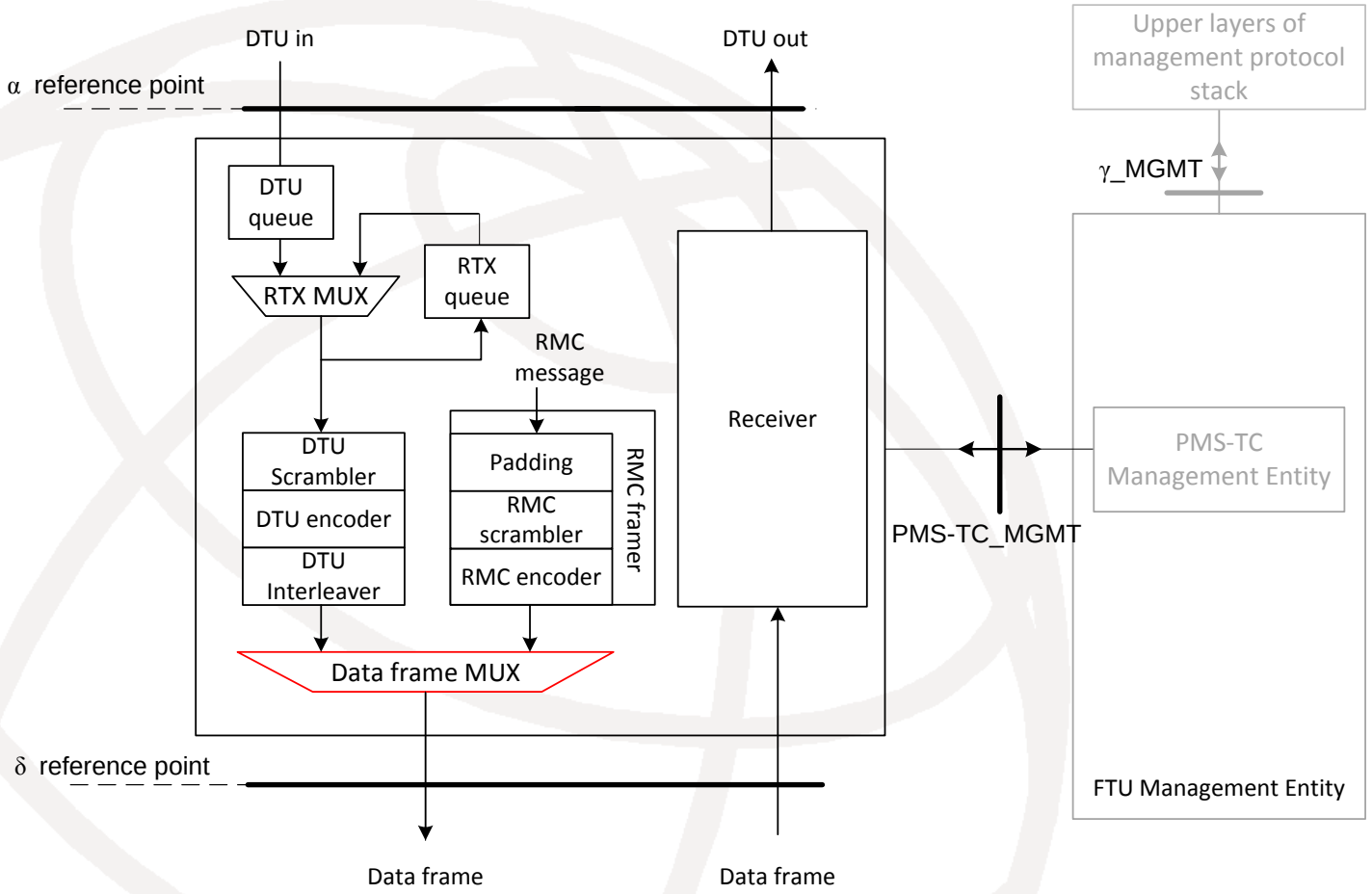
- DTU frame header:
  - DTU frame length and type:
    - Idle
    - Complete data or eoc packet
    - Start of data or eoc packet
    - Continuation of the packet
    - End of the packet

DTU mapper (3/3)



- Packets can span several DTUs

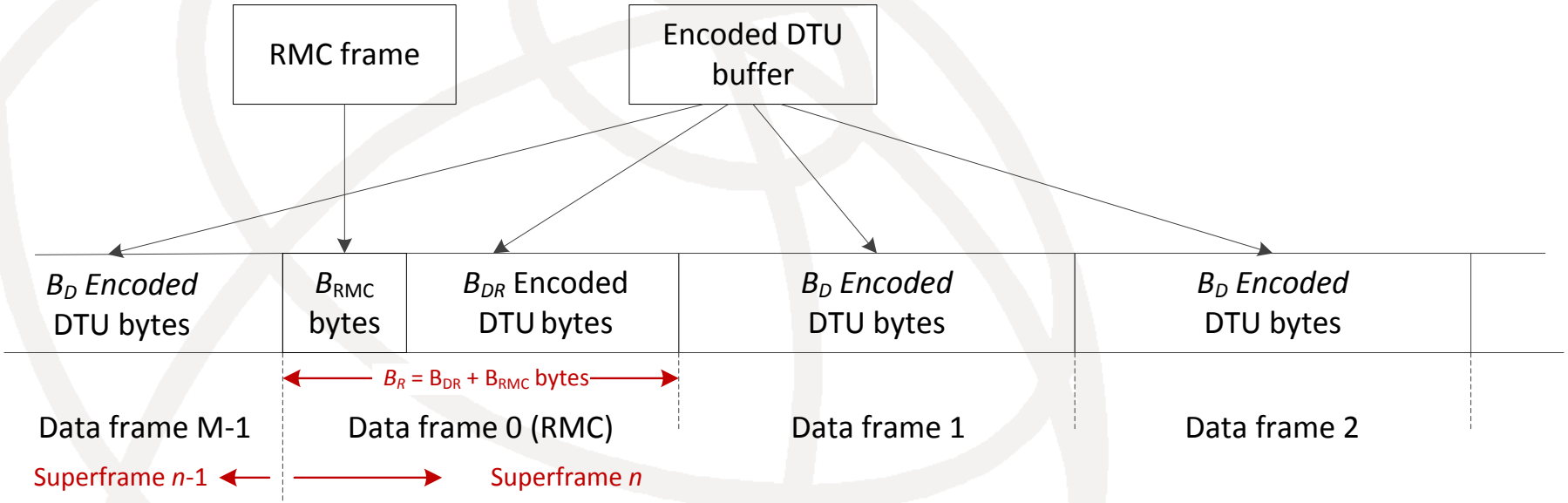
PMS-TC sub-layer



Functional reference model of the PMS-TC

Legend: RMC = robust management channel

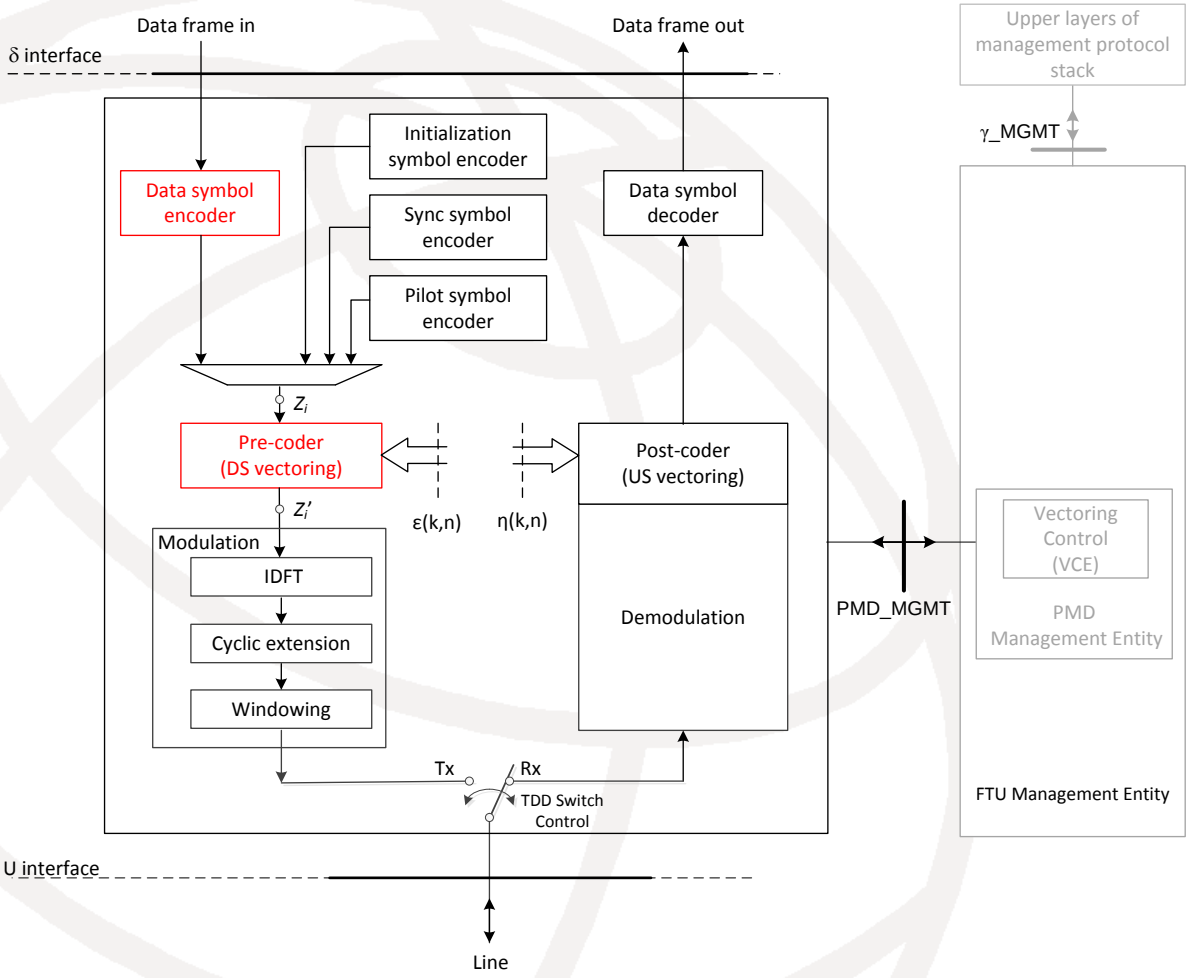
Data frame multiplexer



Multiplexing of RMC frame and DTUs into data frames

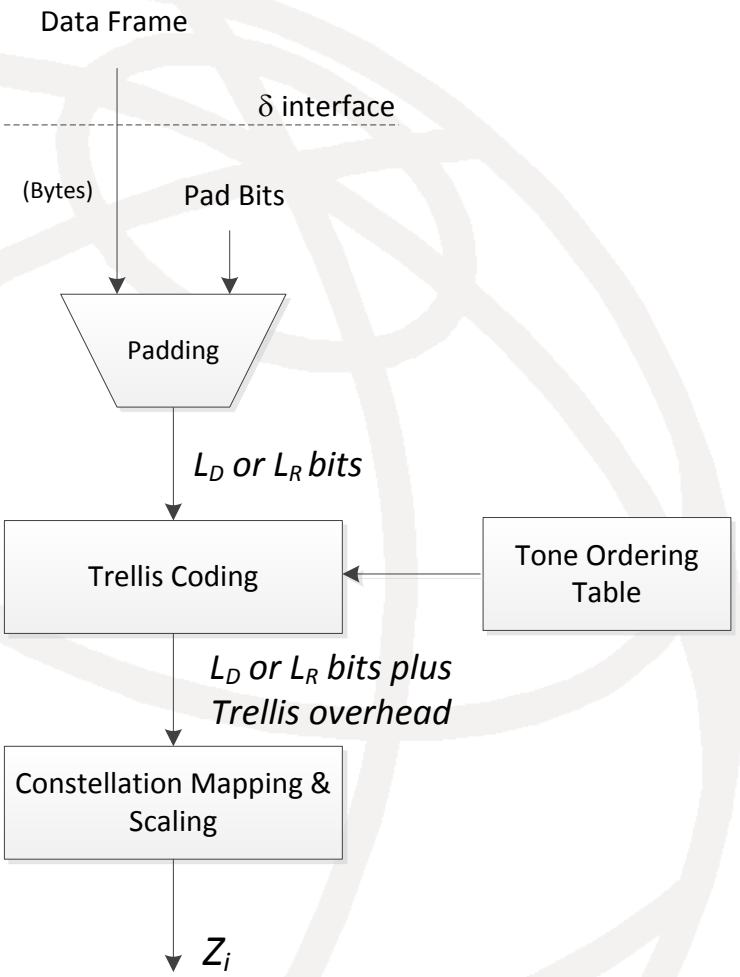
- B_D can be different in NOI and DOI (see slide 37)

PMD sub-layer



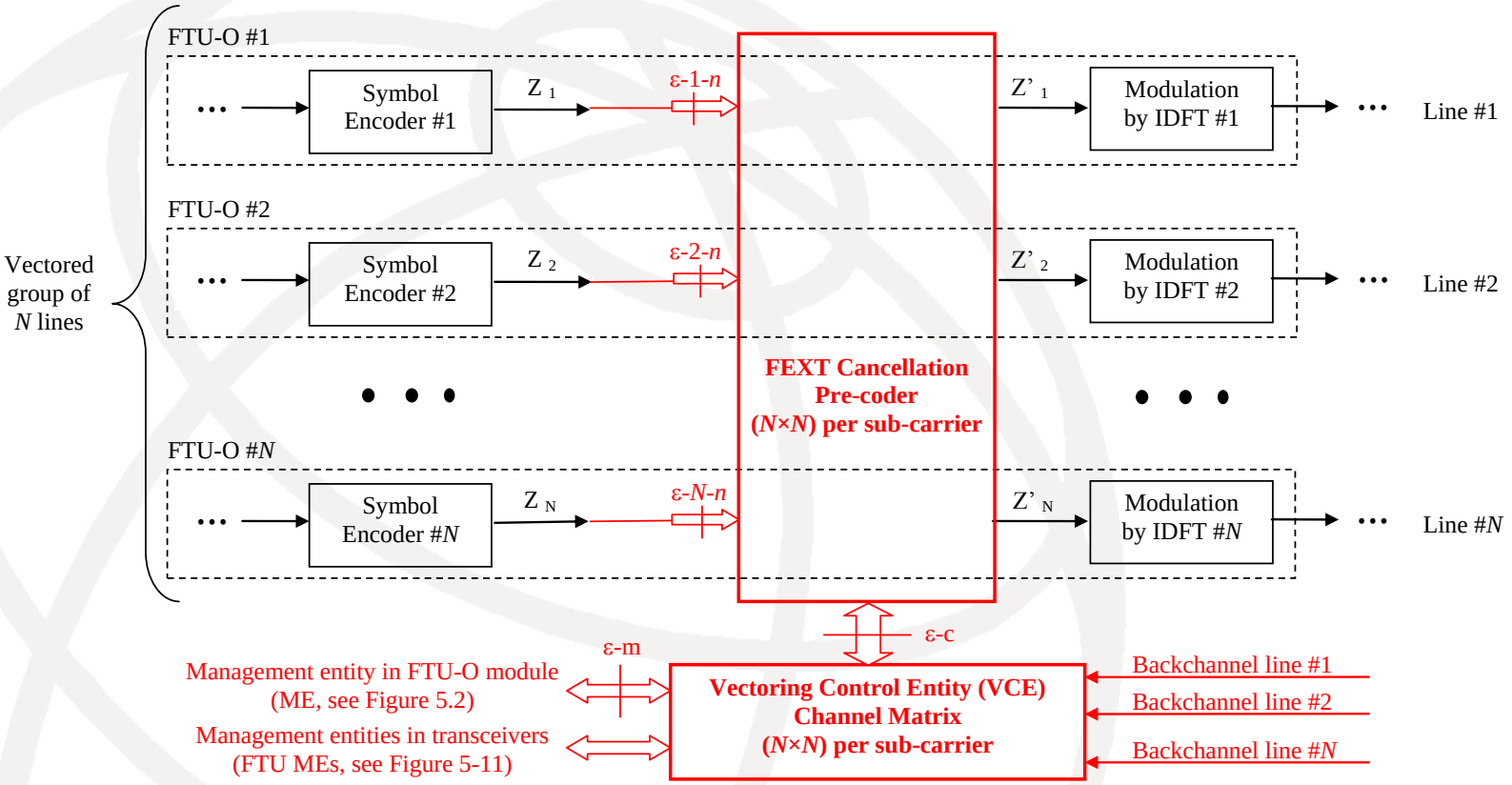
PMD Functional Reference Model

Data symbol encoder



Functional model of the data symbol encoder

Precoder



Symbol Encoder represents the data, sync, pilot, or initialization symbol encoder shown in Figure 10-1.

Vectored group functional model of PMD sub-layer using *N*×*N* precoder for downstream vectoring

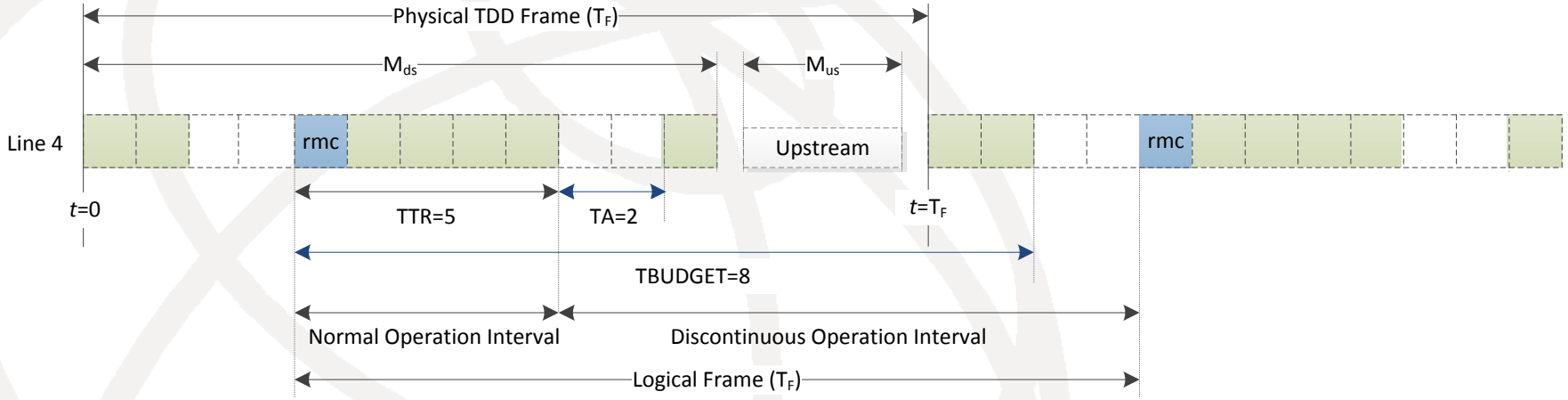
On-line reconfiguration (OLR)

- Seamless rate adaptation (SRA): used to reconfigure the total data rate by modifying the data frame parameters, modifying the bit loadings and gains, and modifying the DTU size.
- Bit Swapping: used to reallocate the bits and transmit power among the allowed sub-carriers without changing the bit rate.
- Transmitter initiated gain adjustment (TIGA): provides the VCE means to address changes in the downstream precoded direct channel gain. Used to prevent violation of the transmit PSD mask as the crosstalk channel matrix changes).
- RMC parameter adjustment (RPA): provides reconfiguration of the RMC parameters (RMC sub-carriers set, bit-loading for RMC sub-carriers).
- Fast rate adaptation (FRA): provides fast adaptation of the bit rate. The fast adaptation of the bit rate may be used to mitigate unexpected SNR loss in cases of abrupt changes in the channel. It is an RMC-based procedure rather than an eoc-based procedure.

Discontinuous operation

- For both downstream and upstream, a logical frame is divided into a normal operation interval (NOI) and a discontinuous operation interval (DOI)
- Timing of transmissions is controlled by the following parameters allowing a flexible split between NOI and DOI:
  - Transmission budget (TBUDGET): Total number of allocated symbols in the combined normal and discontinuous operation intervals
  - TTR: the number of symbols in the normal operation interval
  - TA: the number of quiet symbols inserted at the beginning of the discontinuous operation interval
  - TIQ: indicates whether idle or quiet symbols shall be used during the symbol periods of the discontinuous operation interval allocated for active symbols
- Discontinuous operation can be used in the NOI or DOI !
- Discontinuous operation is more challenging for vectoring

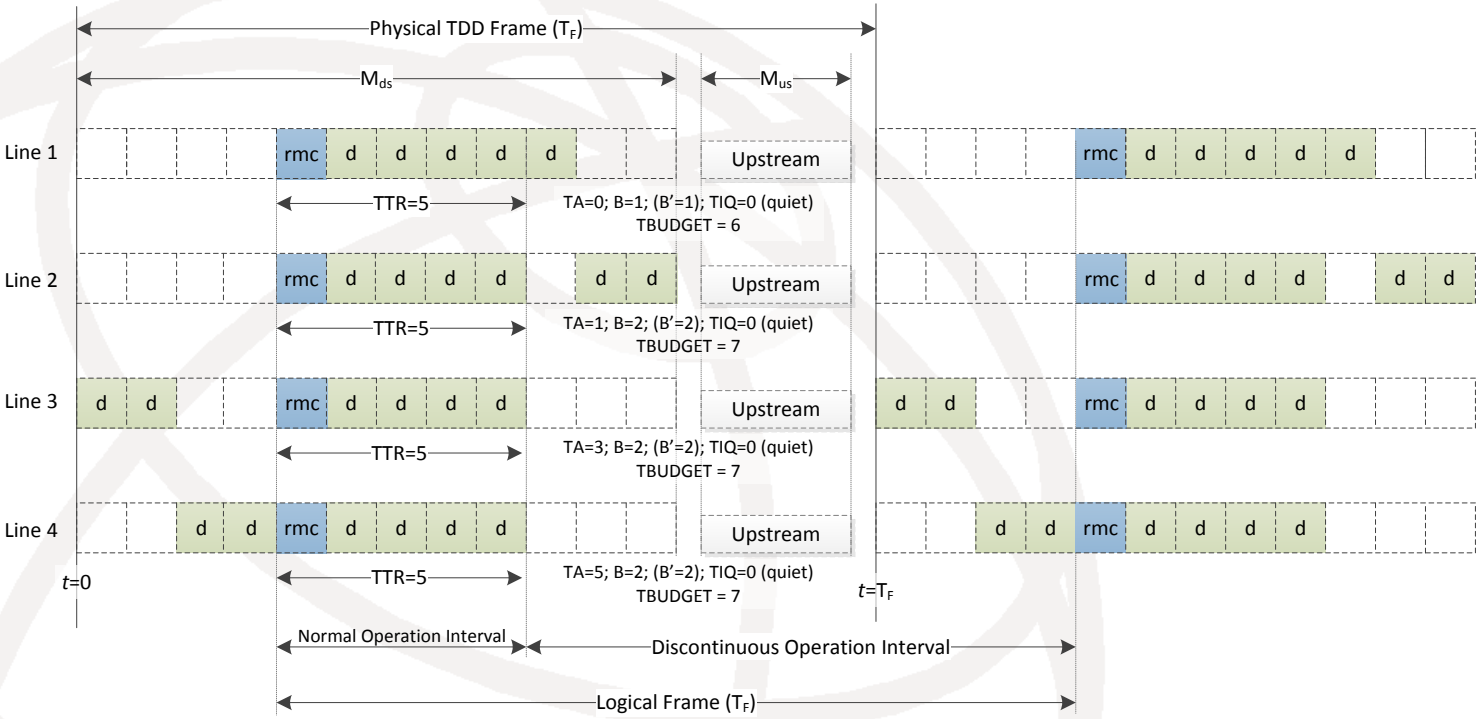
Illustration of discontinuous operation downstream on one line



Legend:
TTR = Duration of the Normal Operation Interval
TA = Number of quiet symbols immediately after TTR
TBUDGET = Total number of symbols allocated for transmission in the combined normal and discontinuous operation intervals

TDD frame: relates to transmission on the physical interface
Logical frame: relates to internal processing of the data

Illustration of discontinuous operation downstream on multiple lines

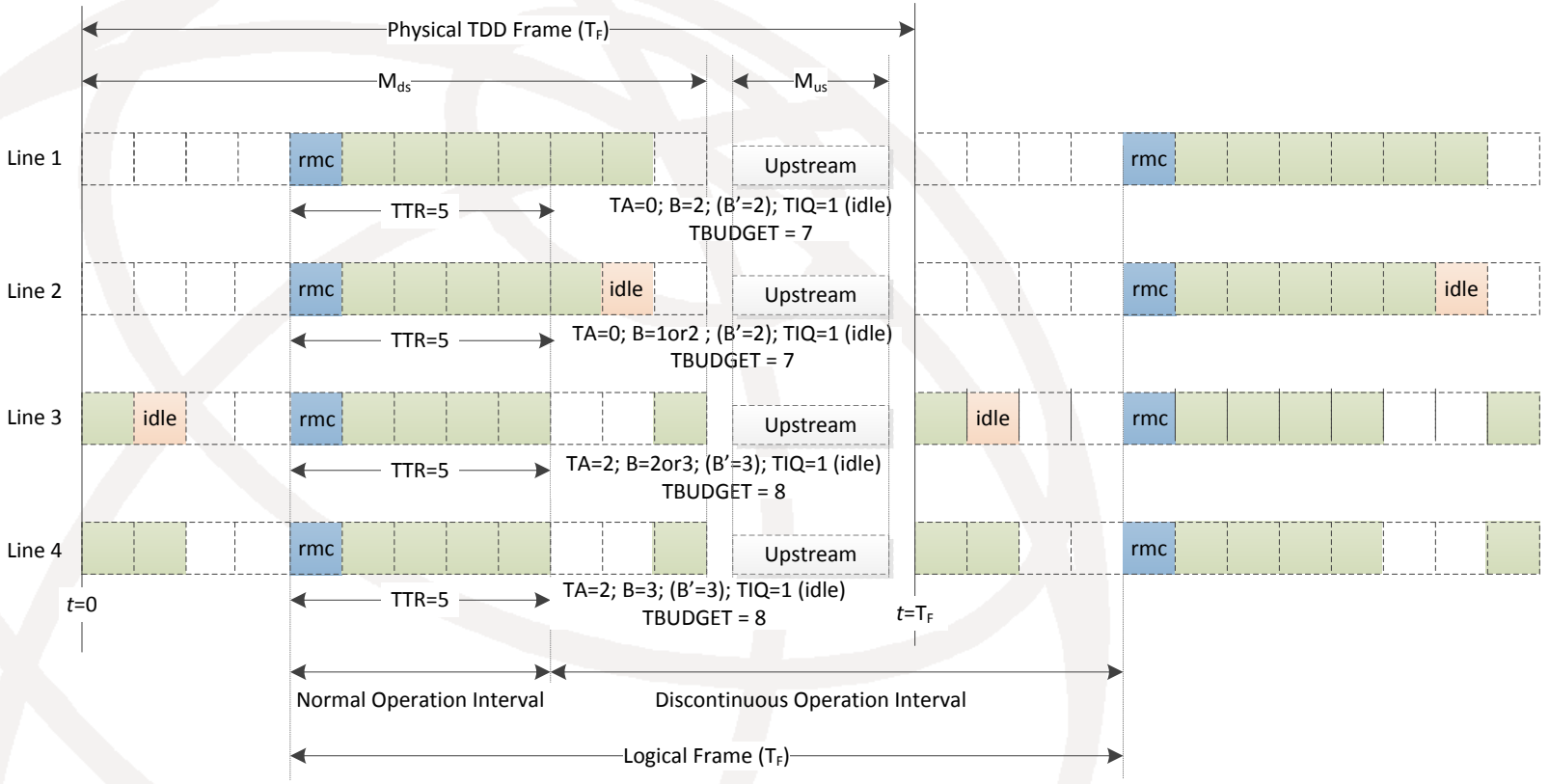


Key:
TTR = Duration of the Normal Operation Interval
TA = Number of quiet symbols immediately after TTR
B = Number of data symbols immediately after TA
B' = is derived from the control parameters sent across the gamma interface
TBUDGET = Total number of allocated symbols in the combined normal and discontinuous operation intervals
TIQ = Assign 1(idle) or 0 (quiet) symbols to slots where in discontinuous operation interval when there is no data to send

d = data symbol rmc = rmc symbol idle = idle symbol = quiet symbol

Avoid overlap of symbol periods in discontinuous operation interval to turn off crosstalk cancellation processing

Another example of discontinuous operation downstream on multiple lines



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The end

Thank you

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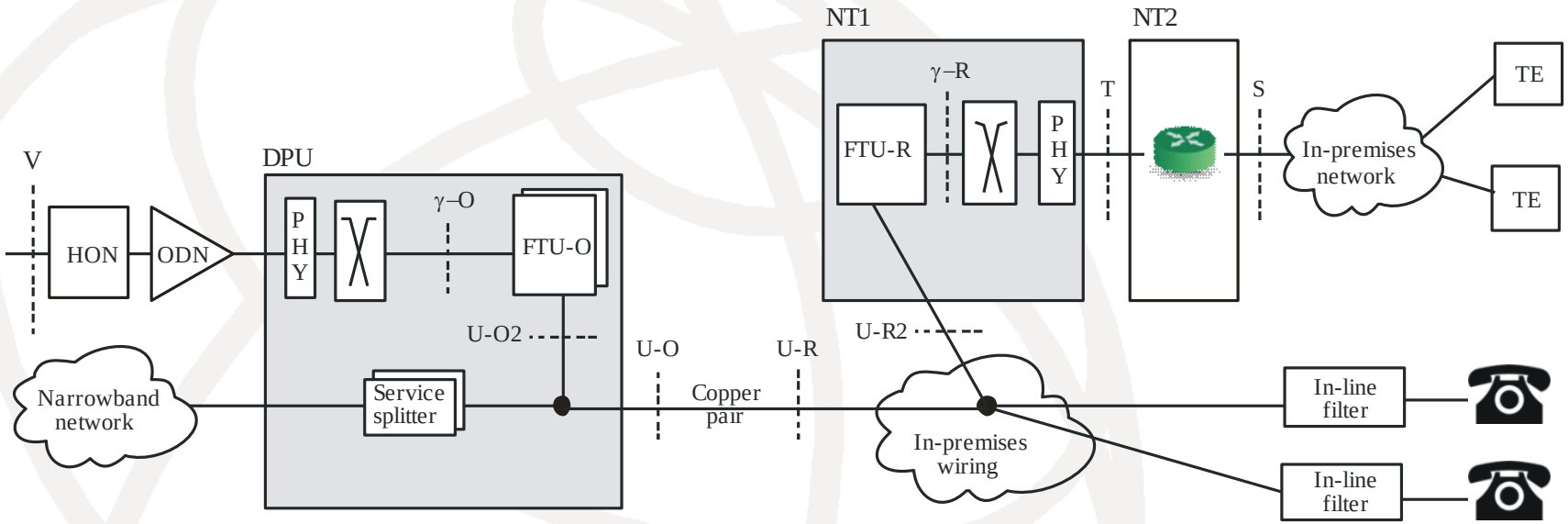
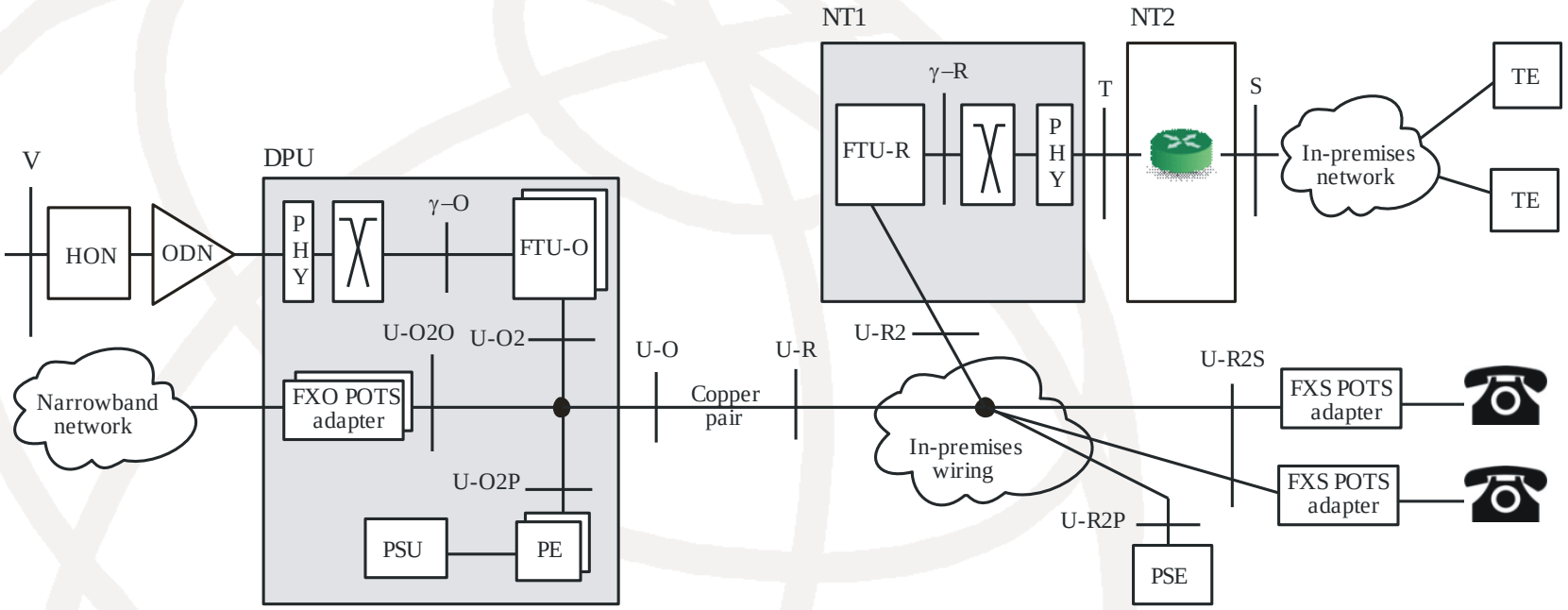
Application reference models

Application reference models 1/4



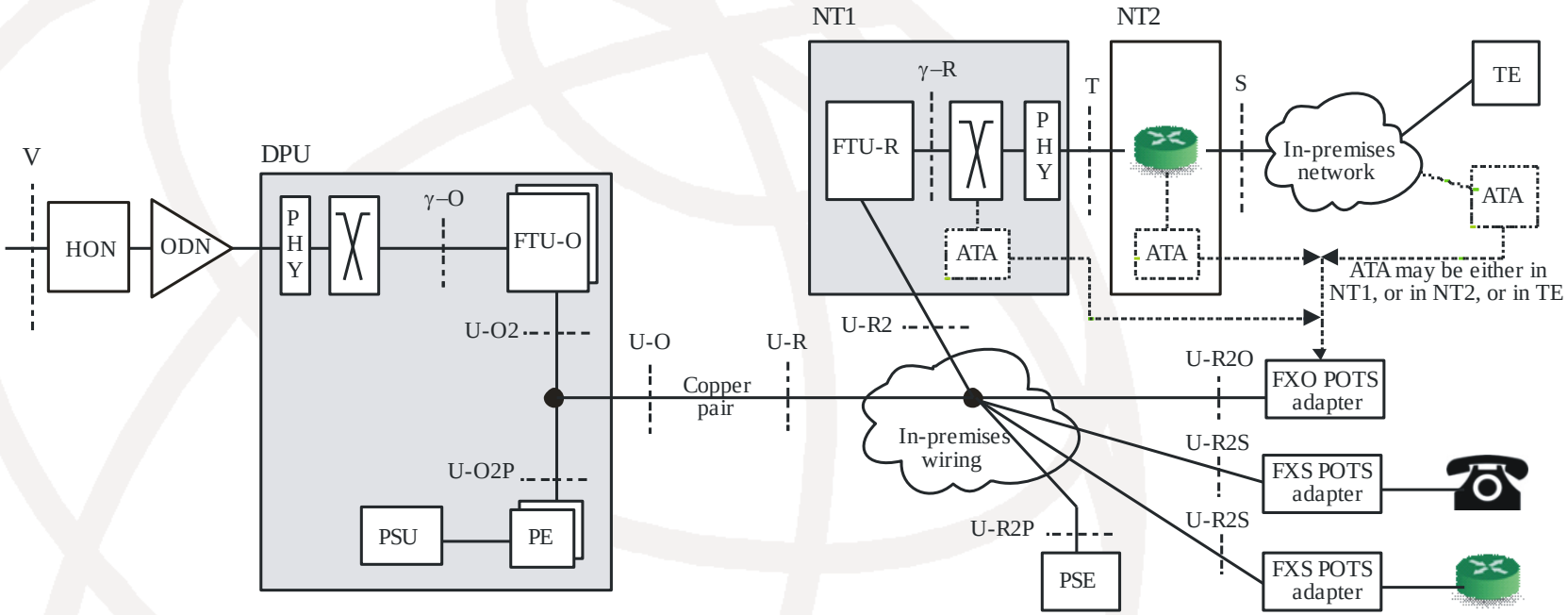
FTTdp with POTS

Application reference models 2/4



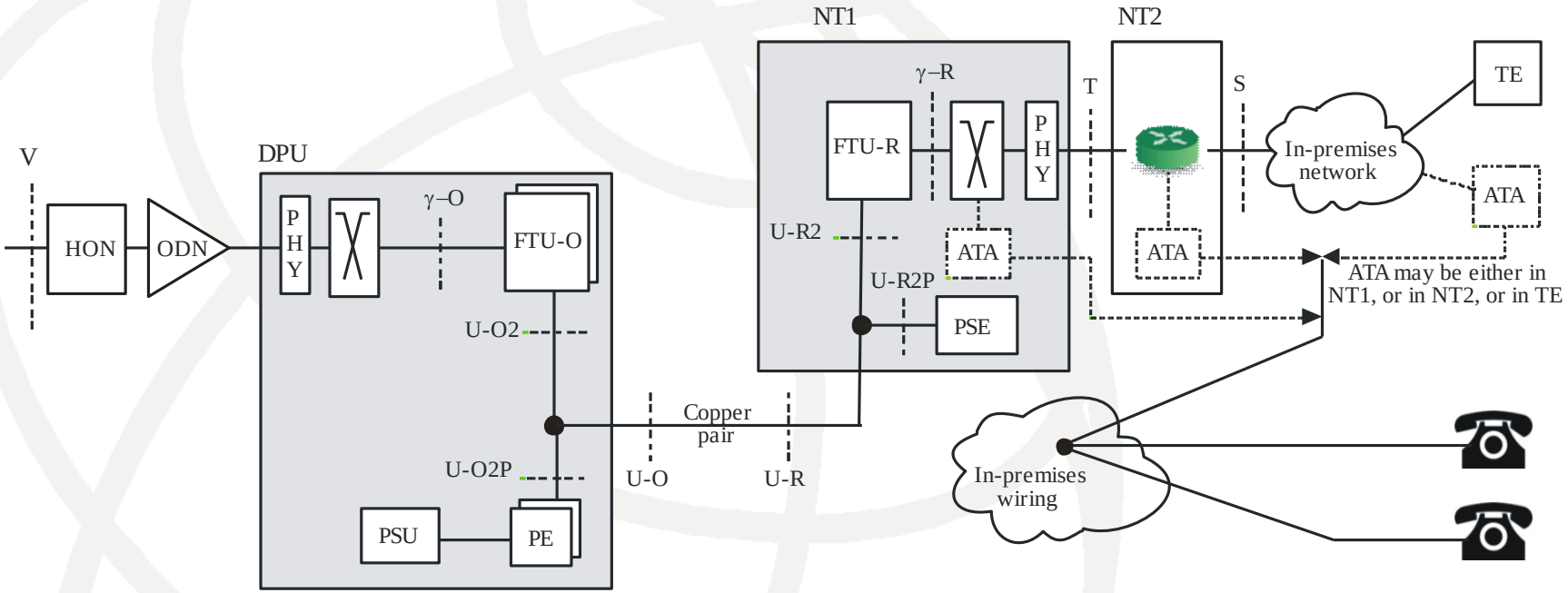
FTTdp with reverse powering and POTS

Application reference models 3/4



FTTdp with reverse powering and derived POTS

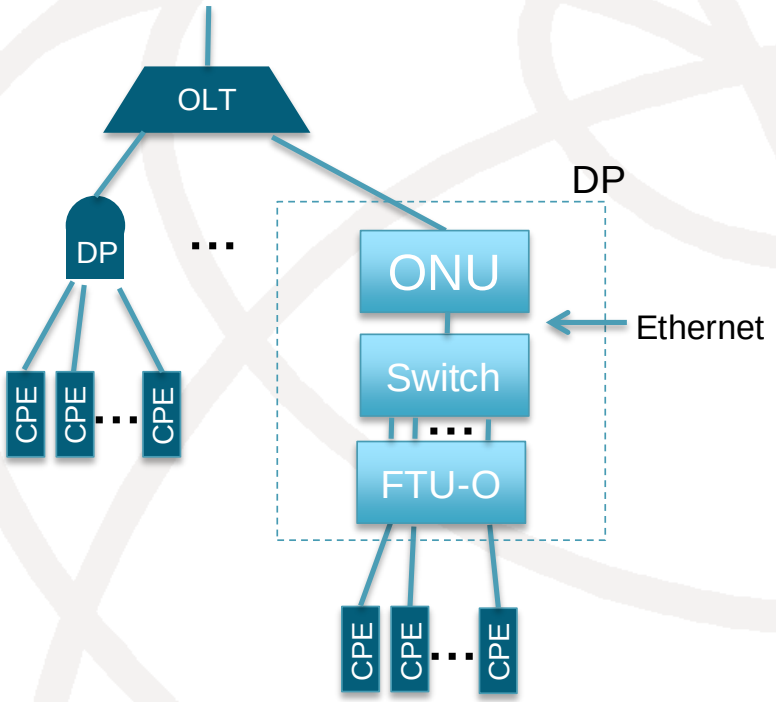
Application reference models 4/4



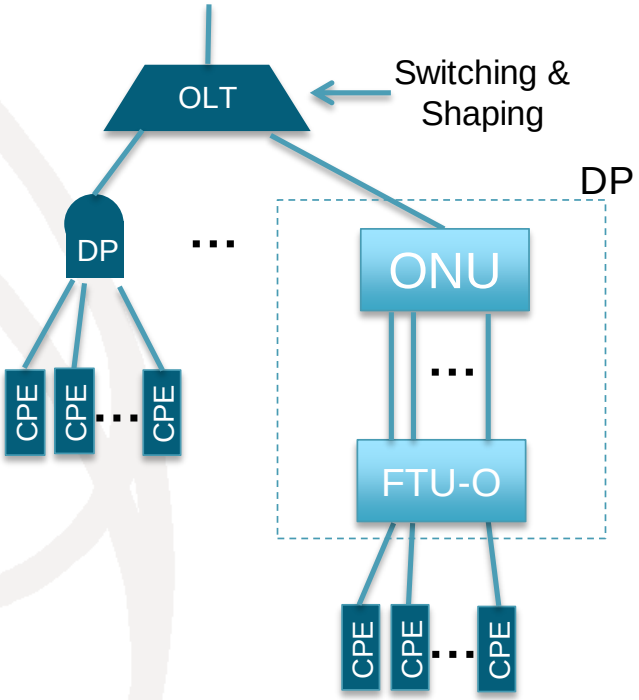
FTTdp with reverse powering and derived POTS not sharing the in-premises wiring with G.fast

Broadband Forum architectures

Broadband Forum Architectures



TR-167 Model
(PON-fed Access Node)



TR-156 Model
(OLT+ONU=Access Node)

Detailed TR-156 Architecture (Downstream)