50 Gb/s DMT and 120 Mb/s LTE signal transmission over 5 km of optical fiber using a silicon photonics transceiver

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Abstract: Combined DMT and LTE data is transmitted over 5km SSMF using a directly modulated InP-on-Si laser and a silicon photonics receiver. We demonstrate DMT net capacity of 50 Gb/s while keeping the LTE EVM below 1%.
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1. Introduction

Next-generation passive optical networks will require the use of low-cost, high-performance transceivers to cope with the increasing bandwidth demands for emerging applications such as fixed-mobile convergence for 5G. Silicon photonics is widely acknowledged as a technology that can provide manufacturing of low-cost photonic integrated circuits by using existing CMOS fabrication infrastructure. Intensity modulation/direct detection solutions can reach 100 Gb/s per wavelength, but require high-speed electronics and photonics, which adversely affects the cost. An alternative approach is to use advanced multi-carrier modulation schemes, such as Discrete Multi-Tone (DMT), a real-valued Orthogonal Frequency Division Multiplexing (OFDM) scheme. This technique uses Digital Signal Processing (DSP) to relax electrical and optical bandwidth requirements on the transmitter and receiver side. It promises high spectral efficiency and granularity, higher tolerance to fiber impairments and channel adaptation through flexible multi-level / multi-carrier coding [1]. DMT transmission at 100 Gb/s and even 4x100 Gb/s using modest bandwidth (~ 20 GHz) electronic and optical components has already been demonstrated [2-4].

Despite requiring computationally more expensive DSP compared to single carrier baseband schemes (e.g., OOK, PAM), DMT's added advantage is that it allows transmission of a mobile data signal within its bandwidth using the same optical transceiver [5]. In this work we demonstrate the combined transmission of a Long Term Evolution (LTE) 4G mobile communication signal (at 3.48 GHz carrier frequency) and a 50 Gb/s DMT signal using a directly modulated InP-on-Silicon Distributed Feedback (DFB) laser. Direct modulation is poised to provide low power consumption and a reduced number of optical components in the transceiver. On the receiver side, a silicon-waveguide-coupled germanium photodiode (GeSi-PD) with a co-designed trans-impedance amplifier (TIA) is used and its performance is compared with a commercial III-V photodiode and TIA.

2. Silicon-based DMT transmitter and receiver characteristics

The directly modulated laser (DML) used in this experiment has a III-V gain section comprising an InAlGaAs multi-quantum well active region. The gain section is bonded by a ~ 50 nm thin DVS-BCB bonding layer on a silicon-on-insulator (SOI) waveguide circuit. The laser cavity is defined in SOI using a 340 µm long quarter-wave shifted DFB grating on the 400 nm thick silicon waveguide layer. The access waveguide, with a grating coupler to provide coupling to single mode optical fiber, is also defined in SOI. More details on the design and fabrication of such III-V-on-silicon distributed feedback lasers can be found in [6].

At 100 mA bias current, the laser has an optical power of 0 dBm in the fiber at a wavelength of 1566 nm. The laser spectrum shows a side mode suppression ratio of > 40 dB. The small-signal response of the DML is measured using a Keysight Vector Network Analyzer, resulting in a bandwidth of ~ 17 GHz. On the receiver side, a germanium PD in a vertical PIN configuration is used. The primary responsivity of the PD is 0.44 A/W at the laser emission wavelength of 1566 nm and it has a bandwidth of ~ 25 GHz. The trans-impedance amplifier (TIA) is fabricated using 130nm SiGe BiCMOS technology and is wire-bonded to the PD. It has a bandwidth of ~ 22 GHz and consumes less than 160 mW. The TIA is optimized for linearity to support higher order modulation formats [7].

2. Experimental Setup and Results

Figure 1 shows the experimental setup for the combined transmission of a DMT and LTE signal using a silicon photonics transmitter and receiver. The DMT signal is generated offline by VPIlabExpert. This offline DMT signal generator comprises a pseudo random bit sequence (PRBS) generator, an OFDM encoder having a cyclic prefix of 12.5% and a Nyquist filter. The signal is fed to a 65 GS/s Arbitrary Waveform Generator (AWG) with a bandwidth of 25 GHz. The RF output power of the AWG is limited to -3 dBm (0.4 Vp-p), which is further amplified by a broadband high-speed RF amplifier (SHF-S708) providing a gain of 14 dB. The LTE signal is generated by an Anritsu MG3710A signal generator. For the LTE downlink, a test signal defined by the E-UTRA test model (E-TM) 3.1 was used. 64 QAM modulation format is used for the LTE test signal, which has center frequency of 3.48 GHz and a bandwidth of 20 MHz. The DMT and LTE electrical signals are combined using an RF combiner which has an intrinsic loss of 6 dB. The 100mA low noise DC bias for the DML is combined with the RF signal by using a bias-T. The multiplexed signal is applied to the laser using a G-S-G probe. The modulated optical output of the DML is coupled to single mode optical fiber via a grating coupler. The loss induced by the grating is compensated by an Erbium Doped Fiber Amplifier (EDFA). After optical filtering, the modulated signal is transmitted over 5 km of optical fiber before being fed to the receiver. To benchmark the silicon receiver performance, the detection of the DMT signal is also performed by a commercial receiver, comprising a III-V PD with TIA, with a bandwidth of 24 GHz. The detected electrical signal is fed to a real-time scope (Keysight DSA-Z63) for offline processing of the received DMT signal or fed to the LTE receiver (Anritsu MS2692A). A 100 MHz clock signal is fed to the real-time oscilloscope in master-slave configuration to provide clock synchronization.

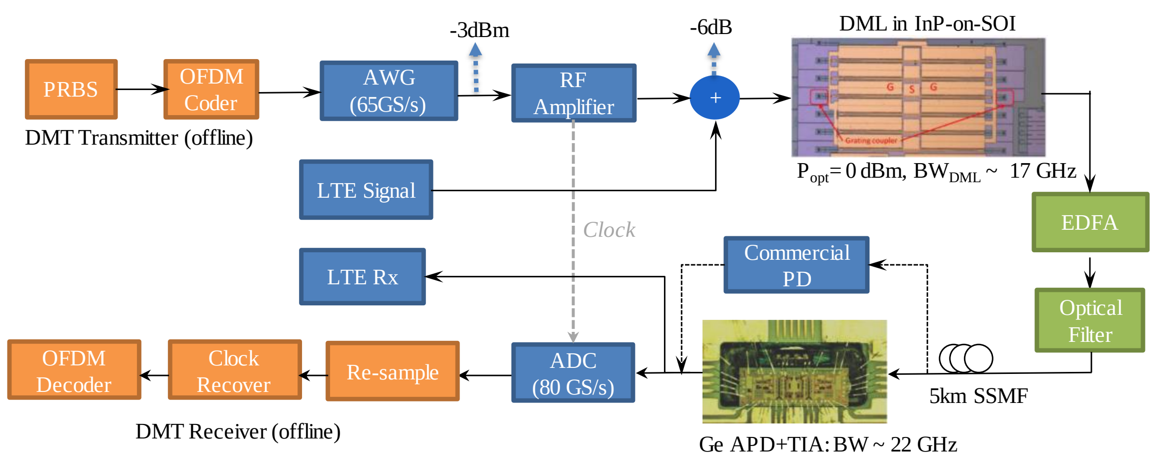

Figure 1: Schematic of the experimental setup for combined DMT and LTE signal transmission using an InP-on-Si directly modulated laser on the transmitter side and a commercial and GeSi-based PD+TIA on the receiver side.

As a first step, the system shown in Figure 1 is optimized for the highest DMT transmission rate by first using a commercial receiver. This optimization is done without including the electrical combiner for DMT and LTE data. A DMT signal with 1024 tones (subcarrier bandwidth of 31.2 MHz) is transmitted over a span of 5 km of SSMF An effective transmission rate of ~70 Gb/s for the commercial receiver is achieved for a target BER of $2x10^{-2}$ (SD-FEC). Afterwards, the performance of the system is tested for the combined LTE and DMT signal. The LTE signal is located in-band of the DMT signal by opening a gap in the DMT spectrum to avoid overlap of the DMT and LTE signal. This is achieved by turning off 7 subcarriers (219 MHz gap) in the DMT spectrum centered at ~3.48 GHz. Over a 5 km fiber span, a net data rate of 59.8 Gb/s is achieved. For both cases, bit loading is performed by first transmitting a QPSK signal with equal power on all subcarriers. Next, a water-filling approach is used to optimize the bit-loading for each subcarrier. In both cases, a maximum of 4 bits-per-symbol is assigned for low frequency subcarriers. The last 152 carriers are not used due to limited signal-to-noise ratio (SNR), resulting in an effective bandwidth of 27.2 GHz. For the case of the commercial receiver, Figure 2 (a) and 2 (d) shows the bit-loading for the DMT signal with and without LTE, respectively. Apart from the disabled subcarriers to open a gap for the LTE signal, the 6 dB loss of the RF power combiner has resulted in degraded SNR and hence a reduced net DMT capacity for the system.

For the case of the GeSi-PD+TIA, the optimum number of subcarriers is 512 (subcarrier bandwidth of 46.8 MHz). For bit-loading, the used strategy is the same as the one for commercial PD+TIA. For this case, the bandwidth was limited to 22.2 GHz and hence subcarriers beyond 474 are not used. A net capacity of ~59 Gb/s is achieved when only the DMT signal is transmitted. For the case of combined DMT and LTE, the net capacity has dropped to 49.5 Gb/s. For the case of the GeSi PD+TIA, Figure 2(b) and 2(e) shows the bit-loading for the DMT signal with and without LTE, respectively.
For all these experiments, -10 dBm of input power for the LTE signal is used on the transmitter side. Figure 2(c) shows the change in representative Error Vector Magnitude (EVM) for the LTE signal when its power of the LTE signal is swept from -20 dBm to -10 dBm. The gap created by disabling the DMT subcarriers is optimized for its width in such a way that the EVM for the LTE signal remains within the standard dictated specifications. Figure 2 (f) shows the constellation for the LTE signal without (left) and with (right) DMT signal. Though these constellations are for the commercial receiver, no significant degradation is observed for the case of the silicon receiver: an EVM of less than 8% is observed, which is within the specifications of the LTE standard.

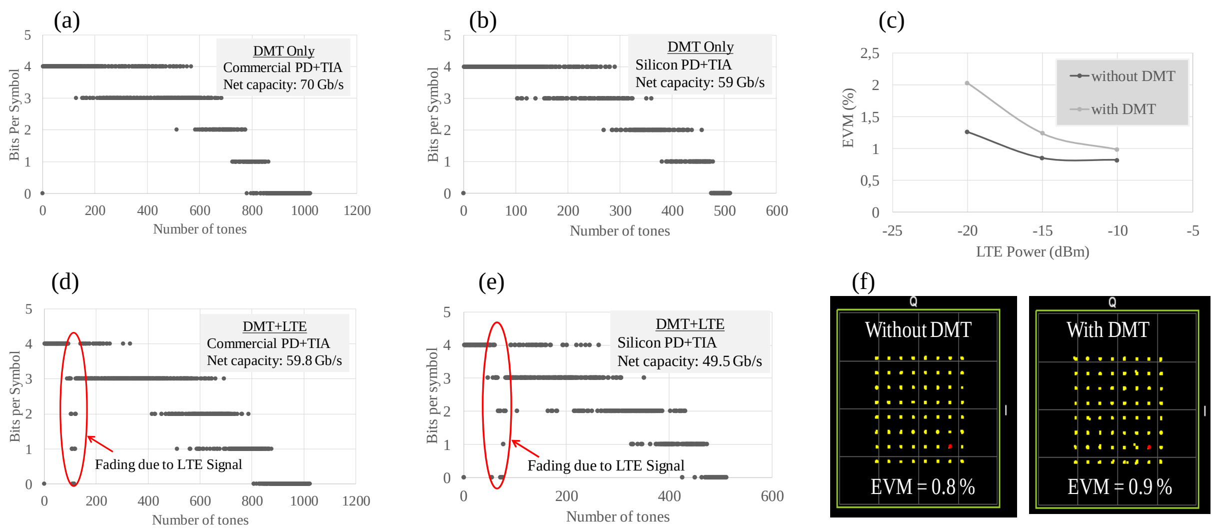

Figure 2: DMT bit-loading for the studied system using a commercial (a) and silicon (b) PD+TIA delivering a net capacity of 70 and 59 Gb/s, respectively; (c) change in the EVM by sweeping the input LTE signal power; bit-loading for DMT+LTE signal using commercial (d) and silicon-based PD+TIA (e) showing a net capacity of 59.8 and 49.5 Gb/s, respectively. (f) Constellation diagram (commercial PD+TIA) for the LTE signal without (left) and with (right) DMT signal showing an EVM of 0.8% and 0.9%, respectively. All capacities for DMT signal are for a target BER of $2x10^{-2}$ over a fiber span of 5 km.

4. Conclusion

Combined transmission of a DMT and LTE signal over a 5 km fiber span is demonstrated by using an InP-on-Si directly modulated laser and a GeSi -based -based PD+TIA. For a target BER of $2x10^{-2}$, a net data rate of 59 Gb/s for standalone DMT only and 49.5 Gb/s for DMT+LTE is achieved while keeping the EVM for the mobile LTE protocol 0.9%.

References

[1] S. C. J. Lee et al., "Discrete Multitone Modulation for Maximizing Transmission Rate in Step-Index Plastic Optical Fibers," in Journal of Lightwave Technology, vol. 27, no. 11, pp. 1503-1513, June1, 2009.
[2] Y. Matsui et al, "112-Gb/s WDM link using two Directly Modulated Al-MQW BH DFB Lasers at 56 Gb/s," in Optical Fiber Communication Conference Post Deadline Papers, OSA Technical Digest (online) (Optical Society of America, 2015), paper Th5B.6.
[3] T. Tanaka et al., "Experimental demonstration of 448-Gbps+ DMT transmission over 30-km SMF," Optical Fiber Communications Conference and Exhibition (OFC), 2014, San Francisco, CA, 2014, pp. 1-3.
[4] P. Dong et al., "Ten-Channel Discrete Multi-Tone Modulation Using Silicon Microring Modulator Array," in Optical Fiber Communication Conference, OSA Technical Digest (online) (Optical Society of America, 2016), paper W4J.4.Top of Form
[5] M. Nishihara, T. Tanaka, T. Takahara, Lei Li, Zhenning Tao and J. C. Rasmussen, "Experimental demonstration of 100-Gbps optical DMT transmission combined with mobile data signal," *OFC 2014*, San Francisco, CA, 2014, pp. 1-3.
[6] A. Abbasi et al., "28 Gb/s direct modulation heterogeneously integrated C-band InP/SOI DFB laser," Opt. Express 23, 26479-26485 (2015)
[7] B. Moeneclaey, et al., "A 64 Gb/s PAM-4 Linear Optical Receiver," in Optical Fiber Communication Conference, OSA Technical Digest (online) (Optical Society of America, 2015), paper M3C.5.