

Application scenarios for optical OFDM

Sander Lars Jansen¹, Susmita Adhikari², Beril Inan³ and Dirk van den Borne¹

1) Nokia Siemens Networks, Munich, Germany, Sander.Jansen@nsn.com

2) Chair for Communications, Christian-Albrechts-Universität, Kiel, Germany

3) Technical university of Munich, Lehrstuhl für Nachrichtentechnik, Munich, Germany

Abstract: Optical OFDM is a potential modulation format for next generation transmission systems. In this paper several application scenarios are discussed for optical OFDM focusing on applications for metro and long-haul transmission systems.

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1. Introduction

With the revival of coherent detection the fiber-optic community is seeing a rapid acceleration in transponder technologies. Next generation systems are evolving to dynamically reconfigurable optical networks with capacities of up to 10 Tb/s. However, the question remains: What comes next?

One potential modulation format to further enhance the flexibility and increase the data rate of fiber-optic transmission systems is optical orthogonal frequency division multiplexing (OFDM). Rapid advances in the field of high-speed digital signal processing have recently enabled the use of OFDM for fiber-optic applications and optical OFDM quickly became an active research topic [1, 2]. Advantages of optical OFDM are that it is easily scalable to higher modulation formats [3], has a well defined spectral shape [4, 5, 6], can relax oversampling requirements [7] and is ideally suited for parallel integration in an ASIC or FPGA [8]. Drawbacks of OFDM are that unlike single carrier QPSK modulation a DAC is required at the transmitter and that it is challenging to keep the OFDM-specific overheads low [7]. Furthermore, OFDM has a relatively high PAPR at low chromatic dispersion compared to single carrier modulation formats. This poses a challenge for the use of optical OFDM on legacy transmission systems with dispersion compensating fiber as the OFDM signal impairs its neighboring channels through XPM [9].

Even though many different companies and research institutes are currently investigating optical OFDM for fiber-optic applications, to date optical OFDM has not been commercialized yet. In this paper several application scenarios will be reviewed focusing on possible applications for metro and long-haul transmission systems.

2. Scaling to high constellation sizes

One of the strengths of OFDM is that it is straight forward to scale the payload to higher level modulation formats and thereby increase the data rate. In an optical OFDM receiver, training symbols are used to train the equalizer at the receiver. These training symbols are independent of the constellation size and moreover different constellation sizes can even be assigned to different subcarriers in one OFDM symbol [10]. Furthermore, one can dynamically set the constellation size of the payload depending on the quality of the transmission link. Taking advantage of this feature it is possible to realize a transponder that can dynamically scale from 50GbE to 200GbE by changing the constellation size from 2-QAM to 16-QAM. This principle is illustrated in Fig. 1. Using a polarization division multiplexed OFDM (PDM-OFDM) modulation format, the required bandwidth would be about 30 GHz and as such can be operated at 50 GHz channel spacing. The requirements for the optical front-end for such a transponder are the same for all constellation size configurations, except for the fact that a higher vertical resolution is required for the ADC and DAC when 16-QAM is used [11]. By scaling the constellation size reach dependent throughput can be provided by scaling from the ultimate reach with BPSK (2-QAM) modulation to the highest data rate with a 16-QAM constellation size. The main challenge for realizing such a transponder might be that at the client side an interface must be defined that can support both a 50-Gb/s and 200-Gb/s throughput.

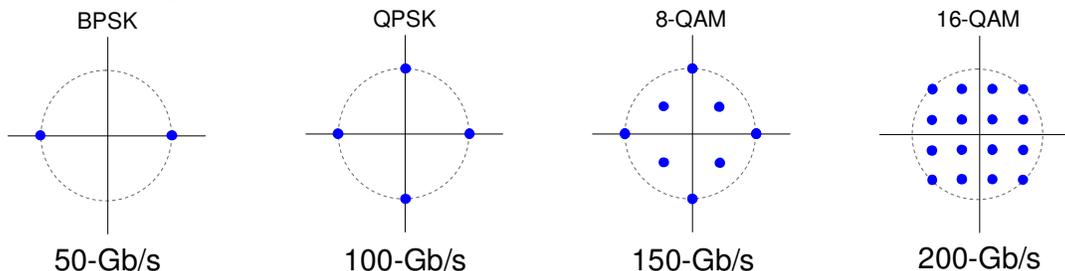


Fig. 1: Reach dependent scaling of PDM-OFDM with a total bandwidth of 30 GHz

In [12] the impact of reach dependent capacity has been investigated for 40-Gb/s transponders in an American ultra long-haul network. Single carrier transponders with a fixed 40-Gb/s PDM-QPSK data rate are compared to PDM-OFDM transponders that can dynamically scale the constellation size dependent on the quality of the transmission link. The bandwidth and optical components are the same for both transponder types. It has been found that by using reach dependent capacity, a gain in traffic throughput of up to 60% can be obtained depending on the fluctuations in the bandwidth demand.

Another interesting application space for optical OFDM might be to realize 100GbE transponders for metro applications where cost is the dominating factor. By using a 16-QAM constellation instead of QPSK, 100GbE PDM-OFDM can be realized with a 15-GHz optical bandwidth. With IQ multiplexing at both transmitter and receiver, this 100GbE transponder can be realized with 7.5-GHz analogue electrical bandwidth for the electronics and a 15-GS/s sampling rate. Essentially this allows a 100GbE transponder to be realized with cost effective 10-GHz electronics. The main drawback of this implementation is that the required optical signal-to-noise ratio (OSNR) for a BER of $1e-3$ is increased from ~ 10.8 dB to ~ 14.5 dB when scaling from 4-QAM to 16-QAM. Furthermore, as the constellation points of 16-QAM are three times closer to each other than in the case of QPSK, the nonlinear tolerance is reduced. Nonetheless, the reach of the 100GbE 16-QAM transponder, should be sufficient for both metro and regional applications (up to ~ 800 km). This would significantly reduce transponder costs while still offering a large tolerance with respect to chromatic dispersion and PMD.

3. Optical agile networks

Because of the well defined spectrum of optical OFDM, continuous band OFDM can be realized as for instance presented in [4-6]. In essence, continuous OFDM allows a more effective use of the EDFA bandwidth by realizing an agile optical network. The concept of such an agile network is illustrated in Fig. 2. In this example three cities are connected through a wavelength selective switch (WSS). In the optical spectrum on the right side of Fig. 2 the concept of agile optical networking with OFDM is shown for the throughput from City A to City B and City C. Instead of defining a guard band between each WDM channel in the form of a 50-GHz channel grid, the capacity per city is grouped and only one single guard band is present in between the two continuous OFDM spectra. To date first experiments with such agile networks have already been reported [13]. One of the major challenges with such networks is that it is more difficult to re-route capacity from one city to another as this requires the continuous OFDM data streams to be reconfigured and the guard band to be shifted. However, the use of large ODU switches that could generate such a continuous OFDM signal might simplify re-routing capacity. Finally it should be noted that to date the realization of continuous OFDM is still impractical and expensive for commercial realizations. However, optical integration of lasers and modulators might make continuous OFDM cost effective one day.

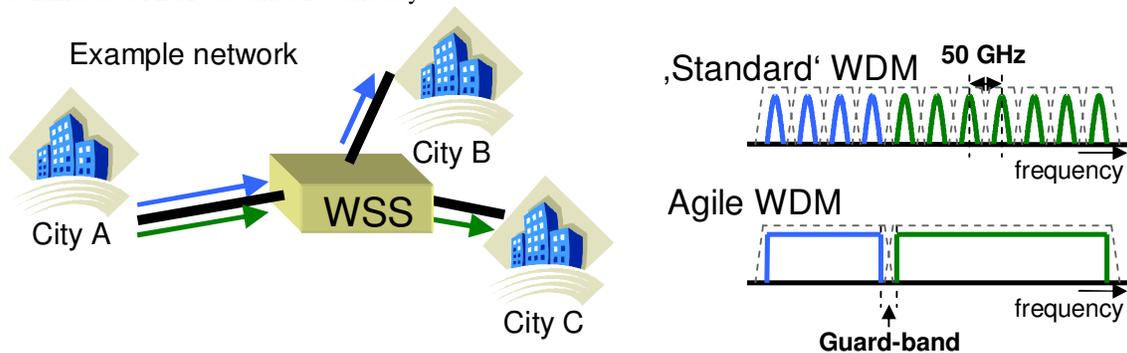


Fig. 2: Example of an agile optical WDM network

4. Conclusion

In this paper we have discussed optical OFDM for high data rate transmission systems. Several application scenarios have been reviewed where optical OFDM can offer distinct advantages in metro and long-haul networks.

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