Applications of Optical OFDM: From Automotive to Ultra Long-Haul

(Invited Paper)

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Abstract—Optical OFDM is discussed as a spectrally efficient modulation format offering the potential to overcome linear and nonlinear impairments. The applications span from automotive networking to high-speed transmission over both multi-mode and single-mode fibers.

I. INTRODUCTION

During the past decade, optical component technology has reached a level of maturity and pervasiveness where further performance increase becomes so costly, that the introduction of electronic signal processing becomes a viable option for lowering the overall complexity of optical data transmission systems. In this scenario, orthogonal frequency division multiplexing (OFDM) has received increased attention as a means to overcome various limitations of optical communication systems such as modal dispersion, relative intensity noise, chromatic dispersion, polarization mode dispersion as well as self phase modulation. This paper provides an overview on recent trends in different application fields of optical OFDM spanning from Gigabit Ethernet transmission in cars to 40 Gbps and 100 Gbps transmission over multi-mode fiber as well as single-mode fiber based DWDM long-haul transmission networks.

II. OPTICAL ETHERNET IN AUTOMOTIVE

The increasing number of electronic control units (ECUs) within automobiles has lead to a large number of co-existing networking technologies such as LIN, CAN, Flexray and MOST [1]. These automotive-specific technologies ensure that the requirements e.g. in terms of electromagnetic compatibility, robustness, and power consumption are met. The resulting networks are complex and require large efforts in terms of development, integration, and maintenance. In this context the question arises whether Ethernet/IP technology being the preferred networking technology not only in offices and homes can reduce these efforts. In Fig. 1 a typical automotive infotainment configuration with 8 ECUs is shown. In MOST these are connected via a uni-directional ring network based on polymer optical fiber (POF) and operates at 25 Mbps and 150 Mbps in the next generation. Ethernet based networks operate bi-directionally at either 100 Mbps or 1 Gbps and they support various topology options [2]. One way to enable 1 Gbps transmission in the automotive environment is to introduce polymer cladded silica (PCS) fiber and vertical-cavity surface emitting laser (VSCEL) based transmitters [3]. However, this approach requires major changes in the component design, as well as in installation and handling specifications.

In [4] it has been shown that optical OFDM can be used to achieve 1 Gbps transmission over 50 m POF with an LED based transmitter. This is enabled by use of adaptive modulation with up to 64-QAM constellations. With only minor adaptation of the electro-optical components and the introduction of an integrated circuit for digital signal processing Gigabit Ethernet can be introduced in cars without the need to change fiber type and connectors.

III. HIGH-SPEED TRANSMISSION OVER MULTIMODE OPTICAL FIBERS

Based on the rising bandwidth demand for interconnects in data centers and high performance computing, the IEEE 802.3ba task force is currently preparing a standard for 40 Gbps and 100 Gbps Ethernet transmission over at least 100 m of laser-optimized 50 μm multimode fiber. While the bandwidth of 100 m of OM3 fiber exceeds 20 GHz the bandwidth of commercial VSCELs still limits them to 10 Gbps NRZ operation [5]. The new standard will thus specify parallel optics with a line rate of 10 Gbps per fiber link. A major challenge in this scenario is to meet the joint reliability requirements of the multiple laser sources and the
connectors will presumably support redundancy in order to solve this issue.

In [6] it has thus been proposed to use spectrally efficient discrete multitone in order to transmit up to 30 Gbps with a commercial 850 nm VCSEL. The concept behind this approach is to modulate a large number of sub-carriers with orthogonal quadrature amplitude modulation (QAM) and to adapt the transmit signal to the channel using Chow’s rate adaptive loading algorithm. Fig. 2 shows experimental results for 30 Gbps discrete multitone transmission over 500 m of MMF obtained with off-line processing. The sub-carriers are modulated with up to 128-QAM and the bandwidth up to 6 GHz is used.

In order to realize 100 Gbps Ethernet long-haul and ultra-long haul transmission systems it is essential not only to overcome the linear distortions but also nonlinear impairments introduced by the Kerr effect. In [10] it has been shown that in case of periodically compensated dispersion maps OFDM is particularly sensitive to self-phase modulation (SPM) and cross-phase modulation (XPM). This reduction in nonlinear tolerance is especially relevant for mixed data rate transmission scenarios where a high data rate OFDM channel is installed on an existing 10 Gbps or 40 Gbps network with periodic dispersion compensation. Du et al. have subsequently shown that through nonlinear pre- and post-compensation SPM impairments can be partly compensated for and thereby the reach of OFDM on periodically compensated dispersion maps can be increased [11]. However, because of the increased XPM penalty of OFDM in periodically compensated transmission systems it is conjectured that optical OFDM will mainly find its application in uncompensated transmission links where the reach of optical OFDM [7] is comparable to that of single carrier modulation [12].

V. Conclusion

As discussed for three example applications optical OFDM can be regarded as an attractive candidate for spectrally efficient modulation. It provides the possibility to compensate linear and to a certain degree also nonlinear impairments in the electrical domain. In automotive networking it allows to maintain LED based POF systems for Gigabit Ethernet and in high-speed transmission over MMF it results in relaxed bandwidth requirements for VCSELs and photo-receivers. The main advantages of optical OFDM for long-haul transmission systems are that it allows a reduction of the sampling rate at the receiver and has negligible linear crosstalk. However, for all applications OFDM requires high-speed electronic signal processing which adds complexity to transmitter and receiver. Therefore, for each application scenario a trade-off exists between the electrical and optical complexity and as such for each individual application an optimal balance must be found.

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