Asynchronous Signal Reception in OFDMA-PON-Uplink

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Abstract: We propose an OFDMA-PON receiver DSP structure that is tolerant to timing offsets of the multiplexed upstream signals. With this technique complex synchronization requirements of the PON can be avoided.
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1. Introduction

To cope with the steadily increasing demand for higher communications bandwidth to the end user, passive optical networks (PON) are being seen as the only long-term solution. To increase bandwidth and number of subscribers different approaches are currently investigated [1]. Most promising are combinations of wavelength division multiplexing (WDM) with multiple access techniques per wavelength including time division multiple access (TDMA) and frequency division multiple access (FDMA). One drawback of TDMA is that the received signal has to be processed at the optical networking units (ONUs) with the same DSP-clock rate as at the optical line terminal (OLT). A major advantage of FDMA is the ability to access a part of the total bandwidth in a WDM-channel with reduced electrical effort [2, 3]. With the concept of orthogonal frequency division multiple access (OFDMA) the individual subscriber signals could be packed much closer in frequency domain due to the rectangular-like spectra [4, 5]. The downstream direction in an OFDMA-PON is relatively simple and comparable to point-to-point transmission, since the whole optical signal is generated using the same DSP and a single optical modulator. Each ONU receives the full OFDM-signal, but processes only the associated part of it. The upstream direction is more complicated, since the subcarrier groups of the ONUs are processed and optically modulated at different locations within the PON, but they reach the OLT-receiver as a multiplexed signal. Orthogonality between the upstream signals is only satisfied, when all subcarriers have the same frequency reference and reach the receiver with alignment in time domain. In this case the whole set of subcarrier groups from different ONU transmitters could be processed with a single FFT. Since this alignment of the OFDM signals is difficult to achieve in practice and requires feedback information from OLT to the ONUs, we propose a receiver DSP-structure that is capable to receive unsynchronized upstream signals [5]. Simulations show that the loss of orthogonality within the multiplexed OFDM system only affects a small number of subcarriers and the required performance could be met with bit-loading to limit BER penalty.

2. Asynchronous Subcarrier Groups

Figure 1 schematically shows the impact of misaligned OFDM signals. Four signals with non overlapping subcarrier groups are multiplexed in frequency domain. In Fig 1.a all upstream signals reach the receiver synchronized in time so it is possible to have an FFT window at the receiver which includes only information of one OFDM-symbol. Figure 1b shows the case where one OFDM signal reaches the receiver with timing offset. If the multiplexed signal is detected with a single FFT, the delayed signal is affected by ISI because two successive OFDM-symbols interfere within the FFT window. In addition, the change of the data symbols within the detection window leads to some "leaking" of power into neighboring subcarriers. This inter-carrier-interference (ICI) leads to degradation of the neighboring subcarriers that are aligned with the common FFT. In our approach each OFDM upstream signal is processed with an individual FFT. In Fig. 1c only two of the four required FFT windows are shown. Here, each window is aligned with the desired subcarriers and ISI is avoided. However, the neighboring subcarriers of other ONUs, which are not aligned with this FFT window, result in some ICI and distort the signal somewhat.

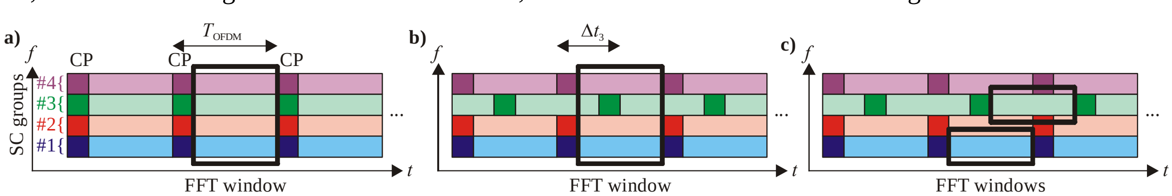

Fig. 1: Receiver concepts: a) synchronous signal reception with a single FFT, b) asynchronous signal reception with a single FFT, c) asynchronous signal reception with individual FFTs.

3. Simulation

The simulation setup is shown in Fig 2. For each ONU an OFDM signal with IFFT-size 64 is generated. 30 subcarriers are filled with QPSK, 8-QAM and 16-QAM data symbols (see Fig. 2b). A pilot subcarrier at zero frequency is used for phase noise estimation. After the transformation into time domain, 4 special OFDM symbols for synchronization and equalizer training are inserted for every 96 data OFDM symbols, and a cyclic prefix of 2 samples is appended. After digital-to-analog-conversion (DAC) with 2.5 GS/s, each ONU signal is up converted with IQ-modulation to an individual frequency slice, non-overlapping with the upstream signals from other ONUs. In this setup the frequency gap between the ONU spectra is a single unused subcarrier. All electrical upstream signals are modulated onto a common optical carrier. This is essential to avoid overlapping of the optical spectra and could be realized by generating the optical carrier at a central location and distributing it to the ONUs [4, 5]. The line width of the optical carrier is 100 kHz, and since different path lengths occur in a real PON, uncorrelated phase noise values are used. The optical modulators are biased for carrier suppression to reduce nonlinear distortions. The optical signals are multiplexed at the remote node and transmitted over 40 km SSMF. Since the upstream signal may be combined with random phase and polarization, coherent reception is required for signal detection at the OLT. The required optical carrier also had a linewidth of 100 kHz and the same wavelength as the distributed upstream carrier. The spectrum of the received signal, consisting of four upstream signals, is depicted in Fig. 2c. Since cost-effective intensity modulation without single-sideband filtering is used, both sidebands of each upstream signal are received. After analog-to-digital conversion (ADC) with 10 GS/s, the combined complex OFDM signal is processed with DSP. If all OFDM subcarrier groups reach the OLT sufficiently synchronized, it is possible to detect them together with a single FFT [6]. Note that the synchronization tolerance needs to be in the range of the CP duration, which is a difficult task to ensure.

As mentioned above, we use an alternative DSP structure (Fig. 2d) that is relatively robust to asynchronous upstream signal reception since here every subcarrier group is processed with an individual OFDM receiver, synchronized to its dedicated subcarrier group [5]. The misalignment of upstream signals only leads to small crosstalk affecting the edge subcarriers, but does not prevent signal reception. Each of the parallel receivers mixes its corresponding subcarrier group to baseband. By suppressing the neighboring subcarriers assigned to other ONUs with a FIR filter, the signal can be down sampled to the transmitter sample rate without violating the sampling theorem. Note that the FIR-filters have to be optimized since suppression of neighboring subcarriers should be high to avoid aliasing and improve synchronization. However, at the same time, linear distortions of the desired subcarriers should be as small as possible. This coarse signal separation is done in time domain for every upstream signal and can be processed in parallel. Each OFDM-DSP is then synchronized with its corresponding subcarrier group using the OFDM synchronization symbols. After blocking into OFDM symbols and CP removal, the signals are transformed into frequency domain using the same short FFT-length as in the ONU transmitters. The linear channel impairments are compensated with the 1-tap-equalizer and the laser phase noise is estimated and compensated for by using the pilot tone. Finally the data symbols are de-mapped and the BER is calculated. The FFT-complexity of this approach using 4 small parallel FFTs is comparable to the complexity of a single FFT four times larger. Although FIR filtering is required, which increases the complexity of the proposed DSP, mechanisms to realize the synchronization of all subcarrier groups are not required. Thus the system complexity is simplified.

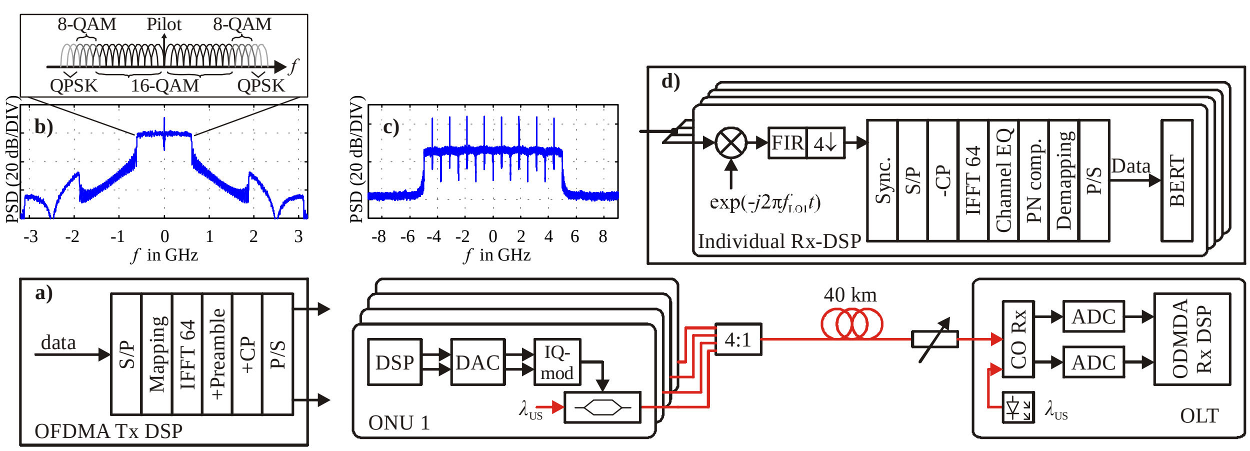

Fig. 2: Simulation setup, a) ONU transmitter DSP, b) baseband spectrum with subcarrier plan, c) multiplexed signal spectrum, d) asynchronous OLT receiver DSP with multiple FFTs.

4. Results

Figure 3a shows the BER of all upstream signals when the timing offset of ONU 3 is varied from the perfectly aligned case for the proposed DSP structures. If all subcarrier groups reach the OLT synchronously, the corresponding BER have minimal values. If the upstream signal of ONU3 is received asynchronously with the other signals, the corresponding BER of ONU3 and the BER values of ONU2 and ONU4 are slightly increased but stay below 10^{-3} allowing successful transmission if FEC is applied. The impact of the asynchronous reception can be seen by the EVM distribution over the subcarriers. With perfect synchronization the orthogonality of the subcarriers is maintained and the EVM is similar for all subcarriers (Fig. 3b). With a delay of ONU3 ($\Delta t_3 = 0.06 \cdot T_{\mathrm{OFDM}}$) some ICI between the subcarrier groups can be noticed (Fig. 3c). However, this crosstalk affects only a small number of subcarriers and can be met by using bit-loading with reduced constellation sizes on these subcarriers. Note that power loading, which is typically used in OFDM systems to adapt the EVM curves, is inadequate here, since increased power on the edge subcarriers also results in increased crosstalk.

For comparison the EVM curves are shown, if a single FFT is used at the OLT receiver. With perfect synchronization the EVM distribution is almost equal compared with the proposed DSP structure (Fig. 3d). However, with a delay of $\Delta t_3 = 0.06 \cdot T_{\mathrm{OFDM}}$, the subcarriers of ONU3 are strongly affected by ISI and the EVM values are significantly increased (Fig. 3e). Since all subcarriers of ONU3 are degraded bit-loading is inadequate and successful signal reception seems impossible, showing that a time synchronization subsystem is mandatory. In addition the neighboring subcarrier groups of ONU2 and ONU4 are affected by ICI similar to the DSP with individual FFTs. In the case of individual parallel FFTs the crosstalk is slightly smaller, since neighboring subcarrier groups are suppressed before FFT operation.

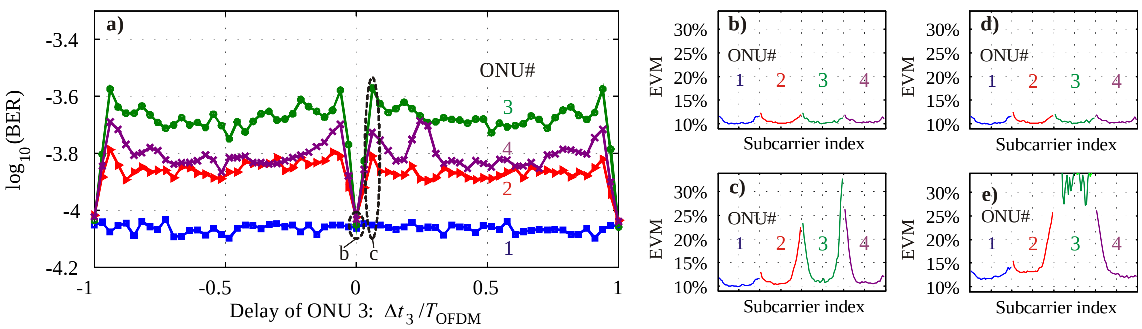

Fig. 3: Simulation results: BER of all ONUs vs. delay of ONU3 using receiver DSP with individual FFTs (a). EVM of each subcarrier is shown with synchronized (b, d) and unsynchronized (c, e) upstream signals for DSP with individual FFTs (b, c) and a single FFT (d, e).

5. Conclusion

We proposed a DSP-structure for OFDMA-PON receivers that are highly tolerant to asynchronous signal reception. Simulation results show that asynchronous signals suffer from a small BER penalty caused by orthogonality violation. However, only some edge subcarriers are affected. By proper bit-loading the BER-penalty can be limited. The main advantage of this approach is that no feedback path between transmitter and receiver is required to initialize and maintain synchronous upstream signals. This will simplify the system concept.

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