Towards Converged Optical and Wireless Fronthaul Solutions for 5G and Beyond Networks

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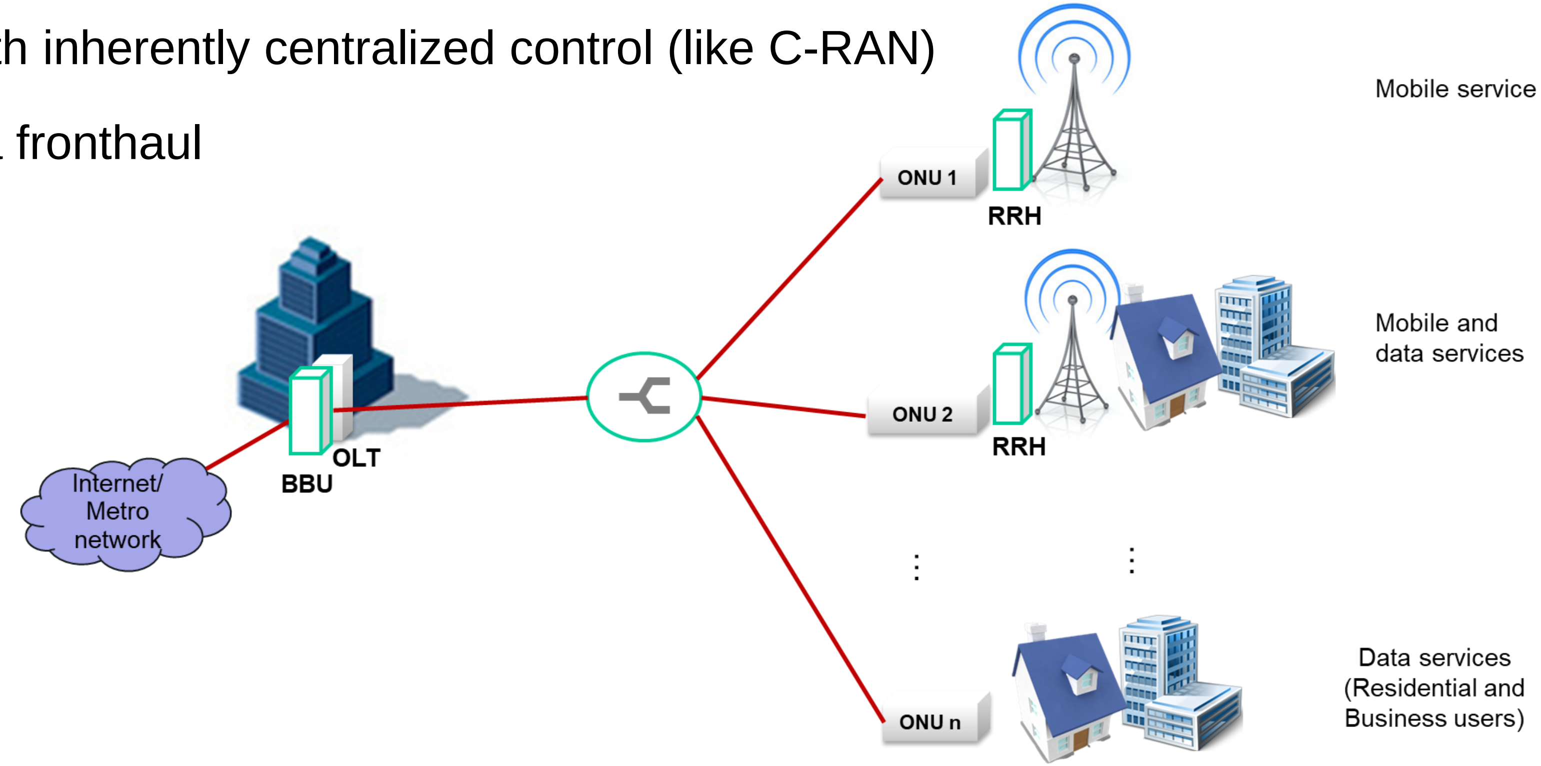
instituto de telecomunicações

Workshop on Optical Network Evolution towards F5G and Beyond (Mo2F-WS)

Fixed Mobile Convergence over PON

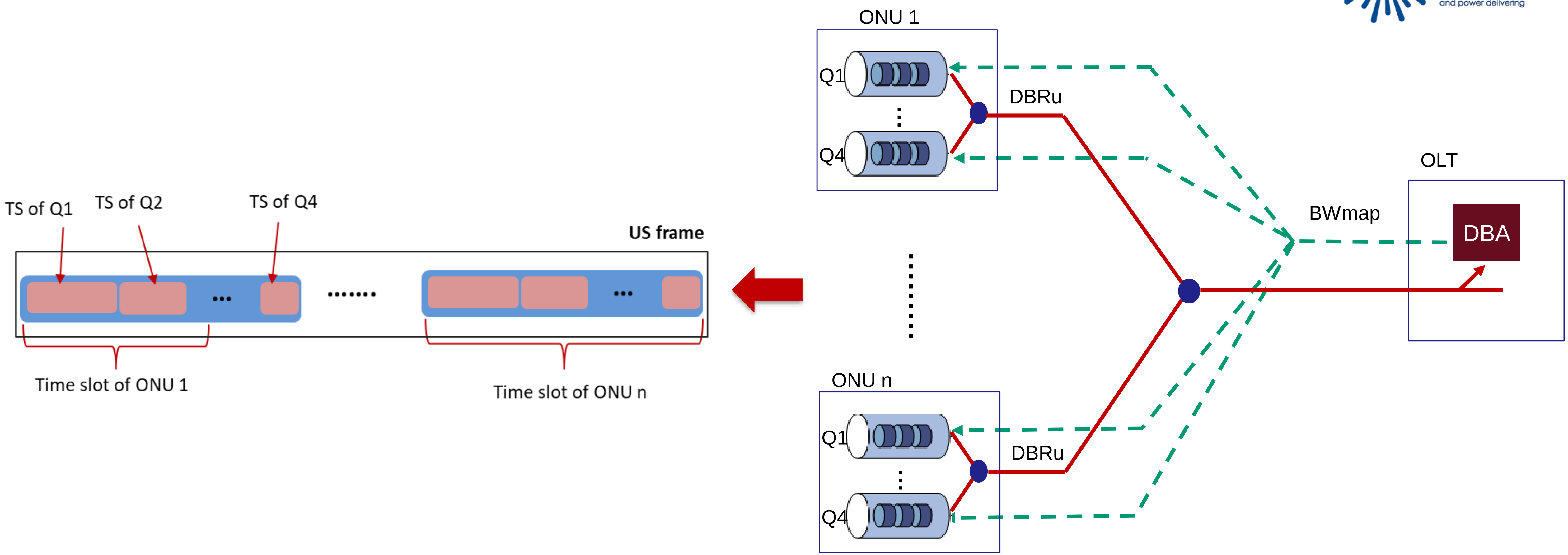
Fixed Mobile Convergence over PON

- More than 500 million FTTH users
- PON is a distributed network with inherently centralized control (like C-RAN)
- Use the PON infrastructure as a fronthaul



- ✓ Assume a PON supporting simultaneously existing data services and the new 5G fronthaul services
- ✓ Guarantee a maximum US 5G delay below 250 µs
- ✓ Guarantee a maximum throughput for data services

DBA mechanism in PON

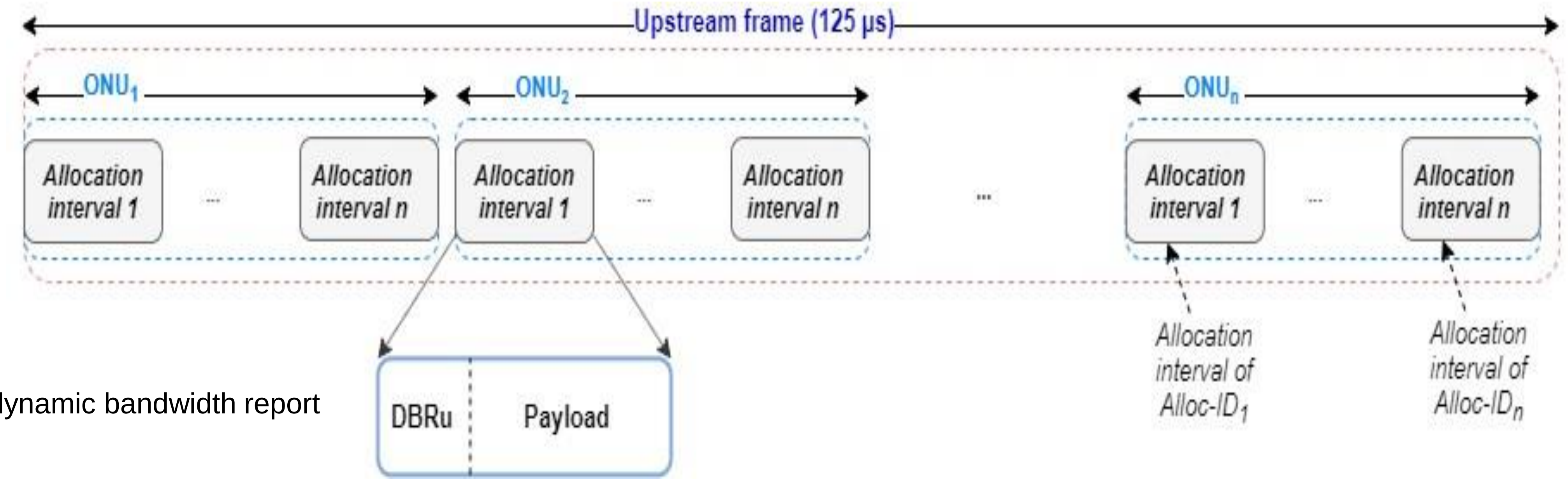


- ✓ In PON, transmission time is organized in frames of duration T = 125 µs.
- ✓ A single time slot is allocated to each ONU on each US frame
- ✓ Each ONU sends a dynamic bandwidth report (DBRu) with the queue occupation information

Self-adjusting DBA algorithm

Conventional DBA scheme:

DBRu-dynamic bandwidth report



A report is sent by each ONU at the beginning of its allocation interval.

The reporting information is the occupation of each of its queues at the moment of the report upstream transmission (i.e., at the beginning of the allocation interval).

This has been shown to be adequate for best-effort services.

Self-adjusting DBA algorithm

Motivations

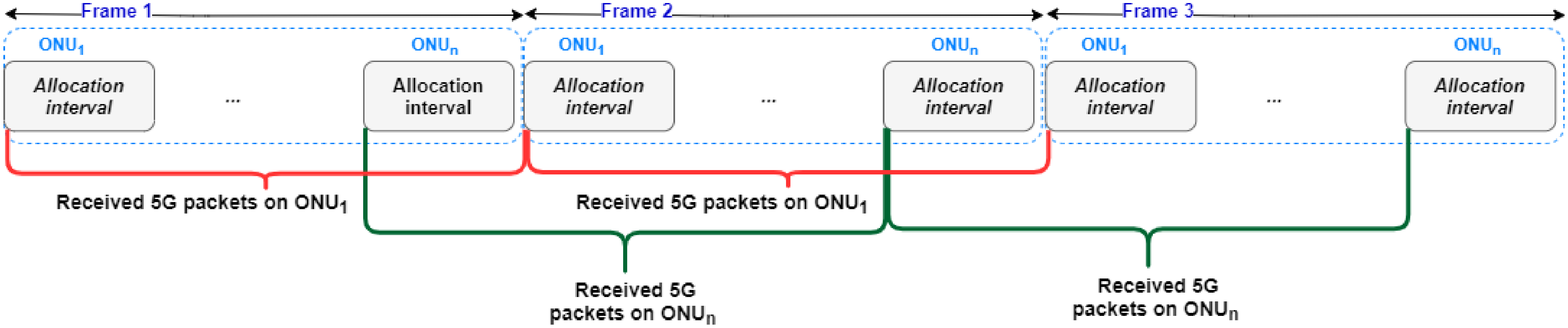
- Proposing an algorithm that:
  - Can jointly support 5G fronthaul and best-effort data services;
  - Is suitable for dynamic 5G scenarios: when a new 5G fronthaul connection is set up and when a current 5G fronthaul connection is tear down.
  - Meets the 5G fronthaul delays requirements

This is achieved by dynamically adjusting the allocation intervals to the current required fronthaul throughput based on the requests reported from the ONUs.

Self-adjusting DBA algorithm

Reporting variants

- Two Reporting Variants (V1 and V2) were proposed besides the Conventional variant (C) :
  - **C:** the 5G queue occupation at the end of the previous allocation interval;
  - **V1**: the total number of bytes received in the 5G queue from the beginning of the previous allocation interval until the beginning of the current allocation interval;



  - **V2**: the sum of two values: (i) given by **V1**; and (ii) given by **C**.

V1 and **V2** enable the DBA to have a correct estimation of the required throughput of the 5G traffic received at each ONU.

Illustrative results (1)

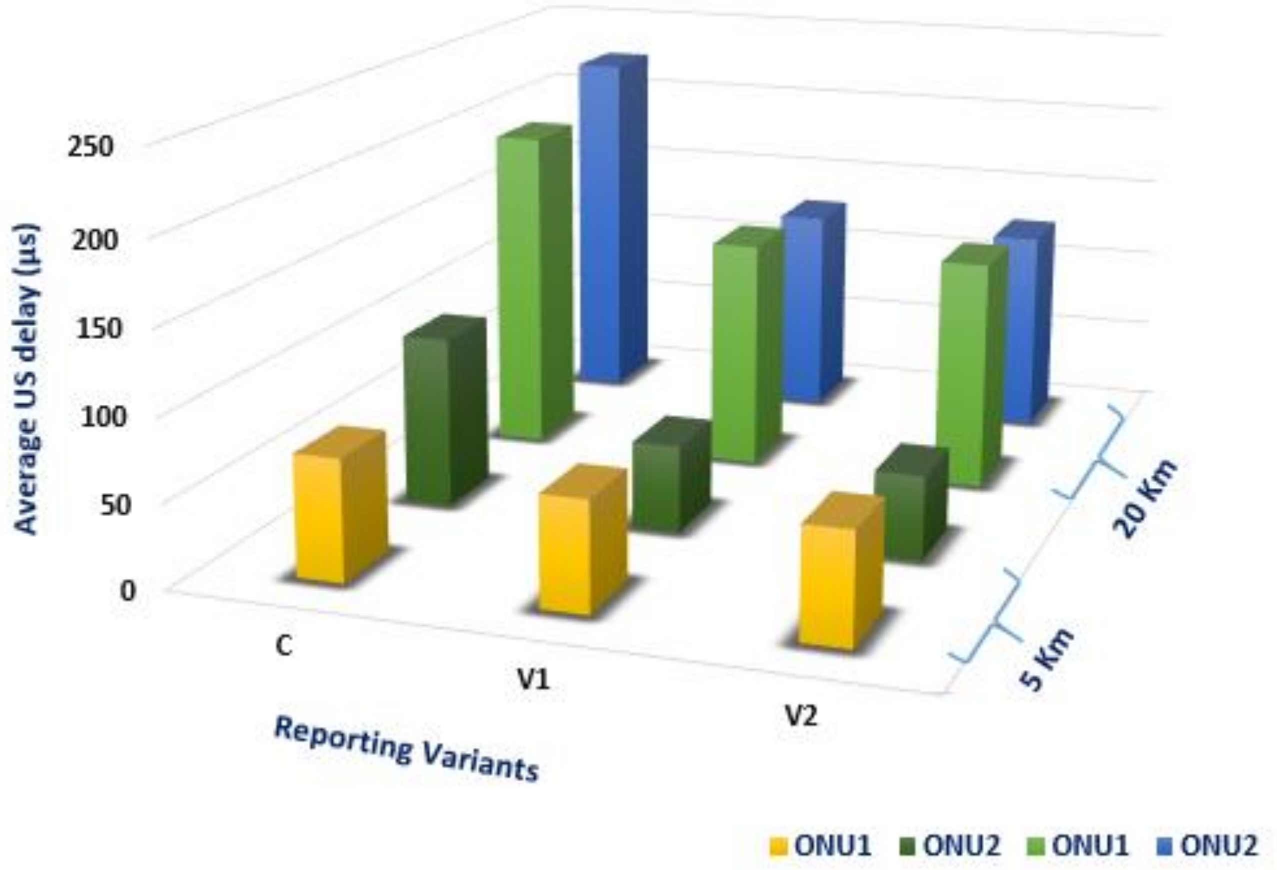
Simulation parameters

Parameters	Value
Functional split option	7.1
System bandwidth (MHz)	100
MIMO	4x4
DBA processing time (µs)	40
Total number of ONUs	8
Number of 5G ONUs	2
Throughput of ONU1 in UL (Gbps)	13.3
Throughput of ONU2 in UL (Gbps)	26.6
Distance ONU-OLT (km)	5 and 20
5G packet size (Bytes)	1518

- PON capacity of 50 Gbps

Scenario: Some ONUs provide 5G fronthaul services and all ONUs provide data services (including the ONUs that provide 5G fronthaul services).

Illustrative results (2)



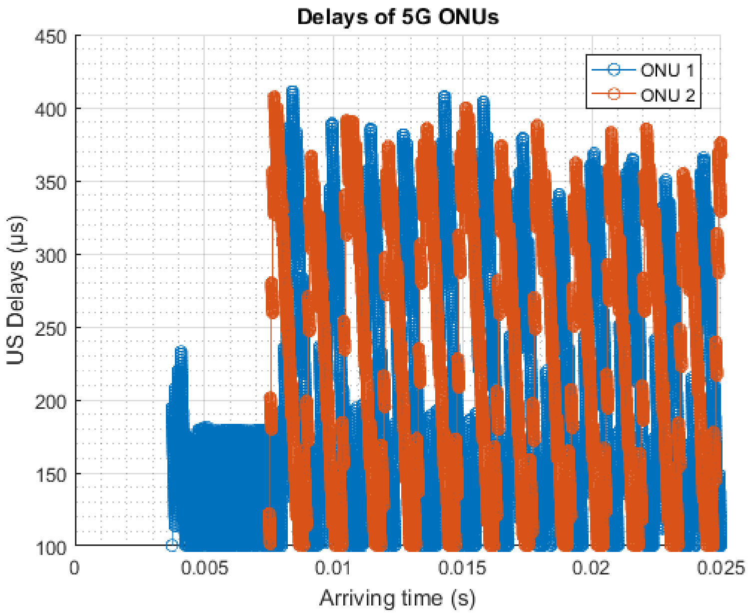
- The average 5G delay does not exceed 250 µs.
- In all cases, V2 achieves lower average delays for both ONUs.

A. Zaouga, A. F. de Sousa, M. Najjar and P. P. Monteiro, "Self-Adjusting DBA Algorithm for Next Generation PONs (NG-PONs) to Support 5G Fronthaul and Data Services," in *Journal of Lightwave Technology*, vol. 39, no. 7, pp. 1913-1924, April, 2021.

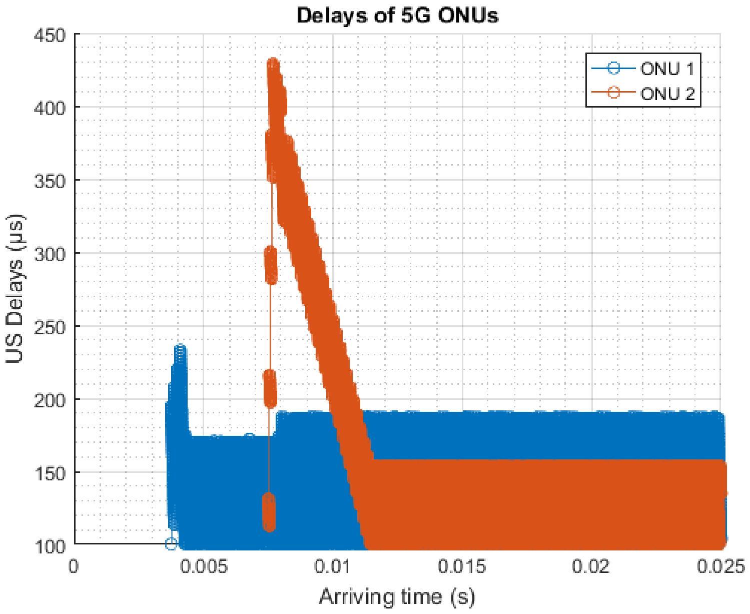
Illustrative results (3)

A single simulation run in scenario for N = 4 ONUs.

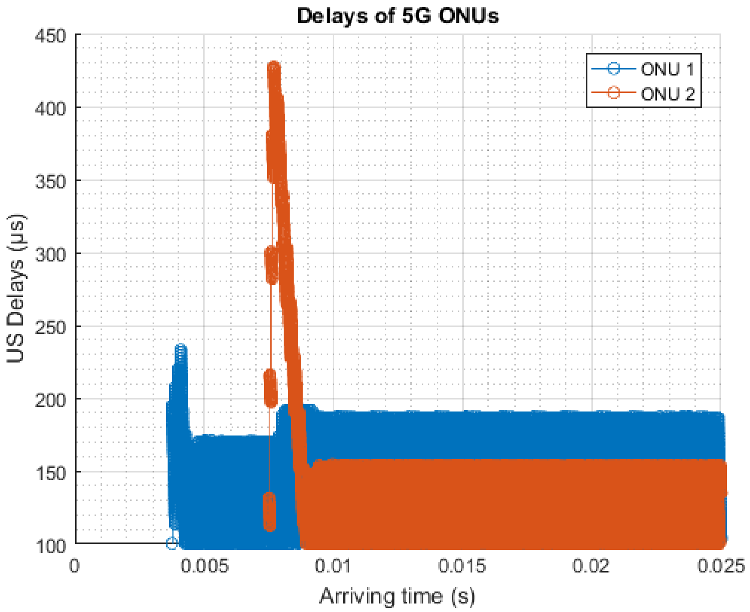
5G packets starting at frame 30 for ONU1 and at frame 60 for ONU2



C



V1



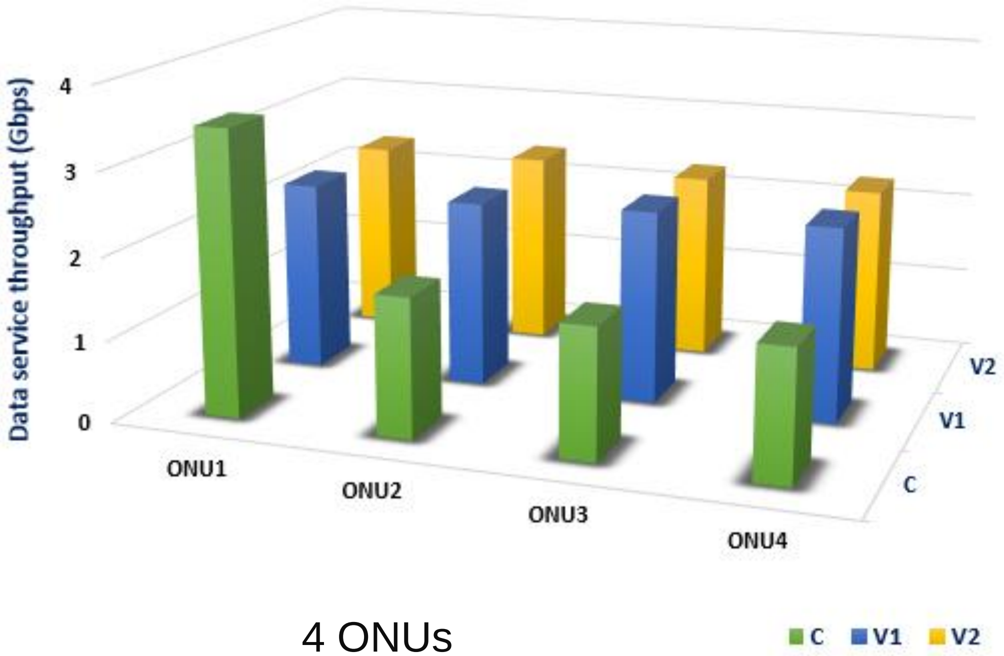
V2

At C the ONUs keep oscillating between an empty queue and an occupied queue which results in an imbalance in requests sent by the ONUs (and, consequently, in the duration of the allocation intervals).

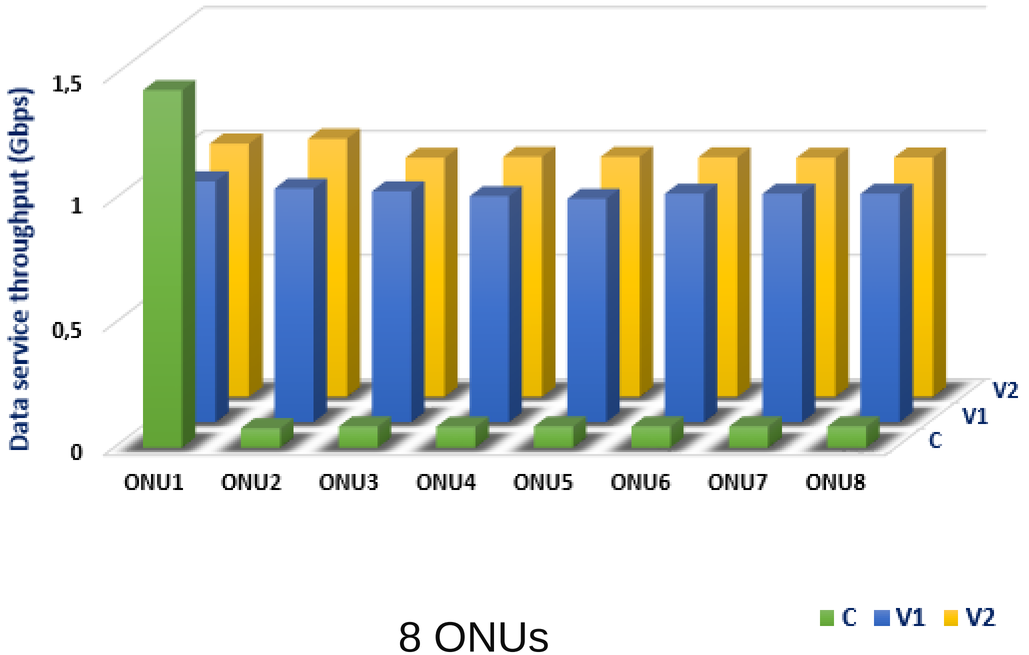
- V1 and V2 eliminate the oscillating behavior observed with C.
- V1 and V2 highly improves the average delays,
- V2 takes less time to achieve a steady state.

Illustrative results (4)

Data service throughput



4 ONUs



8 ONUs

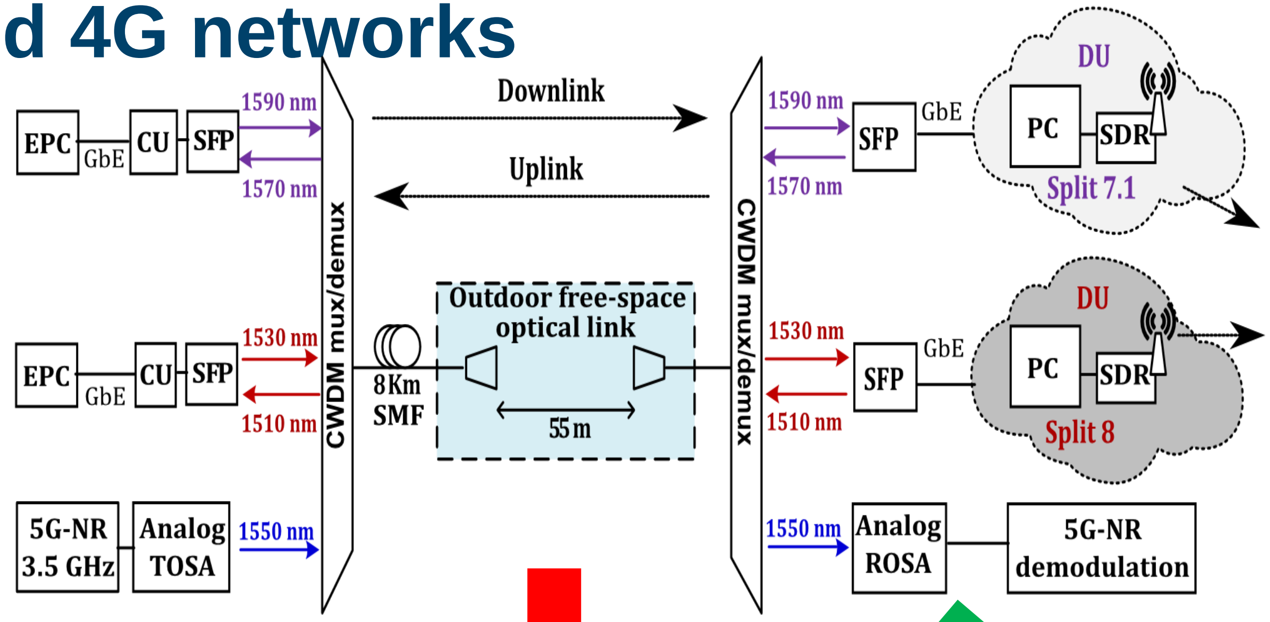
- Compared to C, V1 and V2 are the fairest variants providing almost equal data throughputs to all ONUs,

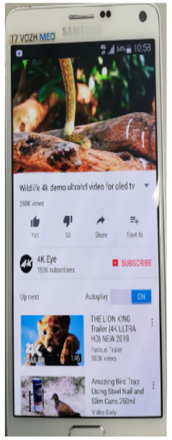
A. Zaouga, A. F. de Sousa, M. Najjar and P. P. Monteiro, "Self-Adjusting DBA Algorithm for Next Generation PONs (NG-PONs) to Support 5G Fronthaul and Data Services," in *Journal of Lightwave Technology*, vol. 39, no. 7, pp. 1913-1924, April, 2021.

Instituições Associadas

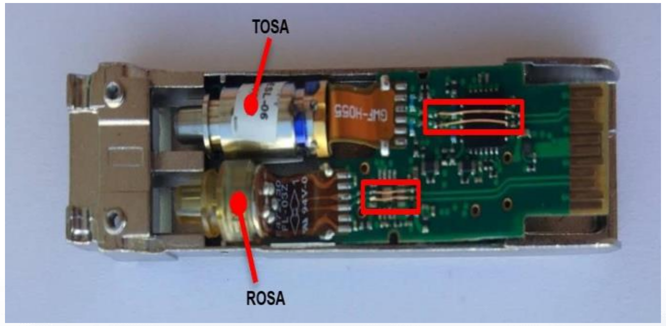
Optical and Wireless Fronthaul Solutions

Hybrid optical fiber–wireless 5G fronthaul coexisting with end-to-end 4G networks





Adaptation of a digital small form factor pluggable (SFP) transceiver for analog transmission



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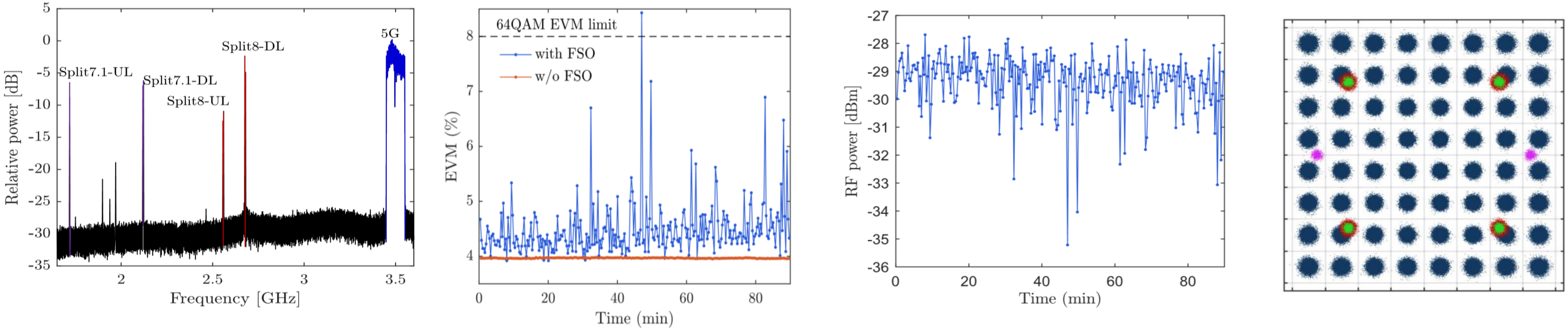
Converged Optical and Wireless Fronthaul Solutions

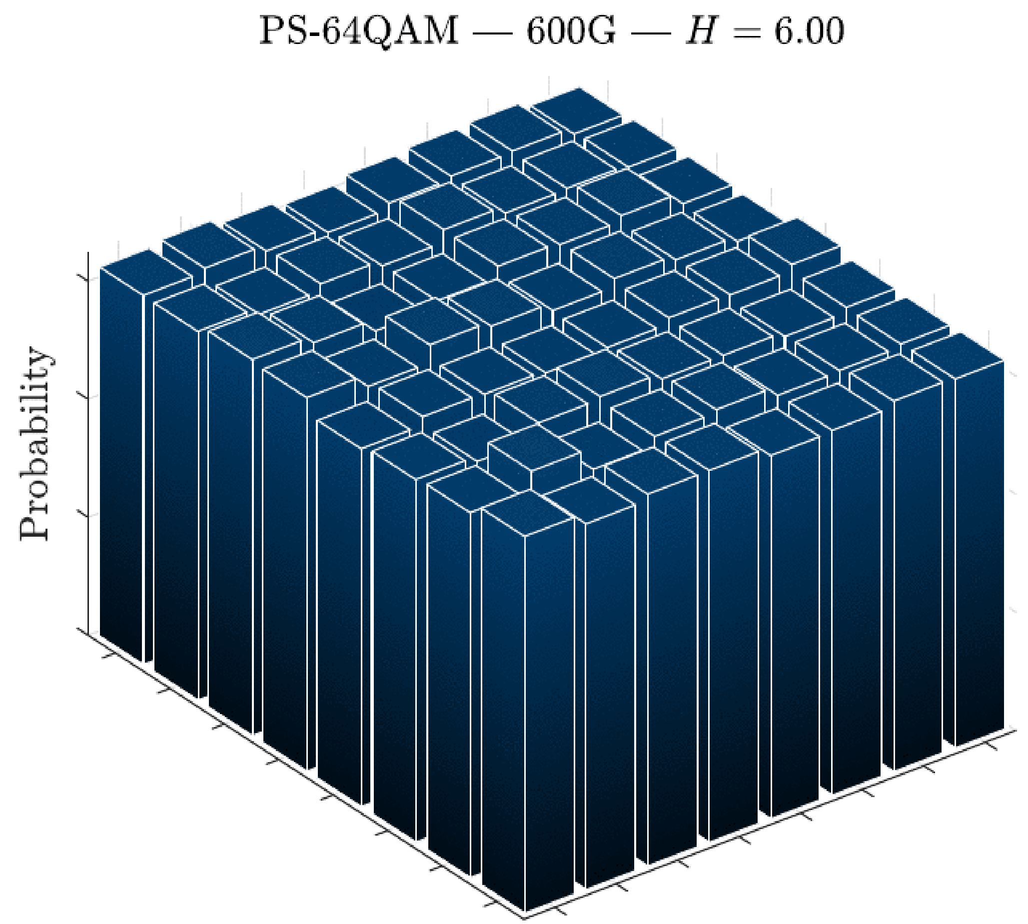
ORCIP
optical radio convergence infrastructure for communications and power delivering

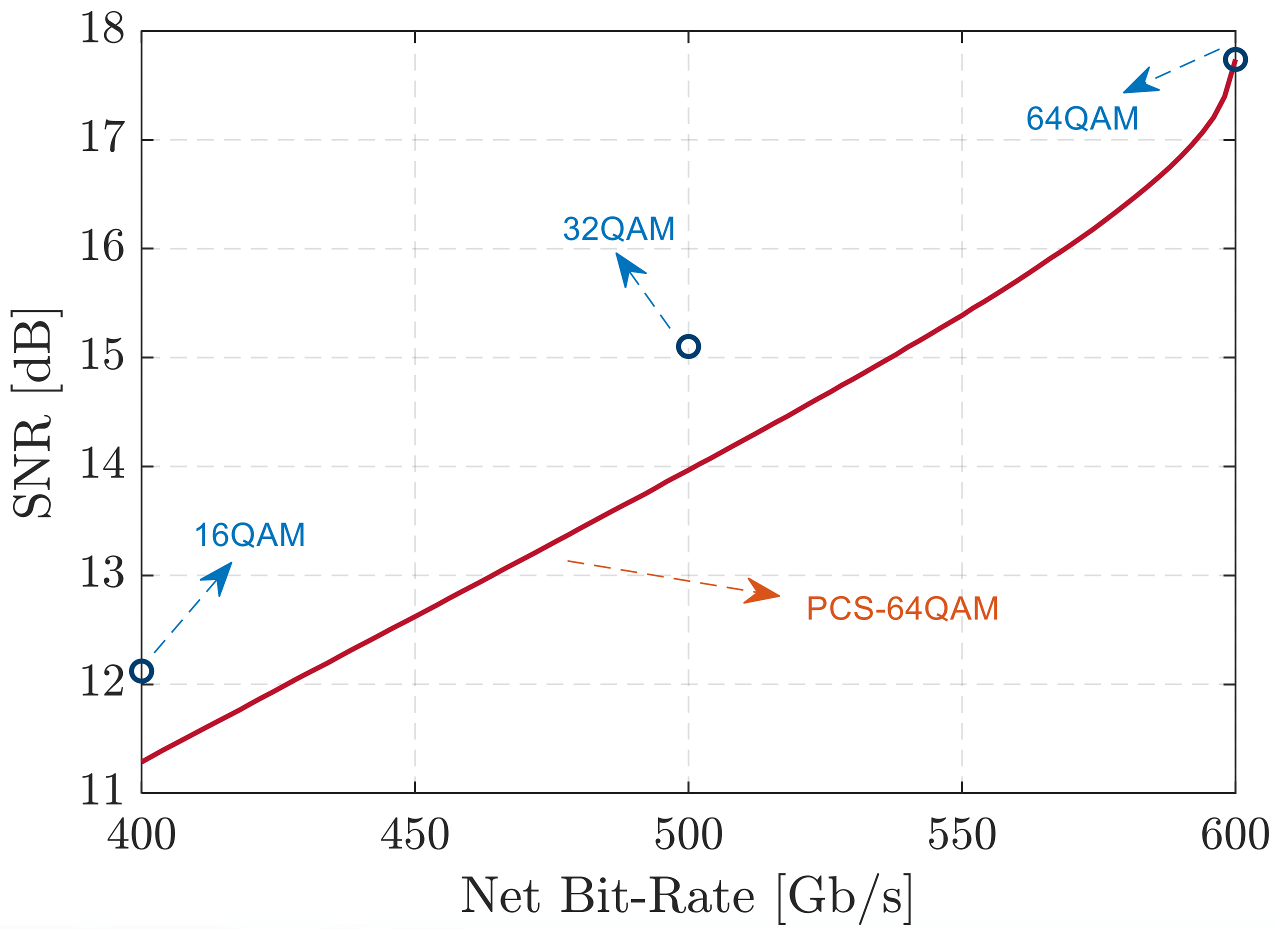
Hybrid optical fiber–wireless 5G fronthaul coexisting with end-to-end 4G networks



Akeem O. Mufutau, Fernando P. Guiomar, Marco A. Fernandes, Abel Lorences-Riesgo, Arnaldo Oliveira, and Paulo P. Monteiro, "Demonstration of a hybrid optical fiber–wireless 5G fronthaul coexisting with end-to-end 4G networks," J. Opt. Commun. Netw. Volume: 12, Issue: 3, pp. 72-78, 2020

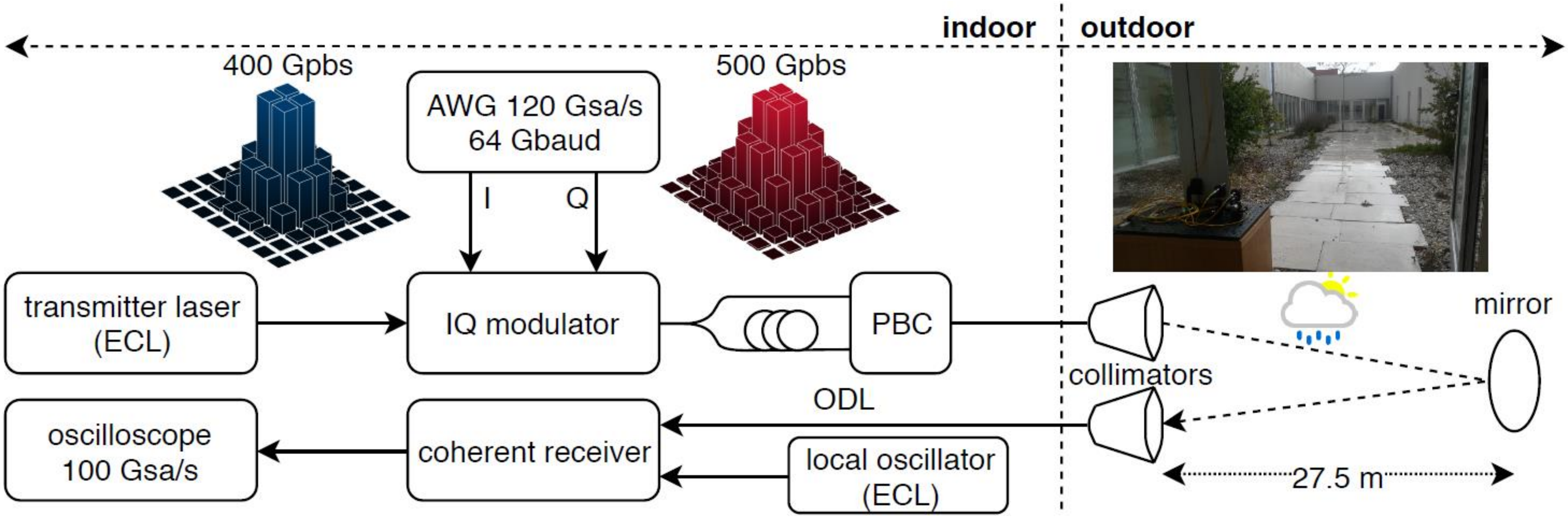
Probabilistic Constellation Shaping for Bit-Rate Flexibility





- PCS provides **continuously adaptive bit-rate** and approx. **0.8 dB gain in SNR**.

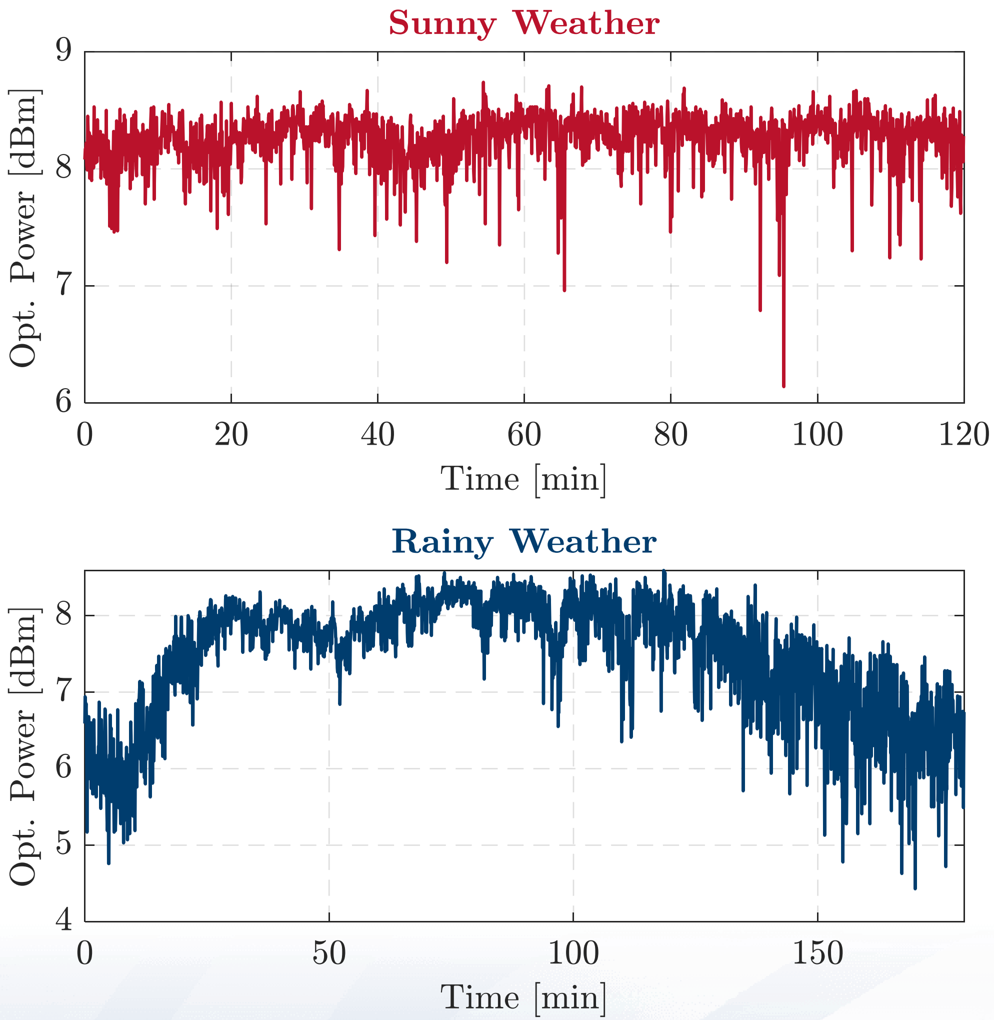
Experimental Setup

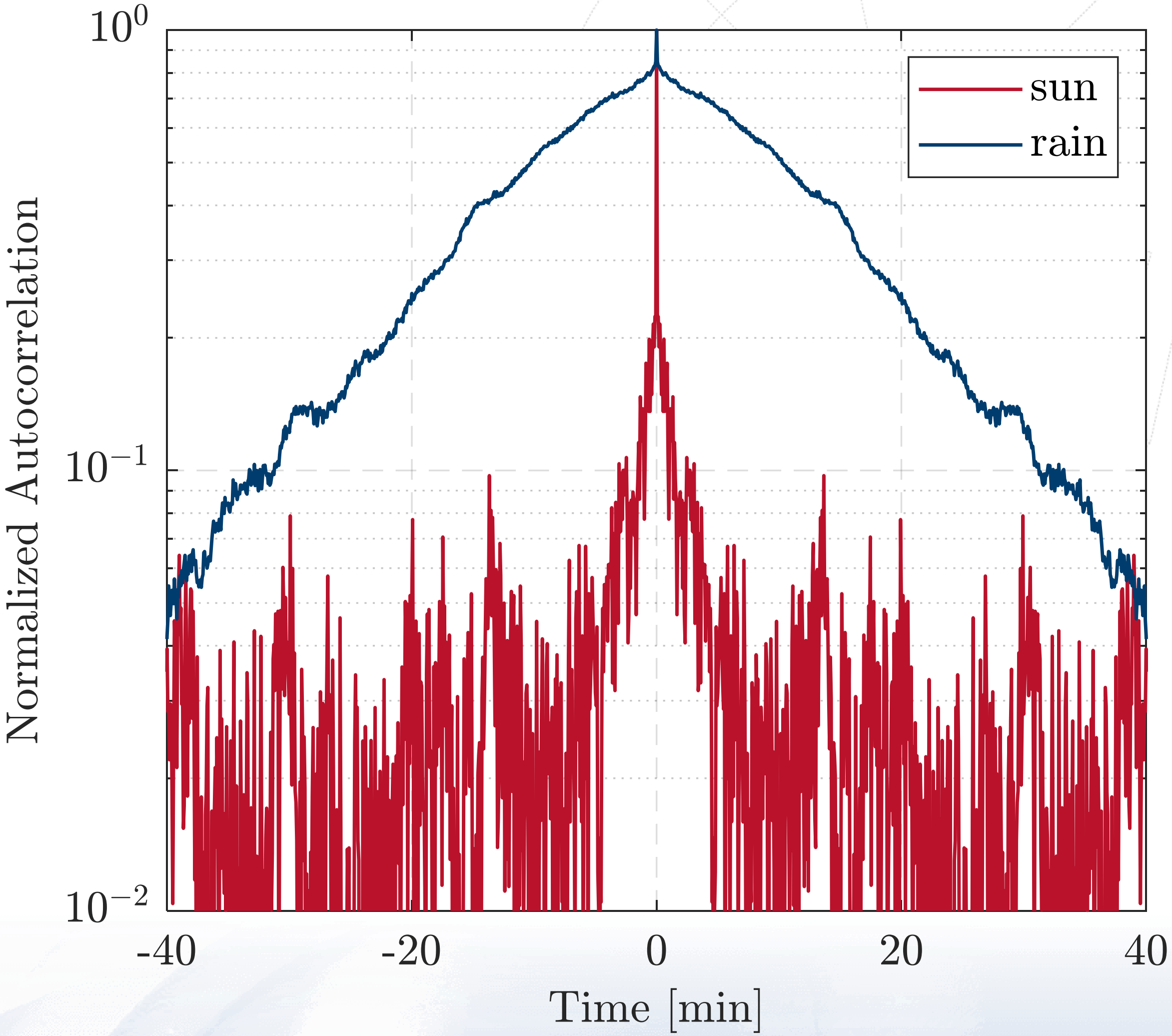


- **64 Gbaud** polarization-multiplexed **PCS-64QAM**;
- **55 meter** outdoor FSO link, with continuous measurement over 3 hours;
- Aim: test resilience against adverse weather conditions (rain showers).

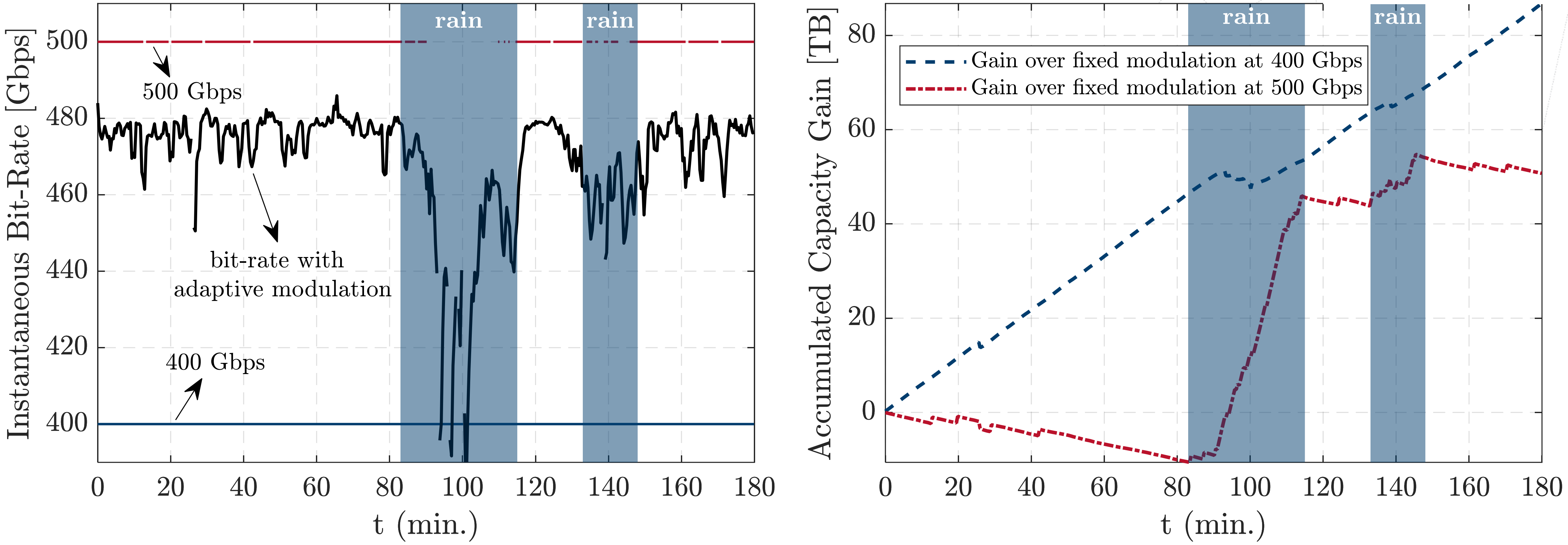
Fernando Guiomar, etal, "Adaptive Probabilistic Shaped Modulation for High-Capacity Free-Space Optical Links", Lightwave Technology Journal of, vol. 38, no. 23, pp. 6529-6541, 2020.

Time-Varying FSO Channel





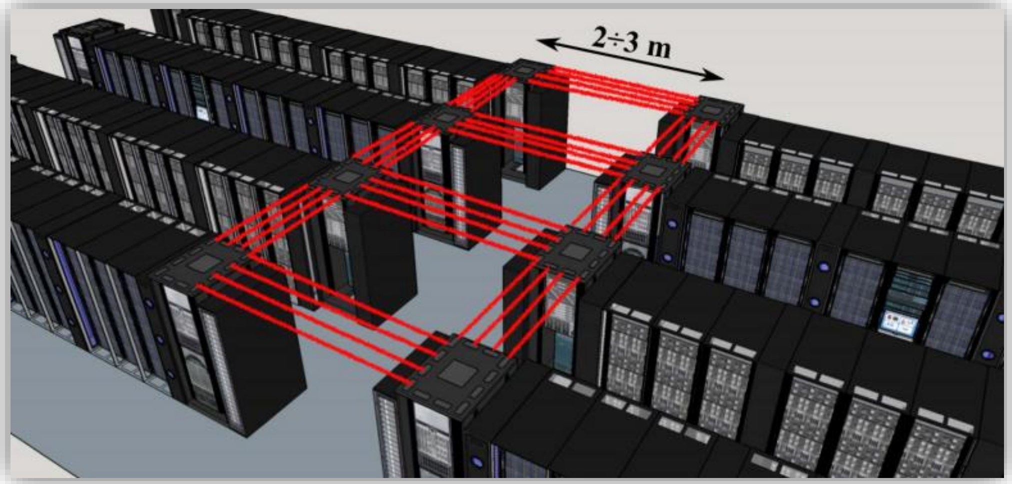
Adaptive Modulation Gain



- With adaptive PCS modulation, the **bit-rate self-adapts to the current channel condition**.
- **> 80 Terabytes** of accumulated capacity gain (3-hours) over fixed 400G modulation (>64 Gb/s gain);
- **> 50 Terabytes** of accumulated capacity gain (3-hours) over fixed 500G modulation (>37 Gb/s gain).

400G+ Wireless Transmission via Free-Space Optics, invited Th1B.1

FSO as a potential for datacenter interconnects



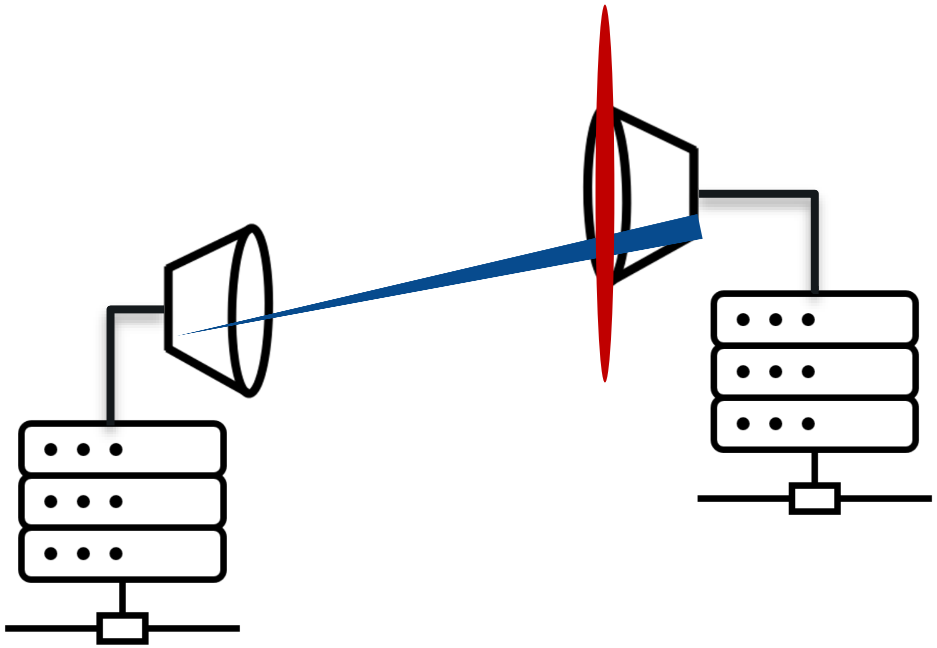
W. Ali , G. Cossu , L. Gilli, E. Ertunc, A. Messa, A. Sturniolo, and E. Ciaramella, “10 Gbit/s OWC System for Intra-Data Centers Links,” IEEE PHOTONICS TECHNOLOGY LETTERS, VOL. 31, NO. 11, JUNE 1, 2019.

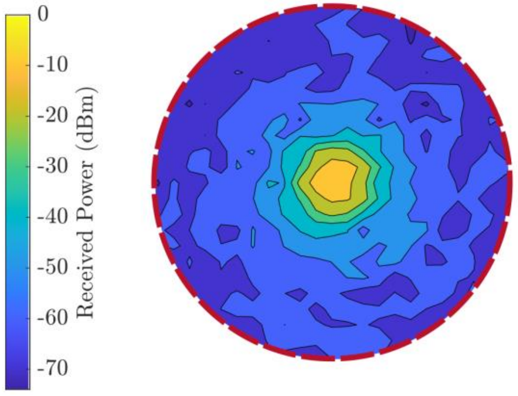
Free-Space Optics (FSO) appears as a candidate for future DCIs, providing advantages as:

- Compatibility with typical optical fiber present in datacenters;
- Reduced cabling and complexity;
- Traffic adaptability through beam steering;
- Reduced latency, footprint and power consumption.

- ❑ One of the main problems with FSO inside DC rely in the required tight and precise beam alignment. A badly aligned system can completely compromise the system…

Pointing errors in FSO-DCI



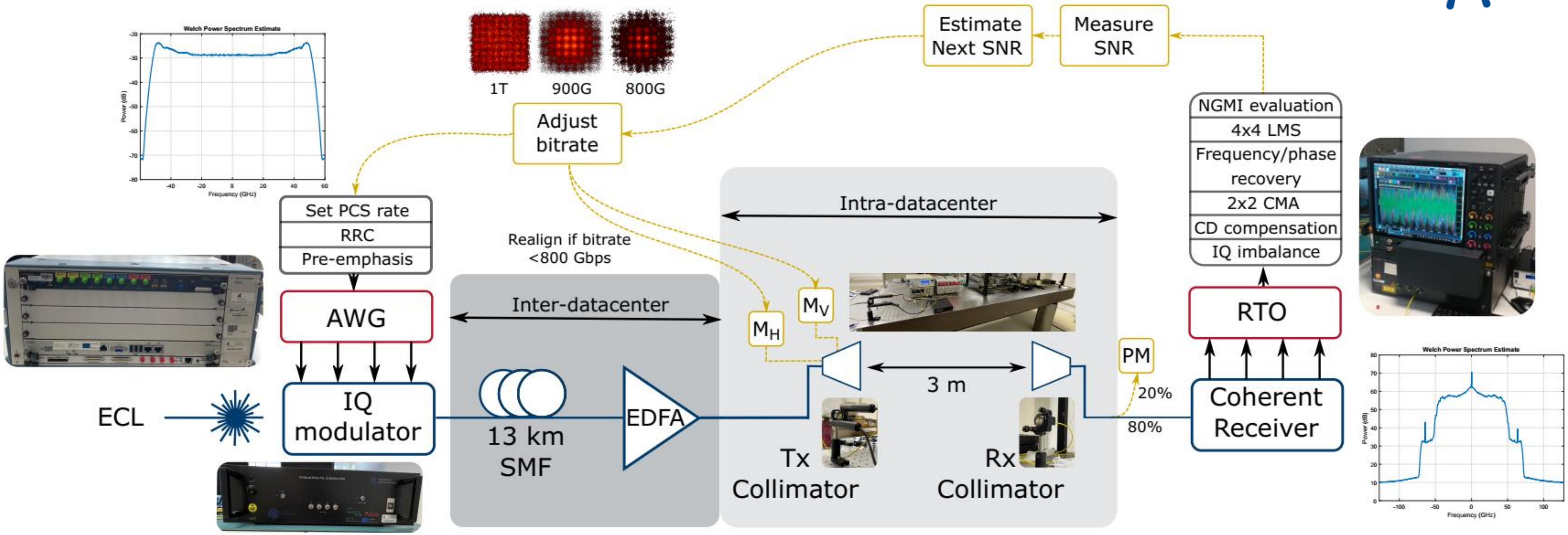


- Besides robust acquisition, tracking and pointing (ATP) systems, powerful techniques must be used to reduce the impact of pointing errors.

- What can we do to mitigate pointing errors?

Pointing errors pose as a daunting impairment in FSO-DCI. A small deviation on the received beam and the performance can be significantly compromised or even lost.

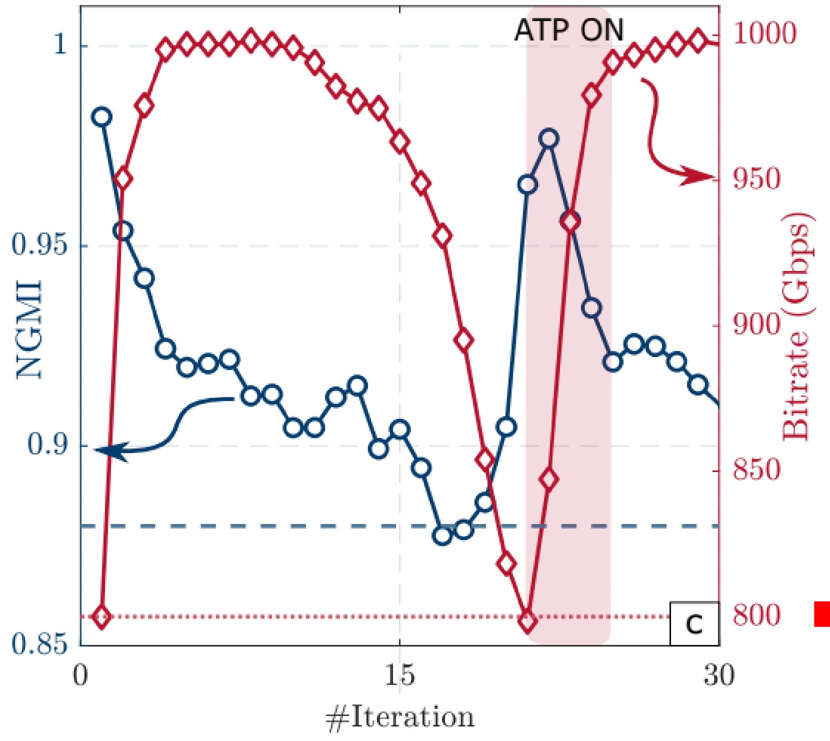
Experimental Setup



ECL: External Cavity Laser; **RRC**: Root-Raised Cosine; **AWG**: Arbitrary Waveform Generator; **SMF**: Single-Mode Fiber; **PCS**: Probabilistic Constellation Shaping; **EDFA**: Erbium-Doped Fiber Amplifier; $\mathbf{M_H}$: Motor Horizontal; $\mathbf{M_V}$: Motor Vertical; **SNR**: Signal-to-Noise Ratio; **PM**: Power-Meter; **RTO**: Real-Time Oscilloscope; **CD**: Chromatic Dispersion; **CMA**: Constant Modulus Algorithm; **LMS**: Least-Mean Squares; **NGMI**: Normalized General Mutual Information

- **64QAM-PCS** signal, with a symbol rate of **100 Gbaud**.
- **Goal:** Use PCS to adjust the bitrate to account for sequential beam misalignment.

PCS adaptation



ATP- acquisition, tracking and pointing

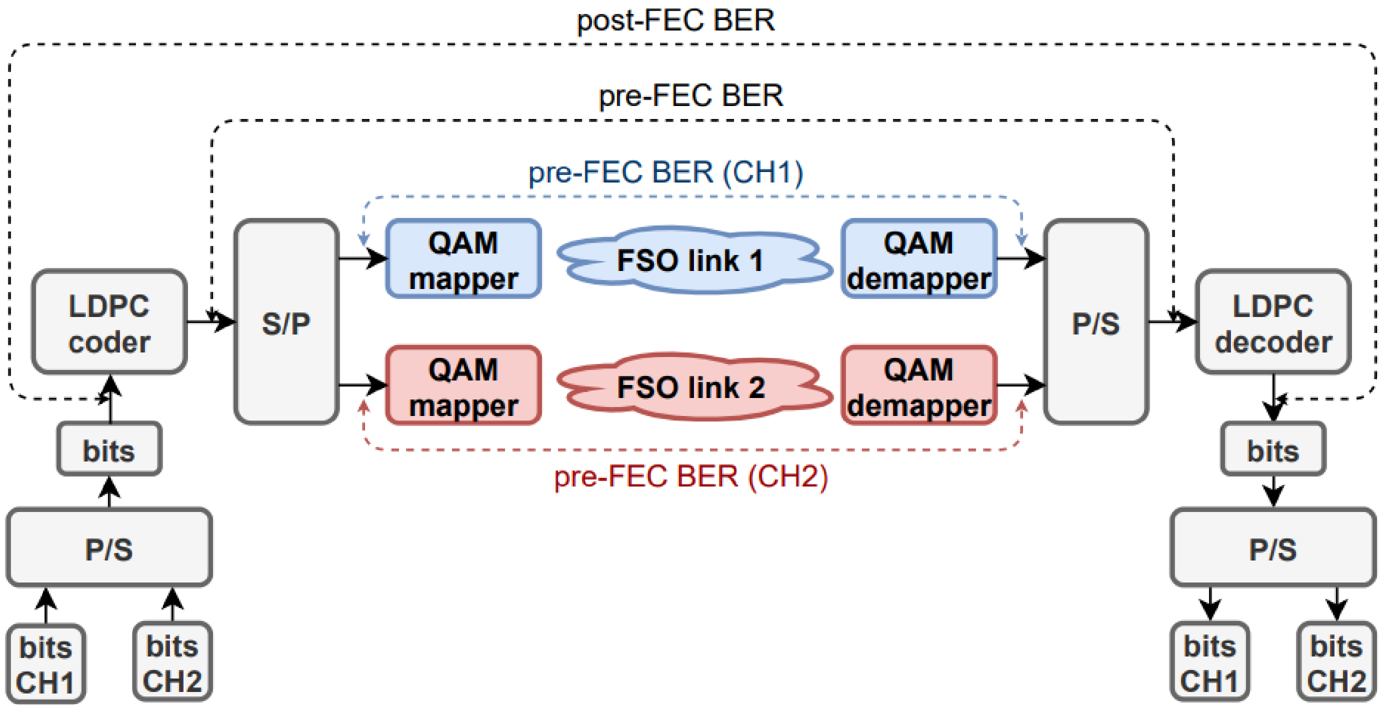
800 Gbps threshold

- PCS adaptation shows itself capable of mitigate pointing errors, keeping the performance constant through bitrate adaptation. In a case of extreme power loss, the ATP system was able to return the system to maximum performance.

Marco A. Fernandes, Paulo P. Monteiro and Fernando P. Guiomar, "Single-Wavelength Terabit FSO Channel for Datacenter Interconnects Enabled by Adaptive PCS", OFC June 2021

Marco A. Fernandes, Bruno T. Brandão, Petia Georgieva, Paulo P. Monteiro, and Fernando P. Guiomar, "Adaptive optical beam alignment and link protection switching for 5G-over-FSO," Opt. Express 29, 2021.

Experimental 400G MIMO-FSO Transmission with Enhanced Reliability Enabled by Joint LDPC Coding



Joint LDPC joint encoding between the channels allows to achieving a gain of 2 dB regarding typical encoding

400G MIMO-FSO Transmission with Enhanced Reliability Enabled by Joint LDPC Coding, Tu1B.5 at ECOC21

ACKNOWLEDGEMENTS

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THANK YOU!

… Questions?

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