Performance Study of Optical OFDM for the ACCORDANCE Ultra High-Speed, Long-Reach Access Network

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Motivation

Access Networks

NG-PONs should support Long Reach (up to 100km), high capacity (up to 100Gb/s shared BW; over 300Mb/s per user) and high splitting ratio (more than 1:128), while maintaining low hardware and operation costs to remain attractive and practical.

WHY OFDM(A)?

1. OFDM(A)-PONs (first introduced by NEC) have extreme flexibility on both multiple services provisioning and dynamic bandwidth allocation (through dynamic allocation of sub-carriers)

2. OFDM(A)-PONs do not require burst-mode receiver at the OLT which still remains challenge for +10Gb/s TDM-PON device vendors.

3. OFDM technology currently used in:
   - Copper, in the xDSL links using DMT (Discrete Multi-Tone) modulation format
   - Radio (WiFi:802.11a, 802.11g, WiMax:802.16e-2005, 3GPP LTE)
   - Indoor Power Line Communications (PLC), with the HomePlugAV specifications

ACCORDANCE Project OBJECTIVES

- **Definition of a novel Access Network architecture achieving convergence among heterogeneous technologies (optical, wireless, copper).**
- **Propose low-cost, low-complexity concepts to achieve ultra high data rates in the access network (up to 100Gbps aggregate and more than 10Gbps in each segment).**
- **Introduction of flexible bandwidth allocation concepts using dynamic FDM and OFDM sub-carrier assignment.**
- **Provision of smooth migration from and coexistence with legacy access solutions.**
- **Demonstration of the ACCORDANCE concepts using experimental test beds.**

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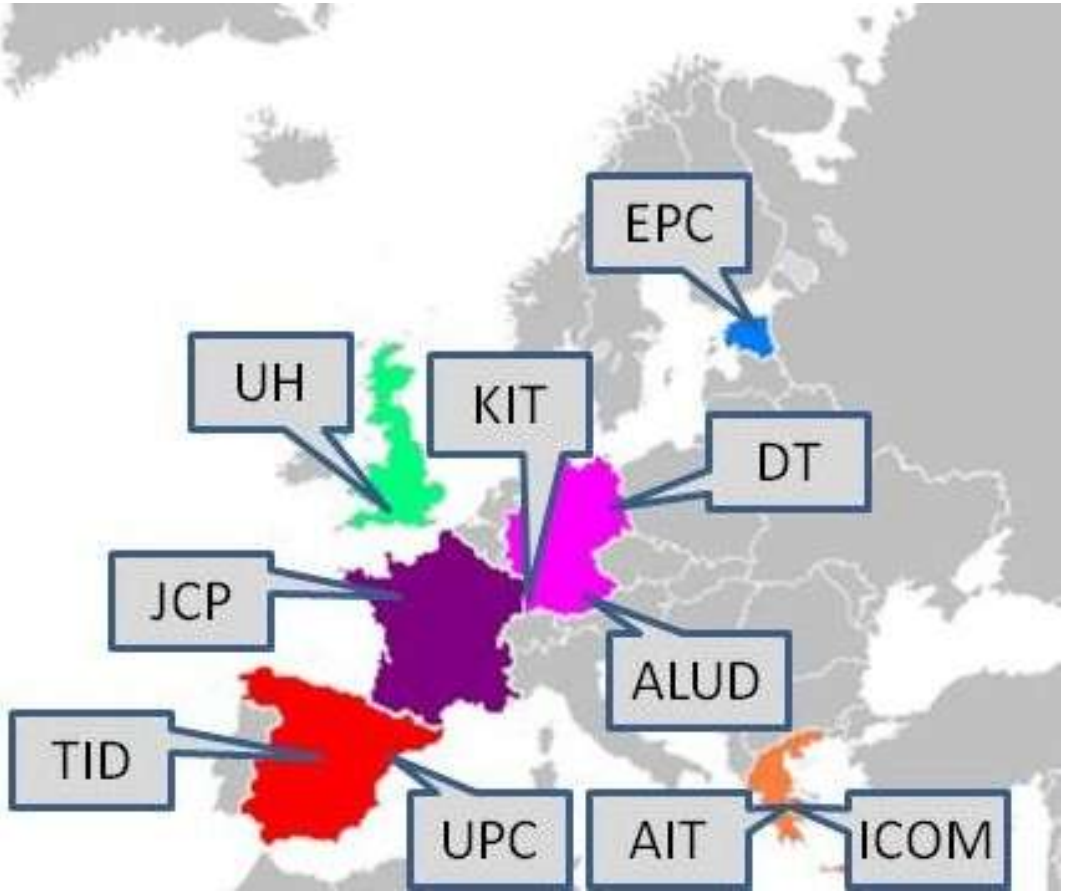
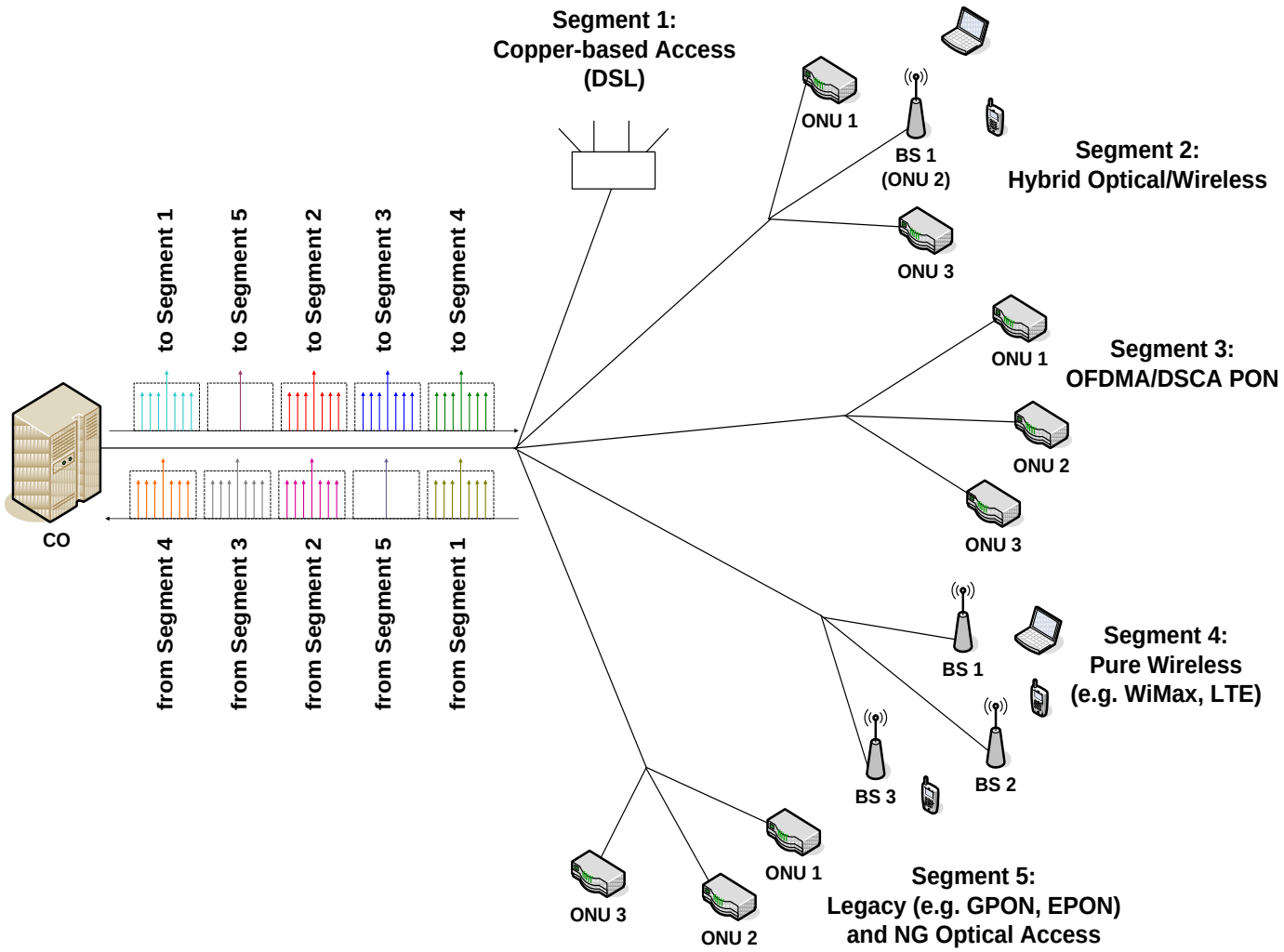
Perceptum ex Optimus



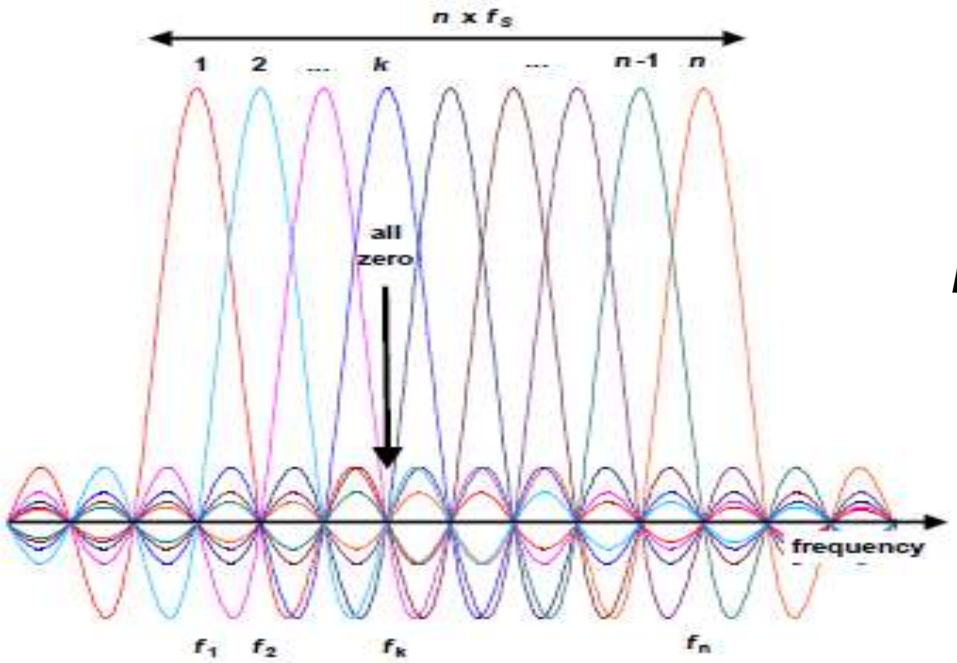
Envisioned Converged Network Architecture



Basic OFDM Principles

• OFDM is multicarrier modulation scheme in which the data information is carried in a multiplexed setup in parallel, over many lower rate subcarriers.

• To generate OFDM successfully the relationship between all the carriers must be carefully controlled to maintain the orthogonality of the carriers.

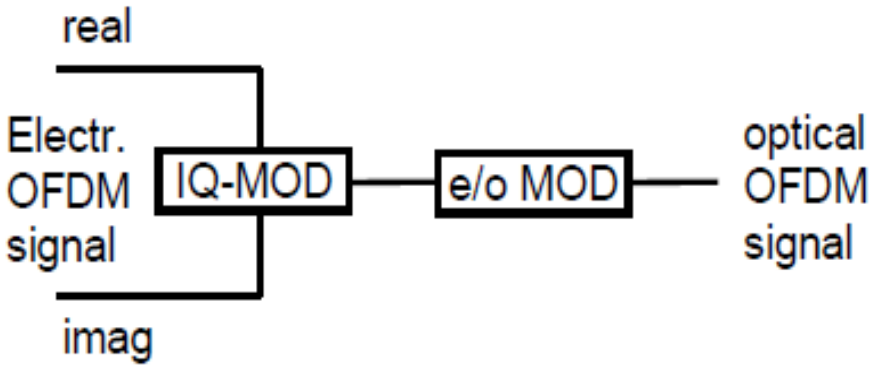


[Buchali 2009]

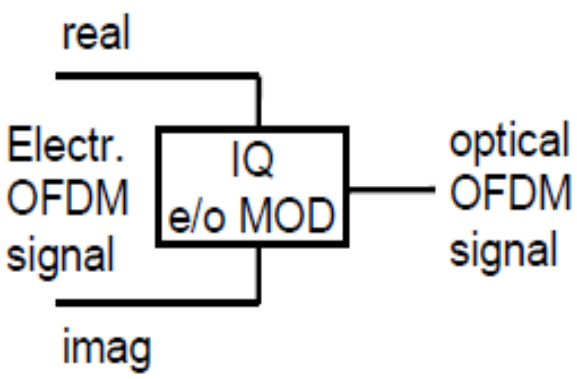
Optical OFDM – Signal Generation

• In general OFDM signals are complex valued data signals.

• The conversion of complex valued data signals to optical domain at the transmitter can be done with 2 fundamental setups ***[Buchali 2009]:***



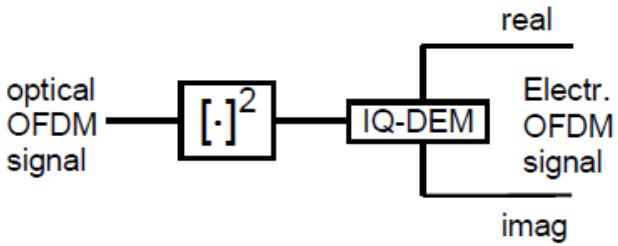
Electrical I/Q Modulation



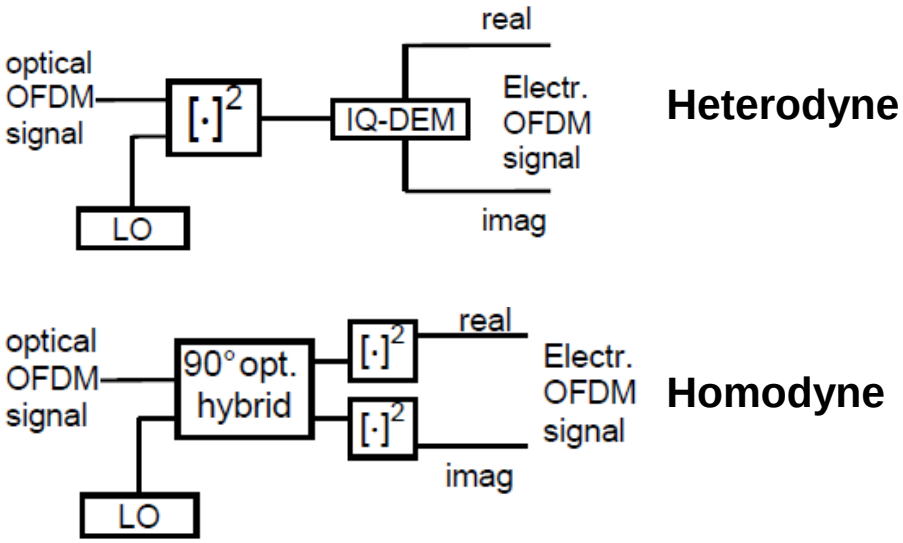
Optical I/Q Modulation

Optical OFDM – Signal detection

•Instead of direct detection of the pure optical OFDM signal an optical carrier is required to be delivered either by the transmitter (direct detection OFDM) or by local oscillator (LO) at the receiver (using coherent optical OFDM).

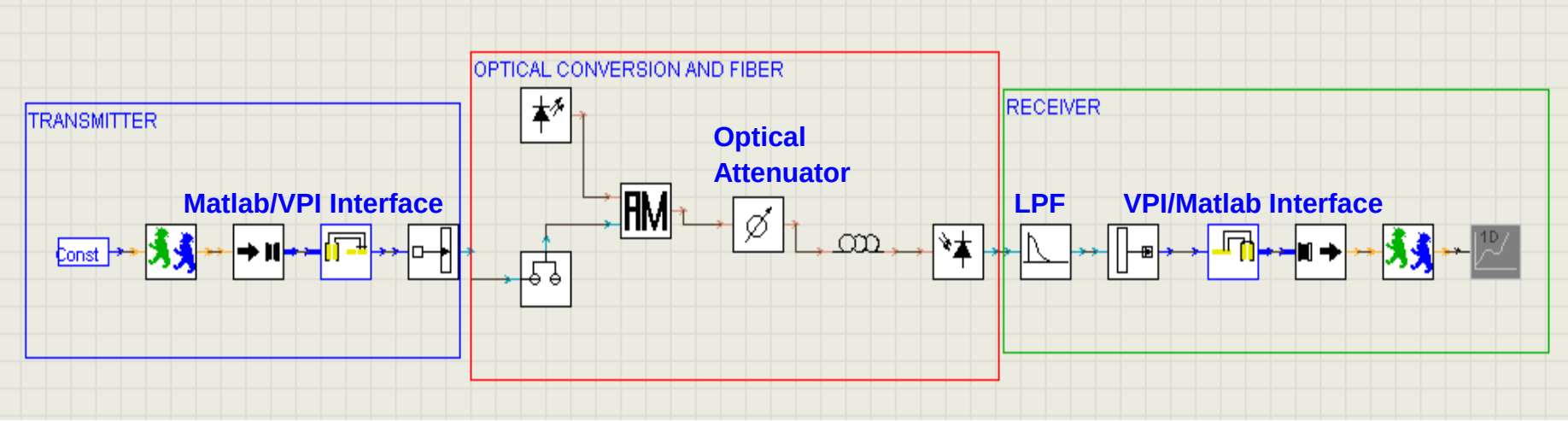


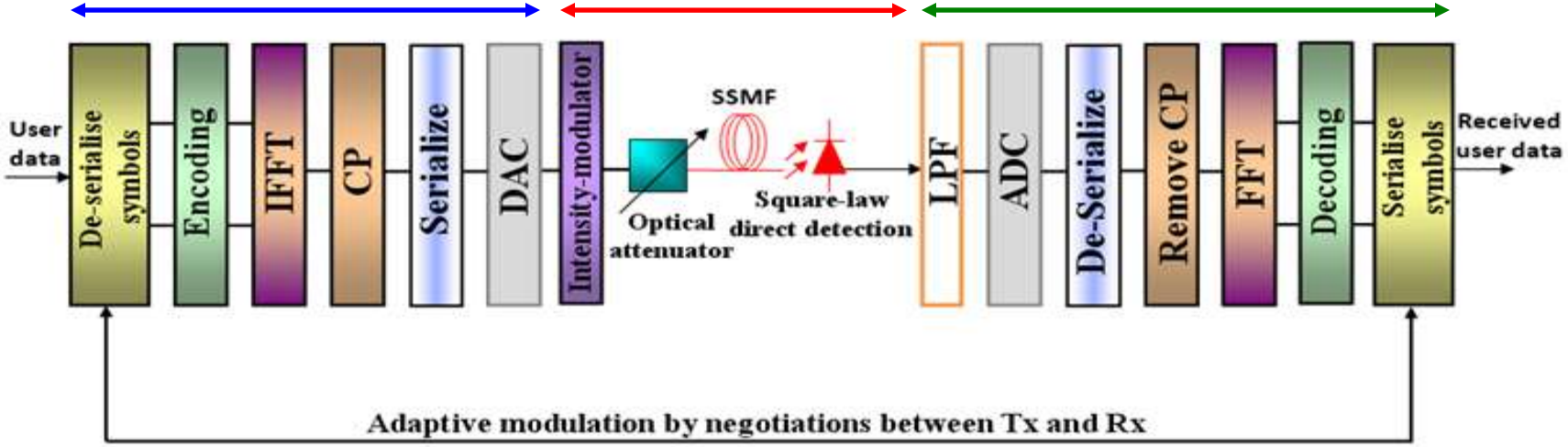
Direct Detection OFDM DDO-OFDM



Coherent Optical OFDM CO-OFDM

Simulation Studies performed





Simulation Parameters

- **Modulation formats:** DBPSK-DQPSK and 8-QAM up to 256- QAM.
- **Number of subcarriers:** Values ranging from 16 to 256
- **Clipping ratio:** Default value 13 dB.
- **Cyclic prefix:** 25% as a default value but it is stretched up to 12% to achieve the target of 100 Gb/s.
- **Sampling Rate:** 12.5 GSa/s as a default value and reached the value of 28 GSa/s to achieve 100 Gb/s.
- **Fiber lengths:** 20, 60 and 100 km are used.
- **Quantization resolution:** 7 bits are chosen since are the minimum allowed for a target BER≤0.001 when 256-QAM used
- **Acceptable BER:** ≤10e-3.

Results from our extensive studies

IM/DD with Fiber length of 20 Km

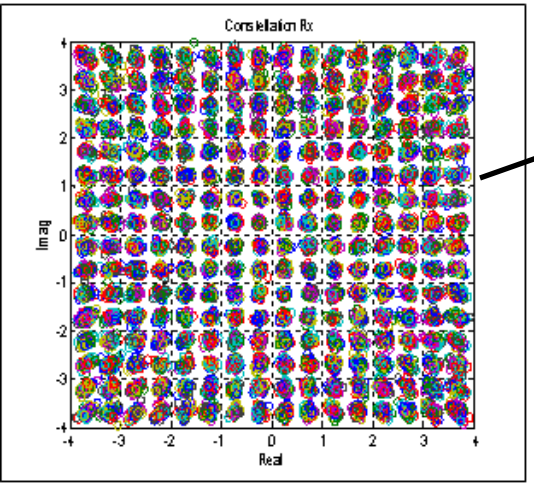
Subcarrier Modulation	No of Subcarriers	Data rate (Gb/s)	BER for an Ideal Modulator	BER for a MZM	BER for a DML
DQPSK	16	9.375	< 10e-12	< 10e-12	< 10e-12
DQPSK	32	9.687	< 10e-12	< 10e-12	< 10e-12
DQPSK	64	9.843	< 10e-12	< 10e-12	< 10e-12
DQPSK	128	9.921	< 10e-12	< 10e-12	< 10e-12
8-QAM	16	14.063	< 10e-12	< 10e-12	< 10e-12
8-QAM	32	14.531	< 10e-12	< 10e-12	< 10e-12
8-QAM	64	14766	< 10e-12	< 10e-12	< 10e-12
8-QAM	128	14.883	< 10e-12	< 10e-12	< 10e-12
16-QAM	16	18.75	< 10e-12	< 10e-12	< 10e-12
16-QAM	32	19.375	< 10e-12	< 10e-12	< 10e-12
16-QAM	64	19.688	< 10e-12	< 10e-12	< 10e-12
16-QAM	128	19.844	< 10e-12	< 10e-12	< 10e-12
32-QAM	16	23.438	< 10e-12	< 10e-12	< 10e-12
32-QAM	32	24.219	< 10e-12	< 10e-12	< 10e-12
32-QAM	64	24.609	< 10e-12	< 10e-12	7.00E-05
32-QAM	128	24.805	< 10e-12	1.98E-05	6.00E-04
64-QAM	16	28.125	< 10e-12	< 10e-12	9.00E-05
64-QAM	32	29.063	< 10e-12	< 10e-12	9.00E-05
64-QAM	64	29.531	< 10e-12	4.80E-04	9.00E-05
64-QAM	128	29.766	< 10e-12	1.36E-04	8.22E-04

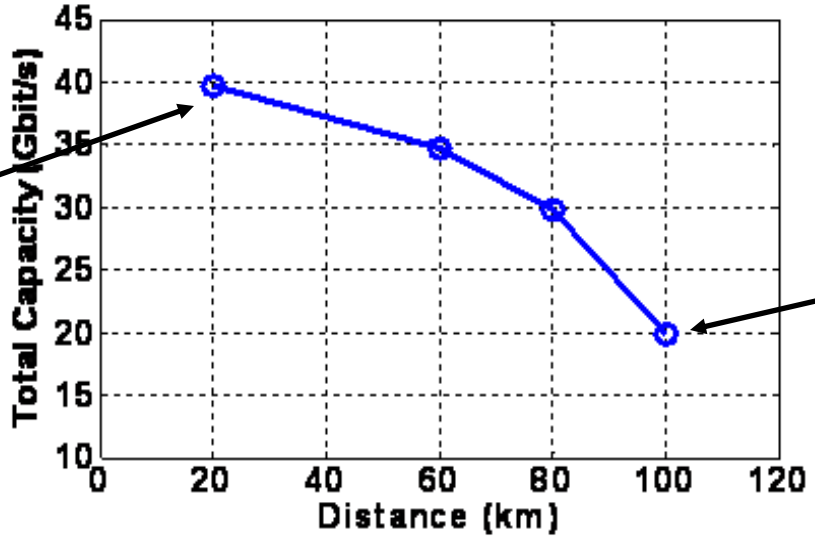
IM/DD with Fiber length of 60 Km

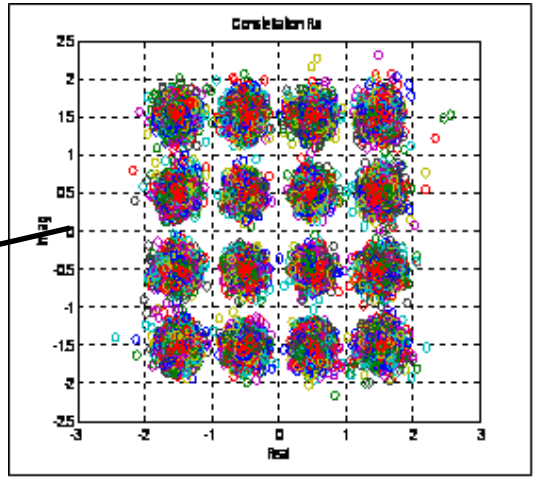
Subcarrier Modulation	No of Subcarriers	Data rate (Gb/s)	BER for an Ideal Modulator	BER for a MZM	BER for a DML
DQPSK	16	9.375	< 10e-12	< 10e-12	< 10e-12
DQPSK	32	9.687	< 10e-12	< 10e-12	< 10e-12
DQPSK	64	9.843	< 10e-12	< 10e-12	< 10e-12
DQPSK	128	9.921	< 10e-12	< 10e-12	< 10e-12
8-QAM	16	14.063	< 10e-12	< 10e-12	< 10e-12
8-QAM	32	14.531	< 10e-12	< 10e-12	< 10e-12
8-QAM	64	14766	< 10e-12	< 10e-12	< 10e-12
8-QAM	128	14.883	< 10e-12	9.40E-04	< 10e-12
16-QAM	16	18.75	< 10e-12	< 10e-12	< 10e-12
16-QAM	32	19.375	< 10e-12	< 10e-12	< 10e-12
16-QAM	64	19.688	< 10e-12	< 10e-12	< 10e-12
16-QAM	128	19.844	< 10e-12	1.46E-04	< 10e-12
32-QAM	16	23.438	< 10e-12	< 10e-12	< 10e-12
32-QAM	32	24.219	< 10e-12	< 10e-12	< 10e-12
32-QAM	64	24.609	< 10e-12	2.30E-05	8.00E-05
32-QAM	128	24.805	< 10e-12	8.00E-04	6.00E-04
64-QAM	16	28.125	< 10e-12	2.00E-04	1.00E-03
64-QAM	32	29.063	< 10e-12	2.20E-04	1.10E-03
64-QAM	64	29.531	< 10e-12	2.43E-04	4.50E-03
64-QAM	128	29.766	4.20E-05	8.00E-04	7.40E-03

Using the default simulation parameters and testing Ideal Amplitude Modulator, MZM and DML

Total Capacity versus Range for IM/DD





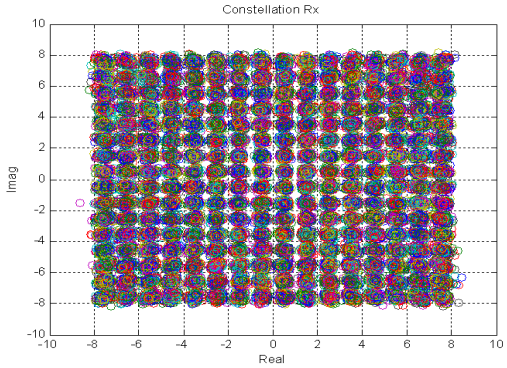


Total Capacity versus range performance using various modulation formats. The left hand side constellation is a 256-QAM at 20 Km and the right hand side constellation is a 16-QAM at 100 Km, which have achieved total capacities of 39.688 Gb/s and 19.844 Gb/s, respectively.

Targeting 100 Gb/s or 100 Km with IM/DD

Target of 100 GB/s:

Total capacity of **99.219 Gbit/s** is achieved at **50 km** using 256-QAM 12% CP and 28 Gsa/s for BER≤10-3

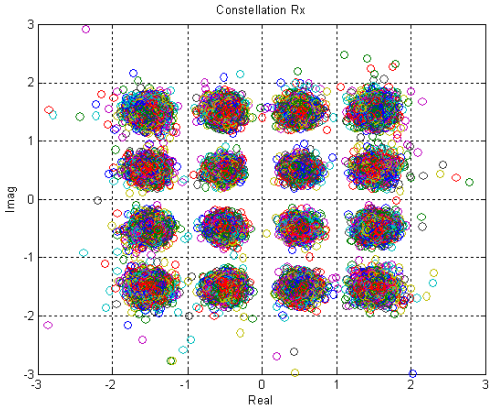


Target of 100 Km:

Total capacity of **49.609 Gb/s** with 16-QAM, 12% CP and 28 GSa/s for BER≤10-3

Total capacity for various sampling rates and cyclic prefixes using 16-QAM and targeting 100 Km

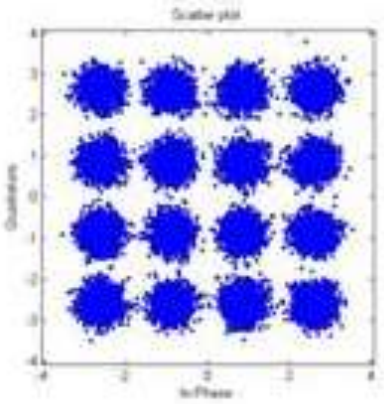
Sampling Rate (GSa/s)	Total Capacity (Gbit/s) for 12% CP	Total Capacity (Gbit/s) for 25% CP
12.5	22.147	19.844
20	35.435	31.750
25	44.294	39.688
28	49.609	44.450

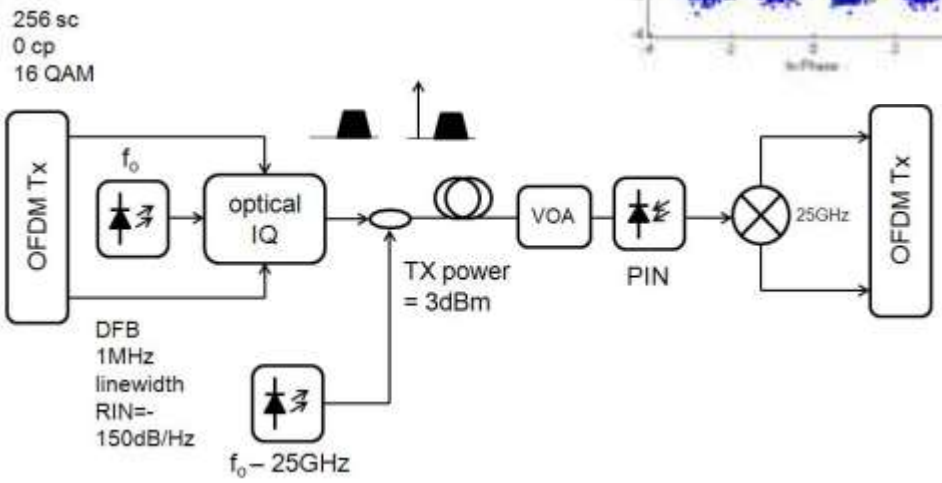


Optical IQ – DD simulation results

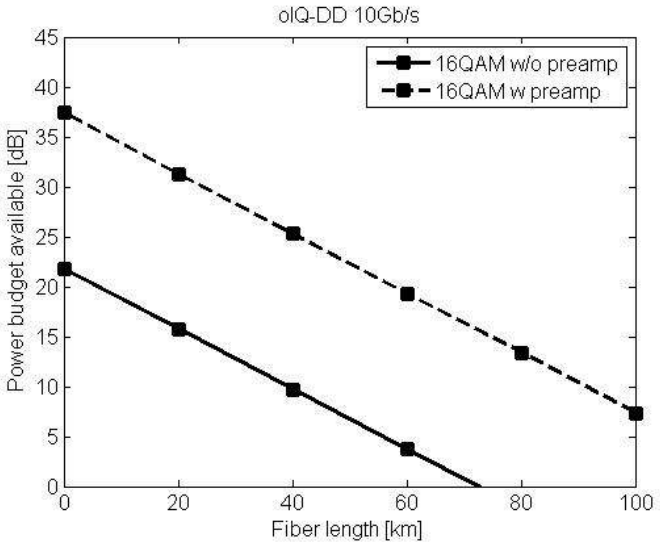
Tx: optical IQ modulator

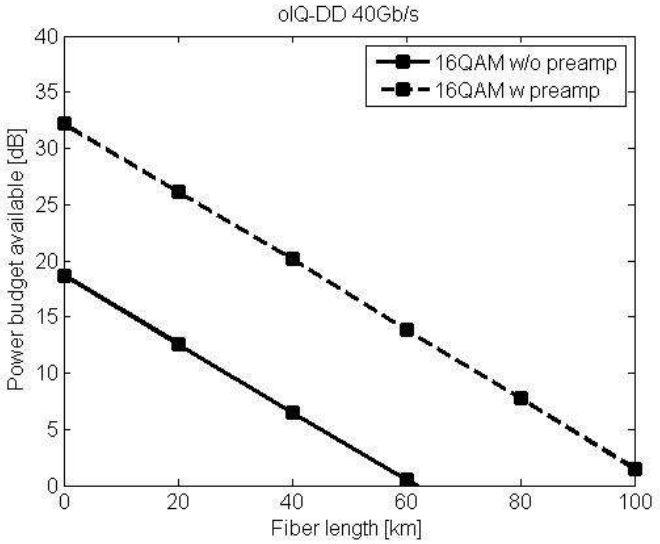
256 subcarriers,
16QAM
0 c.p.





Rx: direct-detection PIN photodiode 50GHz BW with electrical mixer downcoverter (25GHz spectral bandgap)

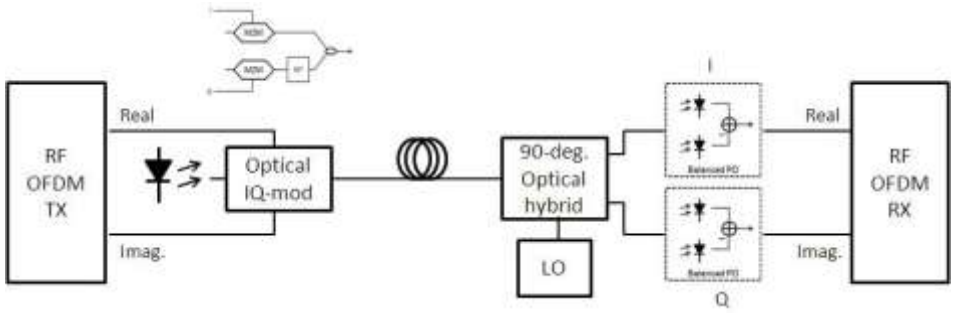


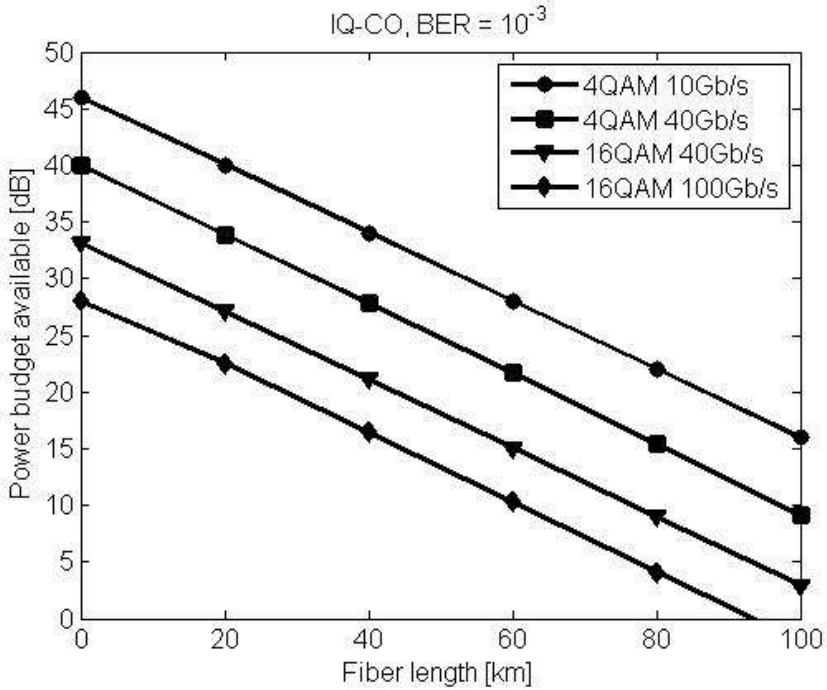


Optical IQ – CO simulation results

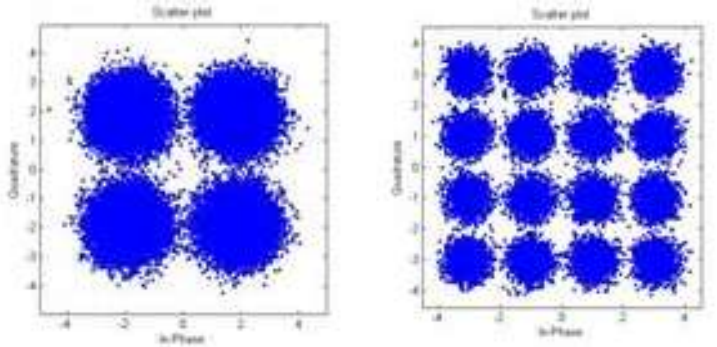
Tx: optical IQ modulator

256 subcarriers
4, 16 QAM
0.2 c.p.





Rx: homodyne coherent receiver with 90-deg hybrid



Summary and Conclusions

• OFDMA PONs is a new approach to realize the requirements of next generation FTTH networks (one of the candidates for NG-PON2)

• OFDM is a powerful transmission technique that, depending on the Tx/Rx implementation, can realize up to 100Gb/s and up to 100Km reach (in some cases without the need of using optical amplification or/and WDM)

• Initial simulation studies suggest that:
  - IM/DD OFDM is a low cost alternative that might be used for 40Gb/s OFDMA-PONs targeting a reach of 20km
  - oIQ-DD OFDM may be used to realize 40Gb/s OFDMA-PONs targeting a reach of 40km
  - oIQ-CO OFDM may be used to realize 100Gb/s OFDM-PONs targeting a reach of 100km

• Investigation of performance degrading impairments (and their mitigation) is currently under study to determine the performance and implementation of up-stream transmission
  - Optical Beat Interference (OBI)
  - Rayleigh Backscattering noise
  - Peak to average power ratio (PAPR)

• The ACCORDANCE project is expected to realize and demonstrate in 2012 the performance of OFDMA for next generation FTTH/FTTA networks used to offer connectivity to business/residential customers as well as backhauling of LTE/WiMax/VDSL originating traffic.

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Thank you for your attention!

For more information contact:
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