Comparison of Rx-DSP-Structures in Experimental OFDMA-PON Uplink Transmission System

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Abstract: We compare a DSP with a common FFT and a DSP with individual FFTs to receive the experimental OFDMA uplink transmission with four individually modulated ONUs in terms of timing mismatch robustness.

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1. Introduction

To increase the number of subscribers in passive optical networks (PON), various multiple access schemes like time division multiple access (TDMA), frequency division multiple access (FDMA) and its special form orthogonal FDMA (OFDMA) can be used [1]. OFDMA is spectrally efficient and allows adaption to the channel and traffic demand by flexible bit- and power-loading. The uplink (UL) direction in such an OFDMA-PON is the challenging part, since here the signals are generated and modulated at different locations and have to be multiplexed without distorting each other. For error free transmission these signals need to be orthogonal leading to requirements in time and frequency domain [2,3]. Most publications of FDMA-PON systems agree that the optical carrier must be generated centrally and distributed to the optical network units (ONUs) in order to ensure synchronization in frequency domain. However, depending on the receiver structure either synchronization of the uplink signals in time domain is required, which can be difficult to achieve and maintain [3,4]. Alternatively, sufficiently large band gaps are needed between the uplink signals which reduce the spectral efficiency [5,6]. In [2,7] we showed an OFDMA-PON concept that allows closely packed subcarrier groups without the need of time synchronization between the uplink signals using individual FFTs per transmitting ONU. In this paper we experimentally compare the impact of asynchronous signal reception using this approach to standard digital signal processing (DSP) structures with a single FFT for all ONUs that require synchronous signals. The downlink transmission is expected to use a different wavelength and is not discussed here.

3. Experimental Setup

Fig. 1 shows the experimental setup of the UL transmission from 4 ONUs to the optical line terminal (OLT). The setup is similar to the one presented in [2] but has some important improvements. Two circulators enable a bidirectional mode for the feeder fiber and all four DACs from the two arbitrary waveform generators (AWG) are

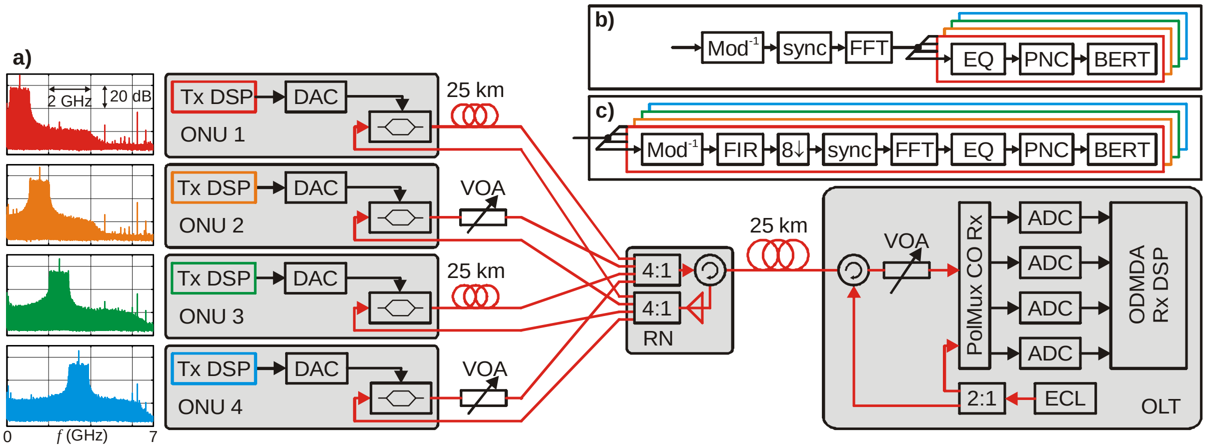

Fig. 1. OFDMA-PON experiment with four individual transmitting ONUs, a bidirectional feeder fiber and coherently receiving OLT. Different path lengths but same power levels of all uplink signals are realized with extra fibers (25 km) and variable optical attenuators (VOA), RN: remote node. (a) Non-overlapping OFDM spectra. (b) DSP using a single FFT for all uplink signals. (c) DSP using an individual FFT for each uplink signal.

now fully synchronized. The relative path delays between the ONUs that results from different ONU-OLT distances can be retrieved by evaluating the transmitted training symbols in the receiver DSP and compensated for by introducing individual delay settings at the ONU. Note that this would require feedback information. Timing mismatch compensation of the received UL signals can be realized by additional delay values through the synchronized DACs. Moreover the phase noise compensation (PNC) is improved by using a pilot subcarrier in the center of each subcarrier group and manual bit-loading is applied to optimize the data rate and the robustness. Since the edge subcarriers of each subcarrier group suffer most from crosstalk of asynchronous ONU signals, 6 subcarriers at the edge are filled with QPSK while 8-QAM is used for the more robust inner subcarriers. This results in an improved net bit rate of 2.24 Gb/s per ONU. For more details about the setup, see [2]. At the OLT receiver, two approaches of DSP of the combined UL signal from the four ONUs are compared offline using Matlab. In the first approach (Fig. 1b) all UL signals need to reach the receiver synchronously, so the receiver can align its FFT-window to the combined ONU signal. The conversion to frequency domain is performed with a single large FFT and the subcarrier groups, belonging to different ONUs can be separated after FFT. In the second approach (Fig. 1c) all signals are separated by a parallel approach before FFT by individual downmixing (Mod^{-1}) and FIR lowpass-filtering to suppress the neighboring ONU signals [2]. The residual power of neighboring ONU signals with timing mismatch leads to a small amount of inter carrier interference (ICI) but does not prevent signal reception. Further downsampling by a factor of 8 is applied to simplify the numerical effort of the following OFDM-DSP. Each DSP part has its own FFT that can align itself to the corresponding UL signal. Note, that due to the additional downsampling an FFT-size of 64 and CP length of 2 is sufficient, resulting in similar system complexities of both concepts. In both DSP approaches the training sections (TS) are used to estimate the channel transfer function in both polarizations and to equalize (EQ) the following OFDM data symbols for each UL signal. PN-estimation is done by first using the pilot subcarrier information to get rough phase estimation without the problem of phase ambiguity. For further improvement decision directed phase noise compensation by all data subcarriers is applied. At the end the serial bitstreams for all ONUs are retrieved and the BERs are calculated.

4. Results

The measured optical spectra of the individual UL signals 1...4 are shown in Fig. 2a with a resolution of 0.01 nm. The carrier suppression and the different spectrally shifted OFDM spectra are visible. The thick line corresponds to the total optical spectrum after coupling. Figure 2b shows an example of the estimated phase noise between two training sections. Although both, the optical data signal and the unmodulated local carrier, originate in the same source, they have very different path delays to the coherent receiver. Since the ECL wavelength slightly varies over time, a small frequency drift (phase wander) and the random laser phase noise must be estimated and compensated for at the receiver. The estimated phase error in the period between two training sections corresponds to the roundtrip paths of 75 km (ONU 1+3) and 50 km (ONU 2+4). This shows, that in a PON with different ONU-OLT distances, PN compensation must be applied for each ONU individually. In short periods the phase wander reaches multiples of 2π and can be positive (like in Fig. 2b) or negative (not shown) but averages to zero in the long term.

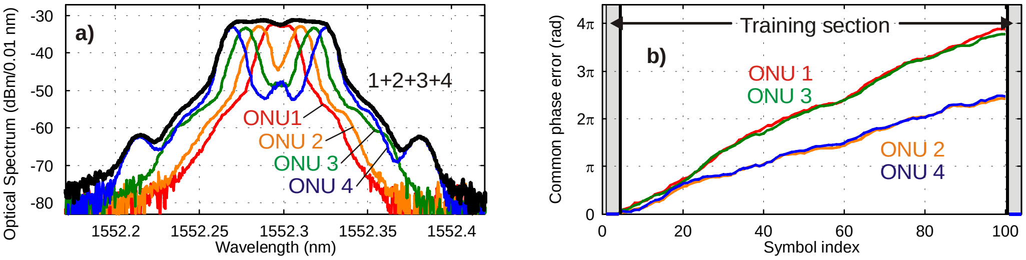

Fig. 2. (a) Optical spectra of the UL signals before and after coupling. (b) Estimated phase wander within one OFDM frame.

Figure 3a shows the BER over the timing mismatch Δt of ONU3 for the four UL signals using the first DSP structure with common FFT at the receiver. T_{OFDM} is the OFDM symbol duration. The insets show the error vector magnitude (EVM) over the subcarriers and the received constellations. When all signals reach the OLT synchronously ($\Delta t = 0$), all UL signals can be detected with BER$\approx 10^{-4}$.With timing mismatch, the FFT-window will be still synchronized to the majority of the total signal. The mismatch of ONU 3 and the FFT-window results in strong inter-symbol interference (ISI) affecting ONU 3 and ICI affecting the edge subcarriers of the neighboring subcarrier groups. With a delay of $\Delta t \geq 0.05 \cdot T_{\text{OFDM}}$ the FEC threshold is already exceeded, showing that precise synchronization of the UL signals is required with this approach. The performance of the second approach is shown in Fig. 3b. Here not only ONU 3 but all ONU signals are delayed against each other by applying additional delays of

0, Δ*t*, 2Δ*t*, 3Δ*t* to ONU 1 to 4. For Δ*t* =0 the BER and EVM distribution is very similar to Fig 3a. However, with asynchronous signal reception only the edge subcarriers are affected by ICI which can easily be handled with bitloading (QPSK instead of 8-QAM on edge subcarriers). Thus, the resulting BER does not depend on the timing mismatch. Most crosstalk is expected when neighboring OFDM signals have the same polarization state.

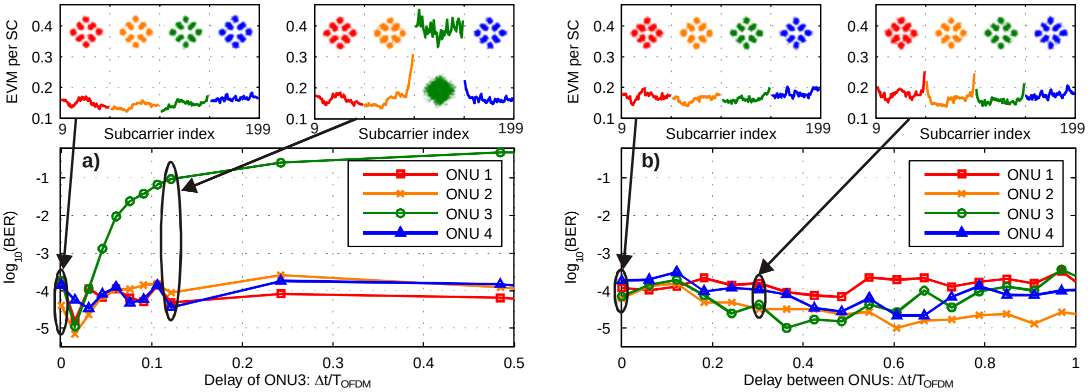

Fig. 3. Measured BER curves of four UL signals vs. their timing mismatch for a common FFT (a) and four individual FFTs (b) in the receiver DSP. Insets show the EVM variation over the subcarriers and the constellations before demapping. The received power is -25dBm.

Figure 4 shows the receiver sensitivity with the proposed scheme for the cases that the inner 40 subcarriers are filled with QPSK, 8-QAM or 16-QAM for all ONUs. The 6 edge subcarriers of each group are filled with QPSK in all cases. With 16-QAM/QPSK the FEC limit of BER=10^{-3} could not be reached with the best input power of -25 dBm, but with 8-QAM/QPSK and QPSK -27.5 dBm and -31 dBm received power result in error free transmission assuming FEC. In a PON with different distances between ONU and OLT, different modulations formats corresponding to the individual loss could be assigned to the ONUs to achieve error free performance for all subscribers.

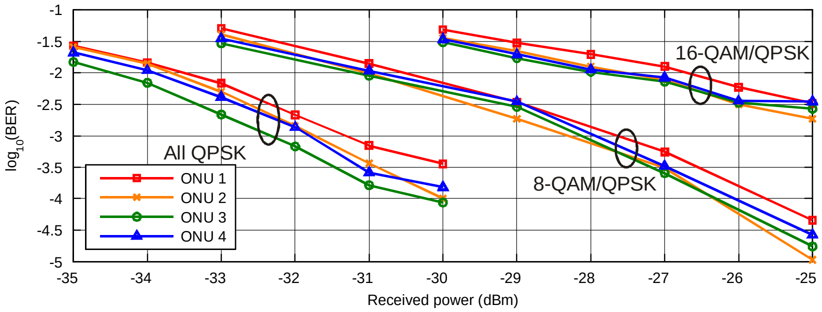

Fig. 4. Measured BER curves of four synchronized UL signals vs. received power if bitloading is applied with QPSK, 8-QAM and 16-QAM on the inner subcarriers and QPSK on the outer subcarriers.

5. Conclusion

We demonstrated a realistic uplink scenario in an OFDMA-PON, including four ONUs which are connected via different fiber path lengths to a central office OLT. The achieved nominal bit rates were 2.58 Gb/s for each ONU, thus 10.32 Gb/s in total. OFDMA was used to combine signals from multiple ONUs operating on the same wavelength, which makes this technique scalable with WDM. This work is part of the project ADVAntage-PON and has been supported by the federal ministry of education and research of Germany under grant 13N10864.

6. References

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