COCONUT

COCONUT WORKSHOP, Pisa

5-Febr-2016

"Research and Development in FTTx technologies and architectures"

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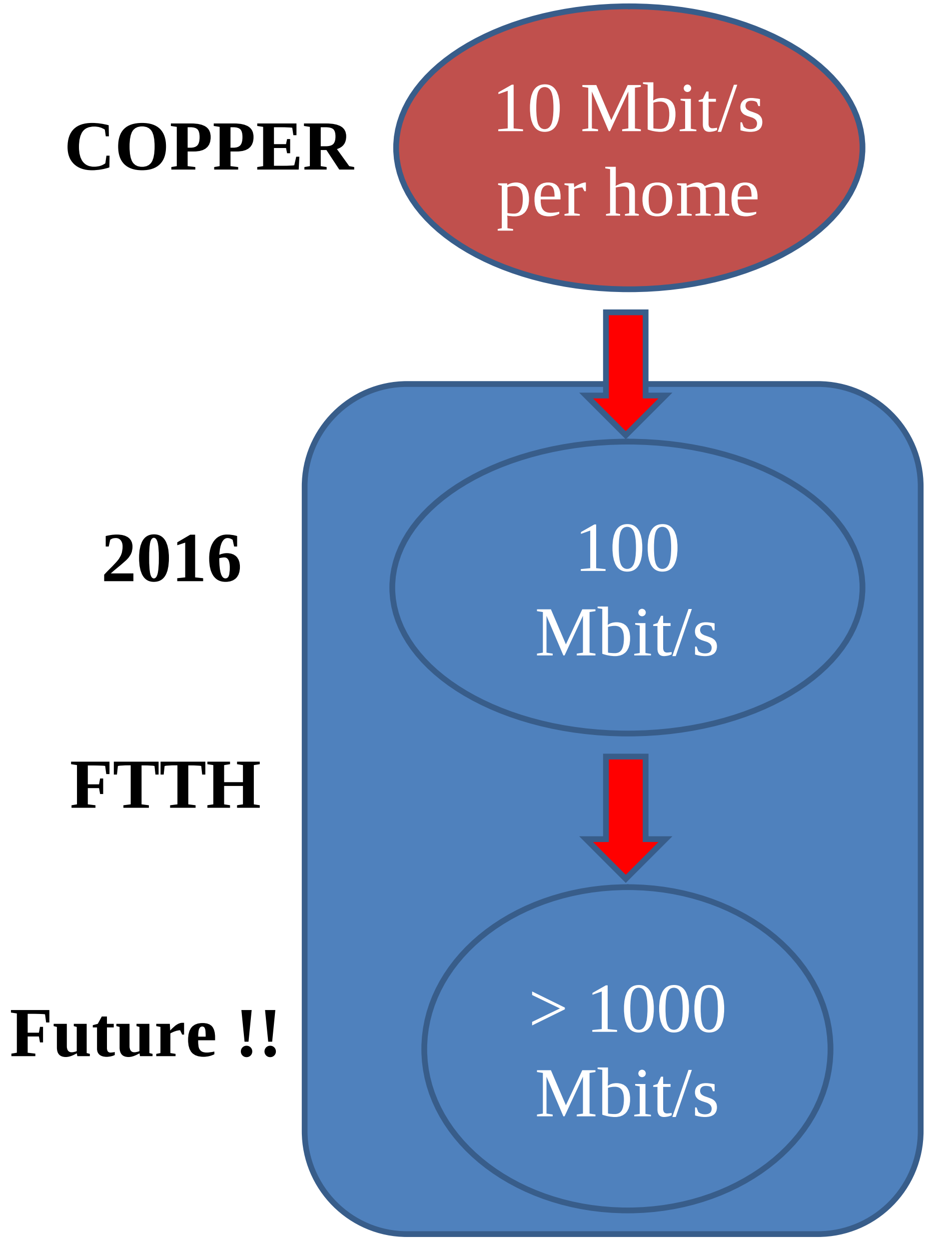
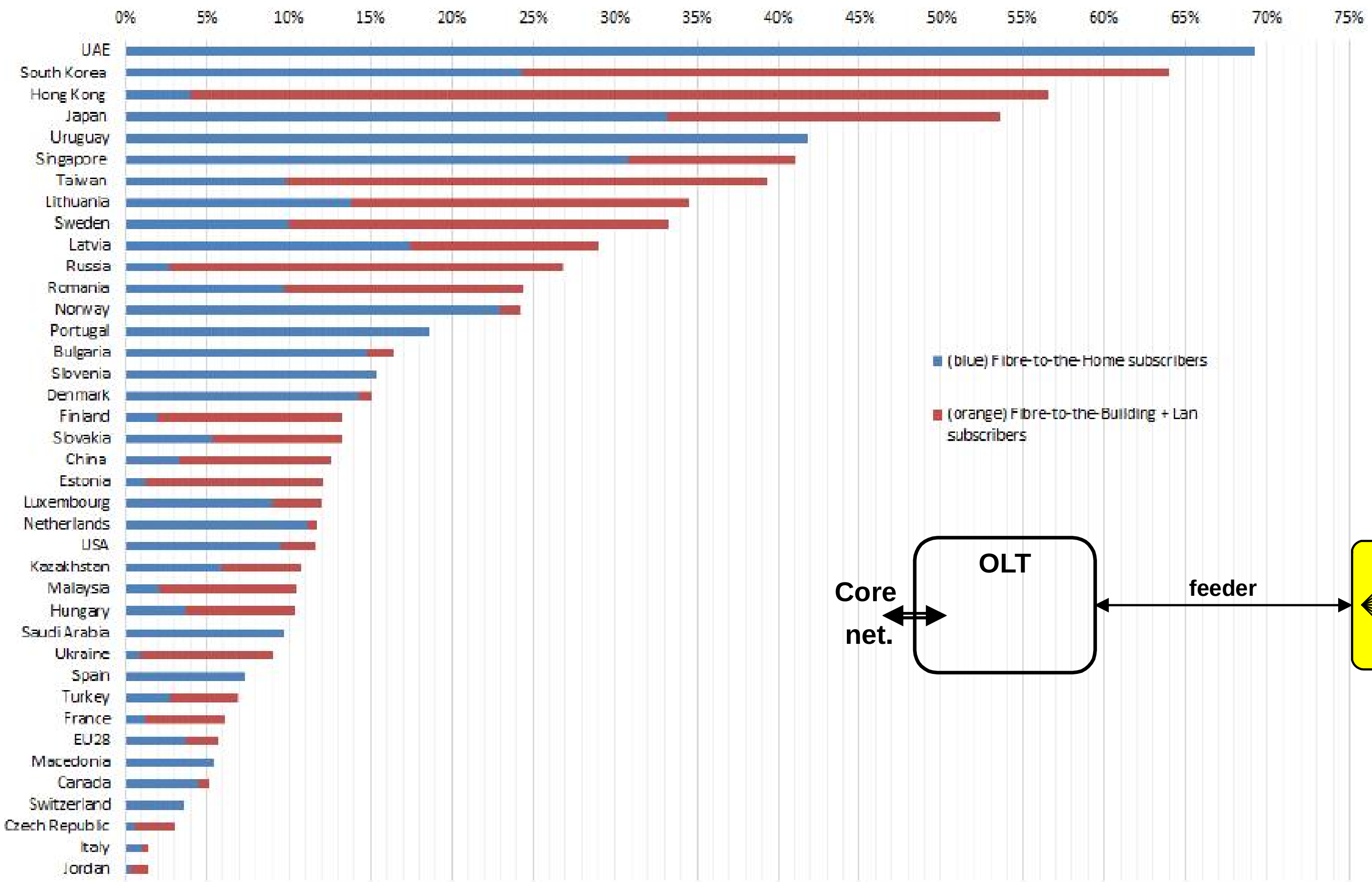
FTTH advantages

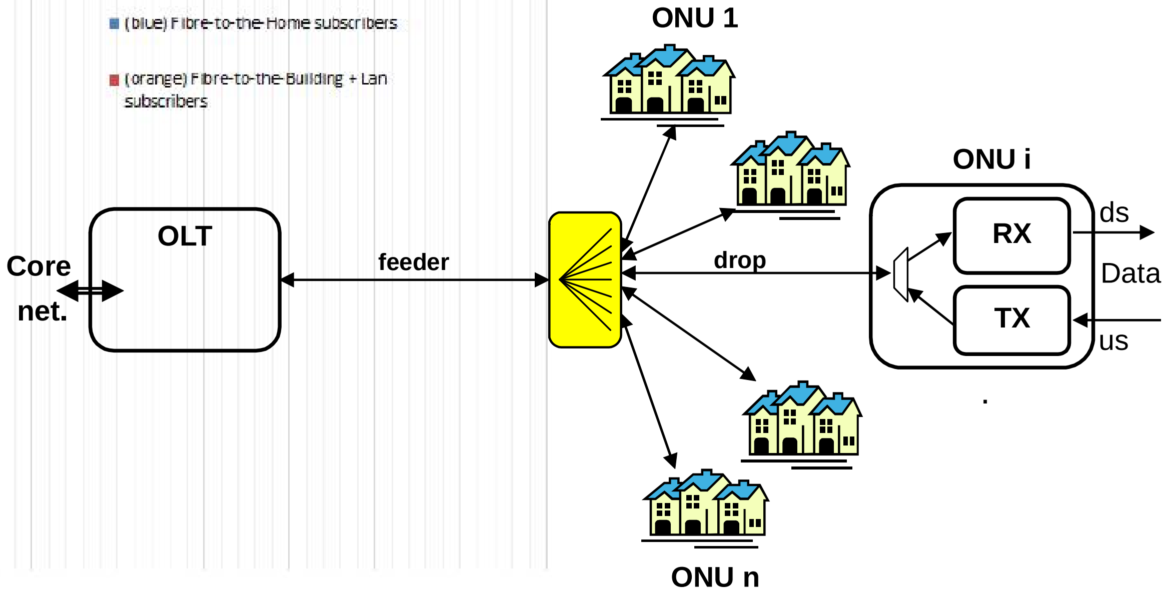
- Fiber-to-the-Home
  - increases the user bandwidth to hundreds of Mbit/s bidirectionally;
  - it does it at lower CAPEX and OPEX **cost** than copper access since
  - the external plant is highly simplified by deploying common Passive Optical Networks (**PON**s),
    - → that avoid powering and maintenance, and even makes local offices redundant.
- This transition started with the
  - cable-TV (CATV) networks with hybrid fiber-coaxial systems,
  - standardization of ITU Gigabit-capable PON GPON and EPON in 2004.



FTTH / FTTB global ranking

FTTH Access networks: 128 million accesses worldwide with a growth rate 30%,

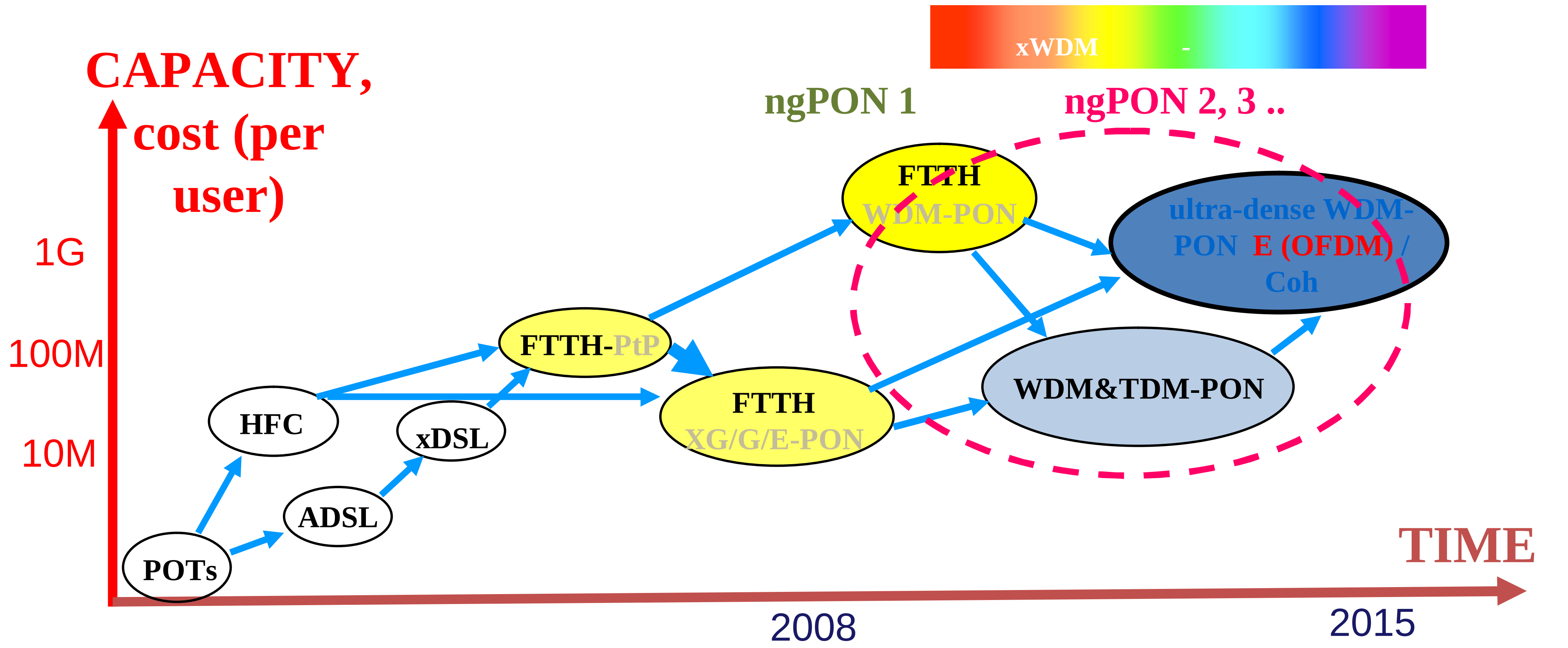




Current and Future Challenges

- substantial increase of bidirectional **capacity**, towards 1 Gbit/s per user and beyond;
- low **cost** user optical network unit (ONU), affordable at comparable cost as current ONU;
  - low cost and small form factor transceivers generally imply to avoid external modulators, optical amplifiers and any high power consuming element.
  - also, all ONUs have to be identical, for effective high volume scale production and user provisioning;
- keeping the **backwards compatibility** and reusing the common infrastructure has become a must, as operators have largely invested in the optical distribution network based on power splitters (Fig. 1);
- higher **distance** reach, beyond 20 km, passively or with active optical reach extenders;
- higher **number of users** (split ratio) sharing the infrastructure;
- effective integration with the new generation **wireless** networks,
  - using fiber as back- and front- hauling; with the increased power budget of the fiber access links,
  - the long spans cover wide urban and rural areas, thus devising and smoothly converging with the metro and core networks;
- other desirable features relate to incorporating enhanced **resilience, security, scalability**.

Optical access evolution

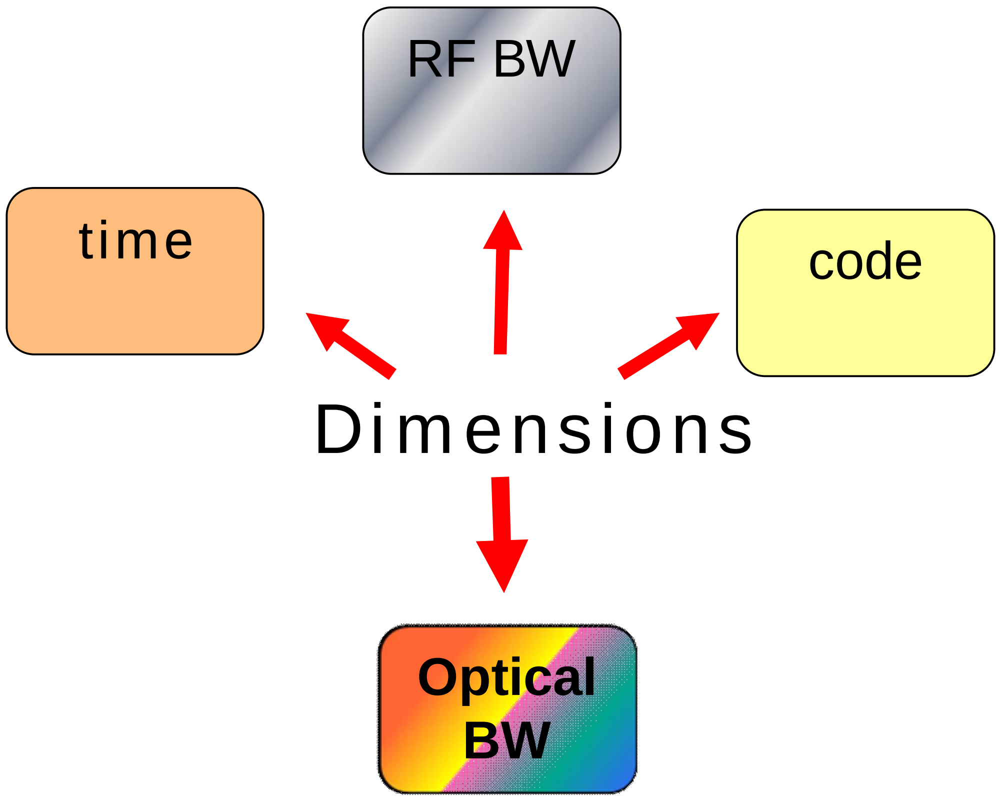


EU projects:

- ACCORDANCE
- SARDANA
- COCONUT
- EUROFOS NoE
- MUSE IP
- ALPHA IP
- OASE IP
- DISCUS IP

Domains to exploit

- **Electrical bandwidth**:
  - Increasing the transceiver bit rate up to **10 Gbit/s**, shared by up to 64 users dynamically, as defined in ITU XG-PON and IEEE 10G Ethernet PON standards.
    - → They incorporate **FEC** to reach the same power budget, typically around 28 dB.
    - → To reduce the power consumption, silent mode operation and bit-interleaving
  - **FDM** and **OFDM** for finer bandwidth granularity.
- **Code multiplexing**, with electrical or optical correlation coding in time or spectral domain;
- **Optical bandwidth: WDM**,
  - **Coarse WDM**, with service spacing of tens/hundreds of nanometers:
  - **Dense WDM**, where the upstream wavelengths have to be precisely generated and managed, in two versions:
    - → With wavelength multiplexer at ODN, and RSOA, ILFP..
    - → With splitter or with cyclic AWG at the optical distribution network, and ONU with thermally tuned distributed feed-back (DFB) laser and tunable filter.
  - **Ultra-dense WDM**, with coherent detection.
  - **Hybrid WDM and TDM, i.e. TWDM**,

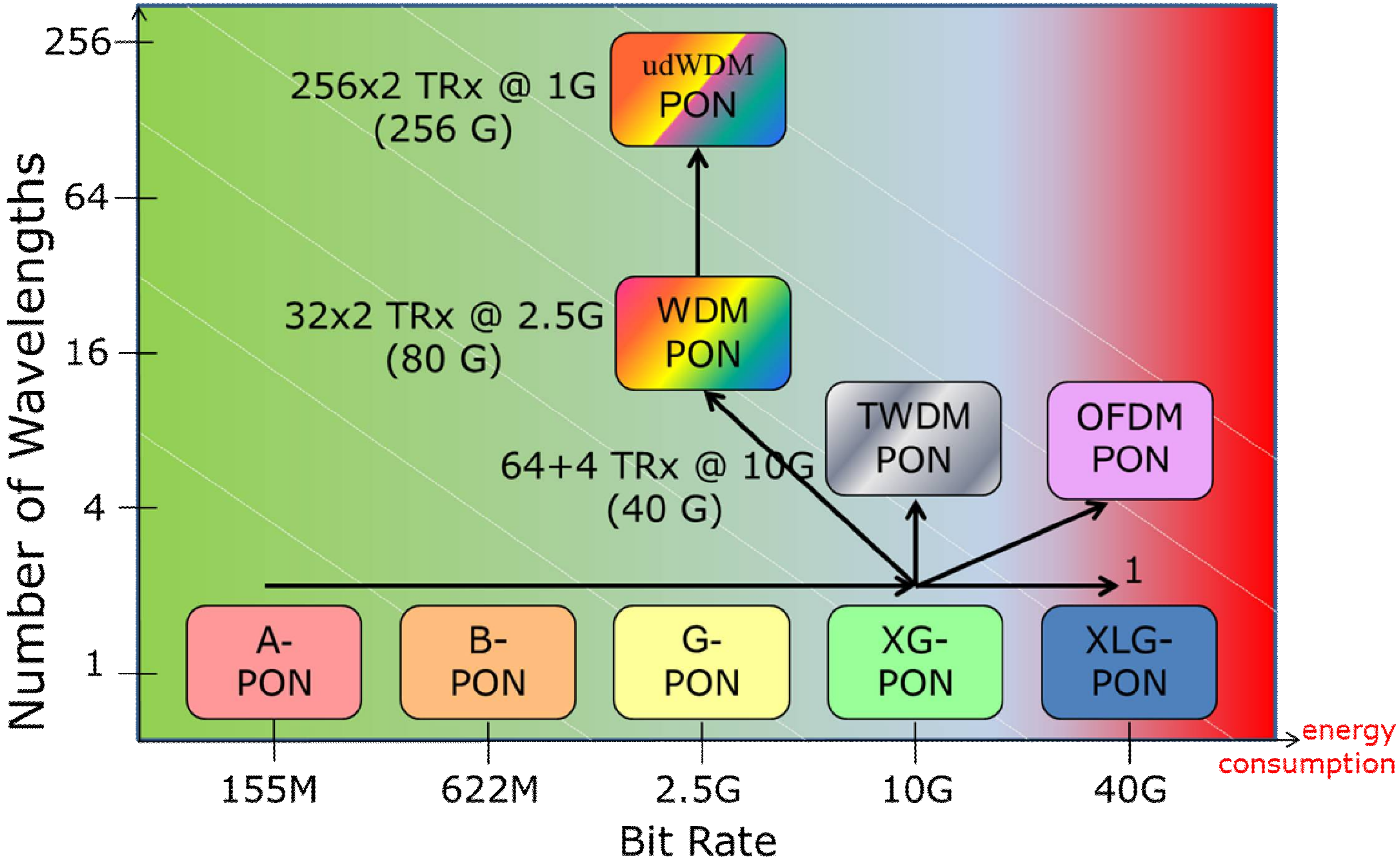


NG-PON: Technology Map

Aggr. BW = userBW x wRb/userBW x #wavelengths

1

- 1G to the Home
- 10G to the Antenna



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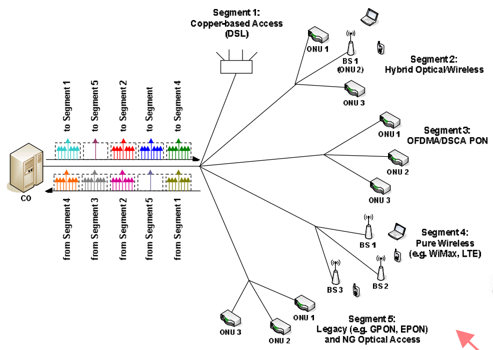
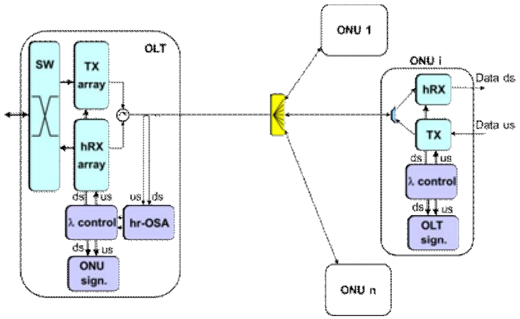
Advances in Science and Technology (with practical results)

- A self-seeded **WDM-PON** with RSOA ONUs, in a ring-tree architecture.
- The orthogonal **OFDM** with dynamic bandwidth allocation with straightforward subcarrier mapping to users and services, wired and wireless.
- Advanced **modulation formats** with simple fast electronics and colourless optics have been demonstrated, like duobinary, QAM, LDPC coding.
- **Ultra-dense WDM** is a new technique that efficiently exploits the optical fiber bandwidth to distribute hundreds of individual channels,
  - minimizing the wavelength spacing and making use of coherent detection;
  - > 40 dB of power budget
  - 6.25 GHz channel spacing have recently been demonstrated without significant increase of the transceiver complexity.
- back-haul and front-haul of **wireless** networks, reusing the fiber-to-the-home technology, for example,
  - in macro cells with MIMO antennas or
  - in high-density in-door pico-cell networks to deliver Gbits/s to the mobile users.
- new **devices** like tunable VCSELs, fast directly modulated DFB, and monolithic integration of transceivers.

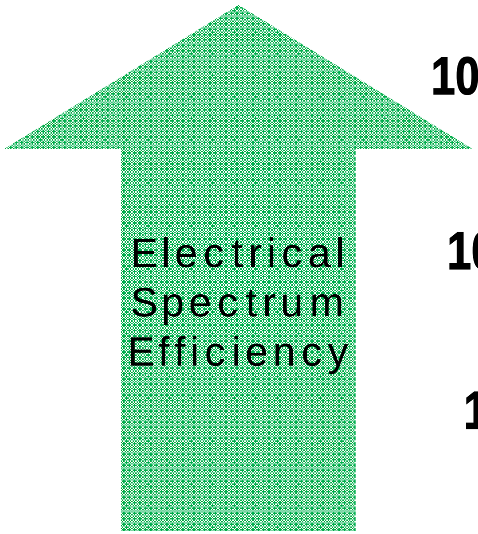
E/O BW & power Efficiency

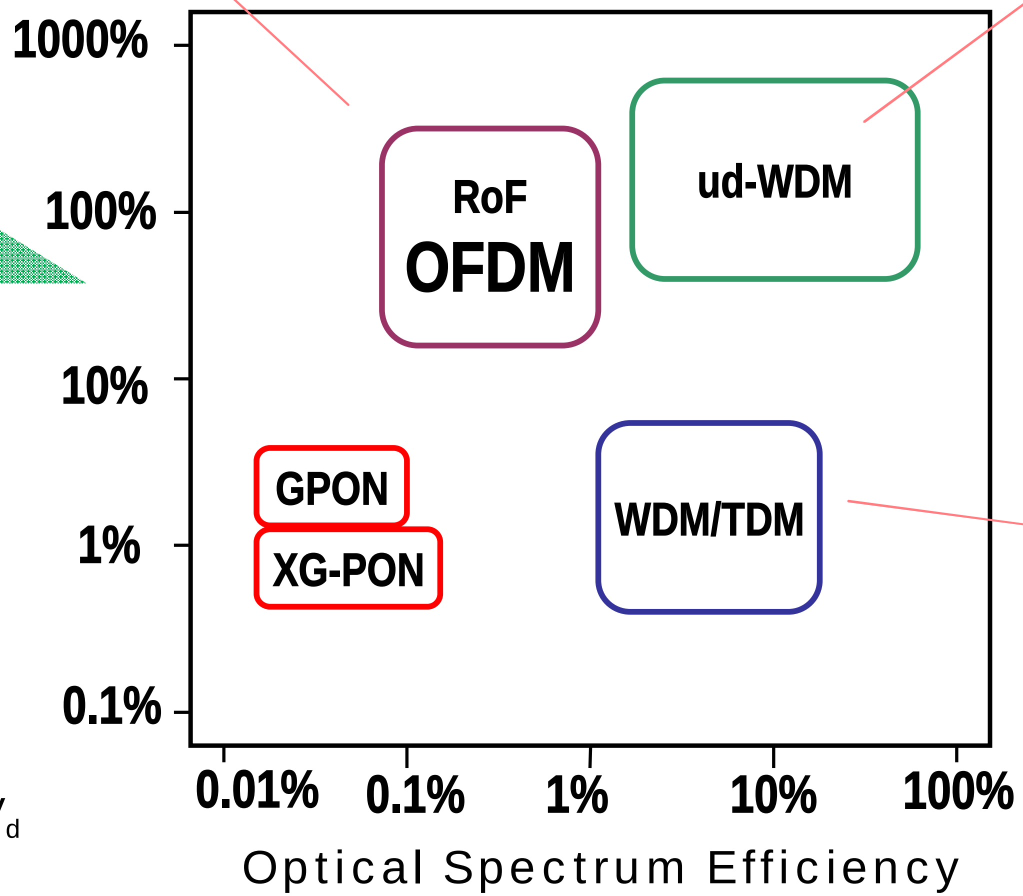


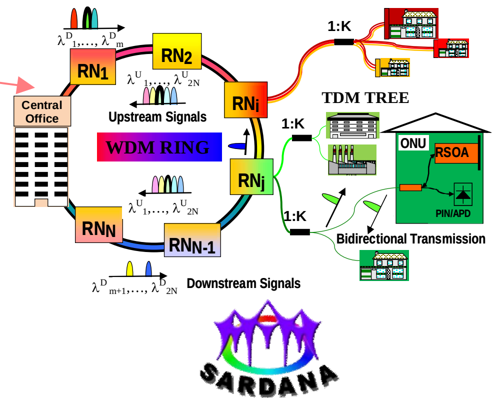


- Statistical WDM multiplexing
- Time-switched phase diversity&modulation

$EF = R_b / BW_\Delta$







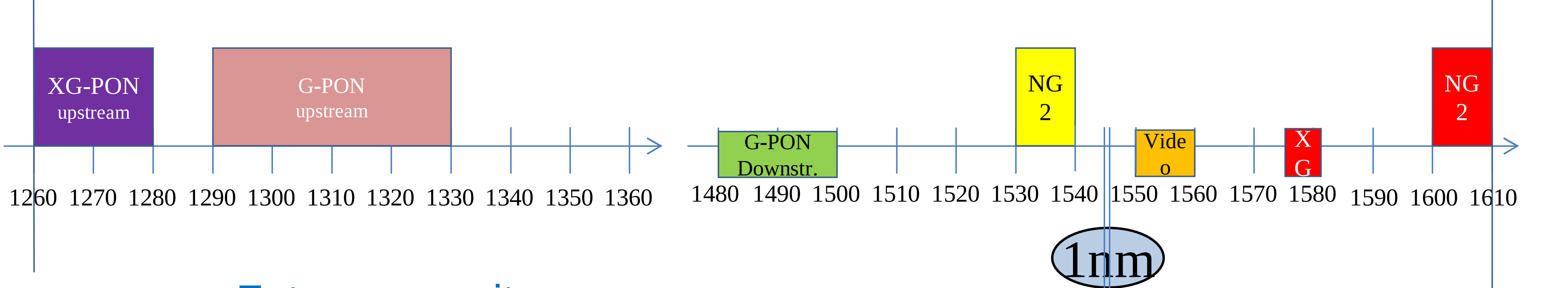
PowerComsumption:

$= \alpha\, C\, V_d^2\, \mathbf{f_r} + I_o\, 10^{V_t/S}\, V_d$

x Activity %

PON Optical spectrum

FSAN-ITU Standards: 6 wavelength channels

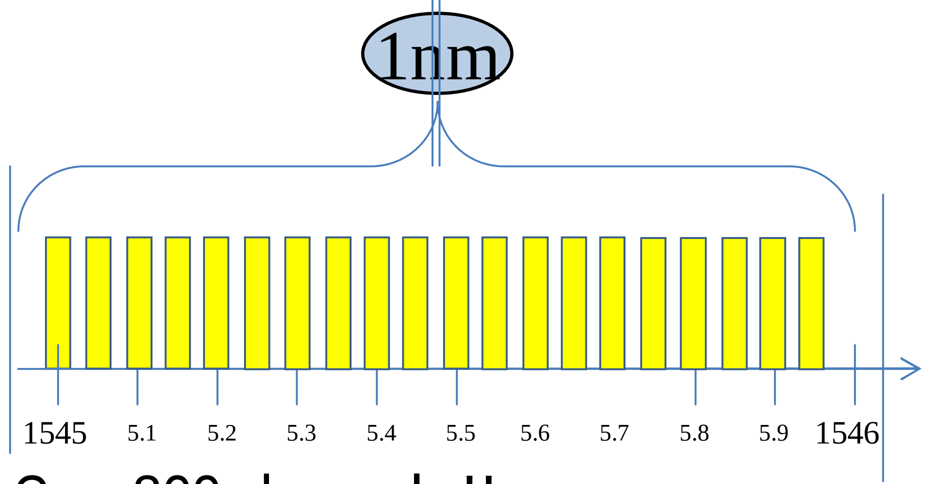


Future capacity:

(our COCONUT proposal for ngPON3)

20 wavelength channels / nm

6.25 GHz = 0.05 nm / channel



- **40 nm, for compatibility:** 40 nm / 6.25 G = 800 channels !!
  - CAPACITY x 80 !!
- **full band 300 nm**: 6000 channels (6 Tbit/s)
  - CAPACITY x 1000 !!

By: Coherent UD-WDM with random-wavelength DFB lasers

Conclusions

Technologies and techniques to enhance x10 the current FTTH networks exist and can be affordable (cost?)

FTTH → λTTH

THANKS!

back-up slides :

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- With the fiber reaching the user premises, and the bandwidth demands exponentially increasing even beyond 100 Mbit/s per user that today PON systems can hardly offer, telecom operators require an **unconstrained upgrade** path and set the next generation PON systems. They will benefit from the huge potential bandwidth of the installed fiber.
  - Different upgrading technologies are being proposed by industry, standard bodies and research institutions, mostly defined by their point-to-multi-point multiplexing form.
- **Architectures** are typically based on
  - tree topology, with one or two splitting stages, sharing the maximum length of feeder fiber and optical line terminal ports;
  - ring and bus topologies have also been demonstrated for protection and load balancing [1,2].

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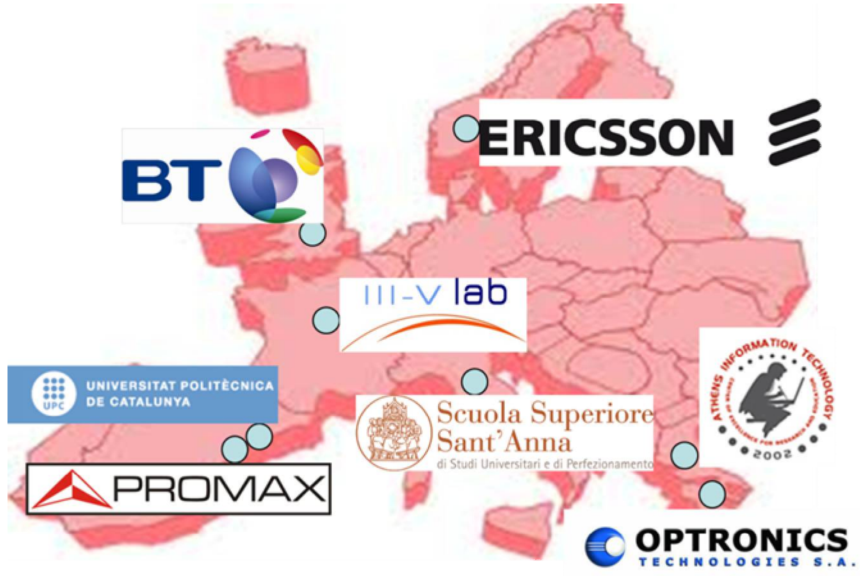
COCONUT MAC and wavelength control requirements

- robust ONU activation system
- inclusion of frame messages to report wavelength tuning availability and control the ONUs to tune to specific channels.
- common protocol for bandwidth over the wavelength and over the time dimension (sWTTU).
- QoS differentiation and inclusion of traffic classes with low delay guarantees

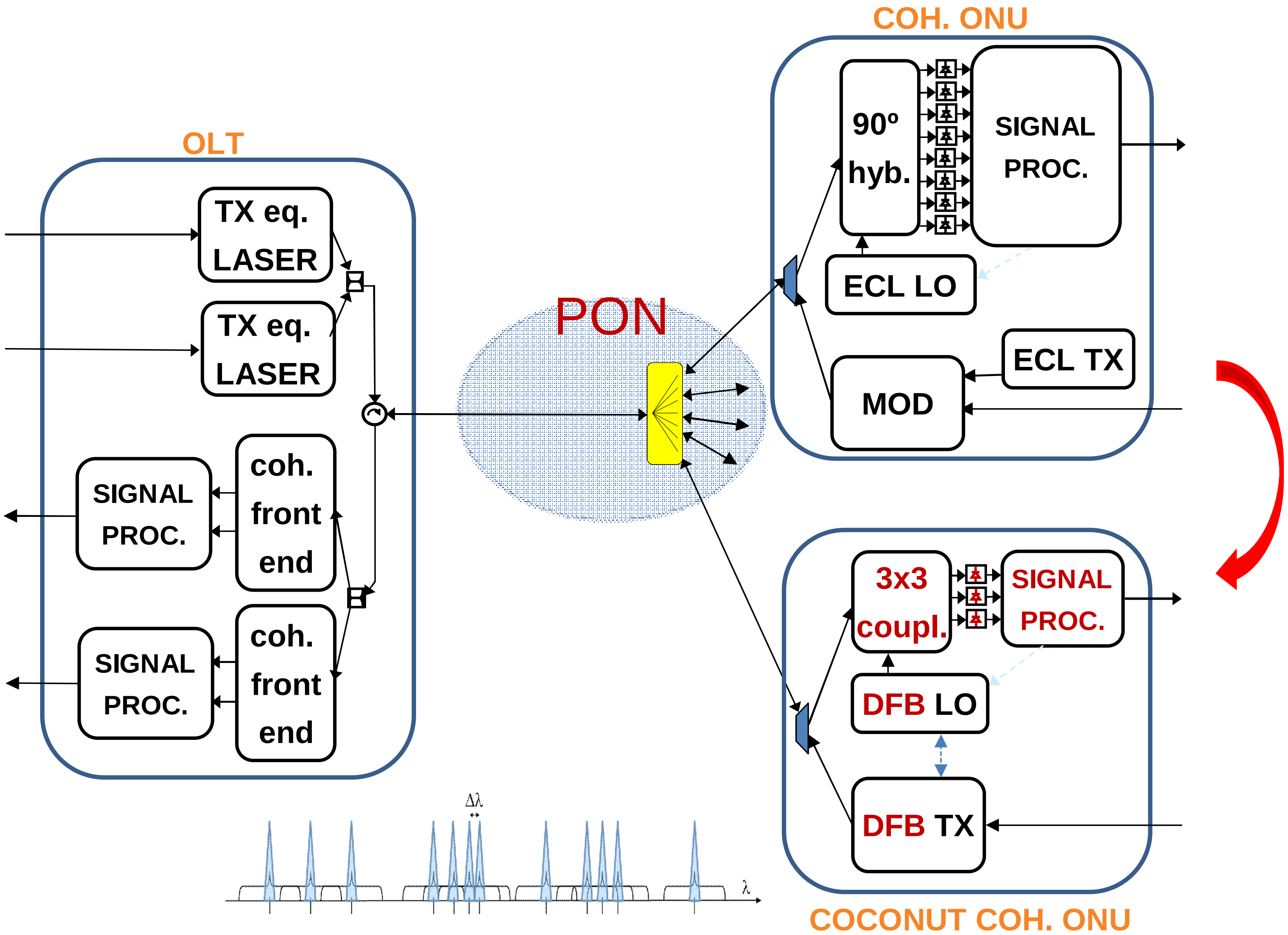
COst-effective COhereNt Ultra-dense-WDM-PON for lambda-To-the-user access

- STREP 318515, ICT Objectives 1.1 a) b)
- 1st-Nov 2012 + 36 months
- Coordinators:
  - SSupSA (Ernesto Ciaramella)
  - Vice-coordinator: UPC (Josep Prat)



- GOAL: efficient **λTTH**
  - 1G-to-the-Home + 10G-to-the-Antenna
  - By: ultra-dense WDM-PON, by:
    - Statistical WDM multiplexing
    - Simplified coherent transmission

Simplified hardware



- Can we improve the spectral efficiency in both **optical & electrical** domains?
- ... and the total & user BW ?
- ... and the power budget ?
- ... and at a similar cost ?

Proposal: Coherent UD-WDM with random-wavelength DFB lasers

PON alternatives

	GPON	XGPON	TWDM-PON	WDM-PON	SCM/OFDM -PON	cUDWDM -PON
Aggregate BW	2.5/1.25	10G/2.5	40G/10G	>40G Depends on type	Good if combined with WDM	>40G
Granularity (min BW/user)				1 AWG port assigned	N subcarriers	1G-10G Good if +TDM
Complexity, cost			Tunable TRX ONUs	Up-stream or tunable laser	Upstream, PAPR, optical amplif. or coherent	Coherent RX, random/tunable lasers ?
Energy efficiency		BWuser / 10G	BWuser / 10G		If ONU only handles assign. subc.	User rate = line rate
Optical spectrum efficiency					Good if combined with WDM or coherent	
Power budget						best
Incremental scalability (n.,BW)				Limited by device, AWG, or RBS		
Compatibility				AWG	Sensitivity issue	Splitter if coherent det.

NGPON2/3 arch. features comparison

	XG-PON	TWDM	WDM/TDM-PON	OFDM-PON **	UD-WDM
Aggregate BW	10 GBit/s	40 GBit/s	320 GBit/s	10 - 100 GBit/s x8	512 GBit/s
User data*	50-200 MBit/s	50-500 MBit/s	50M-1G Bit/s	100 MBit/s	1 GBit/s
Bit rate	10 GBit/s	10 GBit/s	10 GBit/s	10 - 100 GBit/s	1 GBit/s
ONU Elec. BW	kHz - 10GHz	kHz - 10GHz	kHz - 10GHz	Fi – Fi+50MHz	MHz - 1 GHz
Elec.Spectrum Eff.(up)	0.5%	1%	0.5% - 10%	< 200%***	< 200%
Number of users	32	128	512	128	512
Wavelength Channels	1-2	4-8	32	1-8	512
Wavelength Spacing	-	100 GHz	50 - 100 GHz	>50 GHz	3 - 12 GHz
Optical Spectrum Eff. (up)	-	10%	20-40%	1% - 20%	20 - 60%
Passive distance reach	20 km	20 Km	60 km	20 km	100 km
COST (per user, 1G, relative)	1	2	3 – 0.8	*26 - 1*	*10 – 0.8*
ENERGY C. (per user, relative)	1	1	2 – 0.8	*10 – 0.7*	*5 - 0.4*
Added features		compatibility	protection, metro-access converg.	wired&wireless convergence, SC-DBA	user independency splitter
Issues		Tunable ONU	Colourless ONU, Optical remote pump power	Up-stream OBI, PAPR, Sensitiv.	Wavel.tuning, polarization

*(typical-mean values) * Symmetrical PON; ** 16QAM; *** Only odd carriers used.*

What Light Source at Home for WDM ?

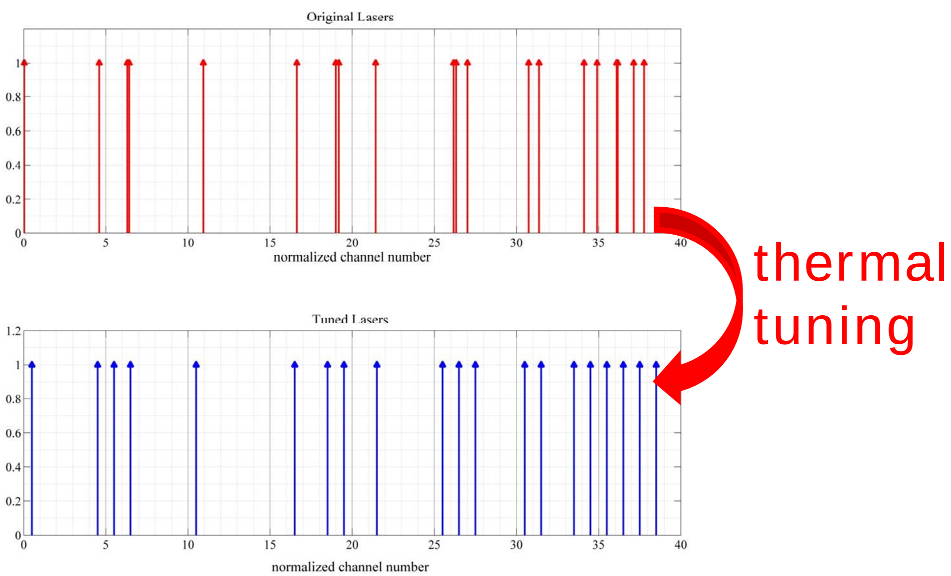
- Requirements:
  - All identical : colourless
  - Broadband : > 1GBit/s
  - User rate = Line rate
  - > 30 dB power budget

- Possible solutions:
  1. Tuneable laser : still expensive and non-repetible
  2. Reflective SOA : limited performances.
  3. Preselected SM lasers
  4. Random-wavelength SM laser !!! ?
     - → Statistical multiplexing
     - → limited thermal tunning
     - → CO adapts to ONU
     - → ... benefit of chaos ..!

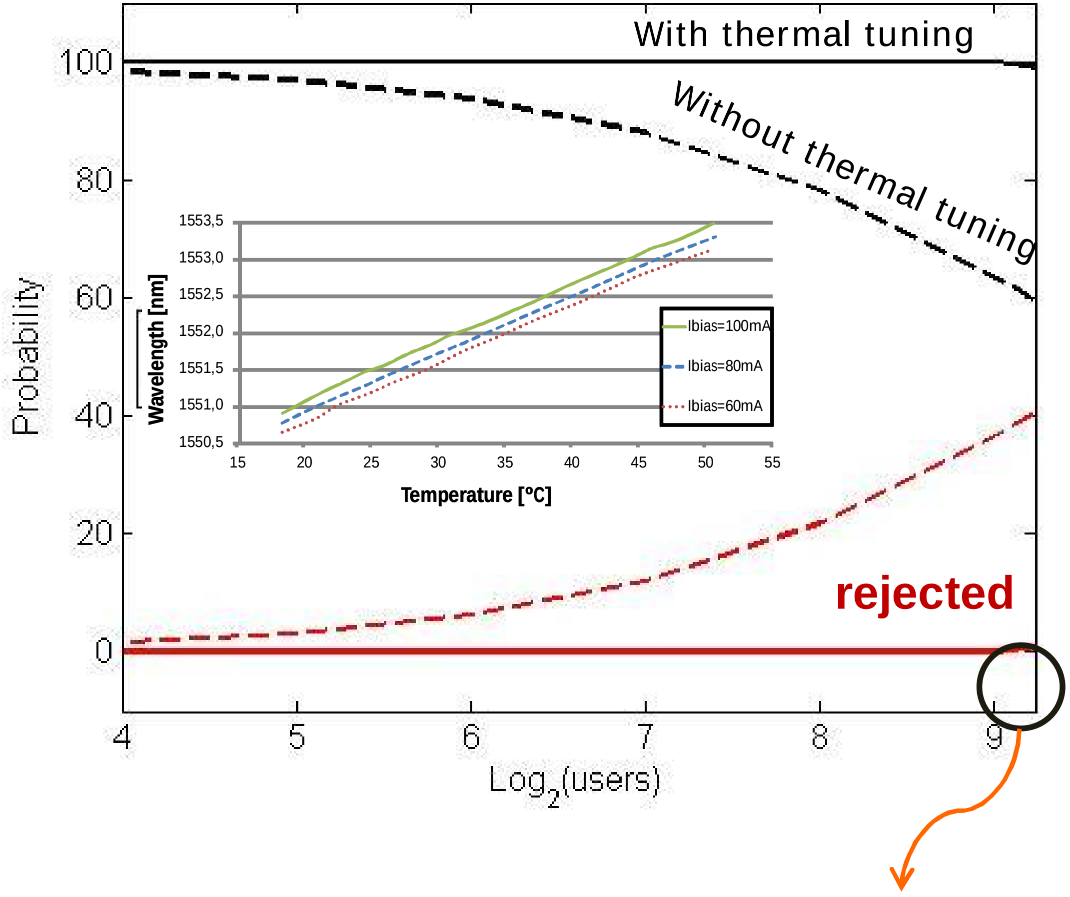
Figure 2. From left; a TEC based thermally tuned DFB in a TO package; a TTx and TRx ass
TO header); and a TWDM-PON XFP modul

Wavelength contention statistics

Spectrum distribution BEFORE and AFTER assignment.



- Grid= 6.25 GHz
- Total BW = 30nm
- Uniform laser statistical distribution
- Max. N. users = **600**
- Thermal tuning 2nm (DFB)



Channel efficiency:

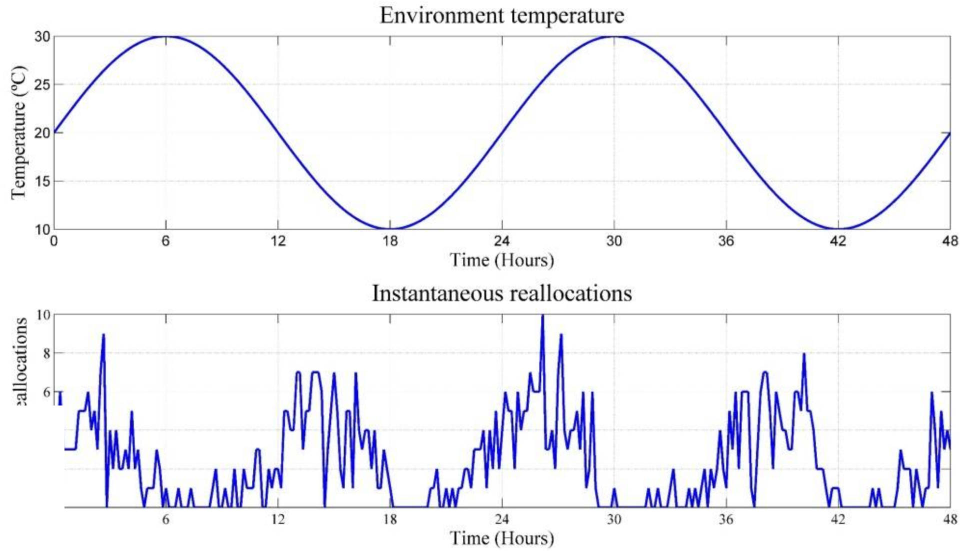
•511 / 600 = 85%

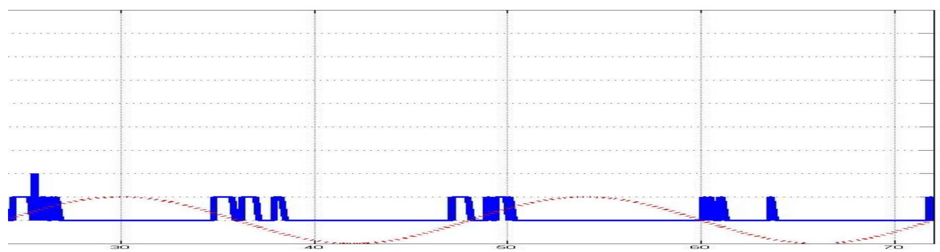
Environmental temperature variations

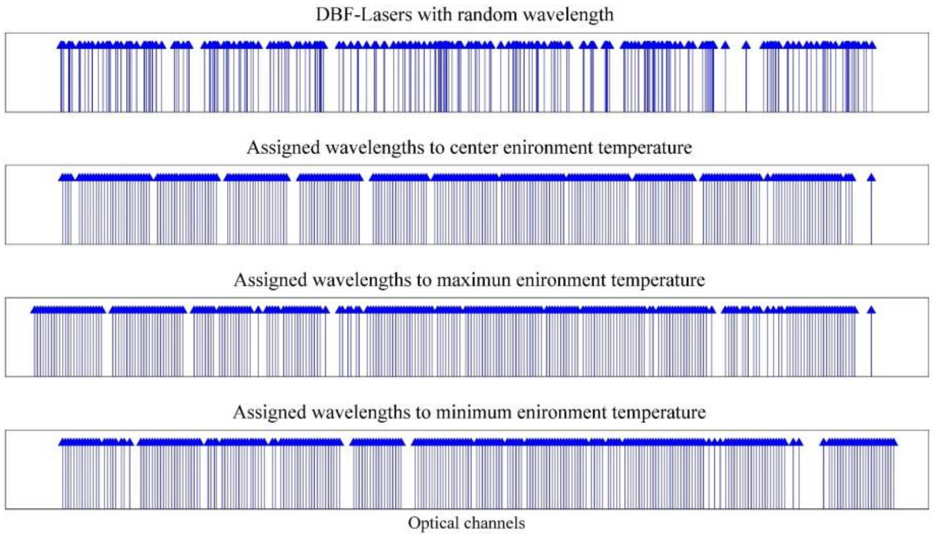
- Temperature variation:
  - 50% ONUs: Outdoor:
    - +/-10ºC dayly (cycles of 24h).
  - 50% ONUs: Indoor:
    - +/-2.5ºC (1-6 cycles in 24h, random)
- Tuning limits +-10ºC. C.
- 256 ONUs (2 lasers per ONU)

This example: 300 channels in C band to remark the blocking process

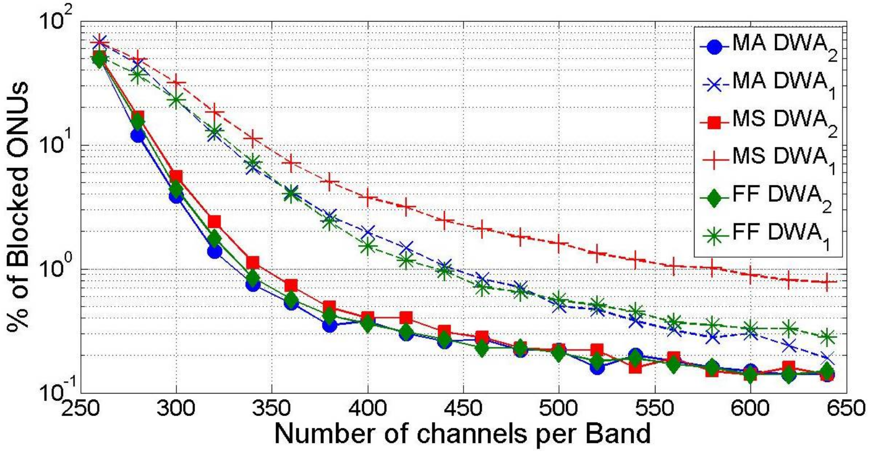
48 hours







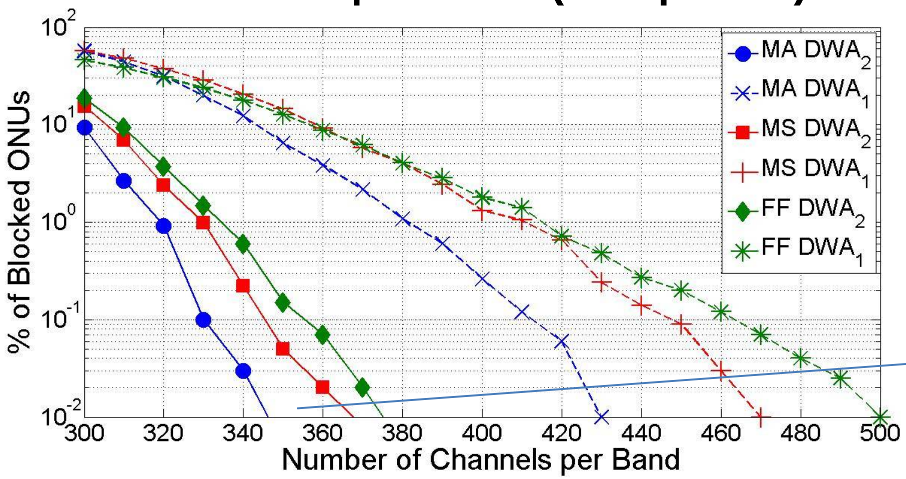
ONU blocking probability during operation using DWA with 1 or 2 reassignments. 256 ONUs.

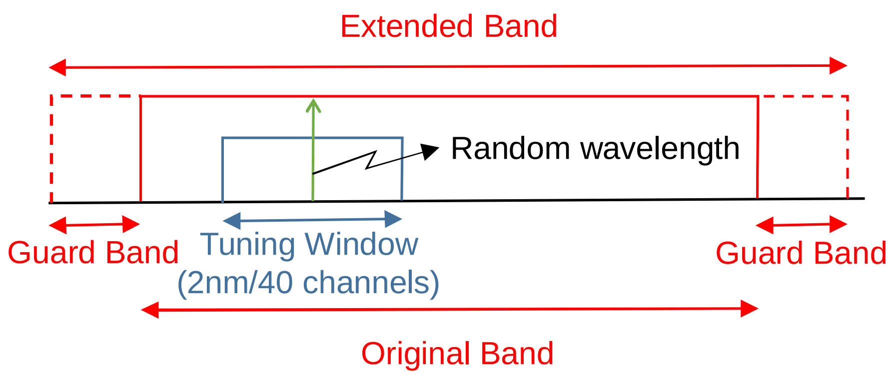


Under these temperature changes, a blocking probability floor (0.1% in a 32 nm band = 640 channels in C-band)

we propose to add a guard band at each side of the original band

ONU blocking probability using DWA with extended optical band (1 nm per side)





A negligible blocking probability (<10^{-2}%) is obtained with 350 slots.

[Sales PTL 1-2015]

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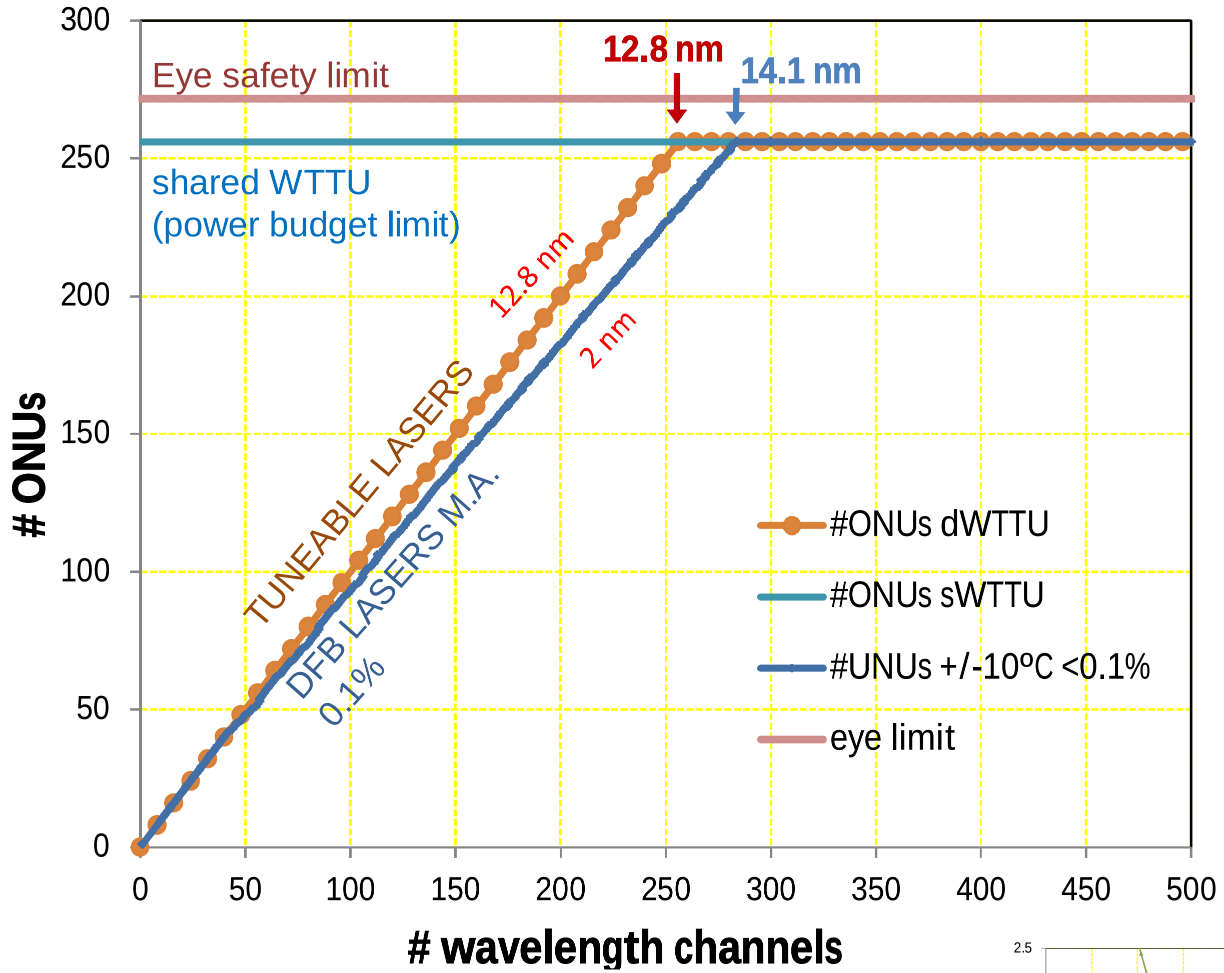
Optical Band

45 dB power budget
6.25 GHz spacing
2 nm tuning
Indoor case
0.1% blocking



- we only lose <10% (12.8/14.1 *100= 90%) in spectral efficiency when using DFB lasers instead of tuneable lasers!
- Sharing wavelengths can be useless if the optical BW > 15 nm.