

Coherent Technologies for Passive Optical Networks

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Abstract—To date, optical access networks have been exclusively based on intensity modulation with direct detection. However, recent advances in coherent transceivers offer the potential to overcome the many limitations of these systems. This work reviews such candidate technologies for low complexity coherent optical access networks.

I. INTRODUCTION

When asked to consider the use of coherent transmission systems for optical access networks, it is often assumed that the direct adoption of long-haul transceiver technology is the proposal on offer. This is, perhaps, because coherent optical transmission systems have seen such widespread deployment in long-haul systems, and it remains unusual to see this technology used in other applications.

In systems where transmission distances can be many thousands of kilometers, coherent detection is a logical choice because it provides a linear mapping of the optical field to the electrical domain, thus enabling chromatic dispersion compensation through digital signal processing (DSP). Coherent transmission also enables the use of advanced modulation formats (for high spectral efficiency), which can be encoded across all four dimensions of the optical field: in-phase and quadrature, in two orthogonal polarization states.

However, such transmission systems require a high optoelectronic complexity, typically using at least one photodetector and transimpedance amplifier (TIA) per modulated dimension, one analog-to-digital converter (ADC) per detected dimension, and at least one external modulator per modulated dimension (integrated in a nested Mach-Zehnder interferometric structure). Coherent systems also require an additional laser in the receiver which acts as the local phase reference or ‘local oscillator’ (LO). This is a far cry from the transceivers deployed in optical access networks, which use a directly modulated laser for transmission and a single photodetector for reception; modulating and detecting only one dimension of the optical field. Given the relatively short transmission distances in access networks, and the generally sparse use of the optical fiber bandwidth, what is the compelling case, if any, for using coherent transmission systems in this context?

This paper details the advantages of coherent receivers in passive optical networks (PON), and discusses candidate coherent technologies which offer a possible migration path from the current PON standards to a coherent PON.

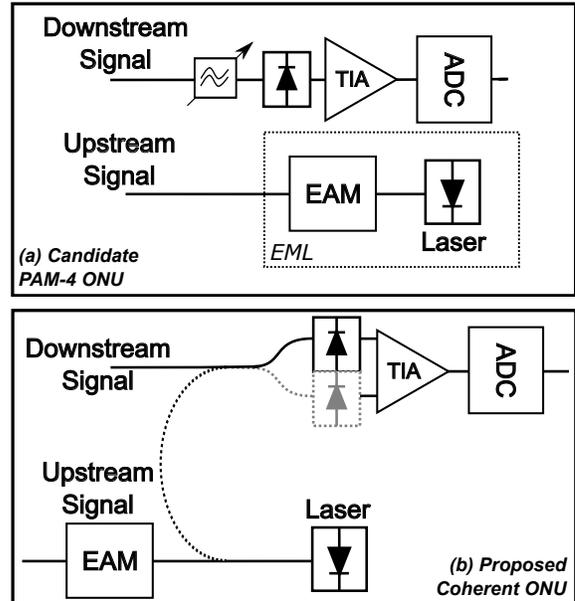


Fig. 1. Candidate optical network units (ONU) for future optical access networks. (a) Similar to an ONU for NG-PON2, this ONU uses a tunable bandpass optical filter for channel selection, but uses an externally modulated laser (EML) to enable PAM-4 upstream transmission. An analog-to-digital converter (ADC) is used to allow a feedforward equalizer for chromatic dispersion mitigation. (b) A reconfiguration of the components in (a) makes the ONU coherent. Note that, the bandpass filter is not strictly required in the coherent configuration, and that rejection of other WDM channels can be enhanced through balanced detection, as shown in grey.

II. FROM NG-PON2 TO ‘Coherent PON1’

The current standardization in PON is largely divided between the ITU and the IEEE. An excellent starting point for this discussion is the most recent ITU standard, NG-PON2 [1], which is a 4×10 Gbit/s wavelength division multiplexed (WDM) transmission system with time division multiplexing on each of the four wavelengths (also known as TWDM). Here, tunable lasers and optical filters are used in the optical network units (ONU) to enable channel selection for downstream and upstream, respectively. The modulation format is on-off keying (OOK) in both the upstream and downstream, with burst mode being used in the upstream.

For transmission beyond 10 Gbit/s/λ, both the IEEE P802.3ca task force [2] and the ITU are standardising higher rate PONs, still based on OOK and TWDM. However, it has become apparent that maintaining an acceptable power budget at 50 Gbit/s/λ is a challenge with OOK, and multi-

level transmission schemes based on duobinary or 4-ary pulse amplitude modulation (PAM-4) have been proposed. This can be achieved through a reconfiguration of the ONU, as shown in Fig. 1(a), to include an externally modulated laser (EML); i.e., a laser integrated with an electroabsorption modulator (EAM).

This raises an interesting question; with the additional ONU components, could one consider making this system cost-effectively coherent, and what would the key advantages be versus direct detection?

The first advantage of coherent for access networks is frequency selectivity. In a coherent system, the tunable optical filters are not required, which reduces the ONU insertion loss and complexity versus NG-PON2. Channel selection can be achieved by including an LO laser in the ONU, which is tuned to the wavelength of the channel of interest and combined with the received signal prior to detection. If it is acceptable to transmit and receive on the same wavelength, then the ONU can simply be reconfigured as shown in Fig. 1(b), and no additional components are required versus the direct detection ONU, Fig. 1(a).

If the optical bandpass filter is excluded from the ONU, the wavelength range available for modulation is determined exclusively by the tunability of the LO laser, thus enabling a dense WDM (DWDM) or even an ultra dense (UDWDM) channel configuration. Until recently, such a configuration would have been challenging to achieve with volume-production lasers, however recent demonstrations of low power, widely tunable, distributed Bragg reflector (DBR) lasers have shown both low-power requirements [3], and high wavelength stability without a thermo-electric cooler [4]. Generally, lasers of this type exhibit a higher linewidth (phase noise) than, for example, external cavity lasers, but their use has nevertheless been demonstrated in (coherent) burst mode operation with high order modulation [5].

Further to the above, it should be noted that coherent receivers also offer an excellent received power sensitivity. Even without the use of optical filters, just a few photons are required at the receiver per bit transmitted in a typical PON configuration [6]; outperforming direct detection systems by several orders of magnitude. When coherent receivers are simplified, for example by using the design shown in Fig. 1(b), the sensitivity of the receiver is unavoidably impaired. However, in this configuration, the sensitivity penalty is typically between 3–6 dB, meaning simplified coherent receivers are still superior in terms of sensitivity [7].

One of the most significant issues in coherent PON is how to handle the polarization selectivity of the coherent receiver. The configuration shown in Fig. 1(b) is not polarization diverse, and thus the receiver will only be able to select the downstream channel if its polarization state is aligned with that of the local oscillator laser; this cannot be guaranteed. This means that the transmitter-side (i.e., the optical line terminal, OLT) must either encode the signal over two polarizations, or be aware of the polarization state of the transmission link. There are already three methods for this in the literature: (1) polarization-time block coding [7], which precodes the

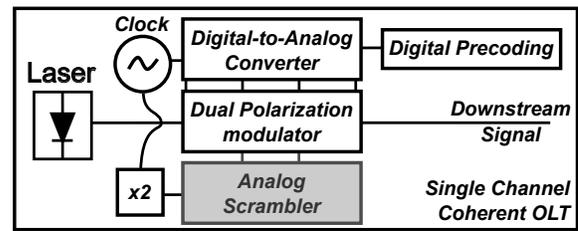


Fig. 2. A single wavelength channel from a coherent OLT. Digital precoding generates signals which can be received with the polarisation-agnostic receiver, Fig. 1(b). Alternatively, polarization scrambling can be implemented; either digitally, or via a partially analog scrambler as shown in grey.

signal with a rate- $\frac{1}{2}$ code such that the signal can always be received, irrespective of the received state of polarization, (2) Polarization scrambling [8], which transmits in orthogonal polarization states alternately, such that the signal can always be received by integrating the received signal over two time slots, and (3) differential group delay pre-distortion [9], which uses knowledge of the transmission system’s state to transmit single polarization signals which are received aligned to the LO at the ONU. All three methods can be implemented using the transmitter configuration shown in Fig. 2.

There are many more ways to configure a coherent PON based on more complicated ONU structures, and these are discussed in [10], and references therein.

ACKNOWLEDGMENT

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