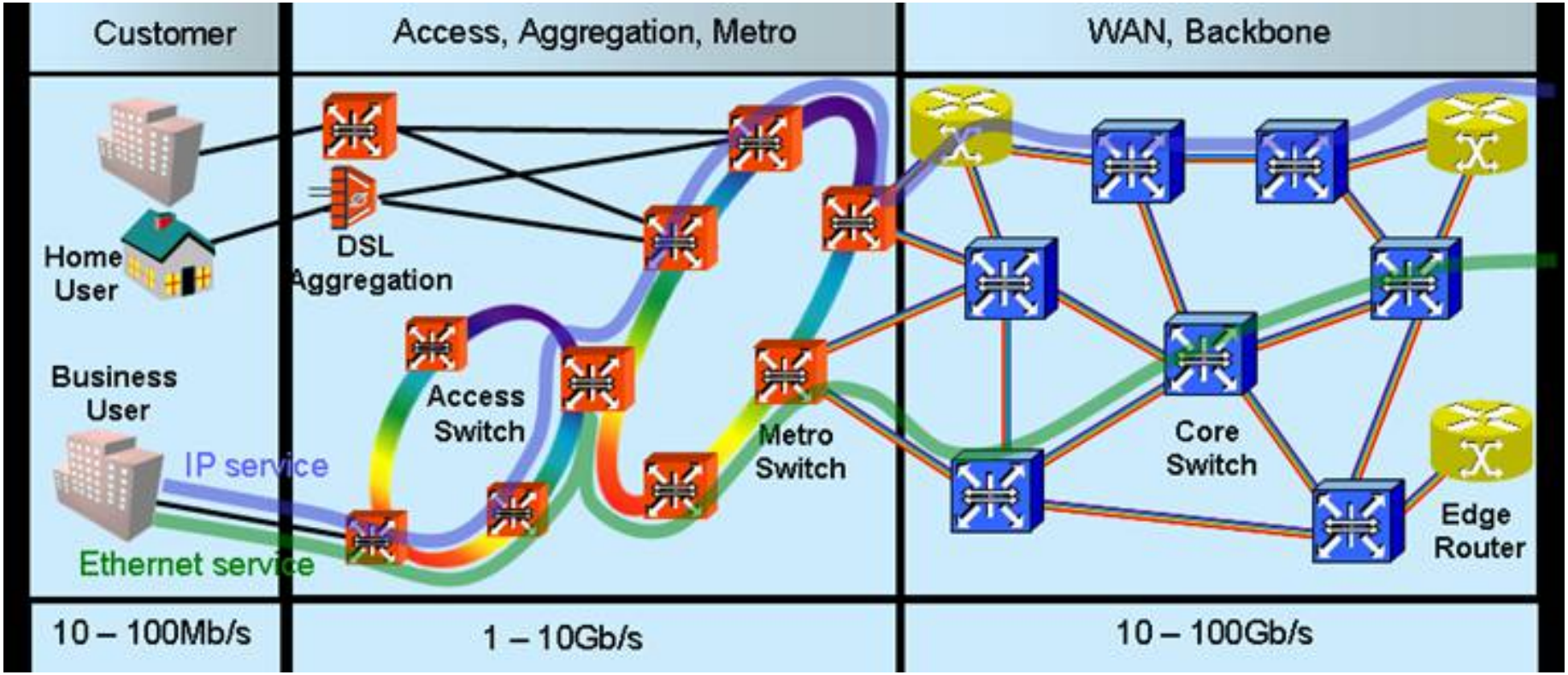
Passive Optical Networks (PONs)

A. Kirstädter, November 27, 2006

SIEMENS

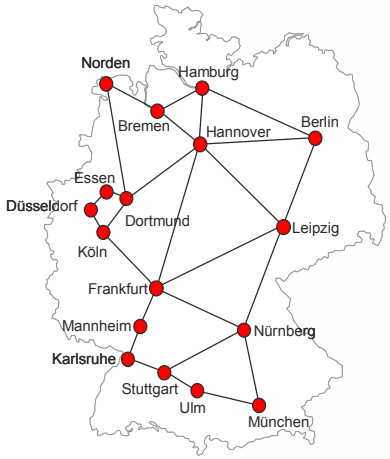
Content

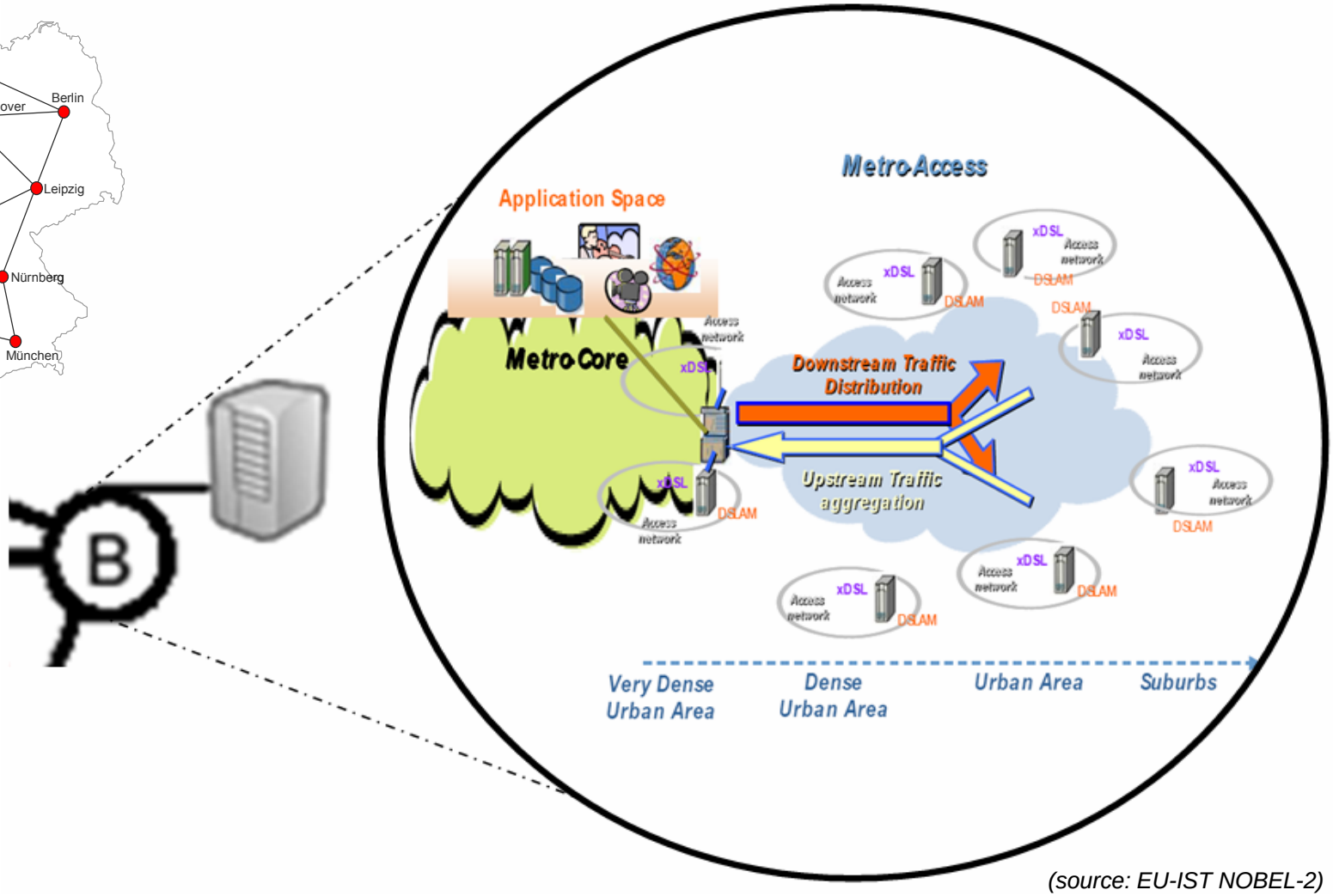
Networks in WAN / Metro / Access



(source: Photonik 2/2006)

Metro and Access

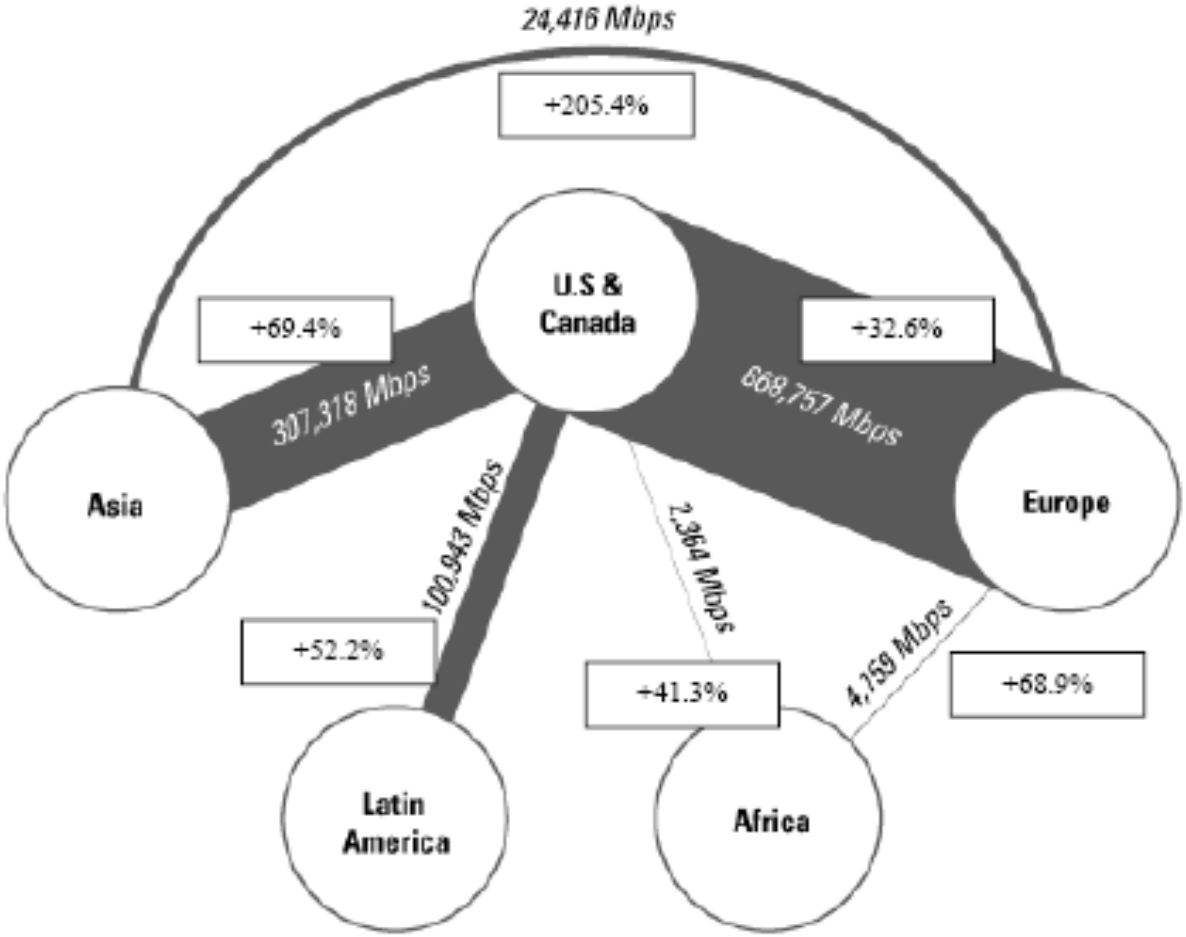




(source: EU-IST NOBEL-2)

Explosive Bandwidth Demand Growth

Interregional Internet Bandwidth, mid-2005 (with half-year growth rates)



(source: DAIWA Institute of Research)

New Applications Drive New Bandwidth Hype

Some Examples:

• **Video Instant Messaging:** MSN Messenger alone, with 26m concurrent users (over 3x that of Skype's peak usage level), had logged 1.1bn minutes of video chat in January.

• **Mass Gaming**: E.g., a study on gaming by the BBC in December 2005 determined that 22.7m Britons aged 11 – 65 play video games of some sort, and 8% of these engage in massively multiplayer online role playing games MMORPGs
➔ around 1.8m MMORPG players in the UK alone

• **Virtual Communities:** „Second Life", „Hive7", …

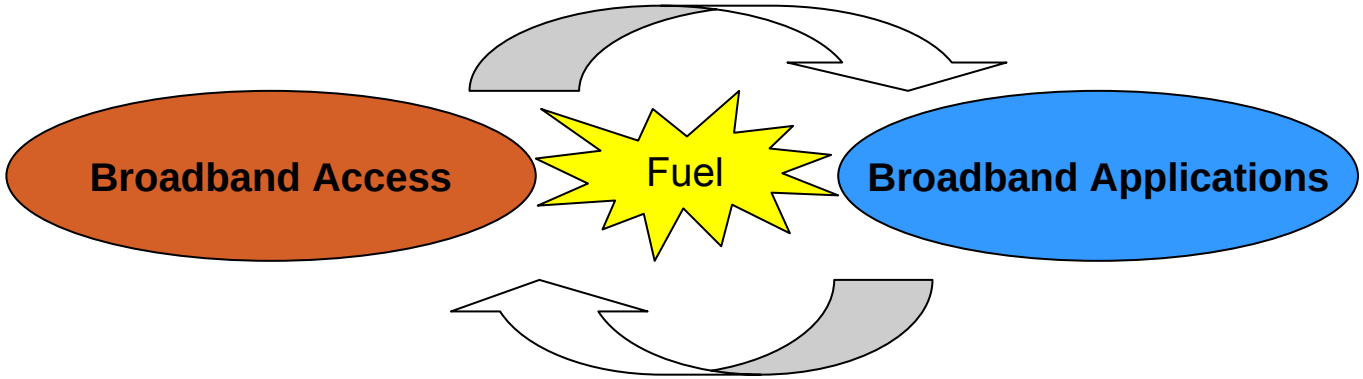
• **Blogging, photosharing, and user generated content:**
- in February, 2005, blog-tracking company Technorati claimed to track 6.9m blogs
- popular site Flickr! now hosting over 120m images and adding 500k images per day

• **Video search and streaming**: YouTube…

• **P2P file sharing**

• ….

„So, what‘s happening there?“



Separation of Services and Infrastructure:

Applications and content move to network borders, to the users.

Content

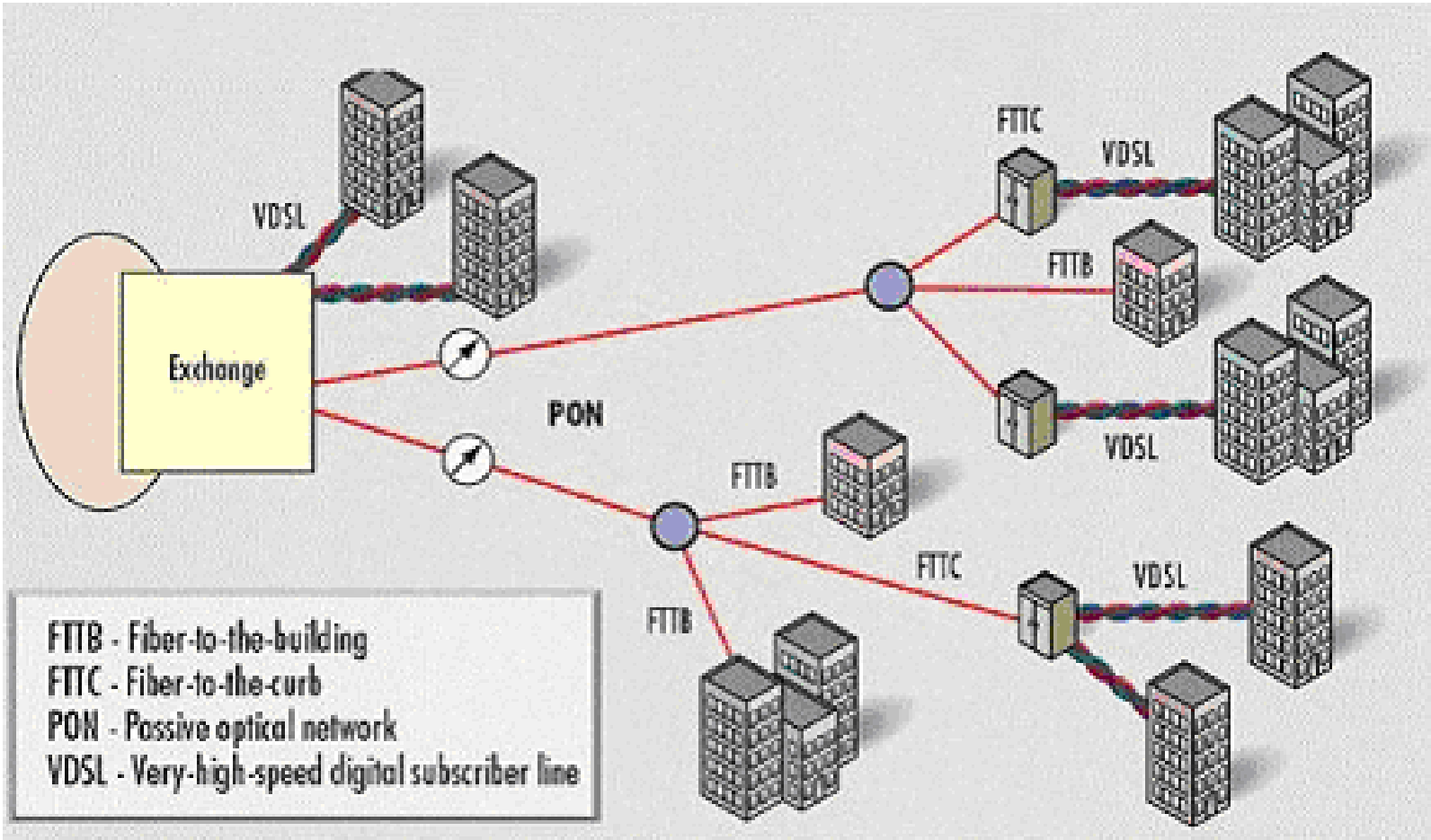
- Introduction
- Generic PON Architecture
- Fiber vs. Copper
- Today's PONs
- Market Perspectives
- Future PON Architectures

Future Bandwidth Requirements

Application	Downstream requirement	Upstream requirement
HDTV (3 per home at 20 Mbit/s each) Standard TV = 4.5Mbit/s	60 Mbit/s	<1 Mbit/s
Online gaming	2-20 Mbit/s	2-20 Mbit/s
VoIP Telephone (3 per home at 100kbit/s)	0.3 Mbit/s	0.3 Mbit/s
Data/ Email etc	10 Mbit/s	10 Mbit/s
DVD download for rental Assume download must take <10 mins i.e. the time to get one from a rental store	14 Mbit/s	<1 Mbit/s
Total	~100 Mbit/s	~30 Mbit/s

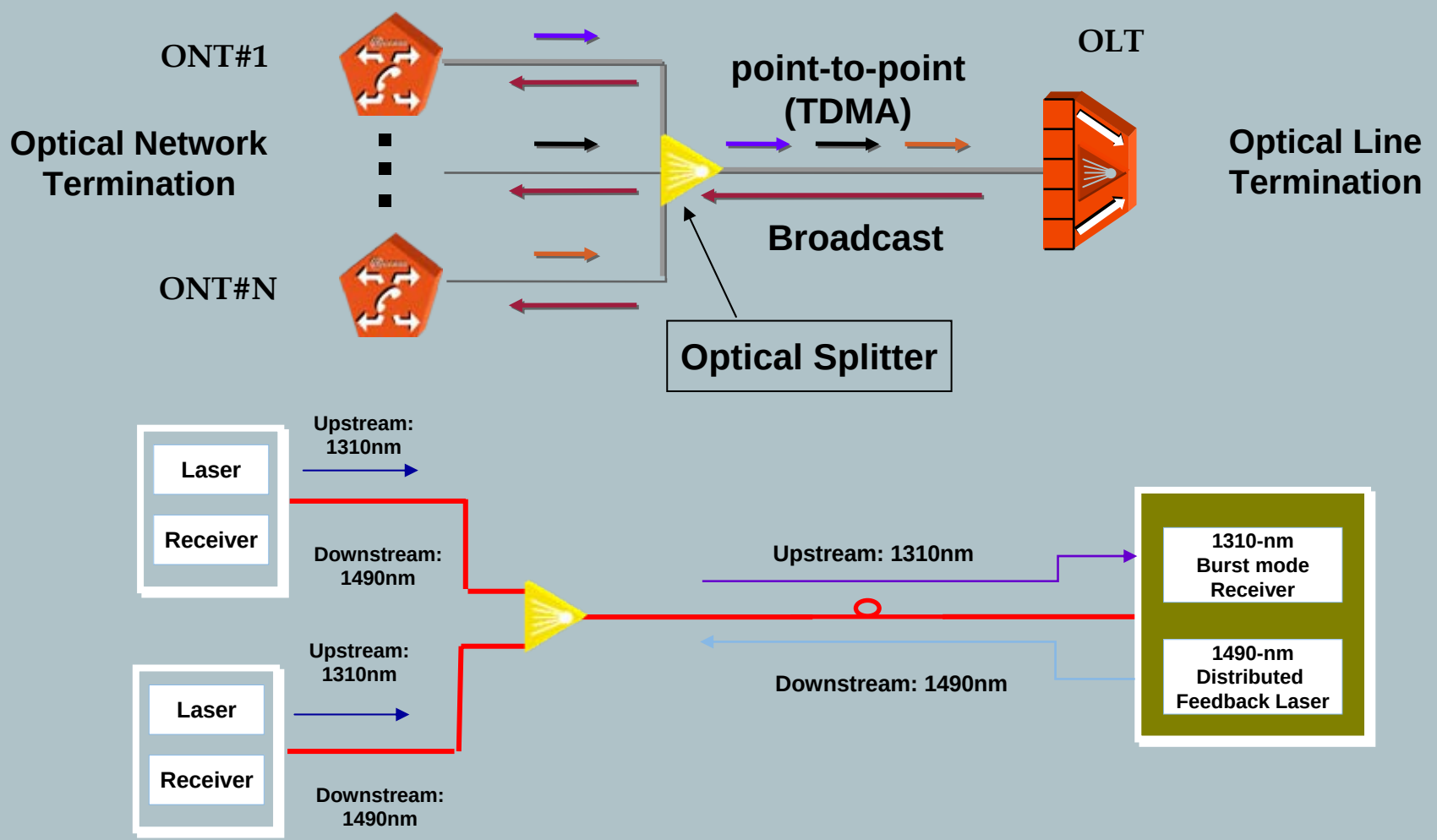
(Source: EU-IST MUSE)

PON Deployment Scenarios



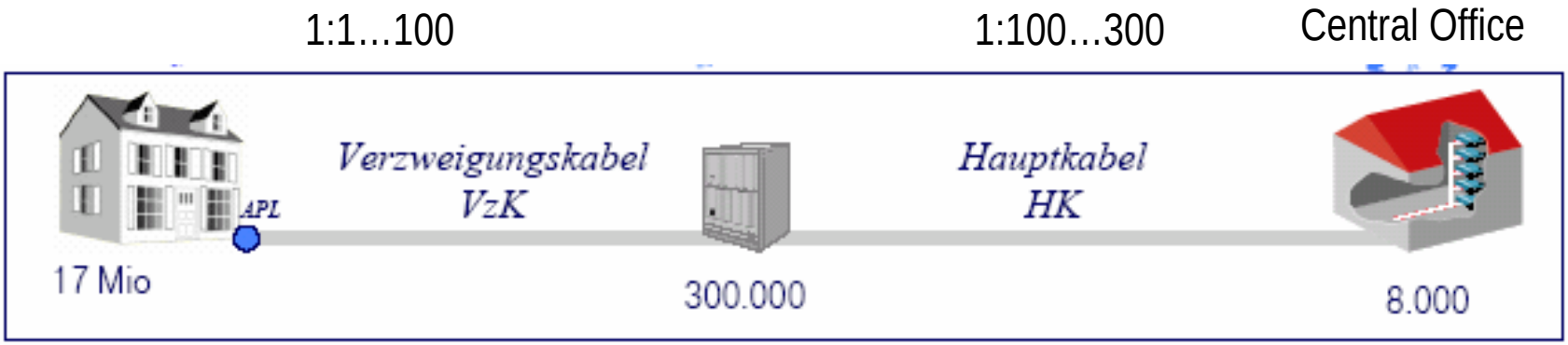
(Source: PON Forum)

xPON Operation



Content

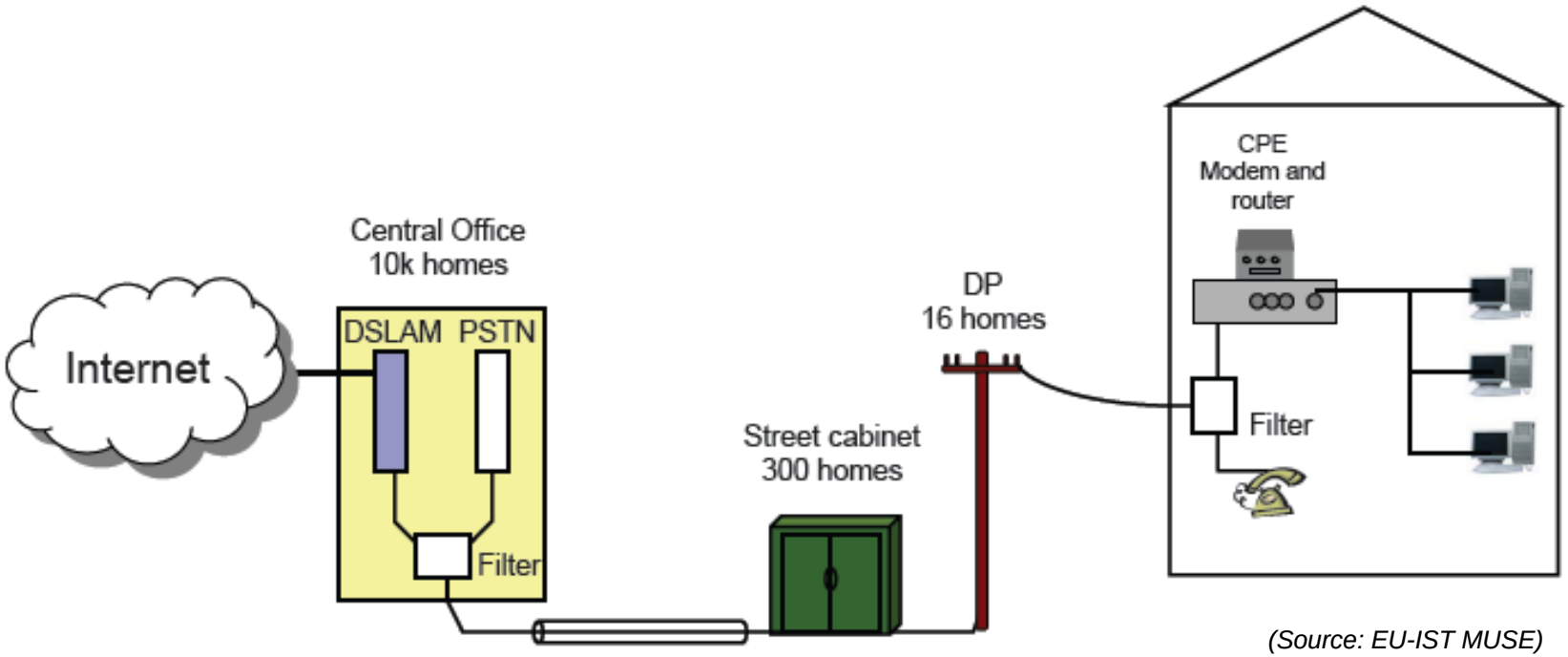
Current Access Network



Cabinet / Kabelverzweiger (KVz)

(Source: T-Systems, Oct. 2005)

DSL LAN wiring configuration



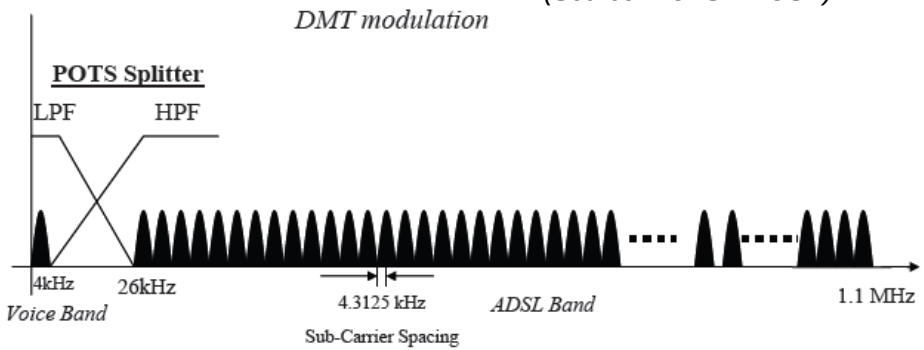
(Source: EU-IST MUSE)

DSL - Impairments

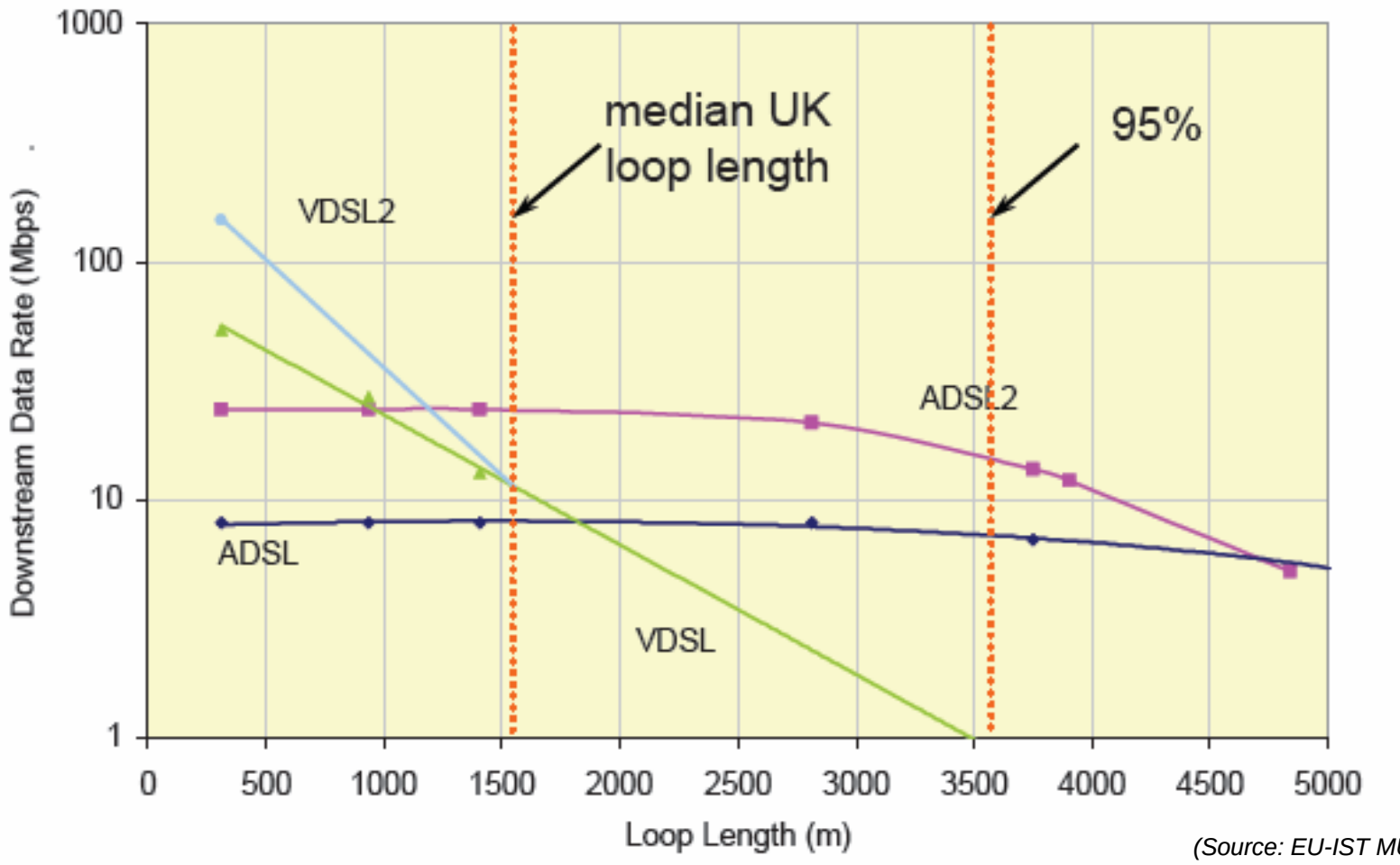
- **Noise**
  - Switches, lighting, power lines, AM broadcasting, Ham radio
- **Crosstalk**
  - NEXT –reflected back to adjacent receiver
  - FEXT –Cross coupling between adjacent wires in binder, attenuated by the line
  - NEXT dominates FEXT where it occurs although reduced for example by non-overlapping DS/US frequency bands
- **Bridged taps**
  - Tap cable not in the direct CPE-CO path, can result in echoes and attenuation glitches
- **Attenuation**…

➔ Discrete Multi-tone Modulation

(Source: EU-IST MUSE)

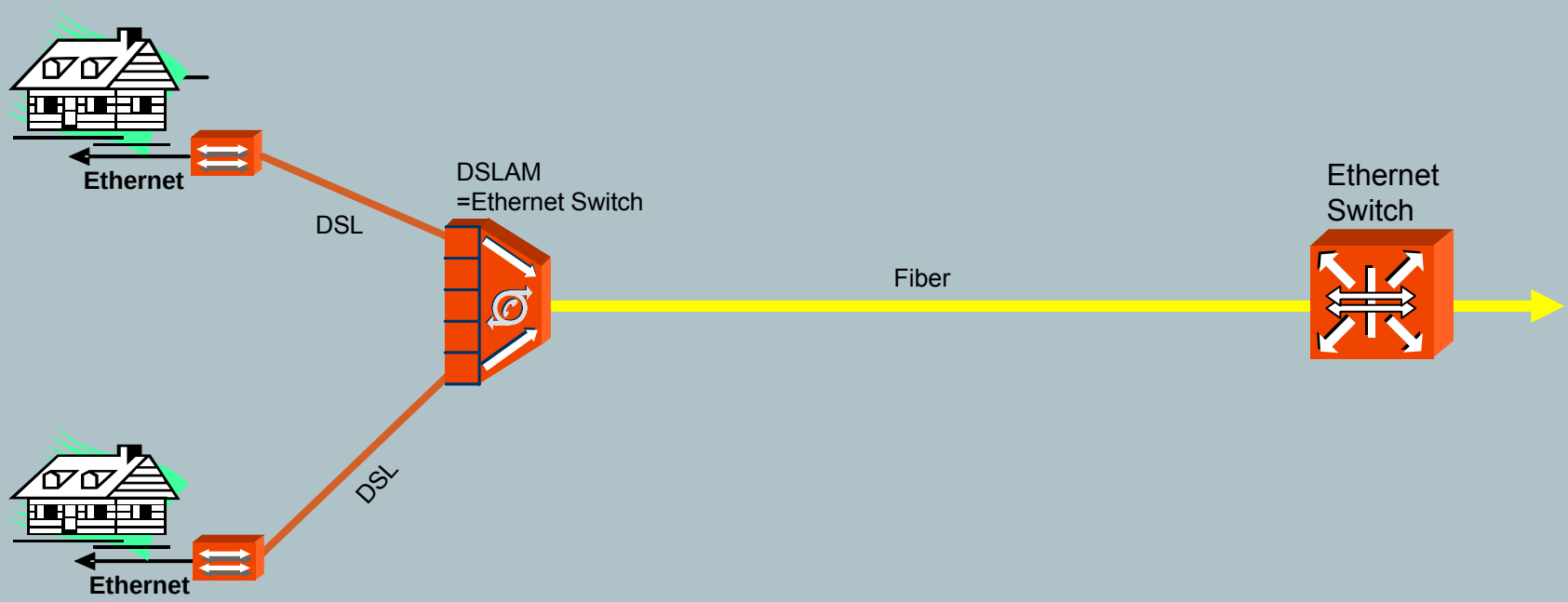


xDSL – Limited Bandwidth-Length Product



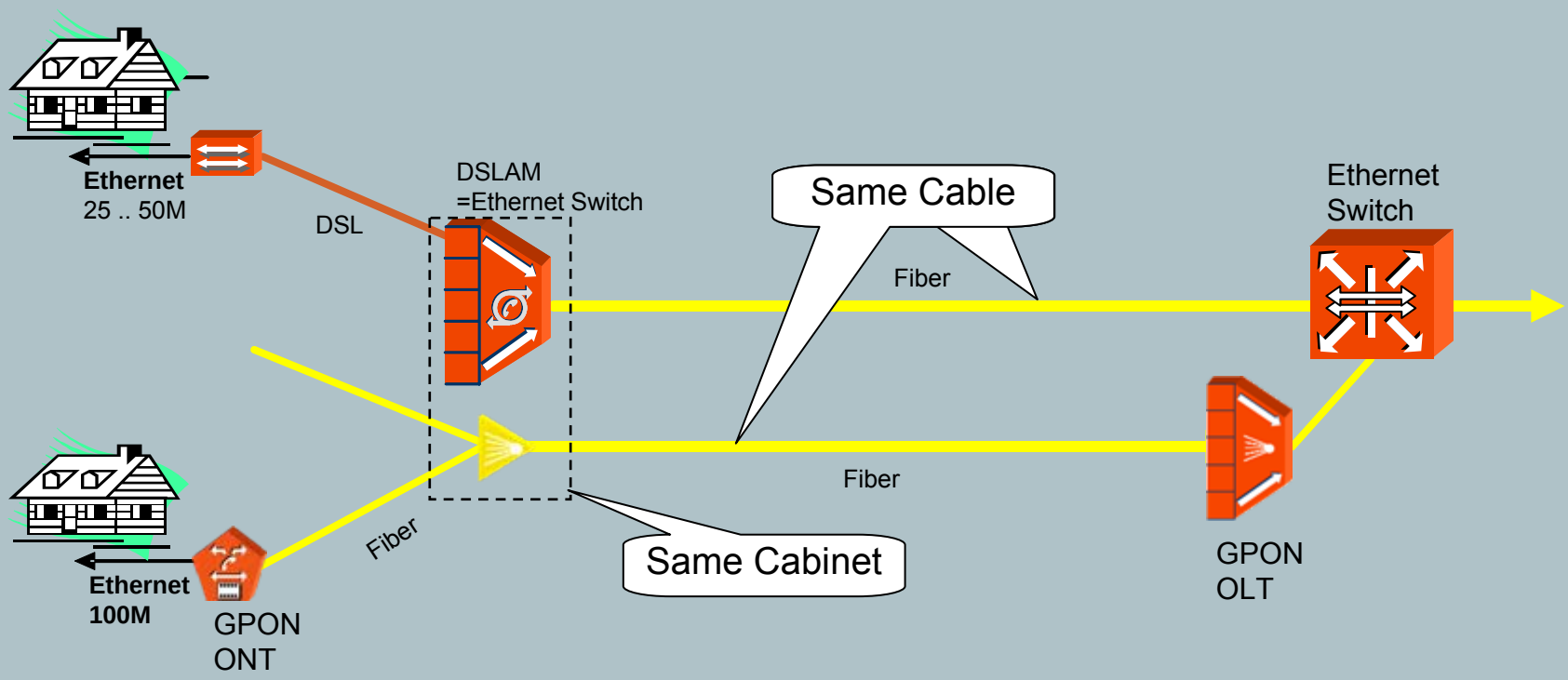
(Source: EU-IST MUSE)

Migration to high-speed Access: Step 1
FttC PtP in 2nd mile, VDSL in 1st mile



25...50 Mbps per subscriber

Migration to high-speed Access: Step 2
GPON FttH Overlay in addition to VDSL deployment



100 Mbps per subscriber

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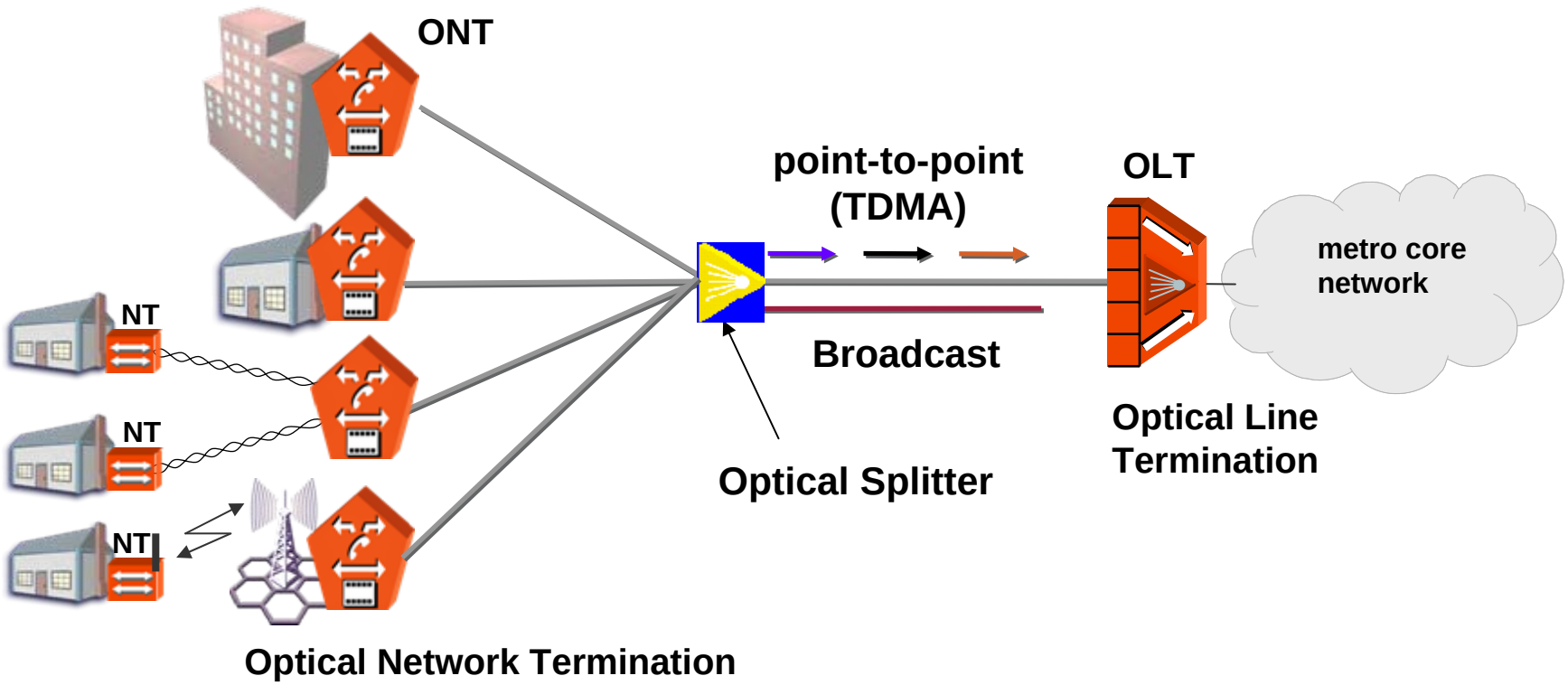
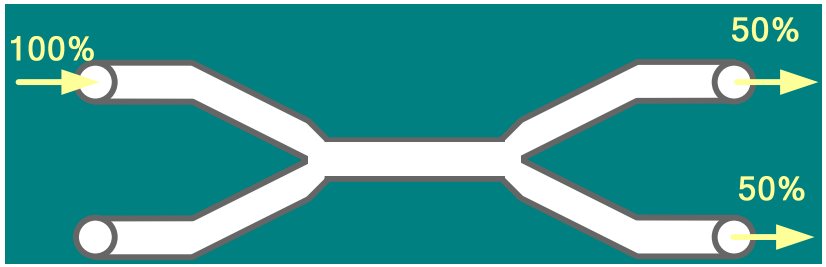
- Future PON Architectures
- Products

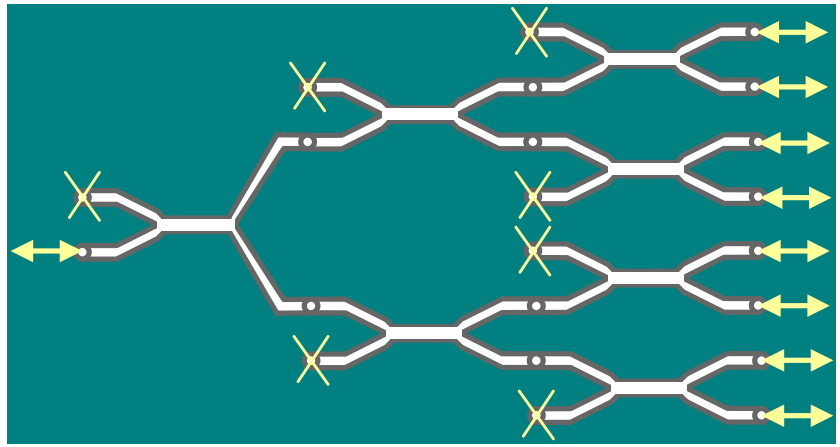
Generic Network Layout

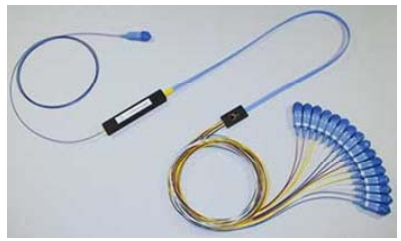


- **OLT –** Optical Line Termination (interfaces to metro core network)
- **Splitter –** wavelength independent passive optical power splitter
- **ONT/ONU –** Optical Network Termination/Unit (fiber termination device at subscriber's home, may integrate connection to set top box, modem etc.)
- **NT** – Network Termination (electrical endpoint at users' premises, e.g. DSL or WiMax/WiFi)

Passive Optical Splitter







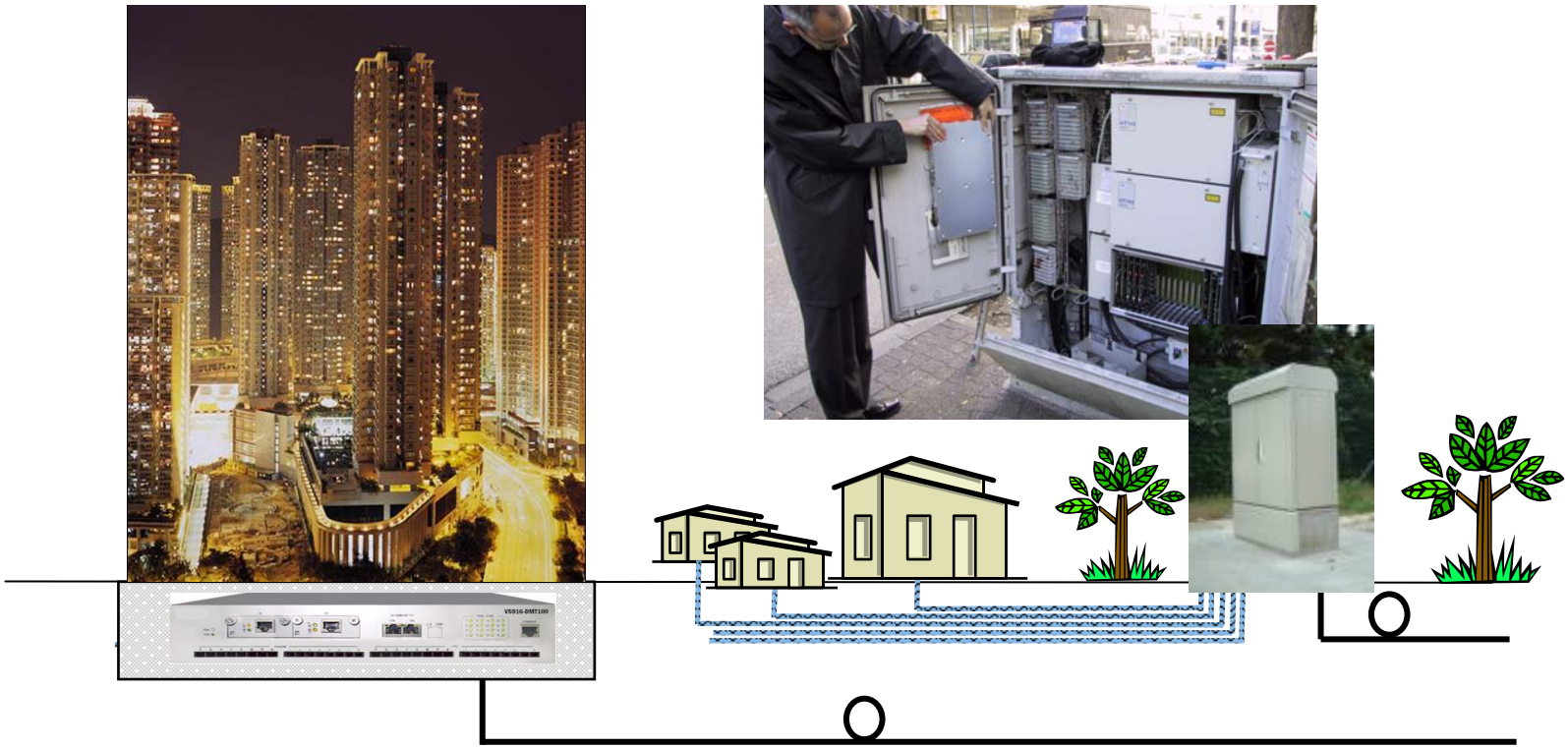
Splitting factor 2^N => Systematic Attenuation = N x 3 dB

(In addition normal, technology dependend insertion loss has to be considered).

Fiber Access Network Architectures : FttH/B and FttN/C

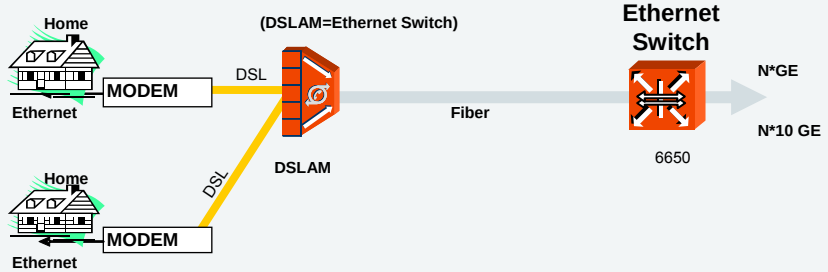
„Fiber to the Home/Building“

„Fiber to the Node/Curb“



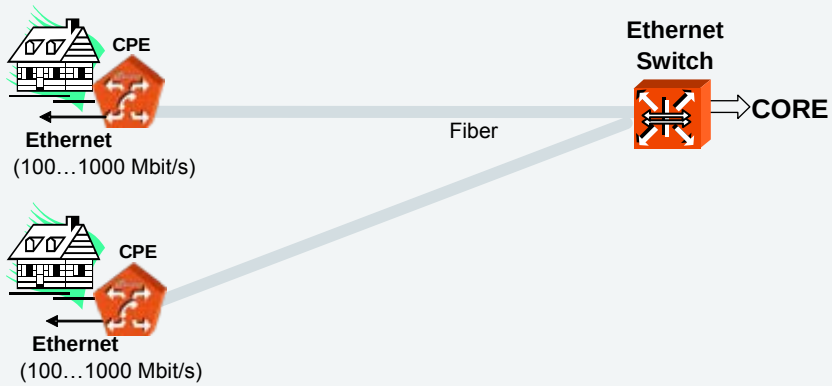
Fiber Access Network Architectures: FttN vs FttH

FTTN



- **Pro:**
  - Reuse of existing copper infrastructure in 1st mile
  - Fiber to the cabinet deployment possible in most cases
  - Sharing of infrastructure (eg ports) in 2nd mile
- **Con:**
  - Active equipment in cabinet (space, power supply, temperature range, maintenance, ..)
  - Limited bandwidth on copper line

FTTH

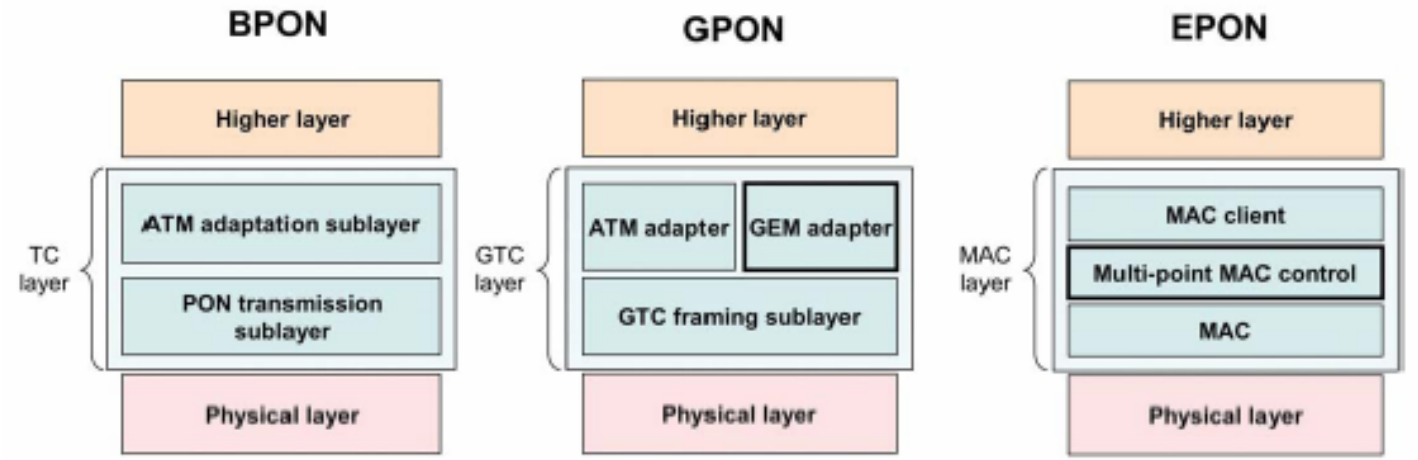


- **Pro:**
  - „Unlimited“ bandwidth per subscriber
  - No active equipment btw subscriber and CO
  - Highest security due to ptp architecture
- **Con:**
  - High-speed fiber optics per subscriber
  - Fiber deployment to subscribers

PON Technologies and Corresponding Standards

There are three main PON technologies standardized within either ITU or IEEE:

- **BPON - Broadband PON (ITU-T G.983, standard based on ATM-PON)**
- **GPON - Gigabit-PON (ITU-T G.984, evolution of BPON (based on ATM or Ethernet)**
- **EPON or GEPON – (Gigabit) Ethernet PON (IEEE 802.3ah)**



- Based on G.983 suite of standards covering all aspects such as physical, management, and control
- BPON maps all traffic to ATM cells
- ATM cells fit into BPON TC frames
- Can use Ethernet uplink

- Based on BPON G.983 and share similar attributes
- Specified as G.984 suite of standards covering all aspects such as physical, management, and control
- In addition to ATM, GEM allows native TDM and Ethernet transport

- Ratified by IEEE as Clause 64 of IEEE 802.3 standard
- Other important aspects are out of the scope of EPON spec

(Source: NORTEL)

Abbreviations:

ATM - Asynchronous Transfer Mode
MAC - Medium Access Control
(G)TC - (GPON) Transmission Convergence

xPON – Variants

	B-PON	E-PON	G-PON
Standardization body	ITU-T	IEEE	ITU-T
First draft of standardization	1995	2000	2002
DS Bit rate	155/622/1244Mbps	1.2Gbps	1.2/2.4Gbps
US Bit rate	155/622Mbps	1.2Gbps	155/622/Mbps 1.2/2.4Gbps
Splitting Factor	32 (64 planned)	Min 16	32-64 (128 planned)
Bandwidth Efficiency			
Payload	ATM cells	Ethernet	ATM or Ethernet (GEM) / TDM
3rd wave length for CATV overlay	Standardized	Not standardized	Standardized
Fiber protection	Standardized	None	Standardized
Down stream security	Churning/AES	None	AES
FEC	None	Standardized	Standardized

(Source: NORTEL)

Ethernet in the First Mile – EPONs, IEEE 802.3ah

Ethernet for subscriber access networks combines:

• Minimal set of extensions to the IEEE 802.3 Media Access Control (MAC) and MAC Control sublayers with

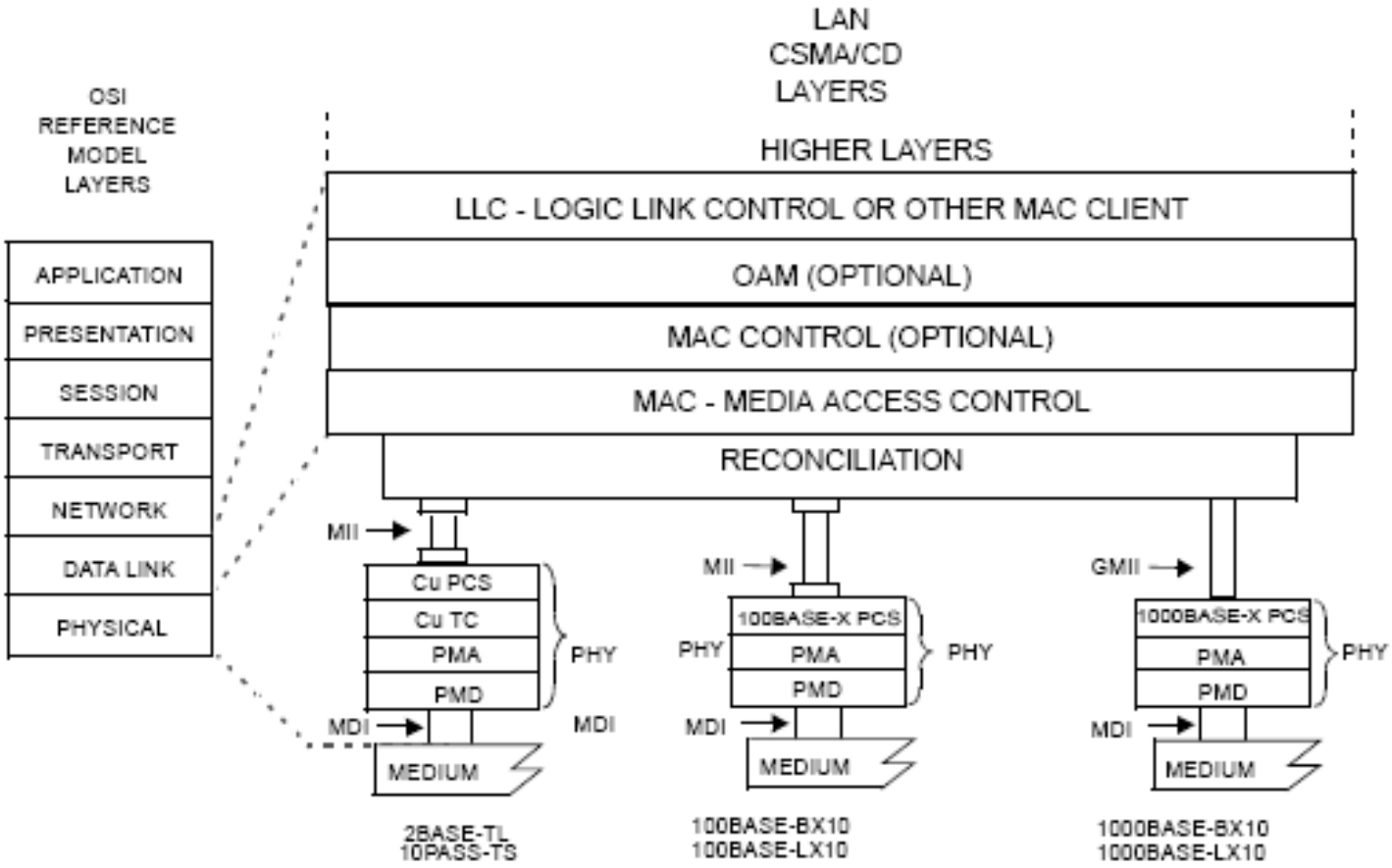
• Family of Physical Layers.

Ethernet Passive Optical Networks (EPONs)

• Point-to-Multipoint (P2MP) network topology is implemented with passive optical splitters

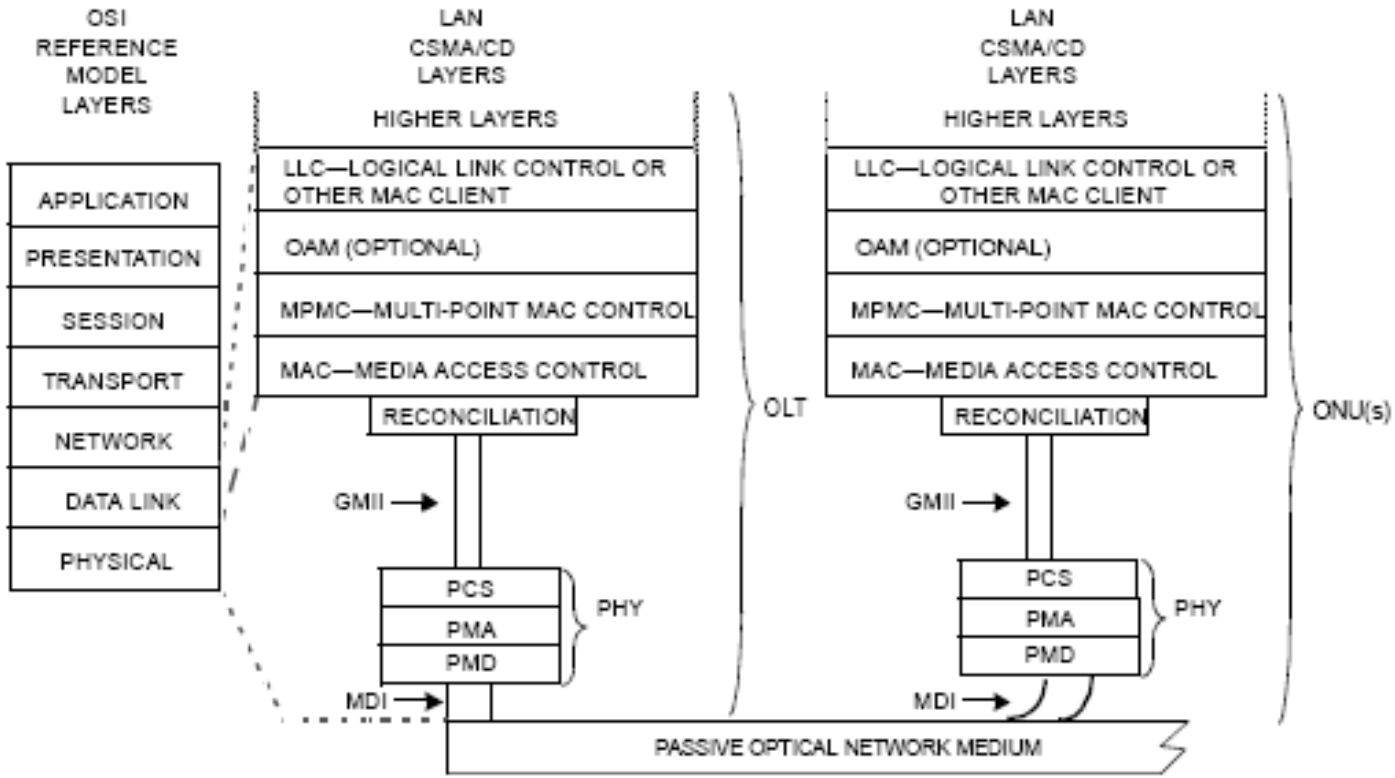
• Extensions to the MAC Control sublayer and Reconciliation sublayer as well as optical fiber PMDs to support this topology.

Architectural positioning of EFM: P2P Topologies



(Source: IEEE)

Architectural positioning of EFM: P2MP Topologies



GMII = GIGABIT MEDIA INDEPENDENT INTERFACE
MDI = MEDIUM DEPENDENT INTERFACE
OAM = OPERATIONS, ADMINISTRATION, AND MAINTENANCE
OLT = OPTICAL LINE TERMINAL

ONU = OPTICAL NETWORK UNIT
PCS = PHYSICAL CODING SUBLAYER
PHY = PHYSICAL LAYER DEVICE
PMA = PHYSICAL MEDIUM ATTACHMENT
PMD = PHYSICAL MEDIUM DEPENDENT

(Source: IEEE)

EPON Layer-2 Operation

Multi-Point MAC Control Protocol (MPCP):

• The Multi-Point MAC Control Protocol (MPCP) uses messages, state machines, and timers to control access to a P2MP topology.

• Every P2MP topology consists of one Optical Line Terminal (OLT) plus one or more ONUs,

• One of several instances of the MPCP in the OLT communicates with the instance of the MPCP in the ONU. A pair of MPCPs that communicate between the OLT and ONU are a distinct and associated pair.

Reconciliation Sublayer (RS):

• The combination of MPCP and the extension of the Reconciliation Sublayer (RS) for P2P Emulation allows an underlying P2MP network to appear as a collection of point to point links to the higher protocol layers (at and above the MAC Client).

• It achieves this by prepending a Logical Link Identification (LLID) to the beginning of each data frame, replacing two octets of the preamble.

EPON Multi-Point MAC

Functional Blocks:

• **Discovery Processing**. This block manages the discovery process, through which an ONU is discovered and registered with the network while compensating for RTT.

• **Report Processing**. This block manages the generation and collection of report messages, through which bandwidth requirements are sent upstream from the ONU to the OLT.

• **Gate Processing**. This block manages the generation and collection of gate messages, through which multiplexing of multiple transmitters is achieved.

Absolute timing model

• A global clock exists in the OLT

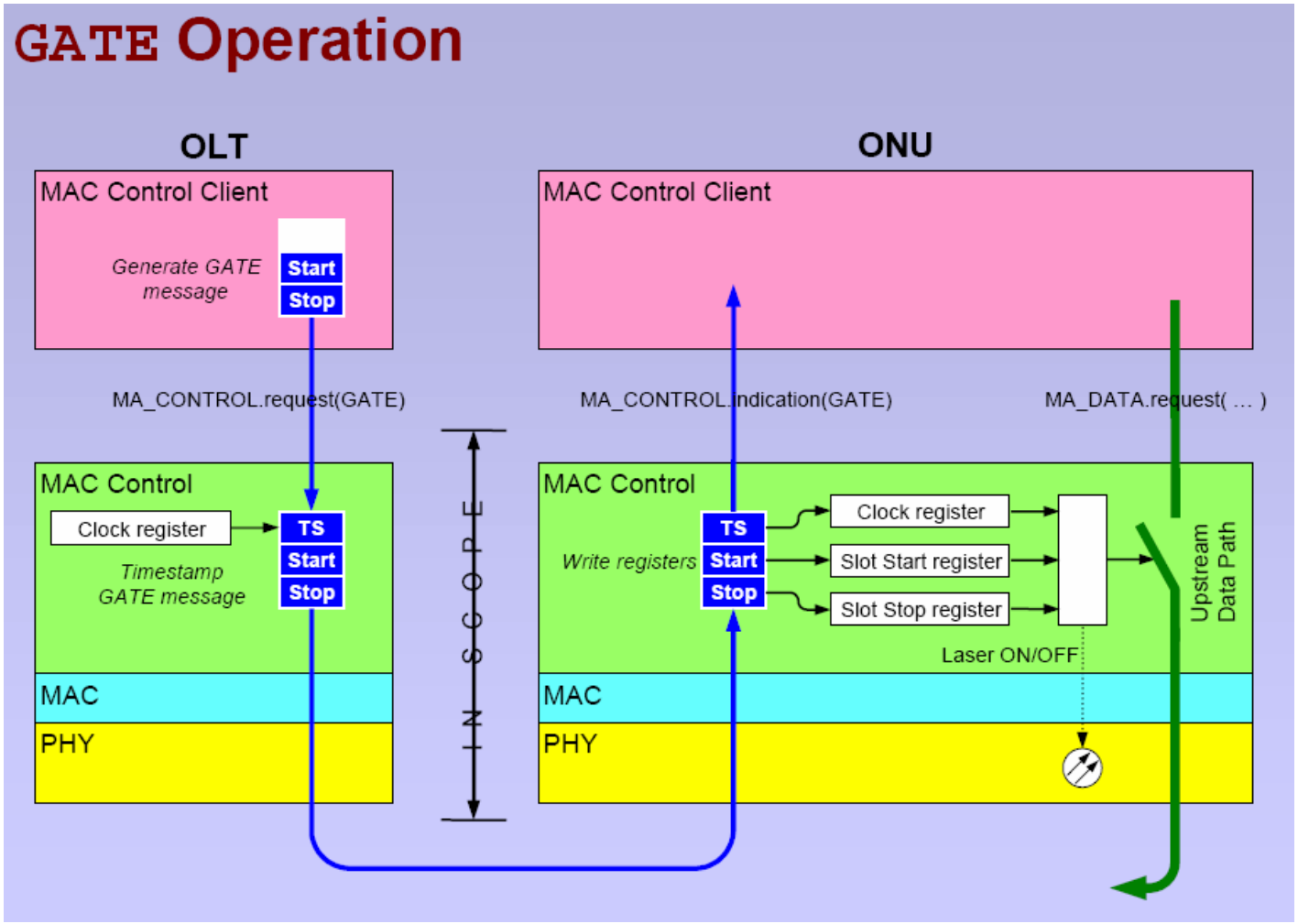
• Absolute timestamps distribute clock

• Timestamp added to all protocol related messages when generated

• Delay compensation is performed at OLT

• All grant start times are pre-compensated for RTT

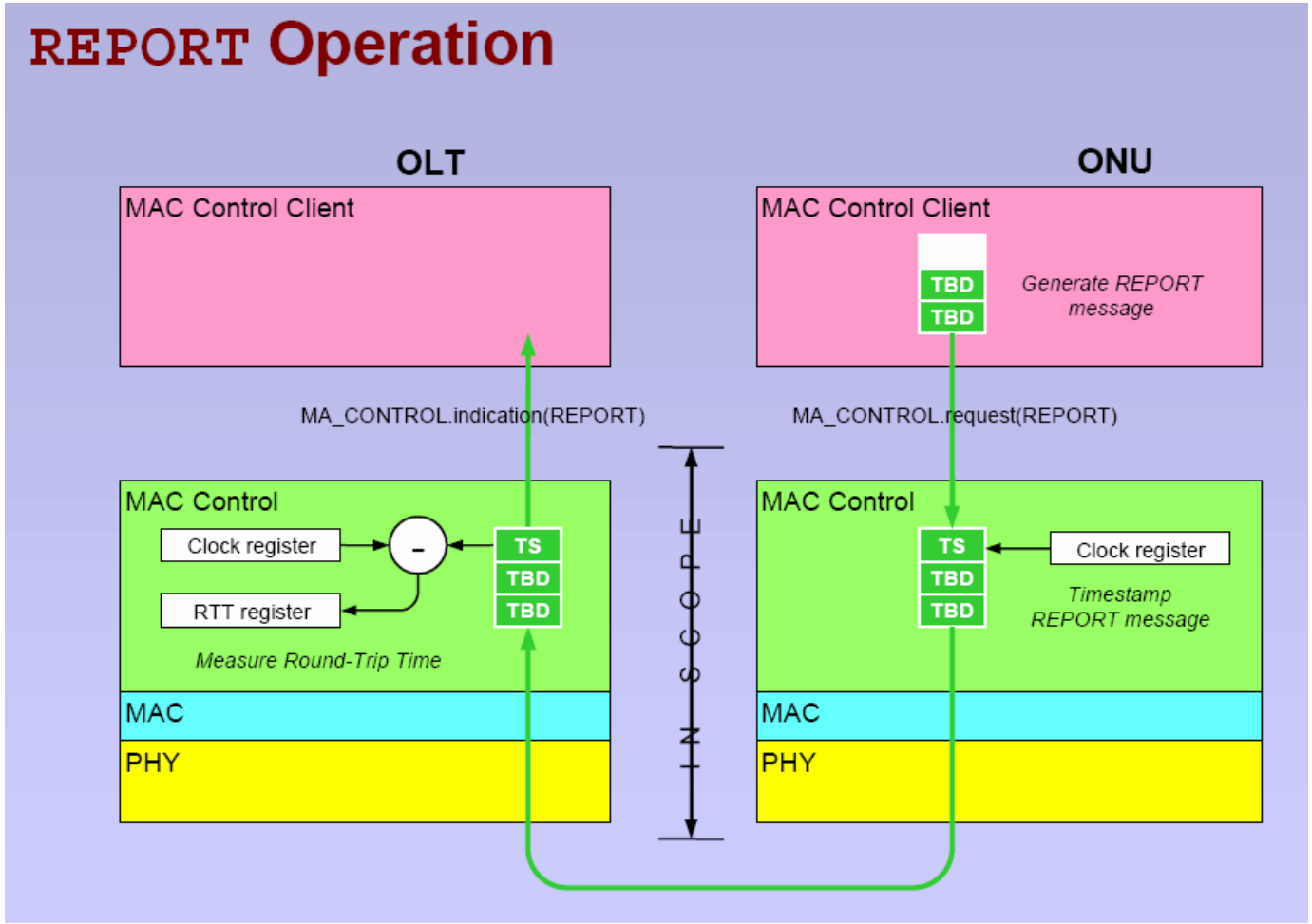
EPON MAC Functions (I)



OLT → ONU bandwidth assignment

(Source: PMC-Sierra)

EPON MAC Functions (II)

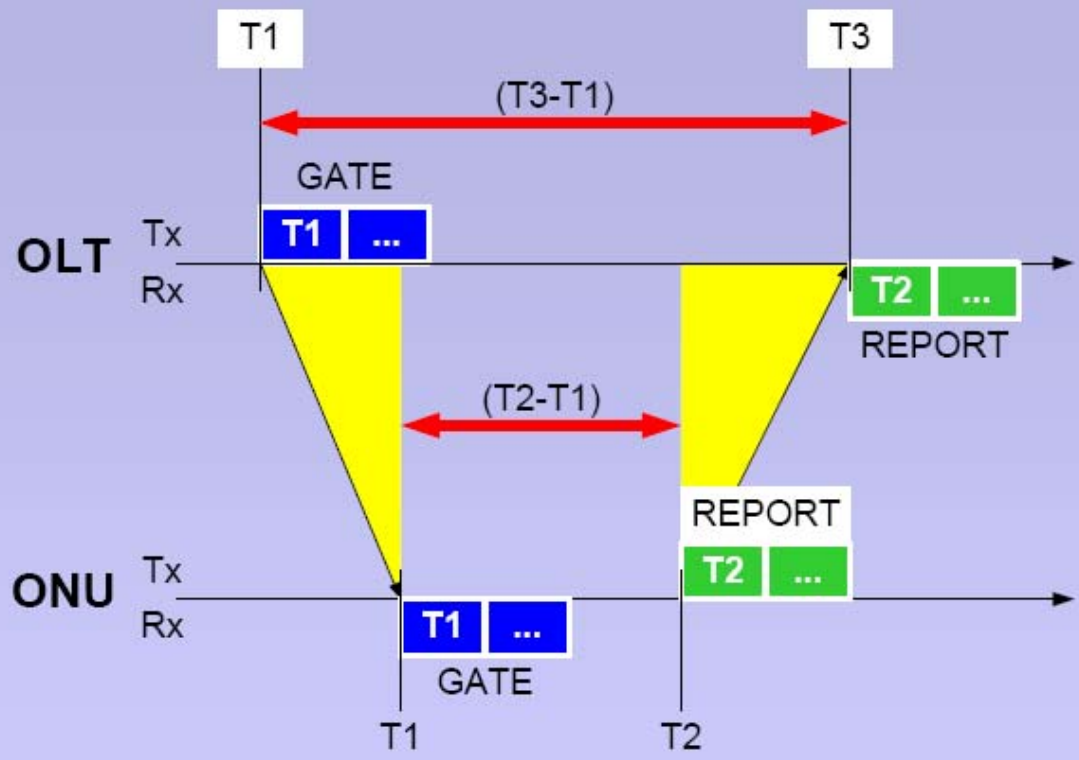


ONU → OLT bandwidth request

(Source: PMC-Sierra)

EPON: RTT Measurement

1. OLT sends GATE at T1
2. ONU receives GATE at T1
3. ONU sends REPORT at T2
4. OLT receives REPORT at T3
5. OLT calculates RTT = T3 – T2

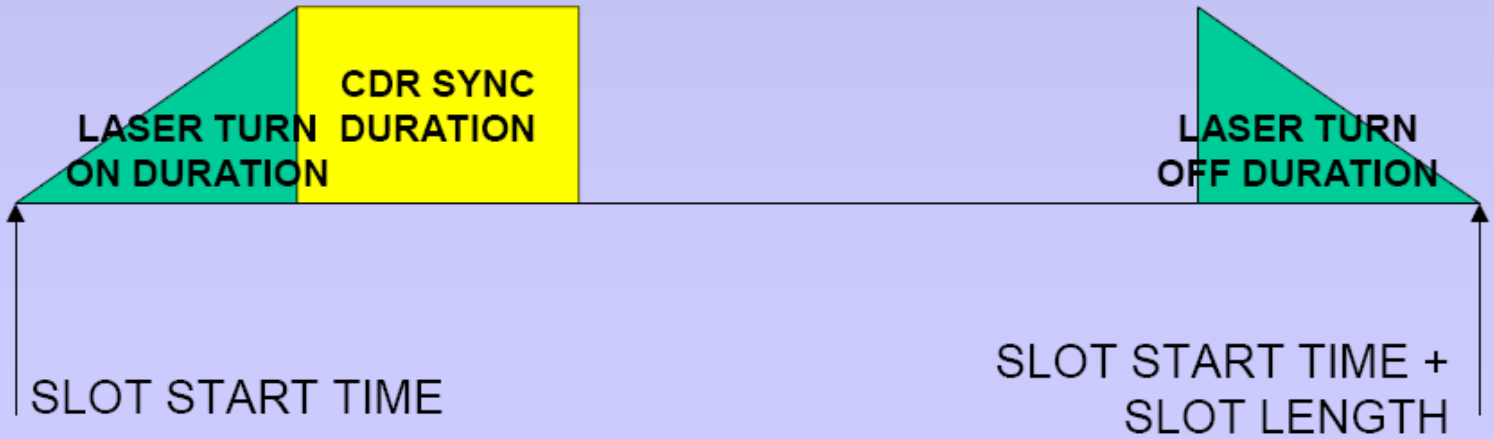


$$RTT = (T3-T1) - (T2-T1) = T3-T2$$

(Source: PMC-Sierra)

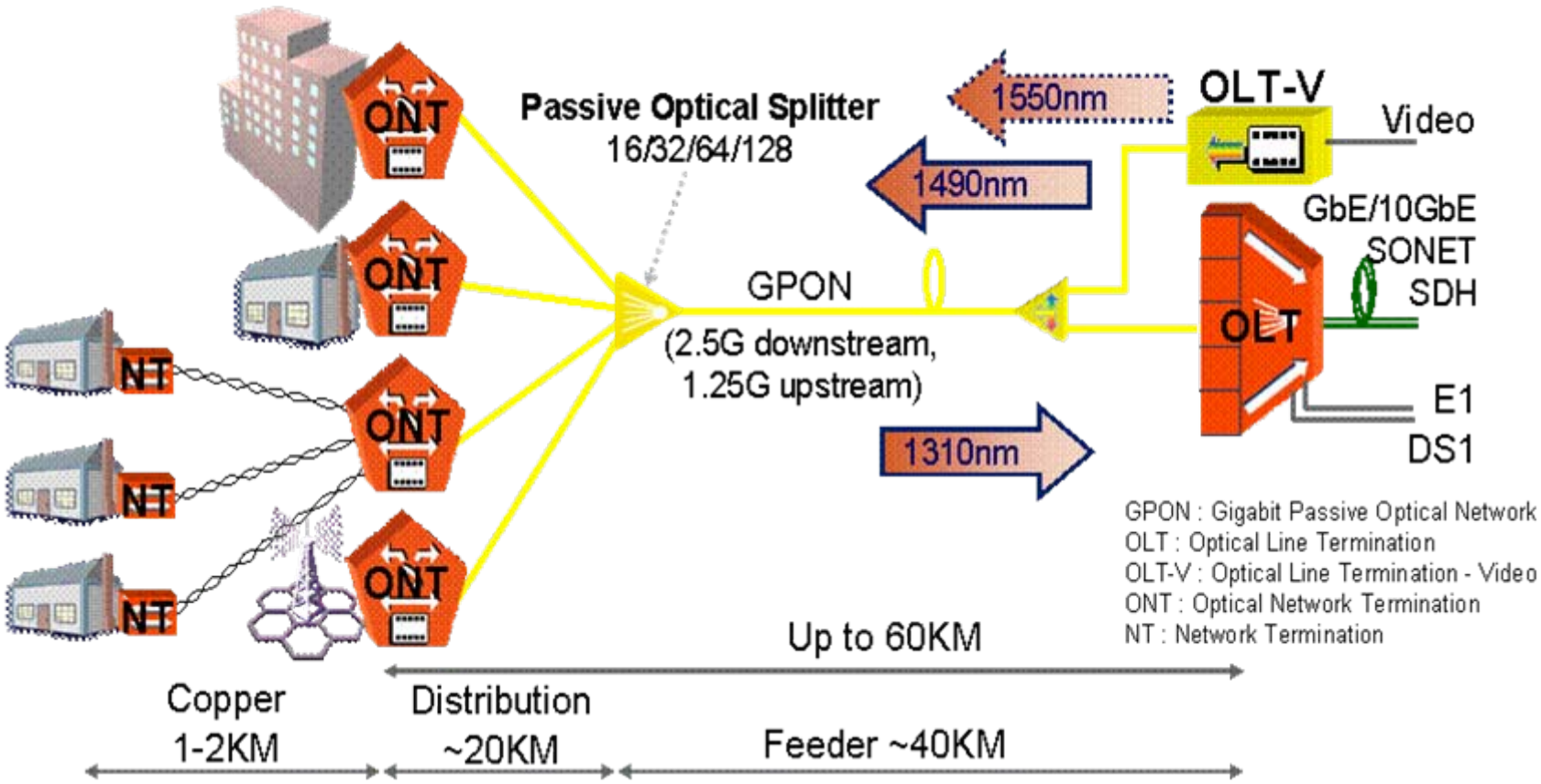
EPON: Physical Layer Interfaces

- Physical layer generates a preamble in the upstream to help the CDR lock
- OLT does not assume of ONU performance before initialization
  - Slot start is laser on event
  - Slot end is laser off event



(Source: PMC-Sierra)

GPON Architecture according to ITU-T



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- **Market Perspectives**
- Future PON Architectures
- Products

Possible Cost Advantages of PONs

Revenue Side:

- **Triple Play**:
  - existing & coming TDM-, ATM- and Ethernet based service demands
  - VoIP everywhere by centralized gateway in ONT/ONU
  - Enables CATV over the same infrastructure
- **Customized tariff structures** with Bandwidth-on-demand mechanisms, ideal access solution for **value-add applications** (e.g. Video Telephony, home control, e-learning)

CAPEX & OPEX Side:

- Reduction in:
  - **Number of fibers** to serve all customers + Footprint + Aggregation ports
- **Increased flexibility**:
  - Simplified addition of new customers
- No powering & cooling in access nodes ("**passive**")
- Minimized **maintenance** cost
- **Centralized control** of the whole access network

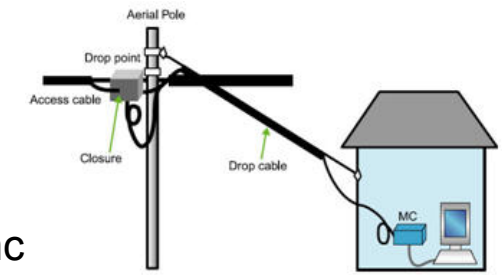
PON Deployment by Region

Typical Asian FTTH installation:

• Typically densely populated areas (short distances)

• Installation over the air via drop cables, often together with power lines is widely accepted

➔ No digging for new FTTH installation required



Typical North American FTTH installation:

• Densely populated areas as well as rural areas with long distanc

• Installation over the air via drop cables accepted in rural areas

➔ Digging only in densely populated areas (cities) required

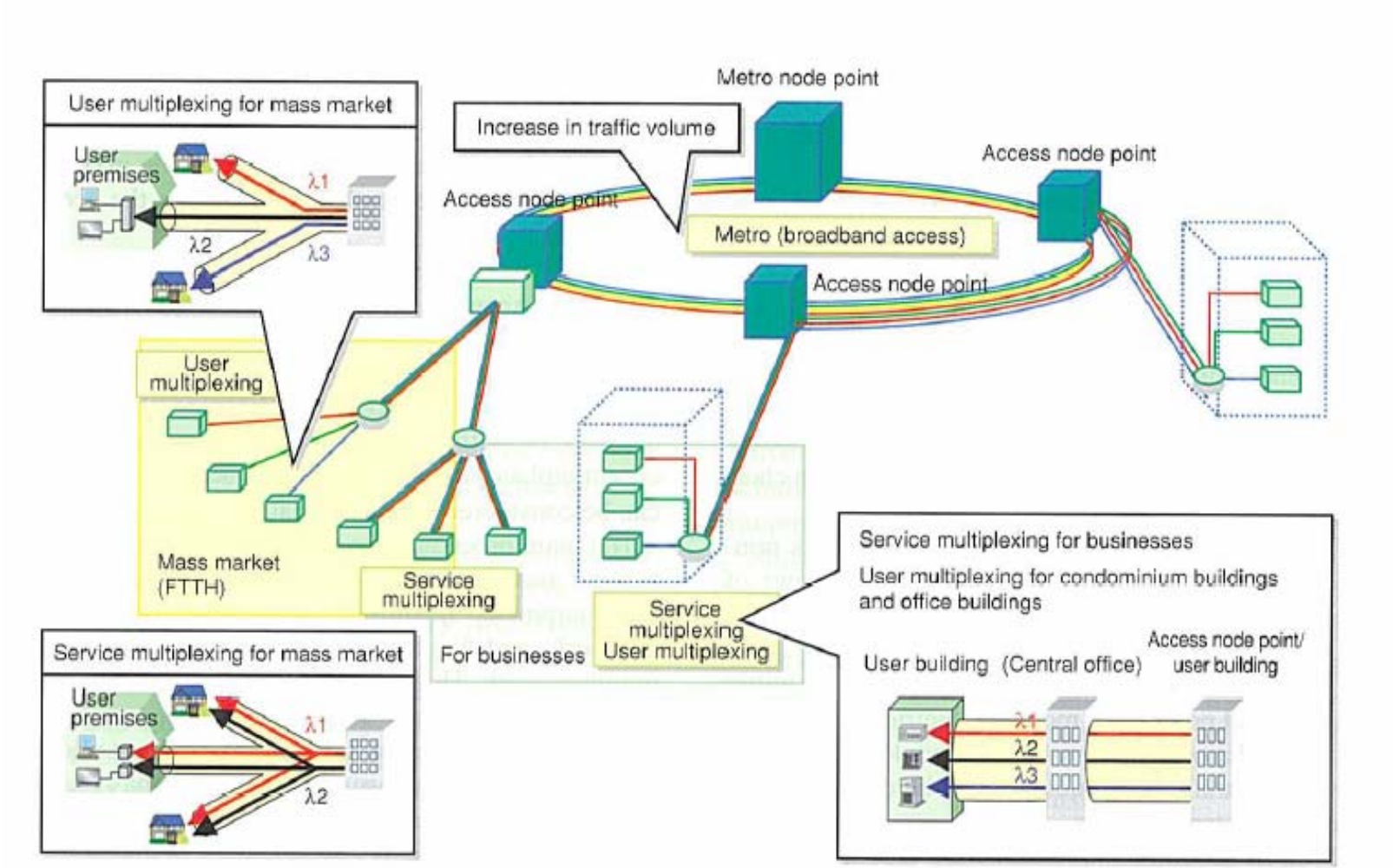
Typical European FTTH migration Scenario

• All cables sub-surface

• Replacing copper stepwise with growing bandwidth demand

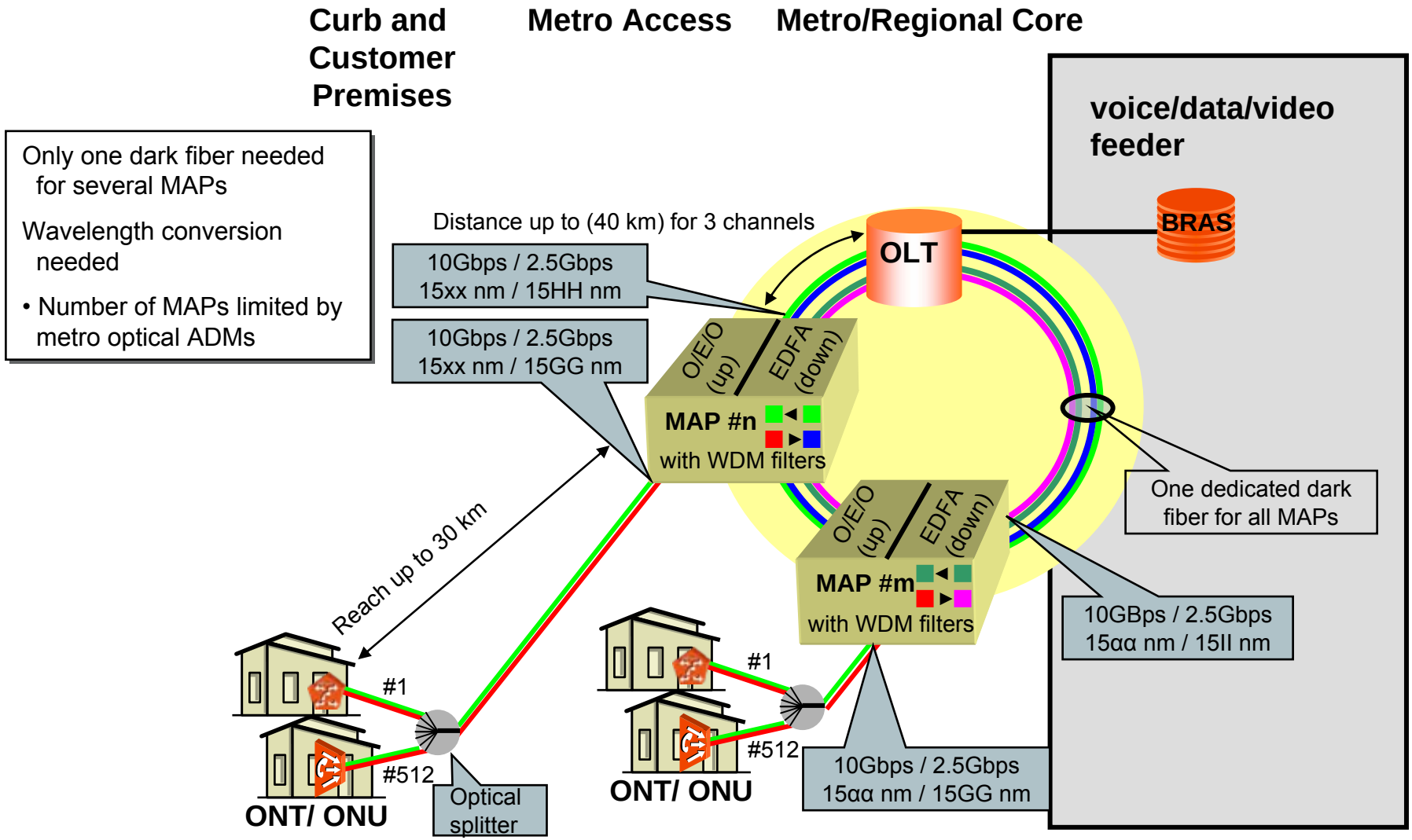
Content

Future PON Solutions
Trend: Convergence of Metro & Access



Source NTT, „Optical Access Trends in Broadband Ubiquitous Service Development“

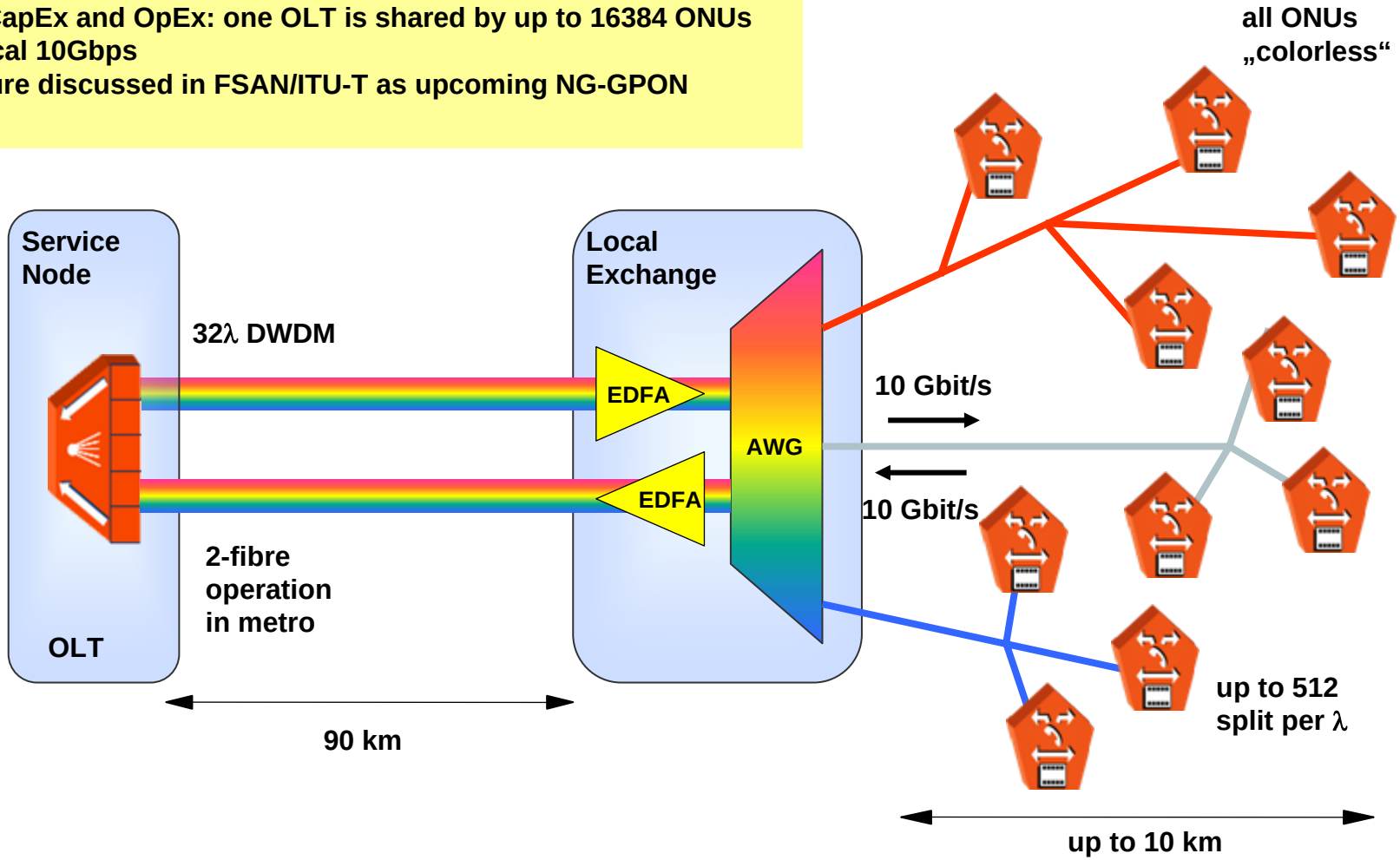
EU-IST Super-PON (MUSE):Architecture Details



EU-IST PIEMAN: Target Architecture

PIEMAN Target Architecture

- Integration of Metro & Access into a single system
- all-optical Local-Exchange
- reduced CapEx and OpEx: one OLT is shared by up to 16384 ONUs
- symmetrical 10Gbps
- Architecture discussed in FSAN/ITU-T as upcoming NG-GPON standard



Future PON Solutions
Current discussions on new Standards

Next Generation EPON: discussion in “10G EPON subcommittee“ of the Ethernet Alliance

Extension to 10 Gbps up & down

Reach and splitting factor expected to be similar to EPON

First Research Results presented (2 ONUs only)

Next Generation GPON: discussion in “Full Service Access Network” (FSAN) group, driving standardization within ITU-T)

Converged Metro & Access Network (similar to PIEMAN, SuperPON)

WDM in the Metro and TDM in the Access, 10Gbps downstream

Discussions in early stage

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SURPASS Carrier Ethernet Products Overview

APM-E – Advanced Provisioning Manager — **NMS & EMS**

EFM / PON | **ACI-E – Access Integrator** — **Solutions**

GPON ONT

SURPASS hiX 5701 ... 5709

Interfaces:
POTS, VDSL, FE
CATV-RF

GE-PON ONT

SURPASS hiX 5804

Interfaces:
FE

Ethernet NT

SURPASS hiD 6605

Stackable Single-board DSLAM

Metro Access

SURPASS hiX 5620

Interfaces:
ADSL2+, VDSL

Stackable Single-board Access Switches

Metro Access

SURPASS hiD 6610/6615

18 Gbps
FE, GE

Shelf-based Multi-service DSLAMs

Metro Access

SURPASS hiX 5625	SURPASS hiX 5630	SURPASS hiX 5635
24 Gbps 5 slots	24 Gbps 8 slots	48 Gbps 16 slots

Interfaces:
ADSL2+, VDSL2, SHDSL, VoIP, FE/GE

Protocols:
L2, CEBS, L3

Shelf-based GPON OLT

Metro Access

SURPASS hiX 5750

150 Gbps / 14 slots

Interfaces:
2.5 G/1.2 G

Shelf-based GE-PON OLT

Metro Access

SURPASS hiX 5830

24 Gbps / 12 slots

Interfaces:
GE-PON, GE

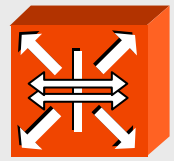
Metro Aggregation Switches

Metro Aggregation

SURPASS hiD 6630	SURPASS hiD 6650
30 - 60 Gbps 3 slots	50 - 320 Gbps 5 slots

Interfaces:
FE, GE, 10GE

Protocols:
Ethernet, MPLS



Metro Core Switch

Metro Core

SURPASS hiD 6670

240 to 640 Gbps
12 slots

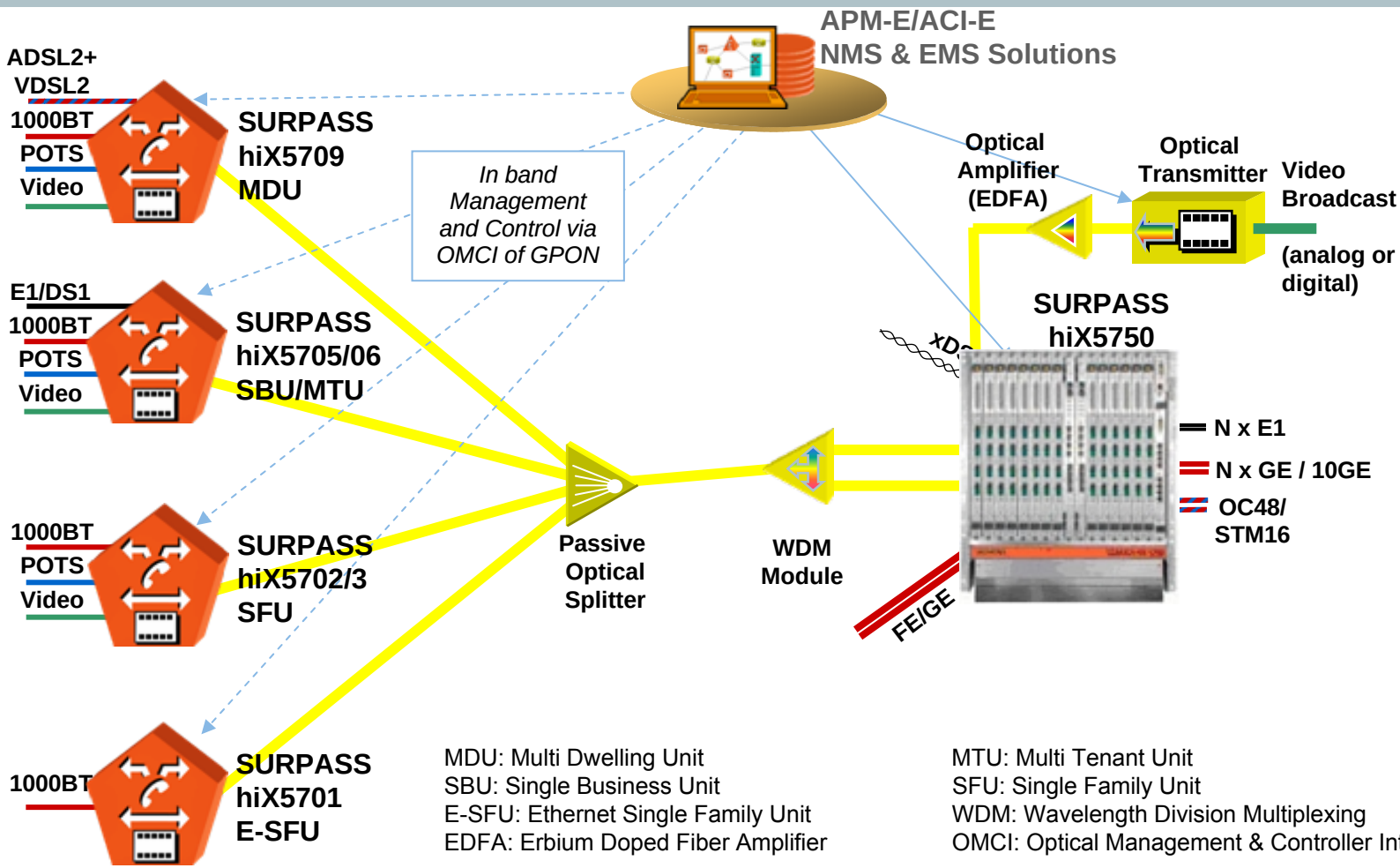
Interfaces:
FE, GE, 10GE

Protocols:
Ethernet, MPLS

Switching capacity „California Count“

1st mile | 2nd mile

Product Example GPON
Siemens SURPASS hiX 57xx Series GPON Solution



MDU: Multi Dwelling Unit
SBU: Single Business Unit
E-SFU: Ethernet Single Family Unit
EDFA: Erbium Doped Fiber Amplifier

MTU: Multi Tenant Unit
SFU: Single Family Unit
WDM: Wavelength Division Multiplexing
OMCI: Optical Management & Controller Interface

- **optical 1:64 split**
- **1.25Gbps up & 2.5Gbps down**
- **>3000 fiber customers per OLT**

SURPASS Carrier Ethernet Optical Broadband Access
SURPASS hiX 57xx Series GPON OLT Product

Feature set:

- **IP Routing** (static, RIP, OSPF, BGP)
- **Spanning Tree: PSTP, RSTP, MSTP**
- **Link Aggregation (802.1ad)**
- **VLAN Stacking**
- **ERP (Ethernet Ring Protection),**
- **SP, WFQ, WRR**
- **4 queues per port**
- **QoS acc. to 802.1p, DSCP/TOS**
- **Static Guaranteed SLA (CIR, PIR, CBS, MBS)**
- **Ethernet First Mile**
- **IGMP Snooping/Proxy for IP Multicast**
- **DHCP Relay Agent (opt.82)**
- **ACL, DoS prevention**

Fully GPON standard compliance:

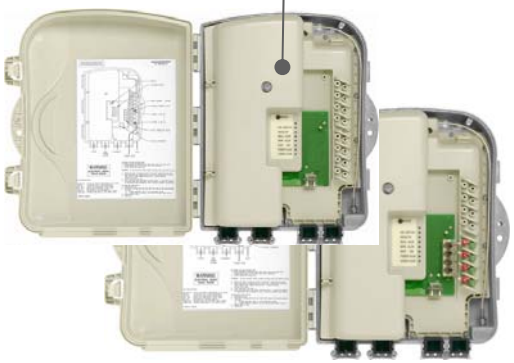
- **2.5Gbps of bandwidth at 93% Efficiency**
- **G.984.1: GSR (Service Requirements)**
- **G.984.2: GPM (Physical Media)**
- **G.984.3: GTC (Transmission Convergence)**
- **G.984.4: GOMCI (ONT MNG & Control I/F)**

SURPASS hiX 5750

14 service-card slots
4 ports GPON card (incl. 8 ports E1)
1 port 10GE card
10 ports GE card
16 ports FE card
Fully redundant switch matrix
GE / 10GE uplinks
STM16 / OC48 uplinks (GFP)
Service Cards of hiX56-Series IP-DSLAM

SURPASS Carrier Ethernet
SURPASS hiX57-Series GPON ONT/ONU Products

SURPASS hiX 5701/02/03



Single Family Units
- Indoor & outdoor variants
- POTS/Ethernet/Video ONT
- Integrated VoIP gateway
- Pure Ethernet ONT

SURPASS hiX 5705/06

Business Units
- Indoor & outdoor variants
- POTS/Ethernet/Leased Lines
- Integrated VoIP gateway

SURPASS hiX 5709

Multi Dwelling Units
- Indoor & outdoor variants
- POTS/Video/data ONU
- Integrated VoIP client
- Ethernet Module
- ADSL2+&POTS Module
- VDSL2 Module
- POTS Module

SURPASS hiX 5701/5702/5703 FTTH Solution
GPON ONT SFU/E-SFU

hiX 5702/3 SFU (Single Family Unit)

- **Single-Fiber GPON uplink** (2.5Gbps down/1.25Gbps up)
- **4 ports POTS**
- **1/2 port 10/100/1000 baseT**
- **CATV-RF** (50...870 Mhz) **+14dBmV (hiX 5702)**
- **VoIP client** (SIP, H.248) **via Software download**

hiX 5701 E-SFU (Ethernet Single Family Unit)

- **Single-Fiber GPON uplink** (2.5Gbps down / 1.25Gbps up)
- **1 port 10/100/1000 BT**