

Reconfigurable Digital Coherent Receiver for Metro-Access Networks Supporting Mixed Modulation Formats and Bit-rates

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Abstract: Single reconfigurable DSP coherent receiver is experimentally demonstrated for mixed-format and bit-rates including QPSK, OFDM, IR-UWB for wireline and wireless signal types. Successful transmission over a deployed fiber link is achieved.

OCIS codes: (060.1660) Coherent communications, (120.5060) Phase modulation

1. Introduction:

Next generation metro-access networks will need to support diverse broadband services including converged wireless and wireline optical access over a unified fiber platform, satisfying bandwidth requirements [1] as well as fulfilling stringent power budget and chromatic dispersion constraints [2]. Another important attribute of future metro-access networks is agile re-configurability to seamlessly accommodate for emerging new services and increased bandwidth requirements [1]. Furthermore, the introduction of mixed modulation formats, bit-mixed rates, support for burst mode transmission into the metro-access networking scenario is creating a highly heterogeneous environment that represents a new challenge to tackle in the near future. Approaches looking for solutions to one or more of the above issues are radio-over-fiber systems for integrating baseband and wireless service delivery over optical fiber access networks [3]. Another approach is developing multi-rate receivers for optical network units (ONUs) from 2.5 Gbit/s-40 Gbit/s to accommodate for mixed bit-rate or service bit-rate on demand [4]. Another promising approach proposed recently is coherent detection based passive optical networks to support closely spaced channels with increased receiver sensitivity to cope with the required large number of users and to extend the reach of metro-access networks [5]. Although experimental demonstrations of converged service delivery have been reported in the literature [2, 3] they use a dedicated receiver for each modulation or bit-rate. In this paper we present and experimentally demonstrate a single, reconfigurable, digital receiver supporting mixed modulation formats, baseband and wireless-over-fiber, with reconfiguration in the digital signal processing domain. We successfully demonstrate its operation for 20 Gbps non-return-to-zero quadrature phase-shift keying (NRZ-QPSK), optically phase-modulated 5 GHz OFDM radio-over-fiber and 2 Gbps impulse radio ultrawideband (IR-UWB), and 5 Gbps directly modulated vertical cavity surface emitting laser (VCSEL) after 78 km of deployed fiber link.

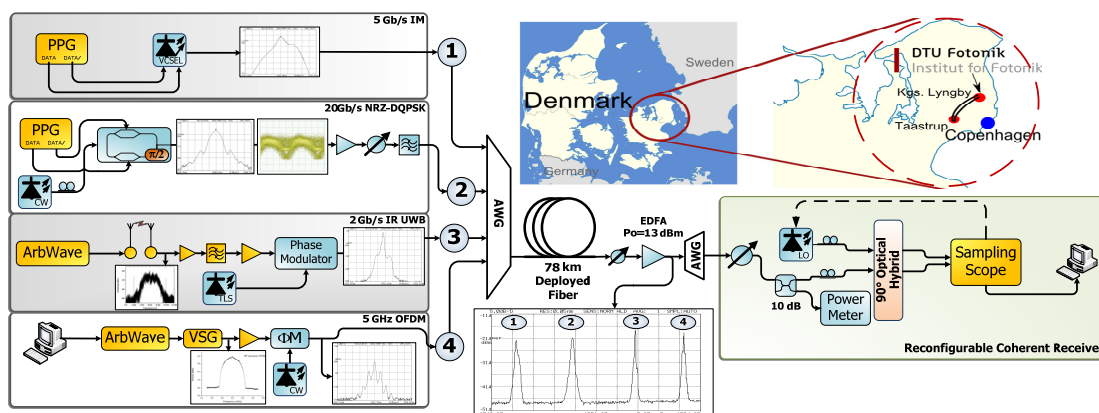


Fig.1 Experiment layout, showing optical and electrical RF spectra at key points; route of installed optical fiber are also shown. Reconfigurable receiver construction allows local oscillator (LO) tuning for channel selection. PPG: pulse pattern generator; ArbWave: arbitrary waveform; VSG: vector signal generator.

2. System description

Fig. 1 shows a block diagram of the heterogeneous optical network and setup used in the experiment. The field-deployed fiber connects the Kgs. Lyngby campus of the Technical University of Denmark (DTU) and the Taastrup suburb of Copenhagen. The fiber is a G.652 standard single-mode fiber (SMF) type (16.5 ps/nm km chromatic dispersion, 0.20 dB/km attenuation). The total link loss was 27 dB. ITU standard operating wavelengths were used for all channels at 200 GHz separation due to equipment availability. Total launch power into the deployed fiber was kept to +4 dBm. At the receiver side, emulating the central office, an erbium doped fiber amplifier (EDFA) was used as preamplifier followed by an optical bandpass filter to reduced ASE noise. The optical power level to the receiver was set to -11 dBm. A tunable external cavity laser was used as local oscillator (LO) for all the received signal types; with a linewidth of 100 kHz. The in-phase and quadrature signals after the 90° optical hybrid were detected with two pairs of balanced photodiodes, having full width at half maximum bandwidth of 7.5 GHz. The detected photocurrents were digitized using a sampling oscilloscope at 40 GSa/s for offline processing. The employed single digital receiver used a digital dispersion compensation module followed by an optical carrier-recovery digital phase-locked loop (PLL) and linear signal demodulation [6] for phase-modulated OFDM and IR-UWB RoF subsystems. Instead of a DPLL, a frequency offset compensation module was used for the NRZ-QPSK optical signal. Reconfiguration for each modulation format was performed by digitally switching between the signal demodulation DSP blocks. Below we present the set-up for each of the signal formats considered.

Gbps Intensity-modulated VCSEL: a pulse pattern generator (PPG) at 5 Gbps directly modulated a 1550 nm VCSEL. Single drive configuration was used for the VCSEL with a driving peak-peak voltage of 1 V. A pseudo random binary sequence (PRBS) with a length of $2^{15}-1$ was used for this experiment. The bias current of the VCSEL was used to tune the wavelength to the assigned AWG channel. Bias current was set to 14 mA. The output power of the VCSEL launched into the fiber was measured to be 0.5 dBm.

20 Gbps QPSK baseband: the transmitter of the baseband QPSK subsystem included a PPG to providing a PRBS (215-1) and a MZ modulator to generate a QPSK signal at the wavelength of 1550.5 nm. The value of the signal laser linewidth was 2 MHz.

2 Gbps phase-modulated IR-UWB: an Arbitrary Waveform Generator (AWG) with 24 GSa/s sampling rate was utilized to program a 5th order derivative Gaussian pulse for good compliance with FCC mask [7]. A PRBS with a word length of $2^{11}-1$ with bipolar modulation at a bit rate of 2 Gbps was used. The UWB signal was transmitted using a Skycross omni-directional antenna (SMT-3TO10M-A, 0dBi gain) and received after 1 m wireless transmission by a Geozondas directive antenna (AU-3.1G10.6G-1, from +4.65 dBi to +12.4 dBi gain within the UWB frequency range). The received signal was amplified by a low noise amplifier, filtered by a high-pass filter and then amplified again to drive the optical phase modulator. The wavelength of this channel was set at 1552.54 nm. The DSP algorithm in the receiver side included matched filtering and a decision block.

5 GHz OFDM RoF: the OFDM baseband signal was generated in software using a $2^{15}-1$ PRBS as input data stream. 256 4-QAM subcarriers were used with 26 samples (10%) cyclic prefix per OFDM symbol. The OFDM frame is composed of two Schmidl training symbols [8] followed by eight data symbols. The signal was fed to an AWG with a 1.25 GSa/s rate which results in a bit rate of 500 Mbps. The signal is then upconverted to a frequency of 5 GHz using a free-running Vector Signal Generator (VSG) whose output is amplified to drive an optical phase modulator supplied with a continuous wave (CW) light at 1553.78 nm. At the receiver, the DSP algorithm implemented a digital PLL, timing offset estimation using a smoothed Schmidl timing metric followed by a carrier frequency offset estimation [8]. The training sequence enabled equalization of each OFDM sub-channel.

3. Results

To demonstrate the performance of our reconfigurable digital coherent receiver, we show in Fig. 2 the measured bit error rate (BER) curves for back-to-back (B2B) and after 78 km of deployed fiber transmission (considering both single and all simultaneous channel performance) as a function of the received optical power. For all four subsystems, a BER value below 10^{-3} (FEC threshold) is achieved for all considered scenarios. **5 Gbps coherently detected, intensity-modulated VCSEL:** as we can see in Fig. 2(a), the VCSEL coherently detected subsystem achieves a sensitivity of -24 dBm for both B2B and 78 km deployed fiber. Chromatic dispersion was completely compensated by DSP, and no penalty was appreciated compared with the B2B case. **20 Gbps QPSK baseband:** Fig. 2(b) shows that fiber transmission incurred 1 dB power penalty (at 10^{-3} BER) difference. Moreover in the simultaneous presence of the other three channels, there was an observable 0.5 dB penalty both for back to back and after transmission; however the reconfigurable receiver showed successful operation.

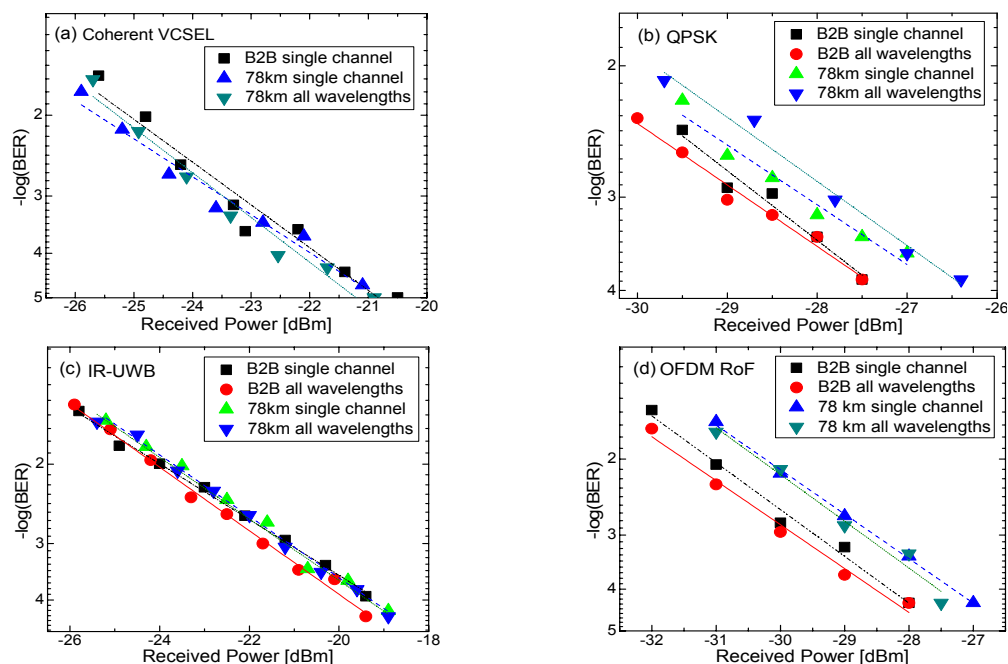


Fig.2 Measured BER performances for (a) 5 Gbps intensity-modulated VCSEL, (b) 20 Gbps QPSK baseband, (c) 2 Gbps phase-modulated IR-UWB, and (d) 5 GHz OFDM RoF.

2 Gbps phase-modulated IR-UWB: as shown in Fig. 2(c) the measured BER performances of the UWB subsystem were consistent for all cases. Errors occurred when the received optical power was less than -21.5 dBm. The BER performance is below the FEC limit when the received power was higher than -23 dBm. **5 GHz OFDM RoF:** Fig. 2(d) shows that for the case of four simultaneously integrated channels, OFDM suffered nearly 0.5 dB of power penalty, for both B2B and 78 km fiber transmission compared to single OFDM channel transmission yielding a receiver sensitivity at a BER of 10^{-4} of 28 dBm for the B2B system, and -27.5 dBm for the 78 km optical transmission link, respectively. The reconfigurable receiver showed stable operation for the 4-QAM OFDM RoF subsystem.

4. Conclusions

A single reconfigurable DSP enabled coherent receiver is experimentally demonstrated for mixed modulation formats and bit rates. In our reported experiment, four different types of wireline and wireless services including 20 Gbps QPSK baseband, 5Gbps OOK, 5 GHz OFDM RoF and 2 Gbps IR-UWB are successfully demodulated after transmission over 78 km deployed fiber link. The receiver used the same optical front-end, is able to switch among baseband and wireless types of signals by DSP reconfiguring to baseband only. This demonstrated digital reconfigurable coherent receiver has potential to enable unified support for signal detection on highly heterogeneous next generation metro- access networks.

5. References

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