Downstream transmission dimensioning in FDMA-PON architectures: results from the EU project "FABULOUS"

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Acknowledgements

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Outline of the presentation

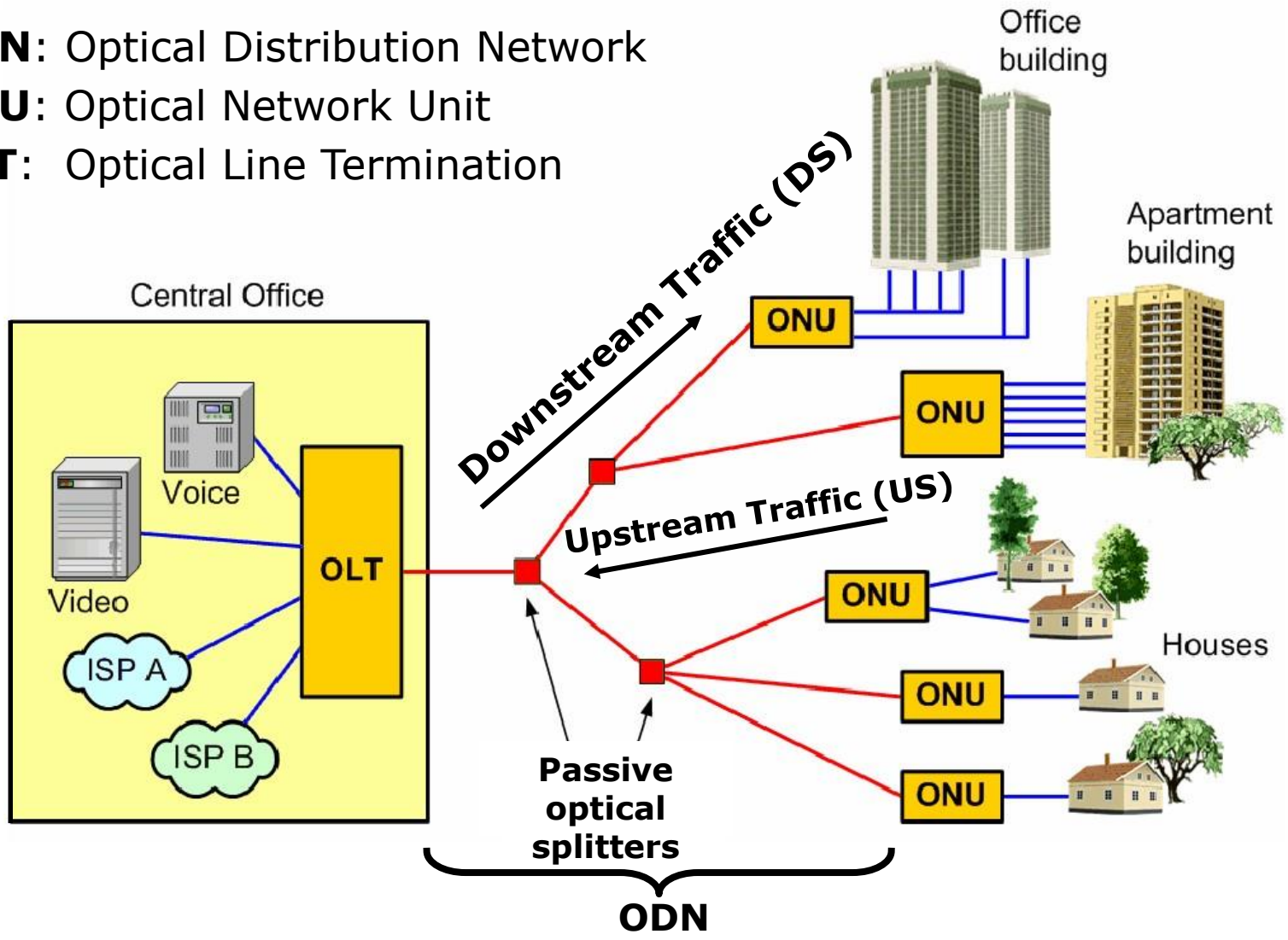
- A brief overview of the FABULOUS architecture
  - Comparison between TDMA and FDMA in PON
- Dimensioning the downstream
- Experimental results

A brief overview of the FABULOUS system architecture

TDMA vs. FDMA in PON

PON Architectures and Acronyns

ODN: Optical Distribution Network
ONU: Optical Network Unit
OLT: Optical Line Termination



Current state of the art in PON: TDMA-approach

- All commercial solutions today are based on time-division multiple access (TDMA) in both directions
  - This is true even in the most recent standard NG-PON2, today under final release by ITU-T as G.989 (which has also added the WDM degree of freedom)

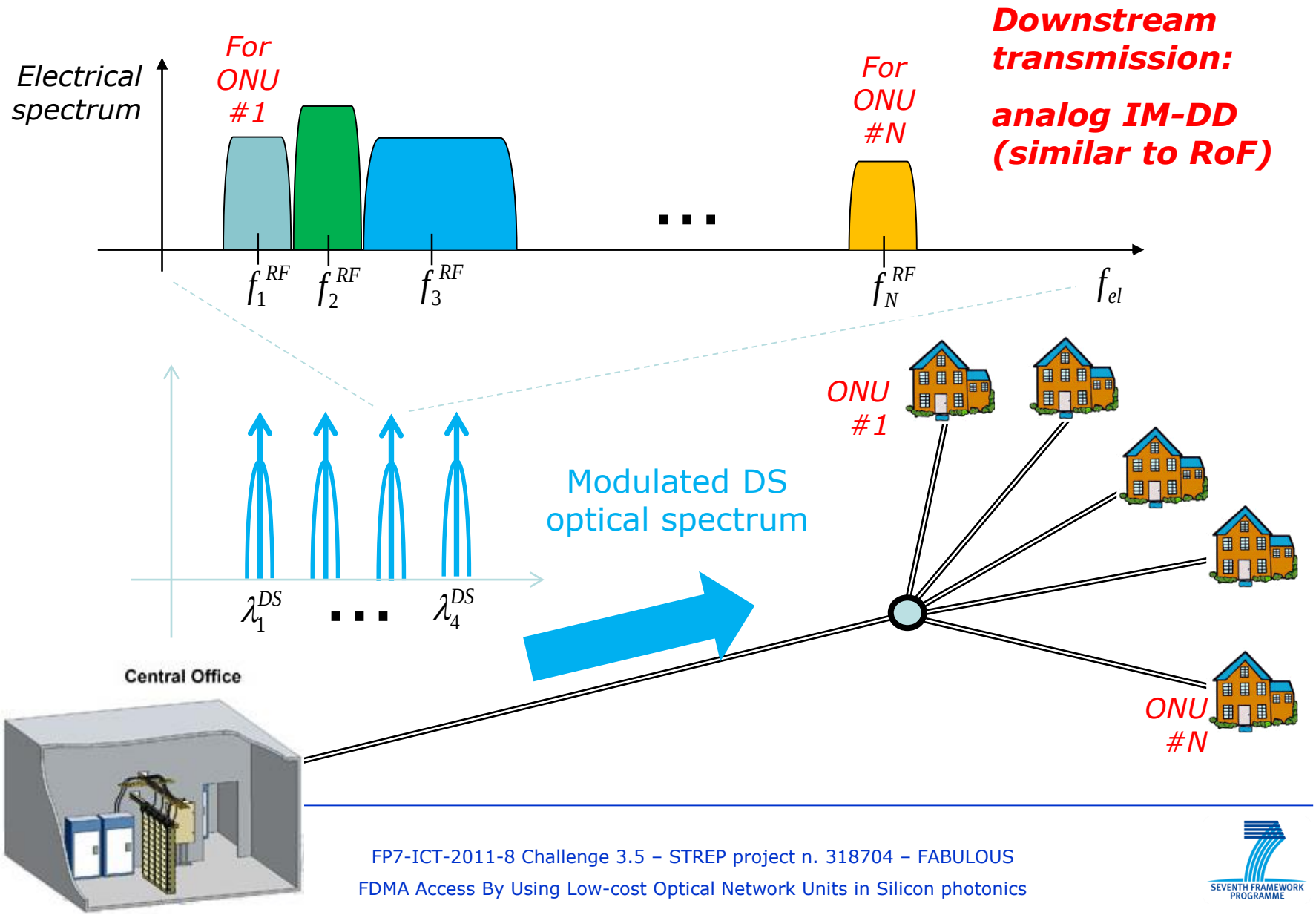
- This approach requires that each ONU works at the (single wavelength) full bit rate, even though it must handle only a small portion of it
  - For instance, in the most advanced commercial standard XGPON G.987, the downstream bit rate is 10 Gbps
    - ➔ Each ONU RX works at 10 Gbps even though in most situations the actual traffic per ONU is well below the 1 Gbps range
- The solution is NOT power efficient
- It does not scale well above 10 Gbps per wavelength (considering PON cost constraints)

FABULOUS project proposal: FDMA approach

- In the FABULOUS EU project we propose to completely change the paradigm, moving to Frequency Division Multiple Access
  - Implemented in the electrical domain
  - In both directions (US and DS)
  - A "radio-like" approach

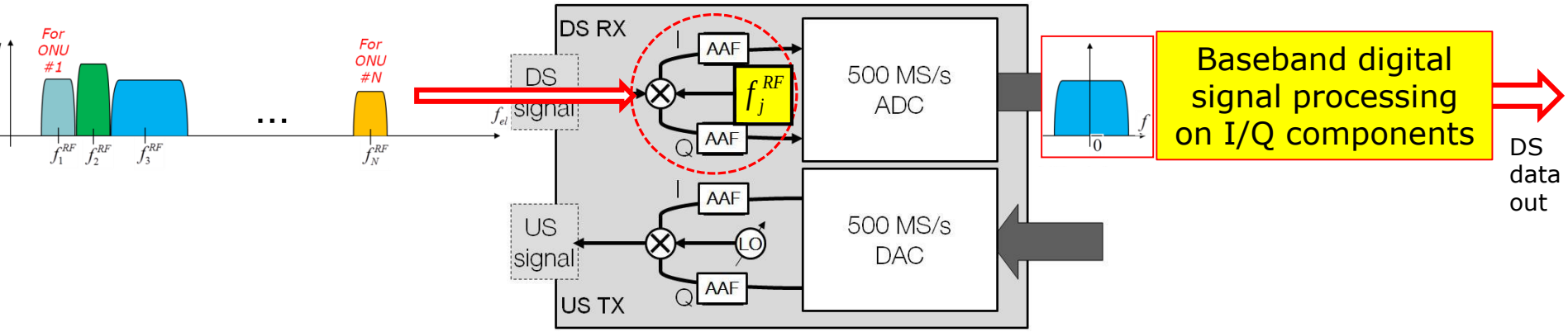
- In this presentation, we focus on our recent works on the downstream
  - *The FABULOUS project is actually more focused on the upstream and on the development of ad-hoc Silicon-Photonics optoelectronic devices*

FABULOUS downstream architecture



ONU architecture

- At the ONU RX and after photo detection, electrical RF down-conversion is applied so that DSP can be at baseband and only on the spectral slice dedicated to each specific ONU



- For instance, targeting 1 Gbps per ONU, and using 16-QAM, the required baseband processing can be done using DAC and ADC working in the 500 Msample/s range

FDMA vs. TDMA in PON

- **FDMA PROS**
  - Each ONU can handle only its dedicated bit rate (for both directions) and not the aggregate bit rate
  - High flexibility in bit rate and power allocation
    - ➔ Techniques similar to OFDM bit and power loading are possible
  - Overall higher bit rate in each direction
    - ➔ Mostly due to higher spectral efficiency thanks to M-QAM modulation
- **FDMA CONS**
  - Linearity requirements in optoelectronic components (similar to CATV over fiber)
  - High Peak-to-average-power ratio PAPR issues (just like in OFDM)
  - Digital signal processing (DSP) required at the physical layer

Is FDMA DSP feasible at PON ONU target price?

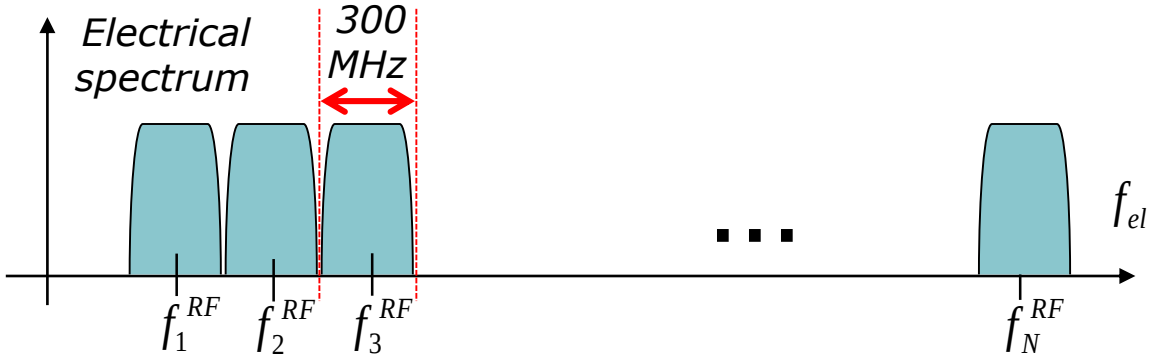
Let's have a look at other fields:

- Wireless Ultrawideband (UWB) Chipsets
  - From one of the vendors datasheets
    - *Worldwide Chipset Covers Entire UWB Spectrum from 3.1–10.6 GHz*
    - *All WiMedia data rates: 53.3, 80, 106.7, 160, 180, 400, and 480 Mbps*
    - *Flexible MAC protocol engine supports all industry standard WiMedia protocols*
    - *128 Bit AES Encryption for secure wireless link*
- Very similar to what would be required for FDMA PON!
  - UWB Chipsets are meant for consumer electronics wireless domotic applications, so they must be very low cost

Dimensioning the downstream

Downstream targets

- Use of MZM external modulators up to 8-10 GHz at OLT, and direct-detection at ONU
- Targeting 1 Gbps net data rate per ONU
  - Using 16-QAM, and envisioning some overhead for signaling and FEC, this target requires less than 270-280 Mbaud
  - Using raised-cosine spectrum (roll-off around 0.1) we require approx. 300 MHz per ONU



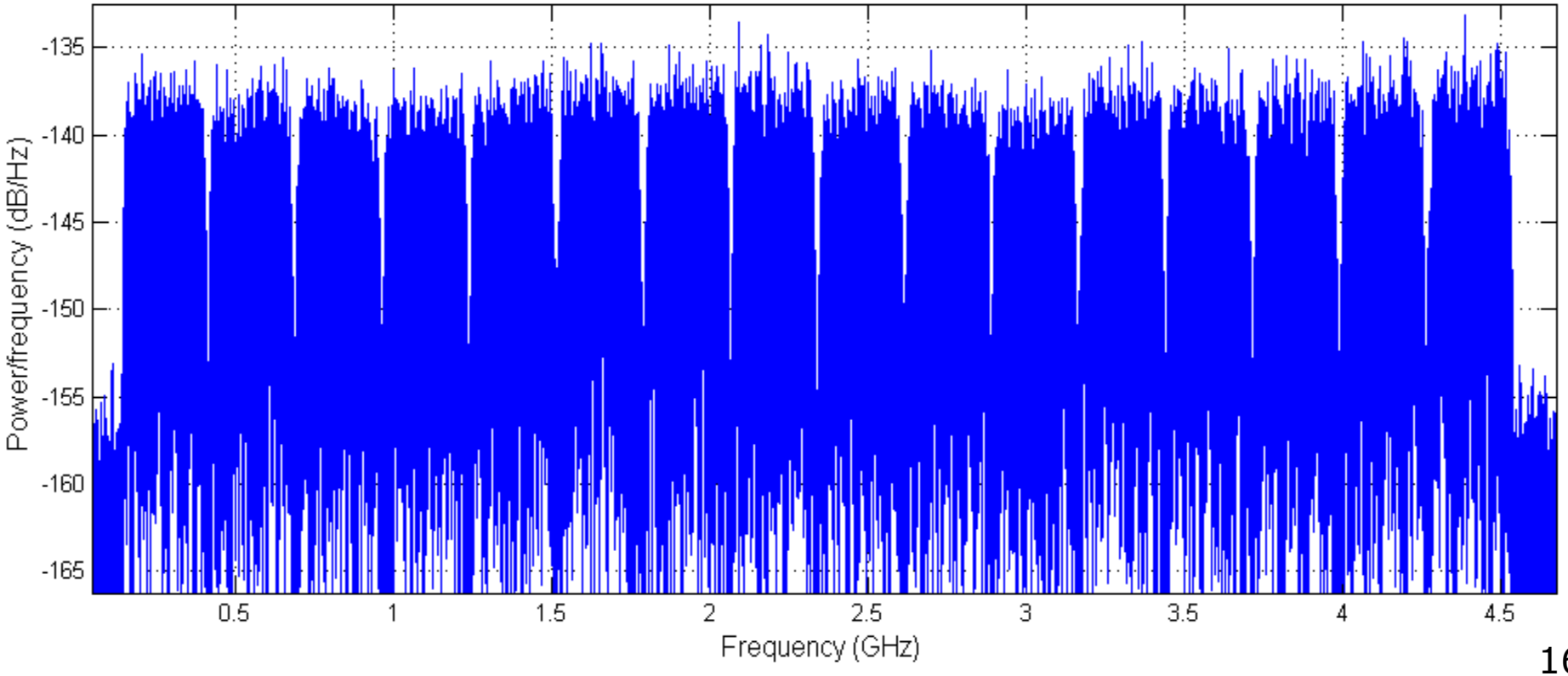
Downstream targets

- We can thus envision up to 32 ONUs over a single wavelength, each at 1 Gbps net data rate in an electrical bandwidth below 10 GHz
  - Potential aggregated capacity around 32 Gbps
- The core of our work was to investigate on the actual achievable data rate considering:
  - Available power and signal to noise ratio as a function of ODN loss
    - ➔ Current standard requires 28 dB ODN loss or higher
  - Transmitter and receiver nonlinearities
  - Finite quantization in ADC and DAC
  - Fiber effects

Experimental results

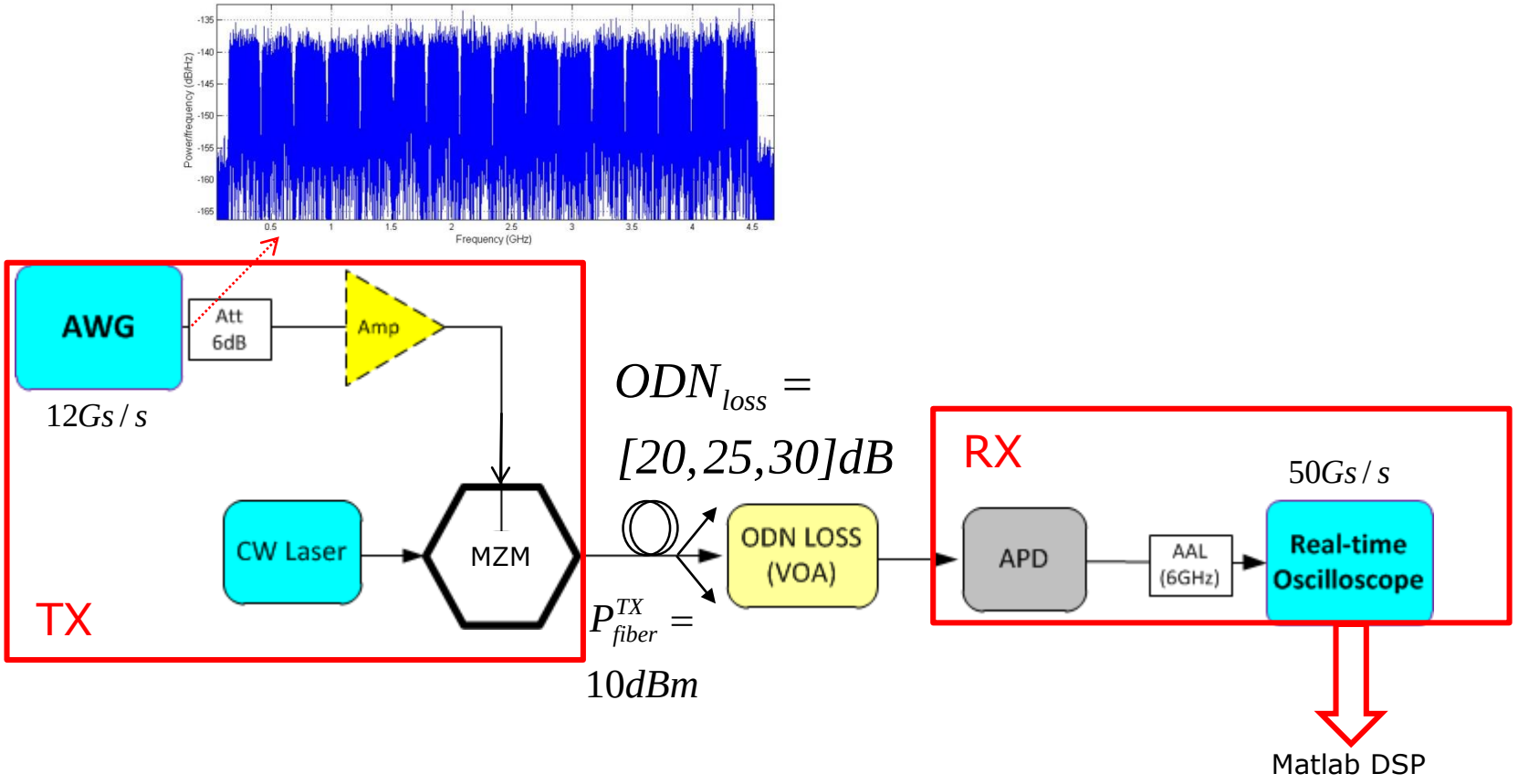
TX electrical spectrum at modulator input

- 16 electrical FDMA channels
- 1 Gbps each, 16-QAM, raised-cosine spectrum, roll-off=0.1
- No spectral guard-band (apart from roll-off)



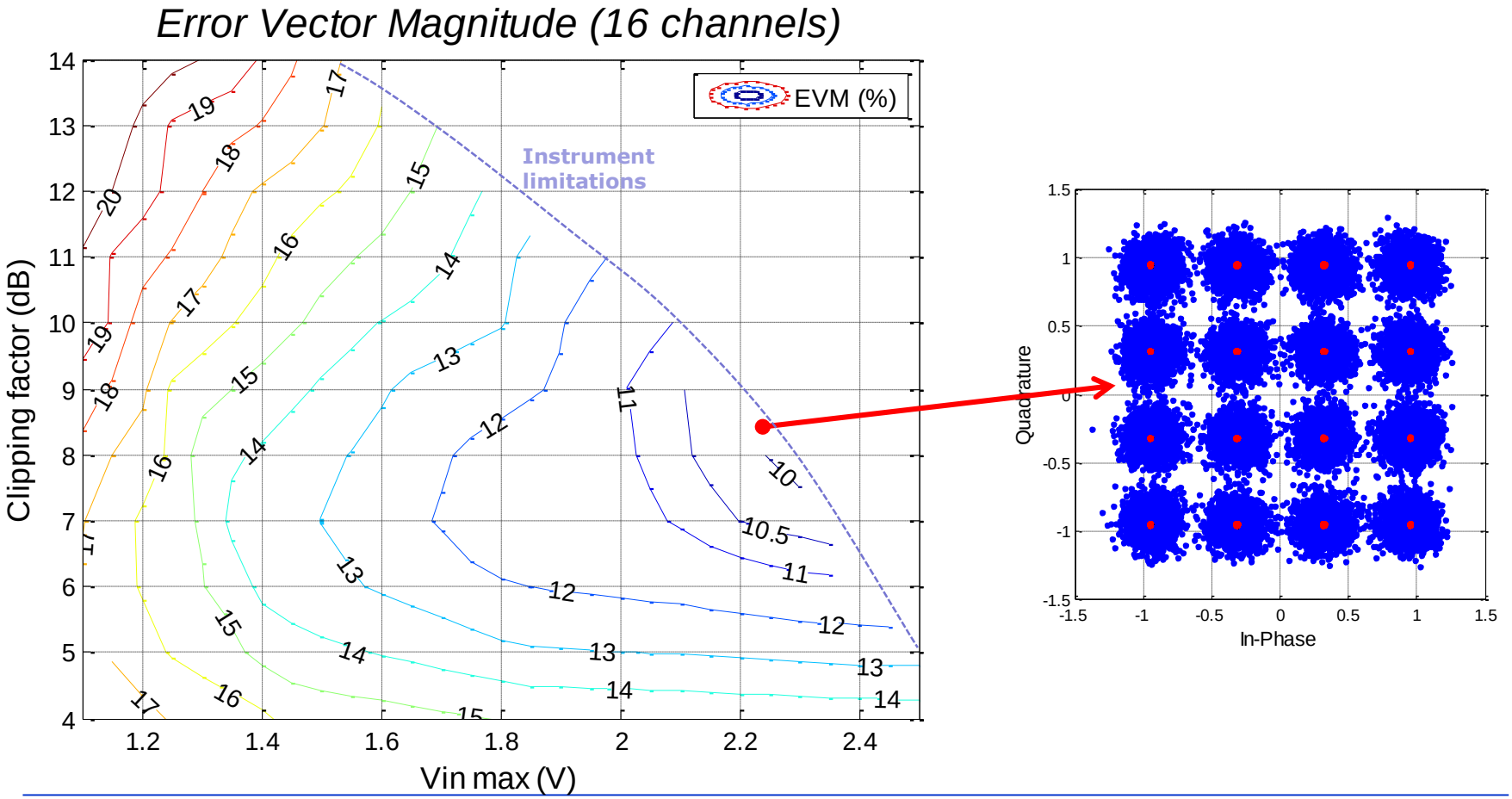
Experimental setup

- Off-line processing experiment



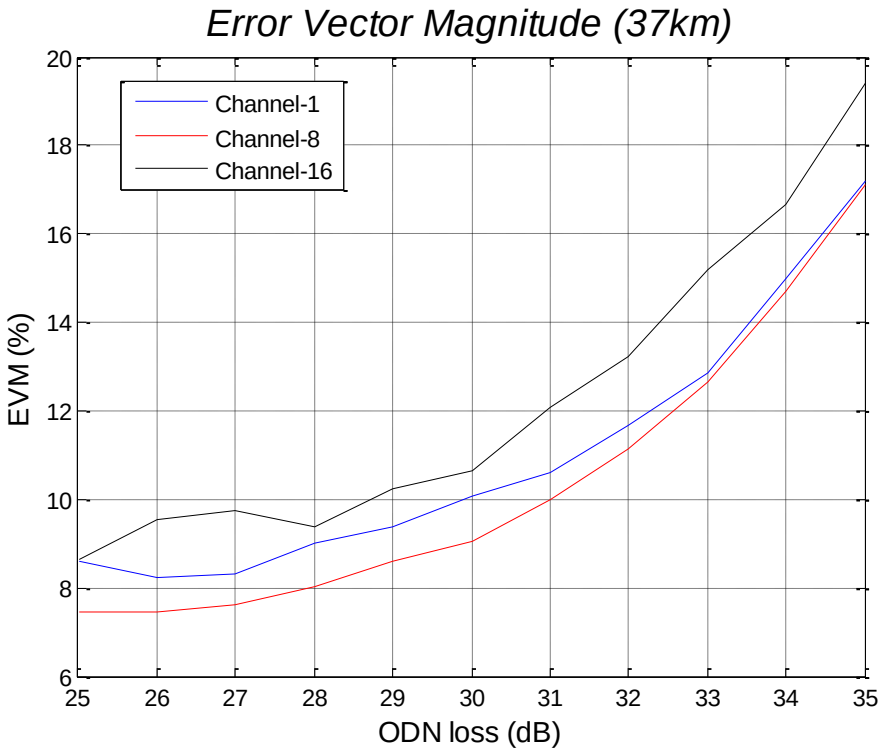
Optimization of transmitter parameters

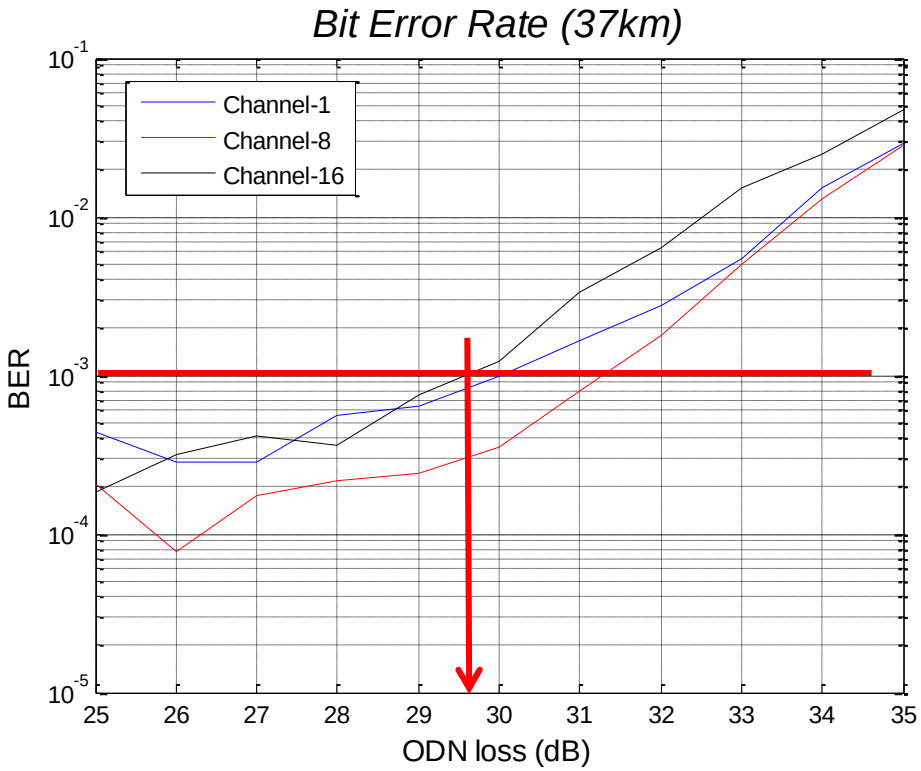
- Error vector magnitude at RX as a function of clipping and amplitude at electrical TX



Maximum ODN loss

- EVM vs. ODN loss, after 37 Km of SMF





Conclusion

Comments and brainstorming

- We experimentally demonstrated a (gross) data rate of 16 Gbps per wavelength
  - Using only 4.5 GHz electrical spectrum
  - Requiring only 500 Msample/s DSP at ONU receiver
  - More than 28 dB ODN loss

- Our experiments have approx. 2-3 dB penalty in ODN loss compared to our simulations
  - We are trying to find the culprit, likely the non-idealities in the DAC in transmission

Future works

- We would like to increase the used bandwidth up to 8-9 GHz, thus doubling the number of FDMA channels

- This would match the same requirements of today XG-PON or TWDM-PON optoelectornic (7-8 GHz electrical bandwidth, 10 Gbps NRZ), but would allow increasing the capacity up to about 32 Gbps

Thank you for your attention!

Acknowledgments

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Figure modificate per l'articolo IEEE