OFDMA Based PONs with Reduced Hardware Requirements through Advanced Signal Processing.

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ABSTRACT

Possibilities of reducing hardware requirements and therefore costs in an OFDMA-PON are shown. This is achieved by reducing the complexity of A/D and D/A converters and of the Digital Signal Processing (DSP) involved. The feasibility is shown experimentally as well. Furthermore, by incorporating techniques of the copper based access network, a flexible transmission network with advanced signal processing can be achieved and by applying techniques like bit and power loading, the data rate or the spectral efficiency can be increased. Moreover by assigning only certain subcarriers to various users, the effect of power fading can be mitigated.

Keywords: OFDMA, NGOA, ACCESS, PON

1. INTRODUCTION

The passive optical network (PON) is a promising candidate for next generation optical access (NGOA). One possible technique that could be used in a PON for high spectral efficiency and bandwidth scalability is orthogonal frequency division multiplexing (OFDM) and its multiple access scheme (OFDMA). Using OFDMA in PONs enables the possibility of reducing hardware requirements at the customer side, the optical network unit (ONU). In this paper different ways of achieving this goal are presented.

In a PON the achievable data rates are in general much higher than the capacity required by a typical end user. Therefore, as also shown in [1] and in [2], it is possible to reduce the hardware requirements by reducing the data rate of the individual ONU. In [3] we have shown that by using a technique from wireless called "Scalable OFDM" [4] and additionally adding a tunable electrical IQ-modulator can help to reduce costs at the customer side. By reducing the FFT size and the sampling speed of the analogue-to-digital converter (ADC), the peak data rate is decreased, but at the same time the subcarrier separation is kept constant. Therefore scalable OFDM receives only a part of the whole spectrum thereby reducing the hardware requirements at the ONU.

The dispersive optical channel causes power fading when employing intensity modulation (IM) and direct detection (DD). Therefore often single sideband (SSB) modulation is used to mitigate that impairment by suppressing one sideband, for example with an optical filter, which however adds additional hardware costs. On the other hand in a PON there are different fiber lengths for different users. Hence different amounts of total dispersion will occur, leading to different frequency responses. In this case each ONU will not be able to receive all of the subcarriers but only the subset of subcarriers that are not influenced by power fading. Therefore, if DSB transmission in combination with OFDMA is used, the problem of power fading [5] can be mitigated by carrier selection [6]. This saves the optical filter for the generation of the SSB-signal and can improve the receiver sensitivity.

Adaptation to the different distances in a PON and achieving high spectral efficiency can be realized by using bit and power loading known from the copper based discrete multitone (DMT) scheme. By using different modulation formats and power loading schemes on different subcarriers the system can be adapted to the individual transmission channels. This can help to exploit the full potential of the system.

After introducing the different methods that will help diminish costs in the access region, in section two this paper will show results on the reduced ONU. In section three the DSB scenario will be further explained and in section four an example of bit and power loading in a DSB point-to-point transmission will be given.

2. REDUCED ONU FRONTEND:

Scalable OFDMA [4] allows for a high-speed transmitter in the optical line termination (OLT) and can realize receivers at lower speeds in the optical network unit (ONU). This will reduce the maximum detectable subcarrier number and the possible peak data rate by the same factor. After conversion into the electrical domain, lower speeds of the electrical frontend can be achieved by extracting only a subset of neighbouring subcarriers. In order to keep the orthogonality, the subcarrier separation, OFDM symbol duration at the transmitter and at the receiver have to be the same. The subcarrier separation and the OFDM symbol duration depend on the size of the IFFT/FFT, the speed of the DAC/ADC and the length of the cyclic prefix. In [3] we additionally use an electrical IQ-modulator with a tuneable local oscillator (LO) that allows us to change the spectral position of the carrier thus enabling the reception of any subset of subcarriers, irrespective of their spectral location. A phase offset from OFDM symbol to OFDM symbol has to be taken into account for the one tap equalizer, if the transmitter and receiver LO frequencies differ. The concept of the reduced ONU and using different LO frequencies is examined experimentally. A scenario with two ONUs is depicted in fig. 1 where ONU F is able to receive the whole spectrum and ONU R is able to receive only the r^{th} part of the spectrum. The downstream signal at the OLT is generated with a 512 IFFT (254 used subcarriers) and converted into the analogue domain by two DACs. An IQ-modulator was used to generate the real valued signal and the frequency gap needed to avoid the intermodulation distortion. The electrical signal is transferred into the optical domain by simple intensity modulation. At the ONU, the optical signal is directly detected by a photodiode. In the electrical domain the signal is transferred into baseband by an IQ-modulator with variable LO frequency and then converted into the digital domain by two ADCs.

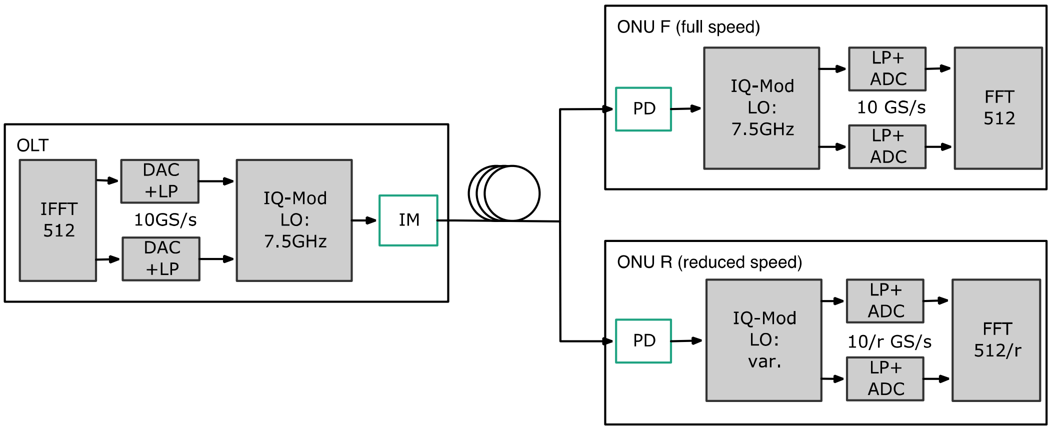

Figure 1: Example setup of a PON with one OLT, a full speed ONU F and a reduced speed ONU R. Further information on the measurement setup can be found in [3]. IM: Intensity Modulation, PD: Photo Detector.

For the experiment, the reduction factor r of ONU R was varied, resulting in:

- ONU 1, which is able to receive the maximum data rate and therefore has the full IFFT length of 512 with 254 data carrying subcarriers. The ADC speed is 10 GS/s and the LO of the IQ-modulator is tuned to 7.5 GHz to receive the whole spectrum. Results are depicted in fig. 2 (a).
- ONU 2, which is reduced by a factor of two, therefore the ADC speed is 5 GS/s and the IFFT length is reduced to 256 with 126 used subcarriers. The LO of the IQ-modulator is varied between 6.25/7.5/8.25 GHz to receive the whole transmitted spectrum (results are depicted in fig. 2 (b) as ONU 2a/b/c). Received spectra overlap at the receiver.
- ONU 4, which is reduced by a factor of four bringing down the ADC speed to 2.5 GS/s with an IFFT length of 128 using 62 subcarriers and the LO of the IQ-modulator is changed between 5.625/6.875/7.5/8.125/9.325 GHz (results are depicted in fig. 2 (c) as ONU 4/a/b/c/d/e).

The experimental results show same mean BER over the different LO-frequencies for each reduction factor. Lower subcarrier frequencies have a lower BER and the BER increases for higher subcarrier frequencies as electrical filters and other band limited devices are lowpass.

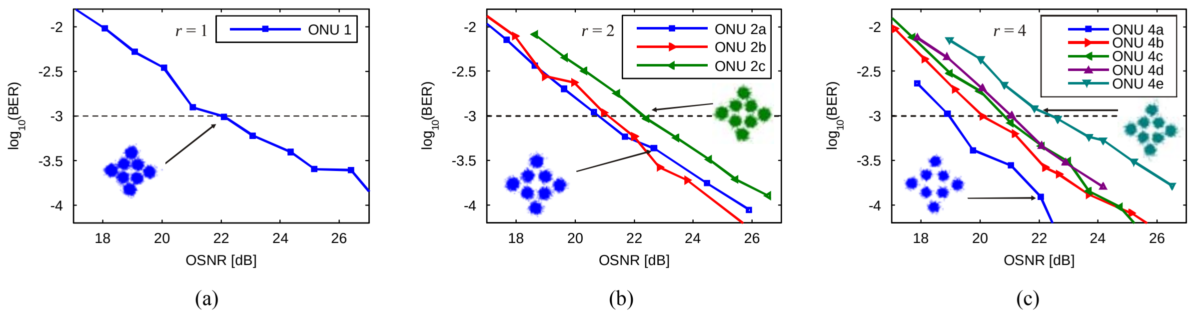

Figure 2: BER curves for ONUs with full frontend (a), half frontend (r=2) (b) and quarter frontend (r=4) (c) with different receiver LO frequencies (b,c) to proof the accessibility of all subcarriers. Each OFDM frame included 32 data and 4 training symbols for synchronization and equalization purposes. The net data rate of the full speed case is 12.173 Gb/s after removing the overheads of CP, FEC=7% and preamble.

Summing up, the potential of the reduced ONU lies in the reduced hardware requirement thereby cutting down the cost for each individual customer. In addition different amounts of reduction and thereby possible peak data rates can coexist, allowing for different business cases. At a later time the deployed PON can be upgraded to higher speeds at the OLT without changing hardware at the customer side.

3. SUBCARRIER ALLOCATION FOR DIFFERENT ONUS WITHOUT SSB TRANSMISSION

The NGOA needs high data rates and improved sensitivity of the receiver to employ high numbers of ONUs and high transmission reach. On the other hand, due to cost constraints low cost receivers and transmitters are required at the costumer equipment. In order to keep this cost low, intensity modulation and direct detection is often used. The transmission over the dispersive channel and the magnitude-squared operation at the photo receiver leads to an effective transfer function that can be described as follows [5]:

$$H(f)=|H_{const}|\cdot\left|\cos\left(-j\cdot\frac{\lambda_c^2}{c}\cdot D\cdot L\cdot\pi f^2\right)\right|^2, \qquad (3.1)$$

were L is the fiber length and D = 17 ps/nm/km the dispersion coefficient. This leads to power minima in the received spectrum depending on the fiber length. The commonly used setup is to get rid of one sideband, either by employing the Hilbert transform at the transmitter or by using an optical filter. This will add additional costs and complexity to the network. Using advanced signal processing and selecting only a certain number of subcarriers for transmission similar performance for a DSB as for a SSB transmission can be achieved [5], if DSB in combination with carrier selection is used. Here only the optimal subcarriers are selected for transmission. This only holds if the different distances between the OLT and the ONUs lead to different spectral positions of the power fading minima and thereby allowing for reuse of subcarriers that have to be dismissed because of power fading for one ONU, by other ONUs. Figure 3 shows an example where two different ONUs are 40 km and 50 km away from the OLT. The OLT can therefore use all subcarriers for data transmission, if only the non-impaired subcarriers are assigned to each ONU, hence avoiding the distance dependent power fading. The error vector magnitude (EVM) is plotted for both downlink transmissions.

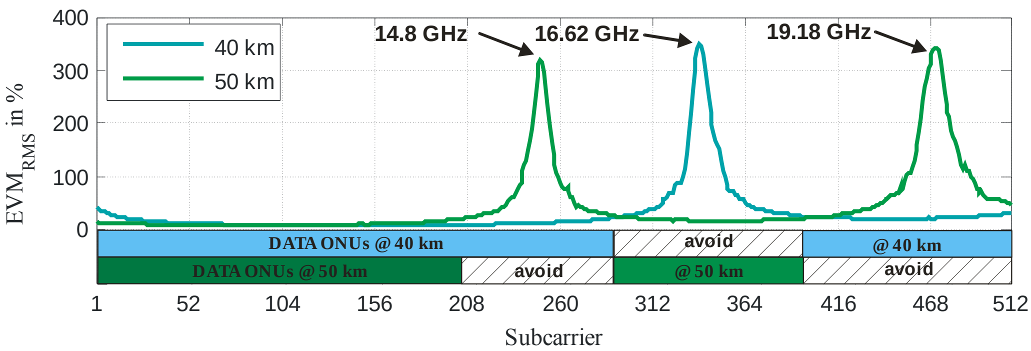

Figure 3: EVM measured for 40 km and 50 km transmission length, with a possible selection of different subcarriers for data transmission. The DACs speed in the simulation was 20 GS/s and the FFT length was 1024 with 512 (data: 10-20 GHz) subcarriers used. Using a cyclic prefix of 4 samples a peak data rate of 16 Gbit/s (QPSK) was achieved.

Fig. 4 shows the simulation results for performance comparison between DSB and SSB transmission over 50 km fiber (neglecting non linear effects). Subcarrier no. 56-156 (out of 512) were selected for both SSB and DSB transmission.

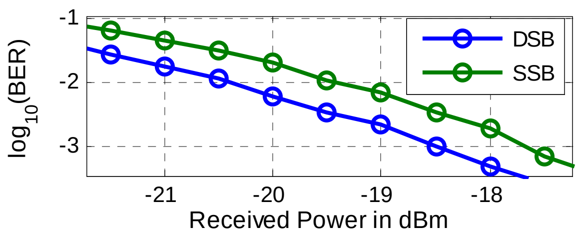

Figure 4: BER over received power for SSB and DSB, selecting subcarrier no 56-155 (3.14 Gbit/s, fiber length 50km).

It can be concluded that for certain subcarriers the necessary received power is lower for a DSB than for a SSB transmission. This can be exploited in a OFDMA-PON and results in improved receiver sensitivity at the cost of lowering the possible number of usable subcarriers for each ONU. Additionally an optical SSb filter can be saved.

4. BIT AND POWER LOADING FOR OPTIMUM USE OF CHANNEL CAPACITY:

Currently deployed copper based transmission systems can fully adapt to the actual channel by employing bit and power loading for each subcarrier. This leads to a higher bandwidth efficiency. Using these well-known algorithms in a PON the power fading described above could in part be mitigated. Each ONU will receive the optimal subcarriers and the number of bits per subcarrier is accordingly adjusted. The downstream transmission system with one OLT and one ONU, that receives the whole spectrum, is experimentally investigated. An exemplary bit loading for a fiber length of 50 km and a signal band from 6-12 GHz, where the fading minimum is located at 8.6 GHz, is shown in fig. 6 (a). The subcarriers that are impaired by power fading (more than 100% EVM) are nulled. To achieve the same data rate as in a SSB transmission, lower subcarriers were modulated with a 16-QAM instead of QPSK. A power loading scheme was applied to reduce the influence of power fading and adapted to the chosen bit loading (as depicted in fig. 6(a)). To transmit 9.57 Gbit/s, 610 subcarriers are realized by an IFFT of length 1024. One frame consists of 26 OFDM symbols that carry data, two symbols that are used for synchronization according to Schmidl & Cox and two reference symbols that are used for equalizer training. The OFDM waveform is generated offline and fed to the 10 GS/s DAC. An electrical IQ-modulator with a 9 GHz LO frequency is used to realize a real valued signal and the frequency gap. The transmission performance for a BER≈10^{-3} at OSNR=16 dB and after 50 km transmission length is plotted in fig. 6(b). Also the EVM for each subcarrier is shown with and without power loading. The BER is almost equally distributed over all subcarriers implying that an almost optimal power loading scheme was found.

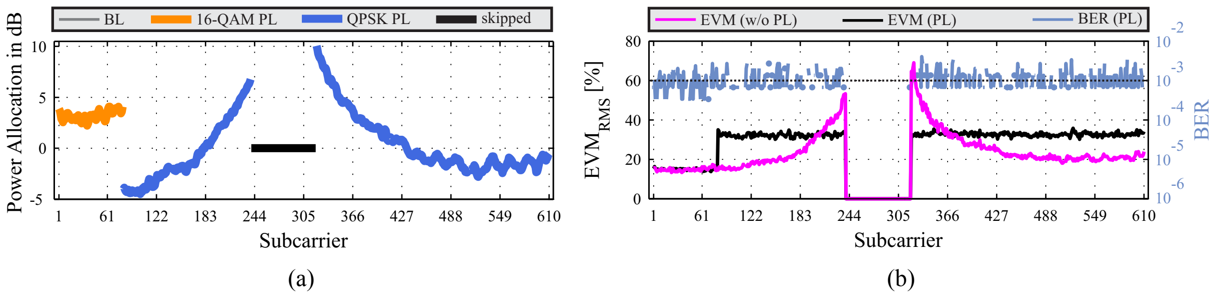

Figure 6: Employed bit and power loading (PL) (a) and resulting EVM for each subcarrier with and without PL (b).

5. CONCLUSIONS

Different approaches that lead to lower hardware requirements in OFDMA-PON were shown. A possible cost decrease was demonstrated by reducing the electrical frontend of the ONU, where the DAC speed and FFT length could be decreased. In addition, the use of an IQ-Modulator with a tuneable LO frequency to access every subset of subcarriers was experimentally investigated. Further a possible subcarrier reuse in the OFDMA network for those subcarriers that are impaired by the transmission length dependent power fading was shown. Finally bit and power loading were investigated experimentally to improve the channel capacity for each ONU. Thus, it seems feasible to obtain lower hardware costs for each ONU whilst still achieving high data rates in next generation optical access.

ACKNOWLEDGEMENTS

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