Performance of Maximum Likelihood Sequence Estimation in 10 Gb/s Transmission Systems with Polymer Optical Fiber

S.C.J. Lee(1), F. Breyer(2), S. Randel(3), B. Spinnler(3), I.L. Lobato Polo(4), D. van den Borne(1), J. Zeng(1), H.P.A. van den Boom(1), A.M.J. Koonen(1)

(1) COBRA Research Institute, Univ. of Technology Eindhoven, Eindhoven, the Netherlands, e-mail: s.c.j.lee@tue.nl; (2) Institute of Communications Engineering, Univ. of Technology Munich, Munich, Germany; (3) Siemens AG, Corporate Technology, Information and Communications, Munich, Germany; (4) Siemens AG, Program and System Engineering, Munich, Germany

The 120 µm core-diameter perfluorinated graded-index polymer optical fiber (GI-POF) is gaining interest for use in local area networks (LAN) such as enterprise or datacenter backbones to support 10 Gigabit Ethernet (10GbE). In this paper, the performance of MLSE equalization on a 100 m GI-POF transmission link operating at 10.7 Gb/s is investigated.

Introduction

Rapid increase of data traffic in data communication applications has pushed the demand for high-capacity and low-cost optical networks for use in local area networks (LAN), such as enterprise or datacenter backbones [1,2]. The use of 10 Gigabit Ethernet (10GbE) in such cases will often require a new installation, because the commonly used CAT-5 copper cables are unsuitable for 10GbE transmission over sufficiently long distances. Although this can be solved by upgrading the cable infrastructure to CAT-6A copper cables, it may not be a future-proof solution.

A promising alternative is the use of fiber optic cables, such as multimode silica fibers. However, short-reach LAN requires very cost-efficient solutions. This makes the use of most optical fibers impractical due to the associated high installation costs. In comparison to multimode silica fibers, the perfluorinated graded-index polymer optical fiber (GI-POF) with 120 µm core-diameter is a promising alternative because the large core-diameter allows large alignment and dimensional tolerances for components. Furthermore, it still allows the use of standard high-speed transmitters and detectors at wavelengths of 850 and 1300 nm. The GI-POF thus offers ease of use and installation, with clip-on connectors requiring minimal training or specialist equipment for termination. Furthermore, cables made from GI-POF are extremely flexible, offering a bending radius of 5 mm compared with 25 mm for silica fiber cables and 30 mm for CAT-6A copper cables.

Due to bandwidth limitations caused by modal dispersion in large-core multimode fibers, 10 Gb/s data transmission on such 120 µm perfluorinated GI-POF is limited to distances less than 100 m [3]. Recent research advances in electrical equalization for 10 Gigabit Ethernet multimode fiber (MMF) links show the possibility to compensate for such modal dispersion, yielding significant performance improvement [4,5].

In this paper, we investigate the performance improvement for a 100 m transmission link with 120 µm perfluorinated GI-POF operating at 10.7 Gb/s, when electrical equalization in the form of maximum likelihood sequence estimation (MLSE) is used. It is well known that for all equalization schemes, MLSE achieves the best performance [6]. These results can therefore be seen as a performance bound for using electrical equalization to combat modal dispersion.

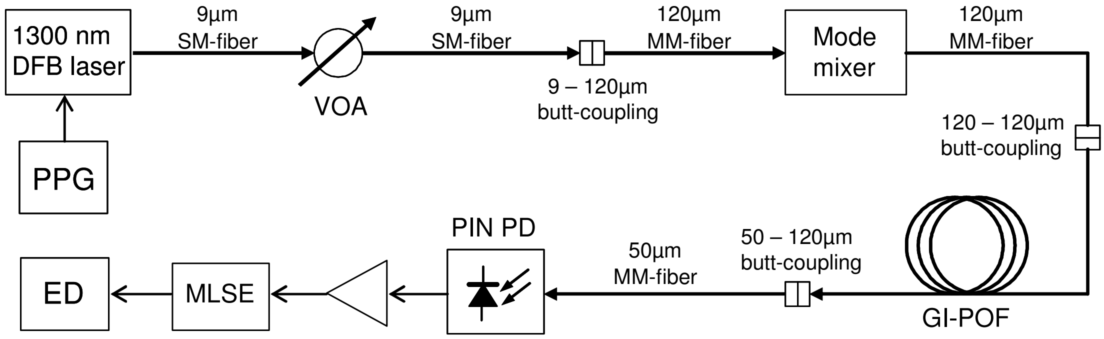

Fig. 1: Experimental Setup.

Experimental Setup

The experimental setup of the GI-POF transmission system is shown in Fig. 1. A directly modulated 1300 nm distributed feedback (DFB) laser with standard single-mode fiber pigtail is used as the transmitter. This laser is modulated with a non return-to-zero 2^{15}-1 pseudorandom bit sequence at 10.7 Gb/s (PPG). A variable optical attenuator is placed after the laser to adjust the power level. Before coupling into the GI-POF, a mode mixer is used. This mode mixer consists of 50 cm of the same type of GI-POF wound 10 times around a cylinder with 20 mm diameter. Using such a mode mixer stabilizes the transmission system, because of the over-filled mode launch.

After the mode mixer, the optical power is launched into 100 m of perfluorinated GI-POF. The GI-POF used is a commercial fiber with 0.185 numerical aperture, 120 µm core-diameter, and 500 µm total diameter including cladding. The attenuation is approximately 40 dB/km at a wavelength of 1300 nm. For the back-to-back measurement, the GI-POF is left out of the experimental setup (compare Fig. 1).

At the receive end, a 50 µm silica multimode fiber (MMF) pigtailed InGaAs PIN detector is used, leading to a 3.5 dB coupling loss due to core-size mismatch between the GI-POF (120 µm) and the silica MMF (50 µm). After electrical amplification, the received signal is fed into a commercial MLSE module [7]. This MLSE module comprises a 3 bit A/D converter operating at a two-fold sampling speed (21.4 GSamples/s) and a four-state (2 symbols memory) Viterbi decoder. Finally, the output of the MLSE is fed to the error detector (ED).

Experimental Results

Fig. 2a and b show the measured bit-error ratio (BER) values after transmission at 10.7 Gb/s over 100 m of GI-POF plotted against time without and with MLSE, respectively. These BER values are measured every second for a total time period of 900 seconds and a received optical power of -7.5 dBm. It can be seen that BER values around 10^{-3} are reduced to 10^{-7} when MLSE is employed. As the measured BER values with MLSE are several orders of magnitude better than the limit of forward error correction (FEC), which is commonly used in 10 Gb/s transmission systems, error-free transmission can be achieved under all circumstances.
The measured BER curves depicted in Fig. 2c compare the performances of the system with and without MLSE in the same 100 m GI-POF transmission link operating at 10.7 Gb/s. Each plotted BER value corresponds to the mean of 300 measured values obtained every second. At a BER of 10^{-4}, the 100 m GI-POF system with MLSE has a 6 dB better receiver sensitivity than without MLSE. For the back-to-back measurements

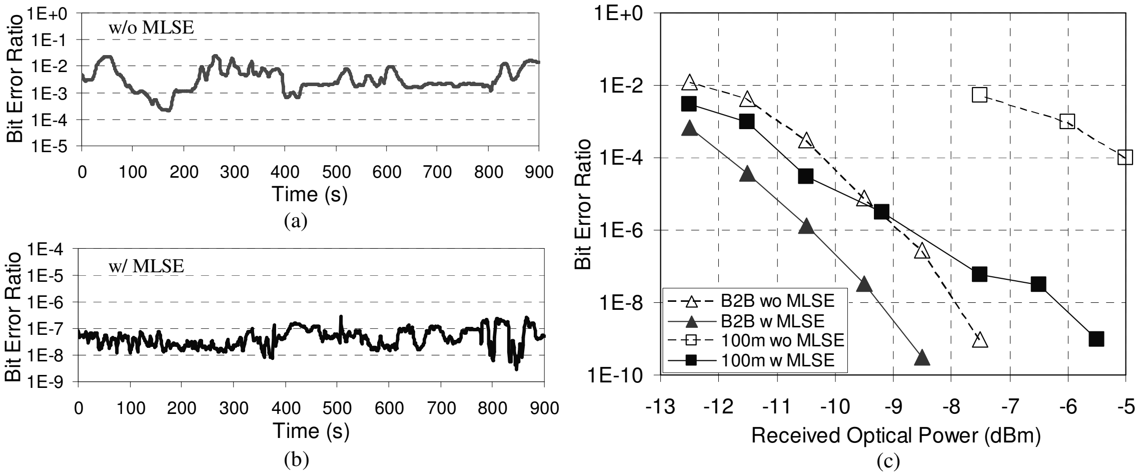

Fig. 2: (a) BER vs. time for 100 m GI-POF without MLSE at 10.7 Gb/s and -7.5 dBm received optical power; (b) same as a., but with MLSE; (c) comparison of MLSE performance for the back-to-back case and transmission over 100 m GI-POF.

without GI-POF, the system performs 2 dB better with MLSE as a result of impairments due to the directly modulated laser and modal dispersion introduced by the mode mixer.

Conclusions

We've shown a 6 dB better receiver sensitivity (at a BER of 10^{-4}) for a 100 m GI-POF link operating at 10.7 Gb/s, using MLSE to combat the influence of modal dispersion. This shows that the system's power budget can be improved by 6 dB when electrical equalization is employed, implying that the GI-POF can support 10 Gigabit Ethernet transmission over distances larger than 100 m. Together with the additional advantages of mechanical robustness, relaxed alignment tolerances and easy, low-cost installation, this makes the GI-POF a promising solution for future enterprise and datacenter backbone networks.

References

[1] C.M. DeCusatis, "Fiber optic cable infrastructure and dispersion compensation for storage area networks," IEEE Communications Magazine, vol. 43, pp. 86-92, March 2005.

[2] S. Randel, S.C.J. Lee, B. Spinnler, F. Breyer, H. Rohde, J. Walewski, A.M.J. Koonen, and A. Kirstädter, "1 Gbit/s Transmission with 6.3 bit/s/Hz Spectral Efficiency in a 100 m Standard 1 mm Step-Index Plastic Optical Fibre Link Using Adaptive Multiple Sub-Carrier Modulation," Proc. ECOC'06, PDP Th4.4.1 (2006).

[3] G. Giaretta, W. White, M. Wegmueller, R.V. Yelamarty, T. Onishi, "11Gb/sec Data Transmission Through 100m of Perfluorinated Graded-Index Polymer Optical Fiber," Proc. OFC'99, PDP, PD14-1 (1999).

[4] P. Pepeljugoski, J. Schaub, J. Tierno, J. Kash, S. Gowda, B. Wilson, H. Wu, A. Hajimiri, "Improved Performance of 10 Gb/s Multimode Fiber Optic Links Using Equalization," Proc. OFC'03, ThG4 (2003).

[5] C. Xia, M. Ajgaonkar, and W. Rosenkranz,"On the Performance of the Electrical Equalization Technique in MMF Links for 10-Gigabit Ethernet," IEEE J. Lightwave Technol., vol. 23, pp. 2001-2011, June 2005.

[6] J.G. Proakis, Digital Communications. New York: McGraw-Hill, 2001.

[7] A. Färbert, S. Langenbach, N. Stojanovic, C. Dorschky, T. Kupfer, C. Schulien, J.P. Elbers, H. Wernz, H. Griesser, C. Glingener, "Performance of a 10.7 Gb/s Receiver with Digital Equaliser using Maximum Likelihood Sequence Estimation," Proc. ECOC'2004, PD-Th4.1.5 (2004).