Performance Comparison between the Traditional Intensity Modulation Direct Detection and Coherent Detection in a High Speed Optical Fibre Communication System

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Abstract: - Passive optical networks (PONs) have become a dominant approach for the fibre-to–the-home (FTTH) network deployments. Reliable and spectral efficient technologies are a necessity for extending the unamplified transmission reach in the FTTH environment. An optical coherent detection scheme that supports higher modulation formats and increases the receiver sensitivity is implemented. A 10 Gb/s data stream, intensity modulates a 1550 nm distributed feedback (DFB) laser with a direct detection scheme. The same modulated signal is enhanced by mixing it with a continuous wave (local oscillator) placed at the receiver in a homodyne coherent detection scheme. The enhanced mixed signal is then demodulated to evaluate and to compare the link performance of the direct detection and coherent cases. A back to back and a transmission through 30 km single mode fibre were simulated for the two transmission modalities. The coherently detected scheme improved the receiver sensitivity by 12.1 dBm at an acceptable bit error ratio (BER) of 10^{-9} as compared to the traditional intensity modulation direct detection (IMDD) scheme.

1. Introduction

The recent injection of new communication applications coupled with an exponential increase in users has further congested the already deployed intensity modulation direct detection (IMDD) optical communication networks [1]. One of the important goals in optical fibre communication system is to transmit the highest data throughput over the longest distance without costly signal regeneration. Amplitude modulated coherent detection scheme that has advantages of increased receiver sensitivity, increased transmission reach and is more spectral efficient is considered an alternative to meet the current communication requirements in a passive optical network in the fibre-to-the-home (FTTH) technology [2]. The coherent detection scheme can be incorporated into the already deployed fibre communication network thereby reducing the cost by maintaining the technology and form of the existing communication links.

In this paper, a traditional intensity modulated direct detection (IMDD) scheme is compared to intensity modulated coherent detection scheme (IMCD). Coherent detection is a modification of the tradition IMDD by beating the modulated signal with a continuous wave signal of the same frequency at the receiver. In a homodyne coherent scheme, phase matching of the transmitted signal and local oscillator is of vital importance in enhancing the quality of the signal at the receiver. Bit error ratio (BER) measurement which is an effective and reliable quantitative evaluation technique was used to compare the performance of the two communication modalities [3]. The receiver sensitivity at an acceptable BER of 10^{-9} and the corresponding penalties after transmission through a G. 652 fibre were determined.

2. Theory

A photodetector in an optical communication link is responsible for demodulating the optical signal to electrical form. Photodetectors are square law detectors. They convert the incident optical power (P_{in}) into a current and transform the incident electric field by a square law into an electrical power. The electric field of the received modulated signal in a direct detection scheme is expressed as:-

$$E_S(t) = A_S Exp[-i\omega\, t + \theta_s] \quad (1)$$

where A_s, ω and θ_s represent the amplitude, frequency and phase of the received signal.

In a direct detection scheme, the detected photocurrent I_p is given by:

$$I_P = \Re.P_{in} = \Re.A_{eff}.\frac{1}{2}\sqrt{\frac{\varepsilon\varepsilon_0}{\mu\mu_0}}.E_0^2 = K.E_0^2 \quad (2)$$

The electrical power, P_{el} generated in the detector with the Ohmic resistor is then given by:-

$$P_{el} = R.I_P^2 = R.(\Re P_{in})^2 \quad (3)$$

where R is the resistance and $\Re$ is the receiver sensitivity.

Coherent demodulation involves beating in a photodiode the received optical signal with a continuous wave (CW) signal. The electric field for the signal from the LO can be expressed as [3]:-

$$E_{LO}(t) = A_{LO} Exp[-i\omega_{LO}t + \theta_{LO}] \quad (4)$$

where A_{LO}, ω_{LO} and θ_{LO} represent the amplitude, frequency and phase of the LO signal.

Considering identical polarization on both signals, the total optical power into the photodetector can be expresses as:-

$$P_{(t)} = P_S + P_{LO} + 2\sqrt{P\,P_{LO}}\cos(\omega_{IF} + \theta_S - \theta_{LO}) \quad (5)$$

where:- $P_s = KA^2_s$, $P_{LO} = KA^2_{LO}$ and $\omega_{IF} = \omega_s - \omega_{LO}$, P_s is the optical power of the received signal, P_{LO} is the optical power of the LO, K is a constant of proportionality and ω_{IF} is the intermediate frequency. The photocurrent is proportional to the incident power and can be expressed as:-

$$I_{(t)} = RP_s + RP_{LO} + 2\sqrt{P_S P_{LO}}\cos(\omega_{IF} + \theta_S - \theta_{LO}) \quad (6)$$

Considering only the AC-coupled output of the photodiode and assuming that $P_{LO} >> P_s$, the above equation simplifies to:-

$$I_{(t)} = 2R\sqrt{P_S P_{LO}}\cos(\omega_{IF} + \theta_S - \theta_{LO}) \quad (7)$$

From (7) it is clearly shown that signal information can be retrieved from the amplitude (P_s), frequency (ω_s) or phase (θ_s) of the optical signal. Depending on the frequency offset between the received signal and optical signal from the LO, coherent detection can be implemented in two forms known as homodyne and heterodyne schemes. In homodyne coherent detection, $\omega_{IF} = 0$, and in heterodyne coherent detection, $\omega_{IF} \neq 0$. *[3,4,5]*

An optimum Homodyne detection scheme is obtained when the photocurrent produced is a maximum. The maximum photocurrent is obtained by matching the frequencies ($\omega_{IF} = 0$) and the phase ($\theta_s - \theta_{LO} = 0$), of the two signal giving [6,7,8] :-

$$I_{max} = 2.R\sqrt{P_{LO}P_S} \quad (8)$$

The ratio of the coherently detected photocurrent (I_{CD}) to the directly detected (I_{DD}) is therefore:-

$$\frac{I_{CD}}{I_{DD}} = 2\sqrt{P_{LO}/P_S} \quad (9)$$

Equation (9) shows that the photocurrent in a coherently detected scheme is more than that in direct detection thereby improving the receiver sensitivity.

3. Research Design

The schematic diagram for the theoretical simulation using VPI Photonics software is shown in Figure 1 [4]. The scheme shows a complete optical transmission link comprising mainly of a transmitter, the transmission medium, local oscillator (LO) and the optical receiver. The intensity modulation direct detection scheme is performed when the LO is switched OFF and the coherent detection scheme is performed with the LO switched ON.

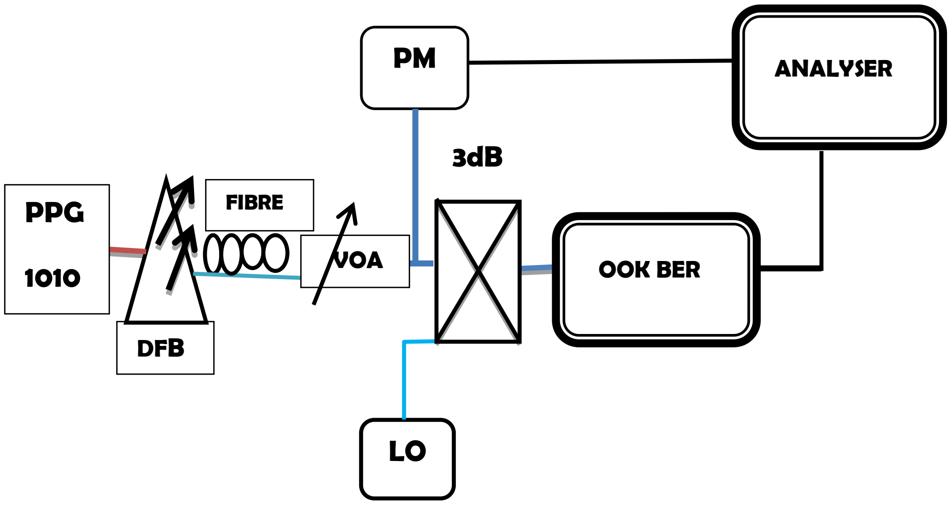

Figure 1: Simulation setup for an intensity modulation direct detection (IMDD) and intensity modulation coherent detection (IMCD) scheme

PPG: programmable pattern generator. DFB: distributed feedback laser. VOA: variable optical attenuator power PM: power meter. OOK BER On-Off keying bit error rate analyser.

The DFB laser signal at 1550 nm is directly modulated at a bit rate of 10 Gb/s by a Non-Return-to-Zero (NRZ) Pseudo-Random Binary Sequence (PRBS) signal and was launched into an optical fibre for transmission to the receiver. The variable optical attenuator (VOA) emulates the actual transmission link by varying the optical power that reaches the receiver and the signal power is measured by the power (PM). The direct intensity modulated signal is directly detected (DD) by the photodiode (PD) in the ON-OFF Keying BER (OOK BER) module. The OOK BER module computes the BER at different attenuation values and the result is plotted against the received optical power in the analyser module. For the coherent detection scheme the local oscillator is switched ON, the modulated signal is mixed with the continuous wave signal before detection at the receiver. The LO signal and the modulated signal are phase matched by first running a sweep at different initial phase angles of the LO thereby noting the best transmitted signal.

4. Results and Discussion

For both direct detection and coherent detection, a 3 mW signal is directly modulated with a 2^7-1, pseudo random bit sequence (PRBS). In a IMDD setup, the same signal is transmitted and is detected at the receiver. In a coherent detection scheme a 4 mW LO signal is mixed with the modulated signal before detection by a photodiode. The beating increases the optical signal power that the receiver gets resulting in improved receiver sensitivity.

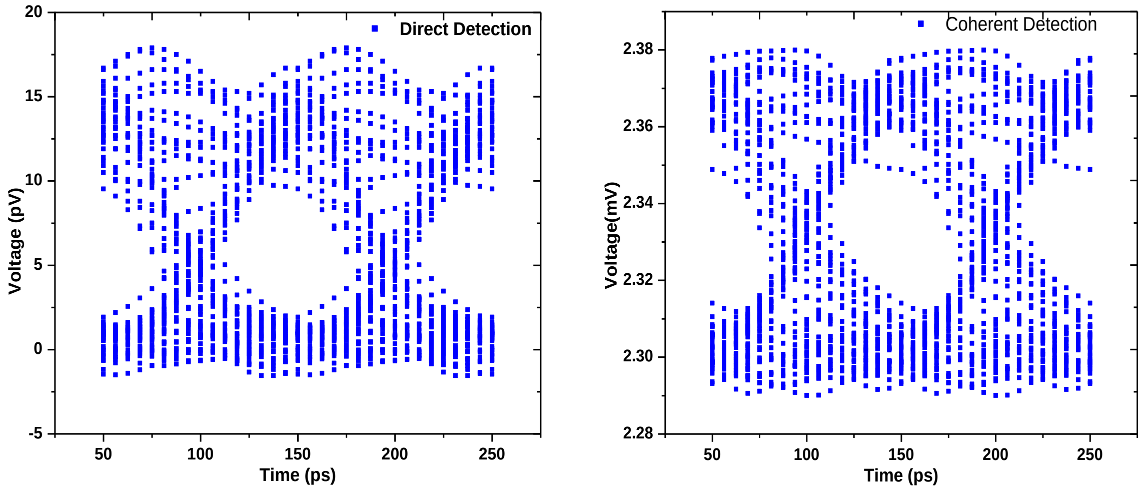

Figure 2: Eye Diagram for both direct detection and Coherent detection

Figure 2 shows eye diagram plots for back to back transmission for both IMDD and IMCD at an acceptable bit error ratio of 10^{-9} on a back to back transmission respectively. An eye diagram a qualitative and inituitive way to evaluate the signal quality. The more open the eye the better is the quality of the received signal .The IMDD transmission shows an open eye with a peak to peak voltage of 15 pV compared to a peak to peak voltage of 0.07 mV for the IMCD setup. The coherently detected signal is five fold greater than the traditional directly demodulated signal. This helps in enhancing the weak signal thereby improving the receiver sensitivity and increasing transmission reach.

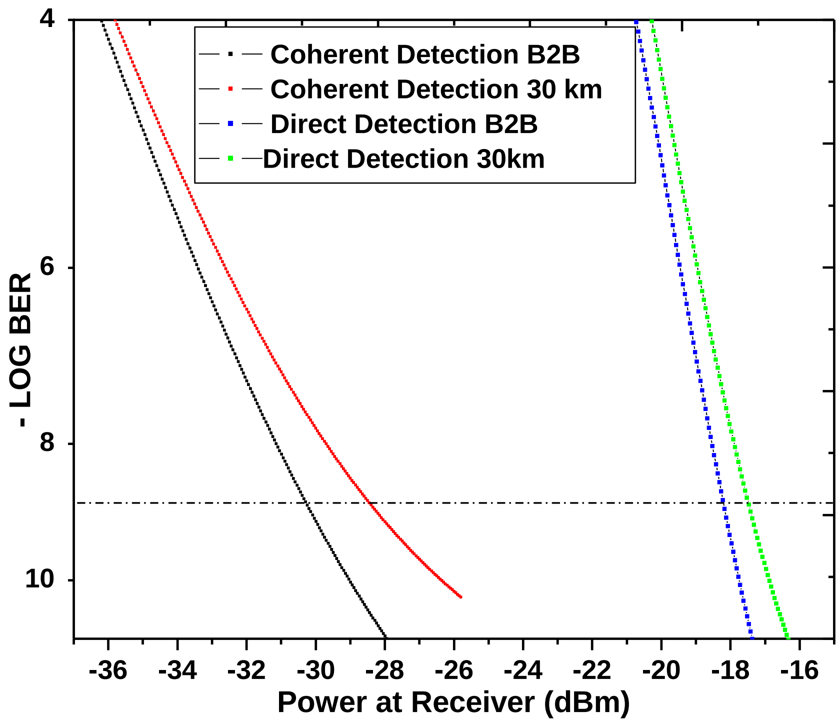

Figure 3: Bit error rate (BER) curves for back to back and after 30 km of G652 fibre

Figure 3 shows the BER curve for back to back and a transmission through a 30 km G. 652 fibre. A receiver sensitivity of -18.3 dBm and -30.4 dBm is obtained for IMDD and IMCD respectively. The IMCD has a 12.1 dB gain in receiver sensitivity compared to the IMDD. A penalty of 1.9 dB is obtained for the coherent detection scheme compared to 0.8 dB for direct detection scheme after transmission through 30 km of fibre. Power budget calculations indicate an unamplified transmission distance of 135 km for coherent detection scheme and 75 km for direct detection. In a PON the power budget gives a splitting ratio of 1:126 and 1:1994 for IMDD and IMCD respectively. The higher receiver sensitivity, higher splitting ratio and a long unamplified transmission reach makes coherent detection scheme a technology of choice for application in FTTH technology.

5. Conclusion

In this paper a performance evaluation of the traditional IMDD scheme is compared to the IMCD. IMCD coupled with the advantages of increased receiver sensitivity and a longer unamplified transmission reach is considered an option to implement in the passive optical network in the FTTH technology. In addition coherent detection scheme can be used to demodulate more spectral efficient higher order modulation formats since information can be retrieved from the amplitude, phase and frequency of received signal [5,9].

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