B5 Special Session Photonics for 5G

Dimensioning the Physical Layer of DSP-Based Radio Waveforms Aggregation for Fronthauling

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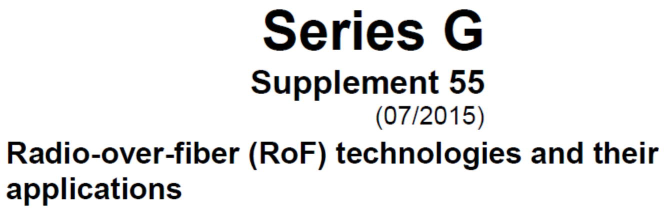
Introduction

The three main optical fronthauling trends (in "chronological" order):

- "Digitized radio over fiber" **D.RoF using CPRI** or OBSAI "de facto" standards
- The **DSP-Based Channel Aggregation** approach
  - Introduced in ITU-T G.RoF in 2015
  - Focus of our presentation today
- An even more recent trend: **Next Generation Fronthaul Interface (NGFI)**



Series G

Supplement 55

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Radio-over-fiber (RoF) technologies and their applications

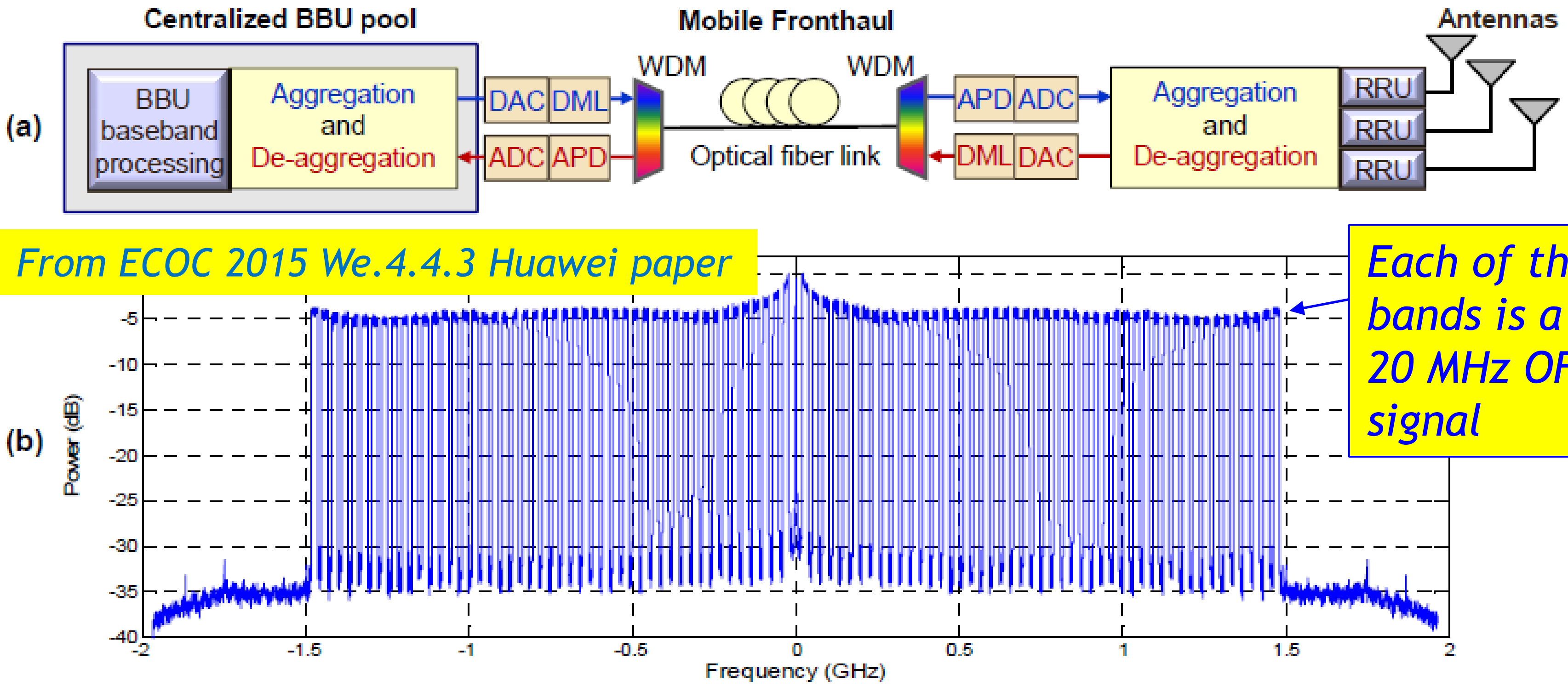
Outline of our talk

- A super-quick review of the DSP-Based Channel Aggregation approach
- Dimensioning the Error Vector Magnitude (EVM) for the front-hauling part
- Our experimental optimization of the system parameters
- Discussion and conclusion

A SUPER-QUICK REVIEW OF THE DSP-BASED CHANNEL AGGREGATION APPROACH

One of the proposed architecture

- An “hybrid” DSP-assisted Radio over fiber
- The key idea is an analog transport of many LTE carrier waveforms using “analog” Frequency Division Multiplexing



From ECOC 2015 We.4.4.3 Huawei paper

Each of these bands is a LTE 20 MHz OFDM signal

Fig. 1: (a) Schematic of the mobile fronthaul architecture with DSP-based channel aggregation and de-aggregation in the frequency domain; (b) Experimentally measured spectrum of 48 20-MHz LTE signals (and their images due to Hermitian symmetry) that are aggregated using seamless channel mapping and transmitted over 5-km SSMF with -6 dBm received signal power. The signal center wavelength is 1550 nm. DML: directly modulated laser; APD: avalanche photodiode.

The required DSP

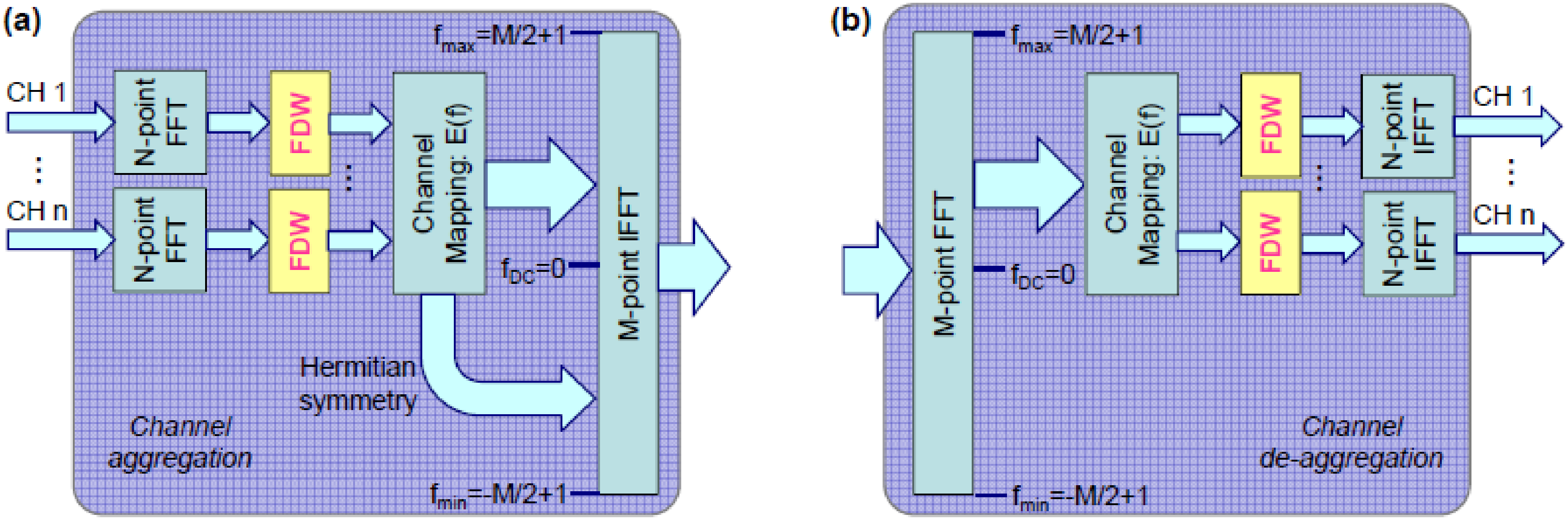
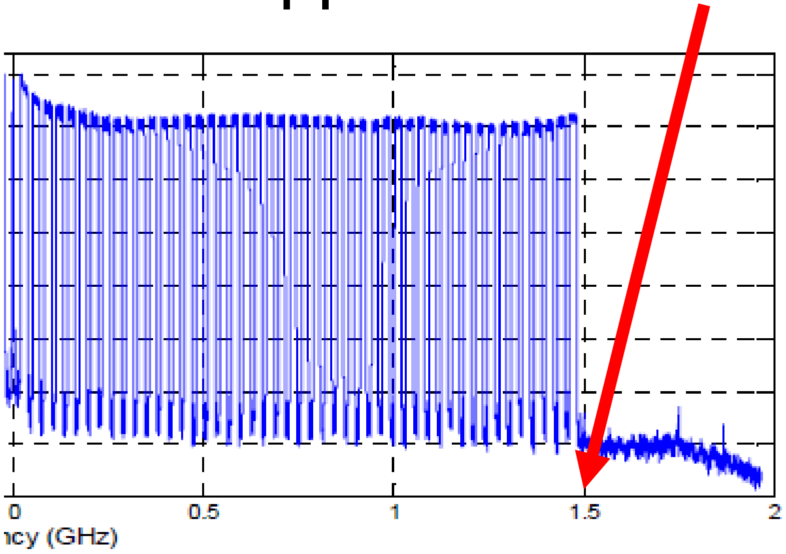


Fig. 2: Schematic of the DSP blocks for FFT/IFFT-based channel aggregation (a) and de-aggregation (b), both with the use of frequency-domain windowing (FDW) to reduce the DSP processing latency.

- **Key idea**: generate the FDM aggregated signal taking advantage of FFT processing for both aggregation and de-aggregation

Comparison of CPRI and G.RoF

- In the Huawei ECOC2015 experiment, they demonstrated this approach using 48 LTE signals over approx. 1.5 GHz of electrical analog bandwidth



- The CPRI approach would have required approximately 48x1.23Gbit/s ≈ 60 Gbit/s
- This is the clear advantage of this new proposal

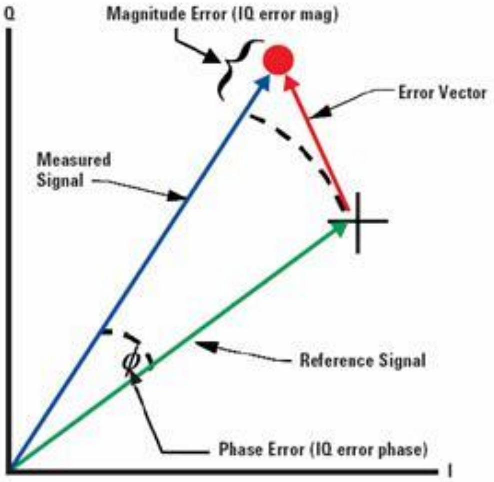
DIMENSIONING THE ERROR VECTOR MAGNITUDE (EVM) FOR THE FRONT-HAULING PART

Error Vector Magnitude from ETSI

- The LTE-A international standard ETSI Technical Specification 136 104 V12.6.0 (2015-02) determines the physical layer transmission quality using the (rms) Error Vector Magnitude parameter

- The ETSI requirements are:

Modulation format	Max EVM_{RMS}
256-QAM	3,5%
64-QAM	8%
16-QAM	12,5%
QPSK	17,5%



$$EVM = \sqrt{\frac{\sum_{k=1}^{M} \left|Z(k) - R(k)\right|^2}{\sum_{k=1}^{M} \left|R(k)\right|^2}}$$

EVM on optical link

- Several papers on DSP-aggregated fronthauling dimension the optical link using the same values
  - For instance, they specify the system “sensitivity” for 64-QAM as the point giving EVM=8% after the optical receiver

- We believe this is largely optimistic: one CANNOT attribute the “EVM budget” completely to the optical part
  - Actually, the opposite would be true, i.e., most of the EVM budget should remain for the wireless part
  - The optical fronthauling segment should be as “transparent” as possible to the wireless segment

EVM on optical link

- Considering that in the proposed approach (and focusing on the downstream) the optical and wireless segment are “analogically” cascaded, we have that

$$SNR_{TOT} = \frac{1}{SNR_F^{-1} + SNR_W^{-1}} \Longrightarrow EVM_{TOT} = \sqrt{EVM_F^2 + EVM_W^2}$$

$$SNR = \frac{E_s}{N_0} = \frac{1}{EVM_{RMS}^2}$$

- We now assume that the “power penalty” on the wireless segment due to the fronthauling segment cannot be larger than a given quantity in dB

$$SNR_{W,dB} = SNR_{T,dB} - K_{pen,dB}$$

EVM on optical link

- After some simple passages:

Maximum EVM on the fiber link

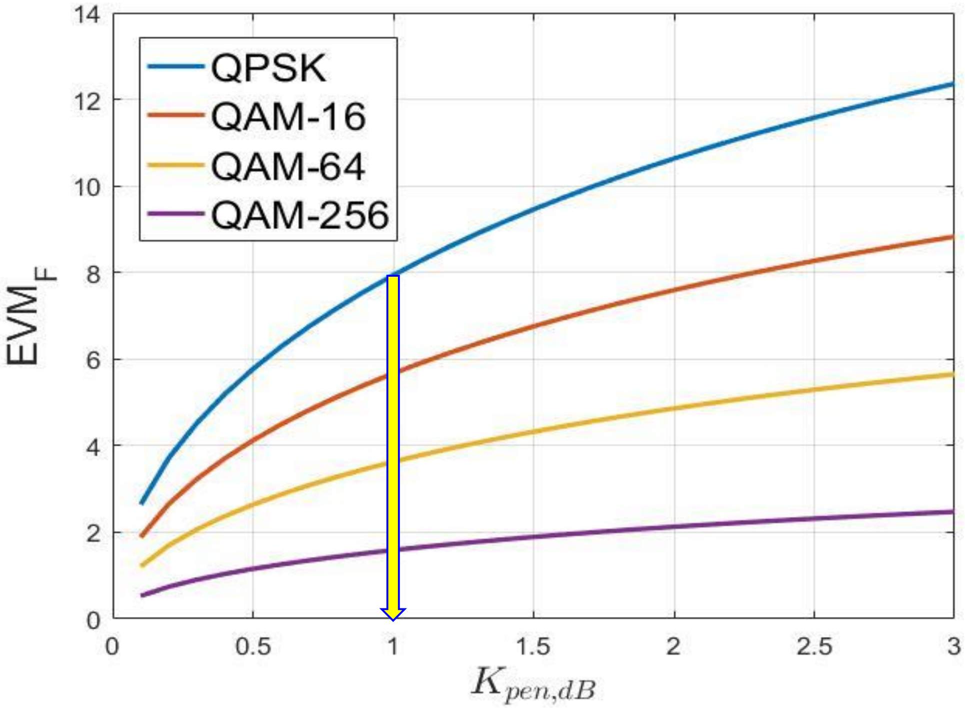
$$EVM_F \le EVM_T \cdot \sqrt{\frac{K_{pen,linear}-1}{K_{pen,linear}}}$$

Acceptable penalty on the wireless part

Target EVM on the full link (optical+wireless)

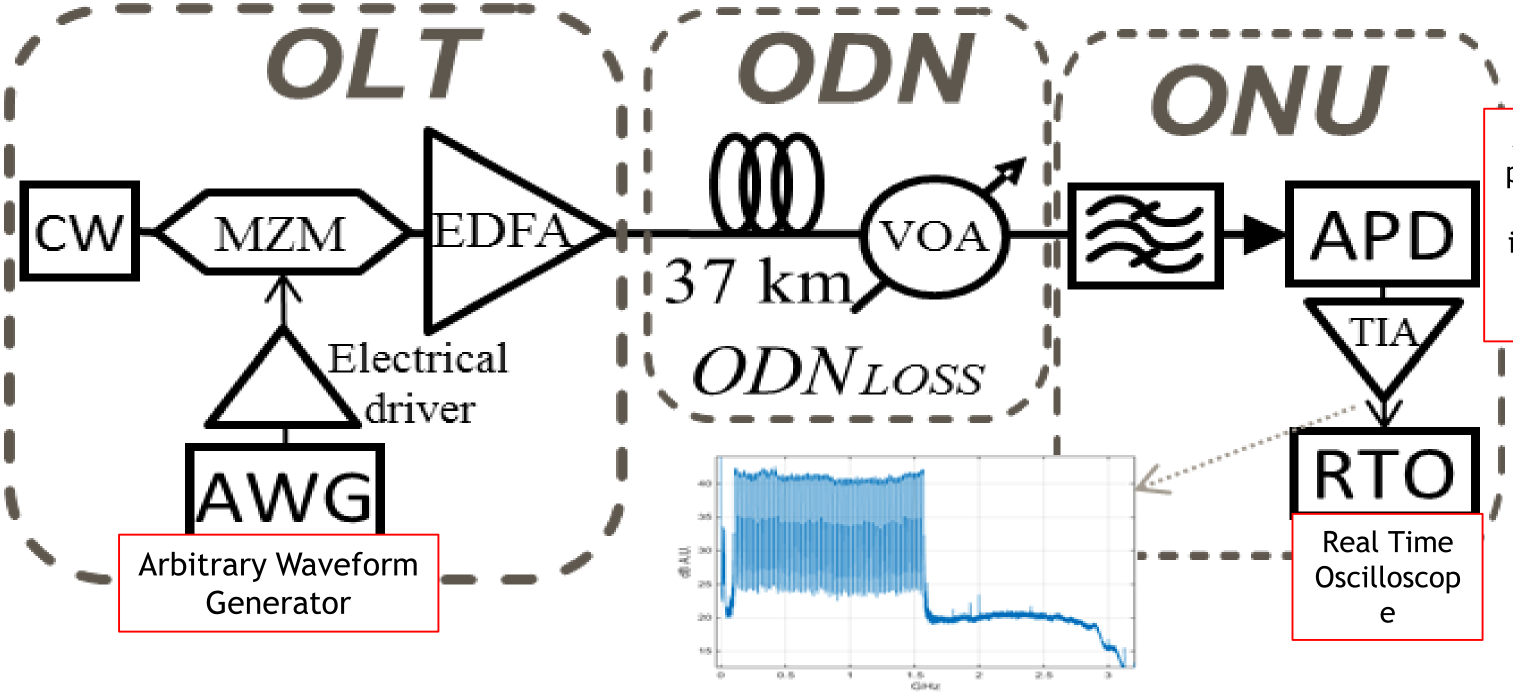
1 dB penalty on wireless part

Modulation format	Max EVM_F
256-QAM	1.58%
64-QAM	**3,62%**
16-QAM	5,66%
QPSK	7,93%



OUR EXPERIMENTAL OPTIMIZATION OF THE SYSTEM PARAMETERS

Experimental Setup: off-line processing experiment for downstream fronthauling transmission



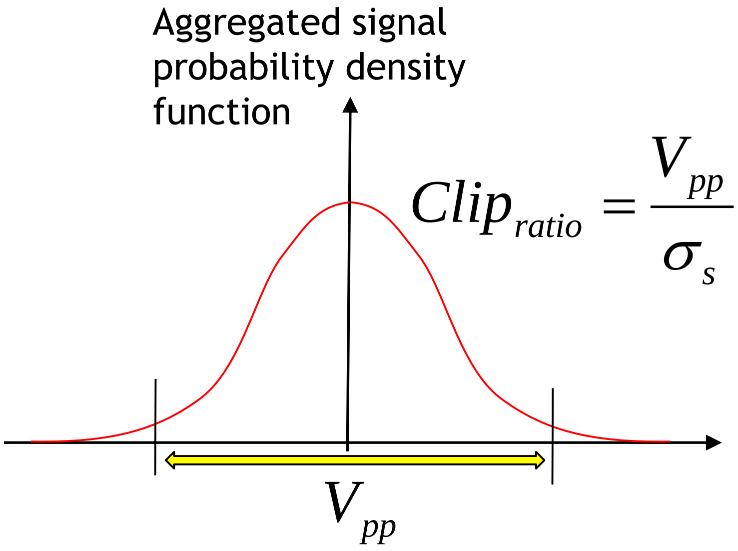
Avalanche photodiode + Trans impedance amplifier receiver

Arbitrary Waveform Generator

Real Time Oscilloscope

TX parameters to be optimized

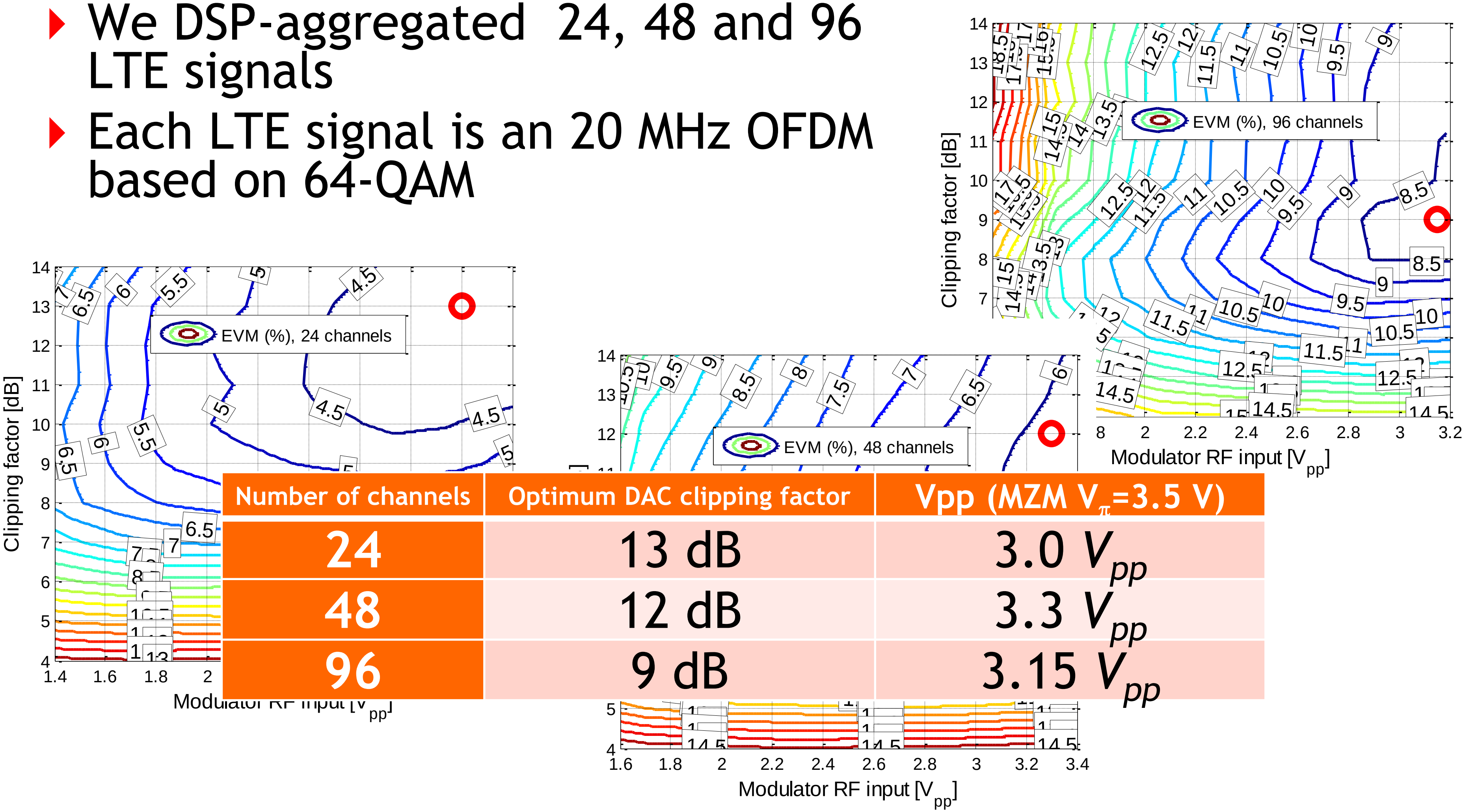
- Clipping on the signal sent to the DAC
- Peak-to-peak voltage at the input of the external modulator
- Transmitted power at the input of the fiber P_{fiber}



$$Clip_{ratio} = \frac{V_{pp}}{\sigma_s}$$

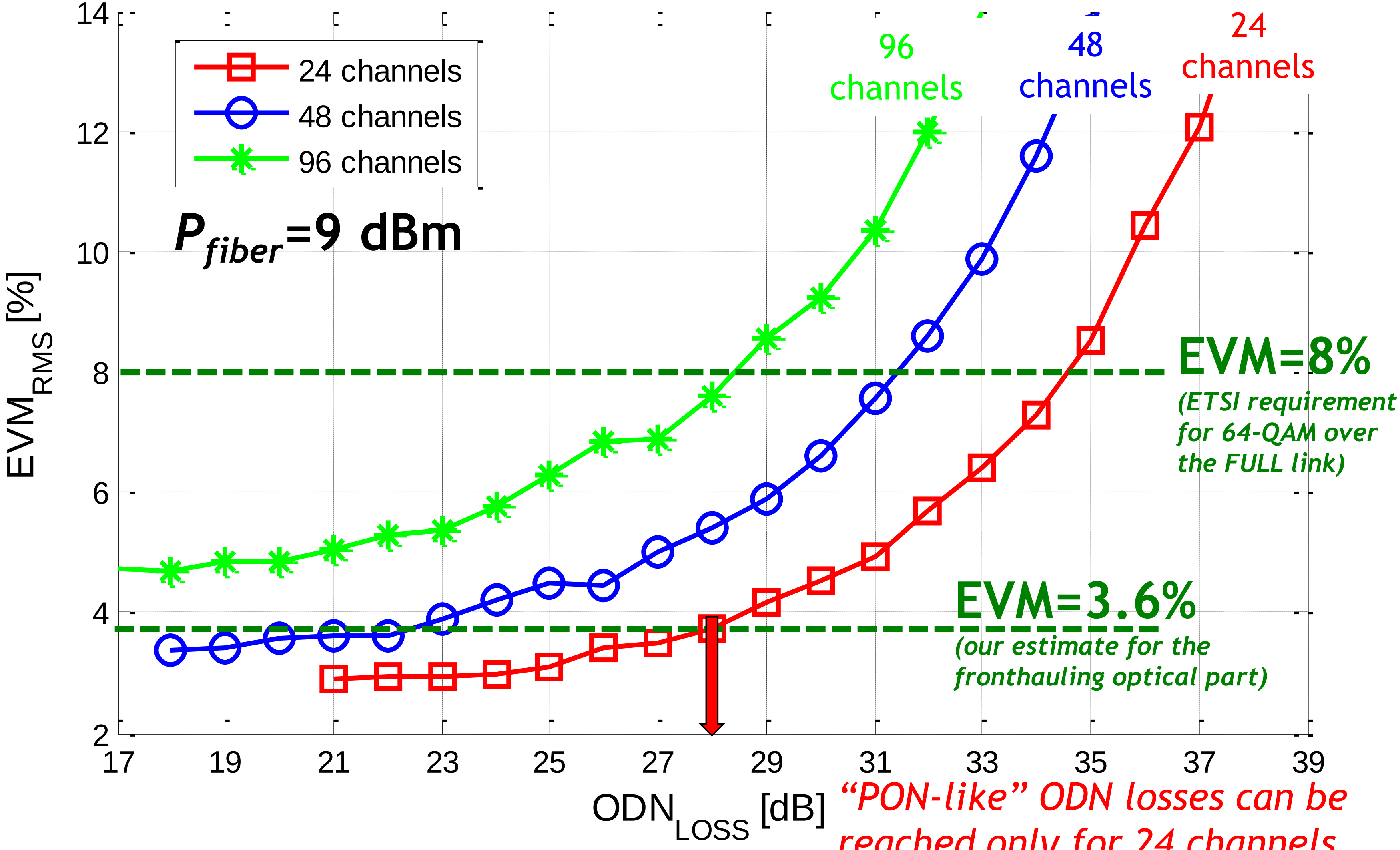
Optimization of clipping and V_{pp}

- We DSP-aggregated 24, 48 and 96 LTE signals
- Each LTE signal is an 20 MHz OFDM based on 64-QAM



Number of channels	Optimum DAC clipping factor	Vpp (MZM V_π=3.5 V)
24	13 dB	3.0 V_{pp}
48	12 dB	3.3 V_{pp}
96	9 dB	3.15 V_{pp}

EVM vs. ODN loss



P_{fiber}=9 dBm

EVM=8%

(ETSI requirement for 64-QAM over the FULL link)

EVM=3.6%

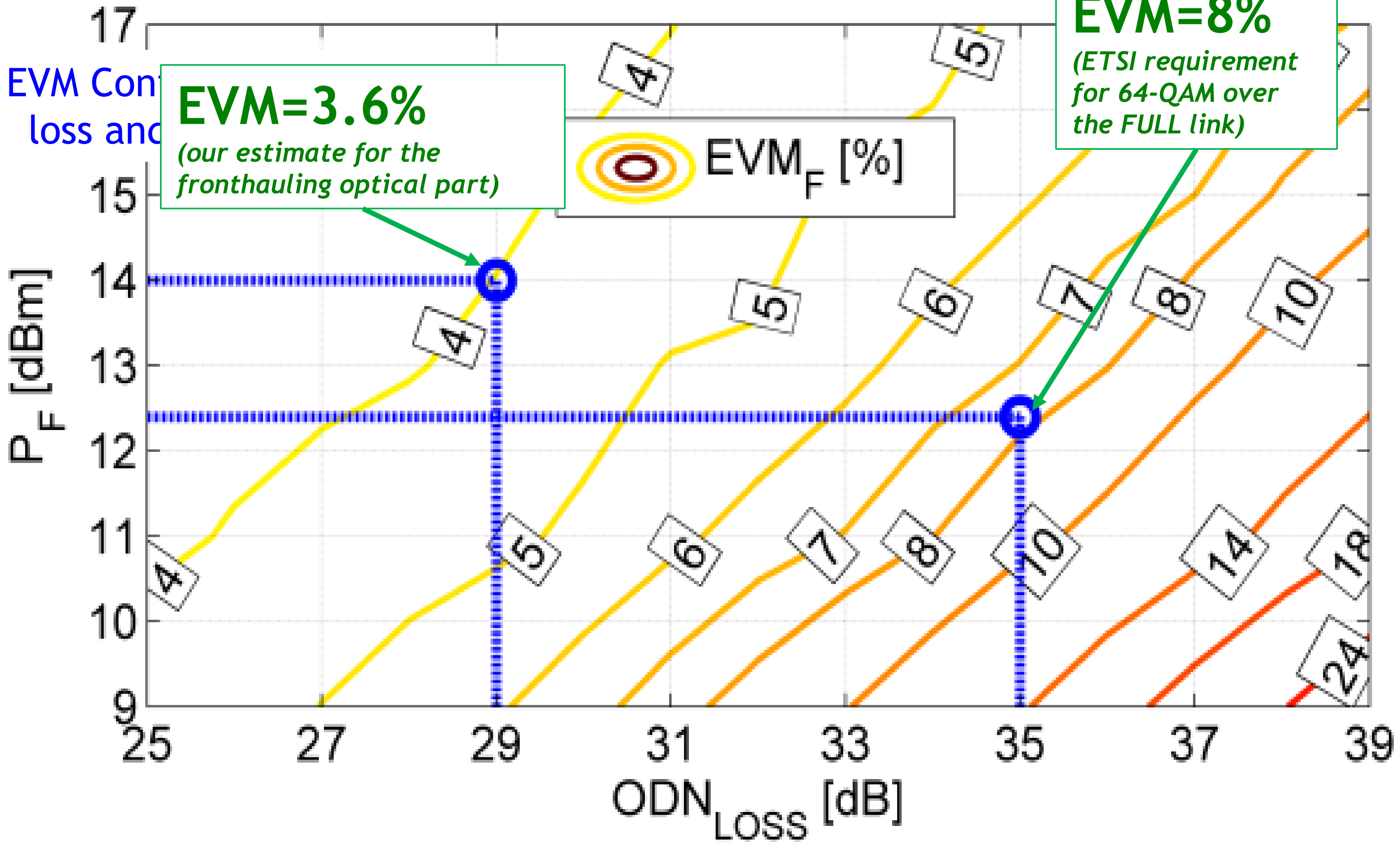
(our estimate for the fronthauling optical part)

“PON-like” ODN losses can be reached only for 24 channels

Increasing P_{fiber}

- 48 channels, Higher P_{fiber}
  - Laser dithering needed to avoid Brillouin

EVM Con
loss and



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CONCLUSION

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Conclusion

- After a careful optimization of system parameters we manage to obtain EVM<4% for 48 LTE channels using manageable transmitted optical power
  - $P_{fiber} \approx 14$ dBm
    - Consider that some CATV video-overly systems launches up to 17 dBm

- We are currently working on finding solutions that allows 96 channel transmission by:
  - Work on some (simple) nonlinearity compensation at the receiver
  - investigate other modulation formats

QUESTIONS?

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