OFDMA for Access Networks: Optical Setup

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Motivation for OFDMA in Optical Access

Goals for Future Optical Access Networks

- **Increase data rate**
  - Introduce WDM, increase data rate per $\lambda$
- **Increase user count**
  - WDM + multiple access (MA) techniques on each wavelength:
    - TDMA, CDMA, FDMA, OFDMA

State of the art discussed here

Advantages of OFDMA:

- Flexibility in time and frequency domain
- Continuous operation (instead of burst operation)

... however, there are challenges!
Outline

• Optics in Downstream Direction
  • Direct Detection vs. Coherent Detection

• Optics in Upstream Direction
  • Aspects of upstream with different wavelengths
  • Aspects of upstream with common wavelength

• Duplex of Up- and Downstream

• Summary
Concept of OFDMA in PON: Downstream

Example with 4 ONUs

Groups of OFDM subcarriers assigned to ONU 1 … ONU 4

OLT

ONU 1

ONU 2

ONU 3

ONU 4

IFFT-window
Characteristics of Optical Modulation/Detection

Optical spectrum

**IM-DD DSB**

- $S_2$
- $S_1$
- $C$
- $f$
- $B$

**IM-DD SSB**

- $S_1$
- $C$
- $f$

**IM-CO DSB**

- $S_2$
- $S_1$
- $LO$
- $90°$ hybrid

Electrical spectrum

- $|E|^2$
- $S_1^2 + S_2^2$
- $C \cdot S_1 + C \cdot S_2$

as in OFC’14 Short Course, OFC’12 Tutorial by Sander Jansen
**OFDMA-Downstream**: Experiment (CAU, OFC’12)  

**Setup**

- Offline processing
- Point-to-point transmission over 100 km SMF
- SSB-filtering to avoid powerfading

**Single Tx:**
- Full data rate

**Single Rx → Emulate multiple Rx:**
- Different reduction factors \( r \)
- Full / half / quarter data rate
- Different LO-frequencies

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v. Hoyningen-Huene et al., OFC 2012, OW4B.
Concept of OFDMA in PON: Upstream

OLT

ONU 4

ONU 3

ONU 2

ONU 1
Concept of OFDMA in PON: Upstream

Challenges:
- Carrier frequency offset
- Different path lengths
- Different states of polarization
- Different optical phase

OLT

ONU 1

ONU 2

ONU 3

ONU 4
Optical Modulation in Upstream
Different Wavelength, Direct Detection

Optical spectrum

Electrical spectrum

Desired parts

Intermodulation products
Optical Modulation on Same Wavelength
Direct Detection

- (Larger bandgap required)
- Equal carrier frequencies required
Optical Modulation on Same Wavelength
Direct Detection

- Equal carrier frequencies required
-Insensitive to polarization
-Destructive beating of carriers possible
  → Loss of sub-signals

No direct detection possible
Optical Modulation on Same Wavelength
Coherent Detection

- Equal carrier frequencies required
- Add carrier at receiver, not at transmitter
- Coherent detection of both polarizations
**OFDMA-Upstream**: Experiments (CAU, OFC’13+14)

**ONUs:**
- Generation of 4 real-valued OFDM signals
- Synchronized AWG → Adjustable timing offset

**PON:**
- Individual distribution fibers
- Bidirectional feeder fiber

**OLT:**
- Coherent reception (dual pol.)

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von Hoyningen-Huene et al., OFC 2014, Tu2F.4.
**OFDMA-Upstream**: Experiments (CAU, OFC’13+14) Optical Spectra

von Hoyningen-Huene et al., OFC 2014, Tu2F.4.
Duplex of Downstream and Upstream

- Different fibers
  - Simple concept, relatively expensive

- Different wavelengths
  - Separation with WDM components
  - Distribution of common US-\(\lambda\) required
  - Small interference of US and DS
  - NEC, CAU Kiel, etc.

- Duplex on same wavelength
  - Remodulation of downlink signal
  - Technion, HHI Berlin, NEC, etc.
Summary

- **OFDMA for flexible capacity allocation among ONUs**

- **Downstream direction: “straight forward”**
  Single optical source, single optical modulation → Cost efficient optics

- **Upstream direction: “challenging but possible”**
  - Individual wavelengths for each ONU
    Cost efficient detection, but (greatly) reduced WDM scalability
  - Common wavelength for all ONUs
    Distribution of optical carrier required (or precise control of optical sources)
    Coherent detection required