Locking Dynamics of an Analogue Coherent TDMA Receiver for Many-to-Any Network Architectures

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The locking dynamics of an analogue coherent receiver based on an externally modulated laser are investigated for on-off keyed traffic. We experimentally confirm fast all-optical locking within 10 ns and the reception of data packets with short guard interval, originating from two free-running optical transmitters.

1. Introduction

As traffic in datacenters and short-reach network continues to soar, the practical introduction of coherent reception is being heavily debated in view of its nature as a technologically challenging exercise. The complexity inherent to coherent receivers is a driver for the cost of this key element of the communication link and often leads to techno-economical decisions towards direct-modulation, direct-detection (DM/DD) solutions. In optical access for example, bandwidth growth is mainly facilitated through inclusion of dense WDM in multi-lane transceiver architectures rather than building on a disruptive migration to coherent reception methodologies that are being intensively investigated [1-3]. In the realm of datacenters, high energy efficiency is paramount and questions the adoption of digital signal processing (DSP) such as employed for optical carrier synchronization. We have recently introduced a laser-based coherent receiver that performs transparent coherent translation from the electrical to the optical domain, and vice versa [4].

In this work we evaluate these low-cost coherent receivers based on externally modulated lasers (EML) for TDMA reception in a multipoint-to-point network with a low inter-packet guard interval of <100 ns. We discuss the locking speed for packet-level reception to elaborate on the ultimate limits of this all-optically locked coherent receiver.

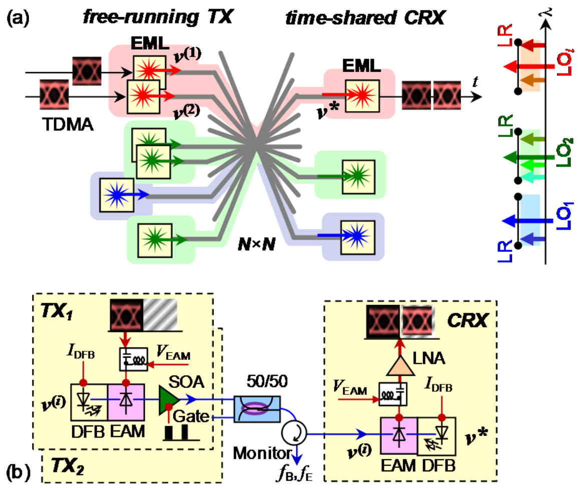

Fig. 1. (a) Many-to-any network architecture and (b) experimental setting.

2. Coherent Receiver in Many-to-Any Network

Figure 1(a) presents the generalized network context for a many-to-any network architecture. Transmitters are passively routed to any of the receivers. Channel allocation is made through choice of the wavelength, meaning that transmitter-receiver pairs are formed on the same sub-wavelength. This case supports the time-sharing of a single coherent receiver among multiple transmitters, which can be attractive for environments where short-lived data flows are competing with longer-lived data streams. Moreover, transmitter-side wavelength switching can in principle support a flexible and agile re-allocation of transceiver pairs. Further, since coherent reception allows the smooth migration towards ultra-dense WDM in virtue of the inherent filtering capabilities of the opto-electronic detection process at the same time, the spectral occupancy and thus the efficiency can be raised.

As demonstrated earlier [4], an EML suffices the coherent detection process as a homodyne receiver that locks to the data signals through the all-optical mechanism of injection locking. Its distributed feedback laser (DFB) section becomes a perfectly synchronized local oscillator (LO) in this way, while the electro-absorption modulator (EAM) as partially absorbing photodiode (V_{EAM} = -0.7 V) down-converts the optically received data to the electrical baseband. The locking assures that no frequency offset results during the homodyne detection process. In combination with simple modulation formats such as on-off keying (OOK), this receiver can exploit its potential to fully omit DSP functions, which would otherwise be required for either signal recovery or demodulation.

3. Experimental Setting

In order to characterize the coherent reception of baseband-modulated signals in TDMA through EMLs, we have chosen a link with two EML transmitters and one EML receivers, jointly operating in the wavelength range from 1547.72 to 1550.12 nm over a passive branching network (Fig. 1(b)). The EMLs had a bandwidth of 7.3 GHz. Therefore, 10 Gb/s OOK modulation has been selected. The transistor-outline package prevented us from co-integrating a transimpedance amplifier (TIA) with the EML at the receiving endpoint, which results in worse reception sensitivity but lets us prove the principal operation. The receiving EML (ν^*) locks to the two free-running transmitting EMLs ($\nu^{(2)}$,$\nu^{(1)}$) that were gated by SOAs, which are time-synchronized to a TDMA frame with a 400 kHz rate and a 50% duty cycle for each of the transmitters (see inset in Fig. 2). A guard interval of <100 ns was set between the TDMA channels and was as short as 37 ns between $\nu^{(2)}$ and $\nu^{(1)}$. Polarization-independent operation, which can be obtained through a diversity receiver configuration [5], was omitted due to lack of further EML components.

4. Receiver Locking and Dynamics

The static locking of the coherent homodyne receiver can be obtained by tuning the transmitting EML into the spectral locking range (LR) of the receiving EML through either temperature or bias current (I_{DFB}) tuning, with efficiencies of ~20 GHz/°C and ~0.8 GHz/mA, respectively. The LR depends on the injection level at the receiver, as shown in Fig. 2(a) in terms of beat frequency f_B of the LO with the externally injected light. Locking results in f_B = 0, which occurs for a span of up to 9.8 GHz at an injected power of -0.5 dBm (□). This large value reduces to 200 MHz at -30 dBm. The co-packaged micro-cooler for the EML ensures a small emission frequency drift of <90 MHz, which is found to be smaller than the LR.

In order to investigate the dynamic locking response, the LO has been heterodyned with a stabilized reference laser while the TDMA frame has been injected to the coherent EML receiver. The beat spectrum resulting from the injection of the TDMA frame with both transmitter signals is reported in Fig. 2(b) for an injection level of -20 dBm. The beat note of the spectrally detuned reference laser (ν_{Ref}) with the LO (ν^*), which is running free during the very short guard intervals, appears at 820 MHz. During the packets at $\nu^{(1)}$ and $\nu^{(2)}$, this beat note shifts to 940 and 720 MHz, respectively. The time-resolved spectrum is presented in Fig. 2(c) as instantaneous frequency f_E after digital acquisition of the beat signal. Although the resolution is limited by the digital estimation, we anticipate the locking time with <10 ns. This short time constant is backed by earlier studies [6].

5. Reception Performance

The eye diagram for a TDMA channel after coherent reception with the EML is shown in Fig. 2(d). An open eye is obtained, which results from the homodyne detection process that does not introduce a frequency offset. For a signal launch of 6 dBm from the transmitter, an optical budget of 24.8 dB is supported at the FEC limit of 3.8×10^{-3}. This loss budget corresponds to a passive 128:128 split and is high enough for direct-detection terms not to deteriorate the reception performance. Moreover, there was no penalty experienced with respect to continuous-mode data transmission with a single transmitter. The packet edges after reception, shown in Fig. 2(d), indicate that there is no transient distortion at the rising or falling edges of the packet envelope. Further improvement in terms of reception sensitivity is expected for a co-integration of the EML detector with a TIA-based electrical front-end.

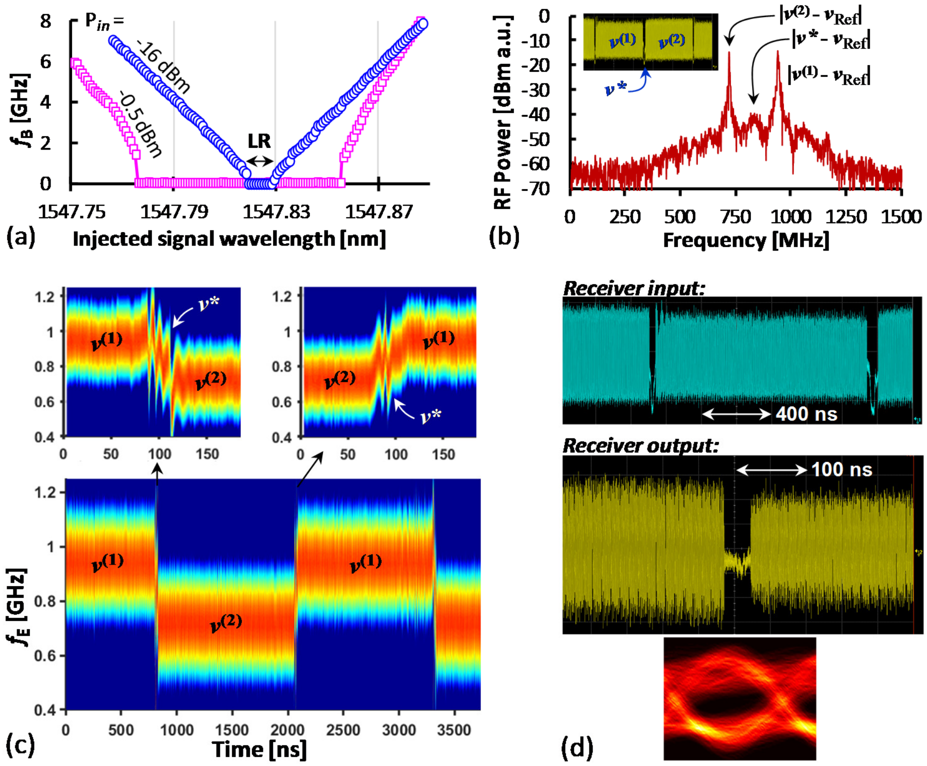

Fig. 2. (a) Injection locking range for high and low injected power Pin, (b) beat spectrum and (c) instantaneous beat frequency of LO and external reference for TDMA injection into EML receiver, (d) TDMA frame at receiver in- and output and received 10 Gb/s OOK eye diagram.

6. Acknowledgement

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7. References

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