13:30–15:30
OM2A • Coherent PON
Presider: Antonio Teixeira; Universidade de Aveiro, Portugal

Advantages of Coherent Detection in Reflective PONs

Invited talk

Presenter: Roberto Gaudino

Politecnico di Torino,
OPTCOM group (www.optcom.polito.it)
Corso Duca degli Abruzzi 24, 10129 Torino, Italy,
E-mail: roberto.gaudino@polito.it

Acknowledgments

Fabrizio Forghieri
CISCO Photonics,
Via Philips 12, 20059, Monza, Milan, Italy

Valter Ferrero, Gabriella Bosco
Politecnico di Torino,
Corso Duca degli Abruzzi 24, 10129 Torino, Italy

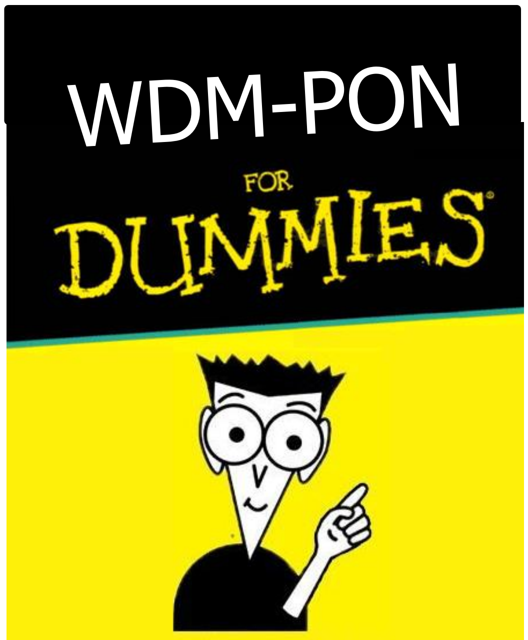
Stefano Straullu, Silvio Abrate
Istituto Superiore "Mario Boella" (ISMB),
Via P. C. Boggio 61, 10138 Torino, Italy

The part on network architecture comparisons has been done also in the framework of the new EU project titled "FABULOUS"
http://www.fabulous-project.eu/

Outline of the presentation

- A review of WDM-PON reflective architecture
- The recent FSAN standardization of TWDM-PON for NG-PON2
- Self-coherent reflective PON architecture
- Discussion and conclusion

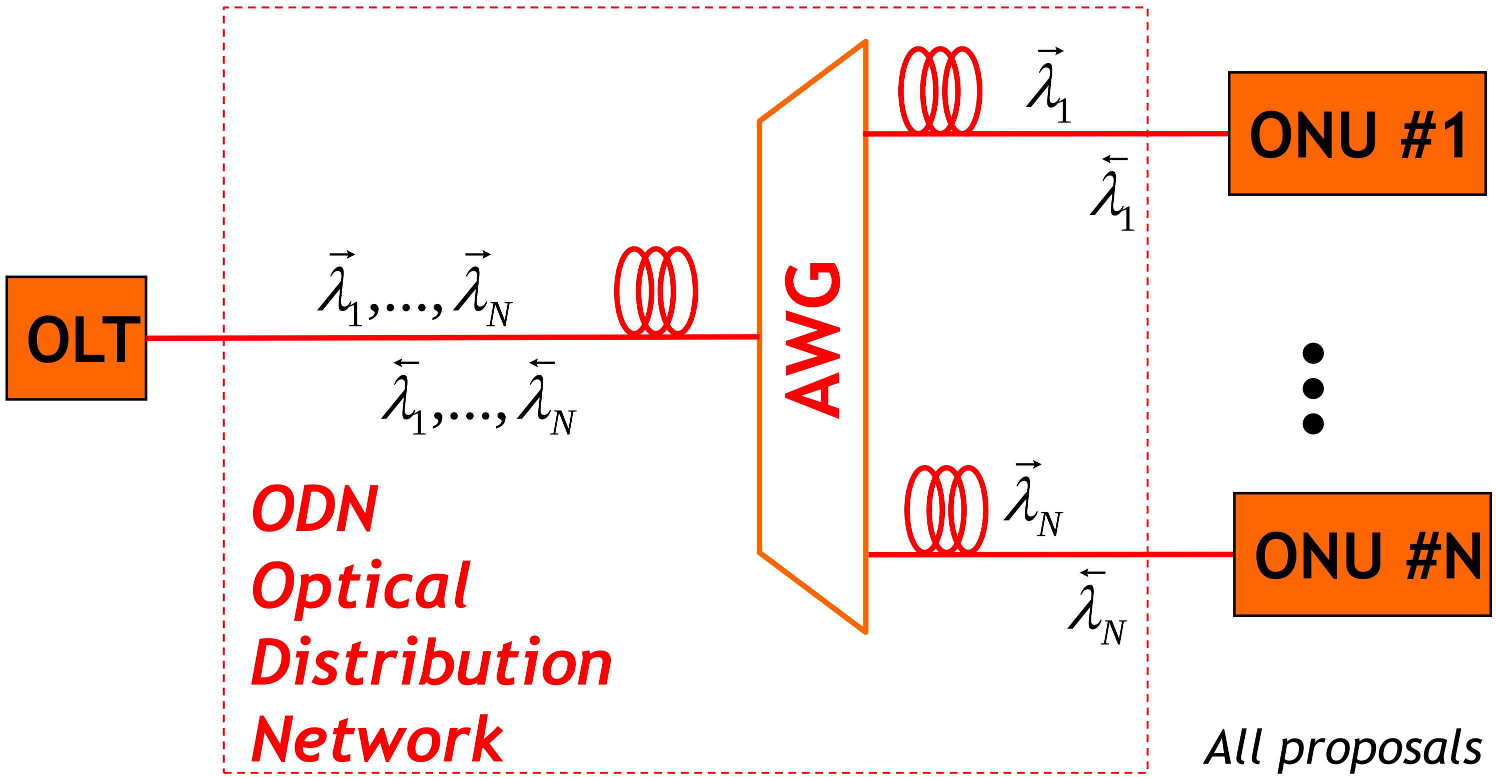
WDM-PON architectures



Reflective solutions for upstream modulation

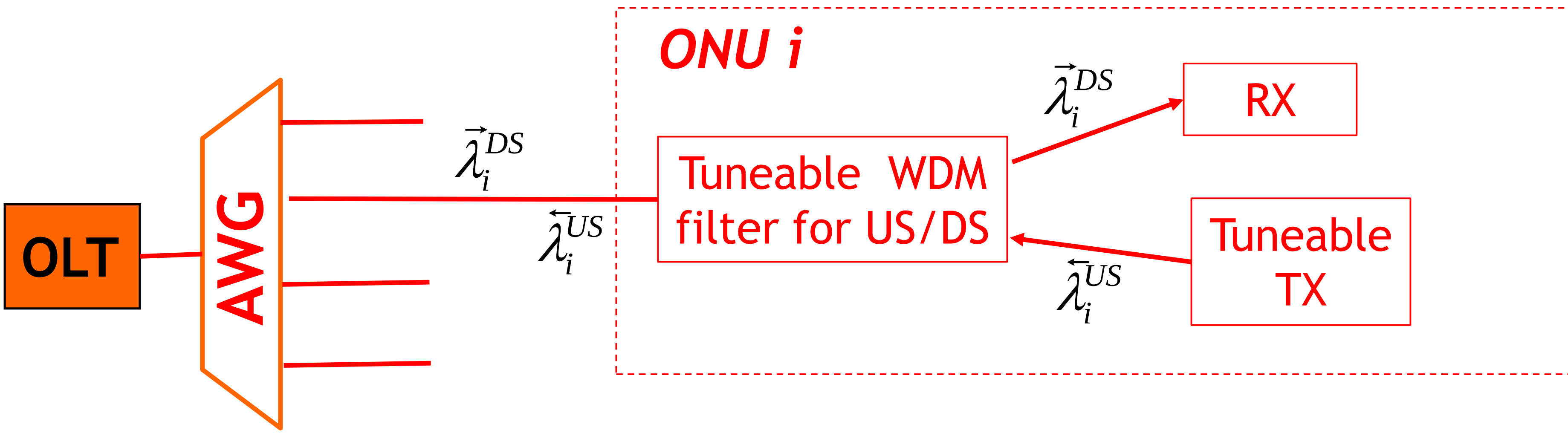
Architecture of "pure" WDM-PON

- AWG filter inside the ODN for WDM demultiplexing
- *N* pairs of wavelengths (a pair per user)



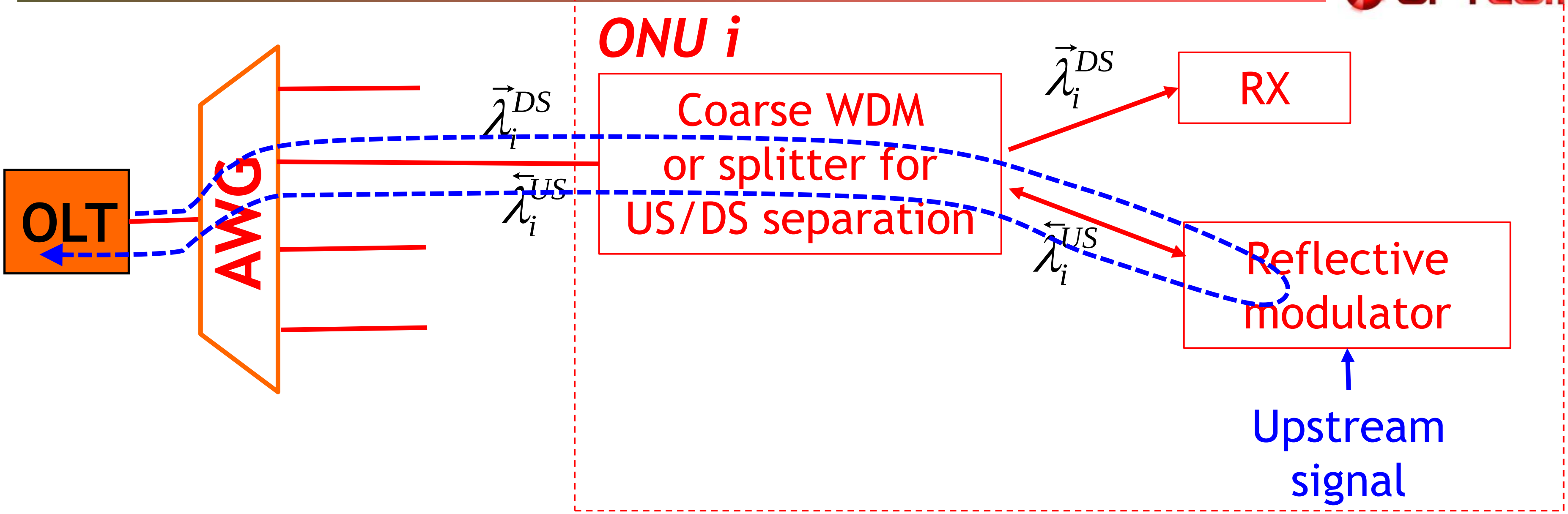
All proposals agree on one fact: ONUs must be colorless

WDM-PON and tunable laser-based ONU

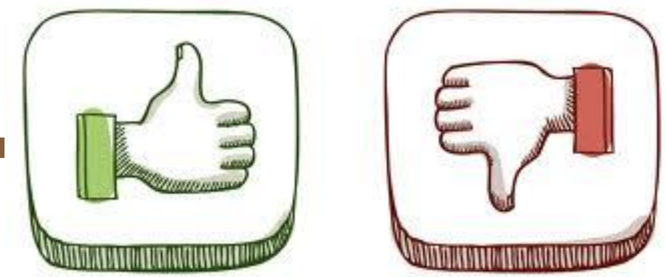


- At the ONU side, a tunable laser and a tunable filter required for US and DS wavelengths
- Very flexible solution
- No particular transmission issue
- Cost is high for wide-tunability (such as for full C band)

WDM-PON and upstream reflective modulation



- Key ideas: upstream wavelengths are generated outside the ONU, and modulated in reflection
- Many different variants proposed:
  - Self-seeded generation of upstream wavelengths
  - Re-use of the same wavelength for upstream (US) and downstream (DS)



US Reflective WDM-PON

From a transmission point of view:

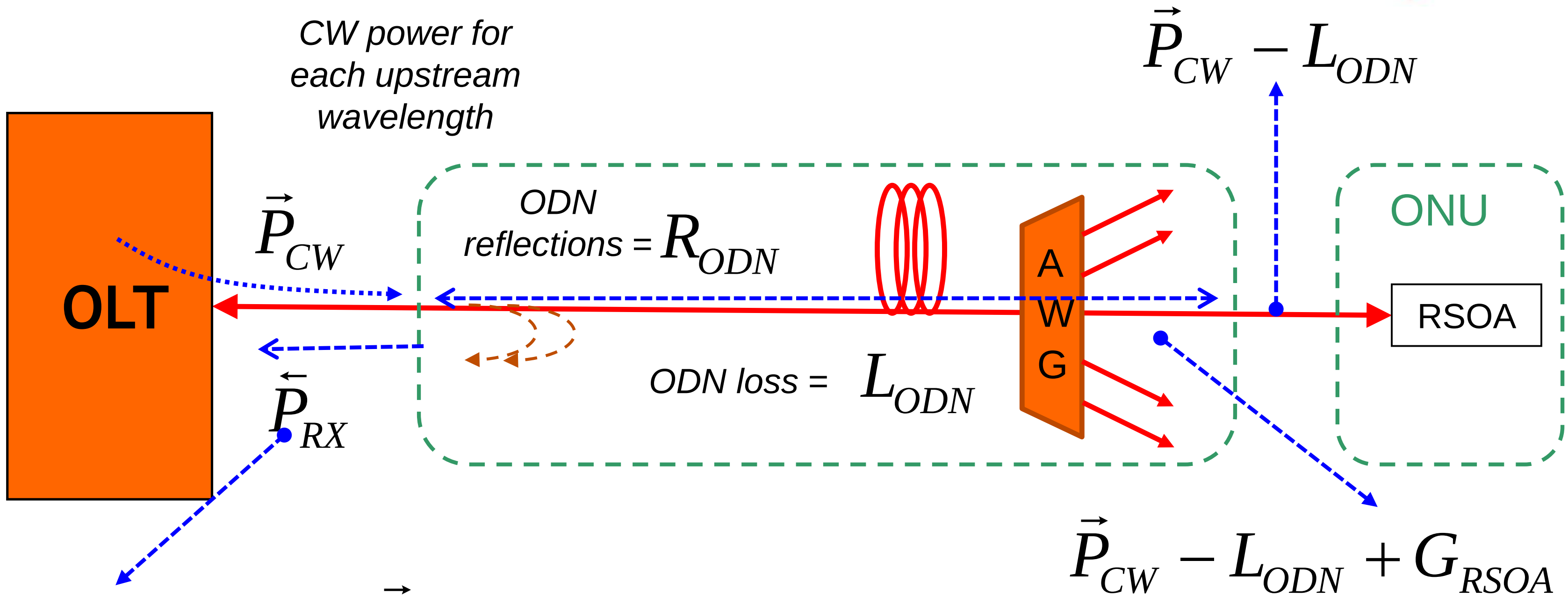
- **PROs:**
  - No need for tunable laser at ONU
- **CONs:**
  - Limited ODN power budget (“ODN loss” in the following) due to several spurious effects, including:
    - Rayleigh Back-Scattering (RBS) and concentrated reflections
    - Limited receiver power

Rayleigh back-scattering and ODN loss

- Let's assume that the upstream wavelengths are generated at the central office, and modulated in reflection at the ONU

- We remind that the spurious back reflections for an SMF fiber are of the order of 30-35 dB below the forward propagating signal, due to:
  - Concentrated reflections on components
  - Rayleigh back scattering

Impact of spurious back-reflections



$$Useful\ signal : \vec{P}_{CW} - 2 \cdot L_{ODN} + G_{RSOA}$$

$$Reflected\ signal : \vec{P}_{CW} - R_{ODN}$$

Signal to interferent ratio $= \left(\frac{S}{I}\right)_{dB} = -2 \cdot L_{ODN} + G_{RSOA} + R_{ODN}$

OFCNFOEC 2013 THE FUTURE OF OPTICAL COMMUNICATIONS IS HERE

Signal-to-interference ratio

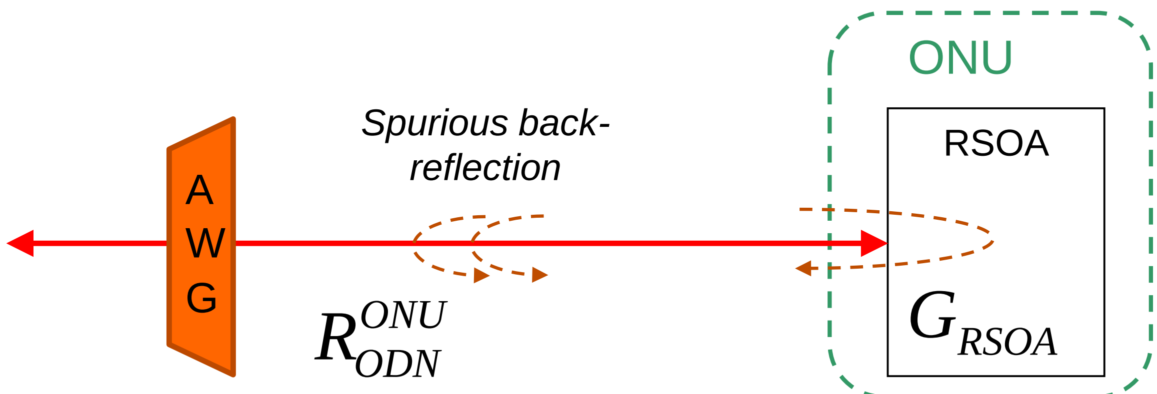
$$\left(\frac{S}{I}\right)_{dB} = -2 \cdot L_{ODN} + G_{RSOA} + R_{ODN}$$

- Let's assume for instance:
  - ODN loss =25 dB
  - ODN spurious reflections=35 dB
  - RSOA gain=20 dB
    - (S/I)= 5 dB
    - The interference is at the same wavelength as the useful signal
- For a standard direct-detection receiver, even for the best tricks proposed in the literature to mitigate RBS:

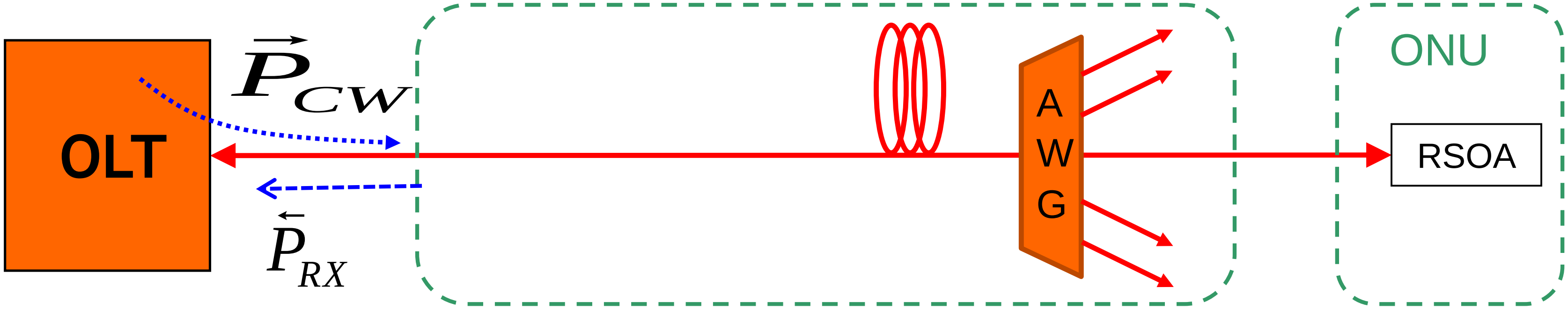
(S/I)>5-10 dB

Increasing the reflective modulator gain

- RBS and spurious reflection set an important limit to maximum ODN loss (i.e. the “class” of the PON)
- To improve the situation, one could in principle increase the gain G_{RSOA} of the reflective modulator to improve *(S/I)*
  - Anyway, there are technological component issues that limits the maximum gain you can obtain with an RSOA
  - Another issues arise again from RBS, on the ONU side



Received power



$$P_{RX} = \vec{P}_{CW} - 2 \cdot L_{ODN} + G_{RSOA}$$

- Even neglecting the RBS issue, the received power quickly decreases for increasing L_{ODN}, since it counts twice
- Let's assume for instance:
  - ODN loss =35 dB (Class C+), RSOA gain=20 dB, and P_{CW}=10 dBm
  - We get P_{RX}= -40 dBm

The recent FSAN decision on TWDM-PON

Is this the end of reflective WDM-PON ??

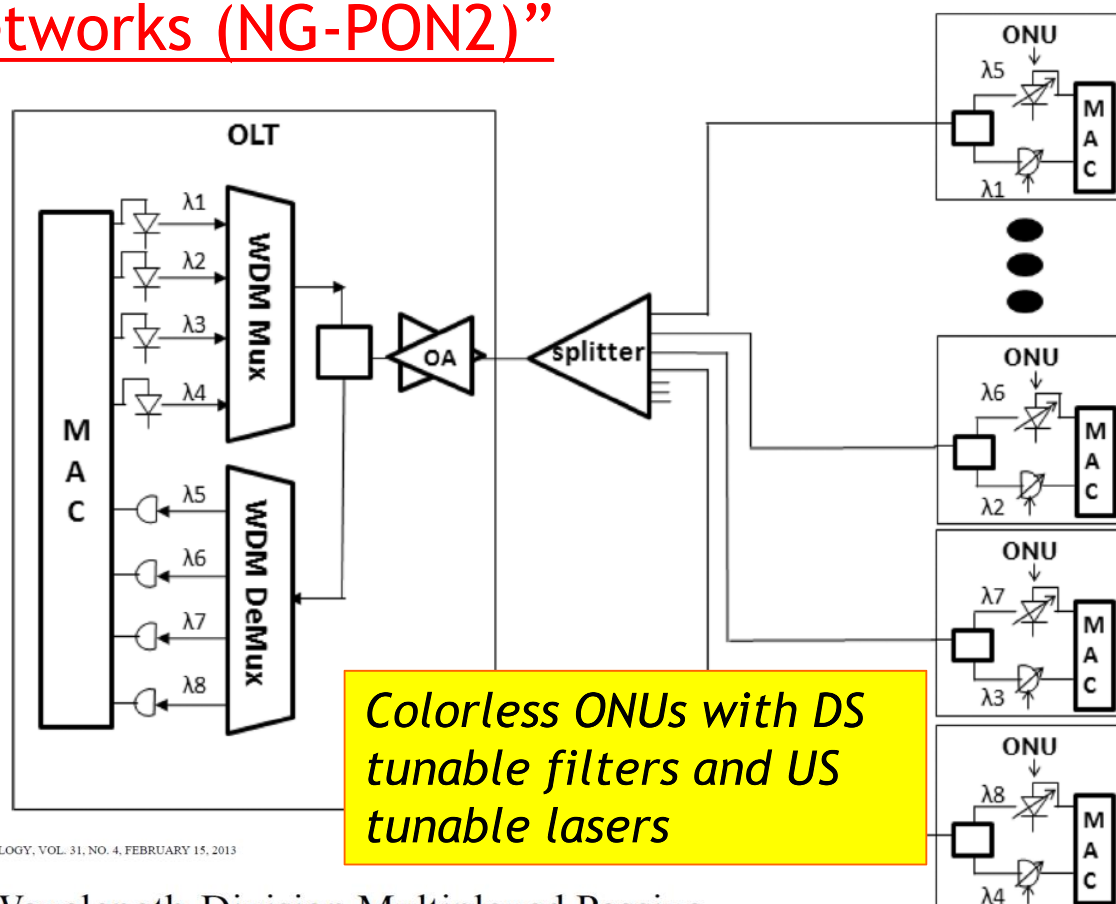
FSAN TWDM-PON architecture

OPTCOM

- Recently defined by FSAN, now being processed by ITU, it will become ITU-T G.989.1 "40-Gigabit-capable passive optical networks (NG-PON2)"

FSAN Full Service Access Network

ITU



Colorless ONUs with DS tunable filters and US tunable lasers

Picture taken from:

JOURNAL OF LIGHTWAVE TECHNOLOGY, VOL. 31, NO. 4, FEBRUARY 15, 2013

Time- and Wavelength-Division Multiplexed Passive Optical Network (TWDM-PON) for Next-Generation PON Stage 2 (NG-PON2)

Yuanqiu Luo, *Senior Member, IEEE*, Xiaoping Zhou, Frank Effenberger, *Senior Member, IEEE*, Xuejin Yan, *Senior Member, IEEE*, Guikai Peng, Yinbo Qian, and Yiran Ma

TWDM-PON key features

- **TDMA on each of the 4 wavelengths**
  - Up to 64 users on each lambda
- Splitter-based PON
  - No AWG in the ODN
  - ODN power budgets will be the same as GPON and XGPON, thus also including class C (32dB) and C+ (35 dB)
    - The TX/RX power budget requirements is actually increased due to the additional optical filters required to handle WDM at the ONU and OLT

Can reflective PON still be applied in such scenario?

(At least) three issues should be addressed:

1. Stick with the splitter-based architecture (i.e. no AWG in the ODN)

2. US transmission should allow high ODN loss
   - Treated in details in the rest of the presentation

3. Make US TDMA possible even on reflective PON
   - Briefly mentioned at the end of this presentation

What if we are able to solve the previous 3 points?

- The key “new” optical components that will be required by FSAN TWDM-PON are Tunable lasers and Tunable filters at the ONU side
  - They should both have a precision compatible with a 100 GHz wavelength grid, and be able to tune on 4 wavelengths
  - They should operate on a very wide temperature range
  - They should have a target price compatible with ONU
  - For upstream, ONU tunable lasers will determine the absolute accuracy for each wavelength
- **In the longer term, if more than 4-8 wavelengths will be used, this issue will be particularly critical**

Tunability requirements for TWDM-PON

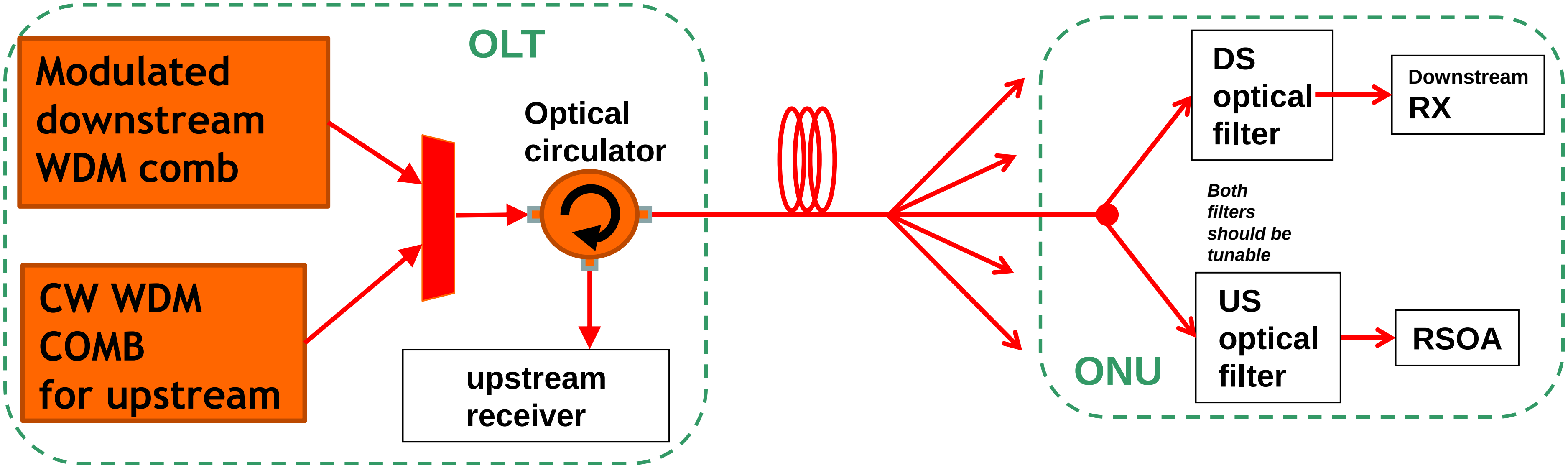
OPTCOM

- DOWNSTREAM: the tunable filter at the ONU can be locked on one of the incoming wavelength,
  - The absolute wavelength accuracy is thus set at the Central Office, NOT at the ONU
  - **Less critical**

- UPSTREAM: the tunable laser at the ONU should be tuned on the proper wavelength without any reference
  - The absolute wavelength accuracy is thus determined by the ONU tunable lasers, not by the Central office
  - **MORE critical** that the downstream situation

Using centralized wavelength generation and R-PON

- Back to reflective PON…



- In the architecture above, the upstream wavelength grid is generated at the central office
  - Its accuracy is thus set by the CO

Conclusion

- We will show in the next slides that a particular implementation of reflective PON can achieve high ODN loss and, possibly, US TDMA

- **Its potential advantages would thus be:**
  - NO tunable lasers at ONU (only tunable filters)
  - Very precise DWDM comb can be generated in the CO

- **Upgrades to 50 GHz spacing, or to a high number of wavelengths may thus be easier**

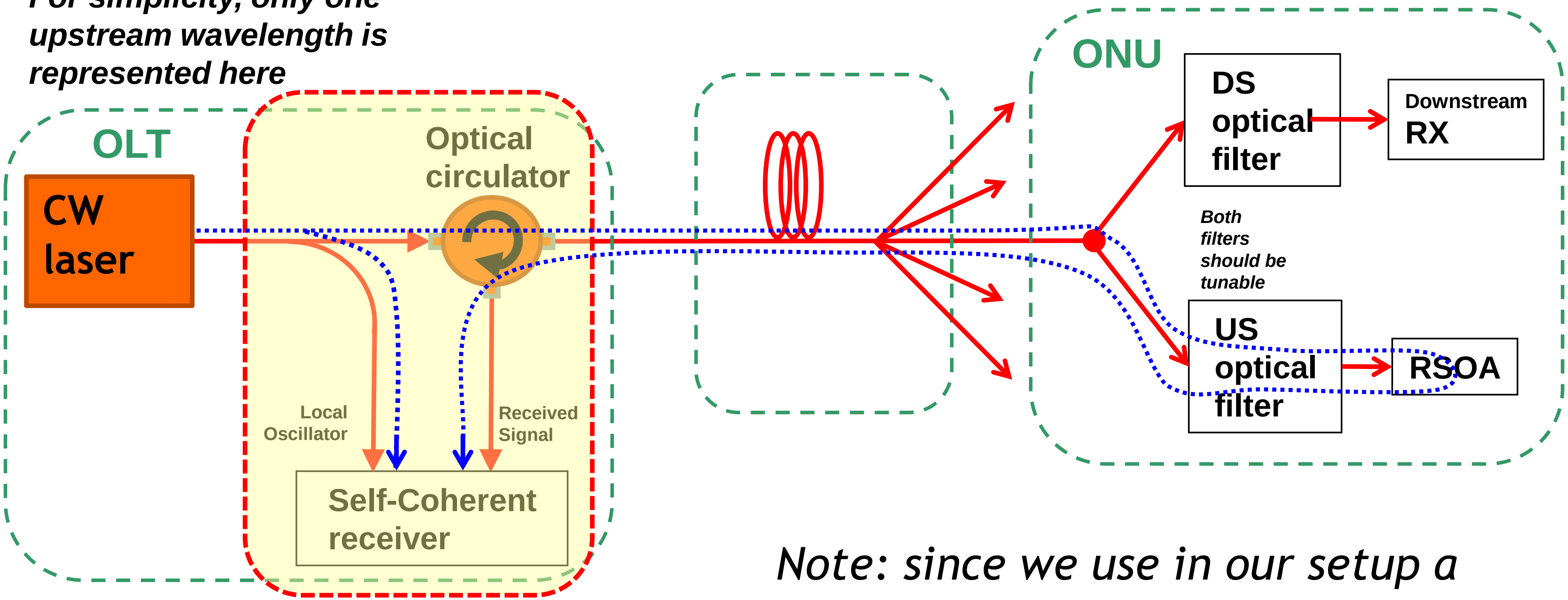
Achieving high ODN losses in reflective PONs

Introducing self-coherent detection on the upstream reflectively-modulated signals

Self-coherent reflective PON

- Proposed architecture

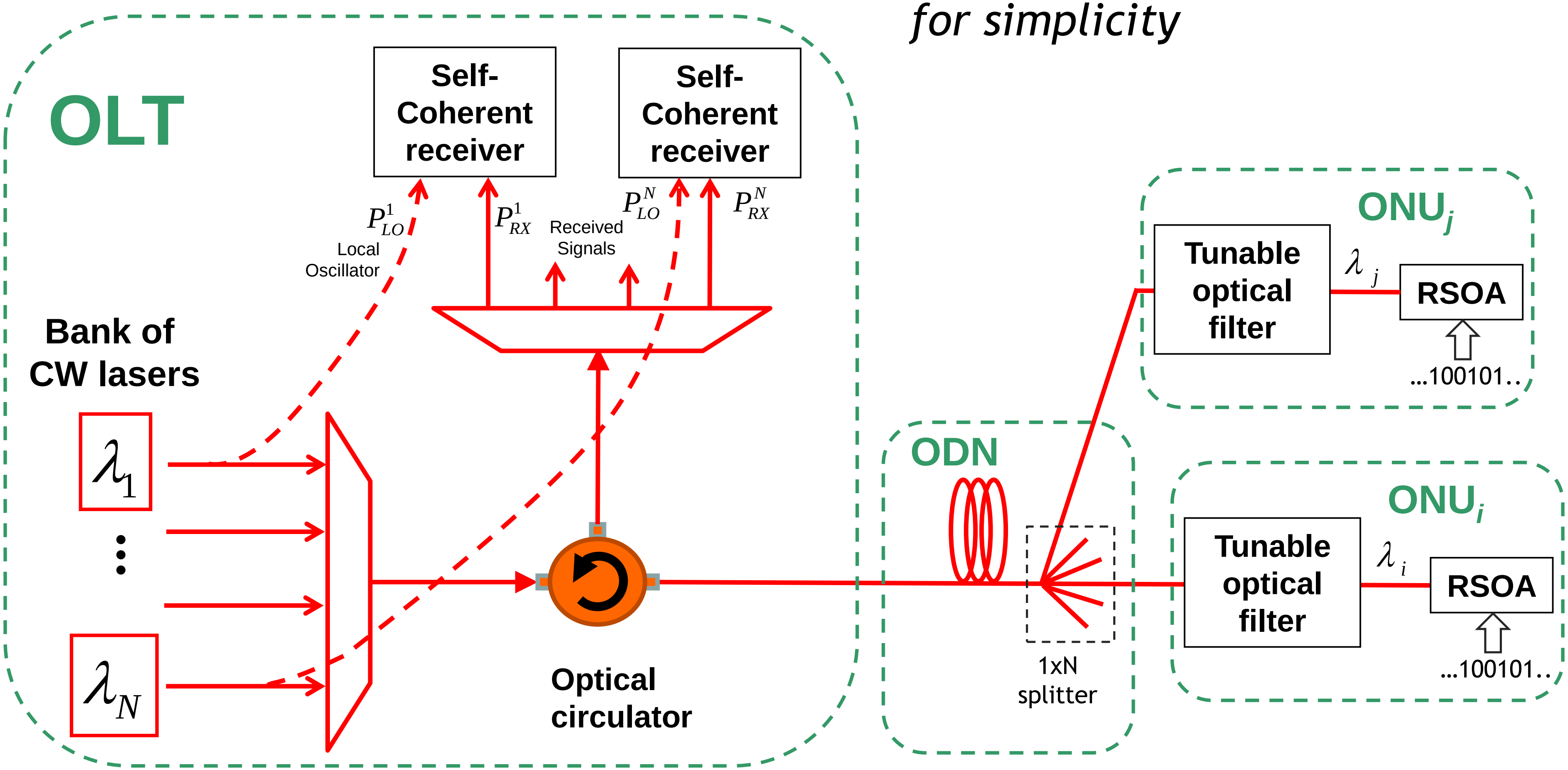
For simplicity, only one upstream wavelength is represented here



Note: since we use in our setup a coherent receiver, we do not consider self-seeded solutions
They would give rise to lasers with large linewidth, incompatible with coherent detection

The overall reflective, self-coherent architecture

ONLY upstream shown for simplicity



Experimental results:

RSOA as modulator
1.25 Gbit/s upstream
Installed metropolitan fiber testbed

ECOC 2012 posteadline paper Th3D.6

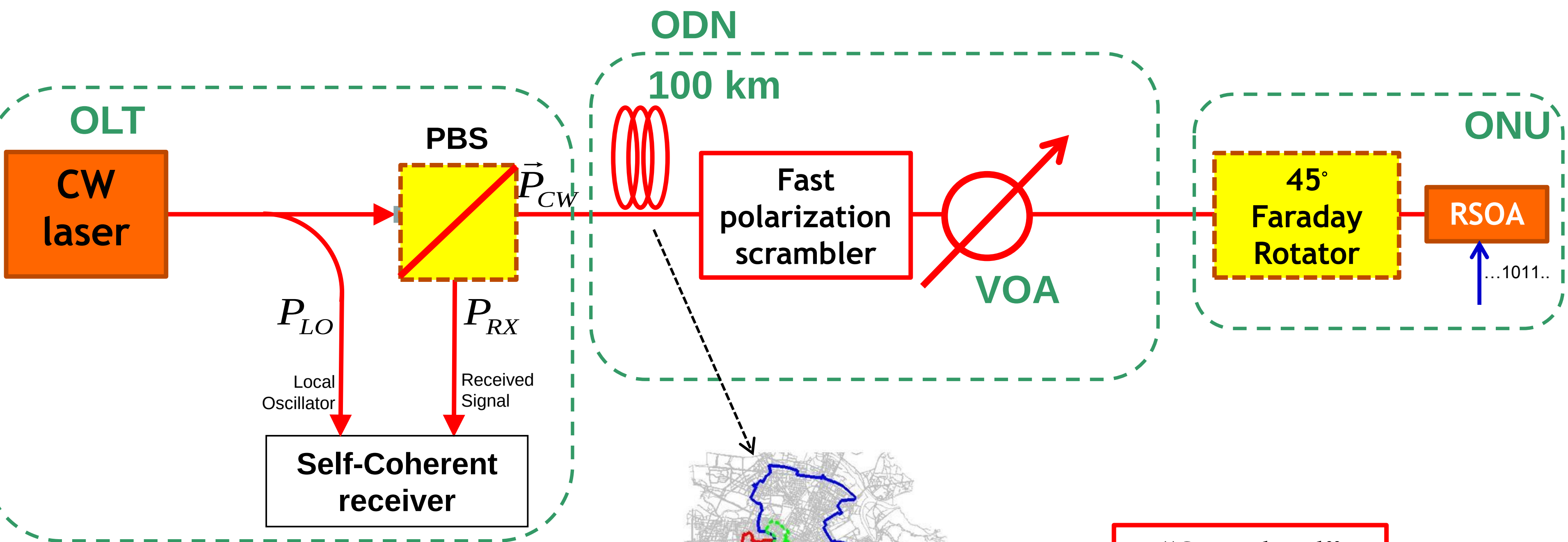
Optimization of self-coherent reflective PON to achieve a new record 42 dB ODN power budget after 100 km at 1.25 Gbps

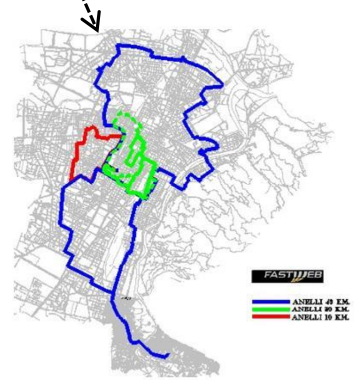
S. Straullu[2], S. Abrate[2], F. Forghieri[3], V. Ferrero[1] and R. Gaudino[1]

[1] Politecnico di Torino, C.so Duca degli Abruzzi 24 – 10129 Torino, Italy, roberto.gaudino@polito.it
[2] ISMB, Istituto Superiore Mario Boella, Via P.C. Boggio 61 – 10138 Torino
[3] CISCO Photonics, Via Philips 12, 20059, Monza, Milan, Italy

Experimental setup

OPTCOM



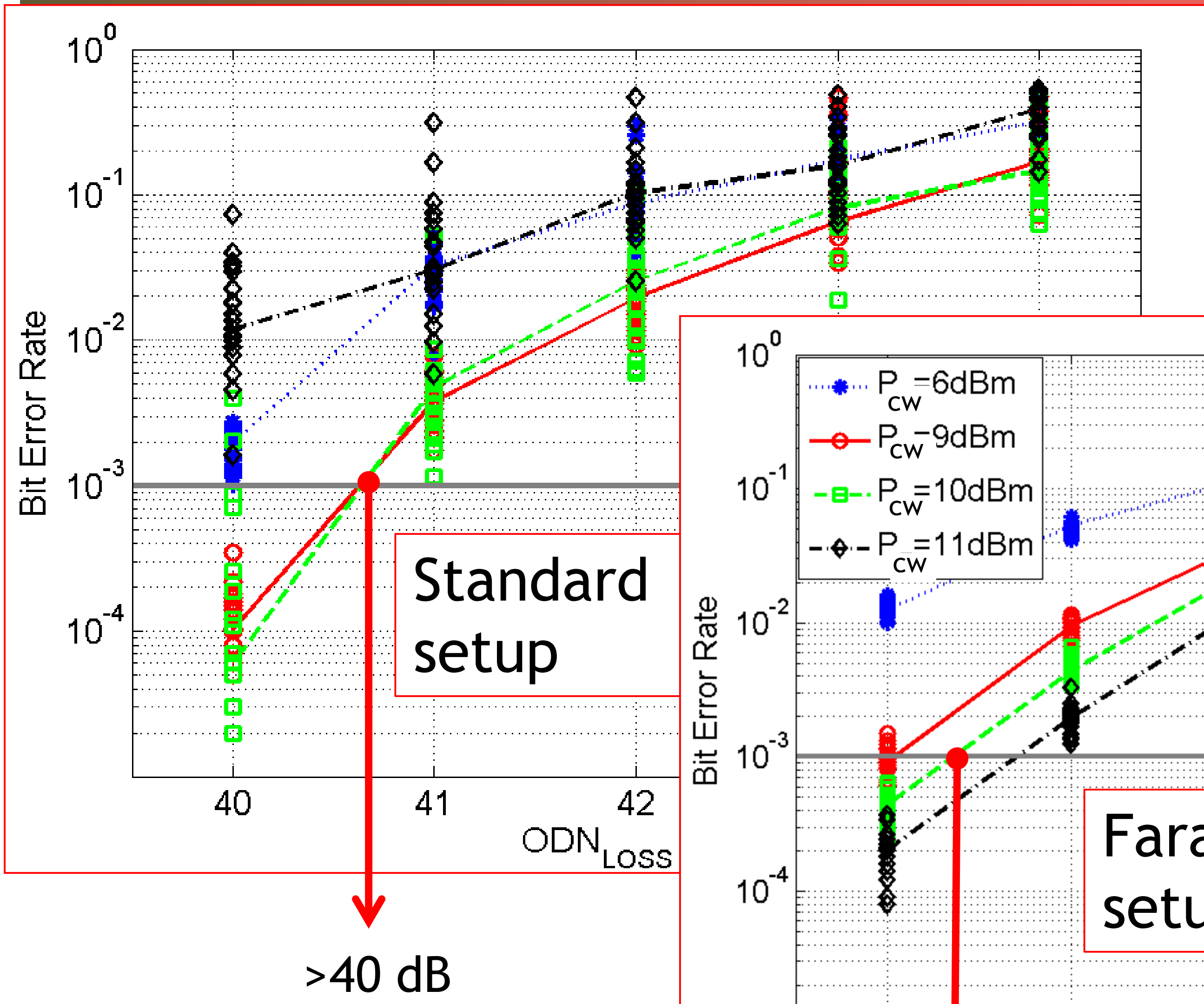


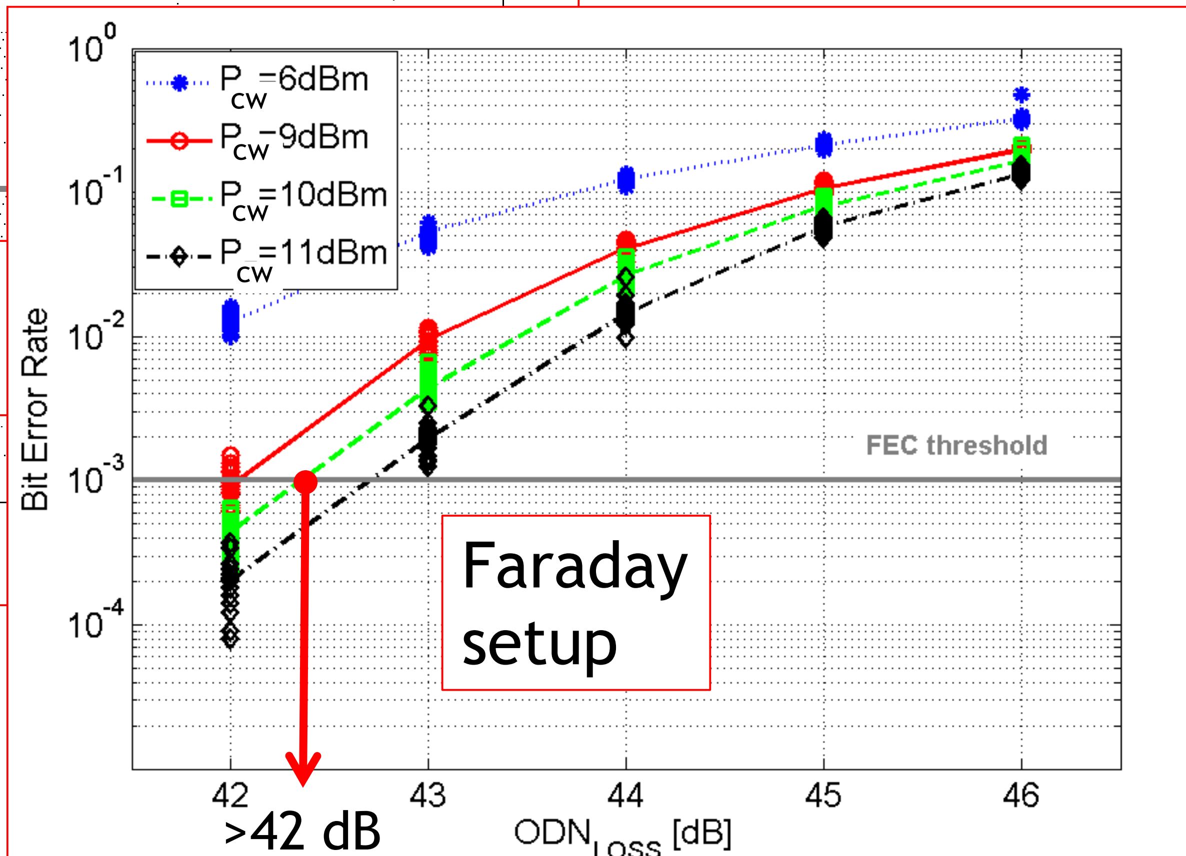
Testbed rings layout in Torino

“Standard” Setup

“Faraday” Setup

BER vs. ODN loss, different launched power





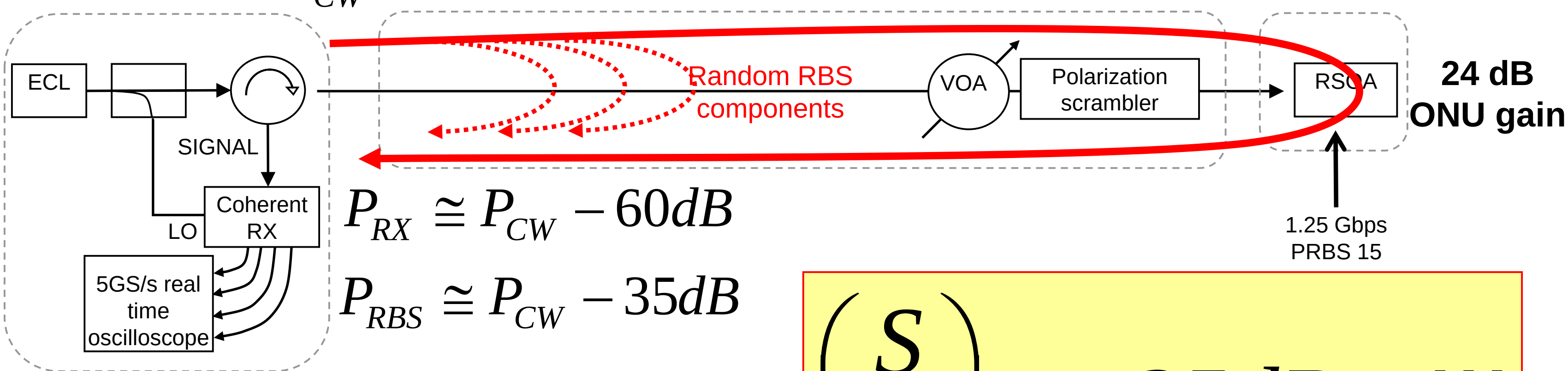
Interpreting the results

- The achieved ODN loss (≥40dB) are significantly higher than those that are achieved by reflective PON solutions

- <u>**Coherent detection + DSP is key in this respect**</u>
  - Better sensitivity that direct detection even in the back-to-back case
    - We had nearly -50 dBm sensitivity using a commercial coherent receiver at 1.25 Gbps
  - Much larger resilience to spurious back reflections
    - Let's analyze this last point in the following slides

RBS levels: estimation by hand

- Let's consider the following values:
  - Demonstrated ODN loss = 42dB
  - ONU gain in this conditions = 24 dB
  - RBS 35dB below the launched power



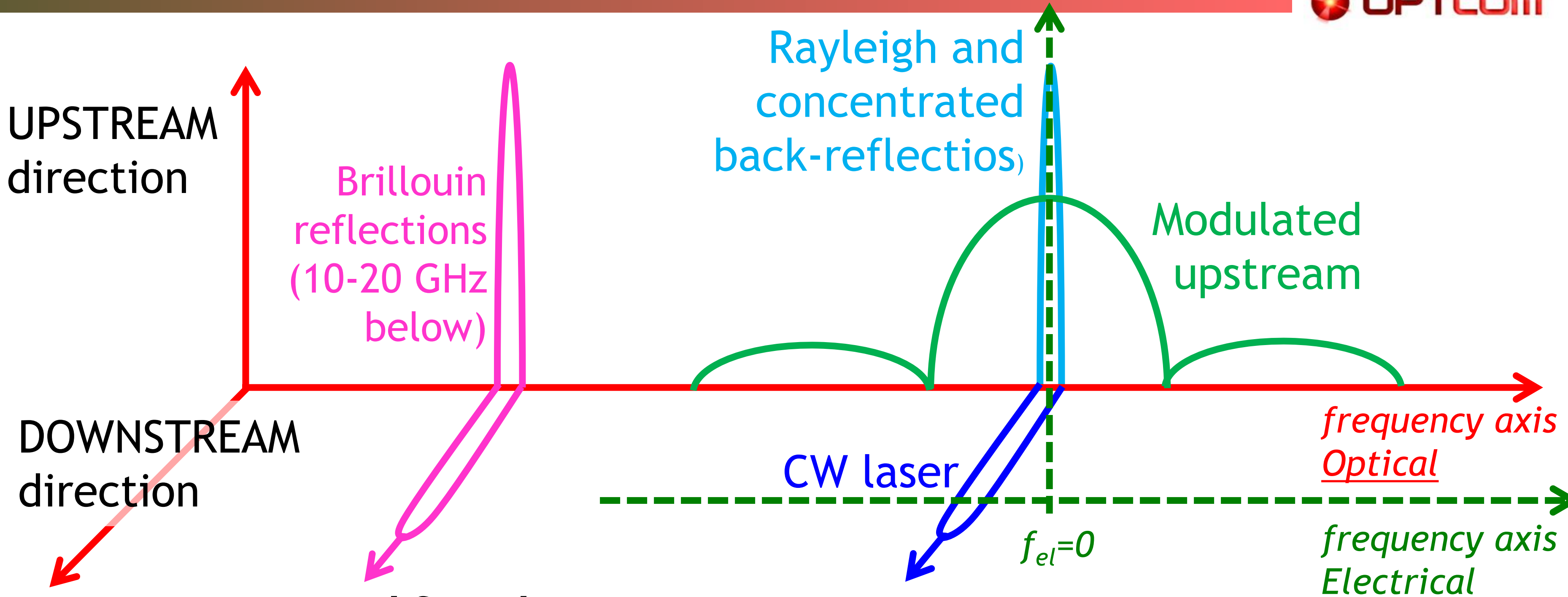
$$P_{RX} \cong P_{CW} - 60dB$$

$$P_{RBS} \cong P_{CW} - 35dB$$

$$\left(\frac{S}{I}\right) \cong -25dB \quad !!!$$

OFCNFOEC 2013 THE FUTURE OF OPTICAL COMMUNICATIONS IS HERE

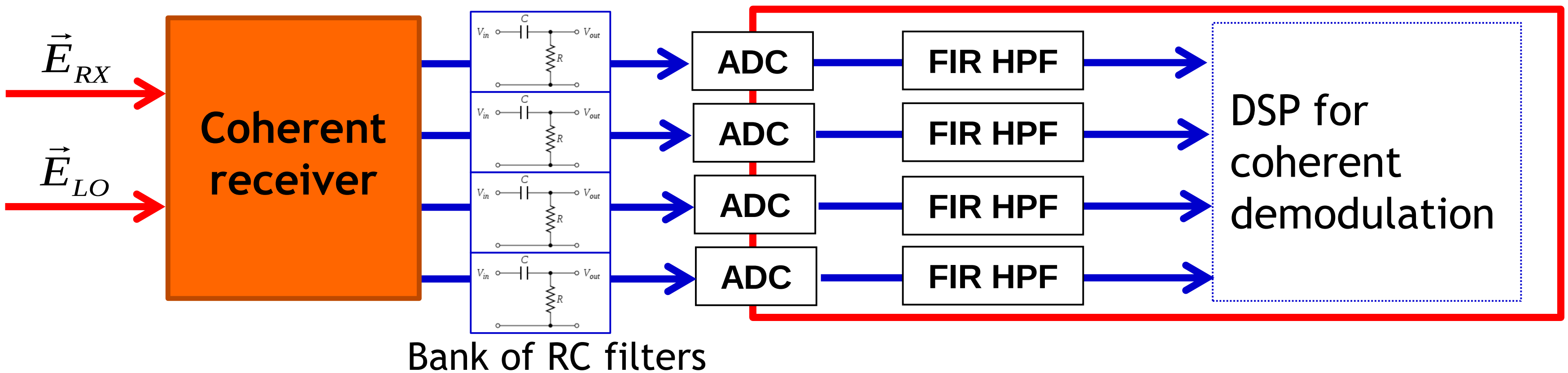
The different contributions to reflections



- Using a self-coherent receiver:
  - The RBS reflections appears as added close to "electrical" DC →it can be filtered out by electrical high-pass filters
  - The upstream Brillouin component (if relevant) is out of band compared to the useful upstream signal

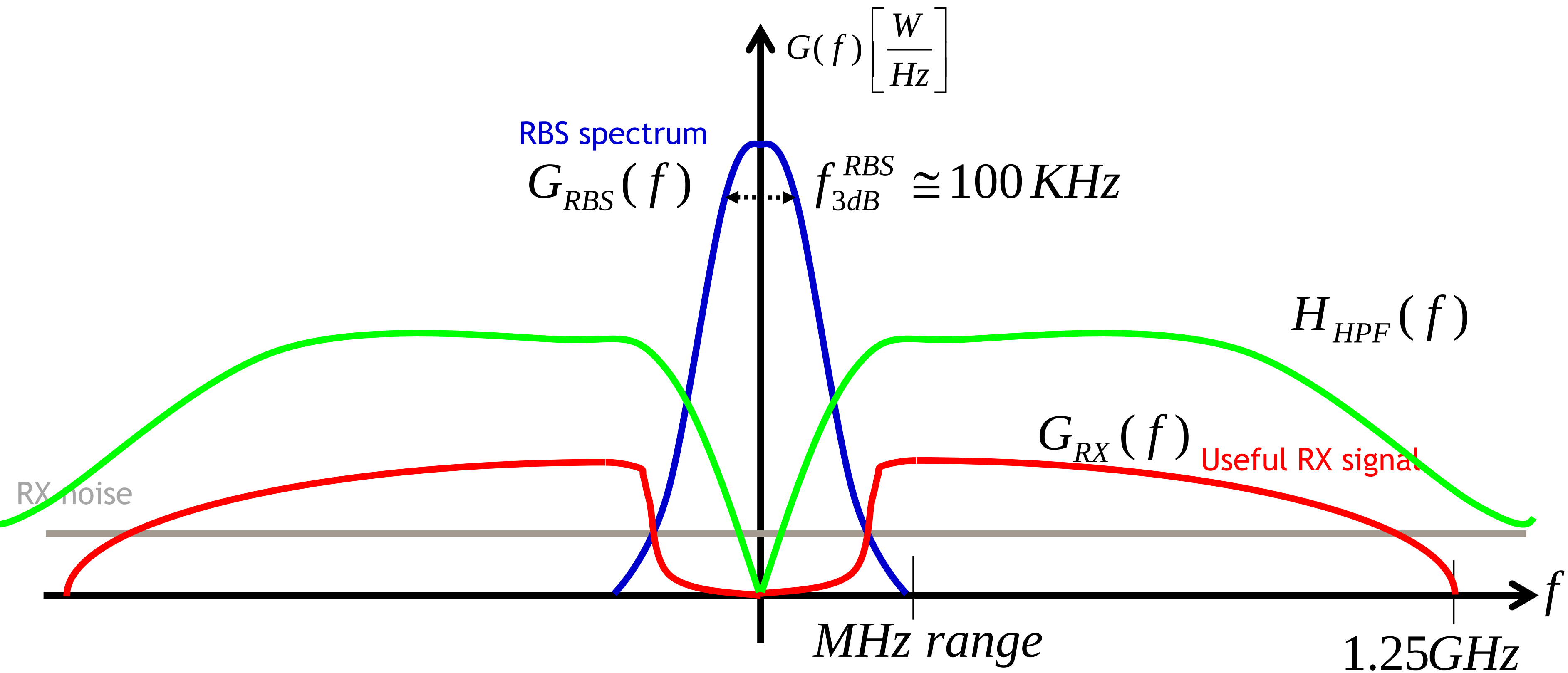
Filtering the RBS noise

- An optimized high-pass filter (HPF) in the coherent receiver was fundamental to solve the problem. Two possible options:
  - Analog electrical filtering before the ADCs
  - Digital filtering in the DSP section after the ADCs



Introducing 8B/10B

- In order to allow a high frequency cut-off we introduced 8B/10B coding to minimize baseline wander effects on the useful signal



Inferring ODN loss at higher bit rates

- We demonstrated >40dB ODN loss at 1.25 Gbit/s
- At higher bit rates:
  - Coherent receiver theoretical sensitivity is inversely proportional to the bit rate. Thus, compared to our 1.25 Gbit/s experiments, we should expect:
    - 3dB penalty at 2.5 Gbit/s, and 9 dB at 10 Gbit/s
  - But ODN loss counts twice
    - 1.5dB ODN loss penalty at 2.5 Gbit/s, and 4.5 dB at 10 Gbit/s
  - RBS impact will likely be even smaller, since the "spectral notch" in the signal will be at higher frequency

Conclusion on ODN loss in self-coherent PON

- In conclusion, we can expect power budget at 2.5 Gbps (XGPON upstream rate) better than the 35 dB ODN loss required by class C+
  - Thus, completely compatible with TWDM-PON upstream at 2.5 Gbps
- Even at 10 Gbps, class C (32 dB) could be achievable
  - Assuming that RSOA bandwidth usage is optimized, see for instance next presentation, or other type of modulators (SOA+REAM)

Reflective coherent PON

Can we make them TDMA-based?

Required developments: Burst mode

- The self coherent solution shown in the previous slides was demonstrated using <u>one dedicated wavelength per ONU</u>
  - This could find applications in wavelength overly solutions, for instance for mobile backhauling
- Anyway, in residential PON:
  - One dedicated wavelength per user <u>does not offer enough granularity</u> and, at least for residential users, is likely <u>too expensive</u>
  - Moreover, a coherent receiver per single user is likely too expensive, even inside the central office

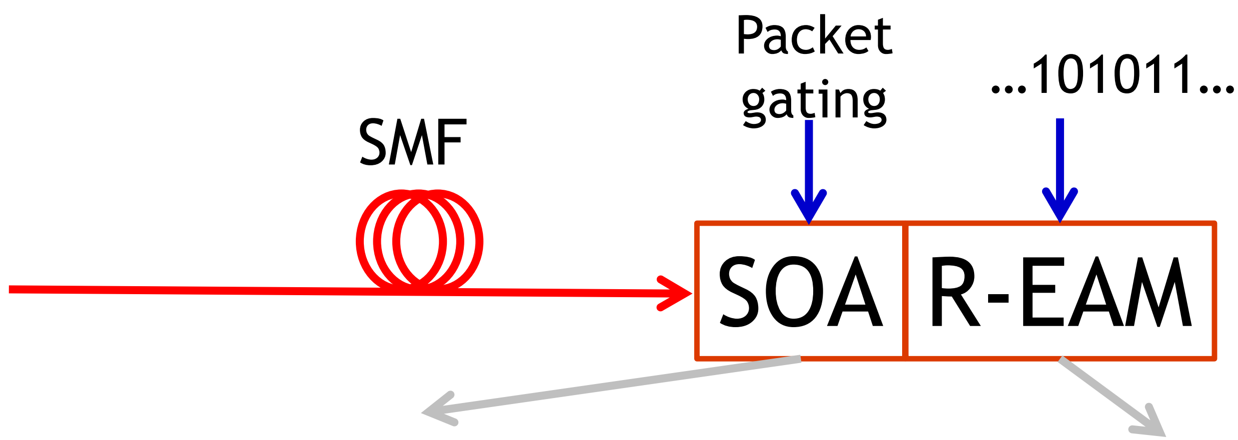
Burst mode, self-coherent reflective PON

- To solve the previous issues, and thus make it completely compatible with TWDM-PON, a burst-mode operation would be needed, requiring:
  1. Burst-mode TX (using RSOA or other reflective modulators)
  2. Coherent burst mode detection

- We have very recently started this activity, obtaining only preliminary results

Burst mode reflective transmission

- Possible TX options under investigation:
  - Using only one RSOA driven as it is usually done for GPON and XGPON burst-mode lasers
  - Use a SOA + REAM combination

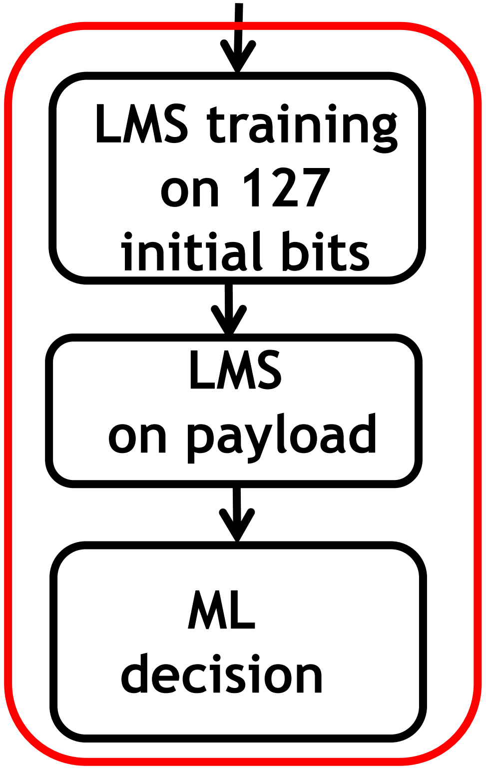


Semiconductor optical amplifier (SOA)
Functions:
- Amplification (20 dB per single pass)
- Gating on the packets (2-3 ns raising time)

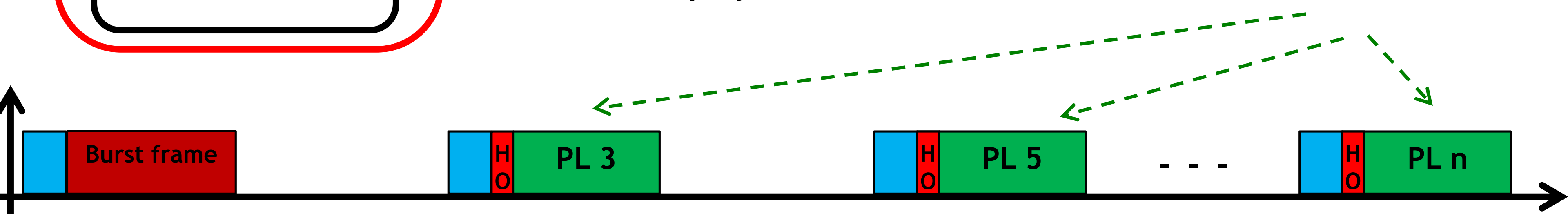
Reflective Electro Absorption Modulator

Modulation bandwidth up to 6-7 GHz

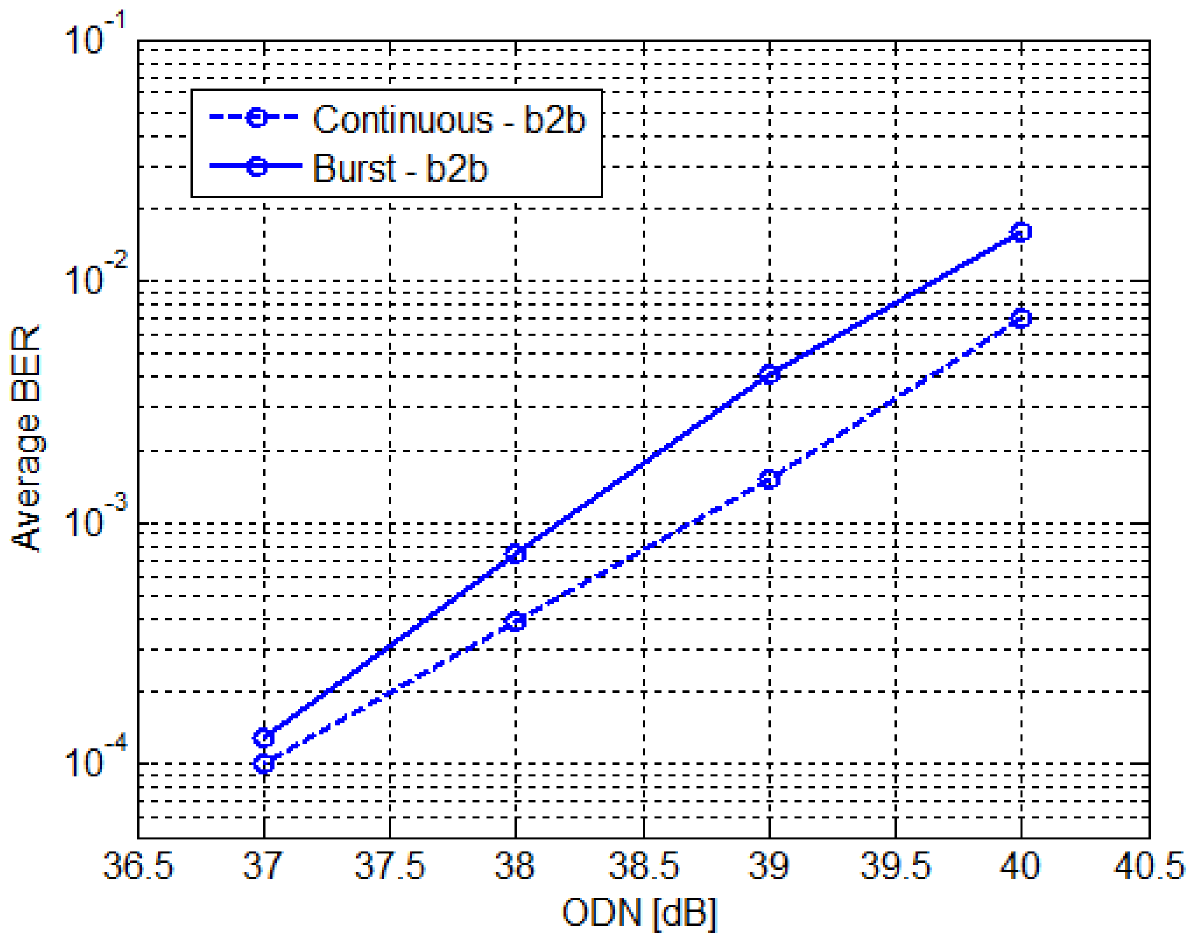
Coherent burst mode receiver



- **LMS (training)**
  - The first **127 bits** in each bursts are used for synch and for training the LMS algorithms
- **LMS (tracking)**
  - After the first 127 bits, the LMS algorithm is switched to "decision directed" to elaborate the payload of the burst



Back-to-back results



- Measurements done on:
  - 90 packets in burst mode (approx 90.000 bits)
  - 100.000 bits in continuous mode

Ok, let's summarize…

Self-coherent reflective PON

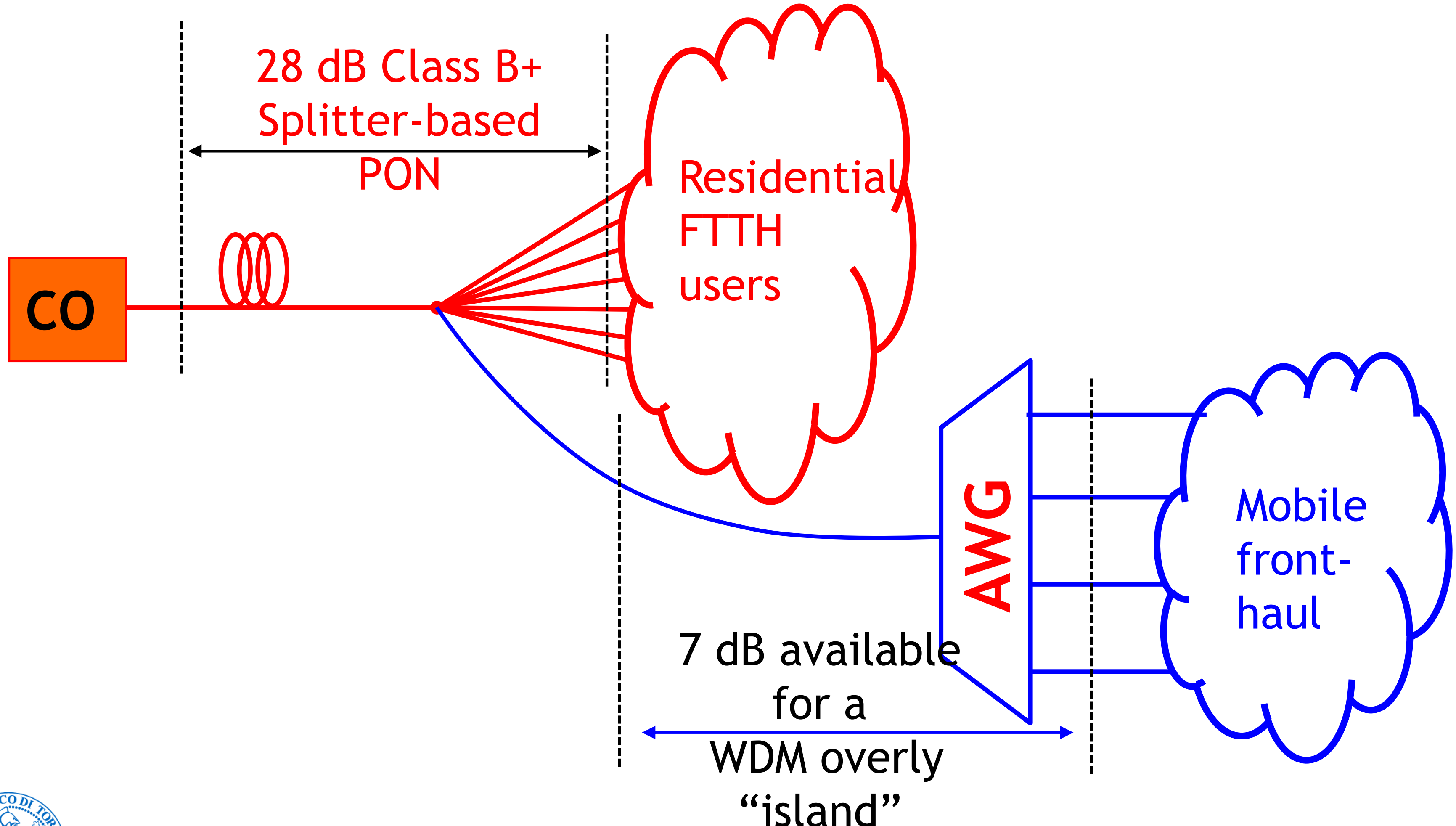
OPTCOM

- We showed that self-coherent reflective PON:
  - Allows for high ODN-loss
    - Even 35dB, as required by class C+, can be achieved
  - Can be made burst mode for TDMA
  - Wavelength accuracy is set by the central office
    - No tunable lasers needed at OLT
    - Only tunable filters locked to incoming CW wavelengths

- This solution seems compatible with TWDM-PON, and easily scalable to DWDM with many lambdas

Envisioning mixed solution

- An available high ODN loss (>35dB) can open innovative mixed solutions, such as:



Reflective coherent PON

What about FDMA rather than TDMA?

EU FABULOUS project

The FABULOUS project

Fabulous

FDMA Access By Using Low-cost Optical network Units in Silicon photonics

ISMB Istituto Superiore Mario Boella

cea leti

france telecom orange

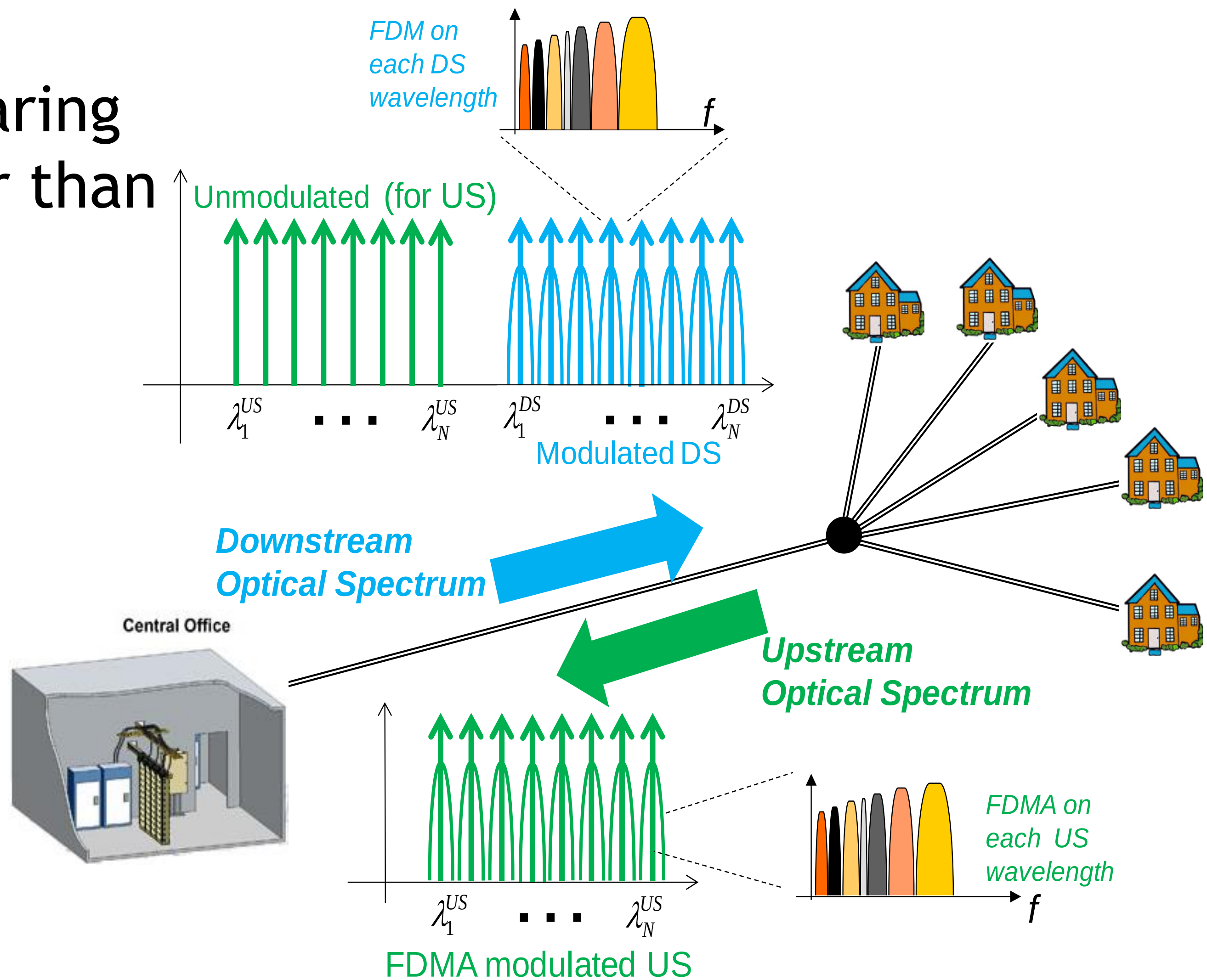
ST

Tyndall National Institute

III-V lab

FDMA architecture in FABULOUS

- Achieving wavelength sharing by FDMA rather than TDMA



In case you are interested:

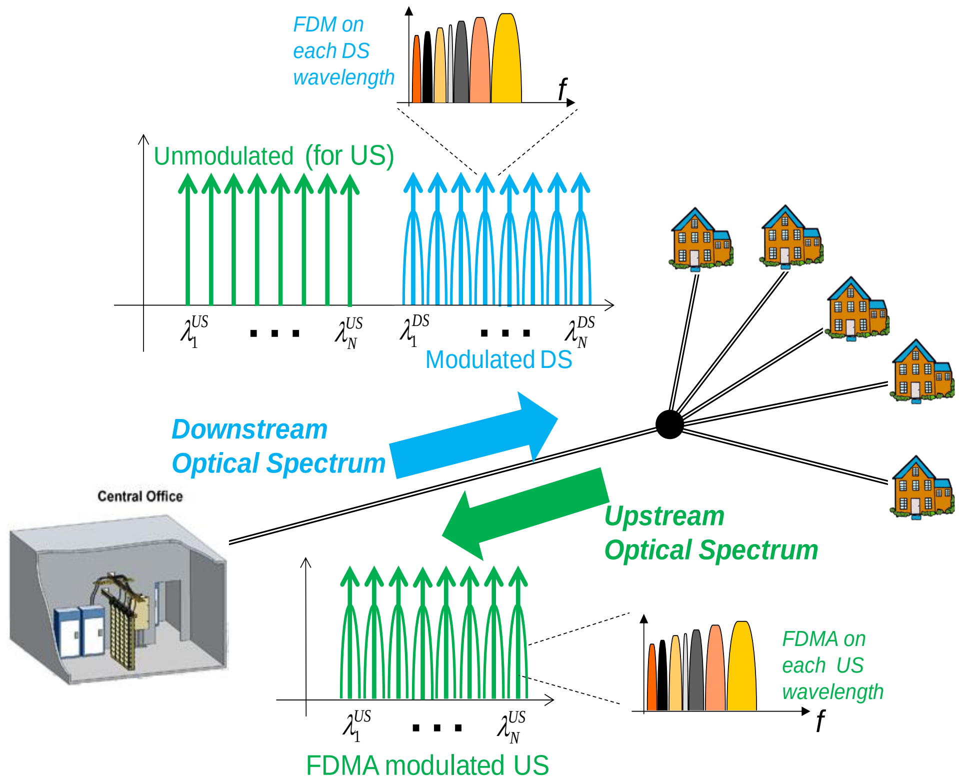
OPTCOM

Thursday afternoon:

13:00–15:00
OTh3A • FDMA and OFDMA PON

OTh3A.7 • 14:30 Invited

Low Complexity FDM/FDMA Approach for Future PON, Benoit Charbonnier[1], Aurelien Lebreton[1], Philippe Chanclou[1], Giovani Beninca de Farias[2], Sylvie MENEZO[2], Rongping Dong[3], Jerome Le Masson[3]; *[1]R&D Orange FT group, France; [2]CEA-LETI, France; [3]Universite de Bretagne Sud, France.* FDMA PON allows the ONU complexity and cost to be tailored to the service level targeted per customer while achieving high per wavelength throughput (35-39Gbps downlink). Initial progress towards an all Silicon ONU is presented.



OFCNFOEC 2013
THE FUTURE OF OPTICAL COMMUNICATIONS IS HERE

Advantages of Coherent Detection in Reflective PONs

Thank you for your attention!

Roberto Gaudino

Politecnico di Torino,
OPTCOM group (www.optcom.polito.it)
Corso Duca degli Abruzzi 24, 10129 Torino, Italy,
E-mail: roberto.gaudino@polito.it