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STIC AmSud

RESOURCE ALLOCATION IN OPTICAL ACCESS NETWORKS

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Introduction

01.

Optical fiber transmissions in a nutshell

02.

Passive optical networks
Topologies
Standards
Protocols
Virtualization

03.

STIC-AMSUD RAMONaaS

04.

01.

INTRODUCTION

OPTICAL SEGMENTS, TOPOLOGIES & GENERATIONS

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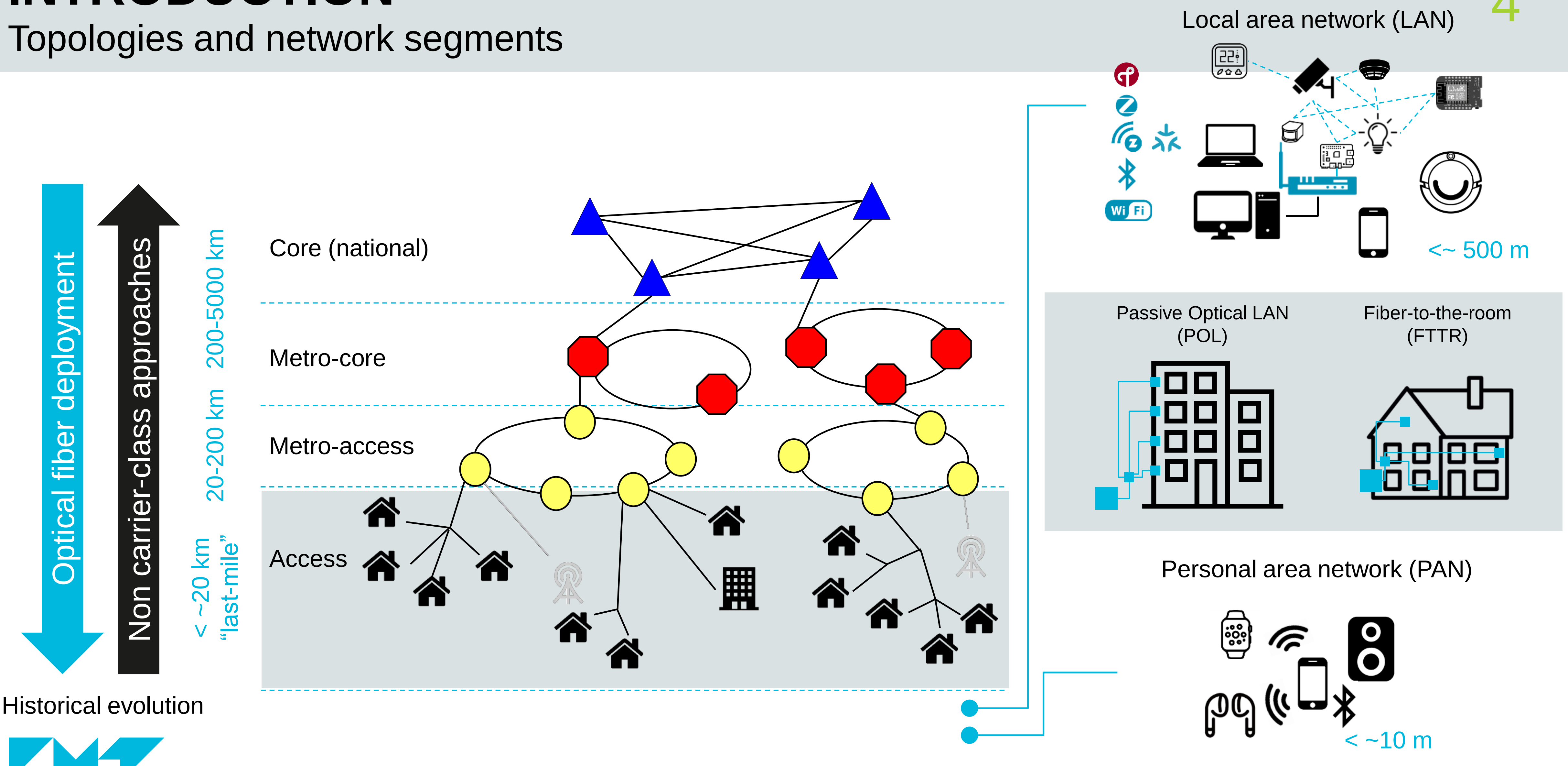
INTRODUCTION

Topologies and network segments



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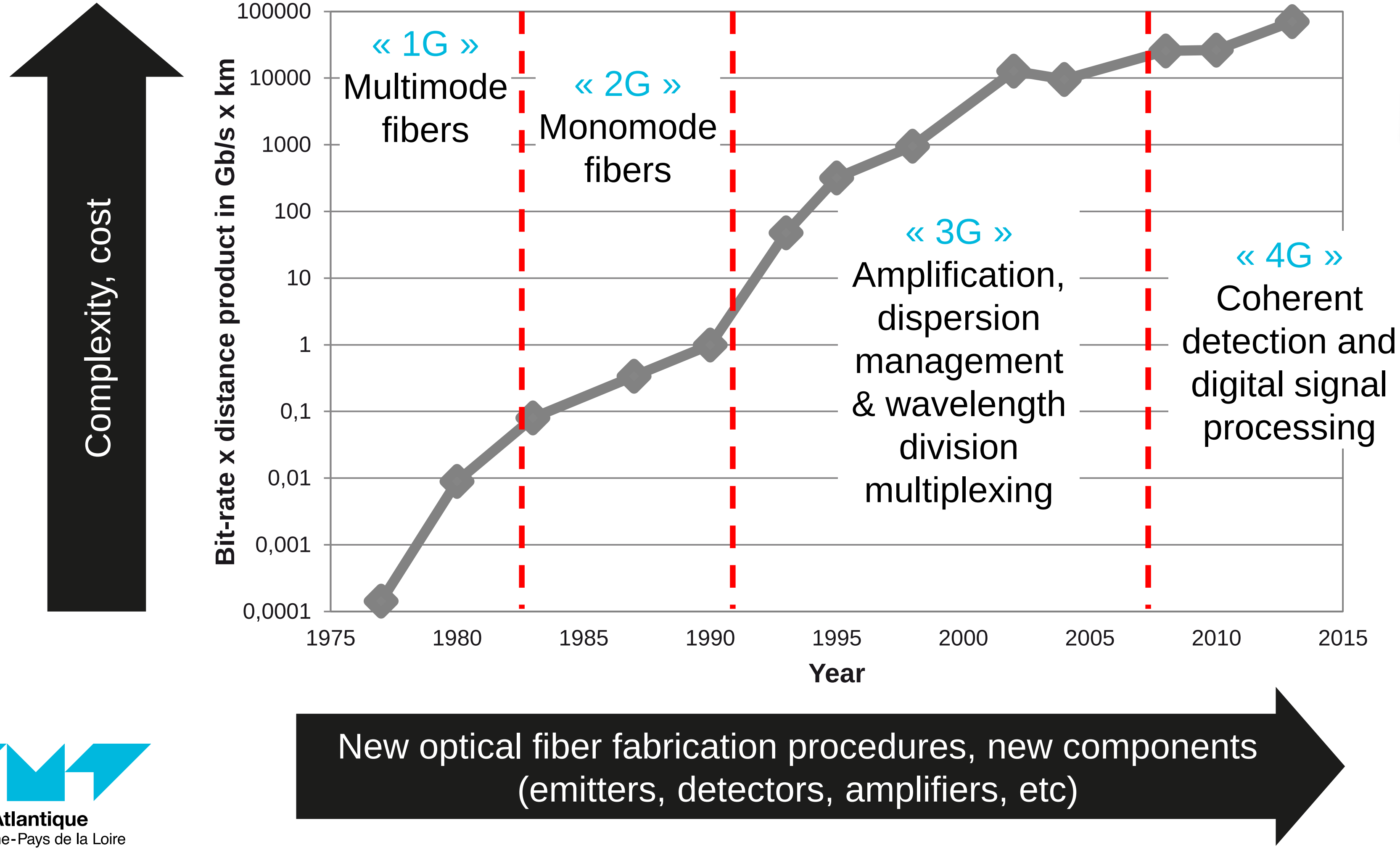
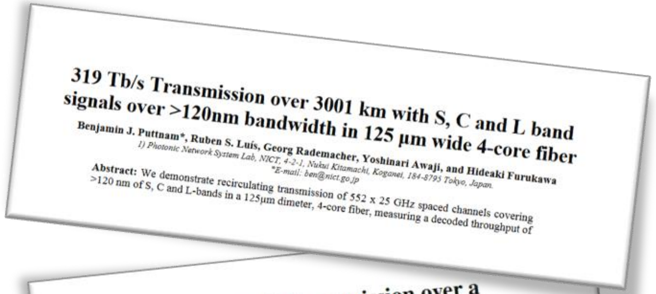
INTRODUCTION

Why bother using optical networks?





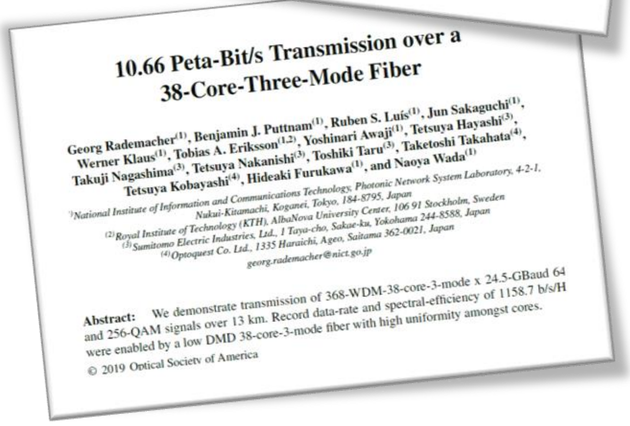
319 Tb/s Transmission over 3001 km with S, C and L band signals over >120nm bandwidth in 125 µm wide 4-core fiber

Benjamin J. Puttnam*, Ruben S. Luís, Georg Rademacher, Yoshinari Awaji, and Hideaki Furukawa

1) Photonic Network System Lab, NICT, 4-2-1, Nukui Kitamachi, Koganei, 184-8795 Tokyo, Japan.

**E-mail: ben@nict.go.jp*

Abstract: We demonstrate recirculating transmission of 552 x 25 GHz spaced channels covering >120 nm of S, C and L-bands in a 125µm dimeter, 4-core fiber, measuring a decoded throughput of



10.66 Peta-Bit/s Transmission over a 38-Core-Three-Mode Fiber

Georg Rademacher(1), Benjamin J. Puttnam(1), Ruben S. Luís(1), Jun Sakaguchi(1), Werner Klaus(1), Tobias A. Eriksson(1,2), Yoshinari Awaji(1), Tetsuya Hayashi(3), Takuji Nagashima(3), Tetsuya Nakanishi(3), Toshiki Taru(3), Taketoshi Takahata(4), Tetsuya Kobayashi(4), Hideaki Furukawa(1), and Naoya Wada(1)

(1) National Institute of Information and Communications Technology, Photonic Network System Laboratory, 4-2-1, Nukui-Kitamachi, Koganei, Tokyo, 184-8795, Japan

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georg.rademacher@nict.go.jp

Abstract: We demonstrate transmission of 368-WDM-38-core-3-mode x 24.5-GBaud 64 and 256-QAM signals over 13 km. Record data-rate and spectral-efficiency of 1158.7 b/s/H were enabled by a low DMD 38-core-3-mode fiber with high uniformity amongst cores.

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Main constraint in optical access: cost! $$$$

02.

OPTICAL FIBER TRANSMISSIONS IN A NUTSHELL

THE WORLD OF OPTICAL COMMUNICATIONS IS VAST. WE FOCUS HERE ON THE OPTICAL ACCESS

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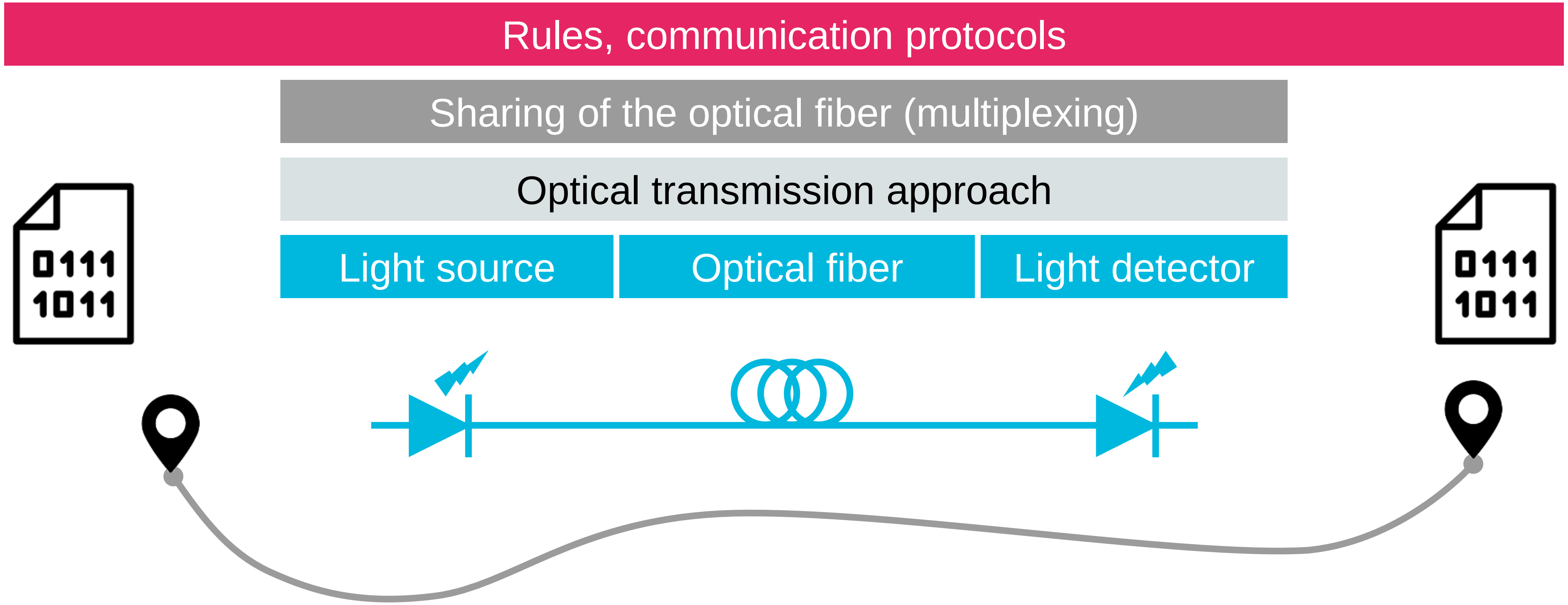
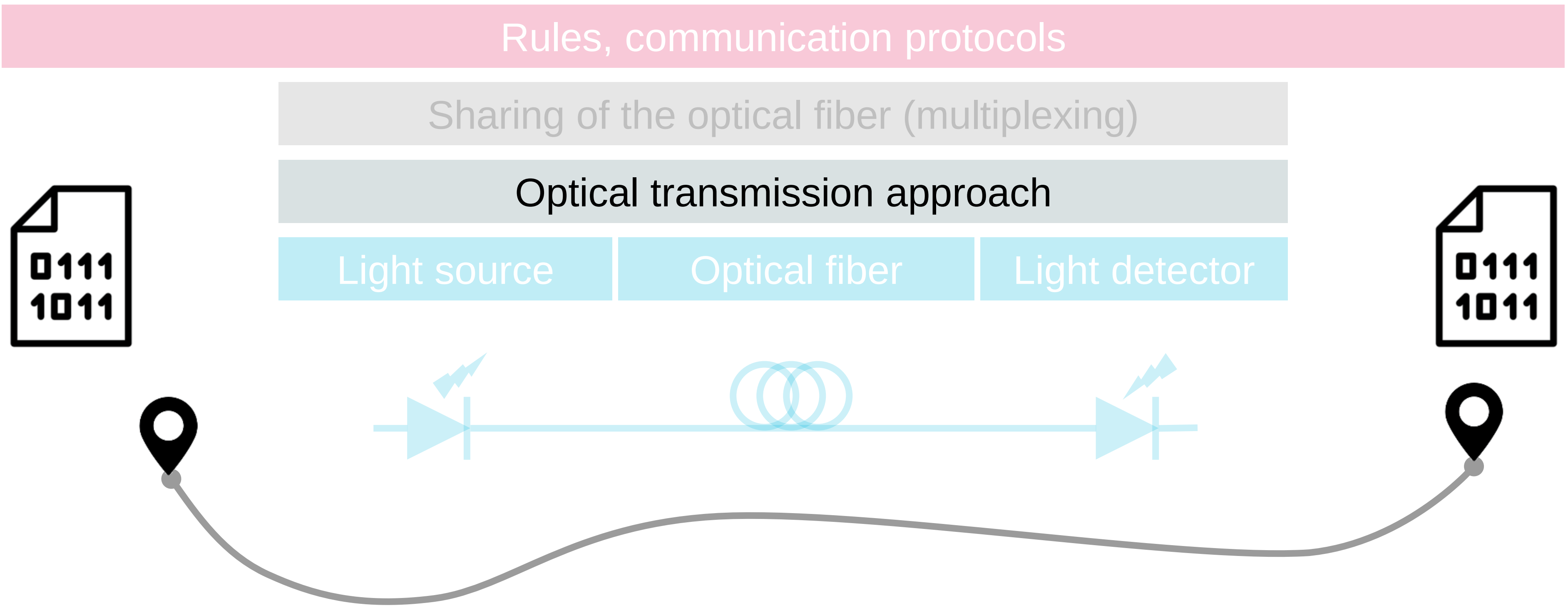
OPTICAL FIBER TRANSMISSION IN A NUTSHELL

Building blocks



OPTICAL FIBER TRANSMISSION IN A NUTSHELL

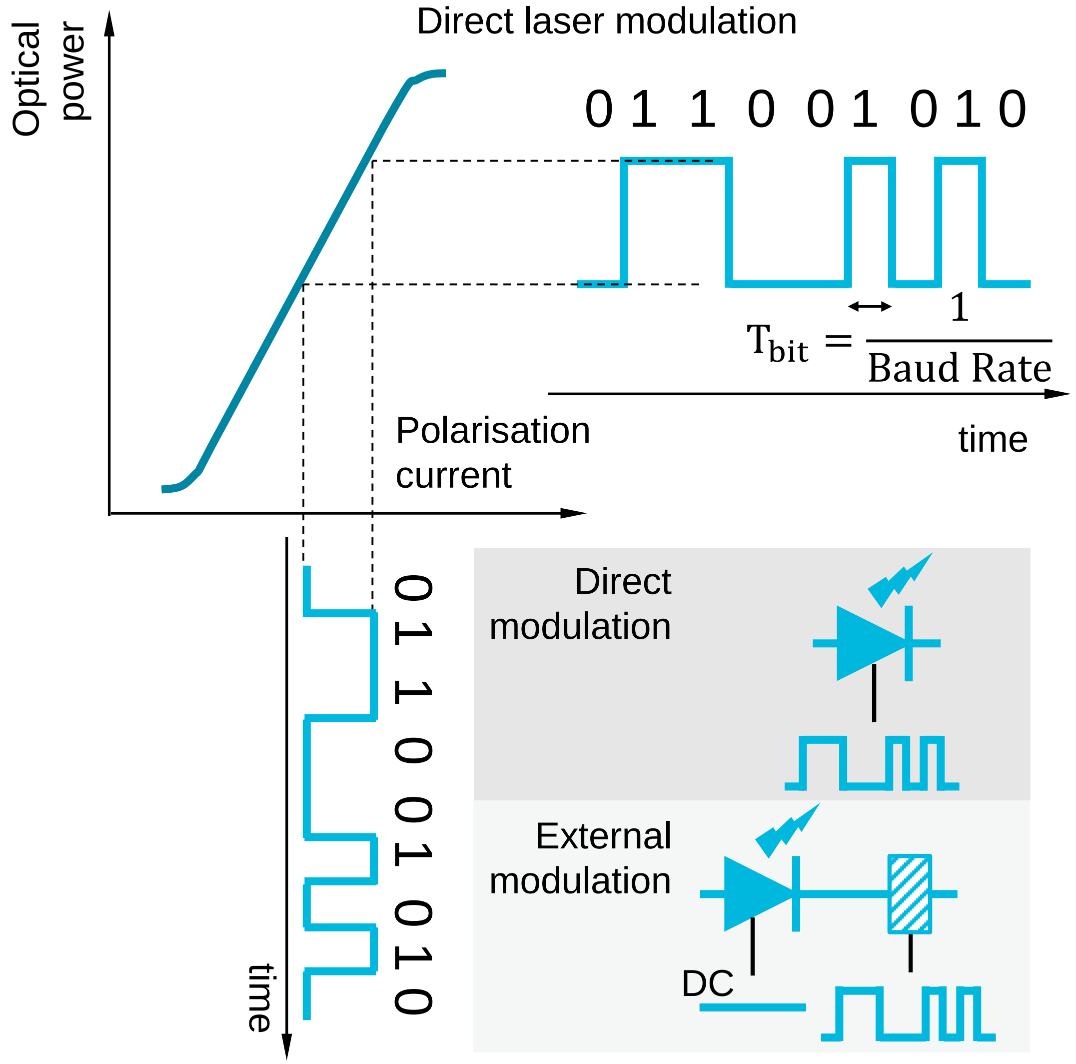
Building blocks



OPTICAL FIBER TRANSMISSION IN A NUTSHELL

Optical transmission approaches

- Intensity modulation with direct detection (IMDD)
  - Simple: information transmitted simply by varying the intensity of light
  - Direct vs external modulation (laser chirp)
  - Detection: $i_{det}(t) \propto |E_{RX}(t)|^2$
- Coherent transmissions
  - Transmission/detection of light intensity and phase
  - Higher bit-rate x distance products than with IMDD
  - More complex and costly than IMDD
  - Different coherent approaches, cost vs performance trade-off



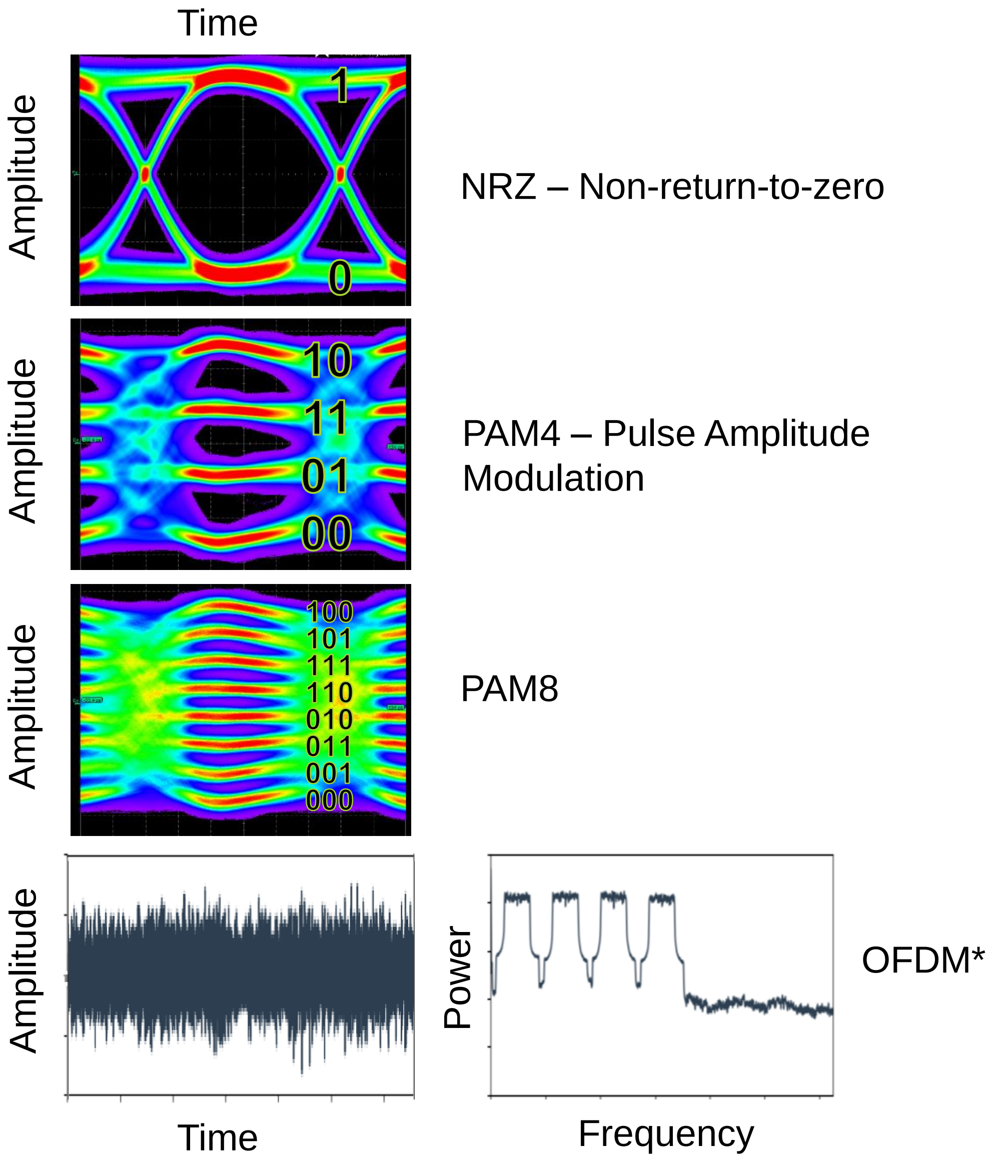
OPTICAL FIBER TRANSMISSION IN A NUTSHELL

Optical transmission approaches

IMDD: the simplest and least expensive optical transmission solution

- Intensity modulation with direct detection (IMDD)
  - Simple: information transmitted simply by varying the intensity of light
  - Different possible modulation formats

IMDD NRZ has been adopted in all PON generations and will continue to be used at least up to 50 Gbps (HS-PON)



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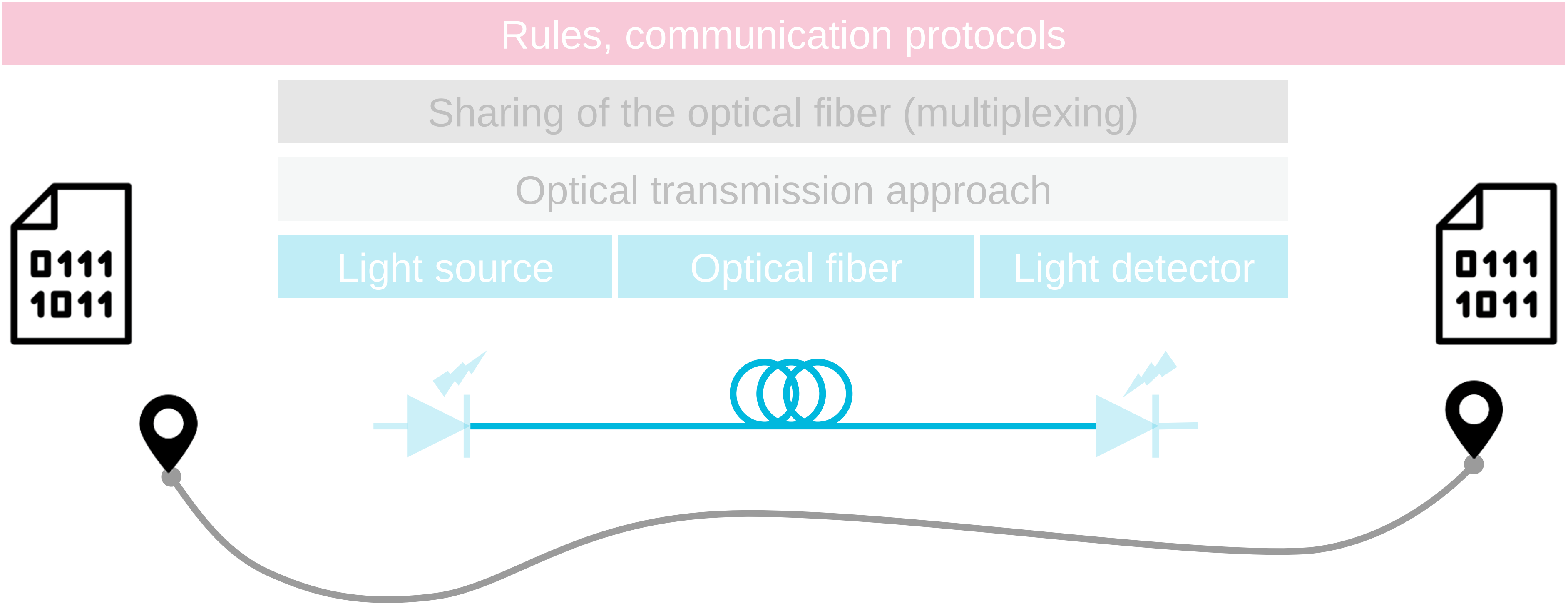
OFDM: Orthogonal Frequency Division Multiplexing

OPTICAL FIBER TRANSMISSION IN A NUTSHELL

Building blocks



OPTICAL FIBER TRANSMISSION IN A NUTSHELL

Optical fibers

Dielectric waveguide, circular section, flexible, compact

- Different materials: silica, plastic and even “hollow”
- Different applications: telecommunications, sensors, audio, decoration, medical…

Different solutions for the propagation equation

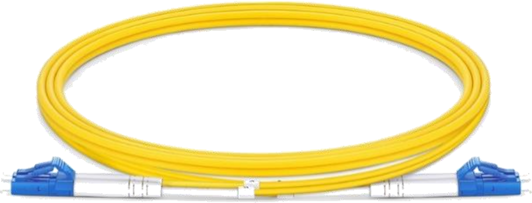
- We will target only standard single mode fibers (SSMF)

Naked fiber

Plastic optical fiber

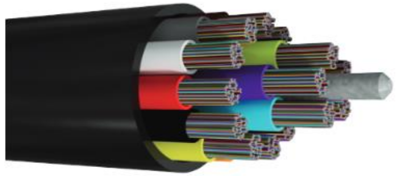
S/PDIF cable

Dual fiber cable

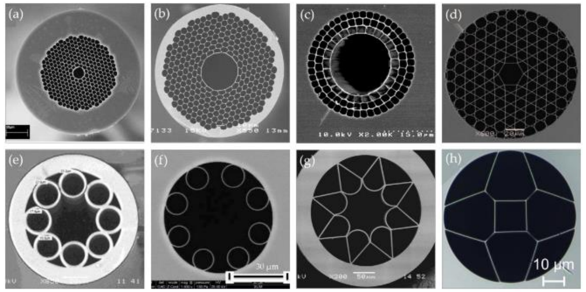


Armored fiber cable

Prysmian cable 3456F Ø28 mm



Hollow core optical fiber[1]

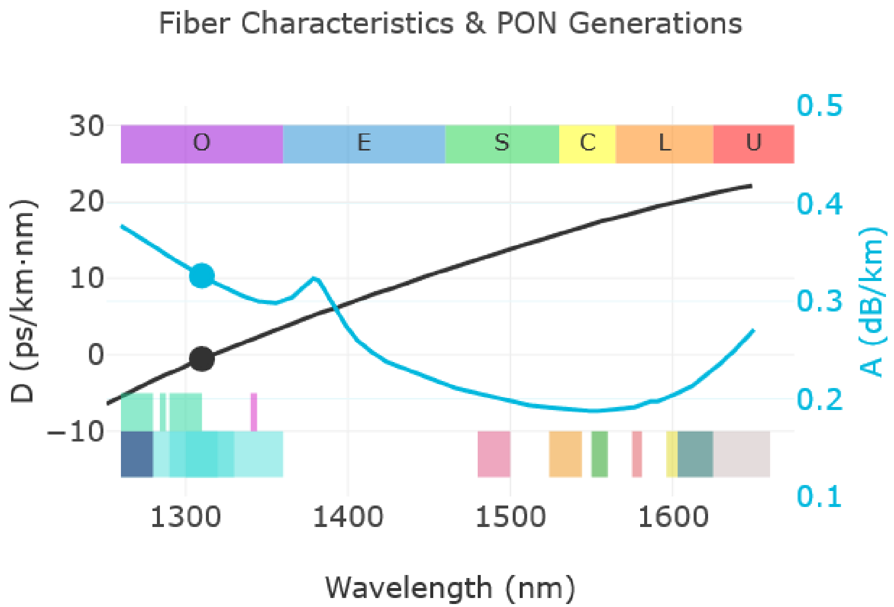


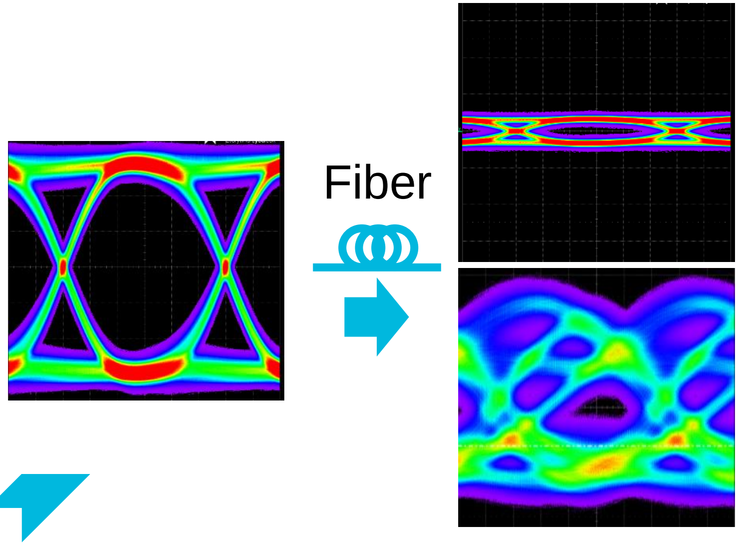
[1] R. Yu et al., “Hollow-Core Photonic Crystal Fiber Gas Sensing,” Sensors, vol. 20, no. 10, p. 2996, May 2020, doi: 10.3390/s20102996

Optical fibers

Propagation phenomena

- Fiber attenuation
  - Reduces signal power
- Fiber chromatic dispersion & laser chirp
  - Group velocity depends on the frequency (“colour”) of the light



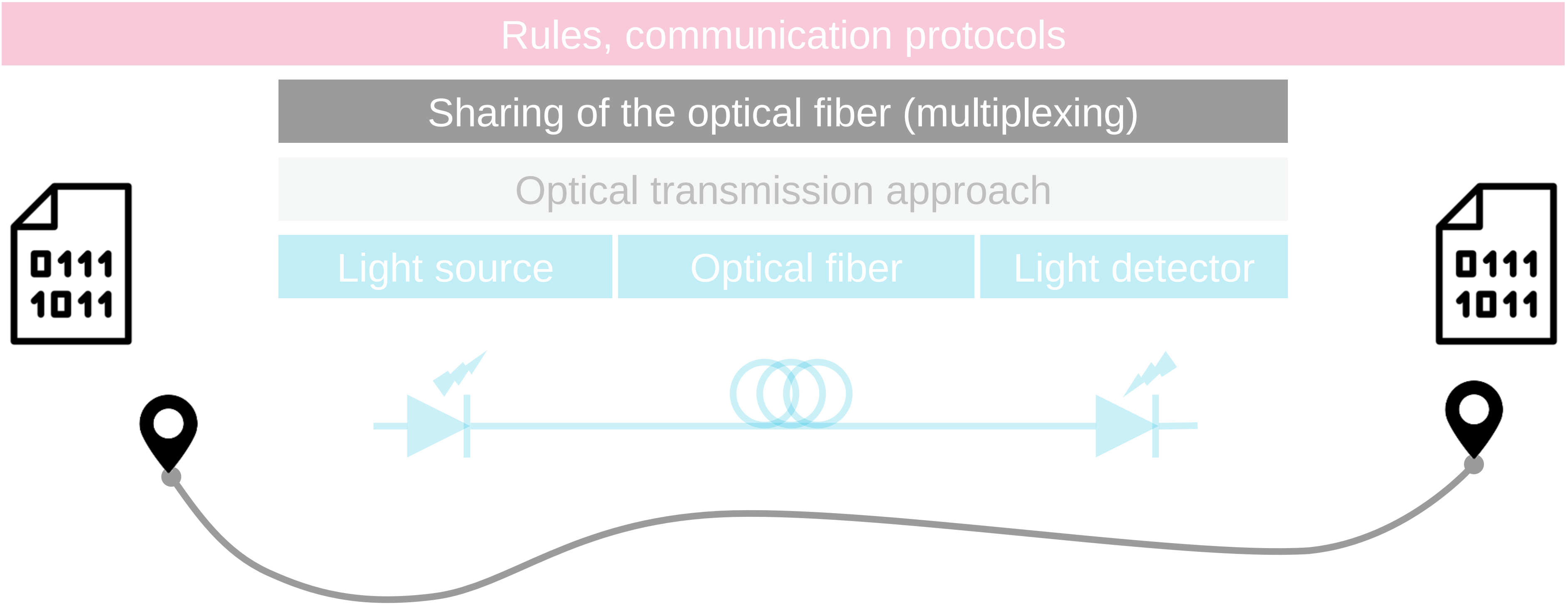


IMDD transmission + chromatic dispersion + parasitic laser modulation + direct detection = frequency fading channel, signal distortions, intersymbol interference (ISI)

One of our challenges: increase capacity in a deployed fiber infrastructure that should exist for decades

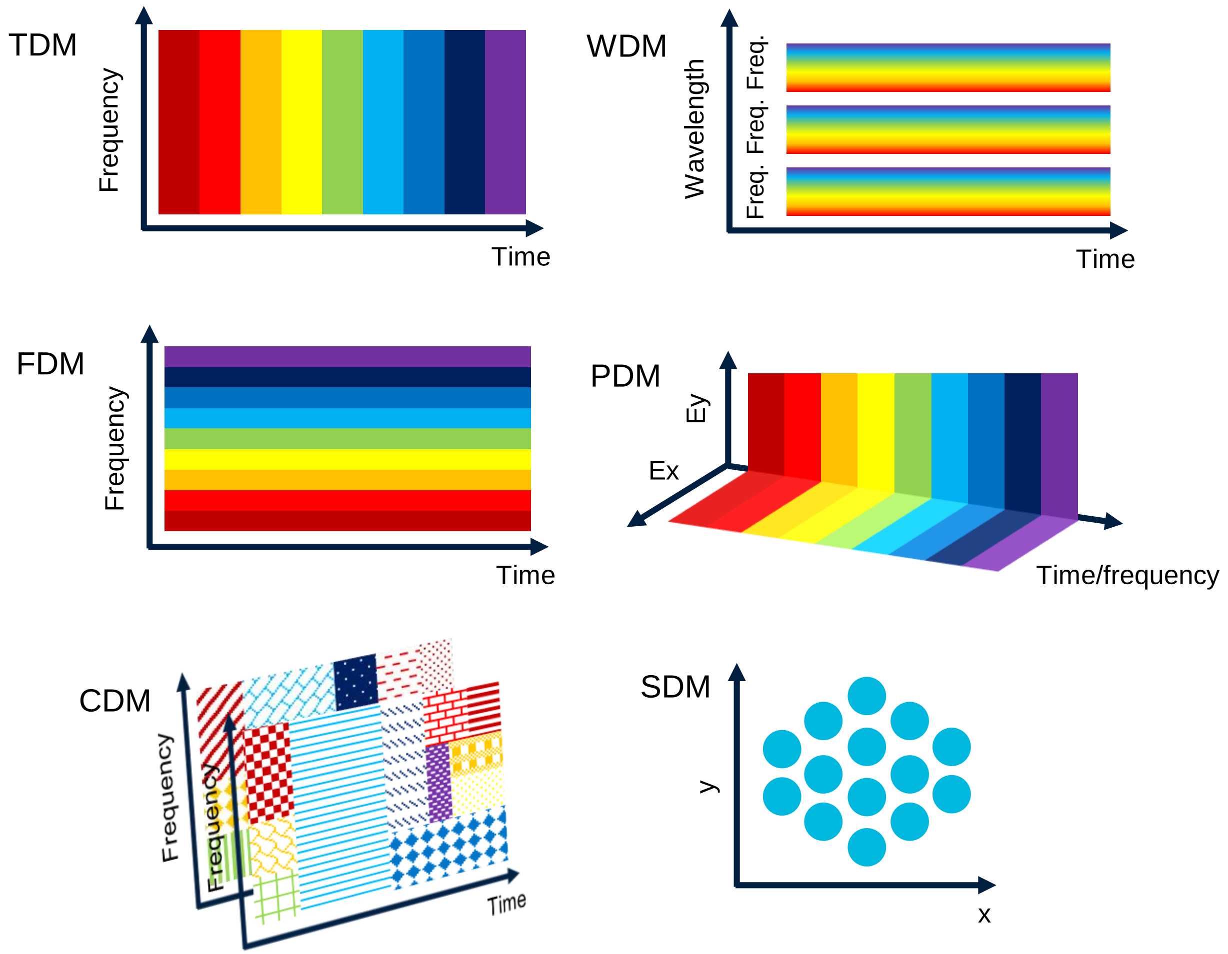
OPTICAL FIBER TRANSMISSION IN A NUTSHELL

Building blocks



Different dimensions allowing sharing and increase of capacity in optical fibers

In passive optical networks, we limit ourselves to time and wavelength multiplexing: the first for sharing the fiber between different clients, the second allowing full-duplex transmissions on a single fiber and increasing the throughput



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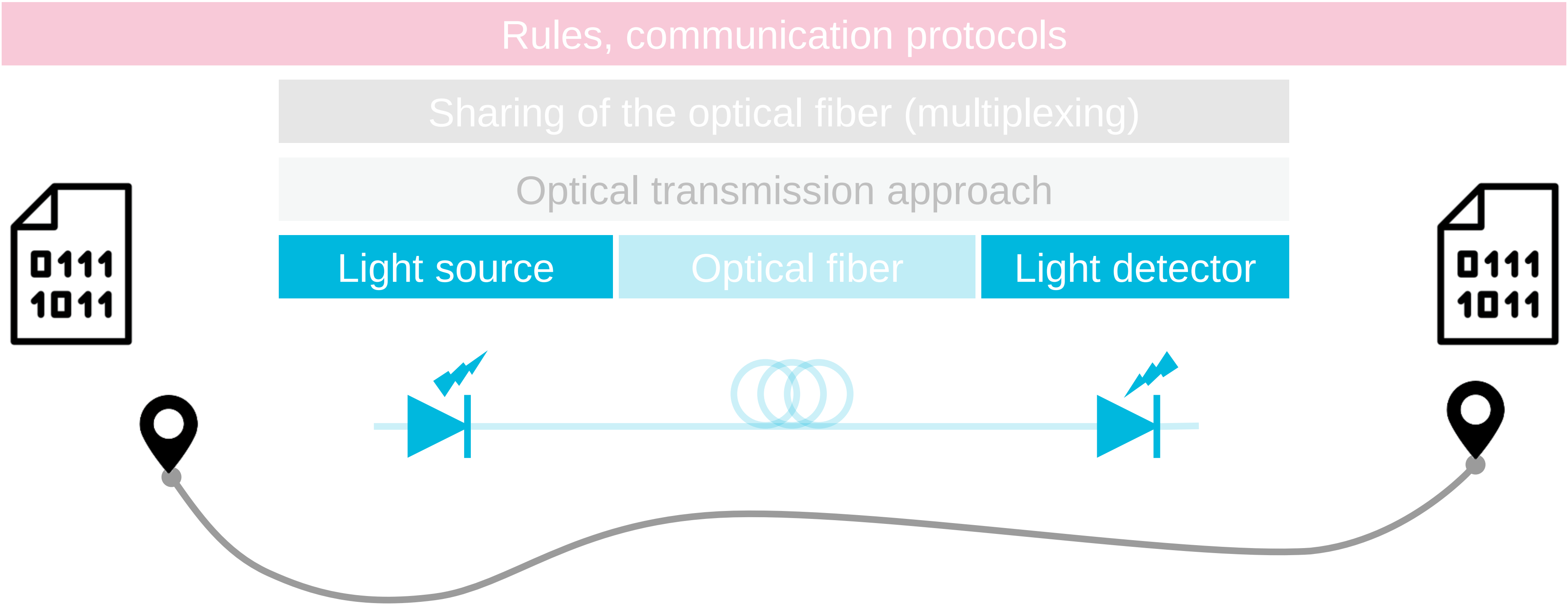
OPTICAL FIBER TRANSMISSION IN A NUTSHELL

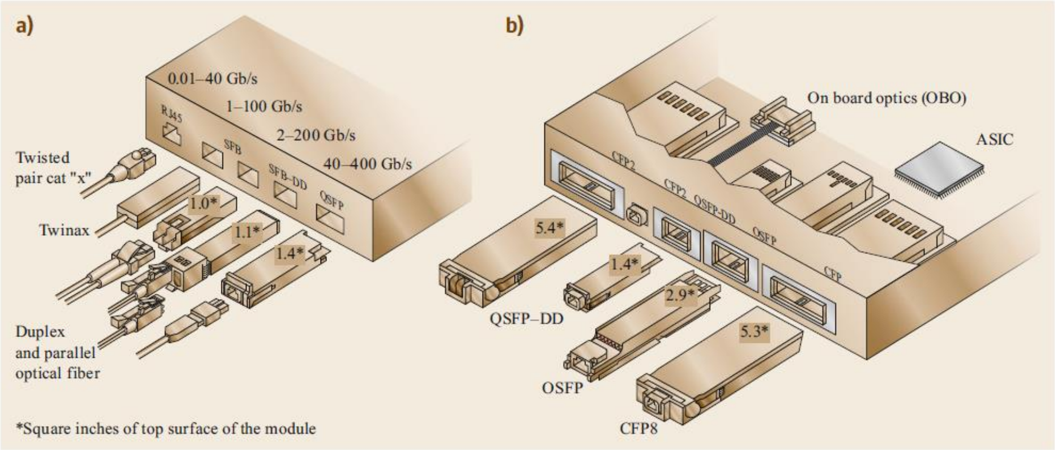
Building blocks



OPTICAL FIBER TRANSMISSION IN A NUTSHELL
Optical transceivers

- Laser/photodiodes semiconductor physics is beyond the scope of this talk
- Pluggable transceivers (TX + RX)
  - Applications : FTTx, datacenters…
  - Explored dimensions: wavelength, space (fibers), time, frequency…
  - Different form-factors, bit-rates, propagation distances, receiver sensitivities, emitter powers, energy consumptions, footprints…
  - Interoperability is not necessarily guaranteed

Springer Handbook of Optical Networks. Germany, Springer International Publishing, 2020.



> Interoperability is a key aspect in optical access networks that allows several vendors to share the FTTx market and thus reduce the costs of the offers for end customer

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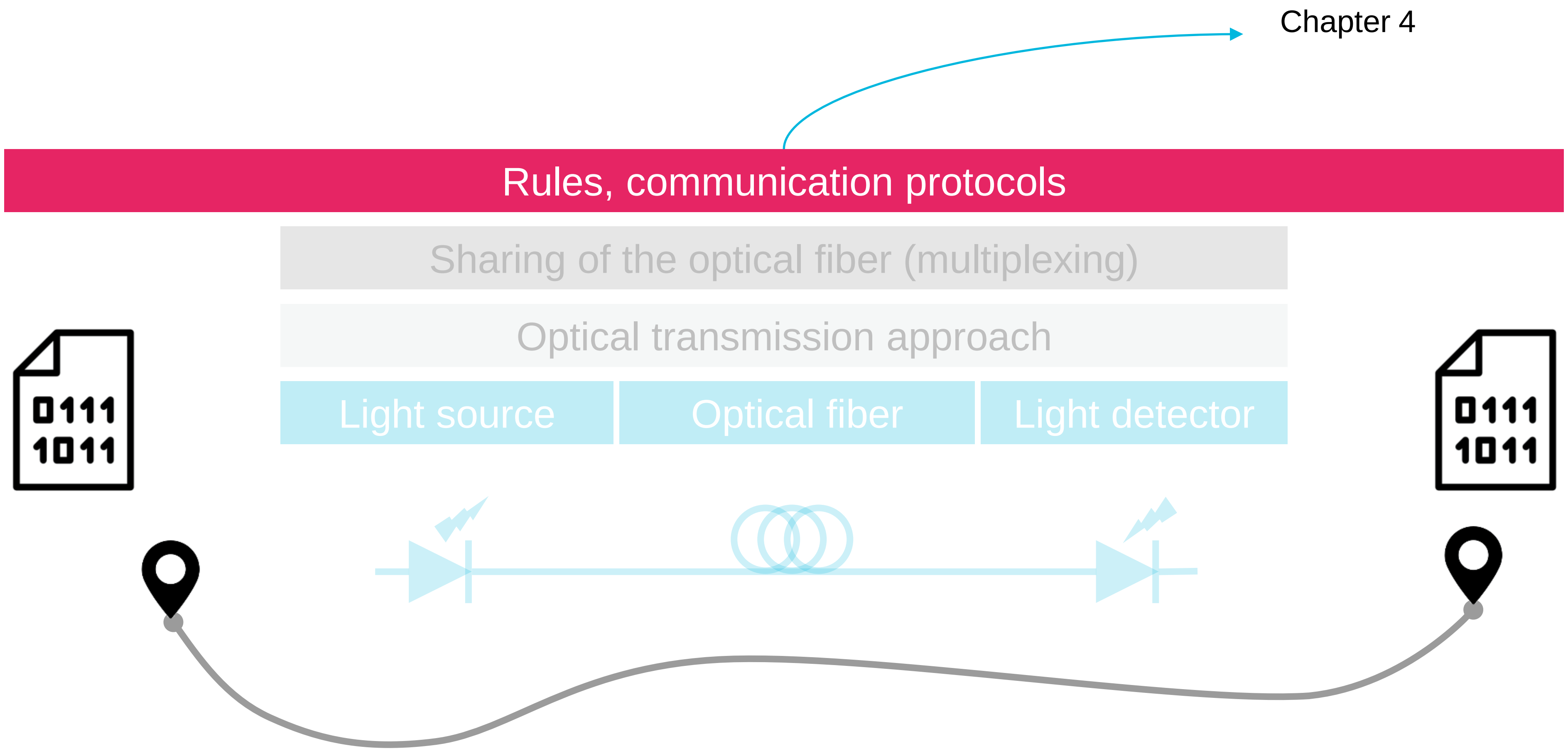
OPTICAL FIBER TRANSMISSION IN A NUTSHELL

Building blocks



SUMMING UP

What you know so far about the optical access

01

Network segment

- We are in the last miles
- Point-to-point and point-to-multipoint topologies

02

Sharing

- Very strong cost constraints, simple IMDD NRZ approach
- Optical access network is shared between several clients
- The dimensions used for channel sharing and capacity increase are time and wavelength

03

Propagation

- Deployed network consists of standard single-mode fiber (SSMF)
- Only chromatic dispersion, attenuation and laser chirp will limit performances

04

Transceivers

- Single fiber transceivers between the central office and the clients
- Interoperability is crucial

03.

PASSIVE OPTICAL NETWORKS

TOPOLOGIES

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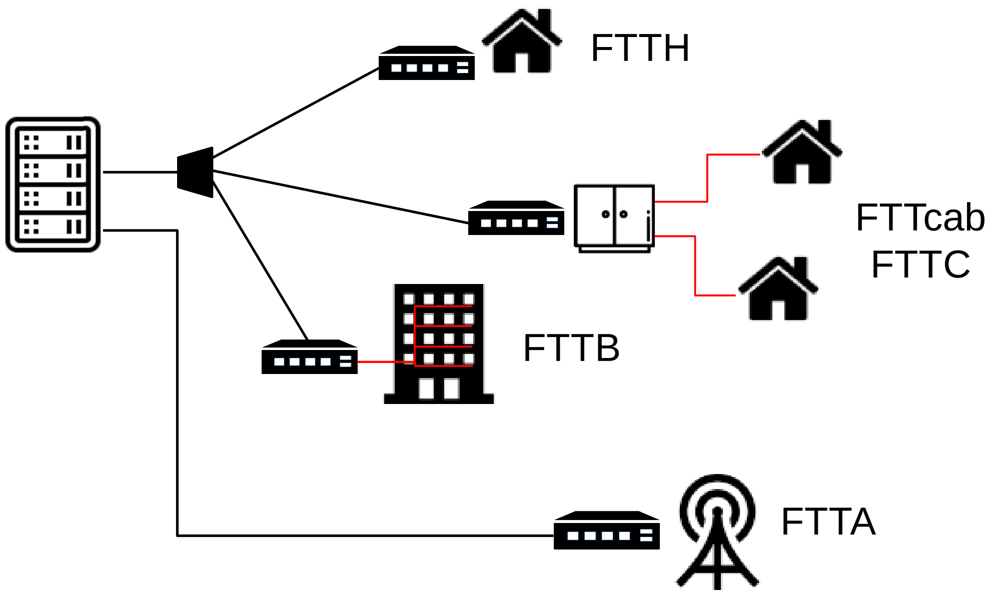
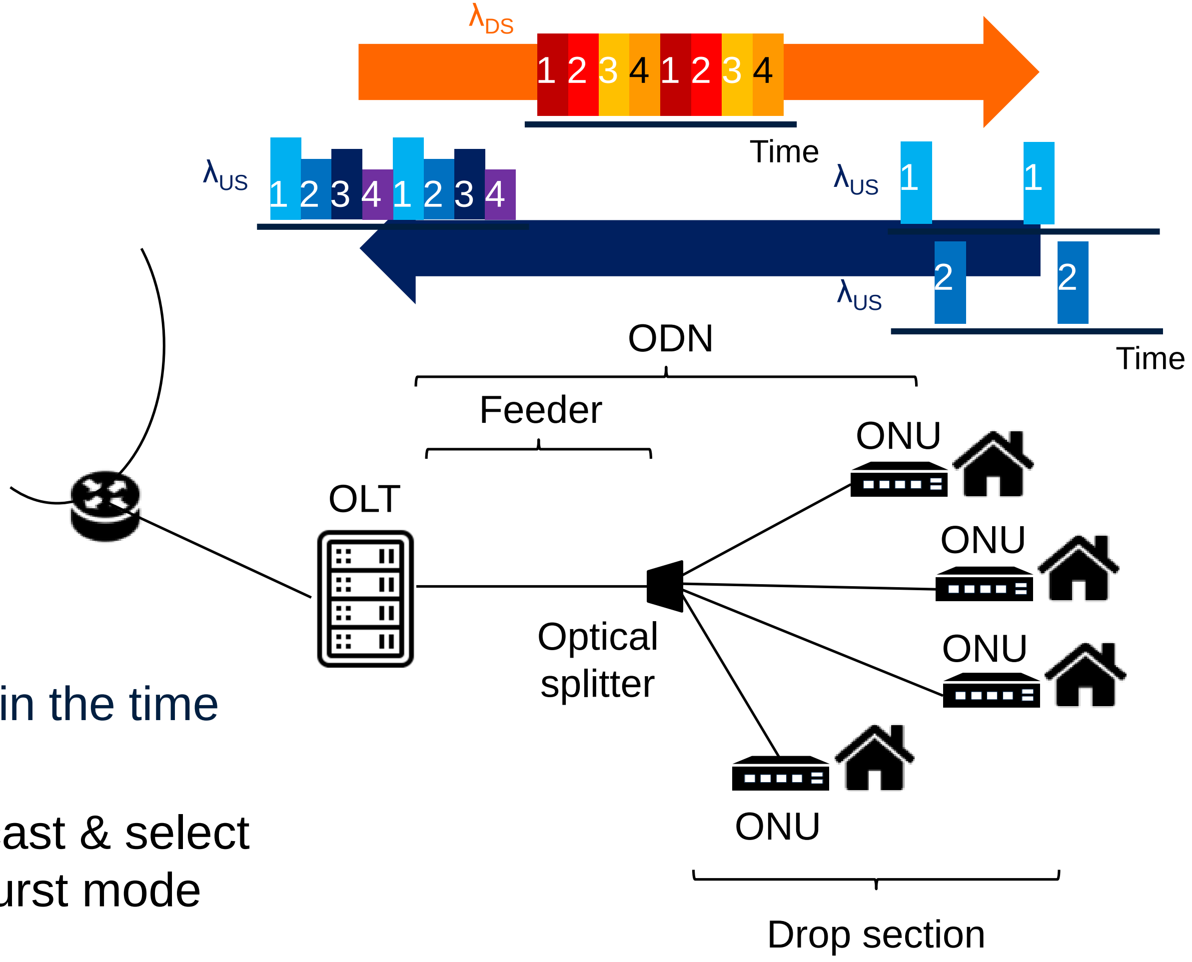
- Passive Optical Networks (PON), at last!
  - Passive: no network element requiring power supply and supervision (active) between the transmitter and the receiver (between the central office and the subscriber's premises)
  - Optical: fiber is the transmission medium
  - Network: implies a more complex topology than a simple point-to-point optical link
  - Different "flavors" (FTTx)
  - Mainly point-to-multipoint topologies but also point-to-point



PASSIVE OPTICAL NETWORKS (PON)

PON Architecture

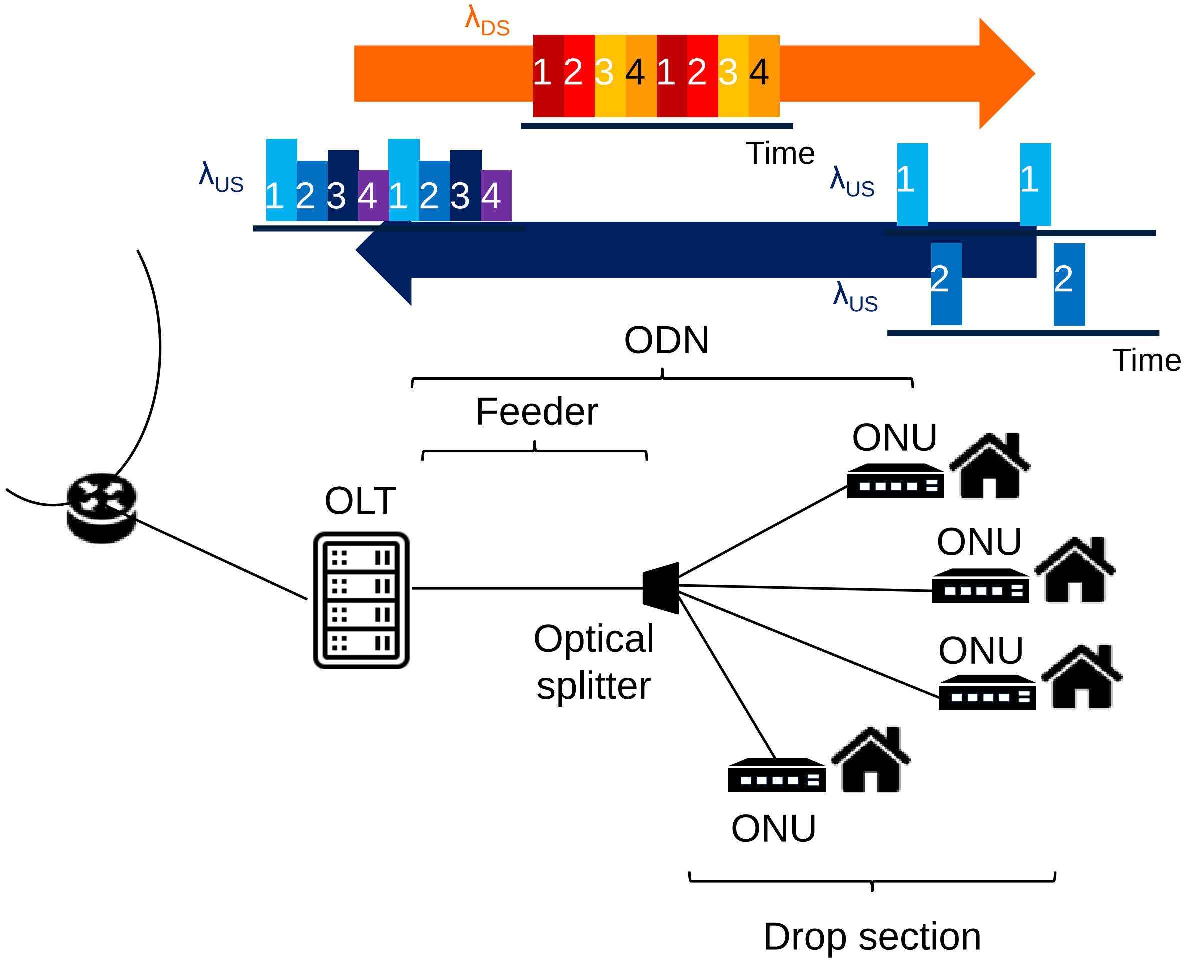
- Network elements
  - Optical Line Termination (OLT)
  - Optical Network Unit (ONU)
  - Optical splitter, simple optical power splitter
  - Feeder fiber, optical distribution network (ODN)
- Network sharing
  - 1 single fiber, λ diplex for the up/downstream
  - Fiber sharing between several clients performed in the time domain
    - DS: time division multiplexing (TDM), broadcast & select
    - US: time division multiple access (TDMA), burst mode transmission



PASSIVE OPTICAL NETWORKS (PON)

PON Architecture

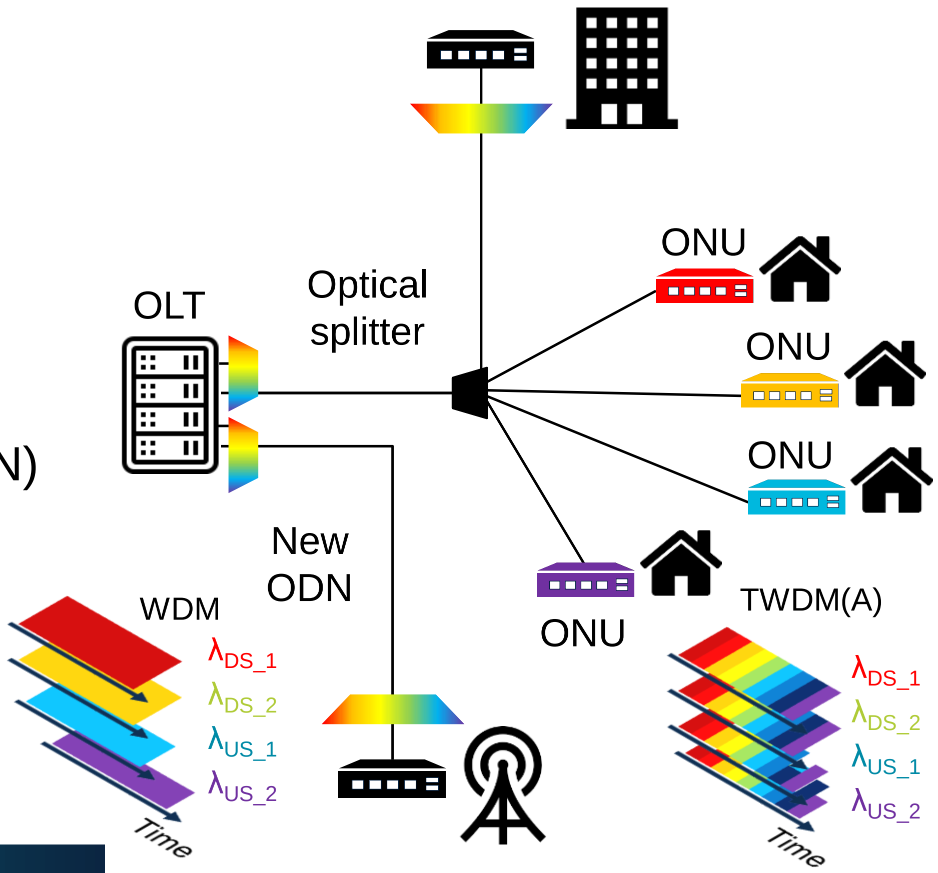
- Pros
  - Minimize optical infrastructure costs by sharing:
    - Optical equipment at the central-office side
    - Feeder fiber
  - Minimize exploitation costs
    - Traffic multiplexing among different clients and services
    - No costly active equipment to maintain in the ODN
- Cons
  - Limited (and varying) available bit-rate/client & impact on latency and packet jitter (statistical multiplexing)



PASSIVE OPTICAL NETWORKS (PON)

Different topologies

- Point-to-multipoint
  - Classic: TDM(A)
  - TWDM(A): standardized but not massively deployed due to the lack of maturity of wavelength agnostic/tunable ONUs
- Point-to-point
  - PON overlay
    - Point-to-point links over point-to-multipoint infra (WDM PON)
  - New ODN
    - Fiber sharing: supernumerary cables, fiber ducts
    - Can evolve to a wavelength multiplexed solution, needs λ plan



Time and wavelength are the dimensions used to share or increase channel capacity in the optical access in PONs

PASSIVE OPTICAL NETWORKS (PON)

PON active equipment

- Central office equipment (OLT)
  - OLT chassis: typically 16 line cards with 8 or 16 ports
  - Each port (PON tree) can connect up to 64 clients
  - 16384 clients/chassis
  - Traffic concentration prone to statistical multiplexing at 2 levels: within the PON trees and int the OLT switching matrix (connection to higher network segments)
- Customer premises equipment (ONU)
  - High volume market, general public
  - Optical box
  - Multifunction: ONU, router, WiFi access point, NAS, etc...

orange™

2006
2 equipment: LAN gateway + ONU

2016
1 equipment : LAN gateway + SFP

2017
1 equipment: LAN gateway with onboard optics

Philippe Chanclou, Optical Access F5G to meet today's needs and support tomorrow's challenges, 20th annual Broadband World Forum, Octobre 2020

03.

PASSIVE OPTICAL NETWORKS

STANDARDS

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PON STANDARDS
Standardization bodies

- International Telecommunication Union (ITU)
  - APON, BPON, GPON, XG(S)PON, NGPON2,
  - SG15 - Networks, technologies and infrastructures for transport, access and home, Question 2
  - Europe, North America

G.9xxx	Definitions and acronyms
G.9xxx.1	Global needs, services and configuration examples
G.9xxx.2	Physical media dependent (PMD), PHY layer specifications
G.9xxx.3	Transmission convergence layer (TC), defines frame formats, access control methods, protocol messages, etc.

- Institute of Electrical and Electronics Engineers (IEEE)
  - Main competitor of the ITU, currently driven by the interests of multi-system operators (MSO)
  - GEPON, 10GEPON, Japan, South Korea
  - Main objective is to preserve compatibility with Ethernet framing and benefit from an ecosystem largely permeated by Ethernet interfaces (reduced costs)
  - Complements Ethernet procedures to provide closer to/farther from carrier-class QoS (adapted Ethernet, watered-down Ethernet)

PON STANDARDS

Standardization bodies

- Broadband Forum
  - Focus on function architectures, management, test plans and software architectures
  - Interoperability driven by operators and independent test laboratories
- Full Service Access Network
  - Pre-standardization forum (operators and vendor), led by operators
  - Explore technical issues through member contributions (consensus before standardization)

The technical framework provided by the standardization bodies played a crucial role enabling the deployment of optical fiber in the access: thanks to the standards, interoperability between equipment from different suppliers is ensured.

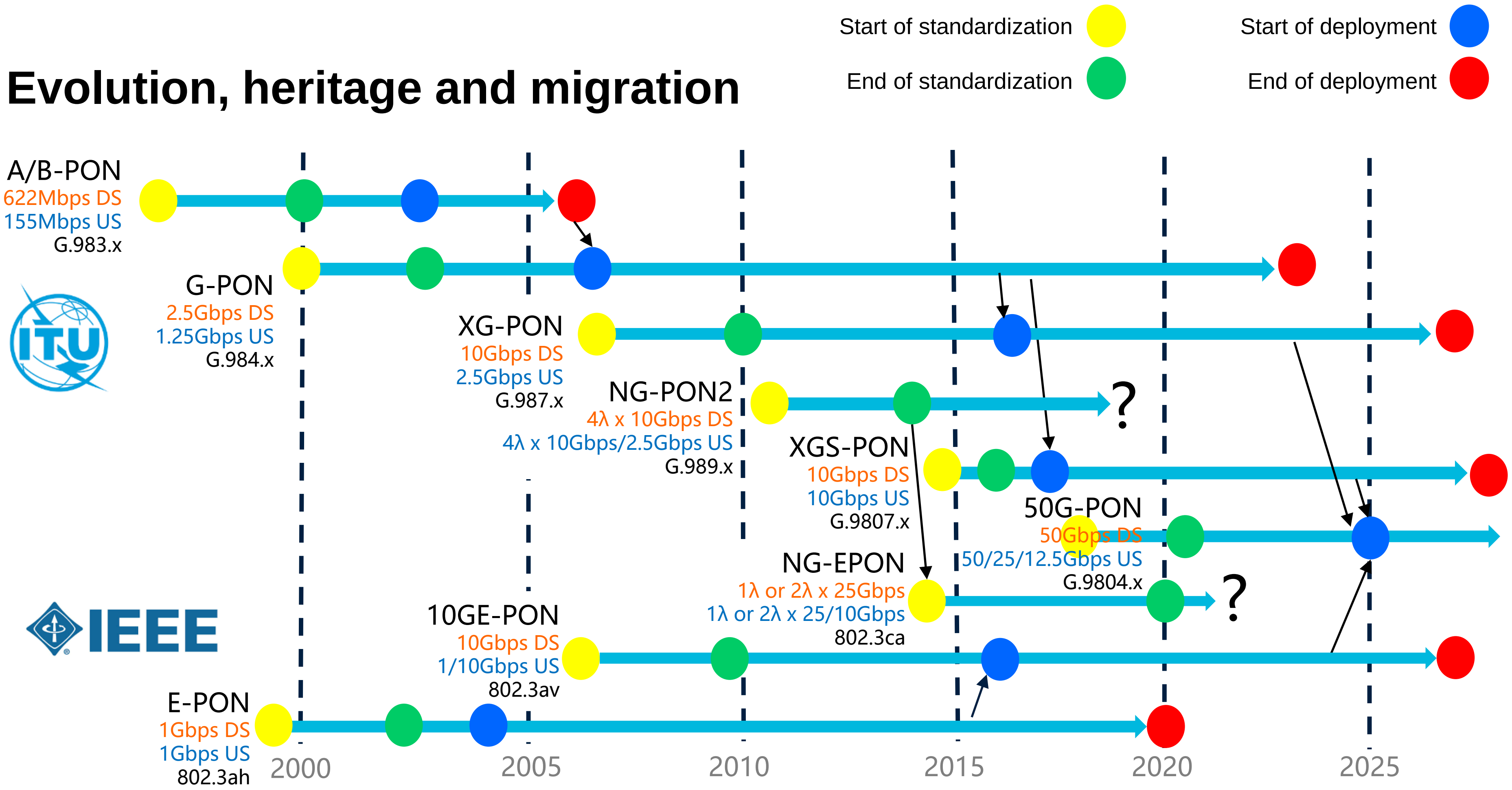
PON STANDARDS

ITU and IEEE PON generations

PON conjecture: bit-rate x4 every ~8-10 years

Different operators will privilege different migration paths according to their investment plans, available infrastructures and market analyses

Synergy between ITU-IEEE PHY layers in 50G-PON



F. J. Effenberger, "PON standardization status and future prospects," 45th European Conference on Optical Communication (ECOC 2019), Dublin, Ireland, 2019, pp. 1-3, doi: 10.1049/cp.2019.0793.

03.

PASSIVE OPTICAL NETWORKS

PROTOCOLS

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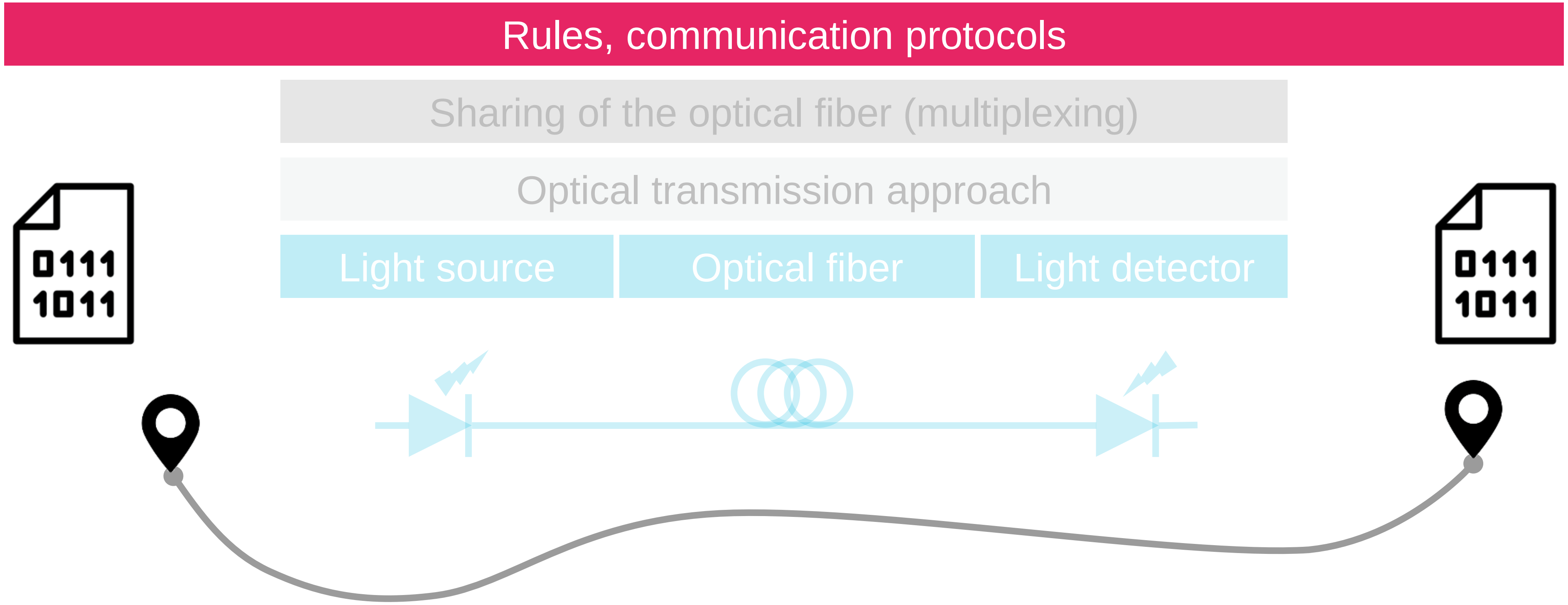
PON COMMUNICATION PROTOCOLS IN A NUTSHELL

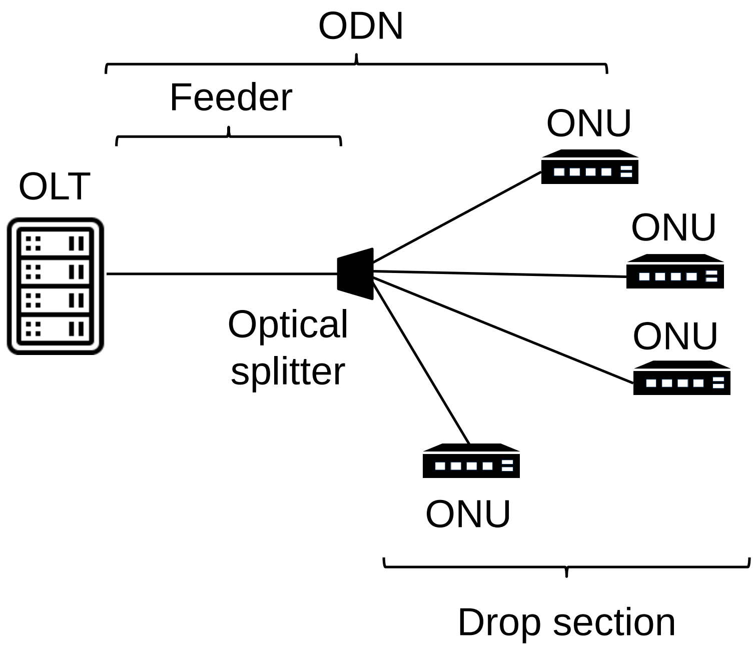
Rules and communication protocols



PON COMMUNICATION PROTOCOLS IN A NUTSHELL

Main challenges

- Sharing of PON infrastructure
  - Mutualization of PON fiber infrastructure possible thanks to TDM/TDMA multiplexing, lower deployment cost, attractive for subscribers
  - Point-to-multipoint architecture
    - Downstream (OLT → ONU): 1 TX, many RX, broadcast & select
    - Upstream (ONU → OLT): several TX at the same λ, 1 RX
    - Needs time slot management in the upstream and a correct data-user association in the downstream

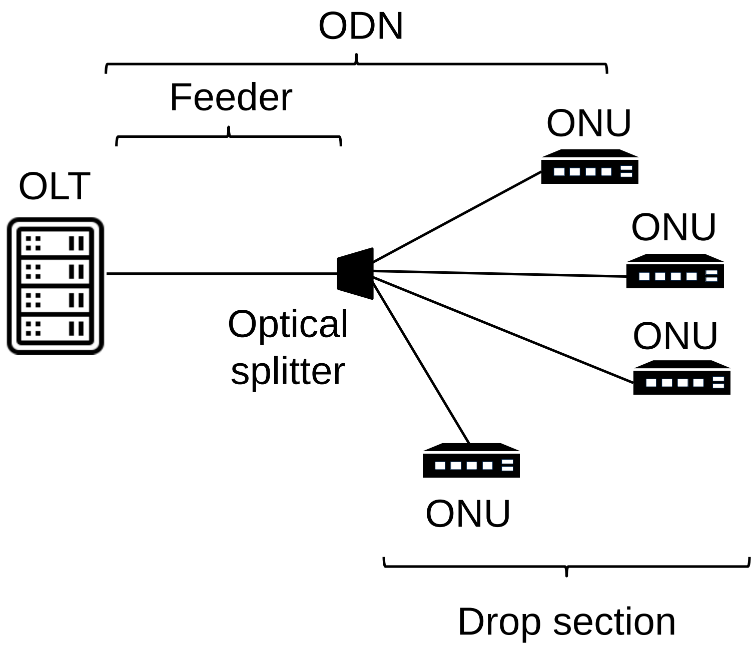


A master-slave relation: the OLT is the orchestra conductor who assigns the time-slots to each ONU

PON COMMUNICATION PROTOCOLS IN A NUTSHELL

Main challenges

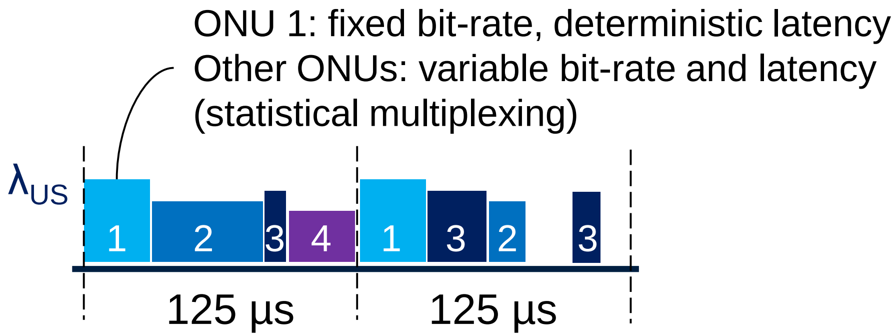
- Time equalization
  - Different OLT – ONUs distances, different propagation times
  - ~5 µs/km, time referencing required (ranging)
- Turning ONUs on/off
  - It is not enough to turn off the modulation of inactive ONUs; we need to turn off their lasers to avoid signal degradation at the OLT
  - Conversely, an ONU needs time to achieve its steady-state light emitting regime
  - Since laser switching on/off is not instantaneous, a guard time is needed between neighboring burst in the upstream direction



PON COMMUNICATION PROTOCOLS IN A NUTSHELL

Two different approaches to the problem

IEEE VS ITU



- Complement an existing protocol
  - Non-career-grade philosophy
  - Extend Ethernet to the access segment by adapting it to the PON topology
  - No transmission periodicity (frame level sync.) therefore no native TDM transport
  - New Multi-Point Control Protocol (MPCP)

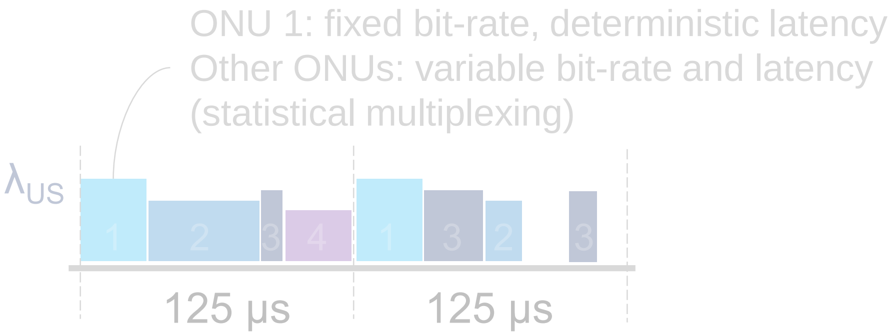
- Creation of a whole new protocol stack
  - Synchronous transmission: 125 µs cycles
  - Can ensure deterministic propagation delays (connection-oriented approach) at the expense of reduced spectral efficiency
  - Can operate in stochastic mode (statistical multiplexing) with flow prioritization according to network load (dynamic bandwidth allocation algorithms – DBA)

In both cases, the OLT is the master and sets the transmission time-slots of the ONUs in the upstream

PON COMMUNICATION PROTOCOLS IN A NUTSHELL

Two different approaches to the problem

IEEE Vs ITU



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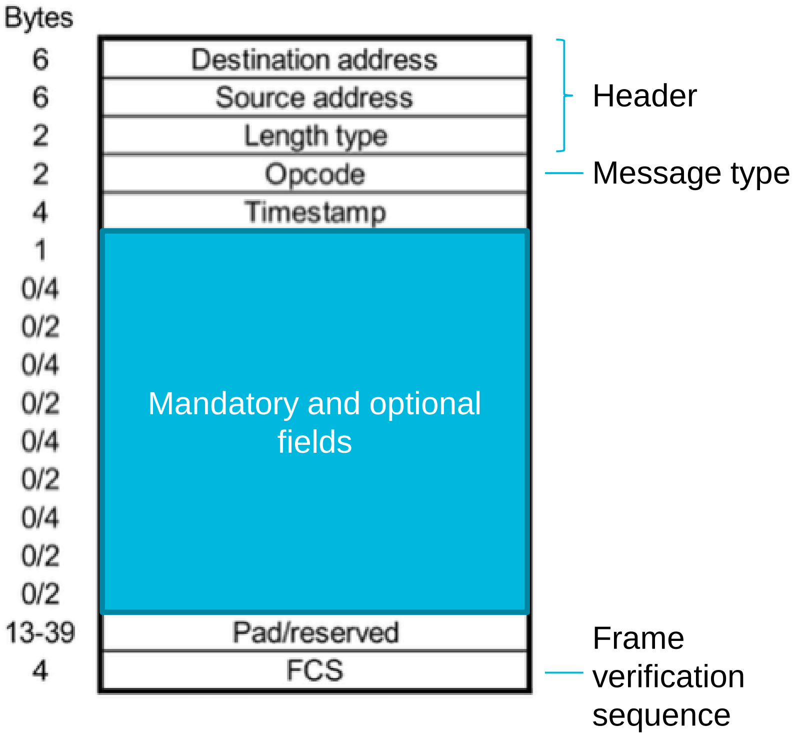
PON COMMUNICATION PROTOCOLS IN A NUTSHELL

EPON MPCP

MPCP FRAME

- MPCP organizes data transmission in the upstream
- Implemented at the MAC layer
- OLT is the master, ONUs the slaves
- MPCP roles: sync., activate and send transmission windows to ONUs
- 2 operating modes and 5 messages, identified by the Opcode field:
  - 00-02 GATE, 00-03 REPORT, 00-04, REGISTER_REQ, 00-05 REGISTER, 00-06 REGISTER_ACK



PON COMMUNICATION PROTOCOLS IN A NUTSHELL

EPON MPCP

- 2 operating modes and 5 messages, identified by the Opcode field:
  - Auto-discovery mode, registration and ranging: ONU discovery and activation
    - GATE (OLT→ONU), REGISTER_REQ (ONU→OLT), REGISTER et REGISTER_ACK (OLT→ONU)
  - Normal mode: allocate ONUs transmission windows
    - REPORT (ONU→OLT), ONU demands bandwidth by sending the states of its queues
    - GATE (OLT→ONU), OLT sends ONU transmission planning after DBA calculation based on REPORT data

Bytes	
6	Destination address
6	Source address
2	Length type
2	Opcode
4	Timestamp
1	Number of grants
0/4	Grant #1 start time
0/2	Grant #1 length
0/4	Grant #2 start time
0/2	Grant #2 length
0/4	Grant #3 start time
0/2	Grant #3 length
0/4	Grant #4 start time
0/2	Grant #4 length
0/2	Synch time
13-39	Pad/reserved
4	FCS

GATE message format

Bytes transmitted from top to bottom

Bytes	
6	Destination address
6	Source address
2	Length type
2	Opcode
4	Timestamp
1	Number of grants
1	Report bit map
0/2	Queue #0 report
0/2	Queue #1 report
0/2	Queue #2 report
0/2	Queue #3 report
0/2	Queue #4 report
0/2	Queue #5 report
0/2	Queue #6 report
0/2	Queue #7 report
0-39	Pad/reserved
4	FCS

REPORT messages format

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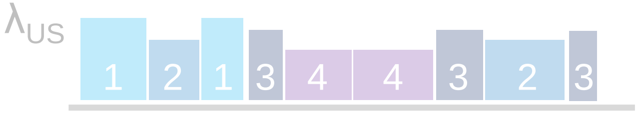
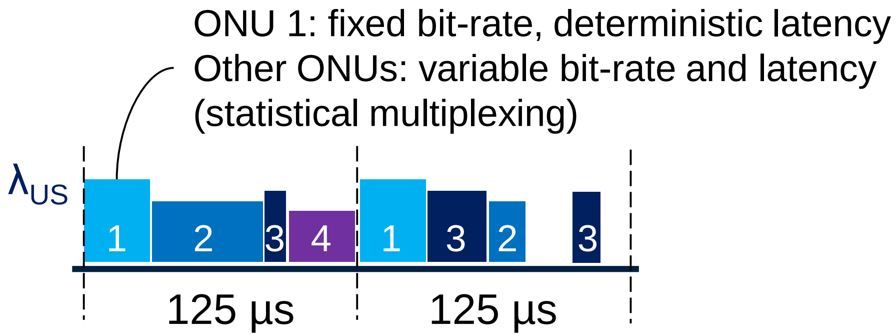
PON COMMUNICATION PROTOCOLS IN A NUTSHELL

Two different approaches to the problem



- Complement an existing protocol
  - Non-career-grade philosophy
  - Extend Ethernet to the access segment by adapting it to the PON topology
  - No transmission periodicity (frame level sync.) therefore no native TDM transport
  - New Multi-Point Control Protocol (MPCP)



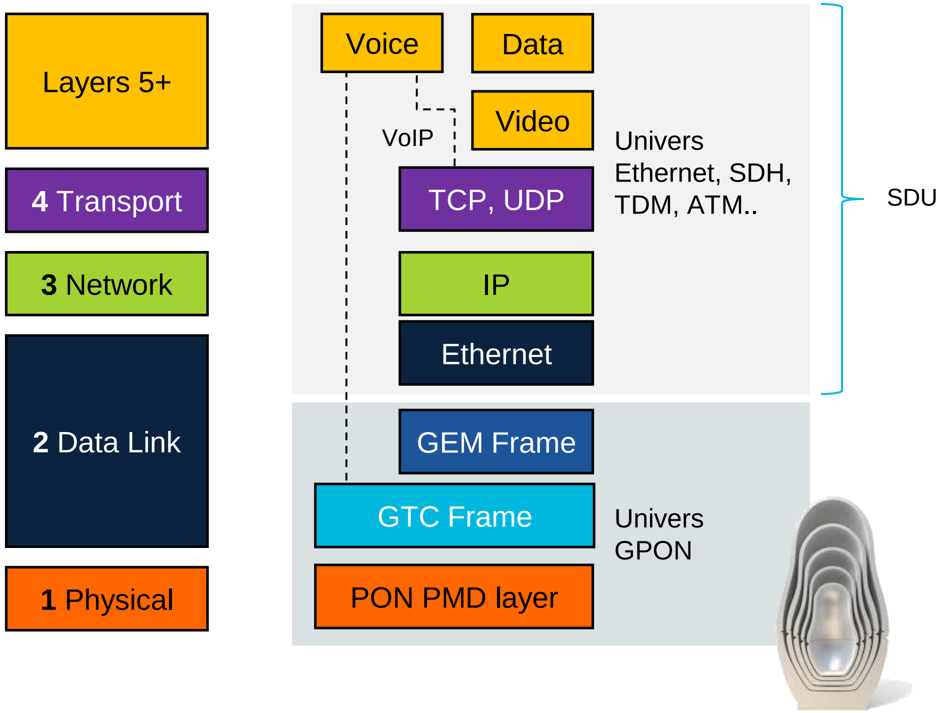
- Creation of a whole new protocol stack
  - Synchronous transmission: 125 µs cycles
  - Can ensure deterministic propagation delays (connection-oriented approach) at the expense of reduced spectral efficiency
  - Can operate in stochastic mode (statistical multiplexing) with flow prioritization according to network load (dynamic bandwidth allocation algorithms – DBA)

In both cases, the OLT is the master and sets the transmission time-slots of the ONUs in the upstream

PON COMMUNICATION PROTOCOLS IN A NUTSHELL

G-PON Encapsulation Method (GEM) and Transmission Convergence (GTC)

- A whole new protocol stack
  - Service data units (SDU), typically Ethernet frames
  - GEM frames: encapsulate SDUs
  - GTC Downstream Synchronous Transport Frames
    - 125 µs, header + payload (GEM frames)
  - GTC Upstream Synchronous Transport Frames
    - 125 µs, group of bursts sent by different ONUs and delimited in time according to different bandwidth map allocation units



ATM – Asynchronous Transfer Mode
GEM – GPON Encapsulation Method
GTC – GPON Transmission Convergence
PMD – Physical Media Dependent
SDU – Service Data Unit
VoIP – Voice over IP
SDH – Synchronous Digital Hierarchy

PON COMMUNICATION PROTOCOLS IN A NUTSHELL

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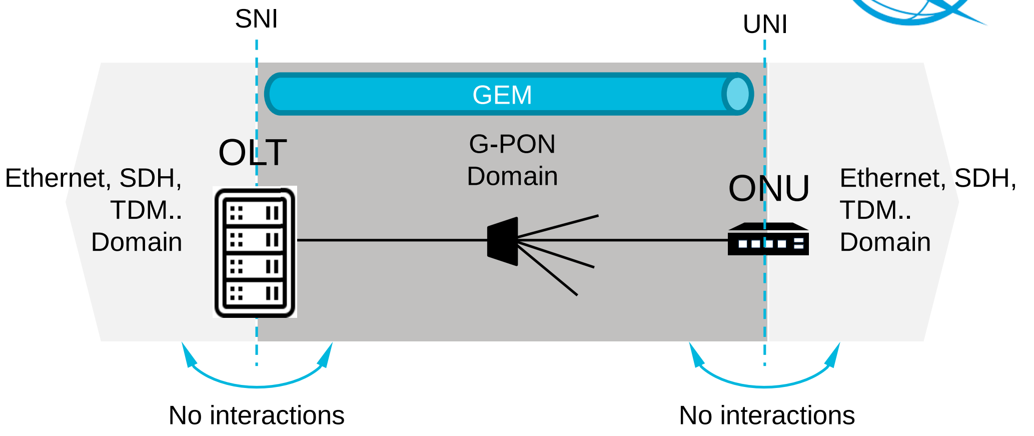
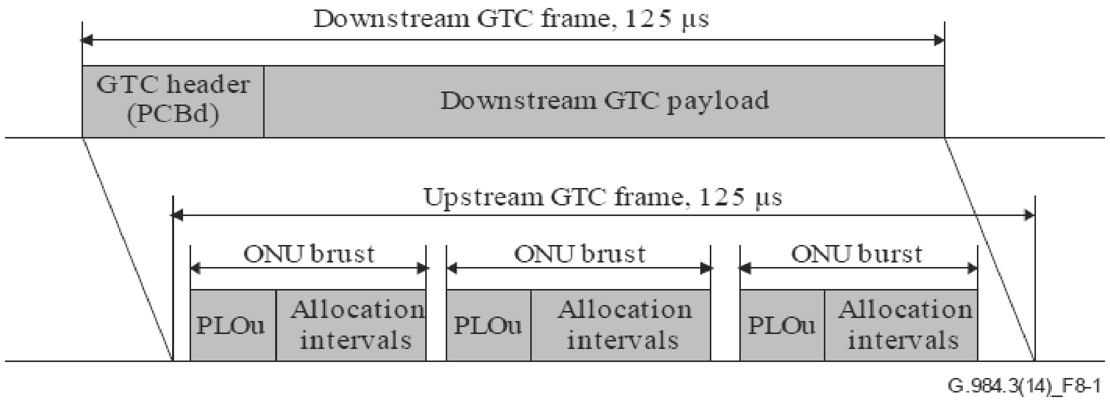


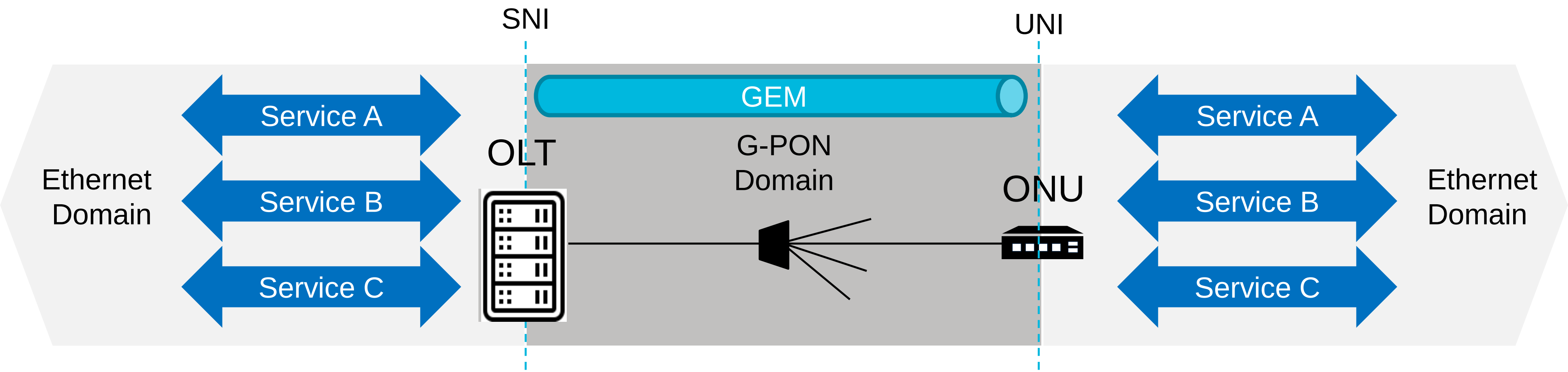


GEM – GPON Encapsulation Method
GTC – GPON Transmission Convergence
PCBd – Physical Control Block downstream
PLOu – Physical Layer Overhead upstream

SDU – Service Data Unit
SNI – Service Node Interface
UNI – User Network Interface

PON COMMUNICATION PROTOCOLS IN A NUTSHELL

G-PON Encapsulation Method (GEM) and Transmission Convergence (GTC)



Classes of service/traffic based on 802.1Q (VLANs) and 802.1P (priorities) standards

G-PON protocol must be able to associate different classes of service at the Ethernet domain to priorities of access to the fiber (time slots) for different services and clients (ONUs)

Classes of service/traffic based on 802.1Q (VLANs) and 802.1P (priorities) standards

VLAN – Virtual Local Area Network

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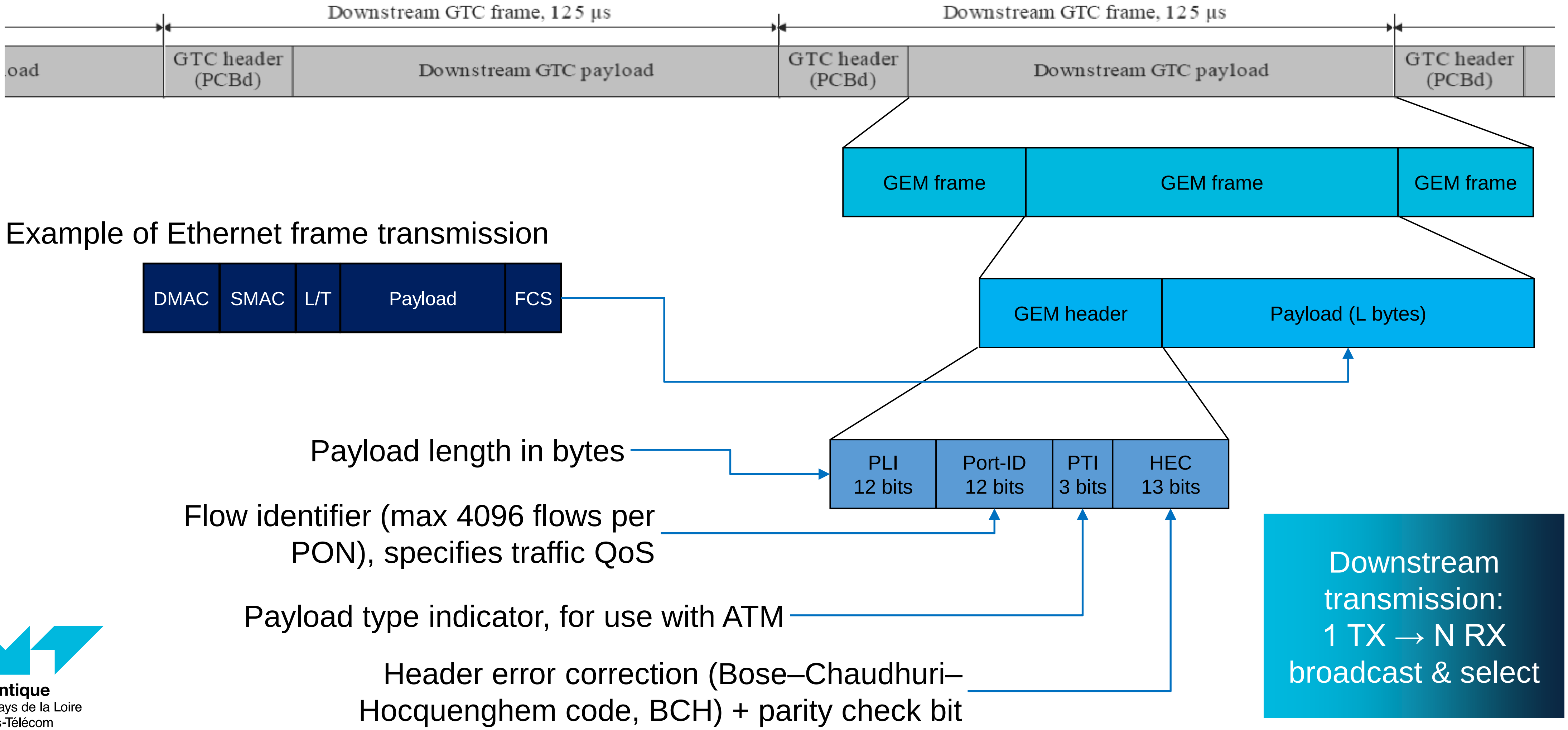
PON COMMUNICATION PROTOCOLS IN A NUTSHELL

GPON downstream frame (payload)

Example of Ethernet frame transmission



Downstream transmission:
1 TX → N RX
broadcast & select

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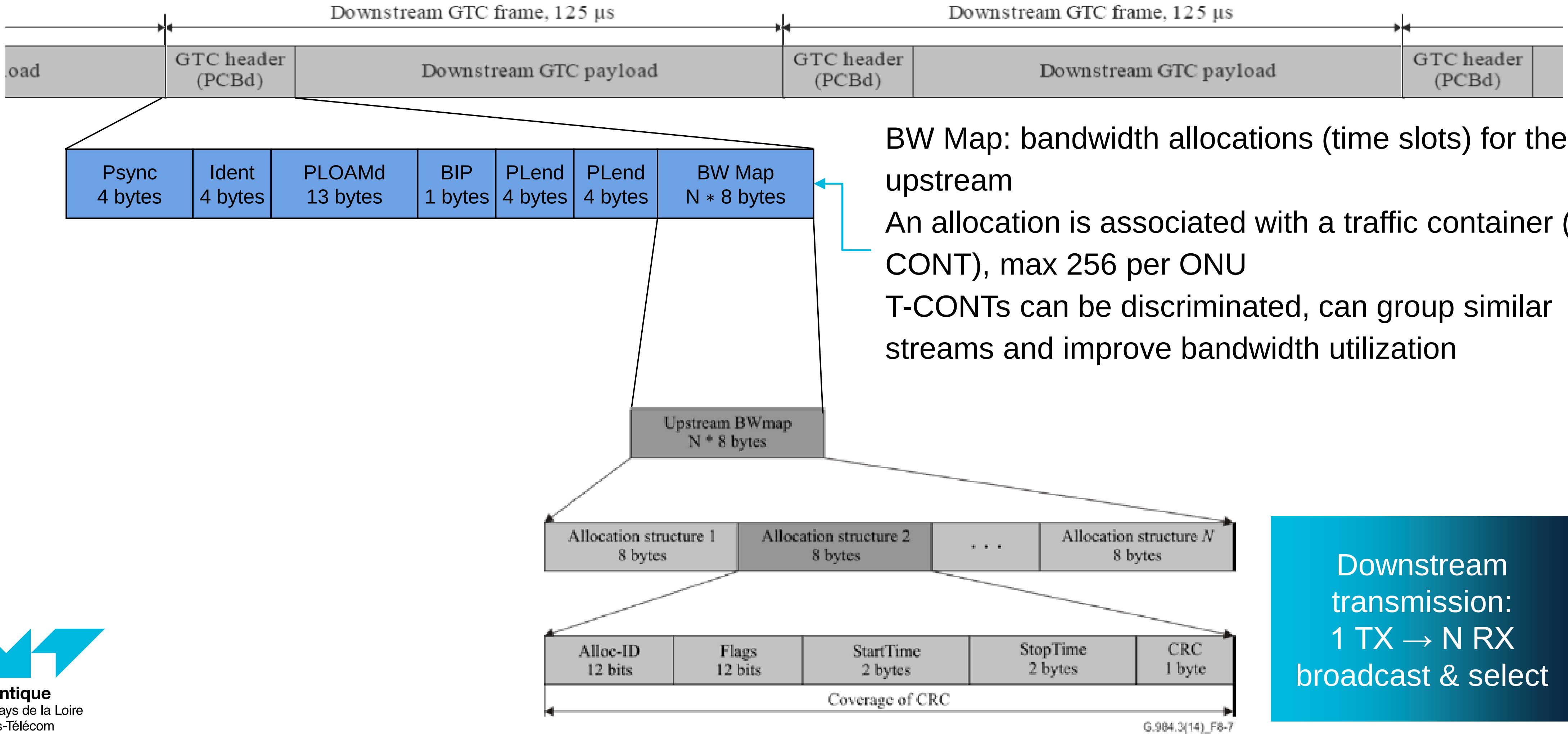
PON COMMUNICATION PROTOCOLS IN A NUTSHELL

GPON downstream frame (header)



BW Map: bandwidth allocations (time slots) for the upstream

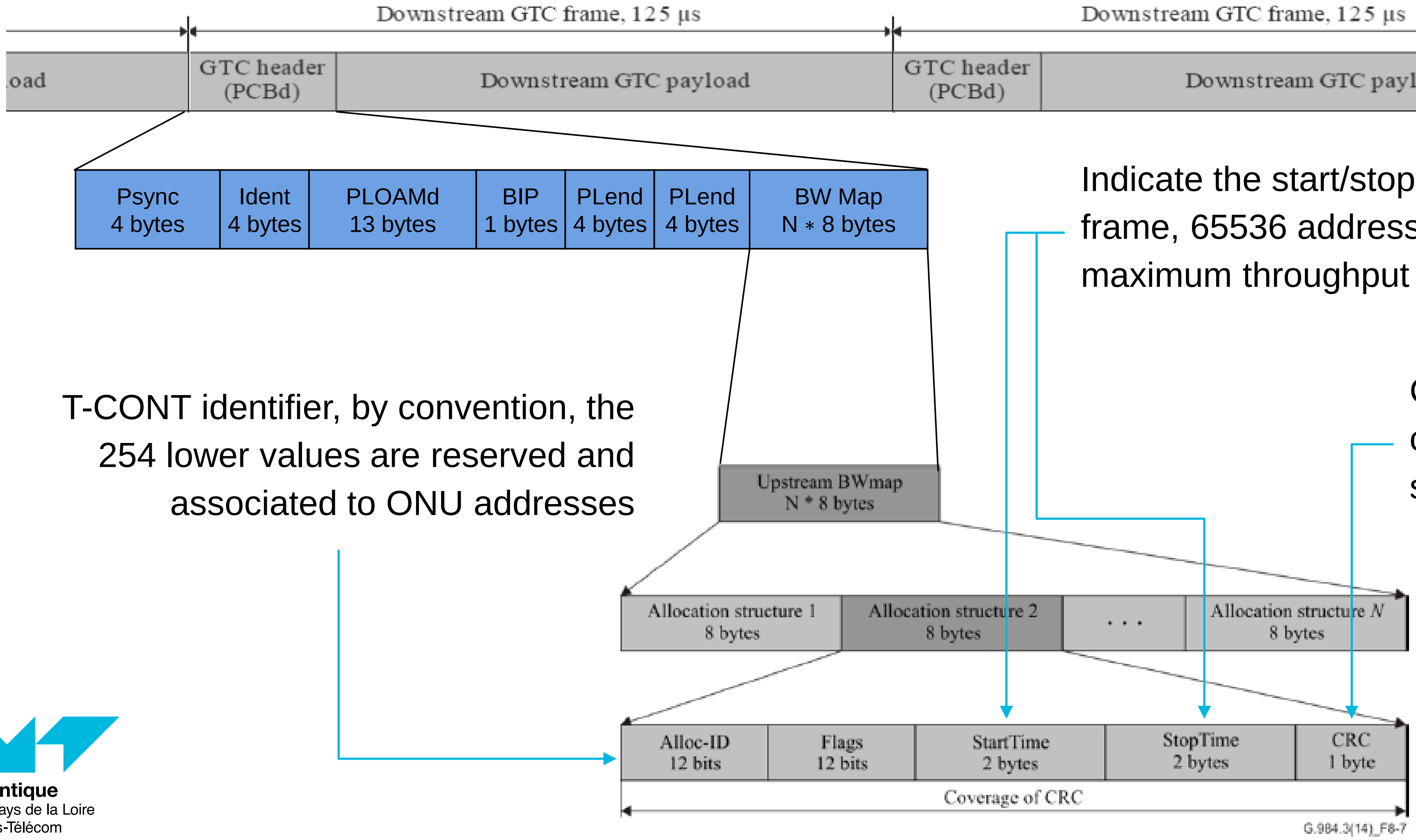
An allocation is associated with a traffic container (T-CONT), max 256 per ONU

T-CONTs can be discriminated, can group similar streams and improve bandwidth utilization

Downstream transmission:
1 TX → N RX
broadcast & select

PON COMMUNICATION PROTOCOLS IN A NUTSHELL

GPON downstream frame (header)



Indicate the start/stop bytes in the 125 µs frame, 65536 addressable bytes, i.e. a maximum throughput of 4.194 Gb/s

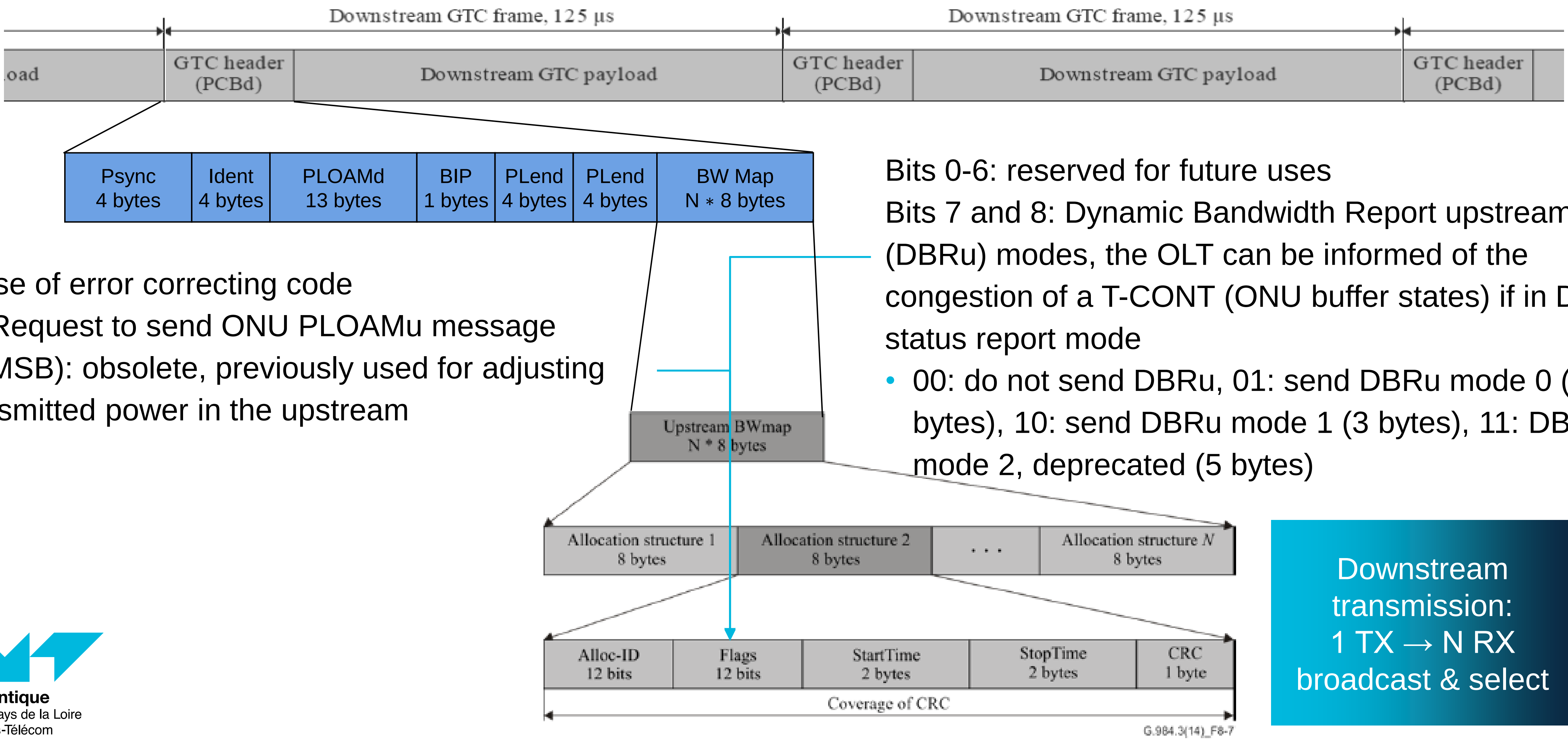
T-CONT identifier, by convention, the 254 lower values are reserved and associated to ONU addresses

Cyclic redundancy check, allocation structure ignored if error

Downstream transmission:
1 TX → N RX
broadcast & select

PON COMMUNICATION PROTOCOLS IN A NUTSHELL

GPON downstream frame (header)



Bits 0-6: reserved for future uses

Bits 7 and 8: Dynamic Bandwidth Report upstream (DBRu) modes, the OLT can be informed of the congestion of a T-CONT (ONU buffer states) if in DBA status report mode

- 00: do not send DBRu, 01: send DBRu mode 0 (2 bytes), 10: send DBRu mode 1 (3 bytes), 11: DBRu mode 2, deprecated (5 bytes)

Bit 9: Use of error correcting code

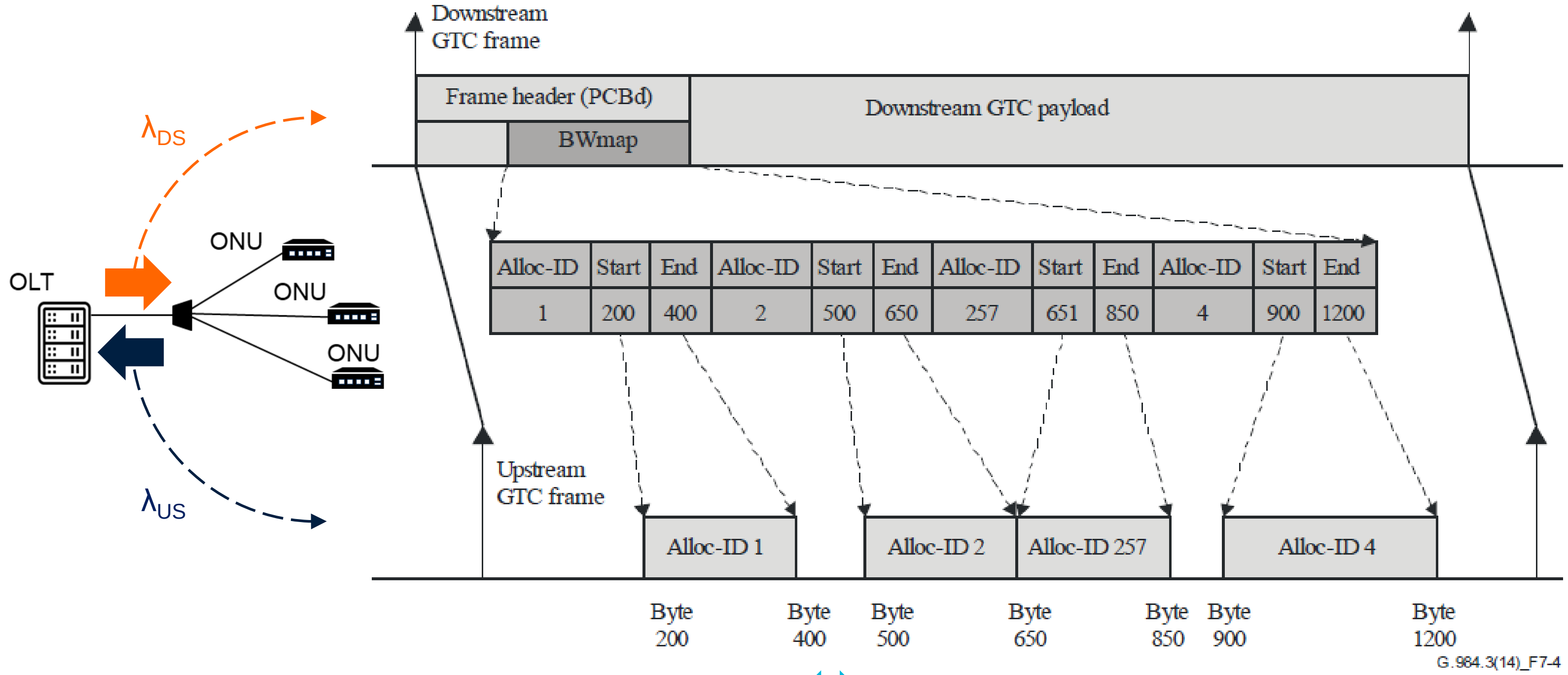
Bit 10: Request to send ONU PLOAMu message

Bit 11 (MSB): obsolete, previously used for adjusting the transmitted power in the upstream

Downstream transmission:
1 TX → N RX
broadcast & select

PON COMMUNICATION PROTOCOLS IN A NUTSHELL

GPON downstream frame



Downlink frames are used not only to transmit traffic from the OLT to the ONUs but also to inform the ONUs of their time slot over each 125 µs window in the uplink as well as to transmitting operation, administration and management information

Ranging window should be accounted for in the upstream: during ranging, registered ONUs can't talk

Downstream transmission:
1 TX → N RX
broadcast & select

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PON COMMUNICATION PROTOCOLS IN A NUTSHELL

G-PON T-CONTs

- An ONU can support several T-CONTs, their number is fixed either during activation of the ONU or by configuration
- T-CONTs can be discriminated and can also group similar flows; they improve the use of upstream bandwidth
- The OLT uses the control channel to acquire the number of T-CONTs supported by the ONUs and manage them, it associates the T-CONT with an Alloc-ID of an ONU

5 types of T-CONT

Traffic descriptor component	Type 1	Type 2	Type 3	Type 4	Type 5
Fixed bandwidth	FIR				FIR
Assured bandwidth		CIR	CIR		CIR
Maximum bandwidth	PIR=FIR	PIR=CIR	PIR>CIR	PIR	PIR≥CIR+FIR
Eligibilité à bande passante supplémentaire	Non	Non	NA	BE	Any

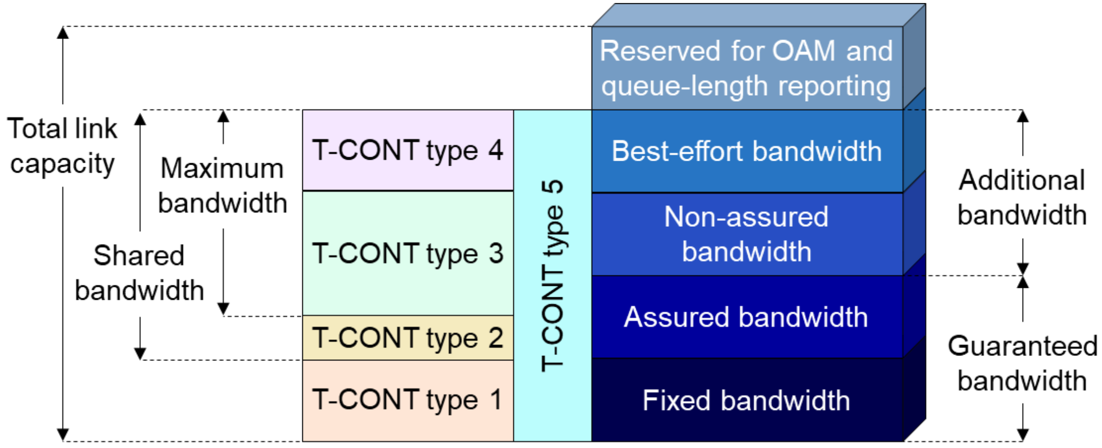
Fixed bit-rate FIR ≥ 0: statically attributed to an Alloc-ID, independently of ONU traffic demands or total PON traffic

Assured bit-rate CIR ≥ 0: attributed to an Alloc-ID as long as it has unsatisfied traffic demands. If a traffic demand is satisfied, the OLT can either fully or partially allocate this time slot to another Alloc-ID

Maximum bit-rate PIR > 0: maximum bit-rate that could be allocated to an Alloc-ID

PON COMMUNICATION PROTOCOLS IN A NUTSHELL

G-PON T-CONTs



- Fixed: statically reserved statically
- Assured: guaranteed if needed, freed otherwise
- Non-assured: given if available
- Best-effort: less priority than best-effort

5 types of T-CONT

Traffic descriptor component	Type 1	Type 2	Type 3	Type 4	Type 5
Fixed bandwidth	FIR				FIR
Assured bandwidth		CIR	CIR		CIR
Maximum bandwidth	PIR=FIR	PIR=CIR	PIR>CIR	PIR	PIR≥CIR+FIR
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Maximum bit-rate PIR > 0: maximum bit-rate that could be allocated to an Alloc-ID

The choice of R_F, R_A and R_M parameters of the T-CONTs and the association of the T-CONTs with services (voice, data, video…) depend on the operators' engineering rules.

PON COMMUNICATION PROTOCOLS IN A NUTSHELL

G-PON T-CONTs

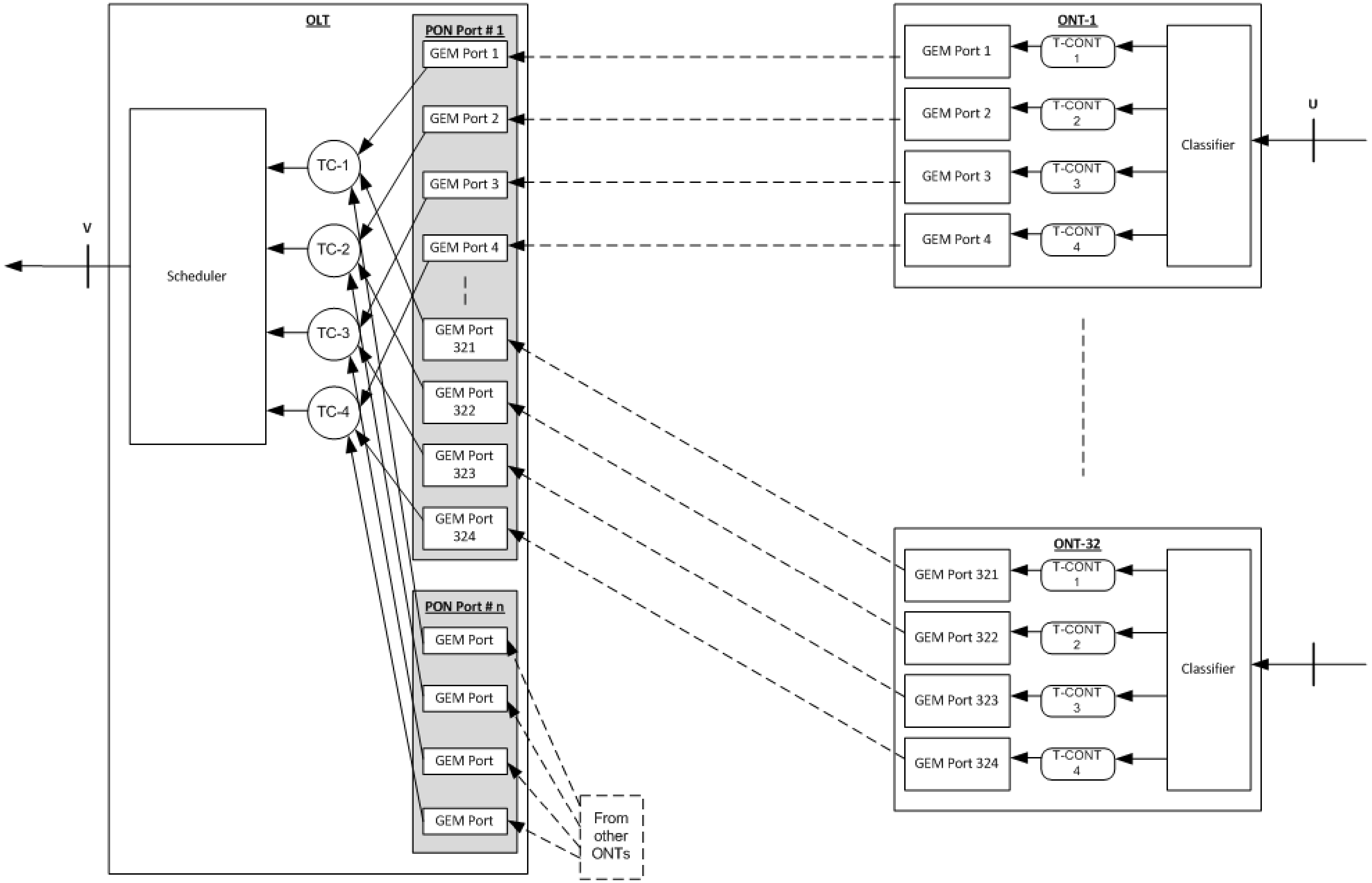


Figure 5. Upstream Traffic Management

- Dynamic bandwidth allocation (DBA)
  - Optimization of the choice of Alloc-ID every 125 µs
  - Allows statistical multiplexing (network “overbooking”)
  - Differentiate flows with different QoS, SLA between operator and clients
  - Clients can be occasionally granted access to high bandwidth requirements
- NSR-DBA (non status report)
  - OLT detects congestions of a T-CONT by monitoring received traffic flows
- SR-DBA (status report)
  - ONU informs OLT of the state of its queues
  - Mode 0: sends volume of data in the buffer associated to an Alloc-ID
  - Mode 1: applies to cases where subscriber traffic is distinguished between guaranteed traffic (CIR) and non-guaranteed/excess traffic (EIR)

The details of the DBA algorithms are generally not known, they are proprietary to the PON network equipment vendor

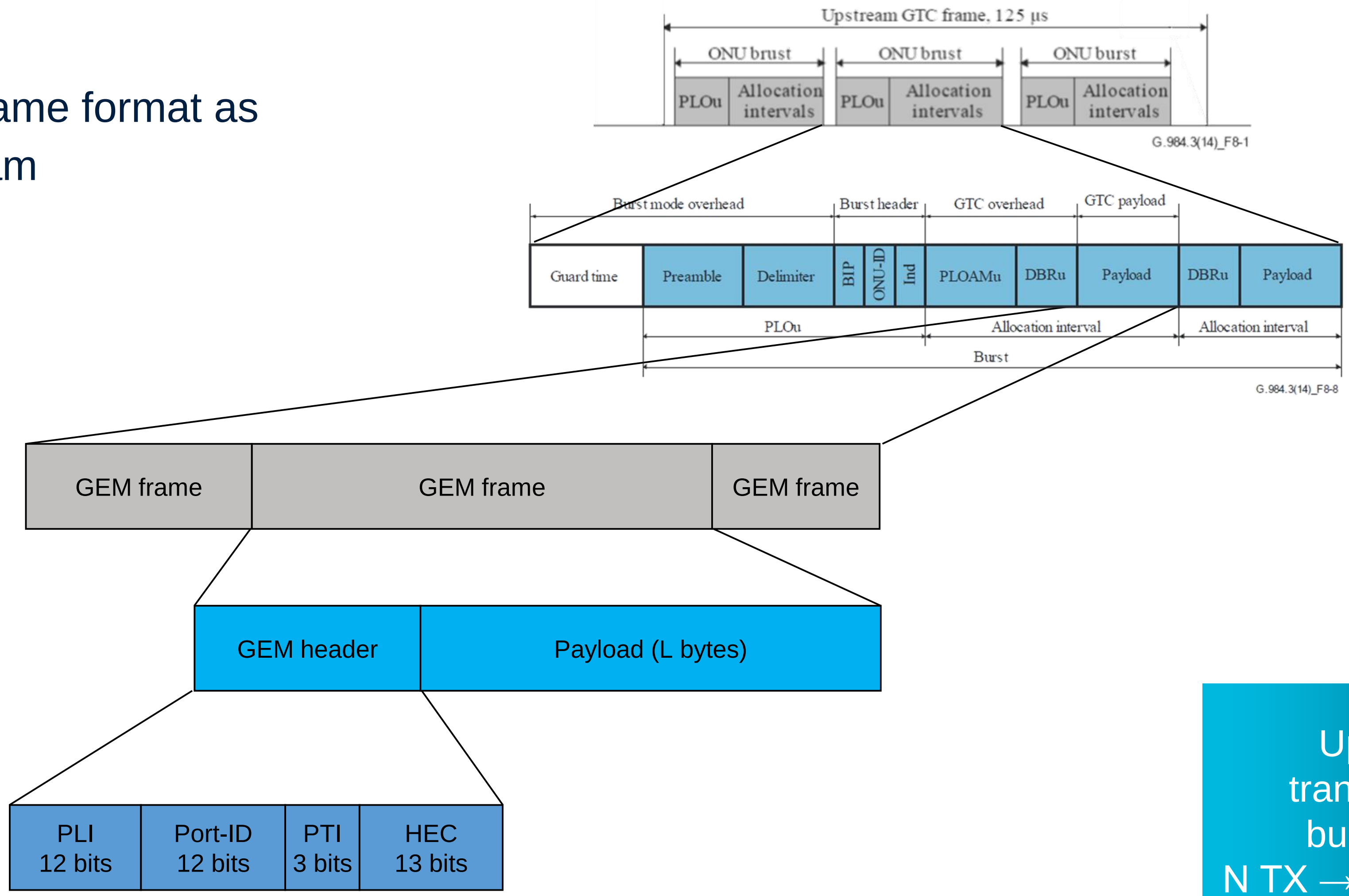
The choice of R_F, R_A and R_M parameters of the T-CONTs and the association of the T-CONTs with services (voice, data, video…) depend on the operators' engineering rules

SLA – Service Level Agreement

PON COMMUNICATION PROTOCOLS IN A NUTSHELL

GPON upstream frame (payload)

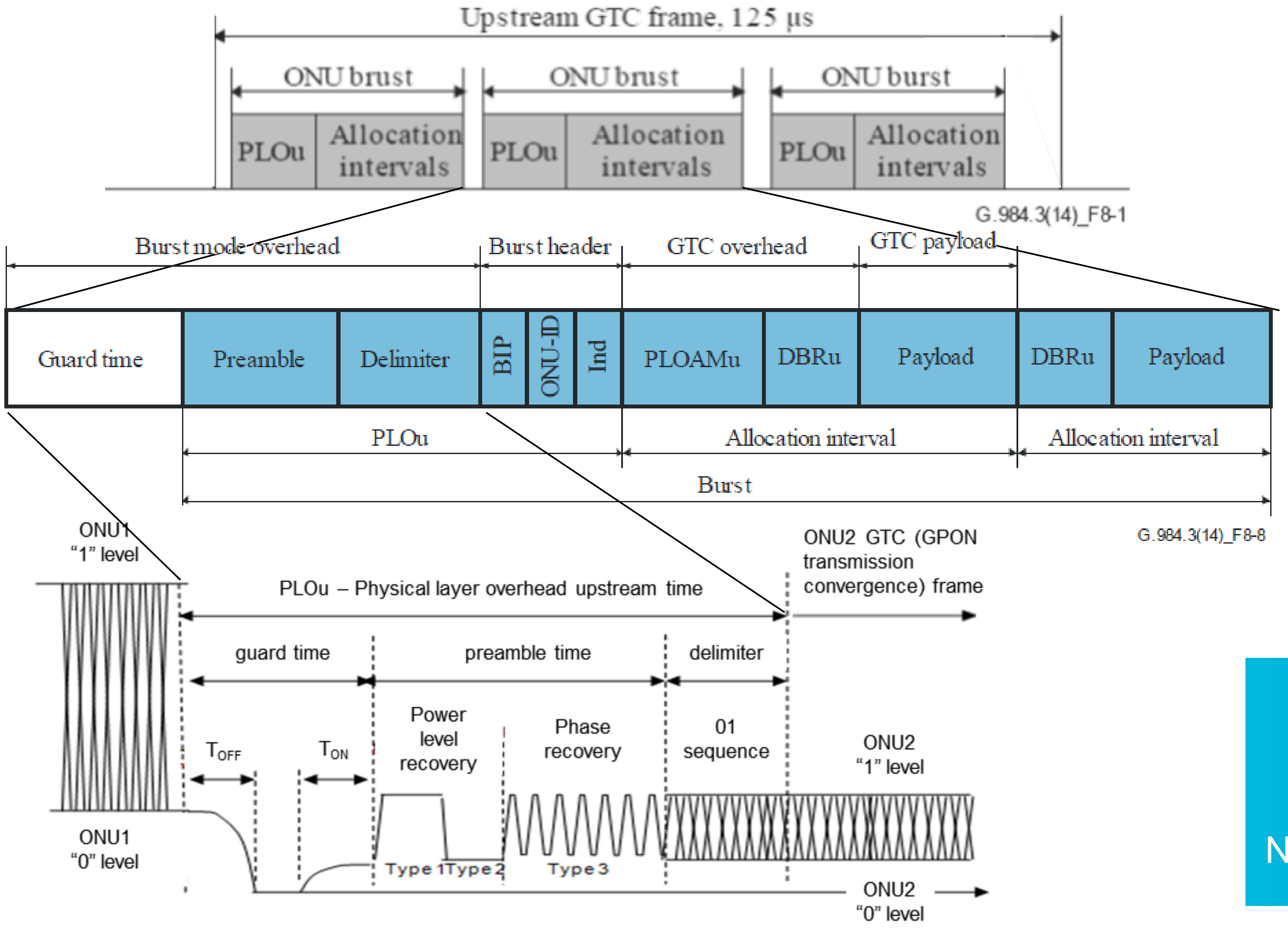
- GTC payload: same format as in the downstream



Upstream transmission:
burst mode
N TX → 1 RX, TDMA

PON COMMUNICATION PROTOCOLS IN A NUTSHELL

GPON upstream frame (headers)



Guard time allowing to turn off ONU_j laser and to turn on ONU_{j+1} laser

Upstream transmission:
burst mode
N TX → 1 RX, TDMA

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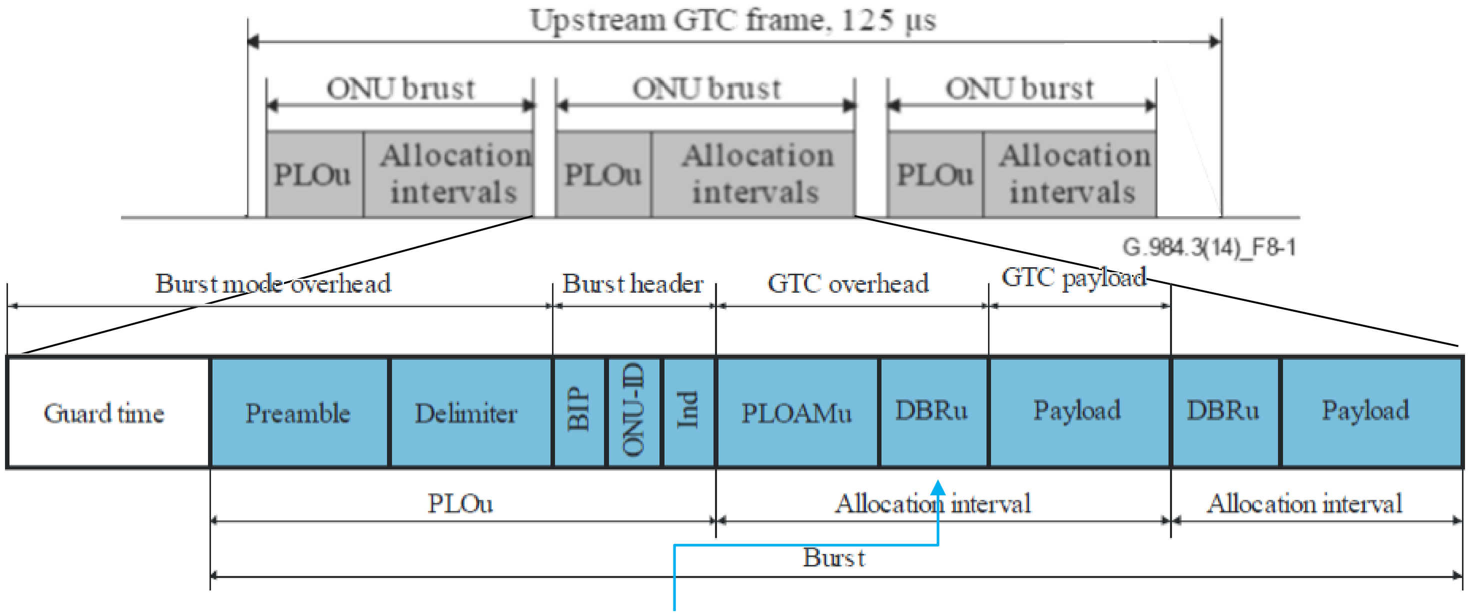
PON COMMUNICATION PROTOCOLS IN A NUTSHELL

GPON upstream frame (headers)



Dynamic Bandwidth Report upstream: sent according to values of bits 8 et 7 of the Flag field in the downstream frame. Associated to a specific T-CONT, 2 possible report modes:

- Mode 0: sends volume of data in the buffer associated to an Alloc-ID
- Mode 1: applies to cases where subscriber traffic is distinguished between guaranteed traffic (CIR) and non-guaranteed/excess traffic (EIR)

Upstream transmission: burst mode
N TX → 1 RX, TDMA

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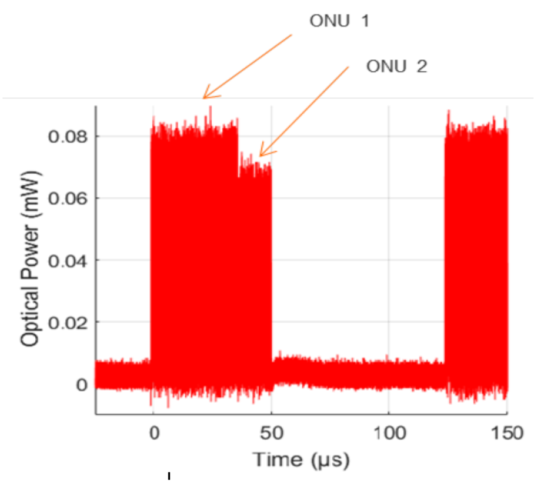
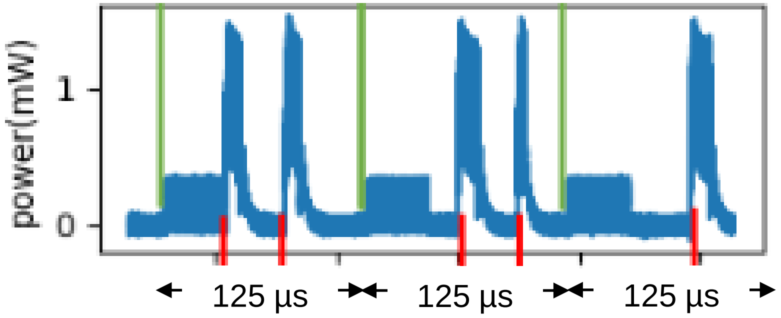
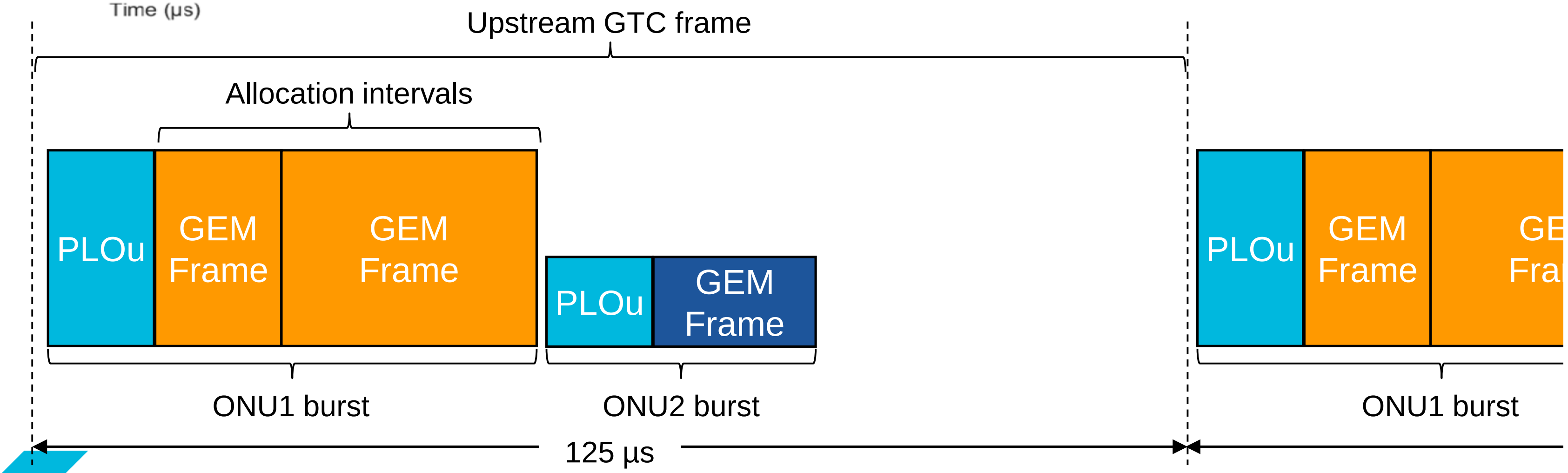
PON COMMUNICATION PROTOCOLS IN A NUTSHELL

Some examples of G-PON upstream transmissions





ONU_{low} – Fixed
ONU_{high} – Assured



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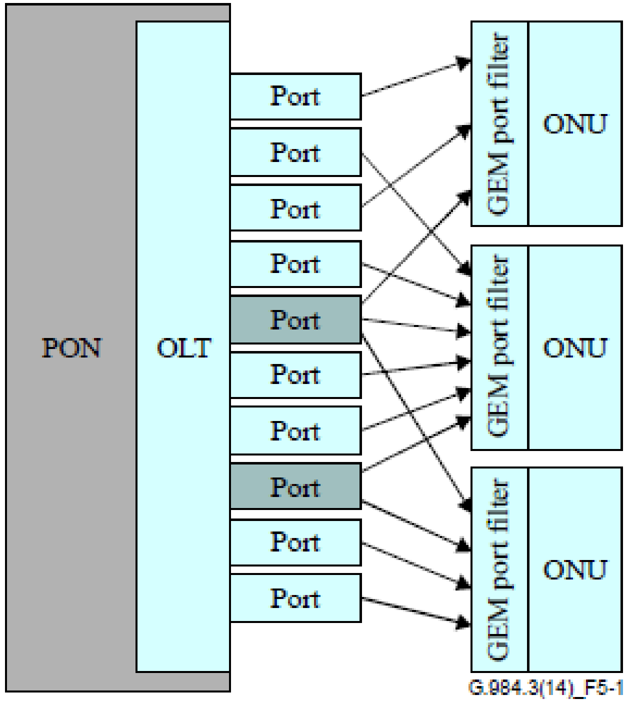
A. E. Ankouri, "Study of Optical Access Solutions in Line with Radio Access Network Interfaces," PhD thesis, IMT-Atlantique

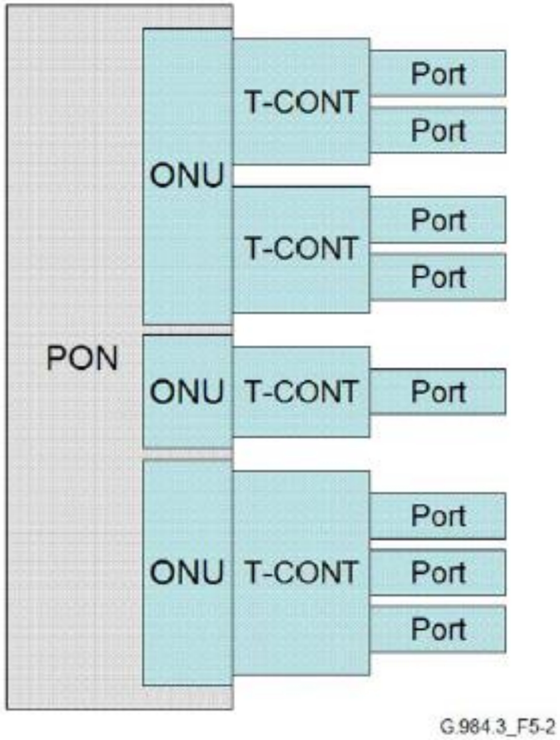
PON COMMUNICATION PROTOCOLS IN A NUTSHELL

G-PON logical architecture

Downstream



Upstream



03.

PASSIVE OPTICAL NETWORKS

VIRTUALIZATION

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VIRTUALIZATION IN THE OPTICAL ACCESS

OLT as a data-center

Towards the “as a datacenter” paradigm

Dedicated hardware, OLT chassis

Data plane

Control plane

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M. Wang et al., "Dynamic Traffic Management of OLT Backhaul/Service Ports with SDN Controller," ECOC, 2020
M. Wang et al., "SDN-based RAN Protection Solution for 5G, an Experimental Approach," ONDM, 2021
M. Wang et al., "SDN-oriented Disaggregated Optical Access Node for Converged 5G Mobile and Residential Services, ECOC, 2021

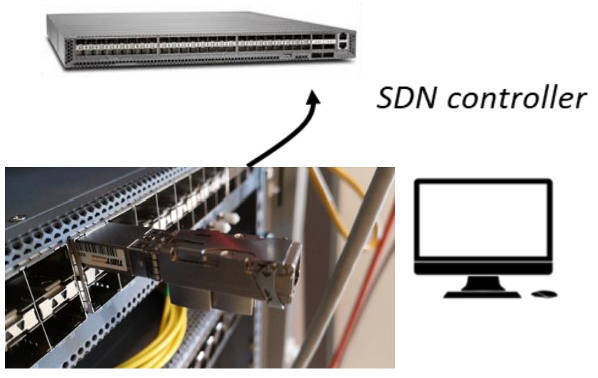
VIRTUALIZATION IN THE OPTICAL ACCESS

OLT as a data-center

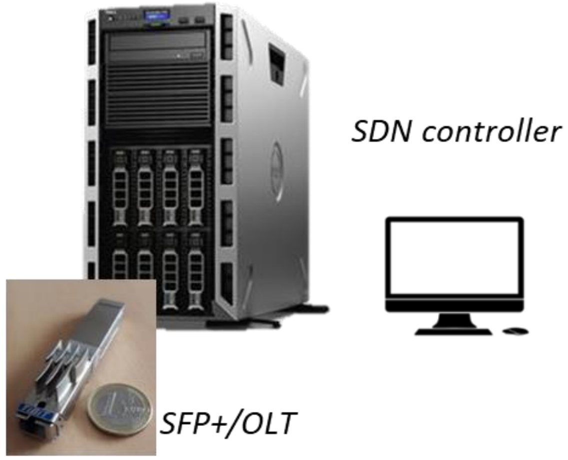
Towards the “as a datacenter” paradigm

Dedicated hardware, OLT chassis

Disaggregated hardware:
switch + SFP+/OLT



Generic + SFP+/OLT



Data plane

Control plane

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M. Wang et al., "Dynamic Traffic Management of OLT Backhaul/Service Ports with SDN Controller," ECOC, 2020
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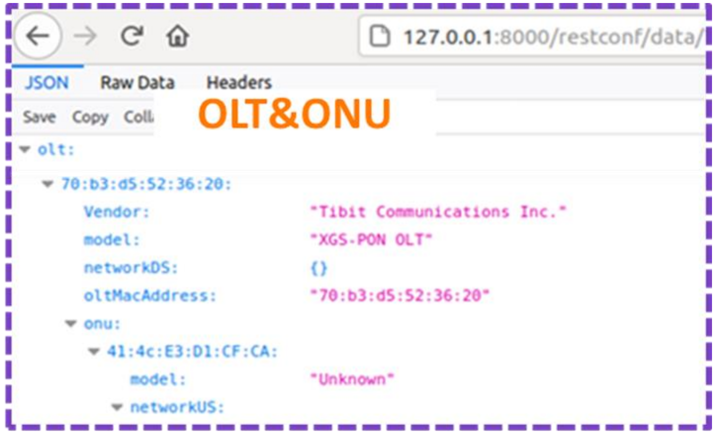
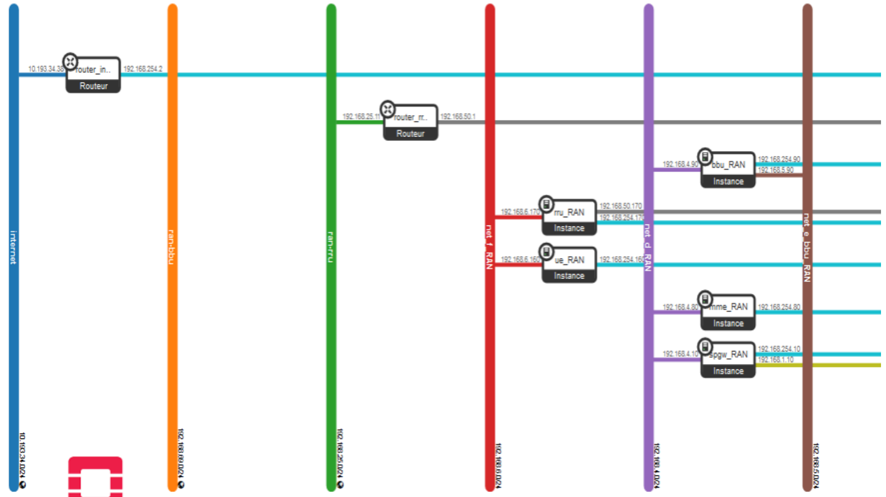
VIRTUALIZATION IN THE OPTICAL ACCESS

Software-defined networking and network function virtualization

- Virtualization
  - Software-defined network (SDN)
    - Separation of data and control planes, new OLT vendors, stronger competition between vendors
    - Equipment configuration: avoid vendor lock-in in the element management system (EMS), facilitates interoperability
    - Network abstraction: reacts to temporary network load variations, isolates sets of configurations, multi-tenant approaches, synergy with other network domains (mobile, LAN, metro, etc.)
  - Network function virtualization (NFV)
    - Software implementation of some network functionalities
    - Optical network demarcation points become capable of embedding some of those software functions

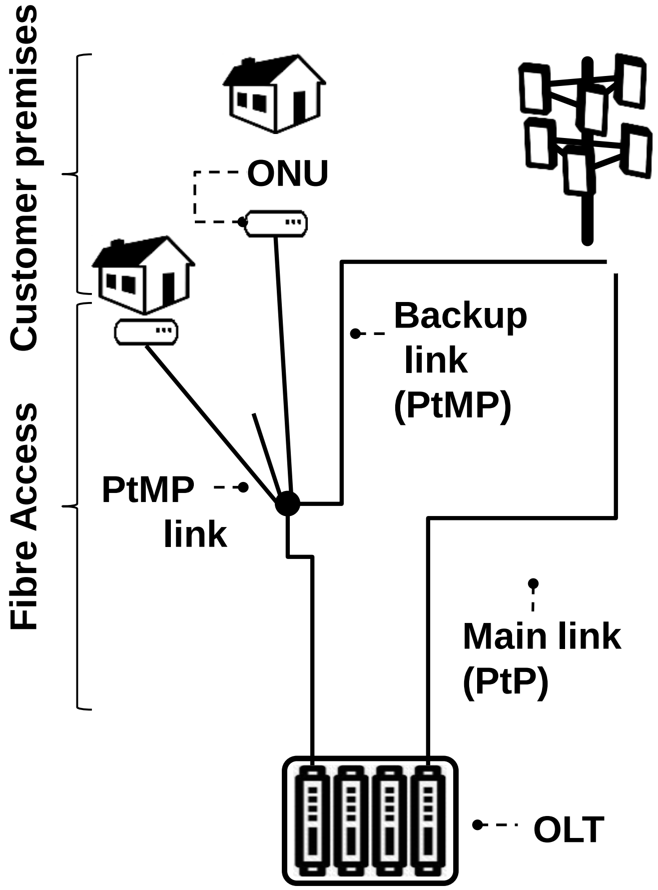


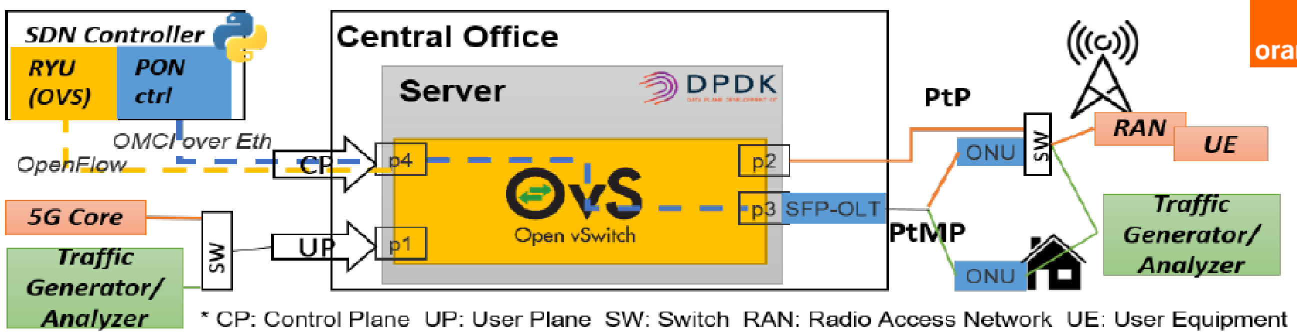


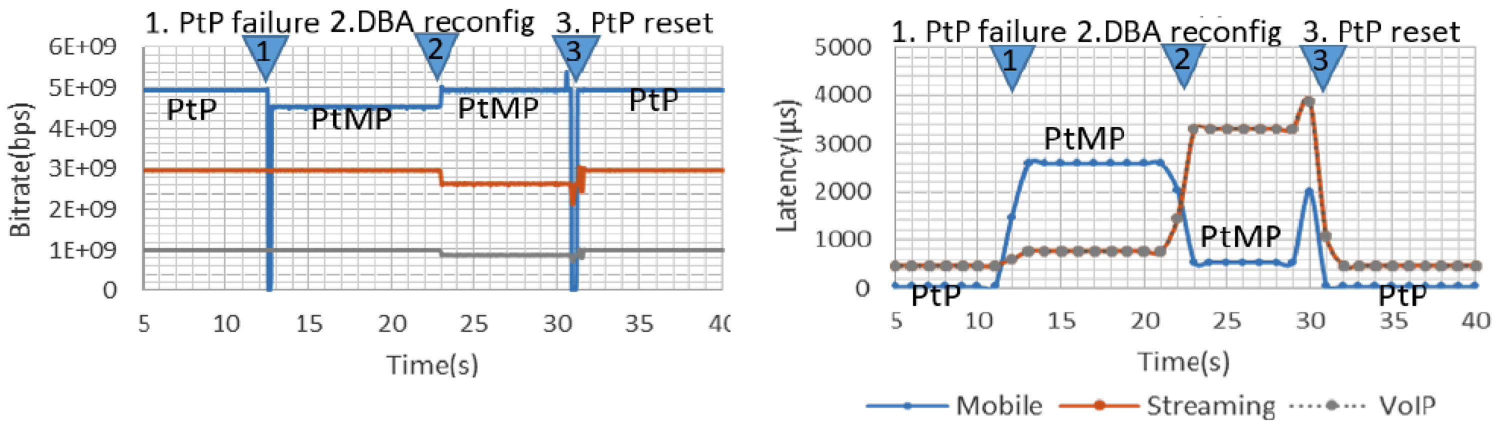
openstack

VIRTUALIZATION IN THE OPTICAL ACCESS

Fixed-mobile convergence use-cases

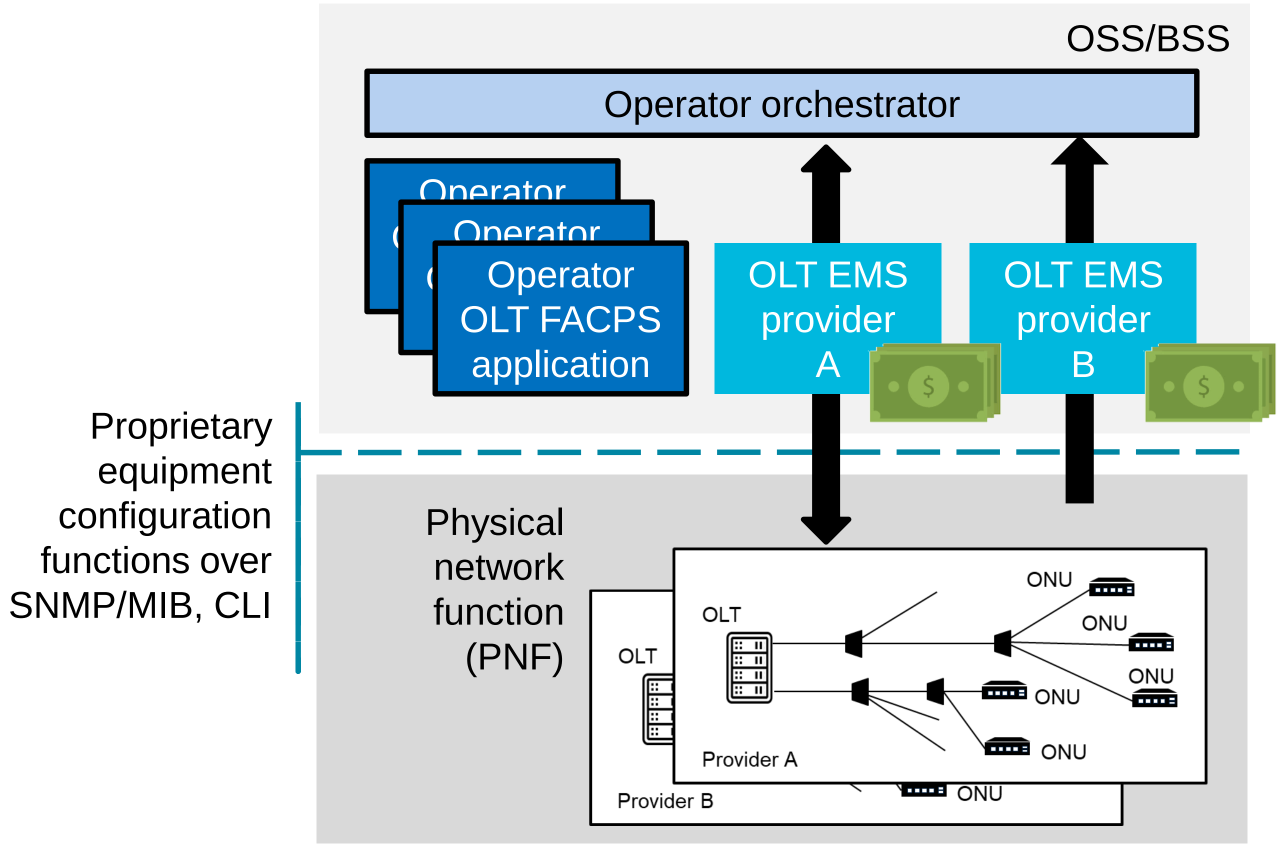






M. Wang et al., "SDN-oriented Disaggregated Optical Access Node for Converged 5G Mobile and Residential Services," ECOC 21

Legacy PON management architecture



The idea is to evolve this architecture towards an "universal" data model for the network equipment, with standardized configuration interfaces and capable of representing and acting on all OLTs/ONUs configuration parameters independently of the vendor

This new approach would make it possible to change equipment configurations in a much more dynamic way while facilitating synergy with other segments of the network (abstraction of optical access) and ensuring proper isolation between services and/or network tenants

EMS : element management system
FACPS : Fault, Config., Accounting, Performance, Security (FCAPS) applications

MIB : management information base
OSS/BSS : operations support system and business support system
SNMP : simple network management protocol

VIRTUALIZATION IN THE OPTICAL ACCESS

A densely populated ecosystem

- Data modeling SDN controller interfaces
  - IETF (Internet Engineering Task Force): Network Configuration Protocol (NETCONF RFC6241), The YANG Data Modeling Language (RFC7950), RESTCONF (RFC 8040)
  - ONF (Open Networking Foundation) : Openflow (originally developed for switch interfacing)
- Reference software-defined network architectures in the optical access
  - ONF SDN Enabled Broadband Access (SEBA)
    - Evolution of R-CORD (Central Office Rearchitected as a Datacenter)
    - Optical access equipment = switches (+ adapters)
  - BBF (Broadband Forum) Cloud Central Office (CloudCO)
    - Based on NETCONF/YANG
  - NTT FASA : Flexible Access System Architecture (long term)

IETF®

ONF Open Networking Foundation

broadband forum

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VIRTUALIZATION IN THE OPTICAL ACCESS

A densely populated ecosystem

- SDN controller adapters to legacy equipment
  - ONF Virtual OLT hardware abstraction (VOLTHA): Openflow, REST in the northbound interface (NBI) towards the SDN controller, legacy (SNMP/MIB, CLI, …) in the southbound interface (SBI) towards the equipment
  - BBF Broadband Access Abstraction (BAA)
- SDN controllers
  - ONF Open Network Operating System (ONOS), Opendaylight, Ryu, …
- Coordination between optical and mobile domains in the access
  - ORAN Cooperative transport interface (CTI), WG4
  - ITU-T Cooperative dynamic bandwidth allocation (Co-DBA), G.989.3
- Slicing in the optical acces
  - ITU-T, ETSI F5G, IETF

…not to mention the orchestration, multi-domain slice coordination and virtual infrastructure layers…

onos Open Network Operating System

OPEN DAYLIGHT

O-RAN ALLIANCE

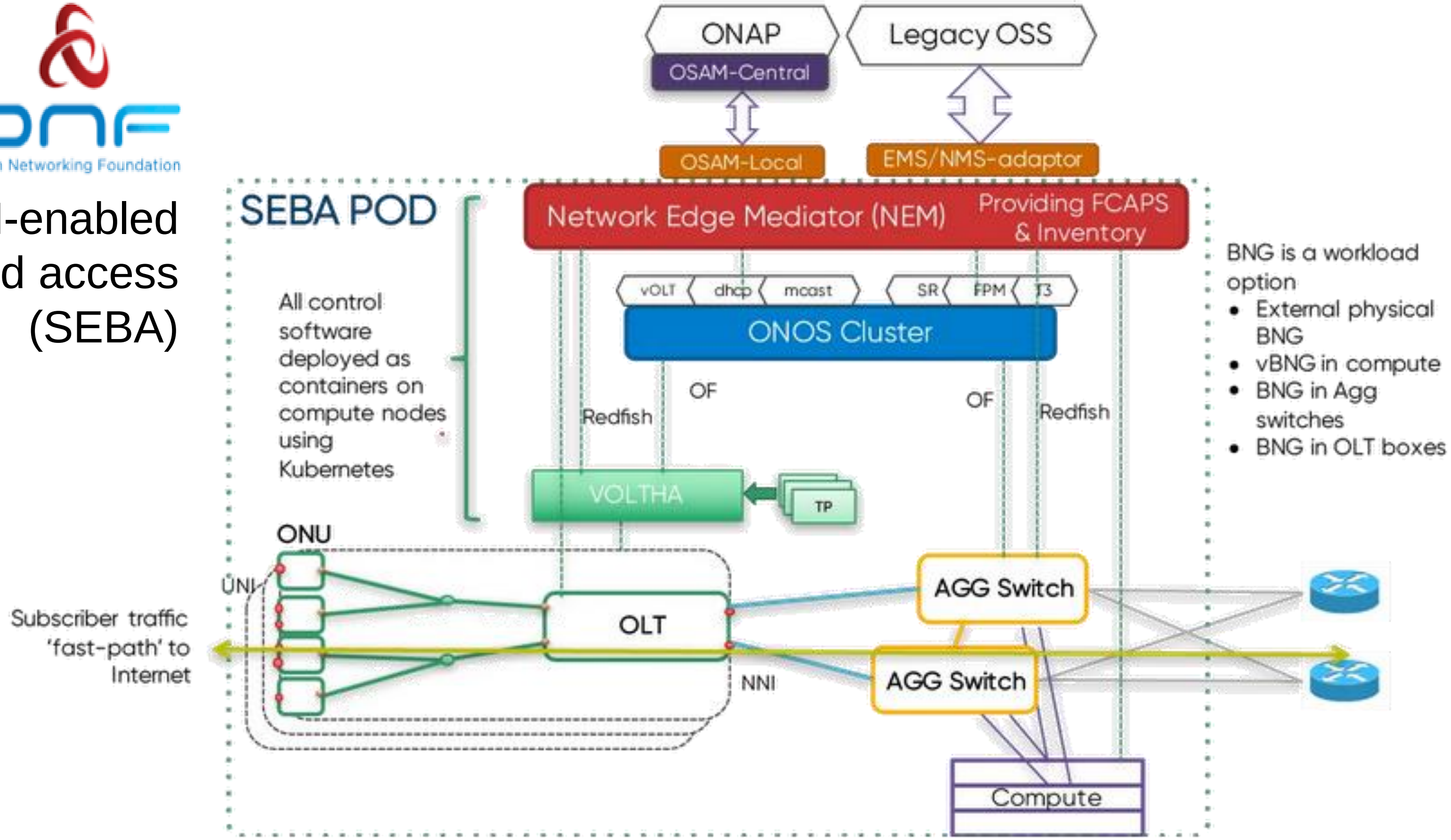
3GPP

ETSI

ITU

https://www.broadband-forum.org/industry-collaboration-with-the-onf-unlocks-open-source-potential
https://tools.ietf.org/id/draft-nsdt-teas-transport-slice-definition-00.html

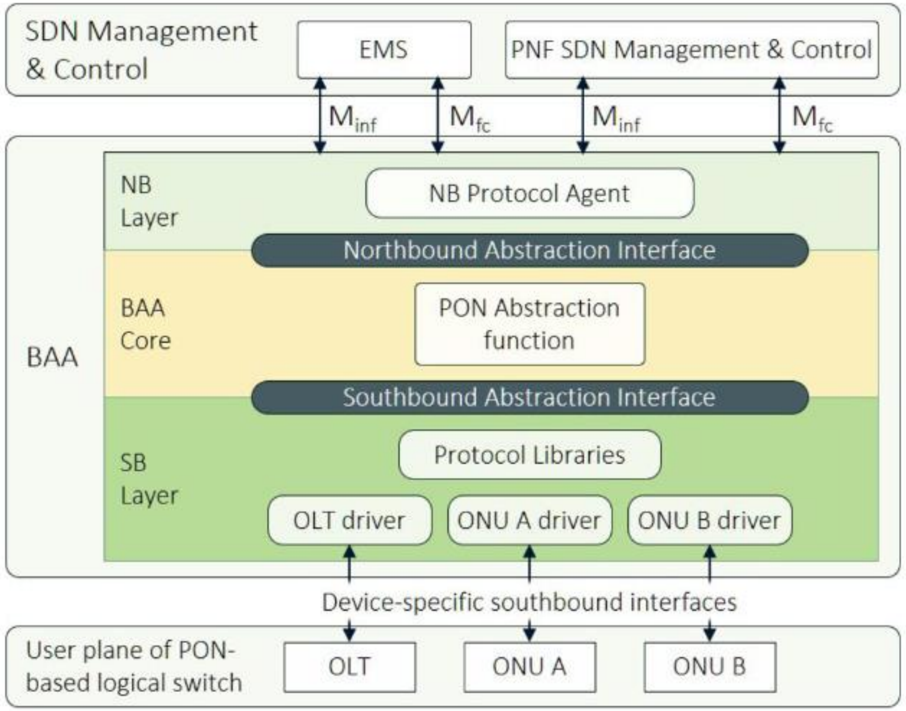
SDN-enabled broadband access (SEBA)

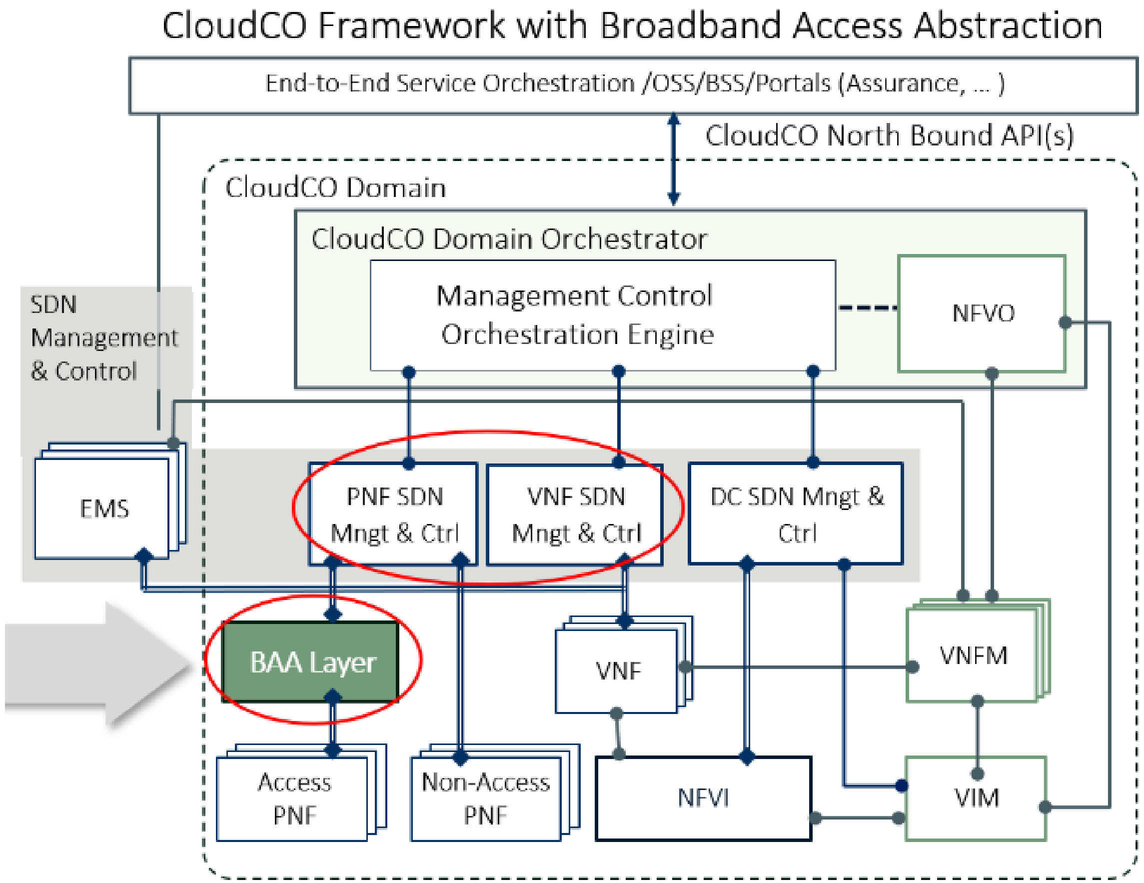


https://opennetworking.org/seba/

VIRTUALIZATION IN THE OPTICAL ACCESS

CloudCO architecture





https://www.broadband-forum.org/download/OB-BAA-002.pdf
https://opennetworking.org/wp-content/uploads/2020/07/Burak-Gorkemli-2020-Broadband-Spotlight-Slide-Deck.pdf

04.

STIC-AMSUD RAMONaaS

RESOURCE **A**LLOCATION **M**ETHODS FOR **O**PTICAL **N**ETWORKS **as a S**ERVICE

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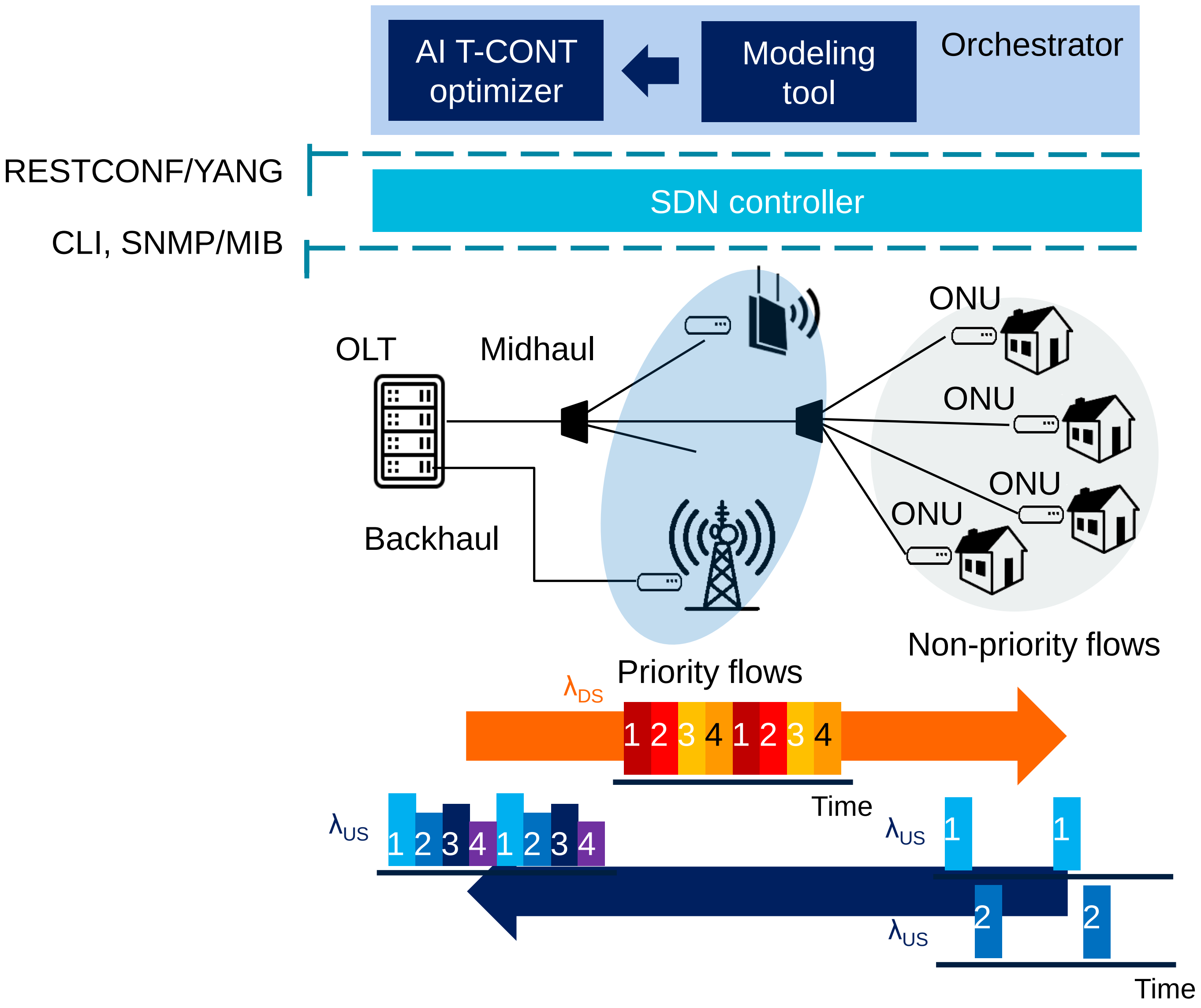
STIC-AMSUD RAMONaaS

Fixed-mobile convergence

- Objective
  - Fixed-mobile convergence with point-to-multipoint PON with both fixed and mobile access clients
  - Optimization of dynamic bandwidth allocation parameters according to network load
- Slicing in the optical access
- IA framework to predict network load and choose optimal T-CONT parameters associated to different services and ONUs

Fine-tune PON bandwidth allocation and change network parameters according to network load so that mobile flows can be prioritized



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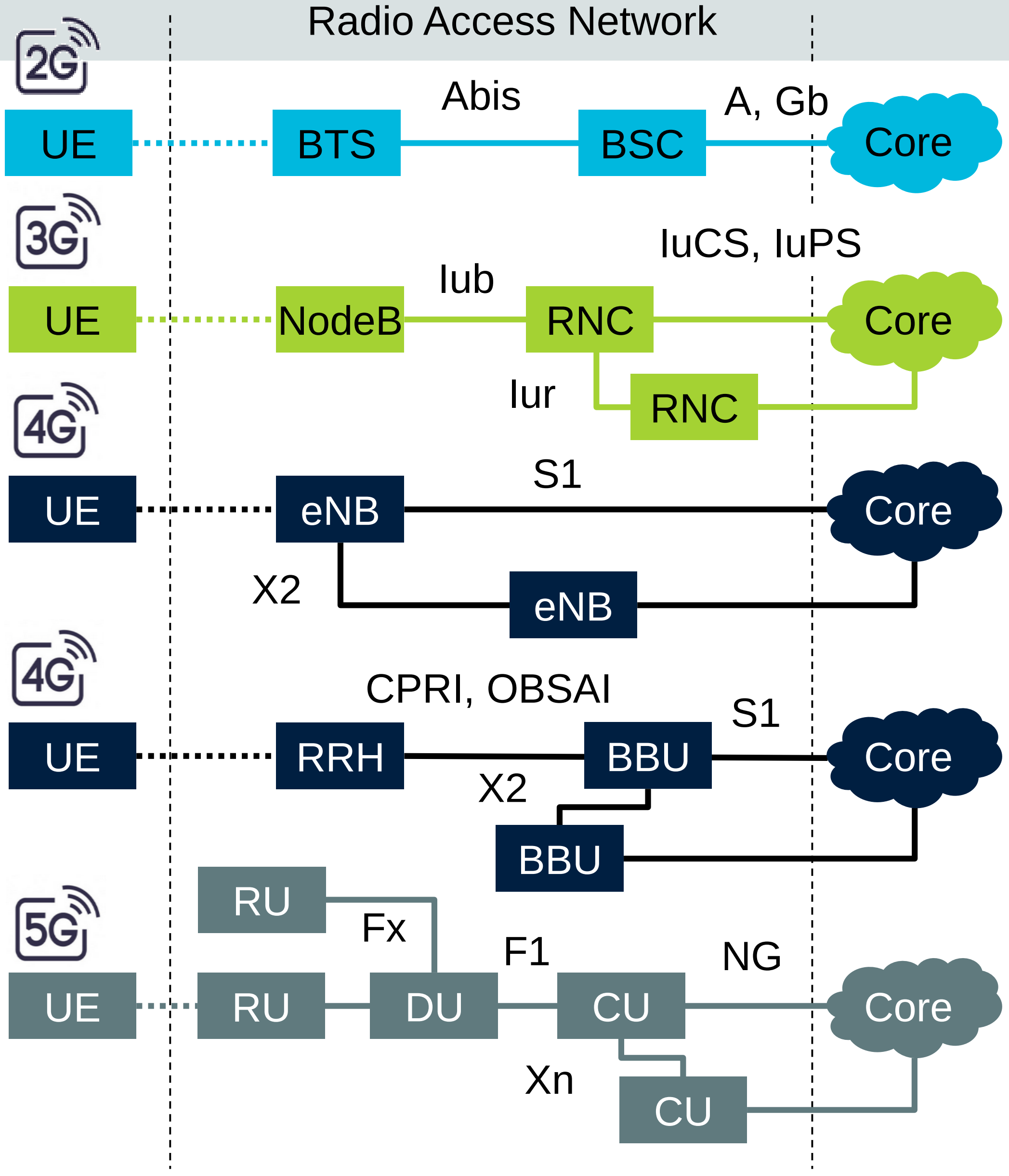
Evolution of RAN Equipment

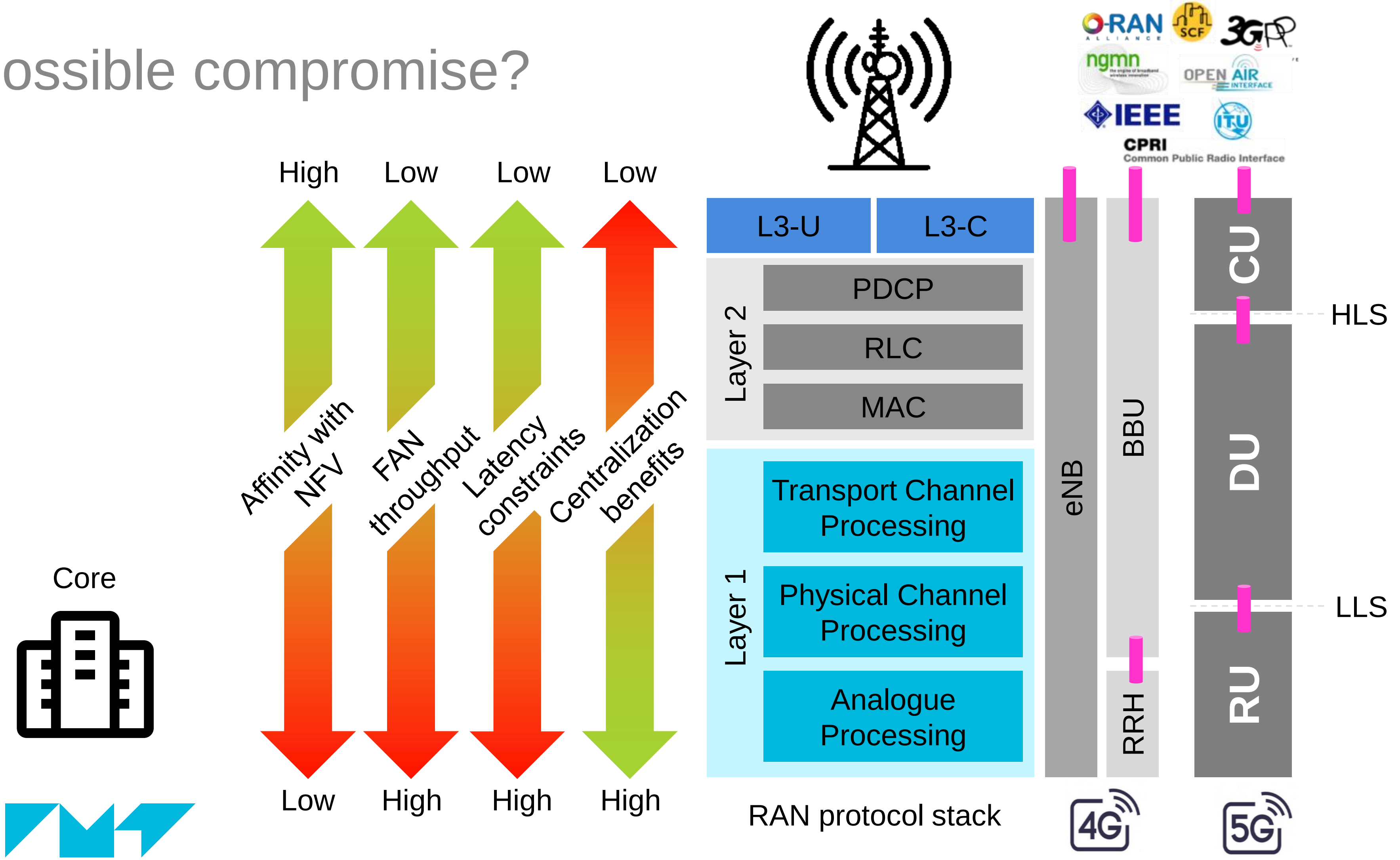
Wavering RAN topologies

- 2G, 3G: more centralized
- 4G: all-in-one RAN stack (eNB), distributed topology (D-RAN)
- 4G + low-cost optical transceivers = centralized topology (C-RAN), BBU + RRH, fronthaul
- 5G: compromise between centralization benefits and needs of latency and bit-rate of optical interface

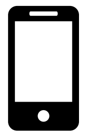


BBU: Baseband Unit
BSC: Base Station Controller
BTS: Base Transceiver Station
CPRI: Common Public Radio Interface
CU: Centralized Unit
DU: Distributed Unit
eNB: Evolved Node B
OBSAI: Open Base Station Architecture Initiative
RNC: Radio Network Controller
RRH: Remote Radio Head
RU: Radio Unit
UE: User Equipment

Possible compromise?



3GPP option 2
eCPRI option B
V1 (4G)/F1 (5G)
6-20% higher throughput than backhaul and relaxed latency constraints
Native Ethernet



3GPP options 7
eCPRI options I_D, II_D, O-RAN option 7.2x, lower throughput than CPRI but tight latency constraints.
Time-sensitive Ethernet

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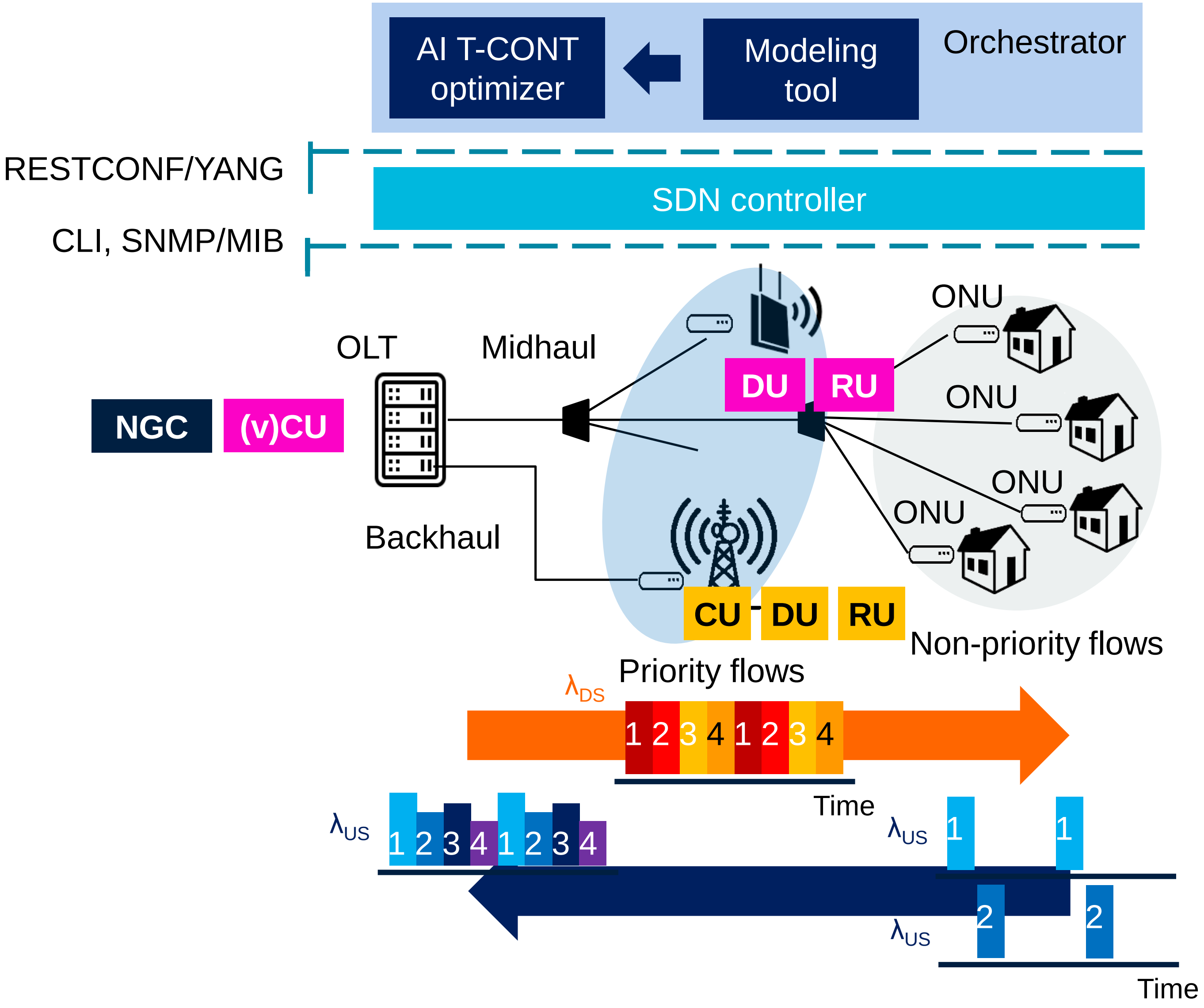
Fixed-mobile convergence

- Objective
  - Fixed-mobile convergence with point-to-multipoint PON with both fixed and mobile access clients
  - Optimization of dynamic bandwidth allocation parameters according to network load
- Slicing in the optical access
- IA framework to predict network load and choose optimal T-CONT parameters associated to different services and ONUs

Fine-tune PON bandwidth allocation and change network parameters according to network load so that mobile flows can be prioritized



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Time scales in communication

RAMONaaS

Transfer Plane	Control Plane	Management Plane
Congestion resolution	Admission Control	Network Dimensioning
Packet multiplexing	Connection	Equipment setup
RTT	Flow switching	Link leasing
…	…	…

µs ms s h day week month

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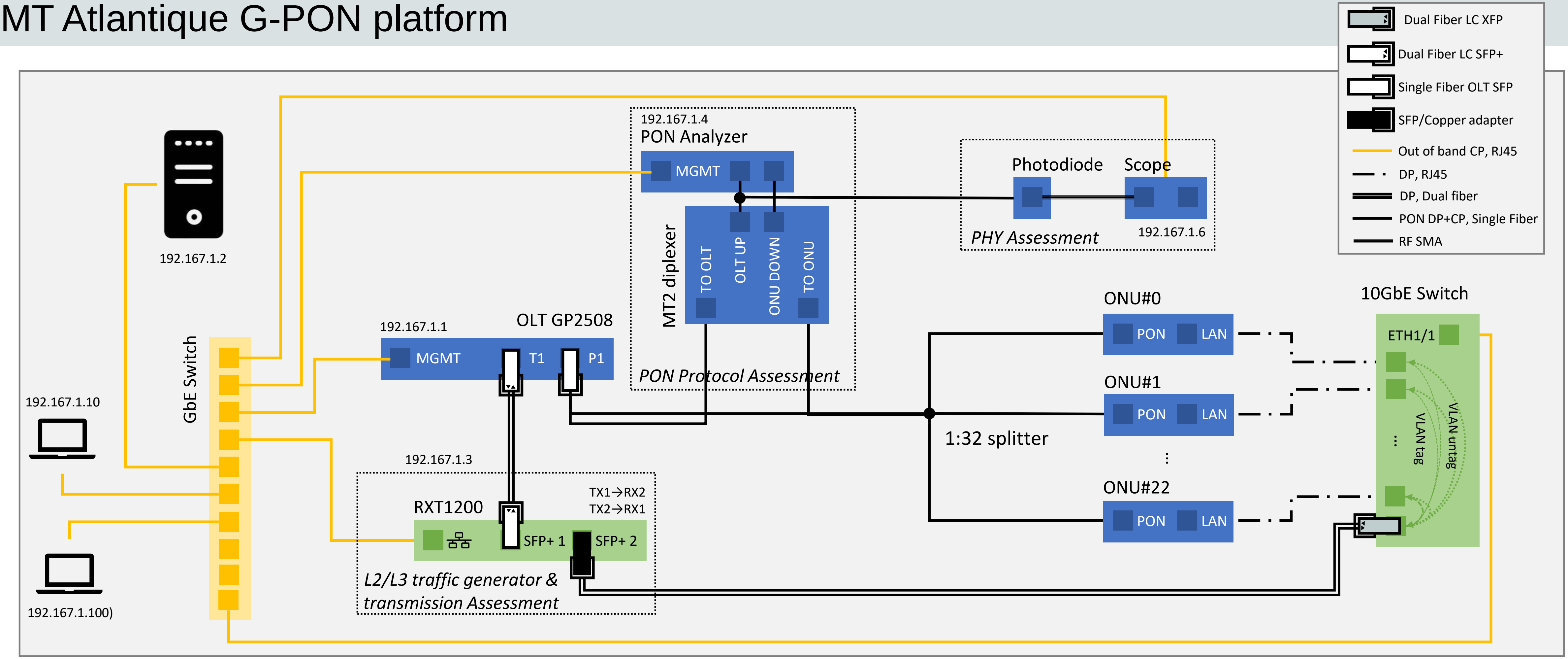
IMT Atlantique G-PON platform



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FTTH test bench

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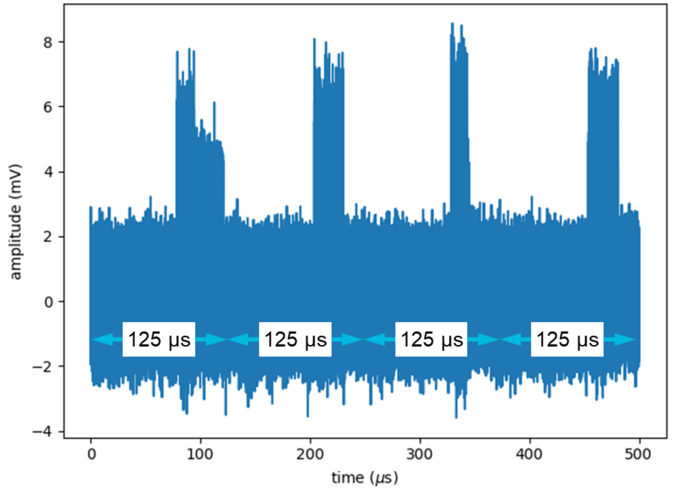
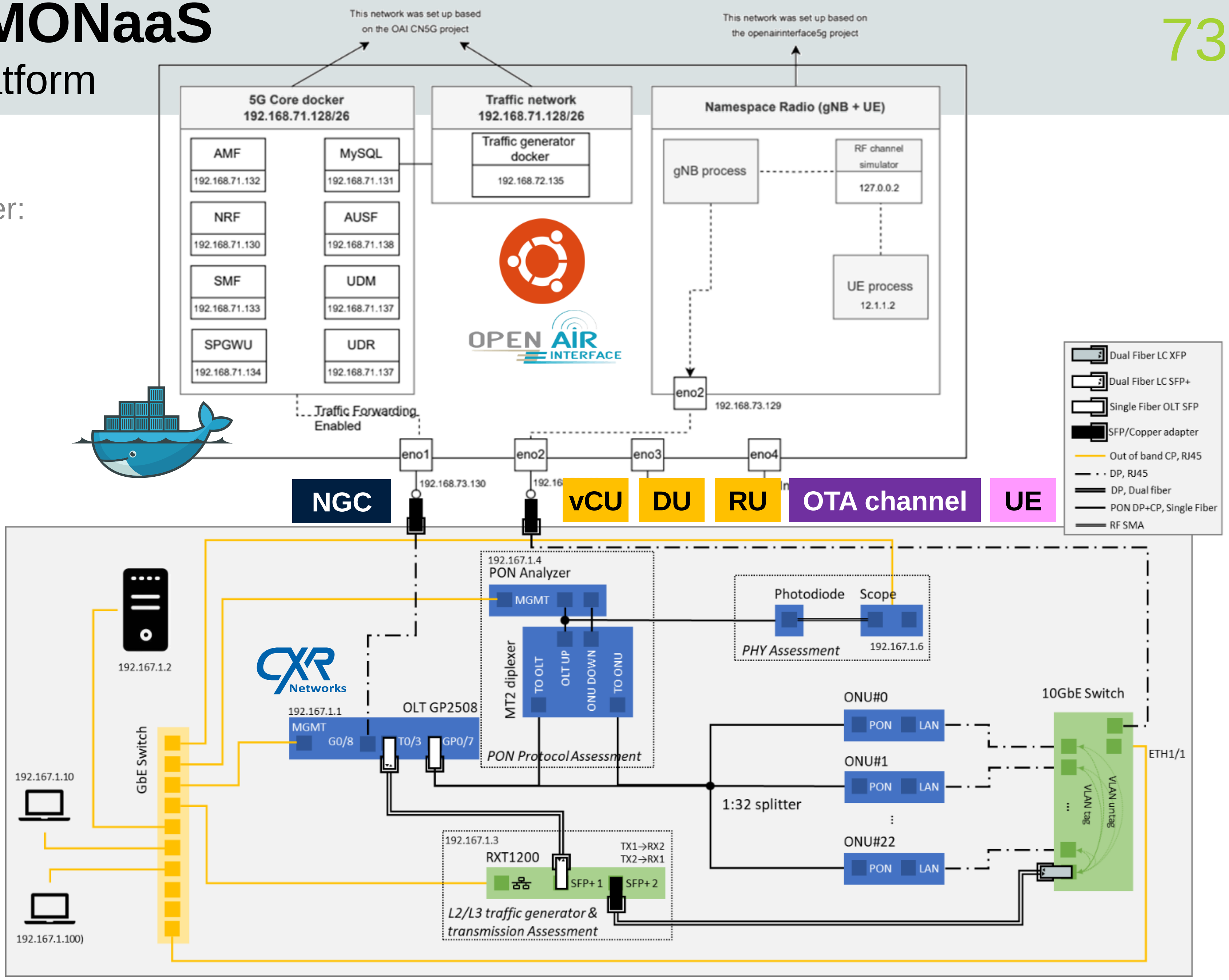
IMT Atlantique G-PON platform

- Ethernet traffic generator/analyzer: only for fixed PON clients
- Server: mobile backhaul traffic generator





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FTTH + FTTA
test bench

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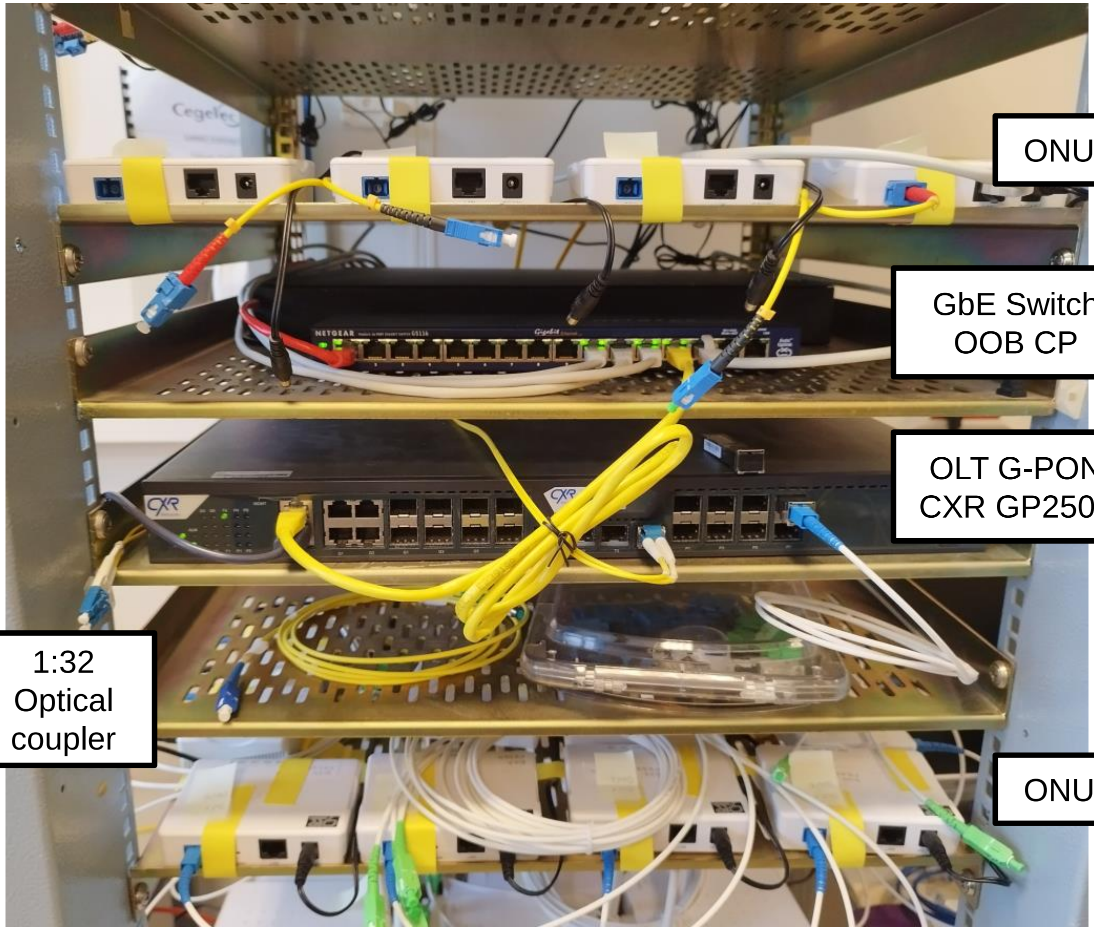
IMT Atlantique G-PON platform



Ethernet frame generator & analyzer
VeEX RXT-1200

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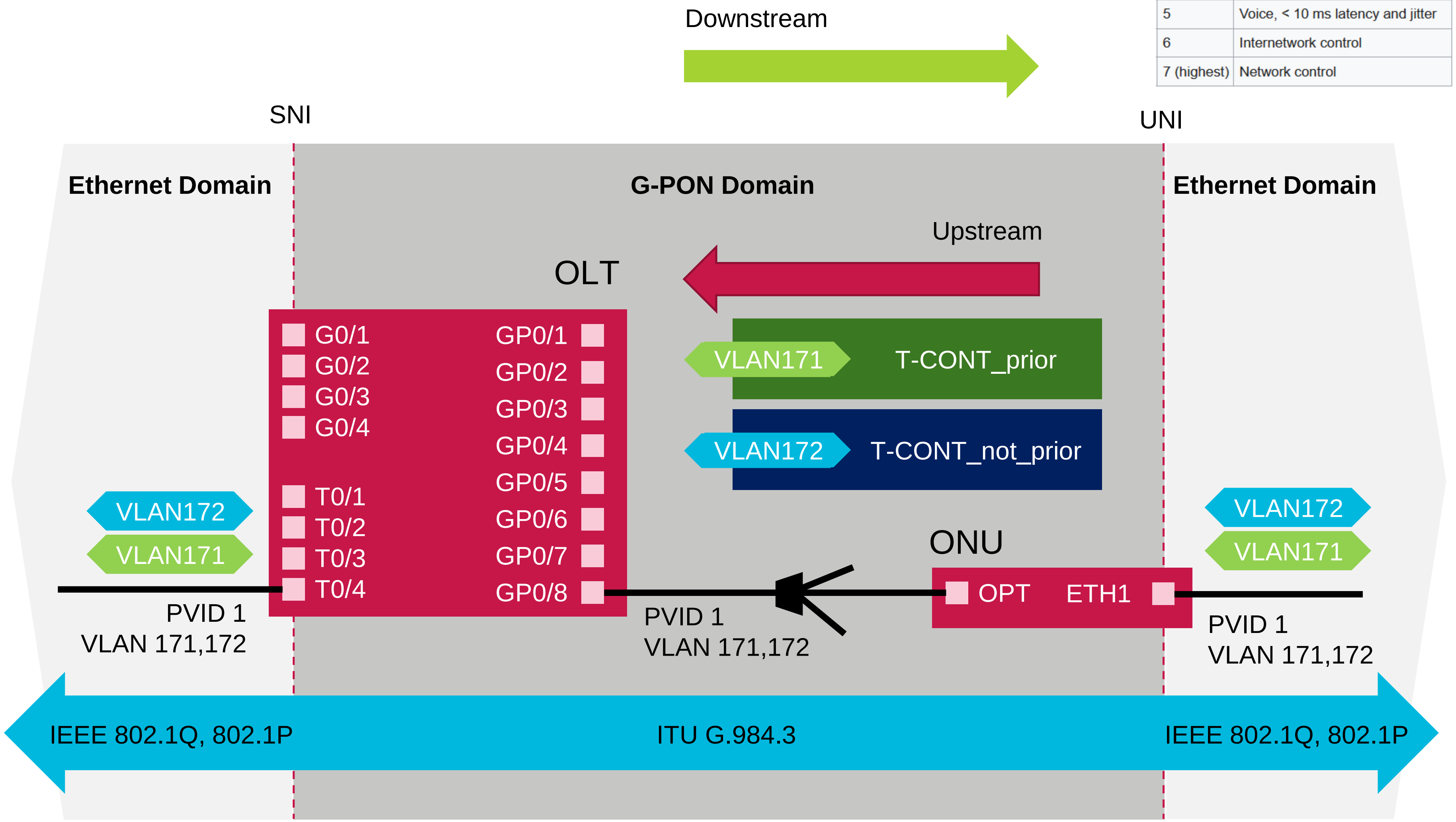
G-PON platform configuration

Priority	Traffic types
0 (lowest)	Background
1 (default)	Best effort
2	Excellent effort
3	Critical applications
4	Video, < 100 ms latency and jitter
5	Voice, < 10 ms latency and jitter
6	Internetwork control
7 (highest)	Network control

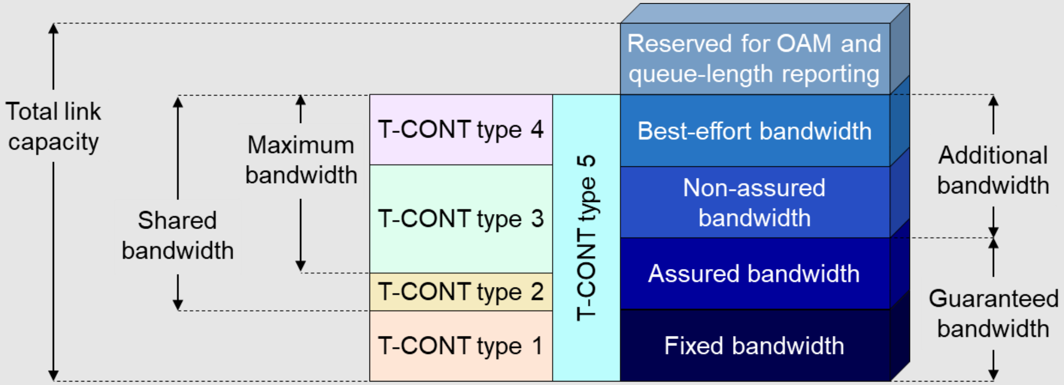


Possible scenarios

Congestion	FTTA (priority)	FTTH (non-priority)
No congestion (< 30% cap.)	T-CONT 3	T-CONT 3
Moderate (30% − 60% cap.)	T-CONT 3	T-CONT 2
Severe (> 60% cap.)	T-CONT 3	T-CONT 4

Simple example scenario

- If all ONUs and services have a type 1 T-CONT, deterministic scheduling
- Optimization
  - Vary number of ONUs and network load
  - Find FIR, CIR and PIR that minimize latency/packet jitter for priority flows/ONUs



T-CONT type	Type 1	Type 2	Type 3	Type 4	Type 5
Fixed bandwidth	FIR				FIR
Assured bandwidth		CIR	CIR		CIR
Maximum bandwidth	PIR=FIR	PIR=CIR	PIR>CIR	PIR	PIR≥CIR+FIR

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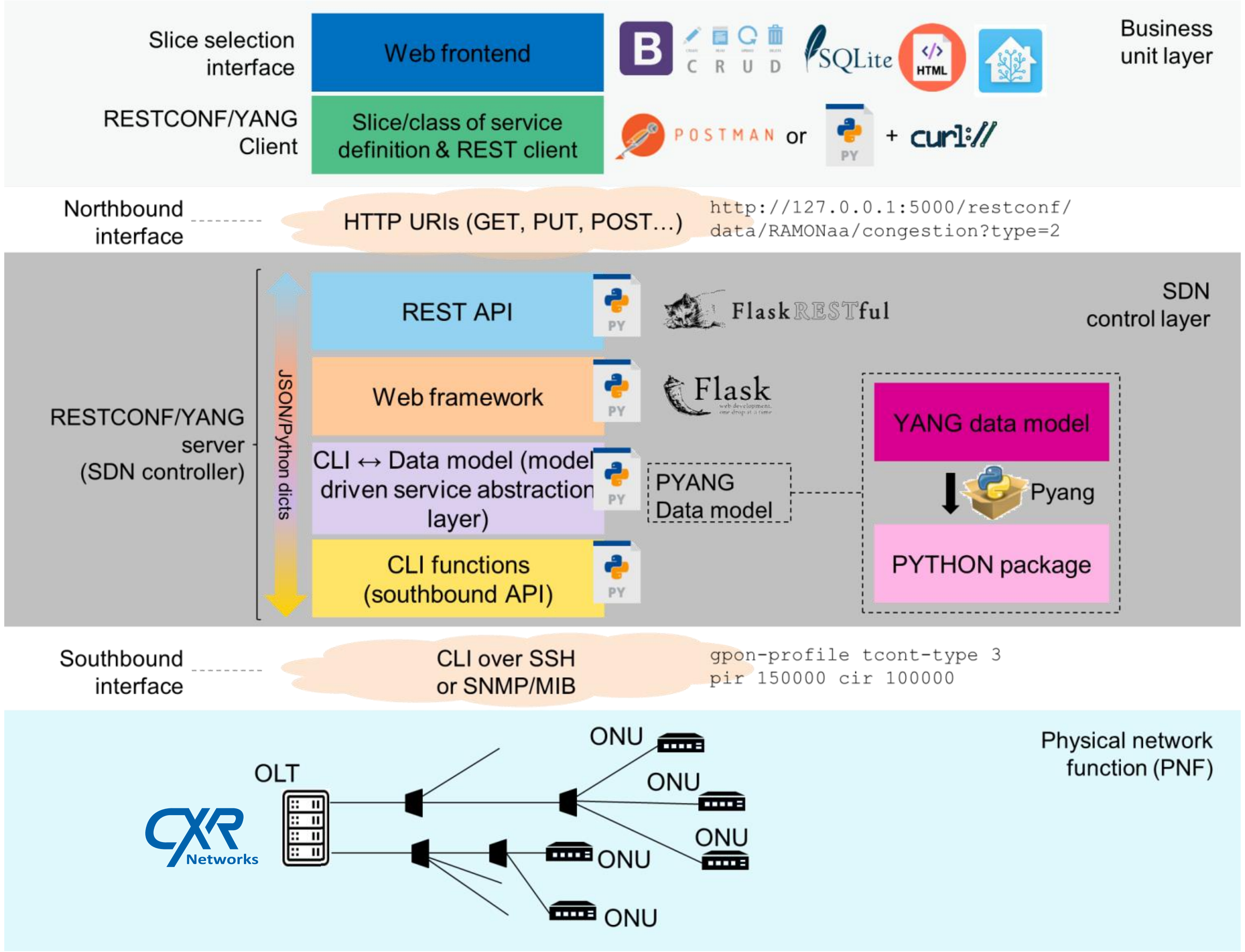
SDN controller, homemade solution

Initial solution, DIY. Simple to implement, mostly based on Python

Could evolve to an architecture closer to ONF's SEBA with VOLTHA and ONOS SDN controller

BBF CloudCO: too complex, outside the scope of the project



Future: Comm. with mobile scheduler

Merci!

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We’re hiring!

Postdoc position in the PEPR (Programmes et Equipements Prioritaires de Recherche) 5G Photonique