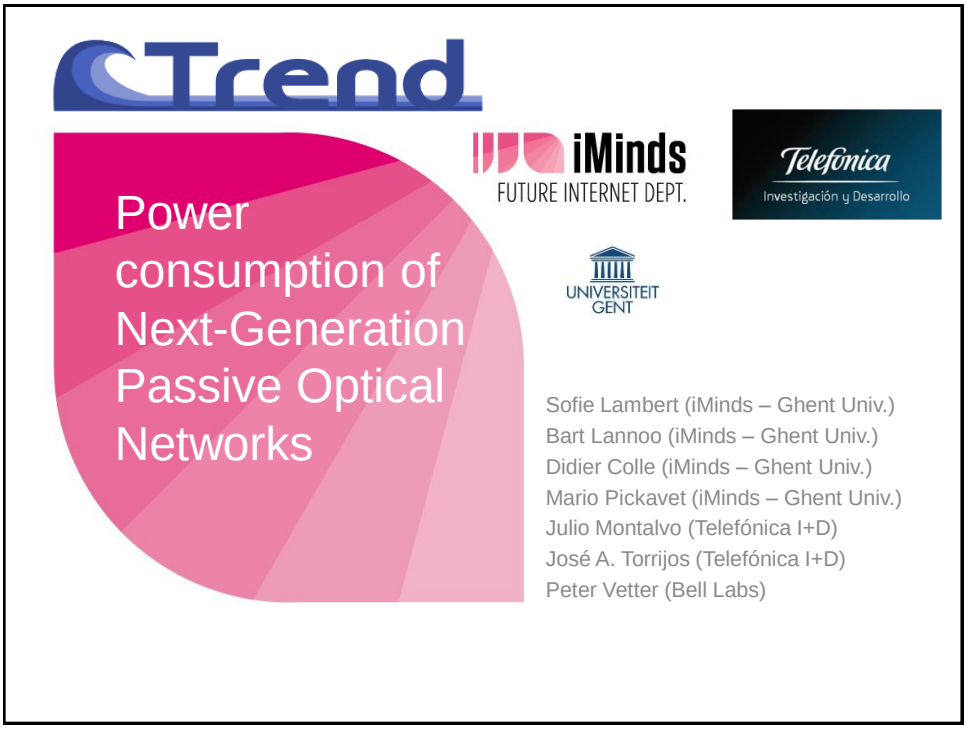

Outline

An introduction to Next-Generation Passive Optical Networks (NG-PONs)

Power consumption evaluation: methodology

- Scope
- Technology-dependent characteristics
- Model parameters

Results

- Power consumption for various technologies
- Sensitivity to input parameters

Conclusion

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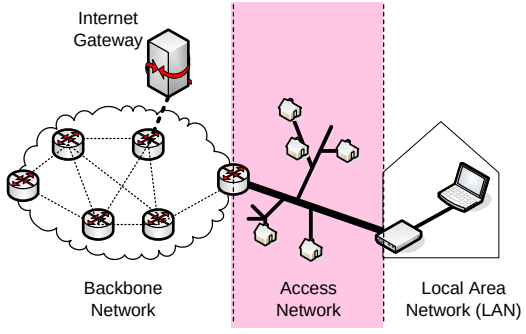
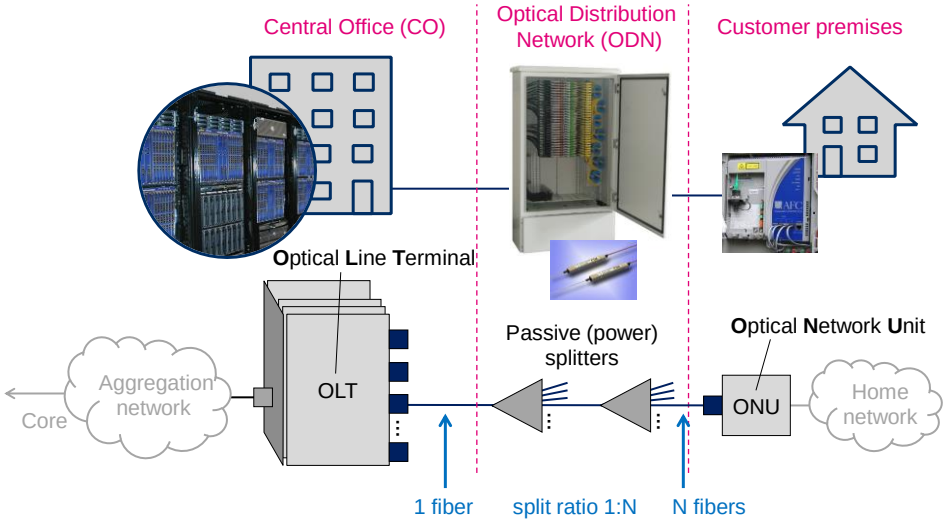
PONs are a type of optical access networks



Copper/Cable networks → Evolution towards higher access speeds → Fiber to the home

- PONs
- AONs
- PtP
- …

Passive optical network (PON) = no active components between the OLT and the ONU



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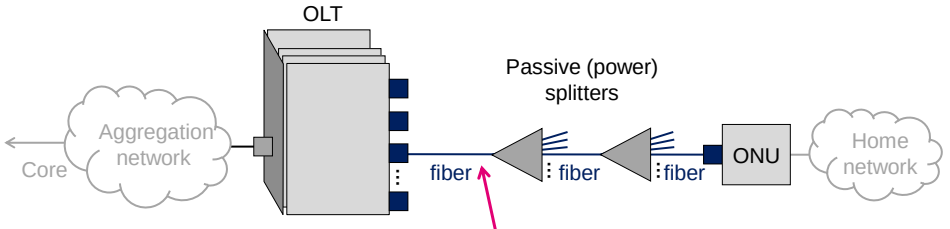
Various implementations of PONs are possible



Currently standardized

- GPON and XG-PON (2.5 Gb/s & 10 Gb/s, to be shared by users in a PON), Time Division Multiplexing-based

Towards NG-PON2 technologies [FSAN 2012]

- Further bandwidth increase (≥ 40 Gb/s downstream, shared)
- Potential for node consolidation (long reach, high split ratios)
- Power consumption?

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NG-PON2 technologies considered here

XLG-PON	40G Time Division Multiplexing
TWDM-PON	Time and Wavelength Division Multiplexing (4 overlaid 10G TDM PONs on different wavelengths)
OFDM-PON	40G Orthogonal Frequency Division Multiplexing
Co-UWDM-PON	Coherent Ultra Dense Wavelength Division Multiplexing (one 1.25G wavelength per customer)

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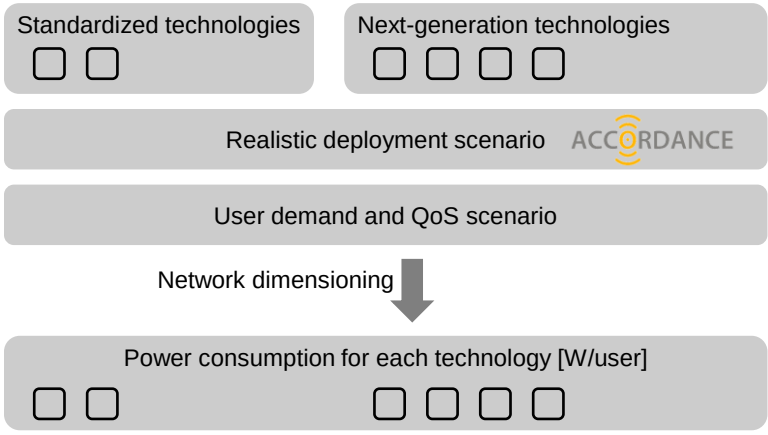
How can we make a fair comparison between different technologies?



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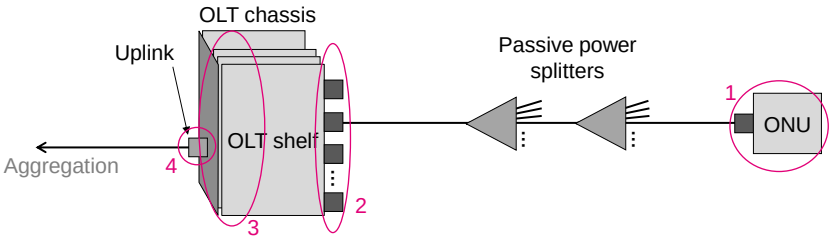
Power consumption in the access network consists of four components



1. Optical Network Unit (ONU)
   # ONUs x (3.65 W baseline + system-specific power)
2. Optical Line Terminal (OLT) PON ports
   # OLT ports x power consumption per port
3. Layer 2 switching, packet processing and traffic management
   # OLT chassis x PONs/chassis x bandwidth (DS+US) x 1 W/Gbps
4. Uplink ports
   # OLT chassis x uplink energy consumption

Customer side
x 1.25 AC/DC

Operator side
x 1.25 AC/DC
x 1.7 site factor

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Technologies considered

Technology	Max. budget (dB)	Bandwidth / PON DS/US (Gb/s)	power / OLT port (W)	power / ONU (W)
GPON	28	2.5/1.25	2	1.8
XG PON	35	10/2.5	5	3.1
XLG PON	31	40/10	17	3.2
TWDM PON	38.5	4x10/4x2.5	20	3.4
OFDM PON	34.5	40/10	9.5 + 0.5 x N_{users}	8.6
Co-UDWDM PON	43	1.25/1.25 x N_{users}	6 + 1.2 x N_{users}	4.7

NG-PON

NG-PON2

increasing bandwidth

increasing power / port

N_{users} = maximum number of connected users per OLT PON port

OLT port power consumption values based on [Skubic 2012] and GreenTouch
ONU power consumption values provided by GreenTouch

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- Model parameters: user demand and Quality of Service (QoS)

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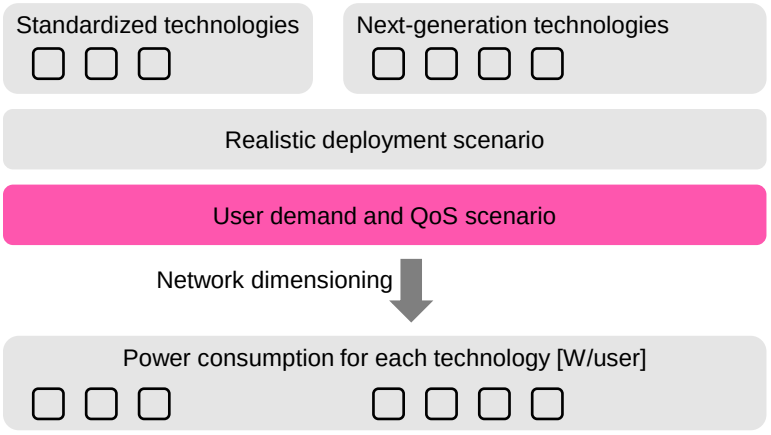
Conclusion

Define user demand and QoS parameters to dimension the network and calculate power consumption



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User demand: probability of activity and requested bandwidth

Assumption: independent users*

p_{active} = probability (time) that a user is active

When active, user requests B_{target}

Considered scenarios:

p_{active} = *50%*

B_{target} = *600 Mb/s, 1 Gb/s*

* based on [Segarra 2011]

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Quality of Service (QoS): availability and packet loss

$p_{avail,min}$ minimum probability (% of time) that users can get the requested target bandwidth

PL_{max} maximum allowable packet loss in the OLT uplink towards the aggregation network

Best-effort internet service:

$p_{avail,min} = 20\%$

$PL_{max} = 10^{-3}$

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Conclusion

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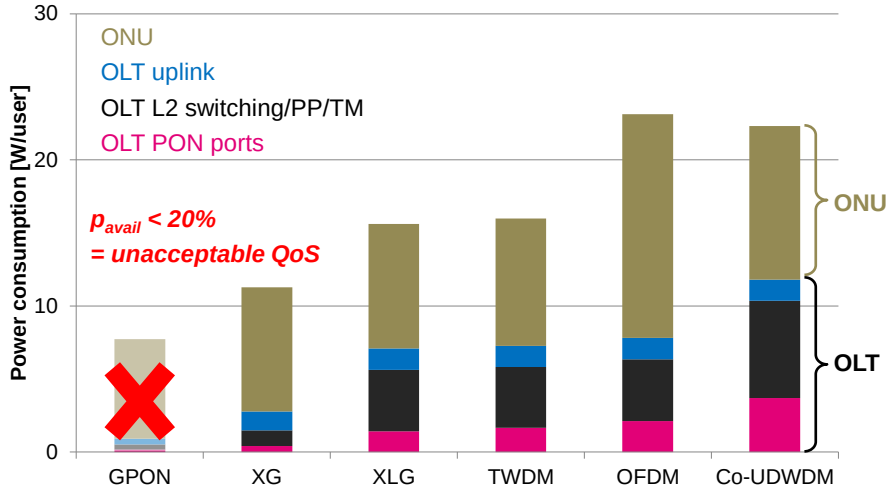
Split ratio fixed at 1:64 – *Medium demand (access rate 600 Mb/s)*



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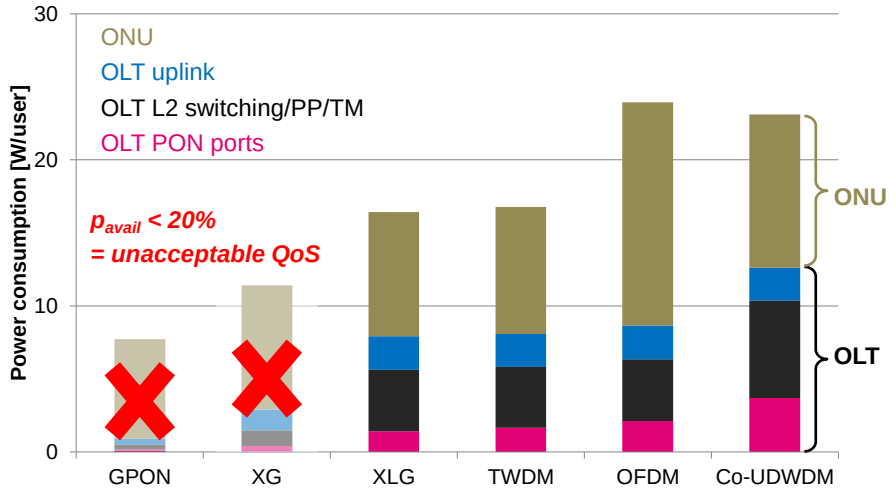
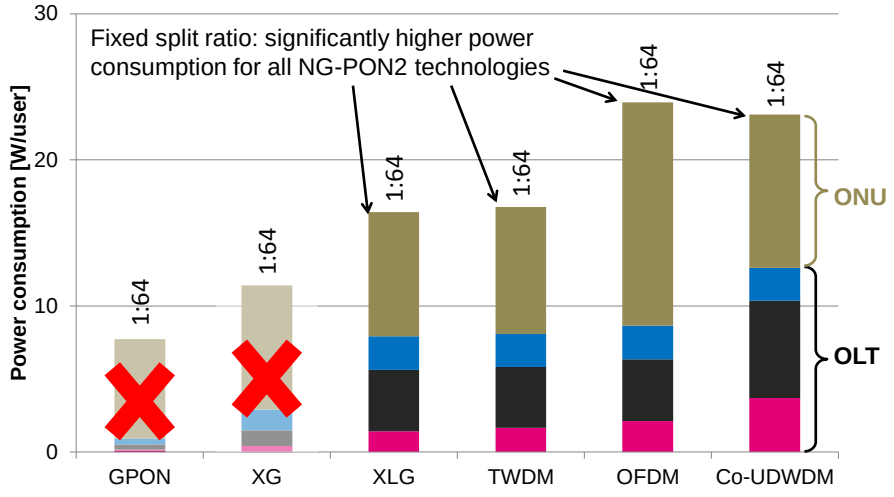
Split ratio fixed at 1:64 – *High demand (access rate 1 Gb/s)*



20

High demand (1 Gb/s) - What if we could update the ODN and change split ratios?



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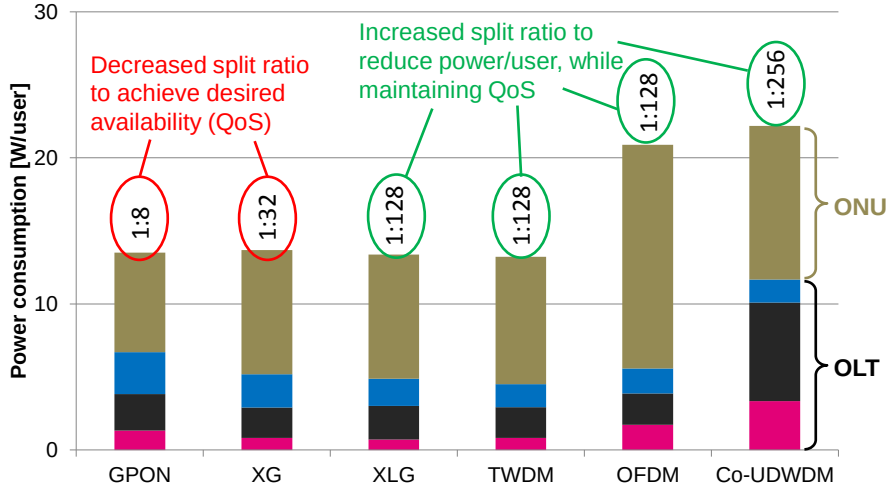
Impact of optimizing the split ratio – *High demand (1 Gb/s)*



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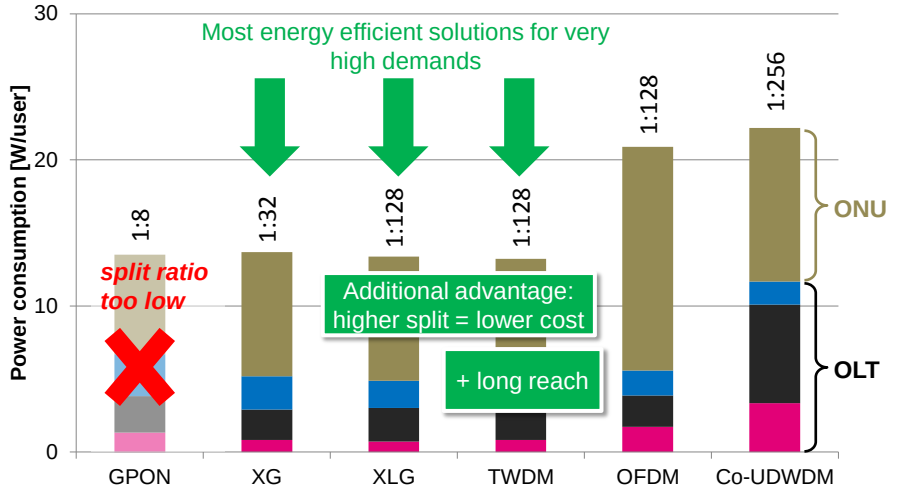
Impact of optimizing the split ratio – *High demand (1 Gb/s)*



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Conclusion for variable split ratios: most energy efficient technology for high future demands?

GPON and XG PON can still be used, but at lower split ratios = not an attractive option for most operators

NG-PON2 technologies offer higher capacities, and longer reach allowing higher split ratios

XLG and TWDM PON are most energy efficient options with higher split ratios

OFDM consumes a lot of power at ONU, making it less energy efficient

Co-UDWDM consumes a lot of power at OLT, but offers PtP access with high QoS, useful for specific applications

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Which PON technology is the most energy efficient?

Depends on various factors:

To what extent are operators able/willing to modify existing networks (change split ratio)?

How will user demands evolve in the coming years (driven by video, wireless backhaul, …)?

Further, validity of the results depends on the reliability of the input parameters.

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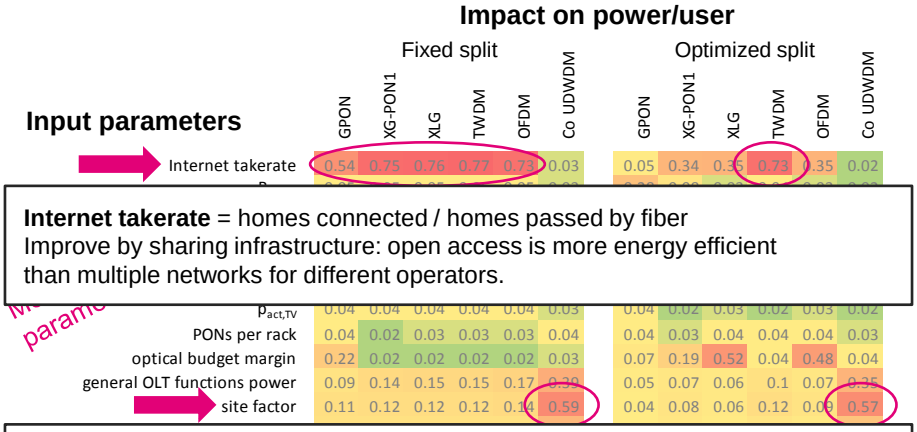
Sensitivity analysis: which input parameters have the biggest impact on the results?



Internet takerate = homes connected / homes passed by fiber
Improve by sharing infrastructure: open access is more energy efficient than multiple networks for different operators.

Site factor = overhead for cooling, energy supply, etc. at central office
Improve by applying energy saving techniques similar to the ones for data centers.

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Power saving techniques will need to be included in standards if we want energy efficient PONs

power for future high-speed optical access
is typically **> 10 W** per household
=
equivalent of a small new refrigerator!

Power saving techniques are needed to make NG-PON2 technologies more energy efficient, e.g.

- Sleep modes / load proportionality
- Virtualization
- Energy efficient cooling (at central office)

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Questions?

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S. Lambert, W. Van Heddeghem, W. Vereecken, B. Lannoo, D. Colle, and M. Pickavet, "Worldwide electricity consumption of communication networks," Optics Express, vol. 20, no. 26, pp. B513–24, Dec. 2012.

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B. Skubic, E. In de Betou, T. Ayhan, and S. Dahlfort, "Energy-Efficient Next-Generation Optical Access Networks," *IEEE Communications Magazine*, vol.50, no.1, pp. 122–127, 2012.

[refrigerator]
LIEBHERR TP 1410-20 (energy label A++), consumes 93 kWh/year = equivalent of 10.6W continuous energy consumption