400Gb/s Real-time Transmission Supporting CPRI and eCPRI Traffic for Hybrid LTE-5G Networks

Son Thai Le[*,1], Tomislav Drenski[2], Andrew Hills[2], Malcom King[2], Kwangwoong Kim[1], Yasuhiro Matsui[3] and Theodore Sizer[1]

[1]Nokia-Bell-Labs, NJ, USA, [*]son.thai_le@nokia-bell-labs.com

[2] Socionext Europe GmbH, Concorde Park, Concorde Road, SL64FJ, UK

[3]II-VI Incorporated, 41762 Christy Street, Fremont, CA 94538, USA

Abstract: We present the first CMOS ASIC to support either 4×25Gb/s eCPRI or 4×24.33Gb/s CPRI-10 traffic per optical wavelength and demonstrate 200Gb/s and 400Gb/s transmissions in O and C bands over 20km for hybrid LTE-5G fronthaul networks.

OCIS codes: (060.2330) Fiber optics communications; (060.1660) Coherent communications.

1. Introduction

Many operators around the world have already announced their plans for introducing 5G services. However, the full deployment of 5G networks might take decades. To provide a smooth transition from 4G to 5G, operators will be forced to significantly increase the capacity of their 4G services with densification and introduction of Long-Term Evolution (LTE) advanced features such as coordinated multipoint (CoMP) transmission. These developments are impacting strongly the overall fronthaul networks in the future hybrid LTE-5G environments.

Common Public Radio Interface (CPRI) is the mainstream transport protocol in current LTE fronthaul networks. The latest CPRI specification adds new CPRI line rates up to 24.33Gbit/s (CPRI Rate 10) [1] which pumps more capacity to the LTE/LTE-A Remote Radio heads for achieving higher order MIMO and multi-carrier configuration. However, as CPRI cannot scale efficiently to meet the bandwidth-hungry services that 5G promises, a new specification called enhanced CPRI (eCPRI) has been introduced with flexible functional splits at the physical layer which allows for a tenfold reduction of the fronthaul capacity. In addition, eCPRI enables packet-based technologies, such as Ethernet and Ethernet/IP/UDP, for the transport of the user plane. For the physical layer, eCPRI will refer most likely to Ethernet rates of 25Gb/s to 100Gb/s.

To enable the co-existence of CPRI and eCPRI traffic in hybrid LTE-5G fronthaul networks, eCPRI v2 [2] has specified an Interworking function (IWF), acting as a CPRI/eCPRI conversion node (Fig. 1). An IWF can be connected with both LTE Radio Equipment (RE) through CPRI link, or with an (enhanced) Radio Equipment Control (eREC) via an eCPRI Ethernet fronthaul link. As a result, having optical transceivers which can support both CPRI-10 and eCPRI Ethernet traffic is strongly required as they simplify the network deployment and they can be re-used when a RE is replaced by an eRE to support 5G services and new radio (NR) signals. In fact, some vendors have already started developing a new class of optical transceivers with selectable retiming and data clock recovery to support both 25GbE eCPRI and CPRI-10 traffic [3-4].

This paper presents the industry-first 16nm complementary metal-oxide-semiconductor (CMOS) ASIC [5] using a Discrete Multi-tone (DMT) format that can support either 4×25Gb/s eCPRI or 4×24.33Gb/s CPRI-10 traffic on a single optical wavelength. Using this ASIC, real-time 200Gb/s transmission in O-band and 400Gb/s transmission in C-band over 20km were demonstrated, showing great potential for both the low-cost grey optics and the DWDM solutions for future hybrid LTE-5G fronthaul networks.

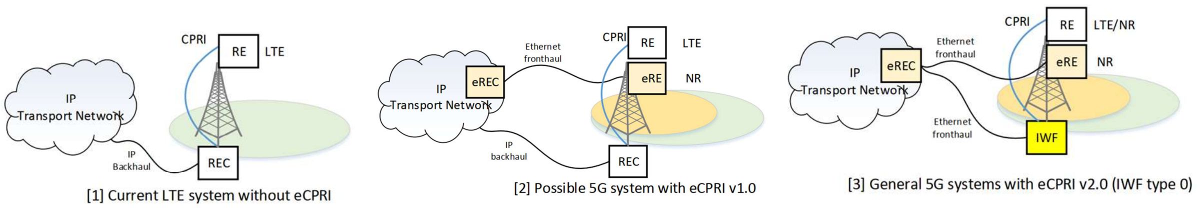

Fig. 1. Current and future hybrid LTE-5G system architectures with IWF as recommended in eCPRI specification v2 [2]

2. 16nm CMOS ASIC for hybrid LTE-5G fronthaul networks

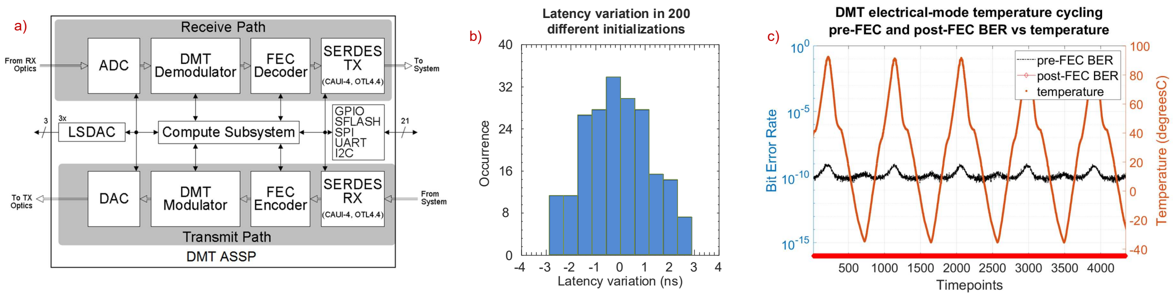

Fig. 2a) – Block diagram of the 16nm CMOS ASIC; b-c) – Latency variation and temperature dependency measurements of the ASIC

The block diagram of the DMT ASIC, which can support both CPRI-10 and 100GbE (IEEE CAUI-4 compliant) client protocols, is depicted in Fig. 2a. It incorporates a complete single channel DMT transmission PHY for up to 100Gb/s data rates over short reach optical fibre. It includes an 8-bit DAC and ADC with sampling rates up to 71GS/s, a DMT core engine, an on-chip digital RX timing recovery, a low-jitter RX clock generation and high coding gain FECs to ensure error free data is passed to the client interface. The DMT core engine uses 512pt FFT/iFFT to encode data onto 256 subcarriers with adaptive quadrature amplitude modulation (QAM) modulation formats with 0-8 bits per subcarrier. For best transmission, the QAM modulation is determined by measuring the signal-to-noise ratio (SNR) of the channel at each subcarrier frequency. A water-filling algorithm then computes the bit and power loading for each subcarrier and an adaptive background equalization guarantees optimum adaptation to any variations in the channel. The DMT ASIC also includes configurable cyclic prefix for total bitrate optimisation and frequency domain equalization.

To meet the strict requirements of LTE/5G fronthaul networks, the DMT ASIC is designed to achieve low latency variation and the full industrial temperature range (-40°C to +85°C). As shown in Fig. 2b, the latency variation of the chip subjected to 200 different initializations is below ±3ns. The latency variation subjected to temperature change from 25°C to 100°C is below 130ps. In addition, Fig. 2c confirms that the ASIC performs stably with negligible pre-FEC BER variation in the electrical B2B configuration when the temperature is swept from ~-40°C to +85°C (with 10s for each timepoint). This makes the DMT ASIC fully qualified for outdoor fronthaul applications.

3. Real-time transmission setup and results

For the real time transmission setup, two DMT ASICs were used in two different system configurations. The first configuration (Fig. 3a) is a 200Gb/s LAN-WDM2 transmission using two 25-GHz-class directly-modulated lasers (DMLs) at 1305nm and 1310nm with + 8dBm of optical output power (at 70mA of bias current). This represents a low-cost grey-optics solution for fronthaul links where DWDM is not required. This system can support 8 eCPRI channels at 25GbE or 8 CPRI-10 channels. For real-time transmission, for each channel, appropriate CPRI-10 traffic at 4×24.33Gb/s and eCPRI Ethernet traffic at 4×25.78125Gb/s (IEEE CAUI-4 compliant) was emulated, which were then mapped onto 256 subcarriers (after FEC-encoding) by the DMT core engine through bit and power mapping based on the channel condition measured during the initialization stage. During operation, the channel condition is automatically tracked and updated by the DMT core engine after each predefined (adjustable) time interval. The modulated DMT signals of the ASIC was amplified using a 25-GHz RF driver before bias-adding for directly driving a DML. After optical modulation, the two optical channels were combined using a LAN-WDM MUX and then launched into 20km of standard single mode fiber (SSMF). At the receiver, two DMT channels were demultiplexed using a LAN-WDM DeMUX. Each channel was detected using a 25-GHz PIN-TIA receiver and then fed back into the ASIC for real-time processing and decoding. The total insertion loss of the link, including 20km of SSMF and LAN MUX/DEMUX in the O-band is ~ 10dB. The second configuration (Fig. 3b) is a 400Gb/s transmission in C-band for DWDM fronthaul applications with optical amplifiers. Herein, each ASIC was used to modulate two interleaved optical carriers (either 1545nm with 1557nm and 1549nm with 1561nm) using a Mach-Zehnder Modulator (MZM). After multiplexing, the WDM signal was amplified and launched into 20km of SSMF. To compensate chromatic dispersion in the C-band, a DCF with -338ps/nm was used. After that, each channel was filtered out using a 0.7nm tunable optical filter and the signal was detected by a PIN-TIA photo-receiver.

The overall real-time transmission results of both systems under test are summarized in Fig. 4. Herein, the pre-FEC BER was used for performance discussion. It has to be noted that for the real-time signal processing, the CI-BCH FEC mode was switched on and all the reported cases here with the pre-FEC BER values under 0.004

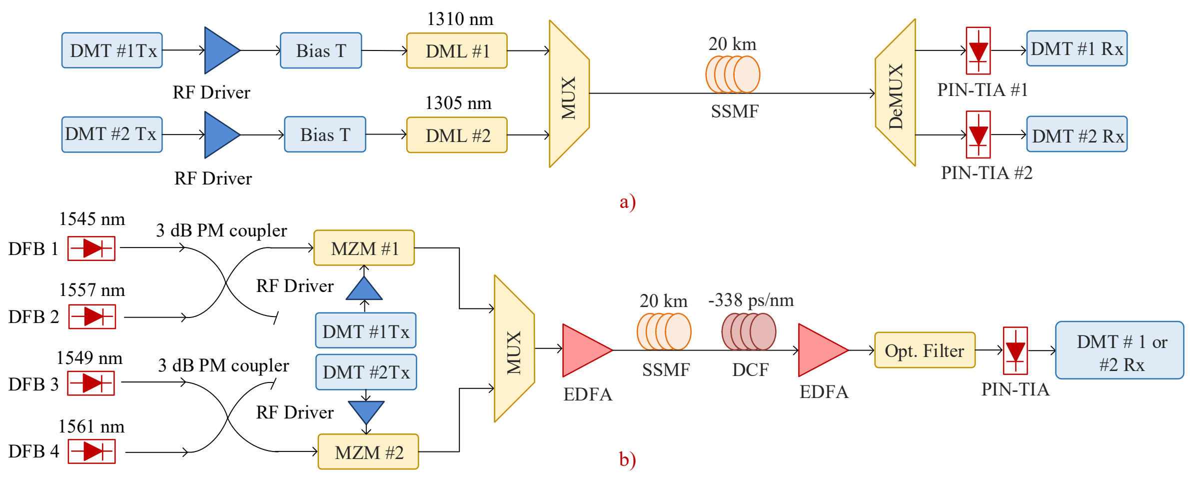

Fig. 3a) – Real time O-band, amplifier-less, LAN-WDM2 200Gb/s transmission setup supporting 8×25GbE Ethernet or 8×24.33Gb/s CPRI-10 traffic over 20km; b) – Real time C-band DWDM 400Gb/s transmission setup supporting 16×25GbE Ethernet or 16×24.33Gb/s CPRI-10 traffic over 20km; DCF – dispersion compensating fibre.

were decoded error free (post-FEC BER < 10^{-15}). For 100GbE eCPRI Ethernet transmission mode, the DAC sampling rate of up to 71GS/s was programmed to achieving the best performance. On the other hand, the CPRI-10 mode was run at a sampling rate of 64GS/s which minimizes the DMT ASIC power dissipation.

In general, for all cases, the CPRI-10 mode shows lower pre-FEC BER compared to 100GbE mode, which is mainly due to its slightly lower data rate and smaller required bandwidth. An example of SNR and number of bits allocated per subcarrier is shown in Fig. 4(c-d) for 1310nm channel at a received power of 0dBm. In Fig. 4(a-b), for both channels (1305nm and 1310nm), the sensitivities of both 100GbE and CPRI-10 modes are ~ -7dBm. On the other hand, over 20km of transmission, both channels show sensitivities of -6dBm (Fig. 4e) which indicates a remarkable optical power budget of ~ 14dB. As the received optical power per channel after 20km is ~ -2dBm, there is still 4dB margin which guarantees the reliability of the demonstrated system.

The performance of the 400Gb/s DWDM C-band system is summarized in Fig. 4(f-g), showing that all 4 channels were transmitted successfully over 20km with receiver sensitivity of -5dBm. This indicates that the DMT ASIC can also be used in DWDM transmissions for achieving massive capacity, great efficiency and flexibility, which will be required in future hybrid LTE-5G or 5G networks.

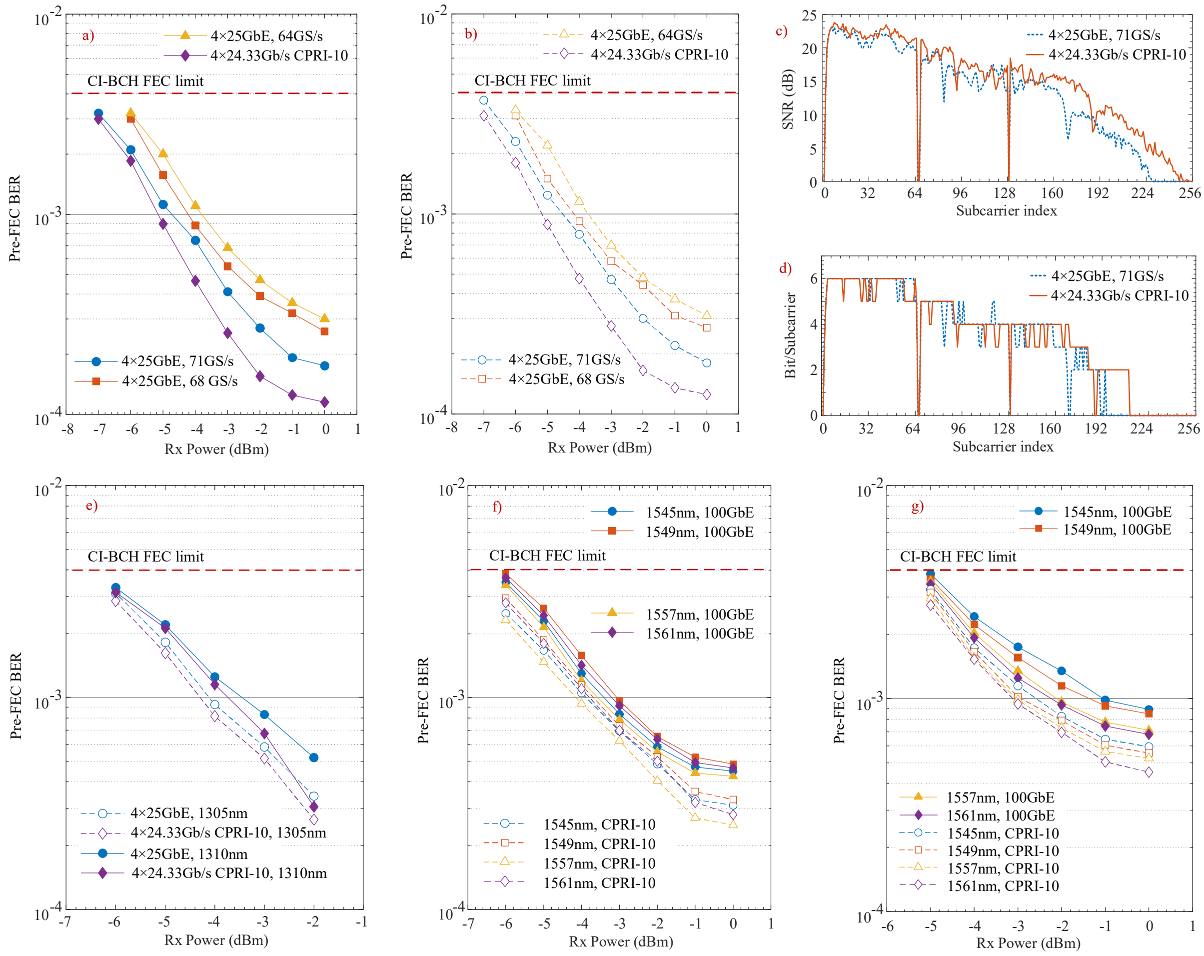

Fig. 4. Overall experimental results including a-b) – B2B sensitivities of 1310nm and 1305nm channels, respectively; c-d) SNR and allocated bits per subcarrier for the 1310nm channel at 0dBm of Rx power; e) – Performance over 20km of 200Gb/s O-band; g) – B2B sensitivities and transmission performance over 20km of 400Gb/s C-band DWDM system.

4. Conclusion

Future hybrid LTE-5G fronthaul networks require optical transceivers, which can support both CPRI and eCPRI traffic. This requirement can be met using our industry-first CMOS ASIC using the DMT format. Using this ASIC, real-time 200Gb/s and 400Gb/s transmissions over 20km in O-band and C-band have been demonstrated. The obtained results show viable solutions for future product implementations.

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5. References

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[2] eCPRI Specification V2.0 (2019-05-10)
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