SARDANA
A Next Generation PON with extended reach and debits

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Oveview of the talk

- SARDANA
  - Presentation
  - General motivations
  - Consortium
  - Network general presentation
  - Driving forces (Gpon actual…)
  - Technological solutions
    - Transmission
    - Remote nodes
  - Architectural solution coverage
- Conclusions

SARDANA

Scalable
Advanced
Ring-based passive
Dense
Access
Network
Architecture"

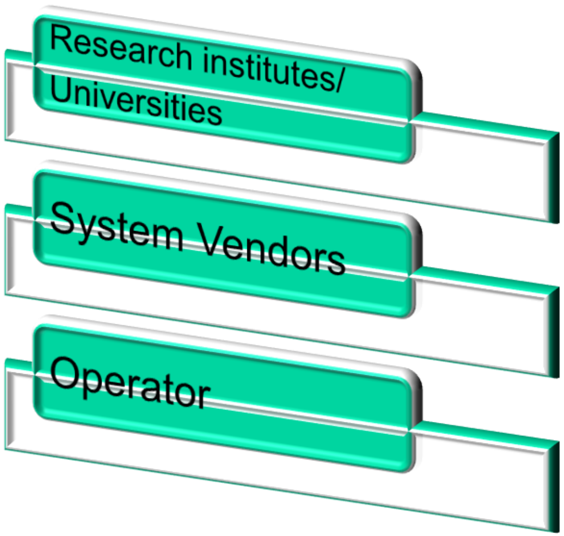
Activity: *ICT-1-1.1 - Network of the Future*
Grant agreement n.: *217122 (SARDANA)*
STREP: *2008-2010, 2.6 MEuro*

www.ict-sardana.eu

Increasing complexity

Who is doing it?

	Participant name	*Short name*	*Country*
1	Universitat Politecnica de Catalunya	UPC	Spain
2	France Telecom / Orange	FT	France
3	Tellabs	TELLABS	Finland
4	Intracom S.A. Telecom Solutions	IntraCOM	Greece
5	Instituto de Telecomumicações	IT	Portugal
6	High Institute of Communication and Information Technology	ISCOM	Italy
7	Research and Education Laboratory in Information Tech.	AIT	Greece



Who is doing it?

Profiles and expertises	***UPC***	***FT***	***TLB***	***ICOM***	***IT***	***ISC***	***AIT***
Netw.&Serv. Operator		X					
PON equipment provider			X	plann ed			
Service platform provider				X			
WDM-PON expertise	X	X					
Monitoring techniques					X	X	
Impairment compensation	X						X
Semiconductor photonics	X	X			X		
Remote amplification	X				X	X	
High bit-rate systems					X		X

UPC: **Coordination, ONU, RN subsystems.**

FT: **Architecture definition, ONU, Field-trial, Technical management, Techno-Economic studies.**

Tellabs: **GPON equipment, MAC, lab-demonstration.**

IntraCOM: **Management &Control plane, Service platform.**

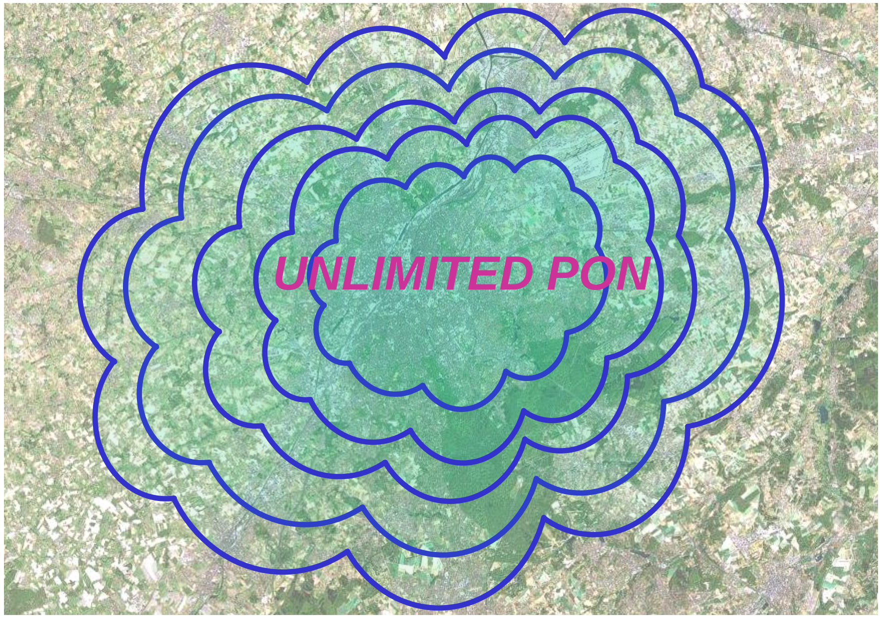
IT: **Monitoring system, non-linear transmission.**

ISCOM: **Remote nodes, non-linear amplification.**

AIT: **Electronic PON impairment compensation, Techno-Economic studies.**

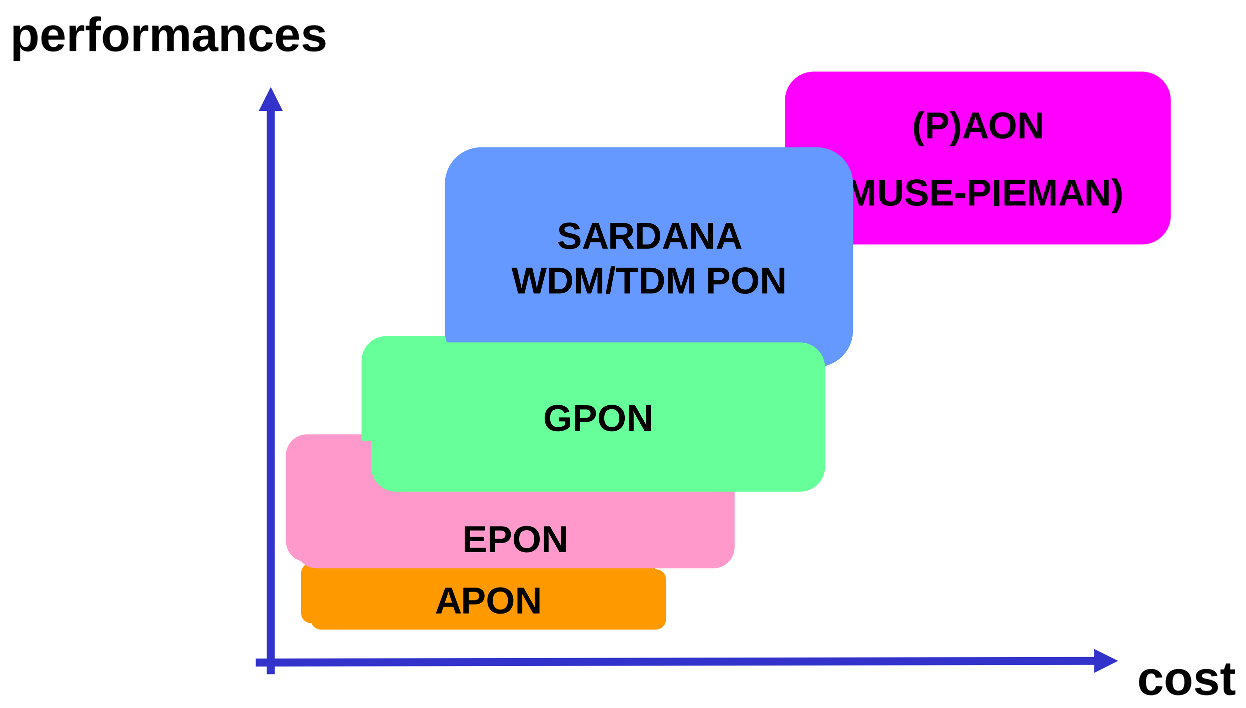
Fundamental goals

- **Maximize:**
  - N. served users (>1000 per fibre ring)
  - Served area (100Km)
  - Served capacity (10Gbit/s x 32)
- **Minimize:**
  - Infrastructure COST
    - N. Fibres / cables
    - N. Cabinets
    - N. Active areas
    - Civil work investments
- **Musts:**
  - Passive external plant
  - Single fibre access
  - Scalability and upgradeability
  - Compatibility with g/e-PON MAC
  - Robustness:
    - Protection
    - Monitoring and electronic compensation



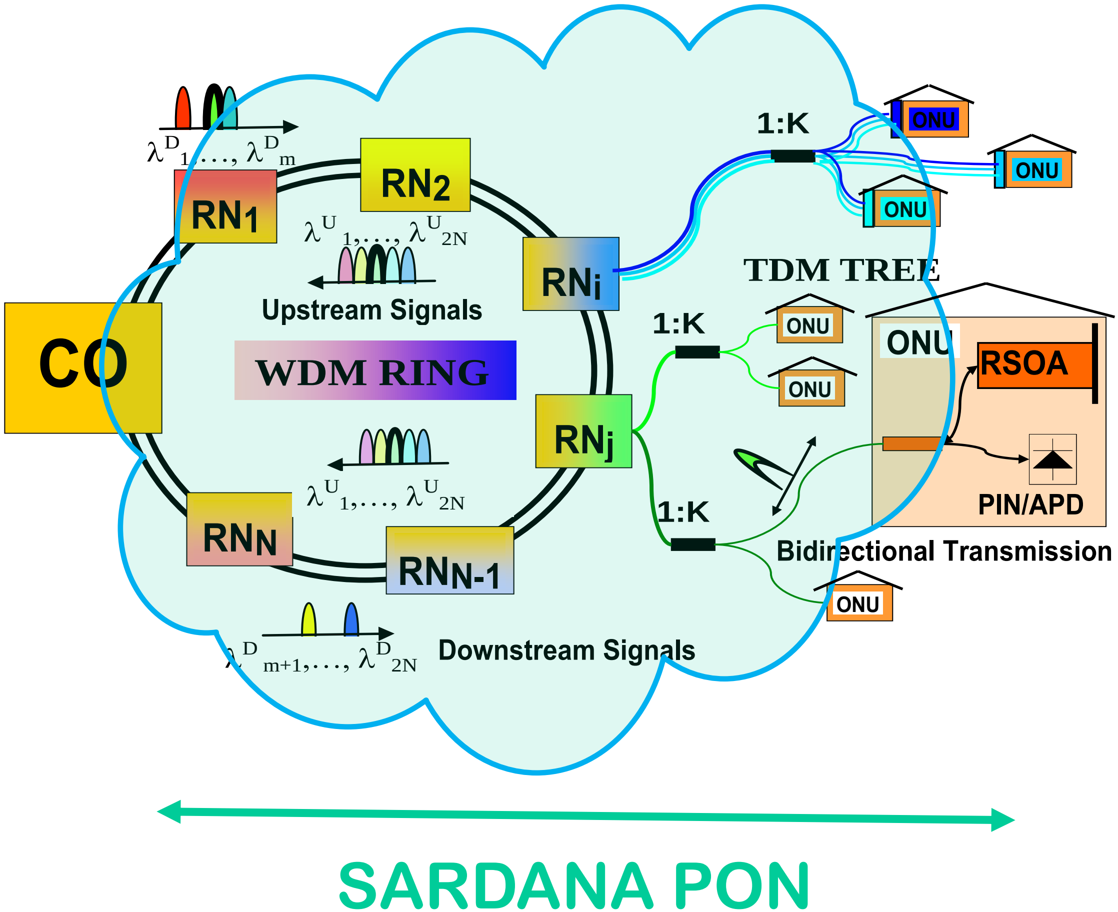
Positioning

- SARDANA aims at achieving:
  - higher performances (L, ONUs, BW, resilience) than GPON,
  - but at a <u>similar cost</u> (passive PON, reflective ONU, etc).

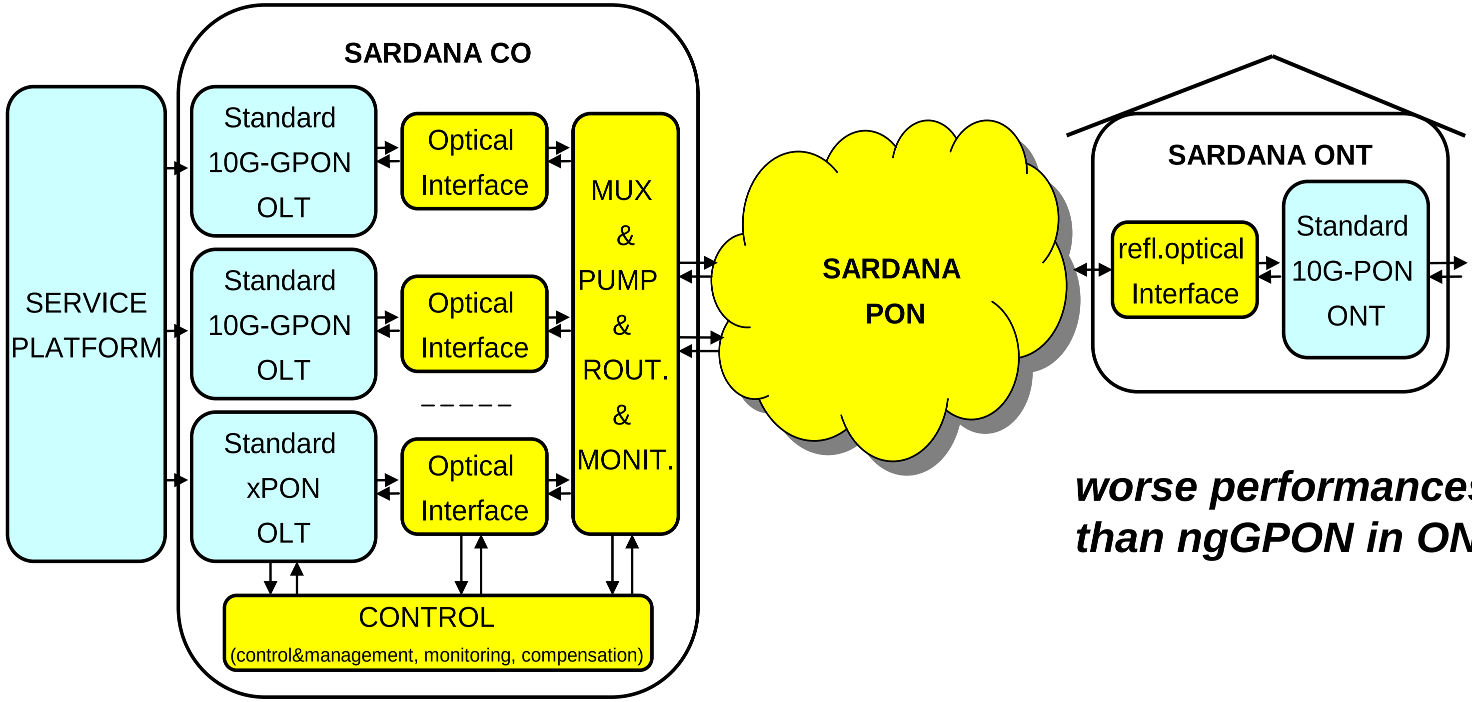


SARDANA architecture

- Resilient trunk
- Fully passive
- Hybrid:
  - WDM Metro ring
  - TDM Access trees
- Cascadable remote nodes
- Colourless ONU
  - RSOA
  - Tunable laser
- New adoption of remotely-pumped amplification
- Multi-operator
- Based on GPON, but transparent.



SARDANA equipment



worse performances of optics than ngGPON in ONU

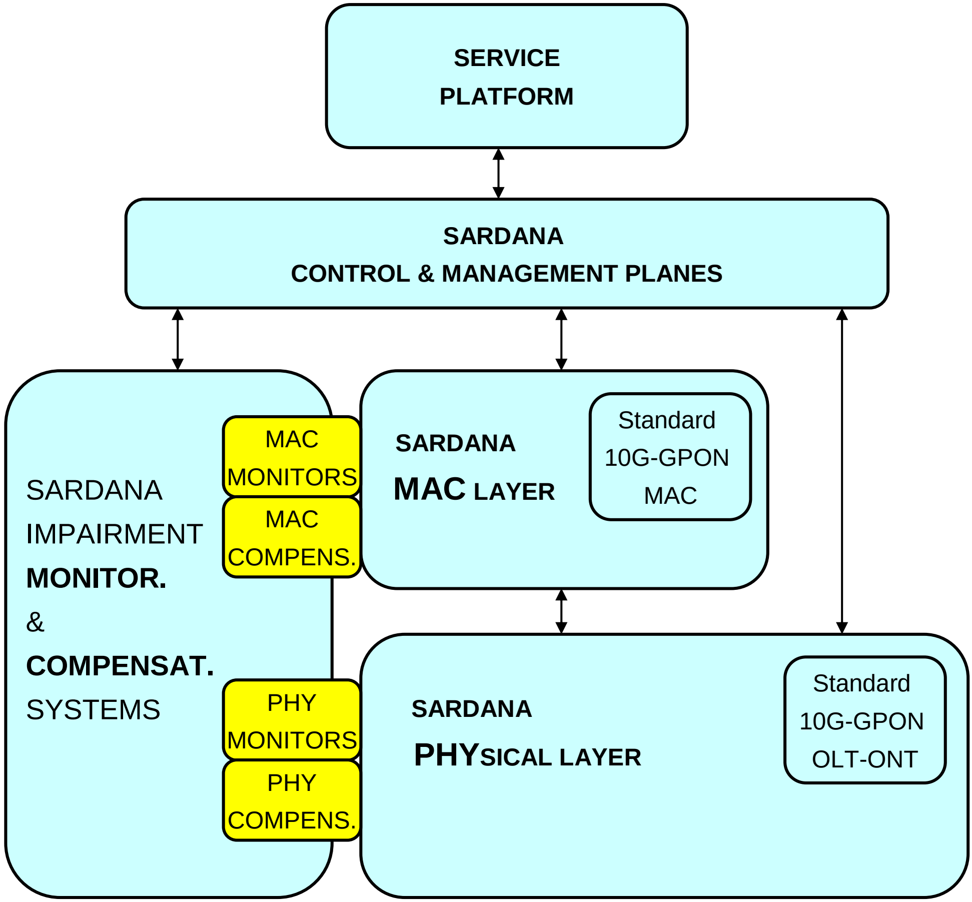
better optics than GPON in OLT

1. Added: **standard GPON (MAC) + SARDANA**
2. Integrated: **adapted GPON + SARDANA**

MAC, the Control and Management planes

FUNCTIONALITIES:

- Resilience
- Multi-operator capability
- Multi-rate coexistence
- Control&Management planes
- 10G DBA MAC
- In-service monitoring
- Impairment-aware routing
- Eye-safeness

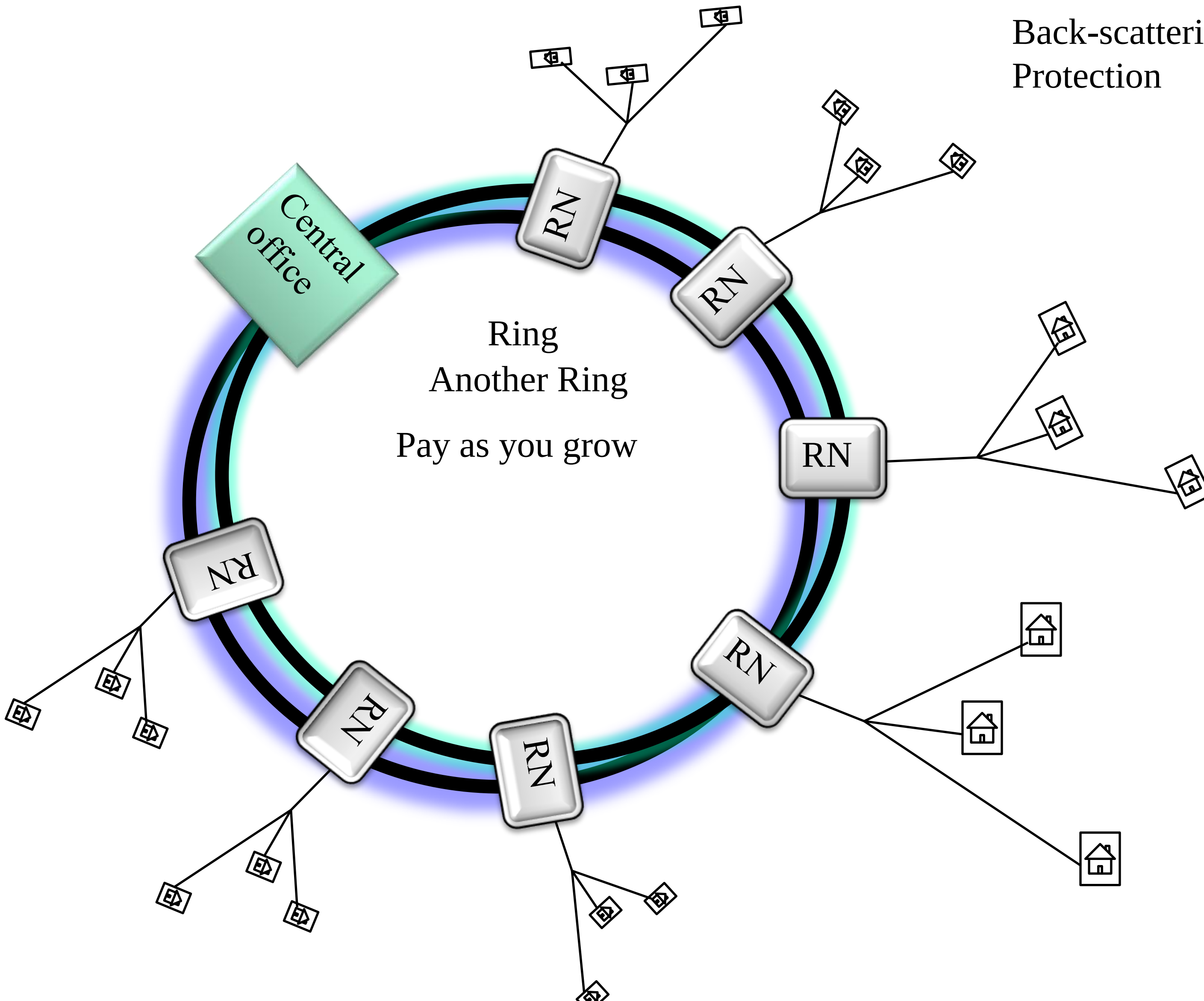


Functional layered model of SARDANA.

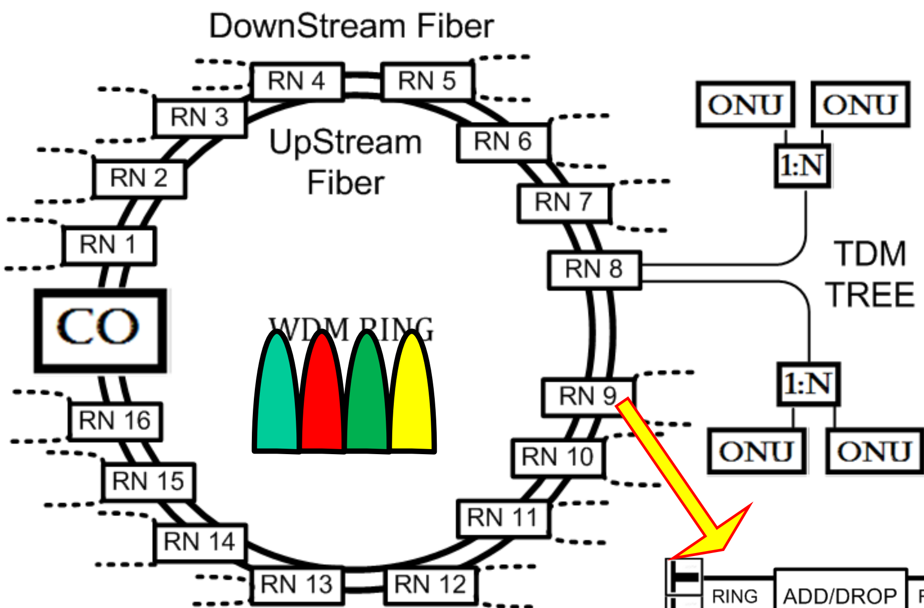
→ **Multi-layer system**

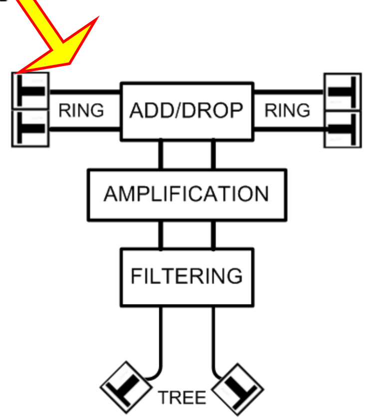
The evolution towards...

Back-scattering+
Protection



Sardana...

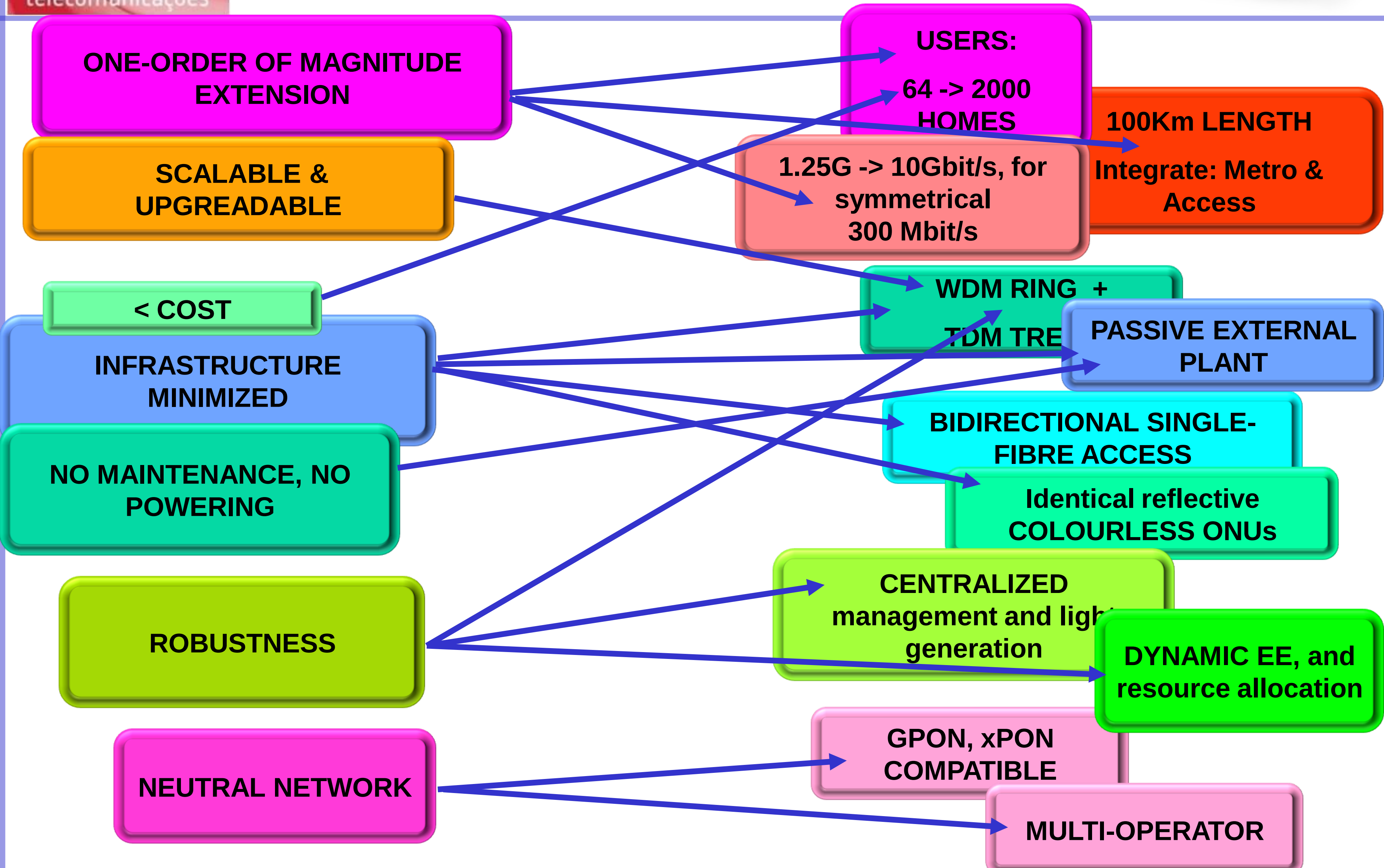




- ❖ Higher User Density >1000
- ❖ Long reach – 100km
- ❖ Symmetric 100Mbps

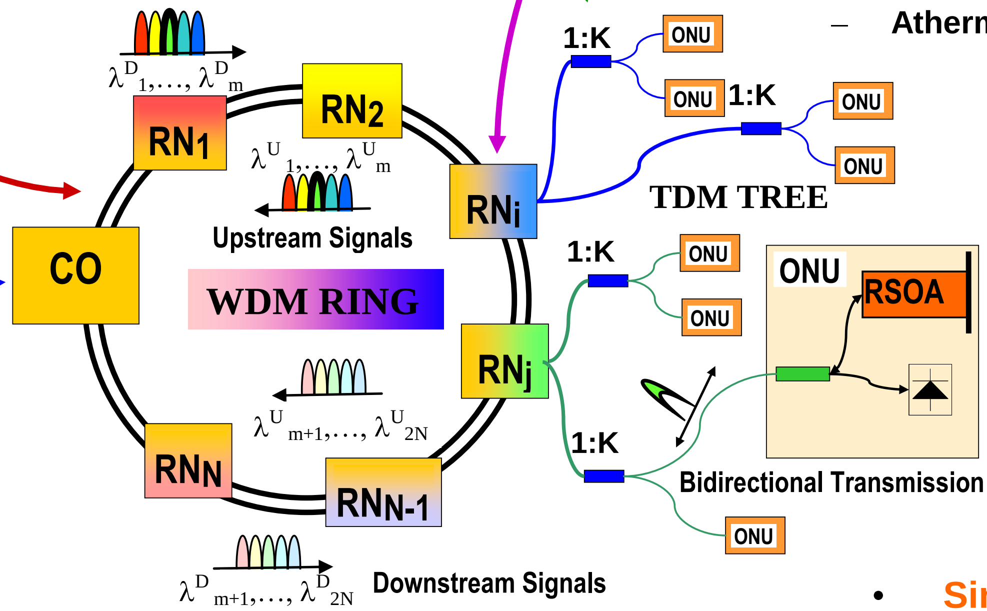
- ❖ Centralized light generation
- ❖ Passive Outside Plant
- ❖ Scalability
- ❖ Resiliency
- ❖ Traffic Balance
- ❖ Multi Operability
- ❖ Remote Amplification

Goals vs Approach



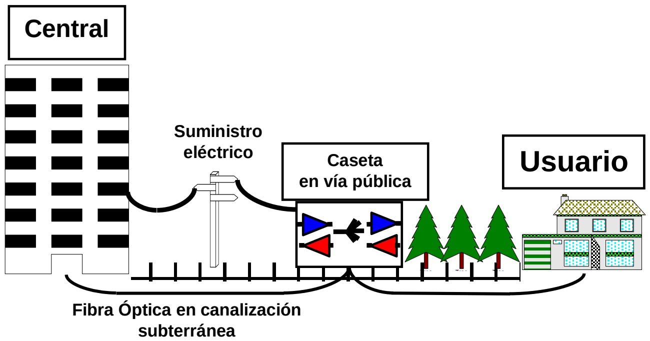
basic modules

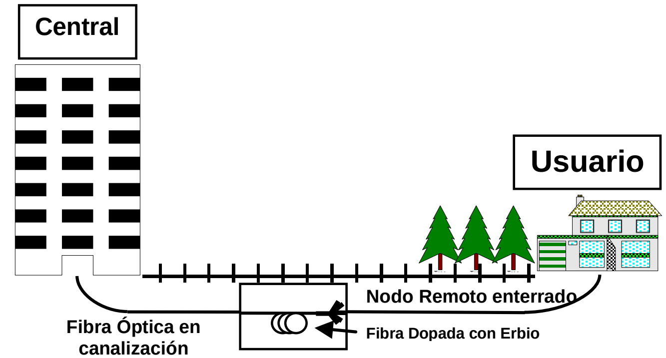
- **WDM ring: Transport & Resilience**
  - **up to 1.2Tbit/s (64 λ for 2000 users)**
- **TDM trees:**
  - **Up to 3 λ for 3 operators sharing common infrastructure.**
- **Passive Remote Nodes (RN):**
  - **Cascadable Add&Drop**
  - **2-to-1 fibre interface**
  - **Remotely pumped (from CO) optical amplification by EDFs**
  - **Athermal splitters and fixed filters**



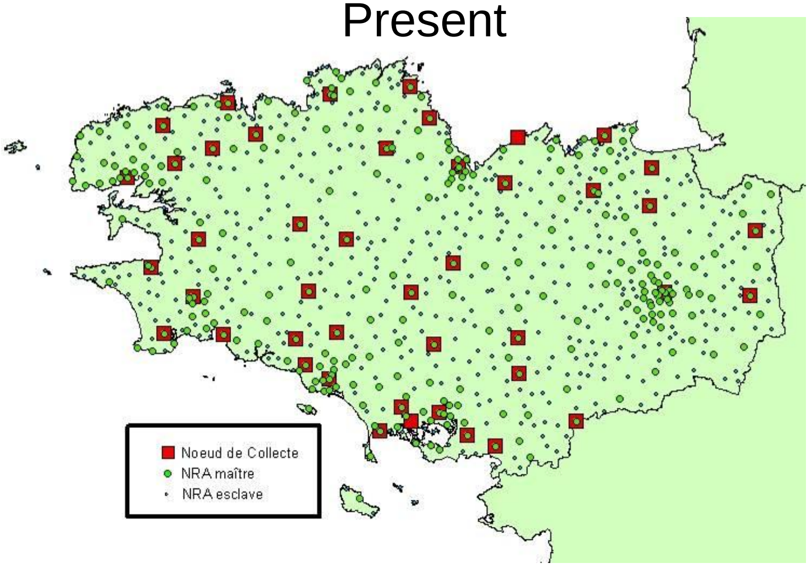
- **CO (OLT):**
  - **Centralizes the light generation and control**
  - **Stack of lasers serving TDM trees**
  - **Standard G/E-PON equipment adapted to SARDANA**
  - **WDM is used for wavelength routing at the central ring**
  - **DBA techniques for TDM trees.**
- **Simplest colourless ONU:**
  - **In line with techno-economical guidelines**
  - **High speed RSOA of SOA+REAM for up-stream remodulation**

Impact over infrastructure

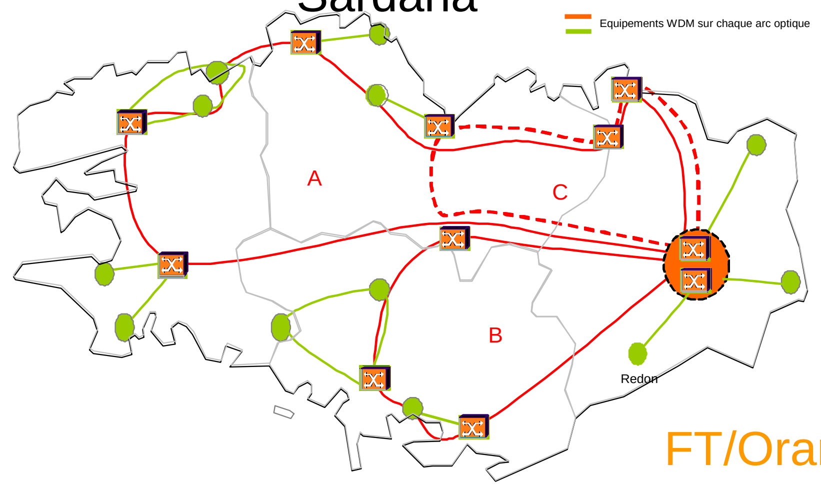




Present



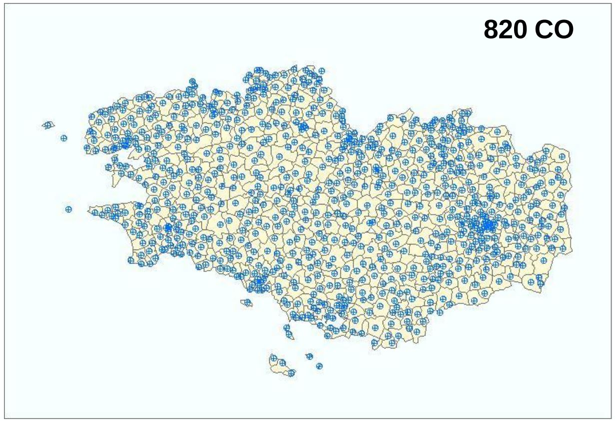
Sardana

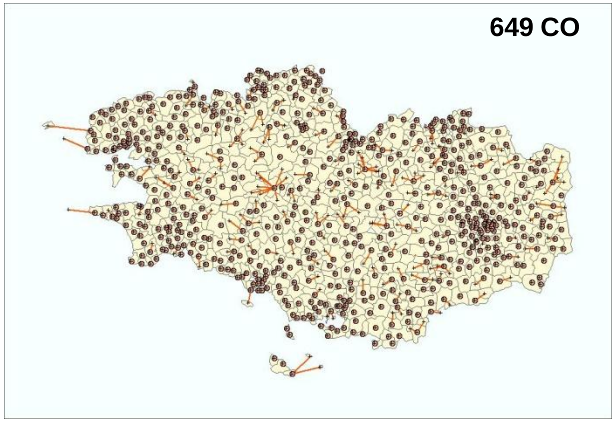


FT/Orange (specimen)

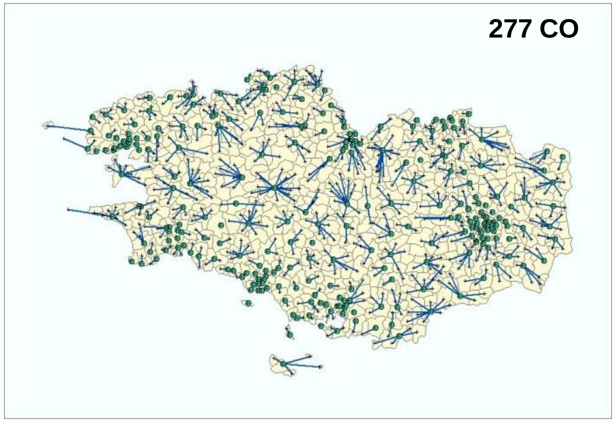
- Elimination of maintenance in external fibre plant.
- Reduction of the number of active central offices.
- Integration: Head-end & Metro node

Impact of OLT location

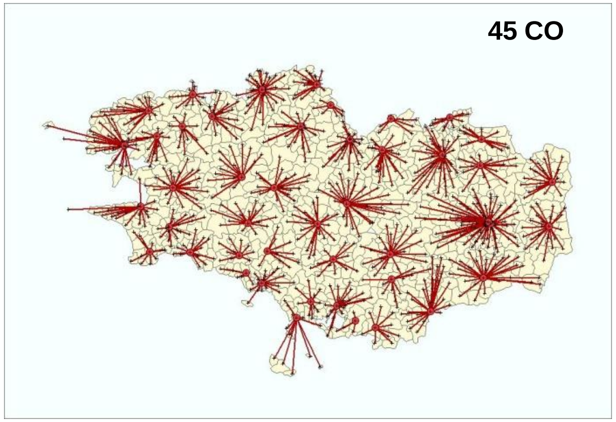




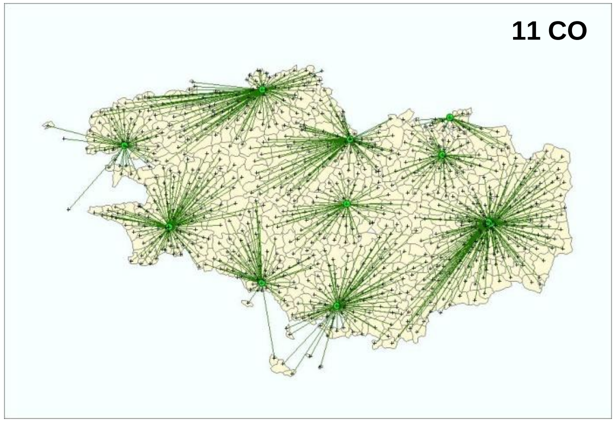
DSLAM with fiber link



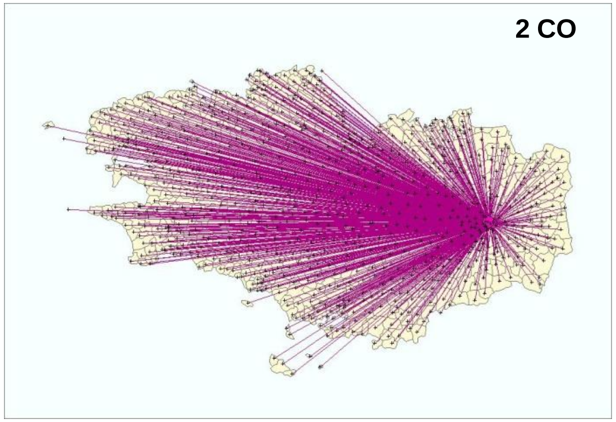
Master DSLAM



Edge node on 1st and 2nd transmission ring

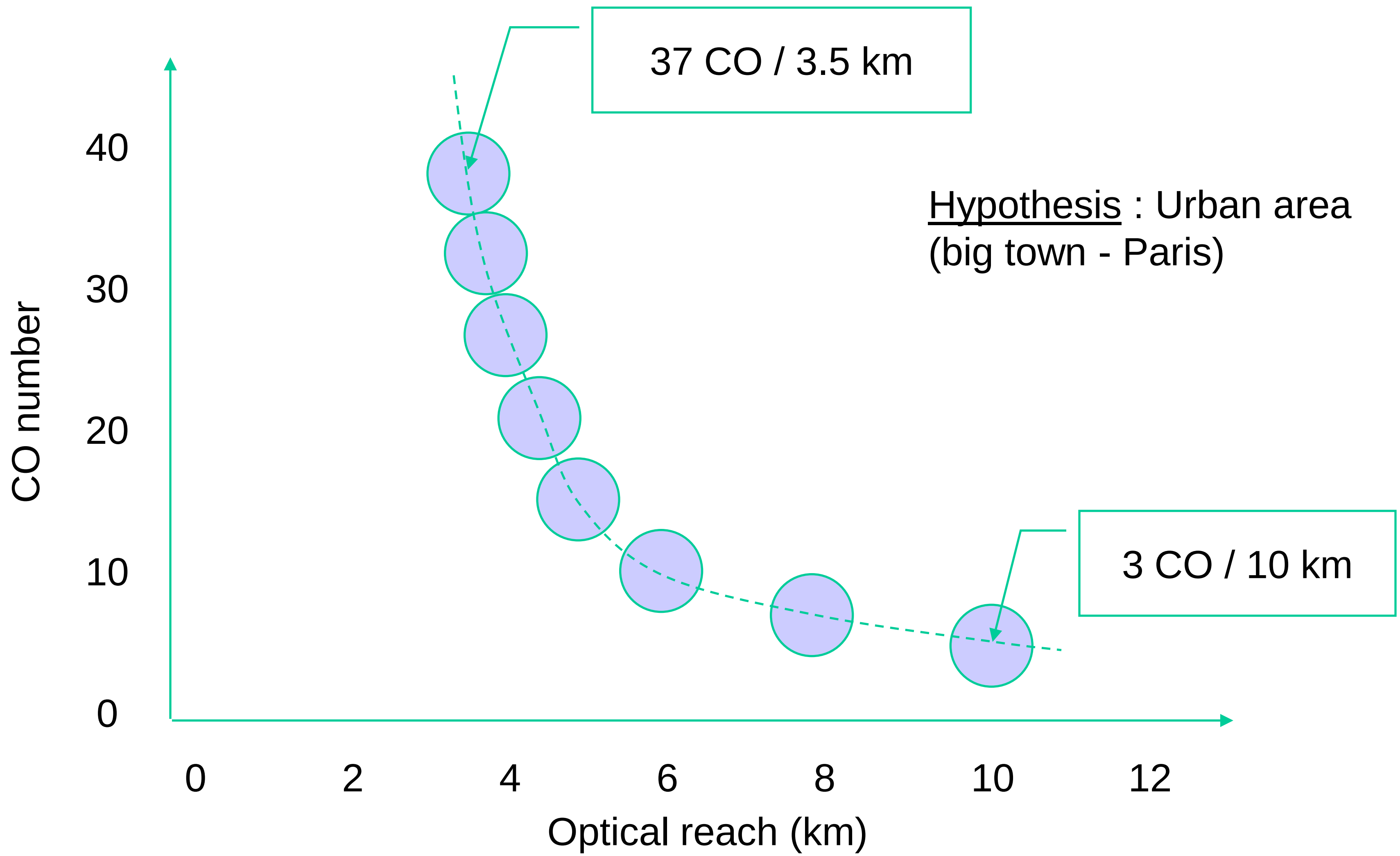


Edge node only on primary transmission ring

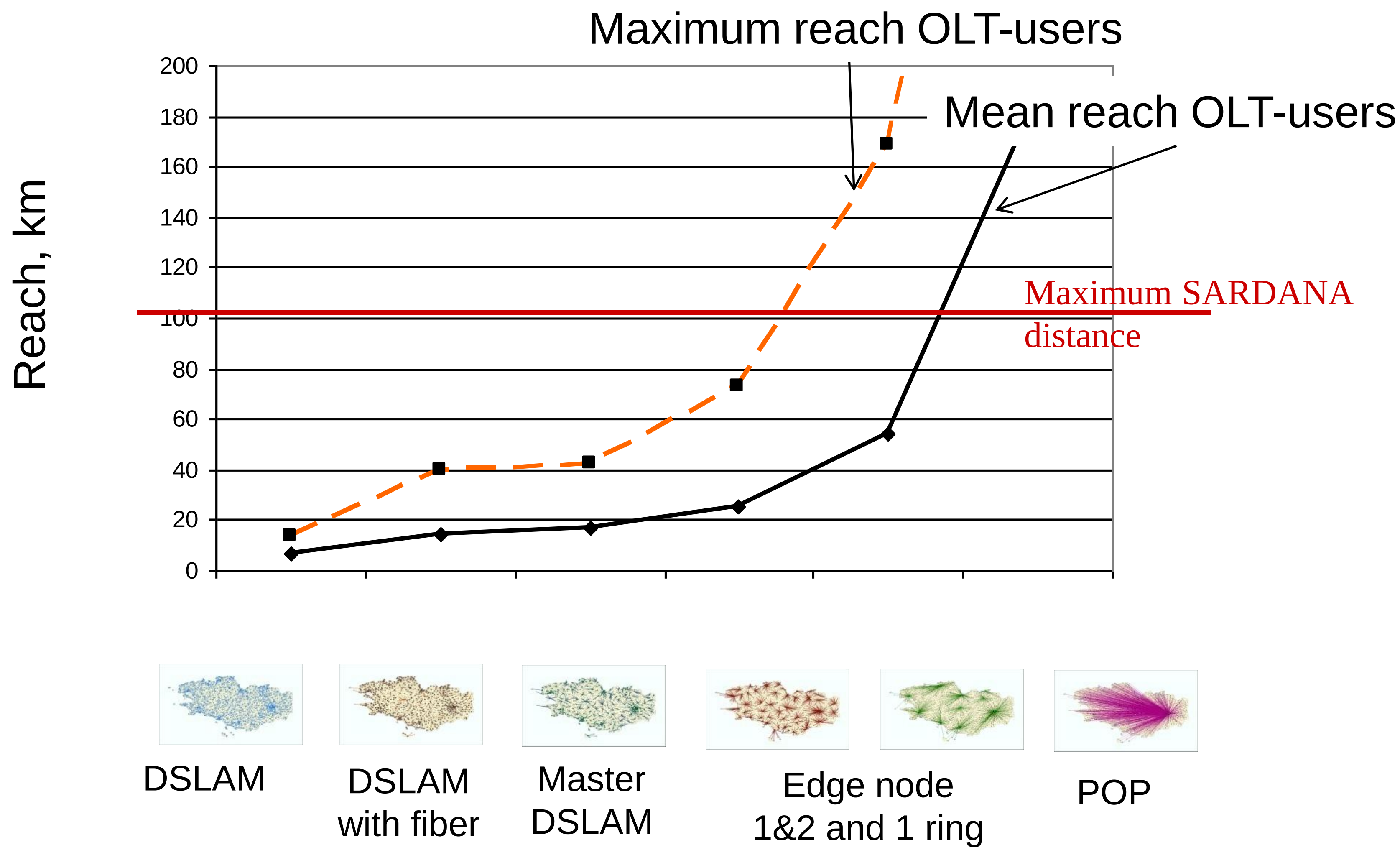


Point of Presence POP

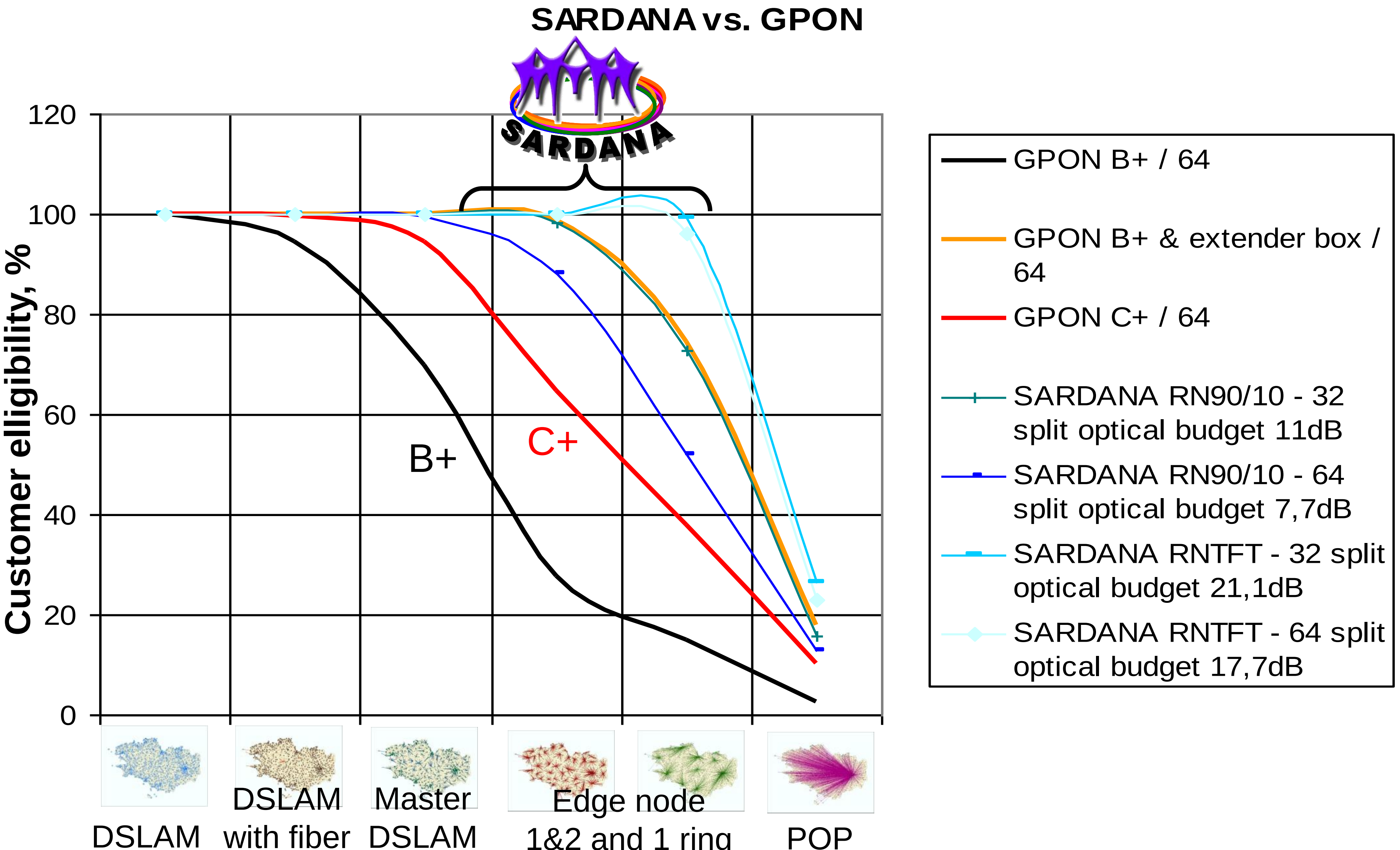
FTTH impact on network architecture



Impact of OLT location



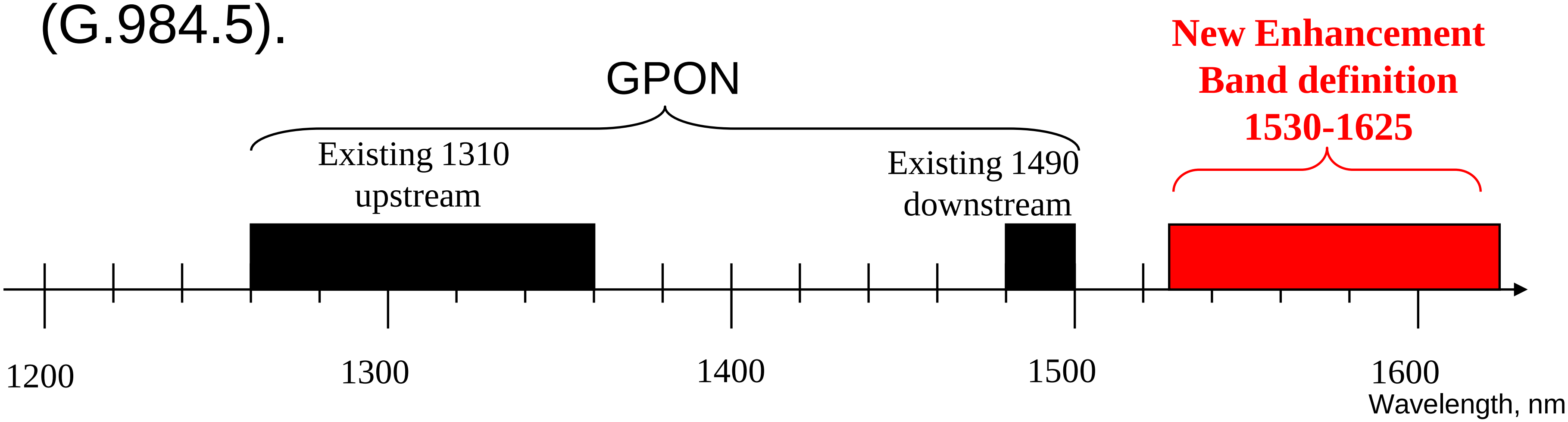
ELIGIBILITY

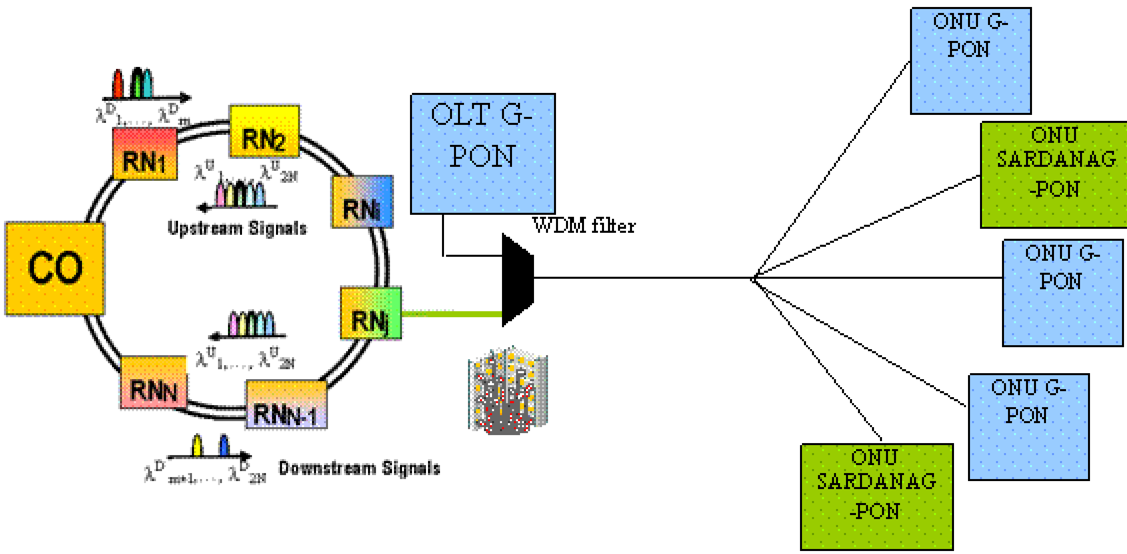


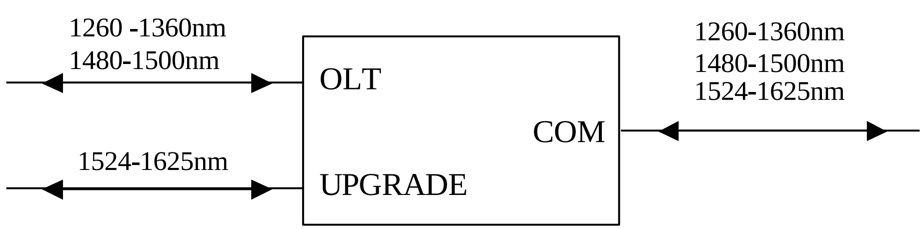
GPON evolution

- Migration topics :
  - We are focussing on a fibre lean scenario where Next Generation Access solution coexists on same fibres as GPON
  - Maximum re-utilization of optical infrastructure installed (ring and ODN)

- Wavelength plan allocation
  Use the WDM to achieve system generation overlay (G.984.5).







MUX "WDM1"

Specification	Value
Loss without connectors – G-PON wavelength span	< 0.7dB (1260-1500nm)
Loss without connectors for enhancement bands	<1.0dB (1524-1625nm)
Isolation – COM – OLT (1524-1625nm)	TBD (> 30dB (higher values may be required depending on the application))
Isolation – COM – UPGRADE (1480-1500nm, 1260-1360nm)	> 30dB
Max optical power	+23dB
Return Loss	> 50dB
Directivity	> 50dB
NOTE 1 - The wavelength range of 1524-1530nm should not be used by NGA downstream signals. NOTE 2 - The specification of WDM1 in the range of 1625-1660 nm for applications such as inserting an OTDR signal onto the PON is for future study.	

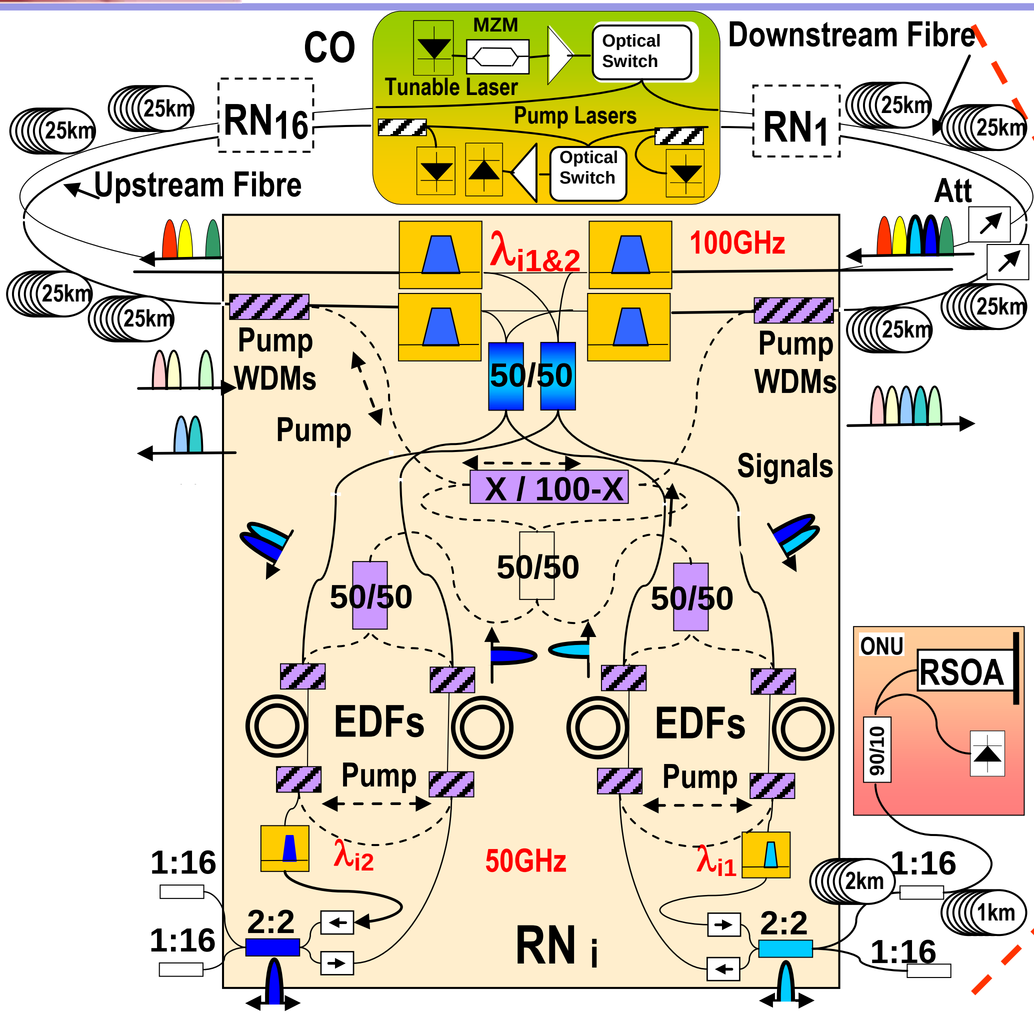
Standardization position

- Standardization :
  IEEE 10GEPON : (standard for end of 2009)
  - 3 classes (20 – 24 – 29 dB)
  - Wavelength allocation :
    - Upstream : 1270nm [1260 -1280nm]
    - Downstream : 1577nm [1575-1580nm]
  - SARDANA could use IEEE chipset
    -

- FSAN / ITU : (standard ITU G.987 for 2012)
  - SARDANA will be present in the white paper NG-PON2 of the FSAN (published beginning of 2010) .

How are we evolving towards the solution?

The network on a table...



- **CO:** Laser, MZM, Pump Laser
- **ONU:** Reflective SOA + Detector

The SARDANA Scenarios

Two main scenarios have been considered

Scenarios
Urban
Rural

High attenuation
High dispersion
Stringent bandwidth
cost targets

With the main chara

Fiber_loss_signal		
Fiber_loss_pump		
RN_FILTER_drop_TYP*		
RN_FILTER_bypass_TYP		
RN_FILTER_bypass_pum		
Splitter losses (50%, 50% basic unit)	3.2	dB
RSOA Gain	21	dB
RSOA NF	10	dB
ONU_splitter	50/50	%, %

*: detailed analysis at Deliverable Sy 1.2

5 dBm
8 dBm
iver.
in two
cases: 0 dBm and 10 dBm

ONU

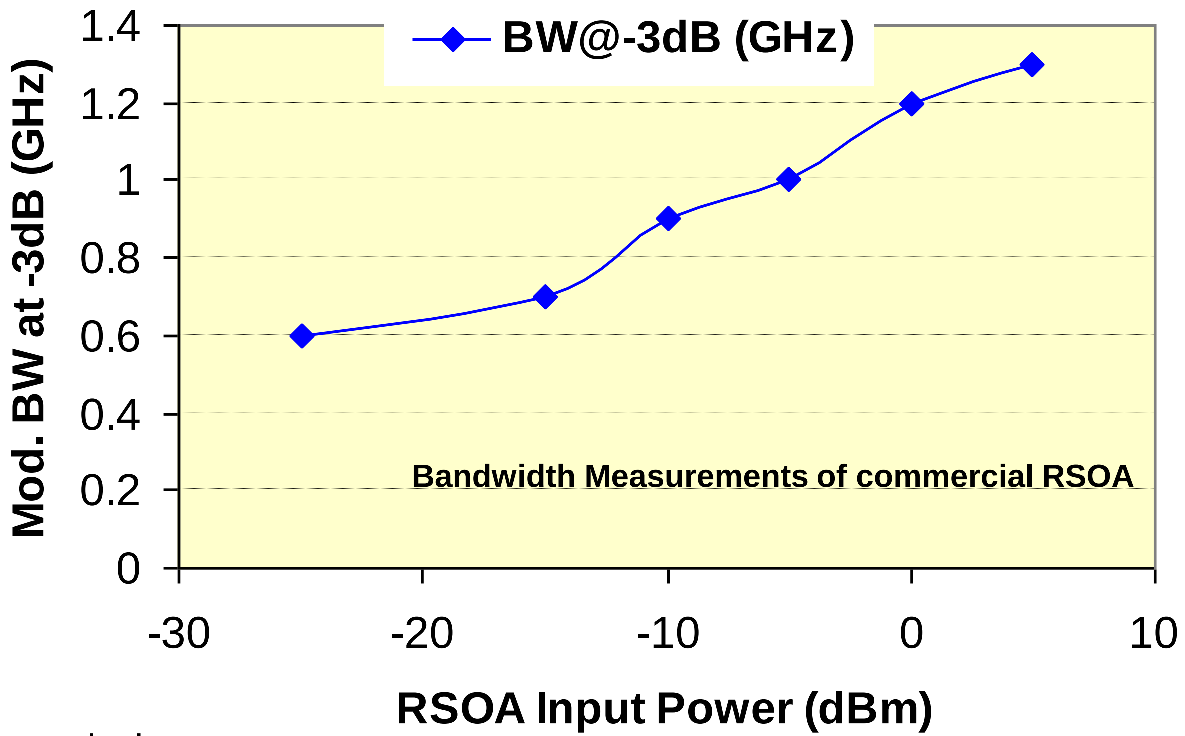
- ONU
  - Collourless
  - Cheap
  - Compatible with GPON

ONU represents about 80% of network cost*
(excluding P2P)

- Solutions
  - SROA
    - Gain
    - Reflective (single fiber)
  - Tuneable laser
    - No remodulation
      - Highr stability at the ONU
  - Other

*: R.I. Martinez et al, "A Low Cost Migration Path Towards Next Generation Fiber-To-The-Home Networks", ONDM 2007, LNCS 4534, pp 86-95 (2007)

RSOA-Colorless ONU



- Potential low cost device
- Input Signal & E/O BW trade-off:
  - Bandwidth limited at small signal levels
- Measurements at: 20 ºC, 80 mA, 1550 nm
  - 15dB gain at -15dBm input power, but only 0.7GHz BW.
  - Gain saturation is required (~0dB gain) for 1.3GHz

The ONU: focus on the SOA

- At the ONU, the presence of Semiconductor Optical Amplifiers (Reflective), for re-use of the wavelength determine a deep study in terms of current/input power in order to understand the better AO (AREA of OPERATION).

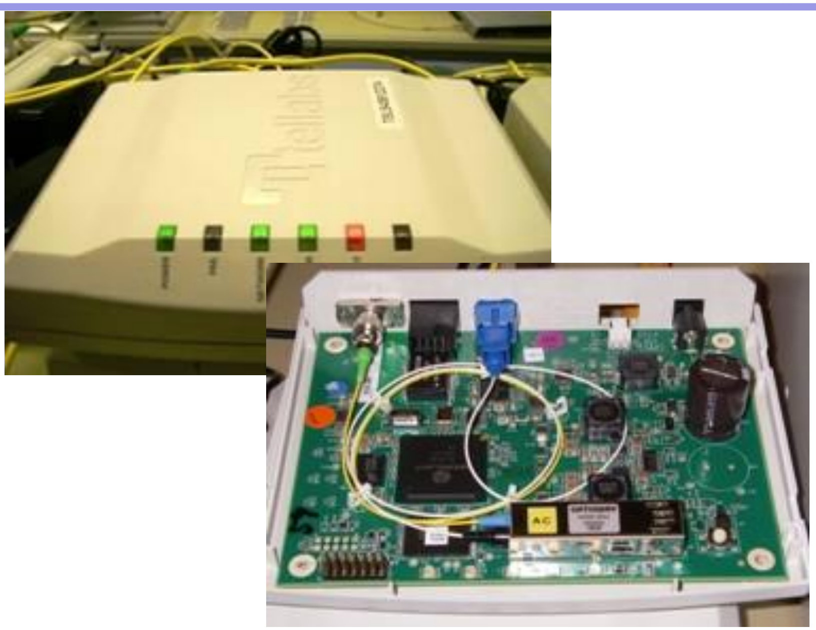
SOA – bias current	optical input power: low $P_{in} < -15$ dBm	medium -15 dBm $< P_{in} < -5$ dBm	high $P_{in} > -5$ dBm
high $I_{bias} > 100$ mA	high gain, NF high for lower input powers, ER stays the same	gain decreases due to saturation but low NF, ER is erased	low gain, NF increases with input power level, ER is removed
medium $60mA < I_{bias} < 100$ mA	moderate gain, NF moderate to high, ER is kept	gain gets lost, NF moderate, ER decreases strongly with higher input power	low gain, higher NF, ER is removed
low $30mA < I_{bias} < 60$ mA	quite low gain, higher NF, ER is not reduced	gain low, NF higher, increases with the input power next to erasing the ER	no gain, high NF, ER gets removed

RSOA – bias current	optical input power: low $P_{in} < -15$ dBm	medium -15 dBm $< P_{in} < -5$ dBm	high $P_{in} > -5$ dBm
high $I_{bias} > 100$ mA	high gain, NF low, ER is kept	gain decreases quickly due to saturation, NF increases, ER is erased	low gain, saturation, NF high, ER is removed, strong patterning
medium $60mA < I_{bias} < 100$ mA	gain is still quite high, NF moderate, ER stays the same	gain gets lost, NF moderate and increases, ER decreases strongly with higher input power	low gain, saturation, high NF, ER is removed, strong patterning
low $30mA < I_{bias} < 60$ mA	low gain, higher NF for lower currents, ER is not reduced	gain low, NF quite high, increases with the input power next to erasing the ER	no gain, high NF, ER gets removed, strong patterning

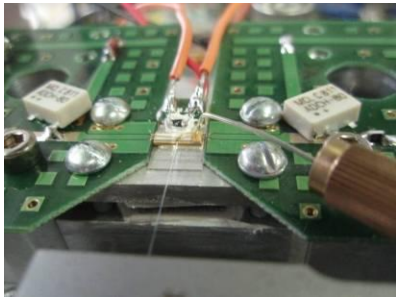
ONU status

Colourless ONT & OLT

- Tellabs Modified OLT and ONU optics in Tellabs 1134 system
- Integrated RSOA based ONU for the first Demo at 1.25Gbps (Optoway module in photography) from France Telecom.
- 3-5Labs has provided higher BW SOA/REAM that have been mounted, tested and adapted for 10G at UPC.



GPON ONT first prototype from Tellabs for 2.5/1.25Gbps using RSOA modules from France Telecom

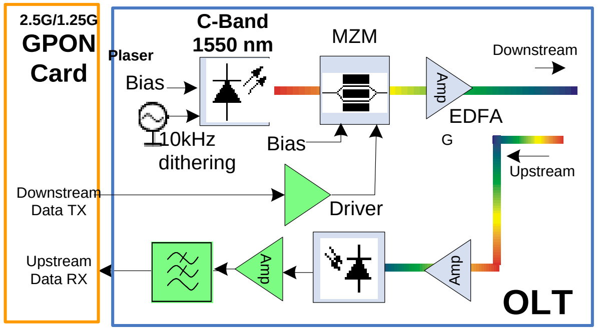


First tests of 3-5Labs SOA/REAM chips

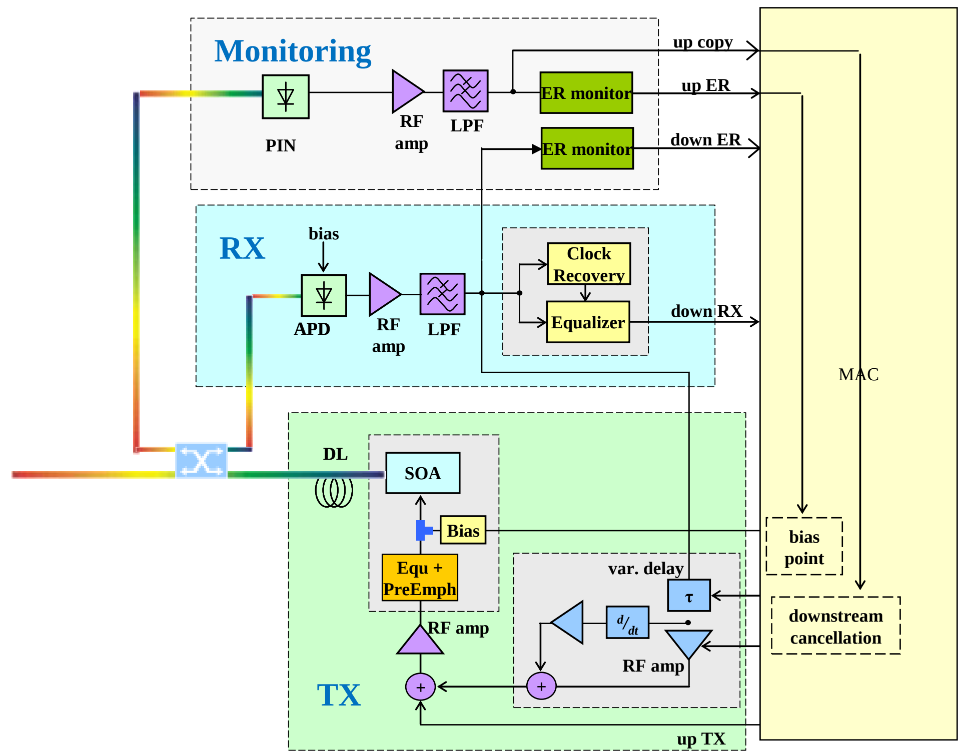
ONU OLT

Colourless ONT (end-user terminal)

- Reflective-ONU optical transceiver:
  - preferred option as cheapest available choice for the WDM-PON
  - Main drawbacks:
    - Full-duplex with wavelength reuse in down&up-stream
    - **-> Solution:** study of the possible optical modulation formats compensating techniques like: **downstream ER cancellation at ONU**, wavelength dithering and adaptive electronic equalization.



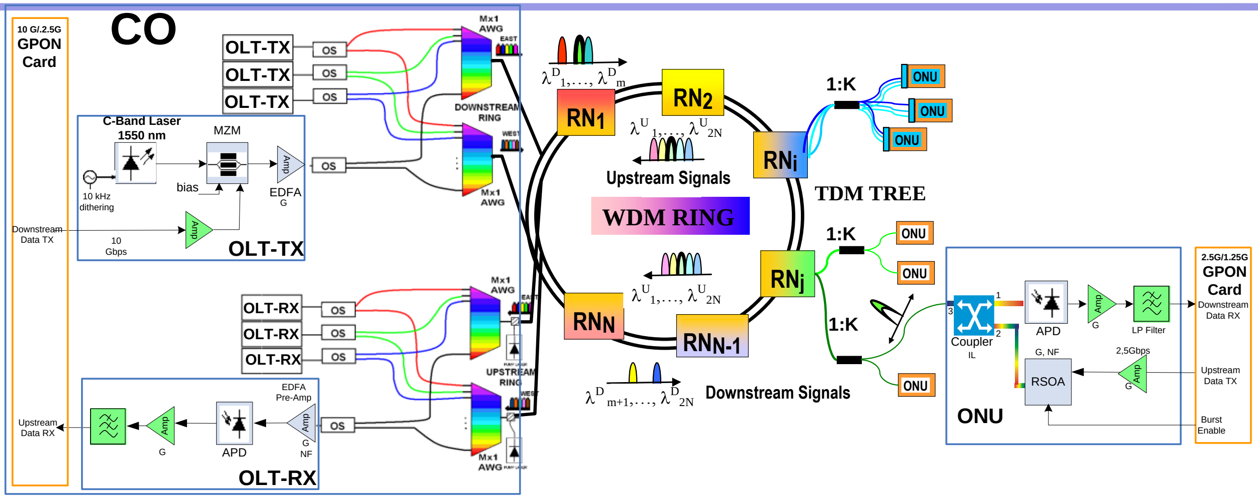
(*) 10kHz dithering for Rayleigh combating



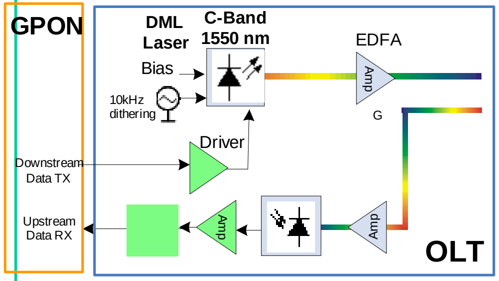
ONT OLT

Colourless ONT & OLT definition

- OLT Optical Modules:
  - Laser source dithered for RB and reflections impairments mitigation
- Implementations:
  - The OLT based on Direct Modulated Laser (DML):
    - Cost-effective
    - Rayleigh-backscattering tolerant (trade-off of dispersion)
  - OLT based on a external modulated laser
    - Higher performance
    - Lower CD impairments.



2 OLT TX implementation considered: a) Low-cost DML; b) High performance external modulated laser



a) Detailed scheme of a OLT based on a Direct Modulated Laser (DML)

First prototype of the optical modules of 2.5 Gbps OLT based on DML

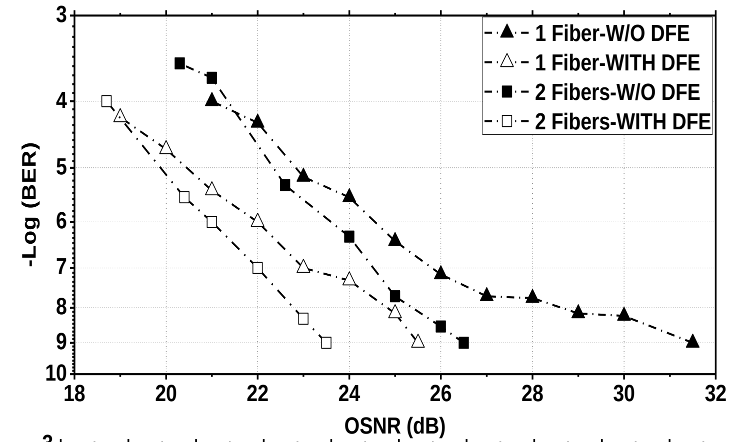
ONT OLT

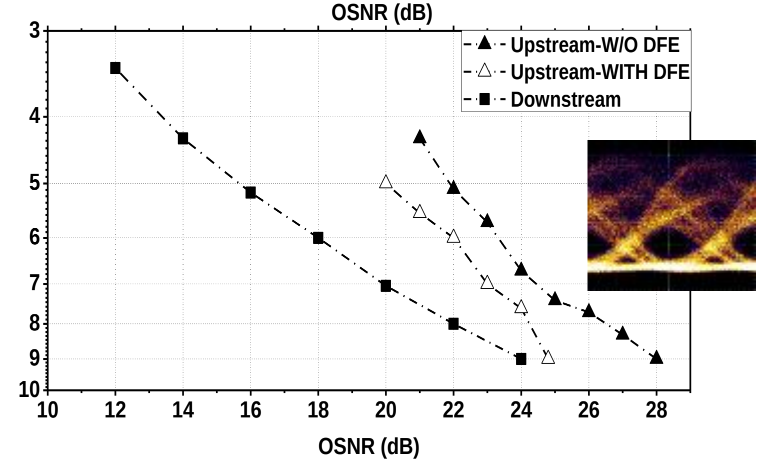
Colourless ONT (end-user terminal)

- Reflective-ONU optical transceiver:
  - Main drawbacks:
    - RSOA electro-optical bandwidth limitation
    - **-> Solution:** off-set optical receiver filtering and DFE/FFE equalization at the OLT
    - **low-cost RSOAs** rated for **1.25Gbps** operation that can be **used** in future PONs modulated **at 2.5 and** even **10 Gb/s in up-stream** [1]
    - By removing the down-stream crosstalk, the distance has been increased **up to 70Km** [2].

[1]: M. Omella et al., "Full-Duplex Bidirectional Transmission at 10 Gbps in WDM PONs with RSOA-based ONU using Offset Optical Filtering and Electronic Equalization", OFC'2009.

[2]: I. Papagiannakis, et al., "Investigation of 10-Gb/s RSOA-Based Upstream Transmission in WDM-PONs Utilizing Optical Filtering and Electronic Equalization," IEEE Photon. Technol. Lett., vol. 20, no.24, pp. 2168-2170 December 2008.





(Up): Upstream 10Gb/s BER versus OSNR with 25 km bidirectional and two fibres of 25 km unidirectional .

(Down): BER versus OSNR with 12 km bidirectional and 2x25 km unidirectional.

ONU related stuff

- In order to remodulate we have to
  - Have convenient modulation format
    - Power in the ‘0’s
    - Cheap to achieve remodulation
    - Receiver sensitivity of -25dBm

Modulation Formats

MOD. FORMAT (2.5G/10G)	BtB Sensitivity Penalty (dBm)	Remod. Penalty on Up (dB)	oSNR (dB) (1dBpen)	oSRR (dB) (1dBpen)	CD (Km) (1dBpen, G652)	eBW	COST	Comment
IM (REF., 2 lambdas)		2 lambdas		CW				ER=30dB,
2.5G	-3.2 / -5	-	17,7	18*	<600**	2G	LOW	Sensit.:-27.0 dBm
10G	0 REF	-	19,42	18,9	48,7	8G	LOW	Sensit.:-23.8 dBm
+ FEC	-3 / -5					8G	LOW-MED	
+ EE						6G	MED	
IM-ER 3dB								
10G	5.6	1,76	28.7	29.9	40,6	8G	LOW	
IM-ER cancellation		ER = 0dB	penalty over ER=3dB w/o canc.					RSOA BW limit / REAM req.
2.5G:SOA, 10G:SOA+EAM		2.5G/10G	2.5G	10G				
10G, ERdown = 3dB	4.65	1.0 / 0.2	-0,2	-2,3	40**	8G	MED	ER:3 to 0.8dB(2.5G) & 0.4dB(10G)
10G, ERdown = 6dB	2.05	2.2 / 0.2	-1,6	-4,9	40**	8G	MED	ER:6 to 1.2dB(2.5G) & 0.7dB(10G)
10G, ERdown = 10dB	0.6	7.6 / 4.4	2,35	-2,15	40**	8G	MED	ER:10 to 1.0dB(2.5G) & 1.3dB(10G)
IM(DML)-ER 6dB								
2.5G	0						Filter at OLT	
10G	0				10 / 80 (w Filter)		Filter at OLT + EE at ONU	
SSB	2, 3, 6dB ER	2dB ER Dw	2, 3dB					
10G	2.6; 1.3; -0.7	6,6	35.6; 34.4		62,5	8G	MED (OLT)	Dual-Arm MZM + Hilbert Transf
Manchester SSB-IM								
10G	-1,08	2.7*			40**	15G	MED (OLT)	
SCM-DPSK								
2.5	-2,8	0,5	-	21,3	45**	7.5G	LOW	
10	0.4	1	-	21	5**	27.5G	HIGH	high speed electronics
SCM-QPSK								
10	0.3	1	-	-	-	18.8G	HIGH	high speed electronics
oPSK								
10		0				8G	HIGH	MZI at ONU
oFSK								
10						7G	MED	MZI (maybe RSOA cav.)
	0.35,0.55,0.75		0.35,0.55,0.75					small ER by b_{ELTx}
Op. Duobinary	1.1, 4.4, 6.1	high	27.5,30.8,32.6		>62.5**	8G	MED	non-linearity sensitivity
El. Duobinary 10G	6	high?			10	4G	LOW	10G
Coherent oPSK /oPSK	6.7	0	-	-	24	20G	HIGH	Sensit.: -30.5 dBm
IM+chirp+offsetF		high?			40*	4G	MED	RSOA chirp variance?
IM+chirp+offsetF+EE		high?			70*	3G	MED	"

Table 7.1: Comparison of different modulation formats

Rayleigh BackScattering

- The relation between the Signal and the Rayleigh backscattering (oSRR), in a determined point of the network, is very important in the SARDANA scenario.

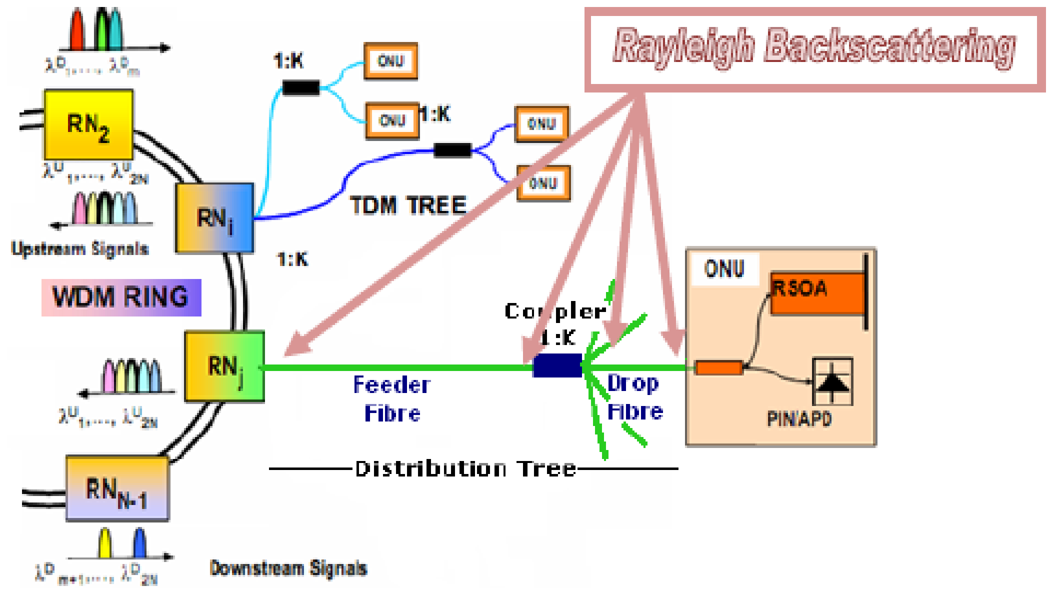


Fig. 3.52.Crosstalk due to Rayleigh Backscattering in SARDANA network

- Considering the Network Parameters, a desidered value for the oSRR has been set to >20 dB.

Rayleigh BackScattering

- RB effect is most relevant and degrading at the RN input.

RURAL SCENARIO +0dBm		Tree_fiber	20 Km	ONU_input_goal	-15 dBm
OLT Output	0 dBm	Spliting Ratio	16	RSOA Gain	21 dB
Fiber_loss_signal	0.22 dB/Km	Splitter_losses	12.8 dB	RSOA NF	10 dB
Fiber_loss_pump	0.25 dB/Km	Tree_loss	17.2 dB	ONU_splitter	50/50
Rural ODN	19km+splitter1x16+1km	ONU-Gain	15 dB	ONU out	0 dBm

	Feeder (Km)	splitter	Drop (Km)	ONU in
	19	16	1	-15
dB/dBm	-4.18	-12.8	-0.22	-15
Signal Power				
Downstream	NR-out	COUPLERin	COUPLERout	ONU-in
dBm	2.2	-1.98	-14.78	-15
Upstream	NR-in	COUPLERout	COUPLERin	ONU-out
dBm	-17.2	-13.02	-0.22	0
Rayleigh Power	RB Coupler Dw	RB-RN (input)	RB-ONU (input)	RB Coupler Up
dBm	-48.71	-33.49	-45.17	-30.39
	-48.71	-33.13	-45.08	-30.39
oSSR	OSRR Coup-Dw	OSRR RN	OSRR ONU	OSRR Coup-Up
dB	46.73	15.93	30.08	30.17

oSRR Downstream	30.08
oSRR Upstream	15.93

Table 3.CI.: Theoretical calculus for Rural scenario

URBAN SCENARIO +0dBm		Tree_fiber	3 Km	ONU_input_goal	-15 dBm
OLT Output	0 dBm	Spliting Ratio	64	RSOA Gain	21 dB
Fiber_loss_signal	0.22 dB/Km	Splitter_losses	19.2 dB	RSOA NF	10 dB
Fiber_loss_pump	0.25 dB/Km	Tree_loss	19.86 dB	ONU_splitter	50/50
Urban ODN	2.9km+splitter1x64+0.1km	ONU-Gain	15 dB	ONU out	0 dBm

	Feeder (Km)	splitter	Drop (Km)	ONU in
	2.9	64	0.1	-15
dB/dBm	-0.638	-19.2	-0.022	-15
Signal Power				
Downstream	NR-out	COUPLERin	COUPLERout	ONU-in
dBm	4.86	4.222	-14.978	-15
Upstream	NR-in	COUPLERout	COUPLERin	ONU-out
dBm	-19.86	-19.222	-0.022	0
Rayleigh Power	RB Coupler Dw	RB-RN (input)	RB-ONU (input)	RB Coupler Up
dBm	-60.17	-36.09	-54.97	-39.87
oSSR	OSRR Coup-Dw	OSRR RN	OSRR ONU	OSRR Coup-Up
dB	64.392	16.21	39.95	39.848

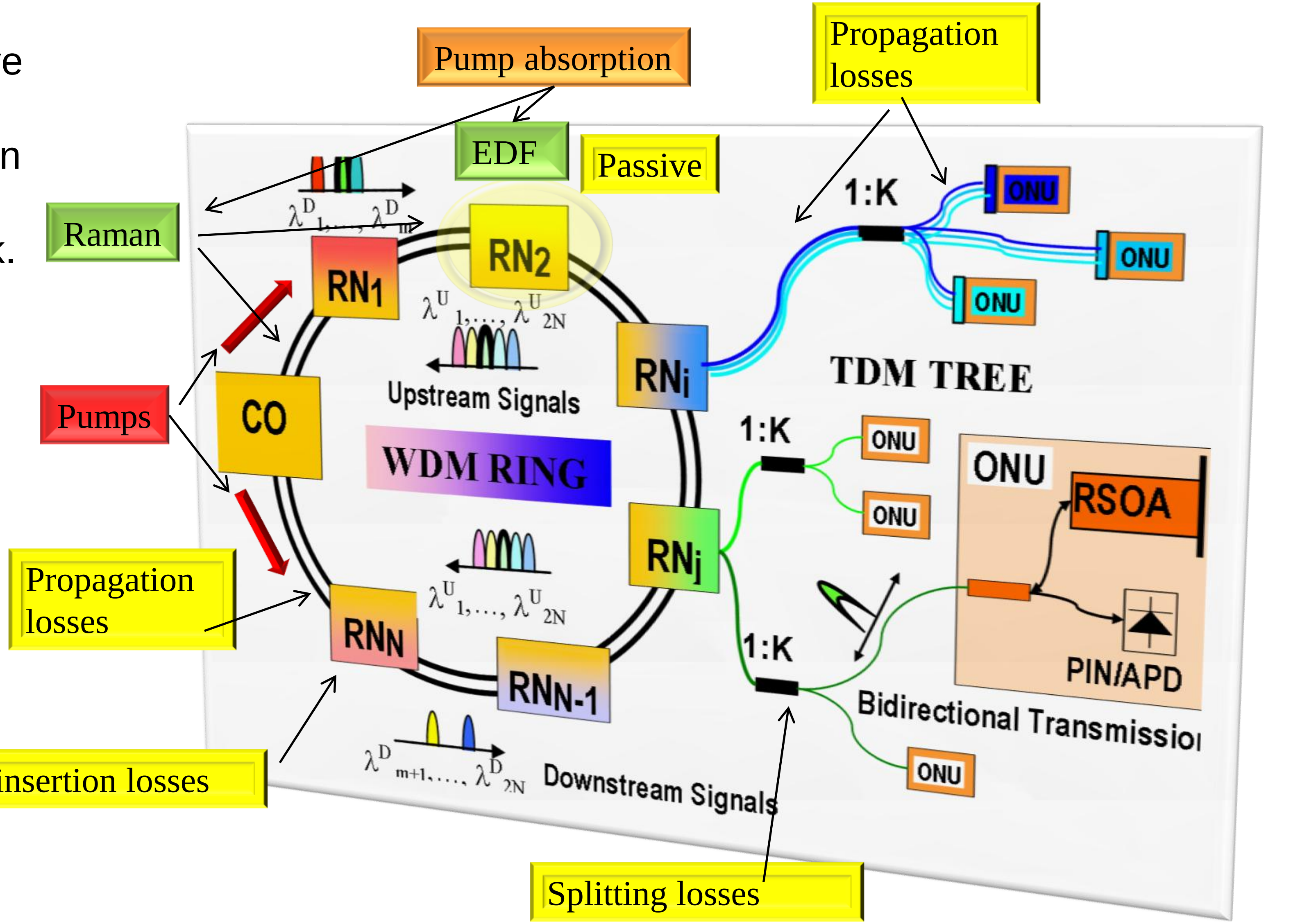
oSRR Downstream	39.95 dB
oSSR Upstream	16.21 dB

Table 3.C.: Theoretical calculus for Urban scenario

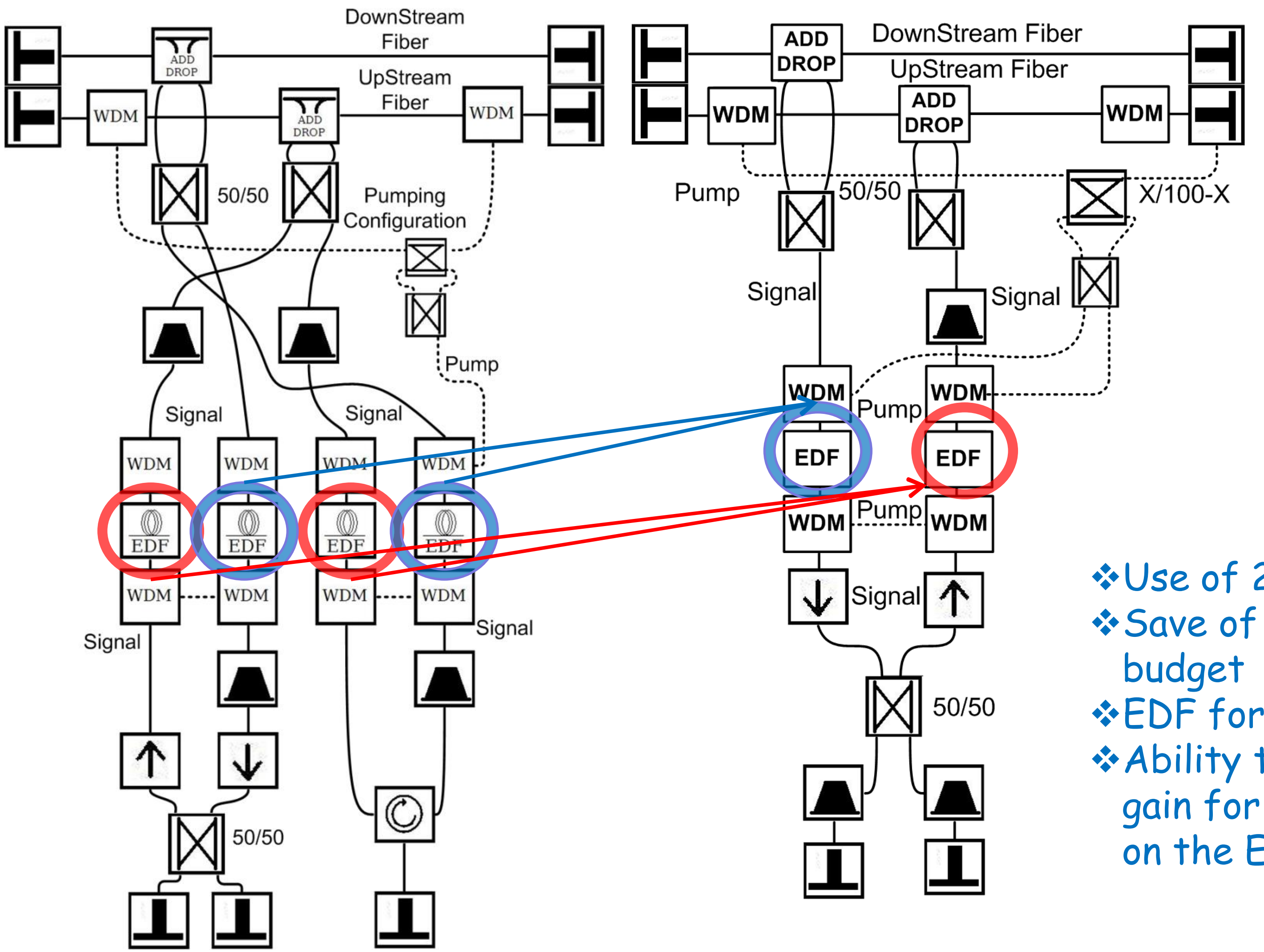
- Mitigation techniques can be: laser linewidth broadening, cross remodulation (C-L bands), FEC, chirped modulation, Carrier Suppressed sub carrier amplitude modulated phase shift keiyng, frequency ditering, et alt

Losses

- We have several losses in the network.

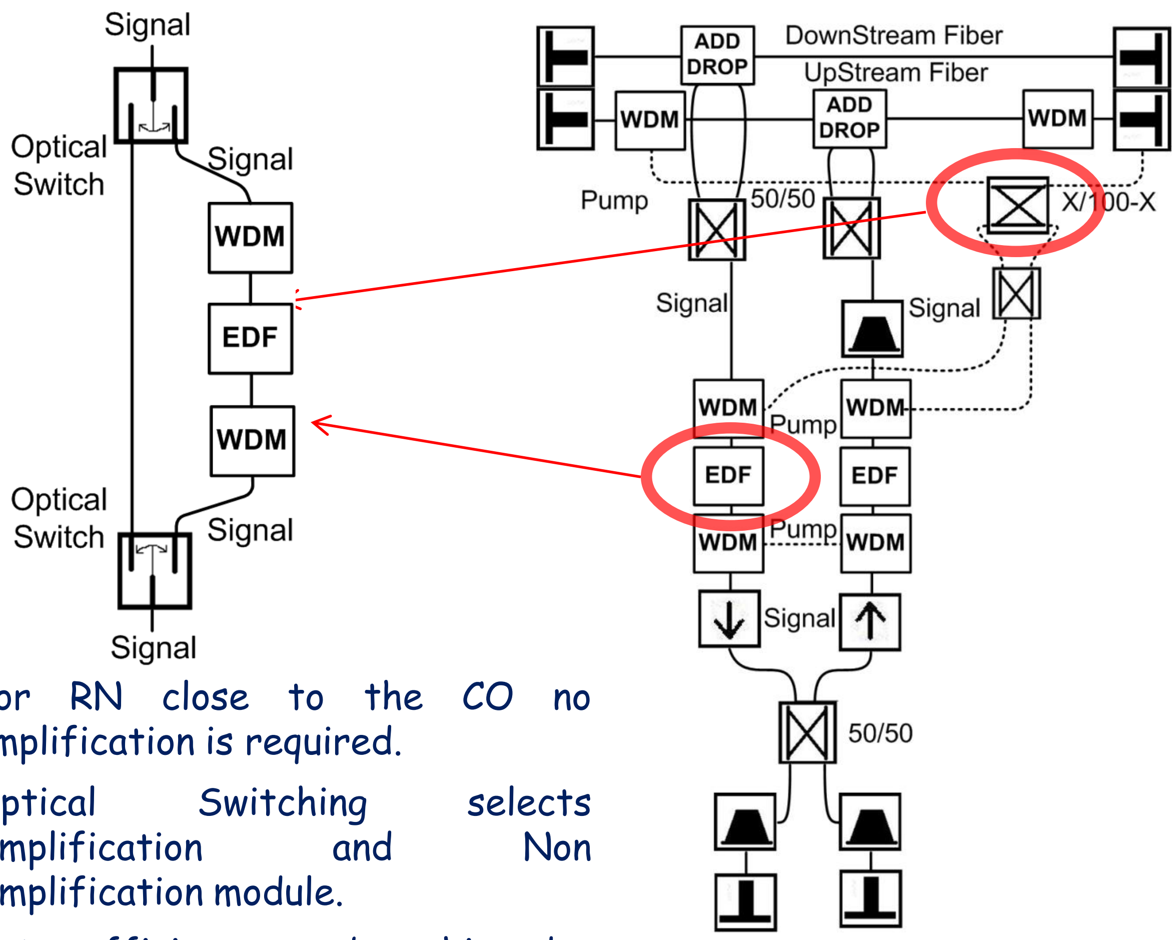


Remote Node evolution



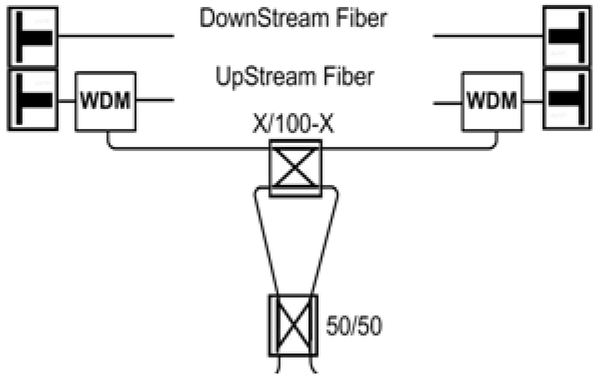
- ❖Use of 2 EDFs instead of 4
- ❖Save of 3dB of pump power budget
- ❖EDF for DS / EDF for US
- ❖Ability to adjust differential gain for DS and US depending on the EDF length.

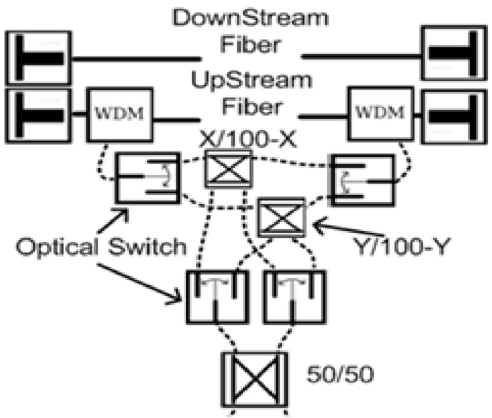
Remote Node evolution

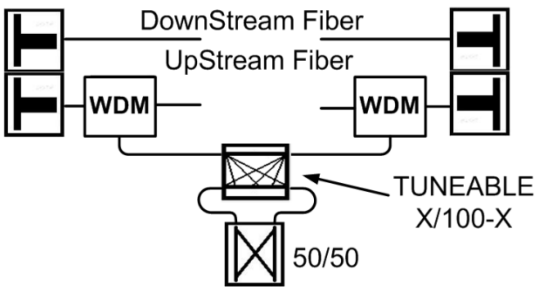


- For RN close to the CO no amplification is required.
- Optical Switching selects Amplification and Non Amplification module.
- Extra efficiency can be achieved.

Remote Node evolution





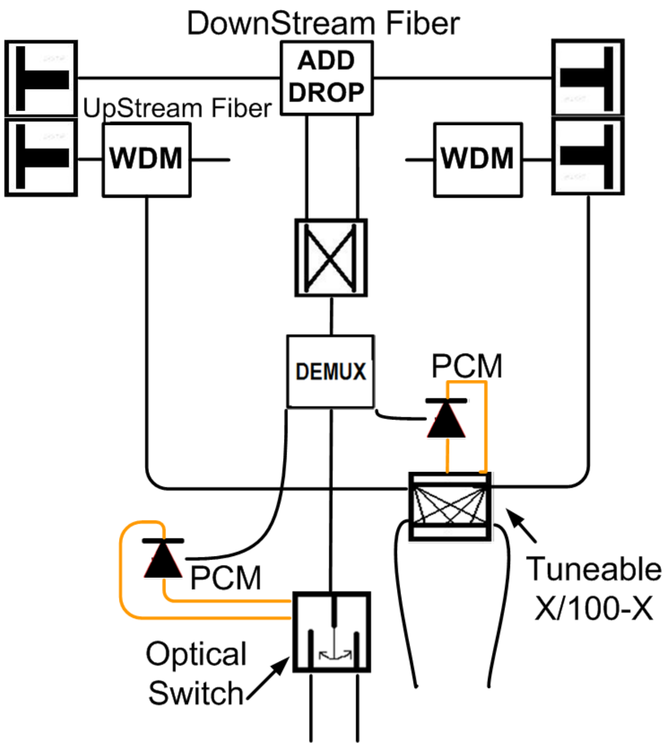


- Static Coefficient
- Excess Power Drop
- Reduced Efficiency

- Dual Case Reconfigurability
- Improved Efficiency
- Extra Loss (switches)

- Multi Case Reconfigurability
- No Excess Pump Power Drop
- Higher Efficiency

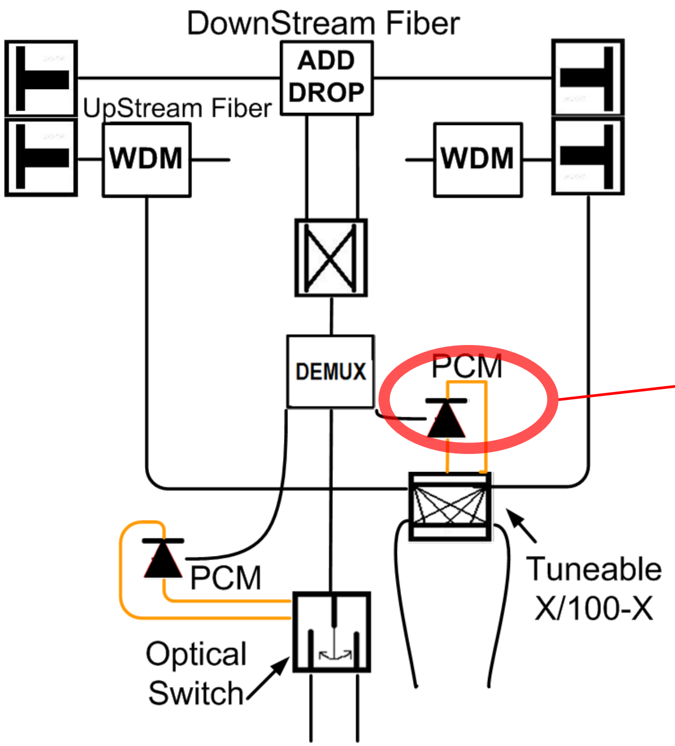
Remote Node evolution

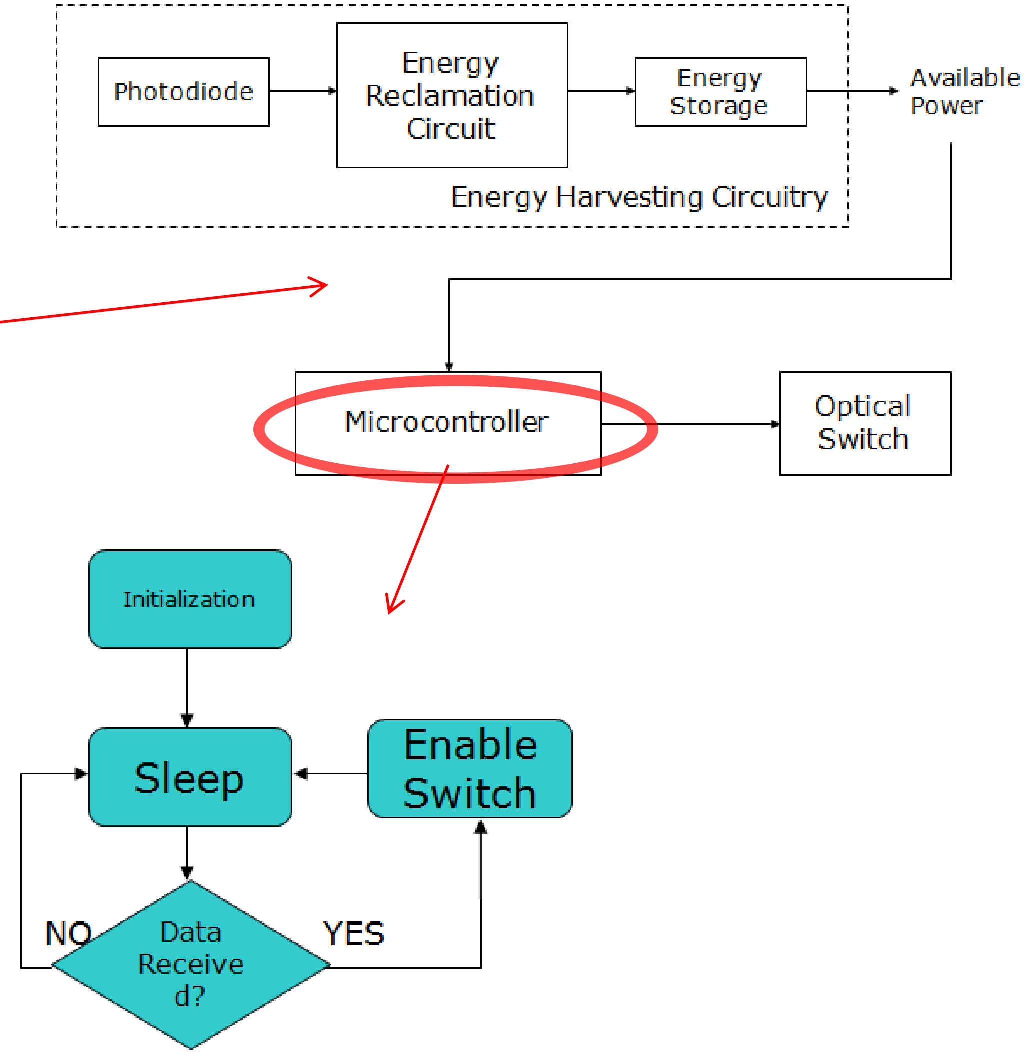


- In sleep mode energy is stored
- Switching optical control sensitivity of -25dBm

- The key is an Optical Power Harvesting Module
- Optical power is converted and stored electrically
- Electrical Power is responsible for powering the Optical Switch.
- Switches can be remotely controlled from the CO
- No local power source is necessary
- The network has a truly outside passive plant.

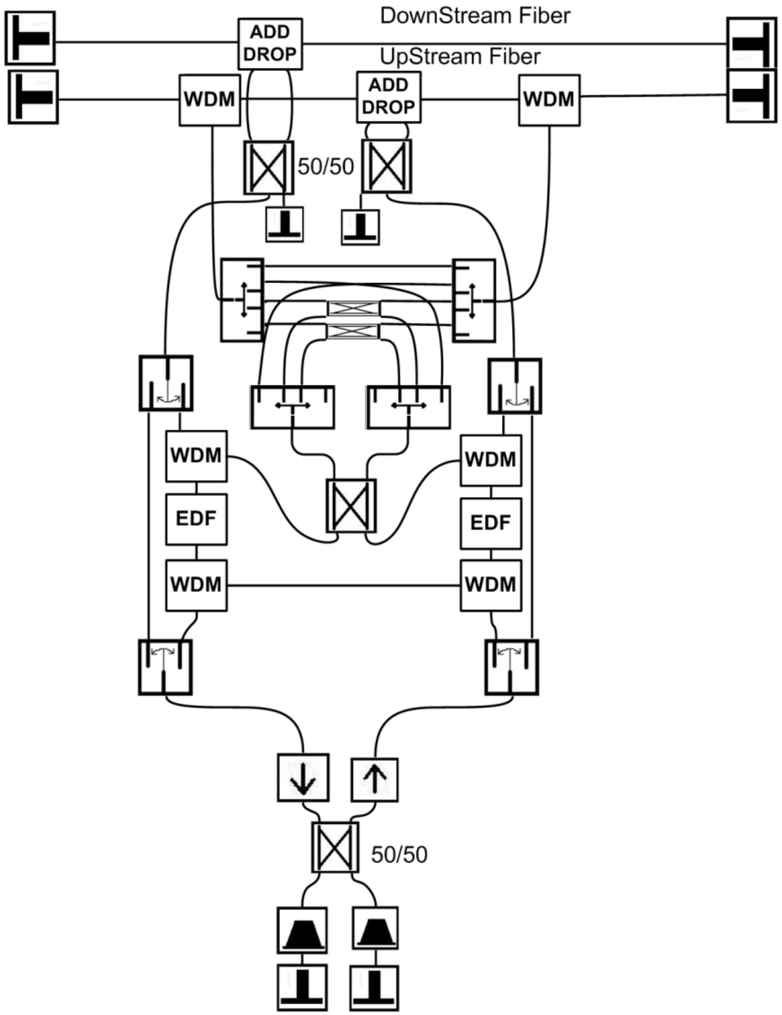
Remote Node evolution





- In sleep mode energy is stored
- Switching optical control sensitivity of -25dBm

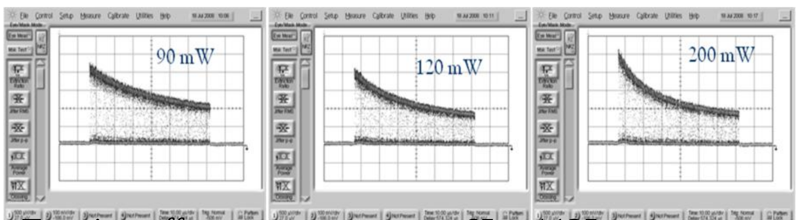
Remote Node evolution



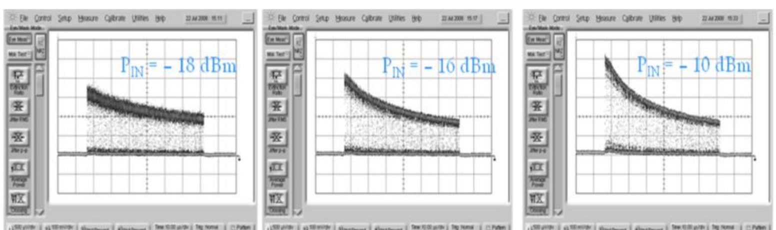
RN impairments

Possible impairments at the RN:

- Insertion losses
- Central wavelength stability
- Reflections
- EDF gain transients ->



Transient effects vs. pump power 65µs / 125µs



Transient effects vs. signal input power 65µs / 125µs

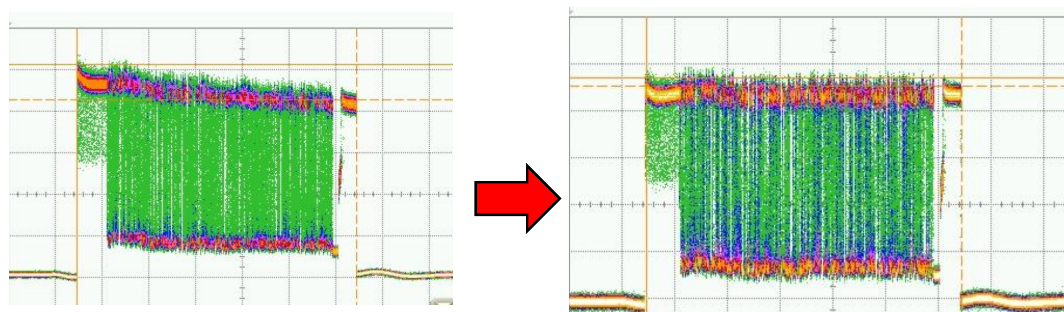
Gain transients mitigation

- Automatic Gain Controlled
- Optical Feedback Loop
- Larger effective Area EDF
- Burst mode (Upstream) gain stabilization by continuous stream signal (Downstream)

In accordance with EDFA dynamics modeling

$$G'(0) = \frac{[G(\infty) - G(0)]}{\tau_0}\left[1 + \sum_j \frac{P_{out}(\lambda_j)}{P_{IS}(\lambda_j)}\right]$$

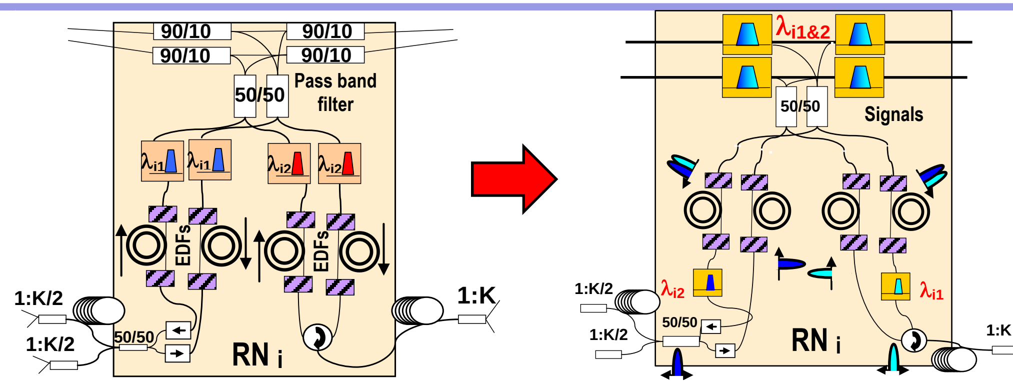
$$P_{IS}(\lambda_j) = \frac{h\nu S}{[\sigma_a(\lambda_j) + \sigma_e(\lambda_j)]\Gamma\tau_0}$$

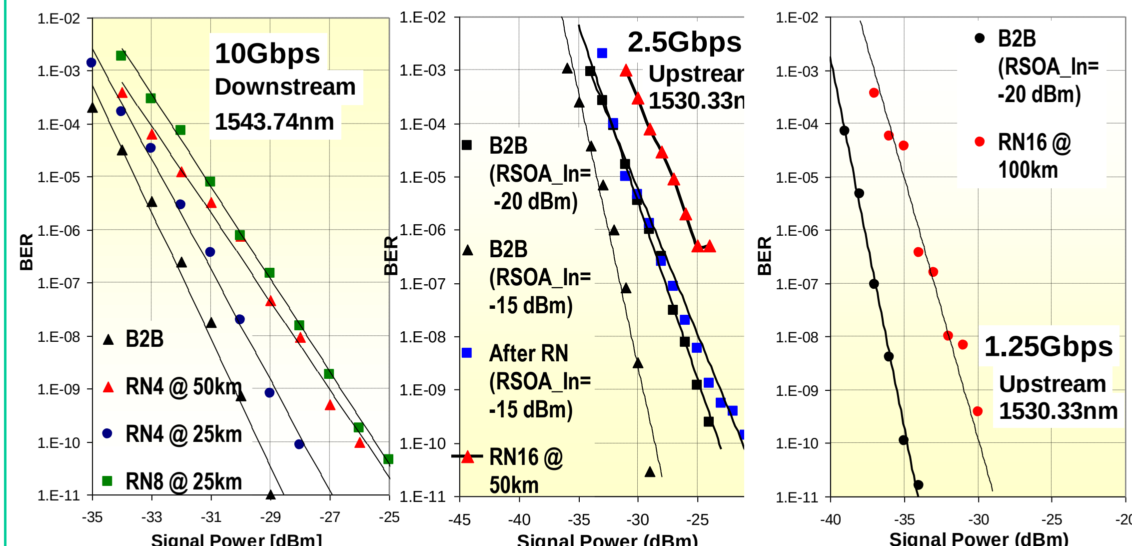


However it works...

"Remote Node test and models

- Design, construction, modelling and characterization of Remote Node designs based in fixed Add&Drops.
- Proof-of-concept experiments using a RSOA based ONU [1]:
  - Downstream @ 10 Gbps half-duplex 1024 ONUs and 50 km (corresponding to 1024 ONUs &100km in non fibre-failure case).
  - Upstream @ 2.5 Gbps for 1024 ONUs along 50 km, even for the worst conditions of fiber cut.
  - Upstream @ 1.25 Gbps 1024 ONUs along 100km (for worse resilience case of fibre failure) at 1.25Gbps.



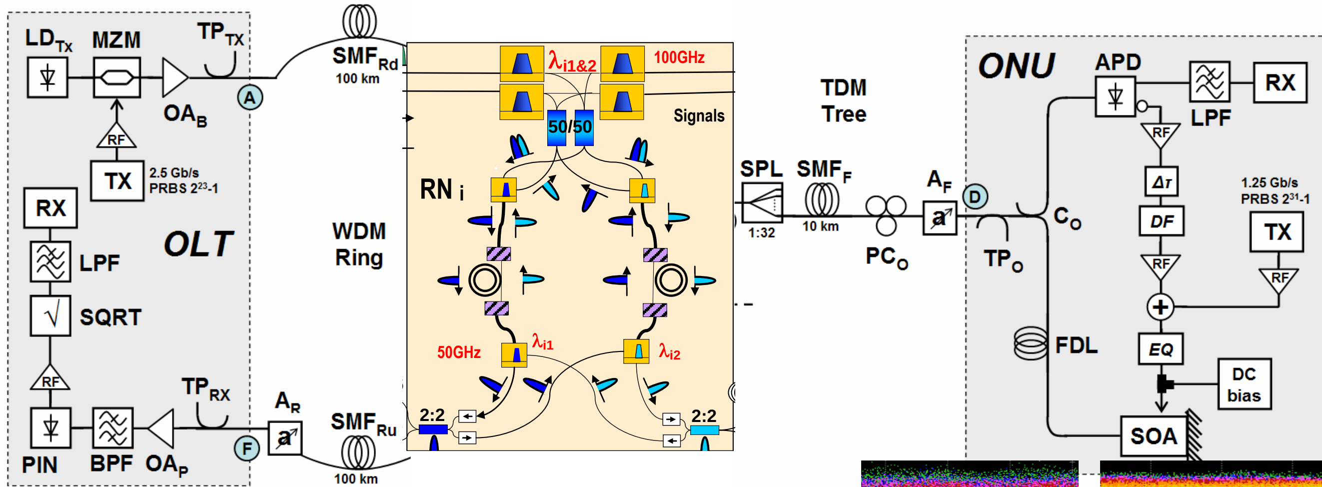


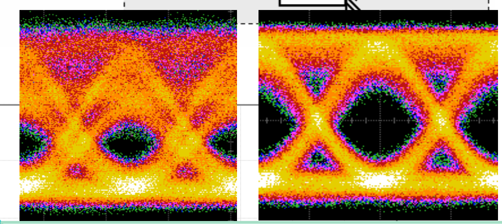
[1]: J.A. Lazaro, J. Prat, P. Chanclou, G. M. Tosi Beleffi, A. Teixeira, I. Tomkos, R. Soila, V. Koratzinos, "Scalable Extended Reach PON", paper OTHL2, OFC/NFOEC 2008.

However it works

"Remote Node test and models"

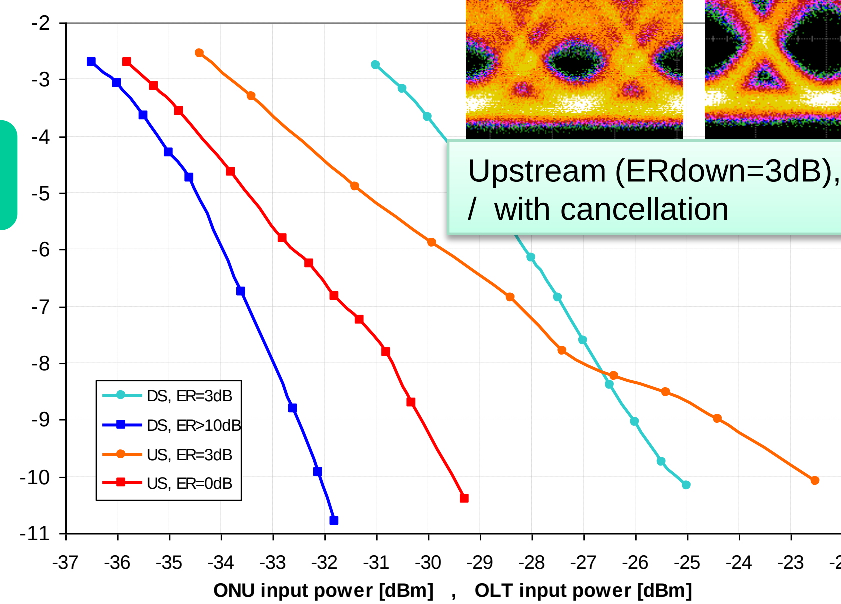
- Design:
  - fixed Add&Drops
  - bidirectional amplification (3dB pump power reduction)
  - for full duplex operation
  - using RSOA
  - downstream cancellation techniques.





Experimental conditions:

- Ring Length: 100 km
- Splitting Ratio: 1:32
- Drop Length: 10 km
- Downstream at 2.5 Gb/s
- Upstream at 1.25 Gb/s
- Sensitivities reached (ERdown = 3dB, BER = 10e-10)
- Downstream (2.5Gb/s): -25.2 dBm
- Upstream (1.25): -22.6 dBm



Upstream (ERdown=3dB), without / with cancellation

OSNR

- Noise sources from DFA, RAMAN and remote amplification techniques fully explored. Gain, NF and oSNR explored for Individual configurations as:
  - In-line EDF
  - Drop EDF
  - Raman
- Combined configurations require combination of different models:
  - Raman + In-line EDF
  - Raman + Drop EDF (explored)
  - Raman + In-line + Drop EDF
  - In-line EDF + Drop EDF
- Results demonstrates that all the remote technologies can provide oSNR not lower that 22 dB matching the goal of 21.4 dB oSNR proposed.
- Analisys performed on additional noise contributions as RBS, Reflections, Down stream cancellation techniques and Gain Transients.

OSNR (worst – best) [dB]					
	URBAN	URBAN	RURAL	RURAL	
	0dBm	+10dBm	0dBm	+10dBm	
Drop EDF	38.3 - 39.5	39.8 - 40.0	36.6 - 39.3	39.5 - 40.0	Non-Resilience
Drop EDF	27.4 - 27.6	27.7 - 28.9	28.0 - 28.4	28.3 - 29.8	Resilience
Raman	36.1 - 41.8	39.3 - 43.8	36.5 - 51.4	42.3 - 50.0	Non-Resilience
Raman	24.6 - 31.0	29.0 - 36.1	36.7 - 42.2	35.7 - 40.0	Resilience
In-line	24.2 - 39.7	24.2 - 39.7	22.6 - 39.7	22.6 - 39.7	Non-Resilience
In-line	21.9 - 39.7	21.9 - 39.7	23.0 - 39.7	23.0 - 39.7	Resilience

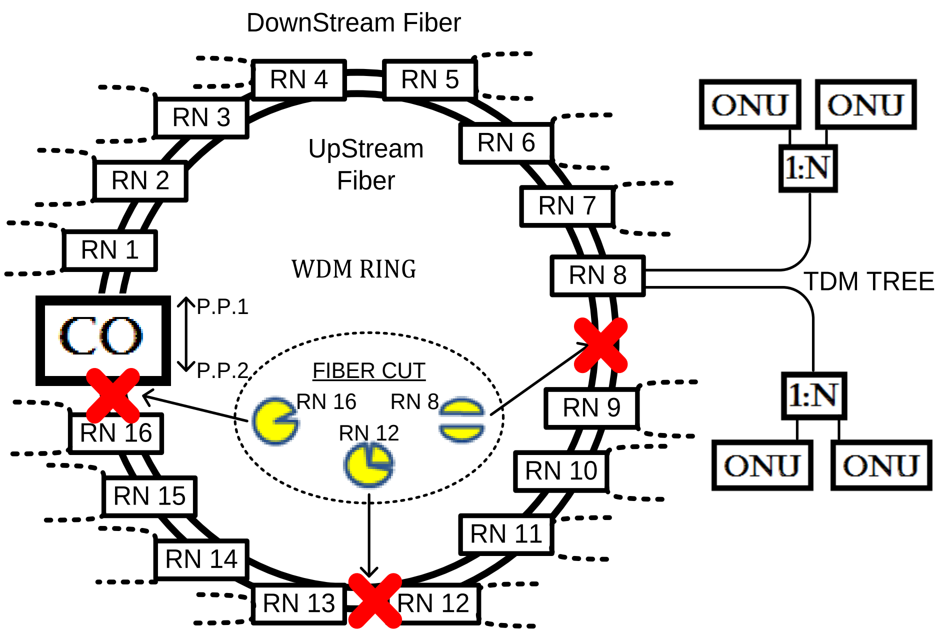
Table 4.I. Summary of OSNR of the signals provided by the different amplification techniques.

The reported OSNR values in Table 4.I have been obtained using the following total pump power consumptions shown in Table 4.II.

Total Pump Power required (East fiber-West fiber)[dBm]					
	URBAN	URBAN	RURAL	RURAL	
	0dBm	+10dBm	0dBm	+10dBm	
Drop EDF	32.6 - 33.2	28.5 - 29.7	32.5 - 32.1	27.1 - 28.0	Non-Resilience
Drop EDF	44	46.4	46.2	46.2	Resilience
Extra Raman consumption (dB)	0.02 - 0.08	0.17 - 0.87	2.11 - 8.42	3.26 - 12.8	Non-Resilience
Extra Raman consumption (dB)	0.02 - 0.09	0.17 - 1.02	2.11 - 10.4	3.26 - 14.7	Resilience
In-line	28.0 (for DS) 24.6 (for US)	26.1	23.1 (for DS) 19.8 (for US)	22.0	Non-Resilience
In-line	28.0 (for DS) 24.6 (for US)	26.1	23.1 (for DS) 19.8 (for US)	22.0	Resilience

Table 4.II. Summary of pump power requirements of the different amplification techniques (for In-line, the pump power consumed by the first amplification stage has been considered).

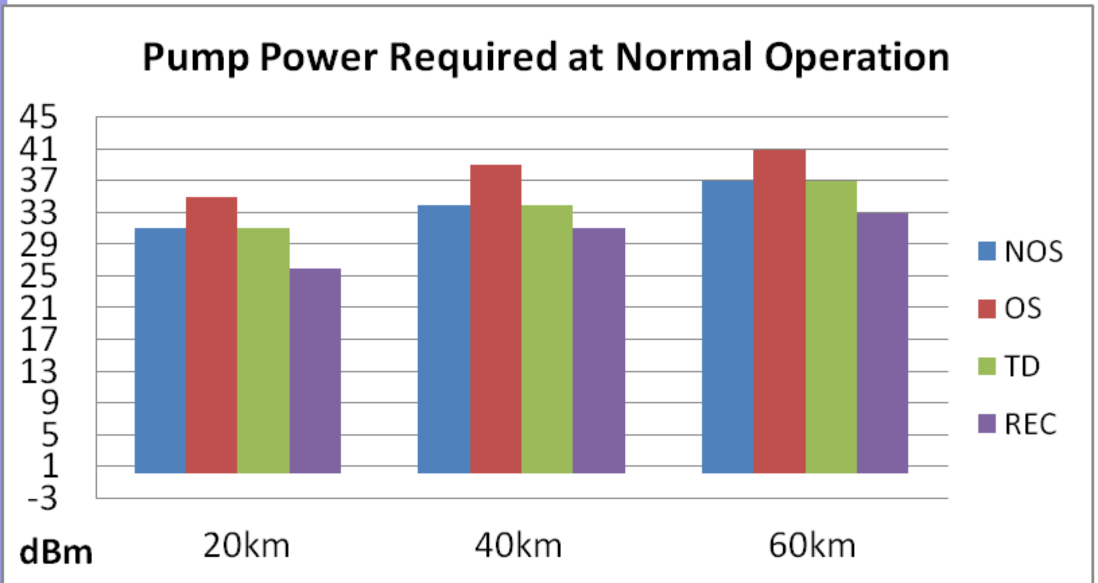
SARDANA - Resilience



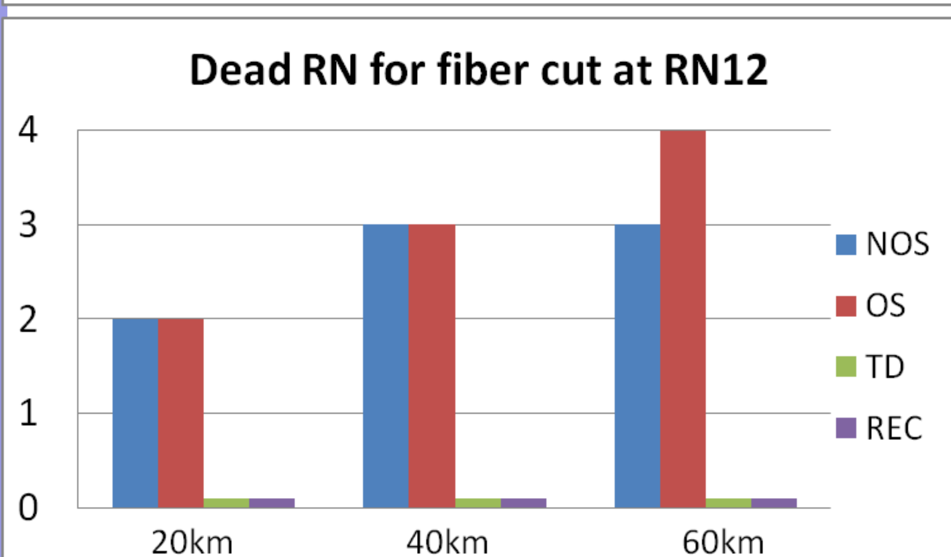
- Comparison between the RN architectures:
  - Non Optical Switching
  - Dual Optical Switching
  - Tuneable Power Splitting
  - Reconfigurable RN
- …for fiber cut at RN8, RN12, RN16

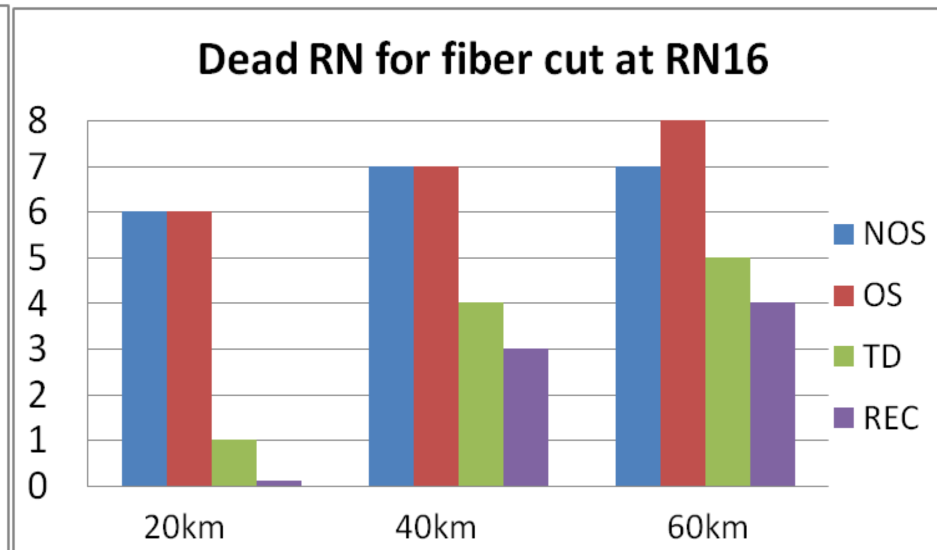
- System parameters
  - Ring Size of 20, 40 and 60Km
  - 16RN
  - Tree size of 2Km
  - 2 trees per RN
  - 32 users per tree
  - 100Mbit/s per user

Remote Node
Results Comparison

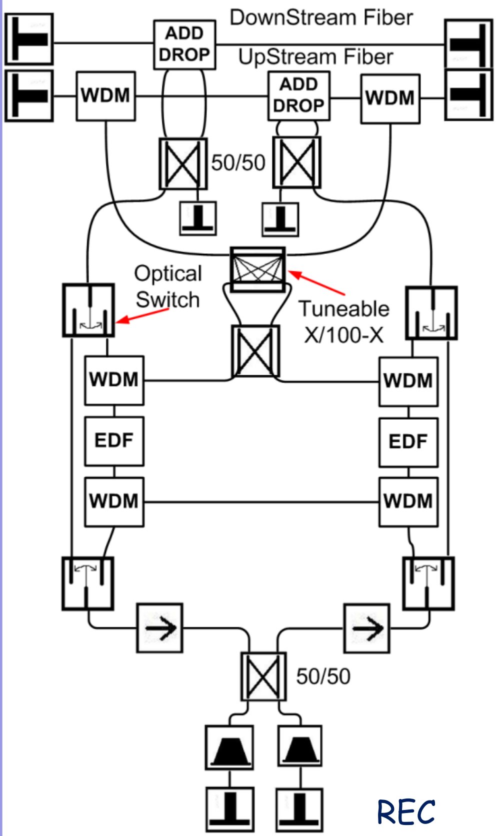


NOS - Non Optical Switching
OS - Dual Optical Switching
TD - Tuneable Pump Drop
REC - Reconfigurable RN

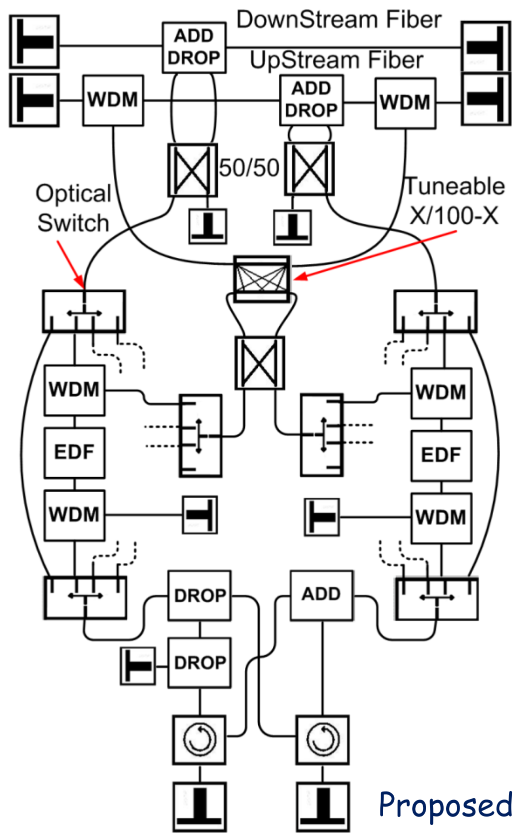




Remote Node Proposal 3 / Results

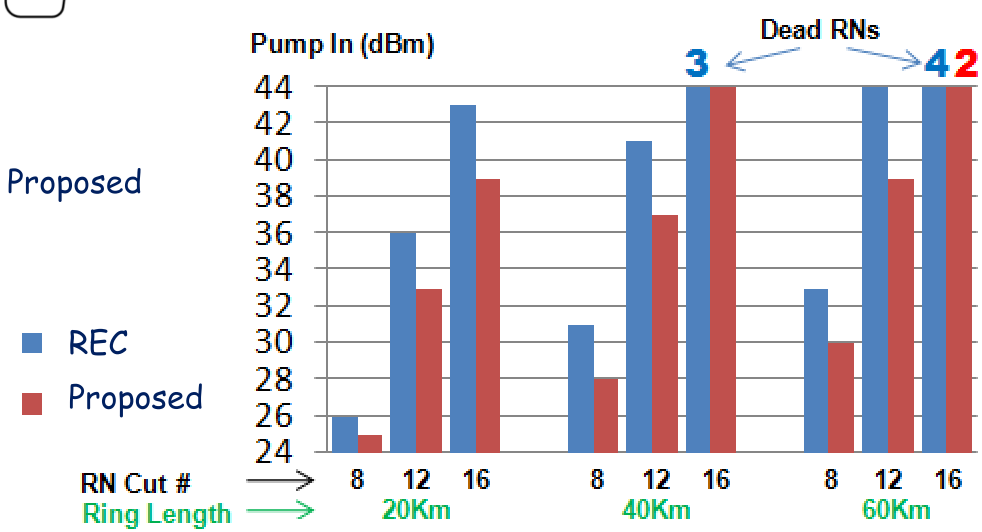


REC



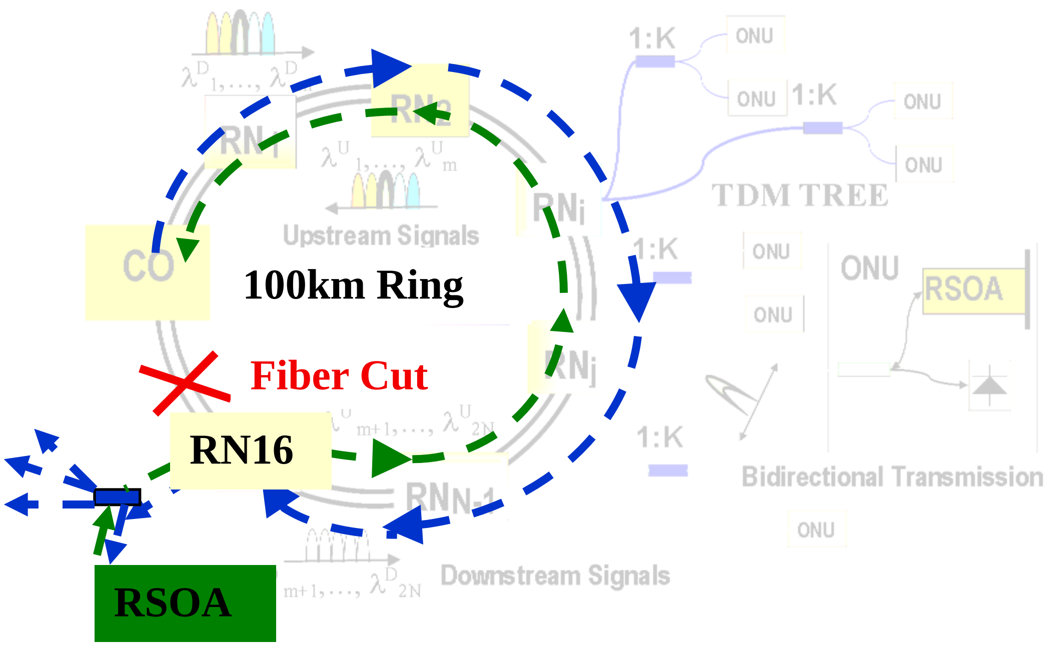
Proposed

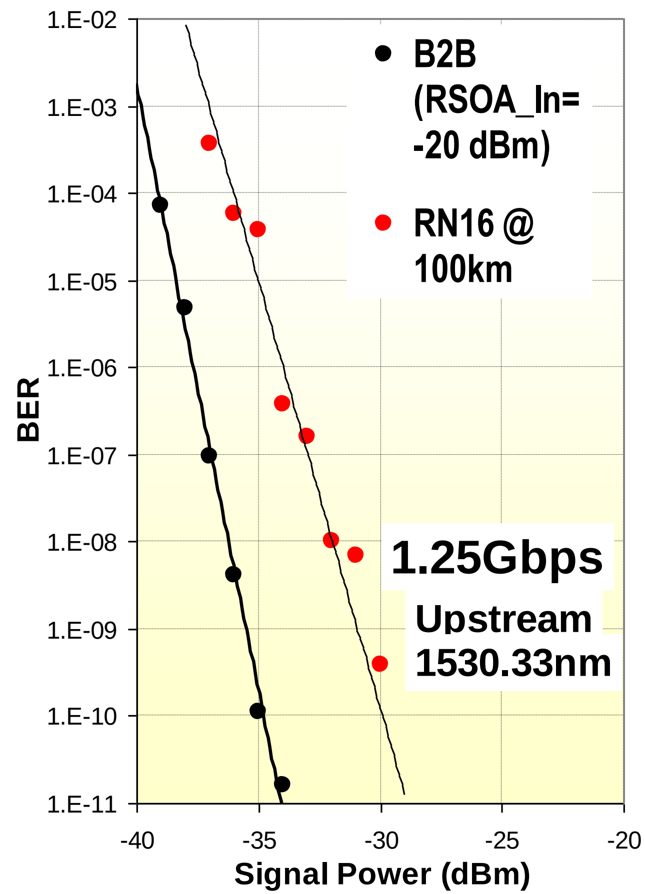
- Proposed RN allow extra resiliency and lower Pump Power consumed.
- But also extra costs due to the insertion of more 6 1x4 Optical switching, requiring more control power.



Transmission experiments: Upstream

- **1.25Gbps**
- **Reaching 1024 ONUs along 100km in the worse conditions of fiber cut**
- **Thanks to:**
  - **Power budget reduction, new RN design**
  - **Lower input signal required for this RSOA at 1.25G (-20dBm)**



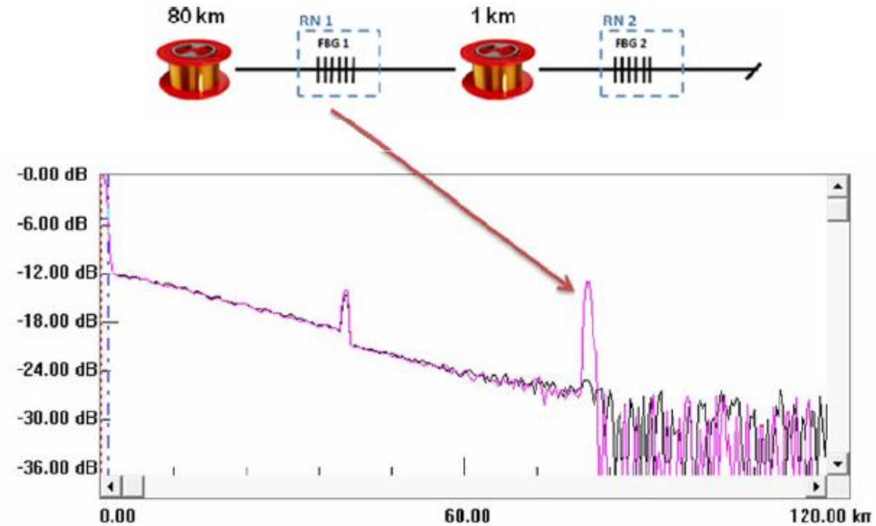


How to react...

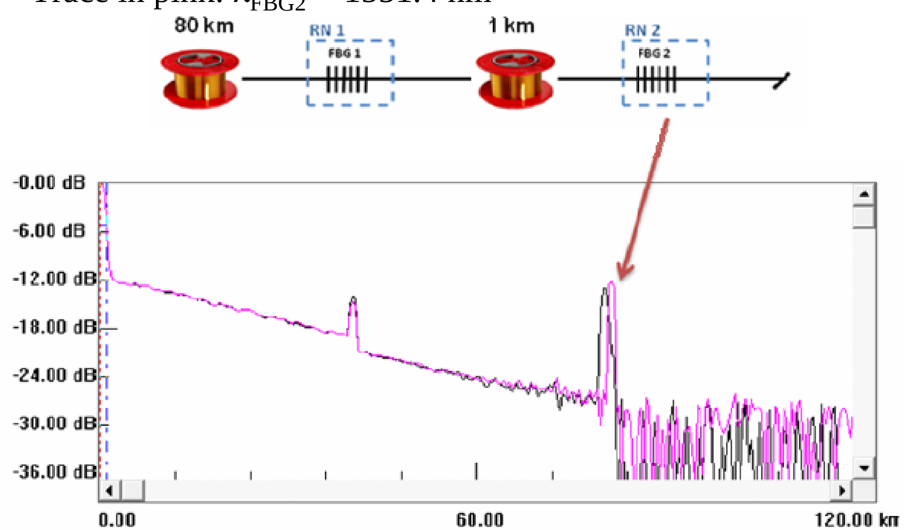
- Monitoring
- Upper layers detection
- OTDR (physical layer)

OTDR monitor in SARDANA

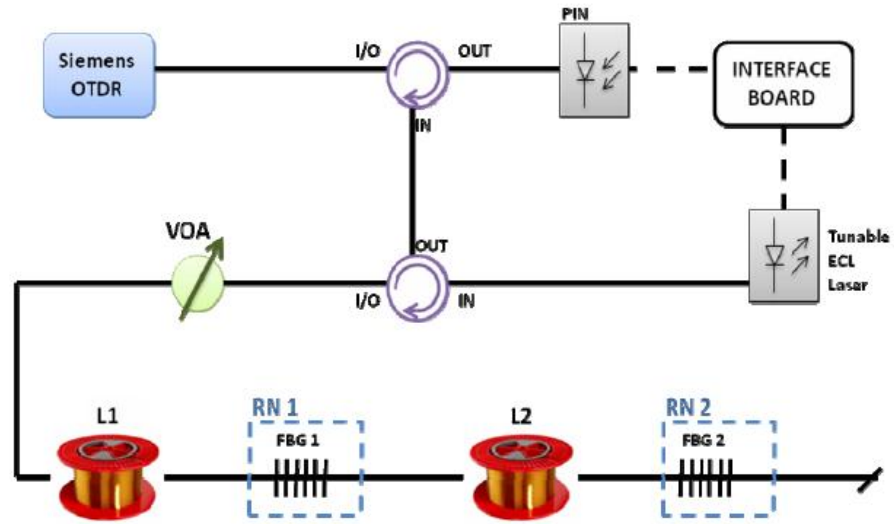
Trace in black: $\lambda = 1553$ nm; $\lambda_{FBG1} = 1550.2$ nm; $\lambda_{FBG2} = 1551.4$ nm



Trace in black: $\lambda_{FBG1} = 1550.2$ nm;
Trace in pink: $\lambda_{FBG2} = 1551.4$ nm



Experimental Setup

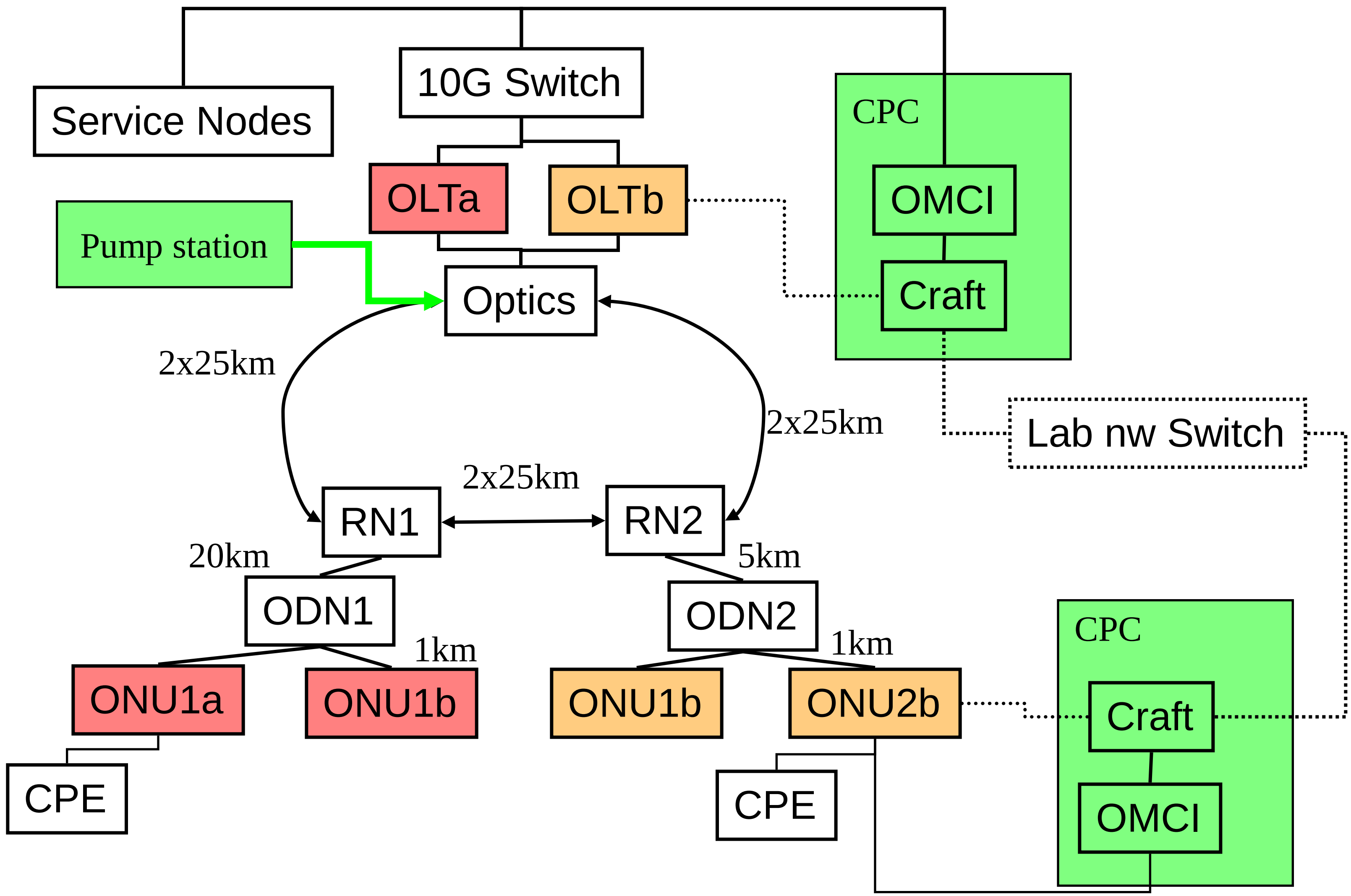


FFE/DFE Electronic compensation

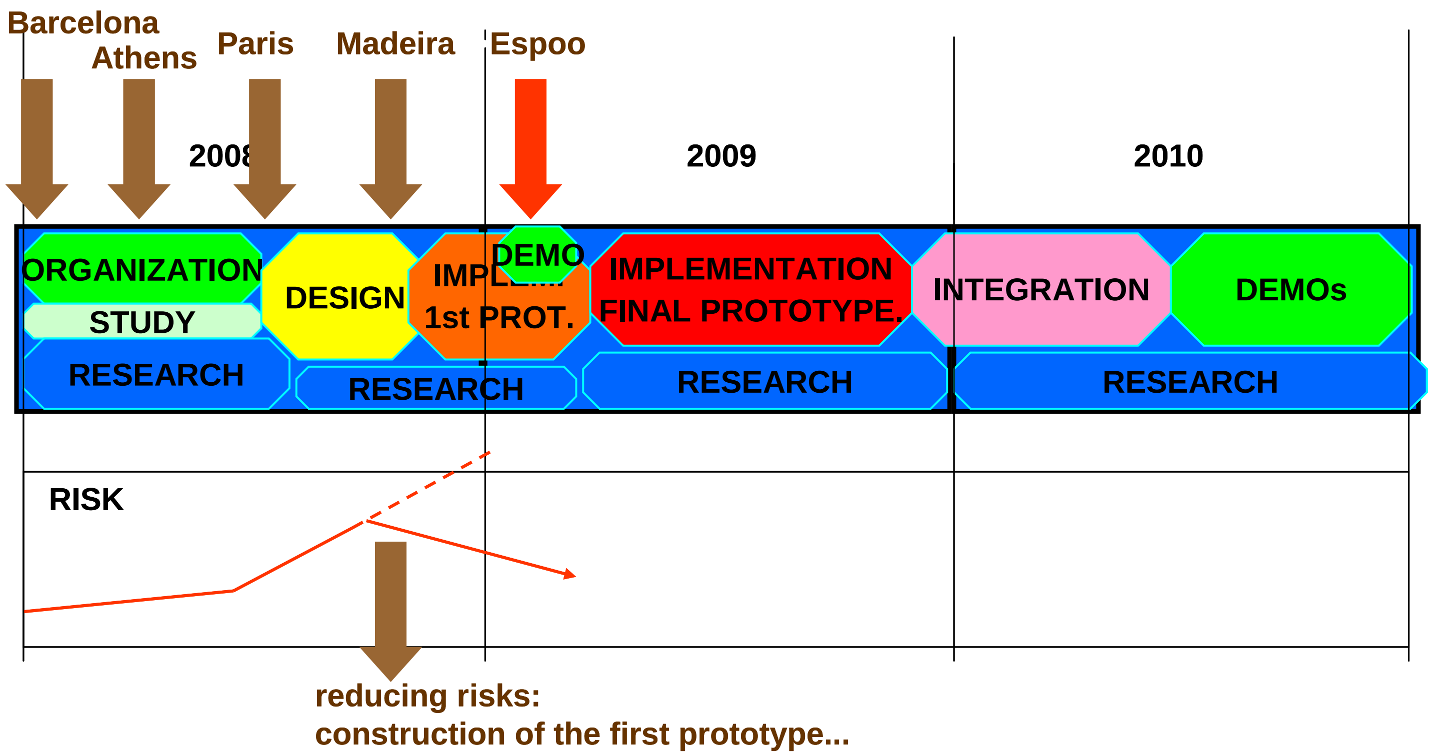
- Experimental test using an FFE/DFE module with following characteristics:
  - Operation at 10Gb/s with 2 samples per symbol
  - Independent FFE (up to 5-taps) and FFE/DFE (up to 2-tap DFE) operation
  - Built-in Clock recovery
- Experimental activities targeted the following: (independently and in combination with WP-Sy):
  - 10Gb/s EML transmission distance improvement
  - 2.5Gb/s DMLs operated at 10Gb/s with FFE/DFE and off-set-filtering
    - CD compensation
    - SPM and non-linear effects
  - 10Gb/s DML with low ER and DFE/FFE at receiver (to be combined with properties of remodulation using RSOA)
  - Equalization of remodulated upstream signal from RSOA
  - Bidirectional transmission to examine effects in tree distribution fibre

→ Results to be presented in upcoming deliverables and associated new publications

Demo setup - 2009



Project planning and status



- Prototype and test Phases of Sardana:
  - Current GPON-compatible 2.5G/1.25G
  - 10G/2.5G for Demo
  - 10G/10G with advanced tecniques.

Final Outcomes

- SARDANA project targets the **ultimate extension** of the limits of FTTH Passive Optical Networks, as a practical transparent approach to **access&metro convergence**.
  - Sardana **Test-bed Demonstration in Espoo-Finland**, with extended scalable reach, number of homes, bandwidth, passively scalable external plant and resiliency.
  - Sardana **Field-Trial in 2010 in Lannion-**France, with new broadband services.

- **Network/system/subsystem/component** design guidelines and prototypes.

- Contribution to
  - **Regulatory Bodies** on Broadband Access to citizens (multi-operator infrastructure sharing strategy).
  - **International Standards** on next-generation FTTH .

Expected Impacts:

- One **order-of-magnitude extension** of current PON performances, aimed at overcoming the expected long term limitations of current internet capabilities, architecture and protocols.
- Smooth and **increased scalability and backwards compatibility** migration solution from currently deployed PONs.
- Establishment of **new intelligent monitoring and compensation** strategies to combat impairment and faults for a trusted robust PON.
- Implementation of the **MAC,** the Control and Management planes, to demonstrate basic resiliency, wavelength balancing and improved service-aware traffic control.
- **Economic effectiveness** of the extended PON approach.
- **Demonstration** (at UPC, Helsinki Oy and ICT'2010) and field-trial (in Lannion) of the SARDANA network.
- Formal proposal for a **technical solution of a efficient multi-operator** shared broadband infrastructure as an input to international Recommendation and national NGA Regulatory bodies.
- SARDANA will result with **experience and IPR** that helps industry and research to develop a competitive advantage.