# Comparison between Direct and Coherent Optical Communication System

*Hani J. Kbashi** *Samar Y. Al-Dabag***
*Hadeel A. Hameed***

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## Abstract:

The work in this paper focuses on the system quality of direct and coherent communication system for two computers. A system quality is represented by Signal to Noise ratio (SNR) and Bit Error Rate (BER). First part of the work includes implementation of direct optical fiber communication system and measure the system quality .The second part of the work include implementation both the( homodyne and heterodyne)coherent optical fiber communication system and measure the system quality . Laser diode 1310 nm wavelength with its drive circuit used in the transmitter circuit . A single mode of 62.11 km optical fiber is selected as transmission medium . A PIN photo detector is used in the receiver circuit.

The optical D-coupler was used to combine the optical signal that come from transmitter laser source with optical signal of laser local oscillator at 1310/1550 nm to obtain coherent detection .

Results show that for direct detection the SNR and the BER (28.5 dB, $9.64x10^{-8}$,) respectively, while for homodyne and heterodyne coherent detection , the SNR(94.36,97.71)dB and the BER are ($1.32x10^{-22}$,$2.43x10^{-23}$) at maximum optical fiber length at 62.11 km. Results show that the homodyne and heterodyne detection are better than direct detection because the large output SNR and low BER of the received signal.

**Key words: Coherent Communication, Optical Fiber, Local Oscillator,Bit Error Rate, Signal to Noise Ratio.**

## Introduction:

Since the invention of the laser in 1960 research efforts have focused on techniques by which the coherent properties of laser light could be utilized for coherent optical communications. However, it was only in the latter half of the 1970s, when single-mode transmission from a narrow line width aluminum gallium arsenide *AlGaAs* semiconductor laser was demonstrated, that the proposals for coherent optical fiber transmission began taking shape [1] . Transmission techniques are usually divided into two main classes, direct and coherent detections, for direct detection systems, the received optical power is directly converted into photocurrent by photodiodes. While in the coherent detection systems, the received light is first combined with the beam of a local Oscillator (LO) laser .In 1995, the performance of the coherent heterodyne optical *FM* receiver employing a discriminator has been simulated under different IF filter bandwidths to find the optimal bandwidth [2].

In coherent detection other parameters of the received electrical field can be modulated, such as, its amplitude, pulse, frequency, or phase. Coherent detection can be performed using two different techniques:

*Universityof Baghdad /College of Science /Department of Physics
**Universityof Baghdad /College of Science for Women/Department of Physics

*heterodyne*, i.e., different signal and local oscillator frequencies, or *homodyne* detection, where the signal and local oscillator frequencies are equal [3]. The competing effects of stimulated and spontaneous emission on the information capacity of an amplifying disordered waveguide were studied in 2002; explicit expressions are obtained for heterodyne detection of coherent states and generalized for an arbitrary detection scheme [4].

In 2006 the development of a coherent heterodyne balanced fiber optic receiver was reported. Several examples of coherent balanced detection as enabling technology for high value applications in fiber optic communication and remote sensing were reported [5]. The best sensitivity is achieved when homodyne detection is used. However, in this case both the transmitter and LO lasers need to have narrow linewidths (LWs) and be phase-locked [6].

In 2008 continuous real time measurements are shown from a coherent 40 Gbit/s transmission system. (1, 64 and 128) G symbol/s coherent quadrature amplitude modulation (QAM) transmissions over 150 km and a heterodyne detection circuit were described [7,8].

## Materials and Methods :

The system was implemented in our work is shown in a block diagram in figure 1.

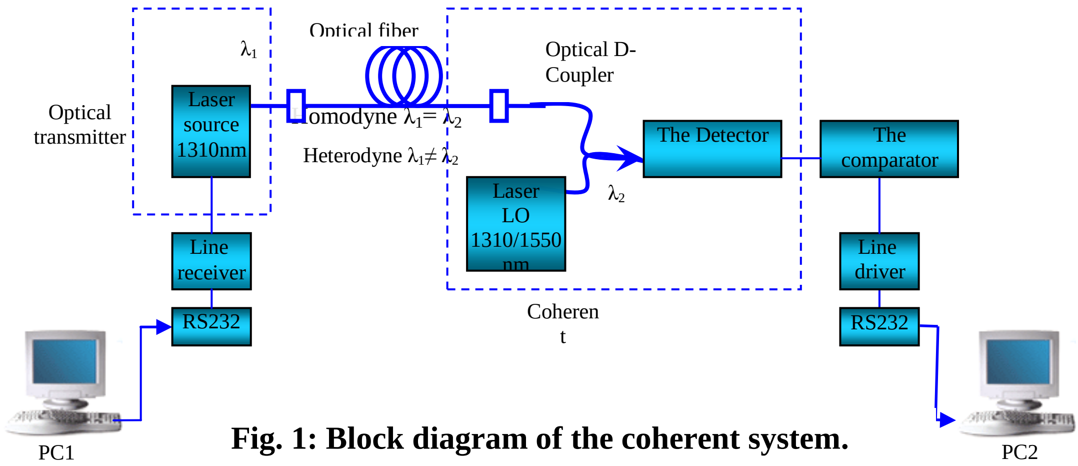


**Fig. 1: Block diagram of the coherent system.**

A same block diagram for direct detection is used except without local oscillator .

The transmitting computer is used to perform a sequence of processes, which are collectively named the *transmitting process*. The setting process is achieved by using the Microsoft comm. control 6 (MS Comm) components. The MS Comm control provides serial communications for an application by allowing the transmission and reception of data through a serial port. The serial port of the computer has been chosen as an output and input port in this work. This conversion of data was achieved by using line receiver MC1489. These data, which are converted to TTL level, are then passed to the optical transmitter. The optical transmitter consists of laser source and its drive circuit. The laser diode module operated at 1310 nm wavelength of high stability with the single mode optical fiber. The optical source used in the transmitter unit is a multiple quantum well laser HFCT-5208M. coupler 1×2 is used (two port of input signal and one port of output signal).

The coherent receiver consists of a laser local oscillator, optical detector.

This laser diode module operated at 1310/1550 nm dual wavelength of high stability with the single mode optical fiber. A PIN detector is used to convert the detected optical data into electrical signal. The signal power is measured by using optical power meter The reshape of the electrical signal in the receiver unit is done by IC 741 comparator. The data that comes from the optical detector and has to pass to the computer throughout the serial port have a TTL voltage level that must be converted to a voltage level of ±12V. This conversion is achieved by using line driver MC 1488. These data are then passed to the PC2 through the serial port. The data were received by this computer will be submitted to a sequence of software processing, collectively named *receiving process*.

## Results and Discussion:

The system quality of direct and coherent optical system is represented by calculations of the SNR and BER. The signal power is measured by using optical power meter OTS-310. The generated signal current of the detected signal in the optical detector depends on the received optical power .The signal current (*Is*) generated in the detector is given by [9]

$$I_S = P_{rec} \times R \quad ..... (1)$$

Where *Prec* is the received optical power by the detector and *R* is the responsivity( 0.36 A/W). The noise originating in the detector are thermal noise current (ith), shot noise current ($i_{shot}$) and dark current (Id). The thermal noise current is given by [9]

$$i_{th} = \sqrt{\frac{4kT\Delta f}{R_L}} \quad .... (2)$$

where *K* is the Boltzmann constant ($1.3805\times10^{-23}$ J/k) , *T* is the temperature in Kelvin , $\Delta f$ is the signal bandwidth (9.6 KHz), $R_L$ is photodetector load resistor (1 kΩ) .

the shot noise current are compute by [9].

$$i_{shot} = [2q\Delta f\,(I_S + I_d)]^{\frac{1}{2}} \quad ... (3)$$

$I_d$, he dark current of the PIN photodiode is about 4 nA, T is (300 k). The SNR is written as [9]:

$$SNR(dB) = 20\log\left(\frac{I_S}{I_N}\right) \quad ... (4)$$

Where $I_N$ is the total noise current

BER is given by [9]

$$BER = \frac{1}{\sqrt{2\pi\, SNR}}\exp\left(\frac{-SNR}{2}\right) \quad ..... (5)$$

Calculations of SNR and BER based on a practical measurements of the received optical power at different values of the single mode optical fiber length of direct detection and coherent (homodyne, heterodyne) detection are show in table 1.

**Table 1: The calculated results of the direct and coherent (homodyne, heterodyne) detection**

| L (Km) | P ( μw) Direct | P (μw) Homo | P (μw) Heter | $I_N$ (nA) Direct | $I_N$ (nA) Homo | $I_N$ (nA) Heter | S/N (dB) Direct | SNR (dB) Homo | SNR (dB) Heter | BER Direct | BER Homo | BER Hetero |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 138.03 | 265.46 | 334.19 | 0.789 | 0.94 | 1.006 | 95.97 | 100.13 | 101.54 | 1.17E-22 | 7.17E-24 | 3.52E-24 |
| 3.37 | 99.54 | 210.37 | 283.13 | 0.73 | 0.881 | 0.958 | 93.81 | 98.68 | 100.53 | 3.51E-22 | 1.49E-23 | 5.87E-24 |
| 7.09 | 59.56 | 169.43 | 241.54 | 0.655 | 0.831 | 0.915 | 90.29 | 97.3 | 99.55 | 2.08E-21 | 2.99E-23 | 9.65E-24 |
| 13.88 | 23.33 | 132.73 | 204.17 | 0.559 | 0.781 | 0.873 | 83.52 | 95.72 | 98.49 | 6.35E-20 | 6.67E-23 | 1.64E-23 |
| 18.47 | 12.38 | 123.02 | 193.19 | 0.515 | 0.767 | 0.861 | 78.72 | 95.22 | 98.14 | 7.21E-19 | 8.59E-23 | 1.96E-23 |
| 23.71 | 6.01 | 115.34 | 186.63 | 0.48 | 0.755 | 0.853 | 73.07 | 94.79 | 97.92 | 1.27E-17 | 1.06E-22 | 2.19E-23 |
| 30.24 | 2.44 | 111.42 | 182.81 | 0.45 | 0.749 | 0.848 | 65.79 | 94.56 | 97.79 | 5.08E-16 | 1.19E-22 | 2.34E-23 |
| 35.69 | 1.15 | 109.9 | 181.55 | 0.434 | 0.747 | 0.846 | 59.57 | 94.47 | 97.74 | 1.2E-14 | 1.25E-22 | 2.39E-23 |
| 41.87 | 0.49 | 108.89 | 181.13 | 0.422 | 0.745 | 0.846 | 52.41 | 94.41 | 97.73 | 4.57E-13 | 1.29E-22 | 2.41E-23 |
| 50.45 | 0.15 | 108.14 | 180.71 | 0.412 | 0.744 | 0.845 | 42.34 | 94.36 | 97.71 | 7.82E-11 | 1.32E-22 | 2.43E-23 |
| 54.15 | 0.09 | 108.14 | 180.71 | 0.409 | 0.744 | 0.845 | 37.96 | 94.36 | 97.71 | 7.37E-10 | 1.32E-22 | 2.43E-23 |
| 58.41 | 0.05 | 108.14 | 180.71 | 0.407 | 0.744 | 0.845 | 32.91 | 94.36 | 97.71 | 9.92E-09 | 1.32E-22 | 2.43E-23 |
| 62.11 | 0.03 | 108.14 | 180.71 | 0.405 | 0.744 | 0.845 | 28.5 | 94.36 | 97.71 | 9.64E-08 | 1.32E-22 | 2.43E-23 |

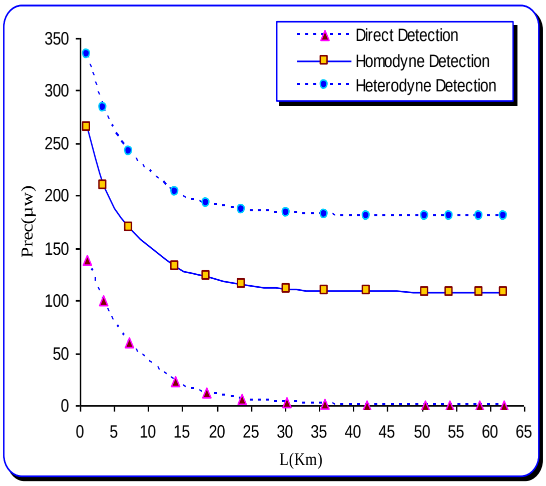


**Fig. 2: The variation of received optical power with optical fiber length**

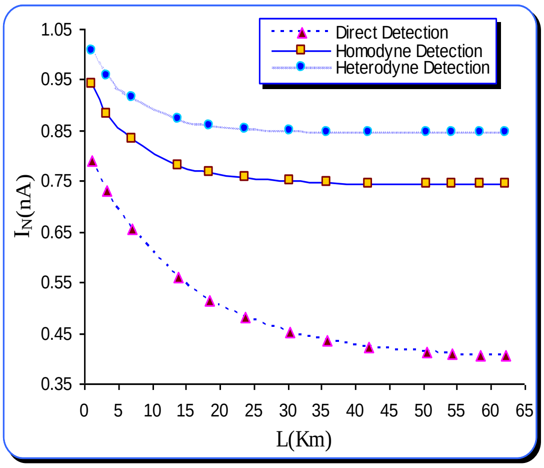


**Fig. 3: The variation of the noise current with the optical fiber length.**

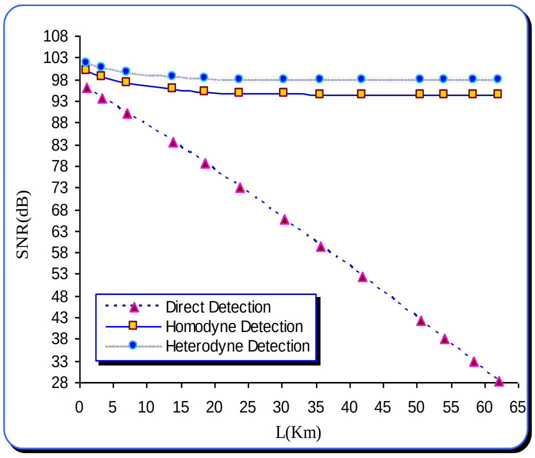


**Fig. 4: The variation of SNR with the optical fiber length**

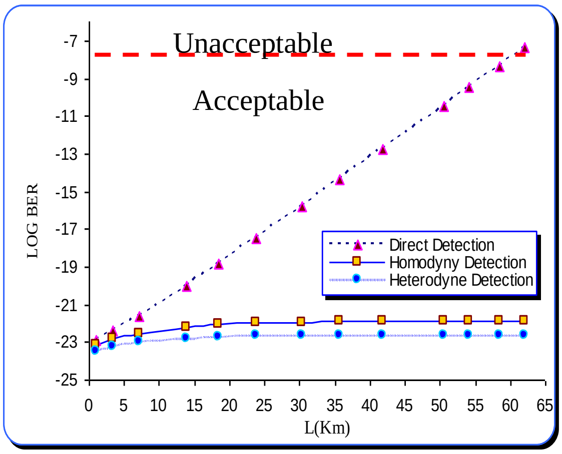


**Fig. 5: The variation of the logarithm of BER with the optical fiber length.**

Figure 2 shows that the received optical power decreases with the increase of the optical fiber length exponentially, in direct detection the optical power is decrease continuously duo to the optical power is ended, and the decrease is stopped at homodyne and heterodyne detection, means the local oscillator is work as amplifier. Figure 3 show the total noise current for coherent detection is more than for direct detection due to the high power incident at the detector which leads to increase the shot noise current. From figure 4 the SNR is decreased rapidly with increasing the optical fiber length in direct detection because the optical power decrease result the attenuation effects and chromatic dispersion in optical fiber while in coherent detection the SNR is semi constant in each fiber lengths. This means that the system is acceptable for 62.11Km. Results show that the SNR is 28.5dB and the BER is $9.64 \times 10^{-8}$, while for homodyne and heterodyne coherent detection , the SNR(94.36,97.71)dB and the BER are ($1.32 \times 10^{-22}$,$2.43 \times 10^{-23}$) at maximum optical fiber length at 62.11 km.

The last value of the BER at optical fiber length 62.11km of direct detection is unacceptable because the acceptable order value of the BER in optical digital transmission is $10^{-9}$, it means need optical amplifier after thislength. While the last value of the BER at optical fiber length 62.11 km of homodyne and heterodyne detection is acceptable. The coherent detection is used to increase selectivity of the receiver. No need to amplify the received optical power after this length in coherent detection

Figure 5 show that BER increased with increasing the optical fiber length due to the depended on the SNR. from this figure the variation of BER is very small in coherent system with increasing of the fiber length. A higher BER as compared to direct detection.

## Conclusions:

1-Results show that the homodyne and heterodyne detection are better than direct detection because the large output SNR and low BER of the received signal.

2-Direct optical communication system need amplifier for optical fiber longer than 62.2 km while coherent optical communication system does not need amplifier.

3- This system uses a simple and low cost interface circuit to connect between two PC using a fiber optic link.

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# مقارنة بين نظام أتصال ضوئي متشاكه ومباشر

***هاني جاسم كباشي*** ***سمر يونس الدباغ***** ***هديل علي حميد*****

*جامعة بغداد/كلية العلوم / قسم الفيزياء
**جامعة بغداد/كلية العلوم للبنات / قسم الفيزياء

**الخلاصة:**

هذا العمل يركز على نوعية االنظام ( System quality) لمنظومة اتصال ضوئي متشاكه ومباشربين حاسبتين. نوعية االنظام تتمثل بحساب كل من نسبة الاشارة الى الضوضاء (SNR) و بمعدل الخطأ في نقل البيانات (BER) .

الجزء الاول من العمل تضمن تنفيذ لمنظومة اتصال مباشربين حاسبتين وحساب نوعية االنظام. اما الجزء الثاني من العمل تضمن تنفيذ لمنظومة اتصال متشاكه (متجانس والغير متجانس )وحساب نوعية االنظام لاجل المقارنة بين المنظومتين .استخدم ليزر دايود ذو الطول الموجي1310nm ودائرة السوق في دائرة المرسلة. ا ختير الليف الضوئي من نوع احادي النمط كوسط ناقل طوله62.11km. استخدم مستقبل الاشارة البصرية من نوع الكاشف الضوئي PIN

الروابط الضوئية من نوع D استخدمت لدمج الاشارة البصرية القادمة من المصدر الليزري المرسل مع الاشارة البصرية لليزر المذبذب المحلي ذو الطول الموجي 1310 nm و 1550 nm للحصول على الكشف المتشاكه (المتجانس والغير متجانس) .

اظهرت النتائج ان معدل الخطأ في نقل البيانات BER($9.64X10^{-8}$,$1.32x10^{-22}$,$2.43x10^{-23}$) *ونسبة الأشارة الى الضوضاء* SNR dB(28.5,94.36,97.71)عند اعلى طول لليف البصري 62.11 km لمنظومة اتصال ضوئي مباشر و متشاكه بين حاسبتين .

اظهرت النتائج ان منظومة الاتصال الضوئي المتشاكه افضل من منظومة الاتصال الضوئي المباشر وذللك لحصول على قيم عالية لنسبة الأشارة الى الضوضاء وقيم واطئة لمعدل الخطأ في نقل البيانات مقارنة بمنظومة الاتصال المباشر