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Design and Implementation of a Network Based on Wavelength Division Multiplexing (WDM)

تصميم وتنفيذ شبكة تعتمد المزج بتقسيم الطول الموجي

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Abstract

The Wavelength Division Multiplexing WDM is a technology used to expand fiber optic bandwidth by enabling signals from different sources to independently travel together on a single optical fiber. The purpose of the work is to increase the link distance between two Ethernet LANs by using the single optical fiber link for both directions of transmission (i.e. one fiber for transmission and reception) since the maximum link distance is limited upto 100m. The link utilizes the Wavelength Division Multiplexing -WDM technique. A bidirectional link was implemented using two port wavelength division multiplexing components (that includes a wavelength division multiplexer and a wavelength division demultiplexer) with optical sources of wavelengths of 1550 nm and 1310 nm. An Ethernet to optical fiber converter card was designed and implemented for the purpose of converting the electrical signal to an optical signal suitable for the transmission over the optical fiber for utilizing the optical fiber transmission characteristics. The implemented system worked correctly. Twelve pieces of single mode optical fiber were used in the work each of length of 5.1 km and they connected with each others by splices each of losses of 1 dB. The total link distance become 61.2 km.

The Bit Error Rate- BER of the full duplex system was investigated as well as the effect of dispersion on the system. From the results it was concluded that the system was not limited by the dispersion effect.

"Optical communication system, Wavelength division multiplexing".

خلاصة

المزج بتقسيم الطول الموجي WDM تقنية تستعمل لزيادة عرض نطاق الليف الضوئي من خلال تمكين اشارات من مصادر ضوئية مختلفة لتنتقل سوية بشكل مستقل خلال ليف ضوئي منفرد . الغرض من العمل لزيادة مسافة الاتصال بين شبكتي ايثرنت من خلال استخدام ليف ضوئي مفرد لنقل المعلومات باتجاهين (ليف واحد للارسال والاستلام) لان اكبر مسافة محدودة ب 100 م . النظام يستفيد من تقنية المزج بتقسيم الطول الموجي. تم بناء نظام نقل باتجاهين باستعمال منفذين للتقسيم المتماثل للطول الموجي (التي تتضمن مازج تقسيم الطول الموجي و فاك مزج تقسيم الطول الموجي) مع مصدر من الليف الضوئي بطول موجي 1550 نانو متر و 1310 نانو متر. تم تصميم و بناء كارت تحويل من الايثرنت الى الليف الضوئي لغرض تحويل الاشارة الكهربائية لاشارة ضوئية تناسب النقل خلال الالياف الضوئية للاستفادة من من خصائص النقل خلال الالياف الضوئية. النظام المصمم عمل بصورة صحيحة . تم استعمال 12 قطعة من الليف الضوئي احادي النمط في العمل كل واحدة بطول 5.1 كيلو متر وهي متصلة كلا ببعضها بوصلات في كل منها خسارة 1 dB . الطول الكامل للسلسلة ستصبح بمسافة 61.2 كيلو متر . معدل خطأ البت BER لنظام مزدوج كان يبحث جيدا التاثيرات الخاصة بالتشتيت في النظام . من النتائج يمكن الاستنتاج ان النظام لم يكن محددا بتاثير التشتت.

1- Introduction

Optical networks using Wavelength Division Multiplexing WDM are powerful techniques to exploit the enormous bandwidth offered by optical fibers [1, 2,3]. WDM is a very crucial component of optical networks that allows the transmission of data: voice, video-IP, ATM and SONET/SDH respectively, over the optical layer [4,5].

WDM involves a small number of physical-layer functions. The system performs the following main functions: generating the signals, combining them, transmitting them, separate the received ones and receive them properly. Thus, each channel (that one can actually considers as a wavelength, simply by assigning to it the proper bandwidth parameter value) can be obtained separately; and in the same way, many channels can be introduced into a transmitter module as if they were different wavelengths, getting separately at its exit the set of wavelengths travelling over the same link (that we can consider a fiber). Multiplexers and demultiplexers can be either passive or active in design. Passive designs are based on prisms, diffraction gratings, or filters, while active designs combine passive devices with tunable filters.

An optical fiber helps transmit signal in both directions. Based on this feature, an WDM system can be implemented in two ways: unidirectional in which all wavelengths travel in the same direction within the fiber. It is similar to a simplex case, and bi-directional in which the channels in the WDM fiber are split into two separate bands, one for each direction. This removes the need for the second fiber, but, in turn reduces the capacity or transmission bandwidth [2].

The primary challenges in these devices are to minimize cross talk and maximize channel separation. Crosstalk is a measure of how well the channels are separated, while channel separation refers to the ability to distinguish each wavelength. The factor controlling channel spacing is the capability of the receiver in identifying two close wavelengths. So it sets the lower bound on the channel spacing [8].

Another important limiting factor is the dispersion. The important form of dispersion is group velocity dispersion (GVD) causes a severe pulse spreading and leads to intersymbol interference (ISI). However, as data rates increased and pulses occupied lesser and lesser time slots, group velocity dispersion and nonlinearities which includes self phase modulation, cross phase modulation and four wave mixing (SPM, XPM, and FWM respectively) became important considerations.

In optical communication systems, chromatic dispersion and nonlinearities are physical limits to the information capacity and transmission distance. The linear nature of light propagation in optical fiber has made these limits are difficult to elucidate [7,8].

2- Performance of the optical fiber communication link

The performance criterion for digital receiver is governed by the bit error rate BER, defined as the probability of incorrect identification of a bit by the decision circuit of the receiver [1]. For a common optical receiver, the required BER is $\leq 1 * 10^{-9}$[8]. The BER with the optimum setting of the decision threshold is obtained as in follows [9, 10]

$$BER = \frac{exp(-SNR)}{\sqrt{2\pi\, SNR}} \qquad [1]$$

And for the PIN photodiode receiver [9]

$$SNR\,(dB) = 20\ log\left(\frac{i_s}{\left[eB\left(i_s + i_d\right)\right]^{1/2} + \sqrt{\dfrac{4KTB}{R_L}}} \right) \qquad [2]$$

where K is the Boltzman constant, T is the temperature in Kelvin, B is the bandwidth, e is the electron charge, and i_s is the signal current generated due to the incident optical power in the optical detector.

A rise time budget analysis is a convenient method for determining the dispersion limitation of an optical fiber system. The system rise time t and the bit pulse width τ are related according to

$$t = 0.35\tau \qquad [3]$$

and must be higher than the overall rise time t_{sys} given in the formula equation: [11, 12,13]:

$$t_{sys}^2 = t_{transmitter}^2 + (D \times \sigma_\lambda \times L)^2 + t_{reciever}^2 \qquad [4]$$

Where σ_λ the root mean square spectral width of the laser diode, D is dispersion parameter in psec/ (km. nm) and L is the optical fiber length in km. Thus, if the individual rise time is known, the calculation of the rise time of the whole system is possible, and by knowing that, a decision can be made whether the system is fast enough for the information rate that it is supposed to carry [11, 12]. The rise times of the transmitter and the receiver will be given by the manufacturer. The fiber rise time, however, has to be calculated, because it depends on the length of the fiber and therefore is different for different systems. Calculation of fiber rise time is composed of two main components modal rise time t_m and chromatic rise time (or GVD) t_{GVD}. In general, Single mode fibers don not experience modal dispersion, so in these fibers the rise time is related only to GVD.

3- Implemented system and Results

The system implemented is based on connecting two Ethernet LANs. The network is based on the TCP/IP protocol. Since the Ethernet LAN is limited to a maximum distance, the 10Base-T/Fiber converter interface card is used to extend the distance between the users (i.e. the tow PCs) by replacing the Unshielded Twisted Pair (UTP) cable by an optical fiber .

The 10Base-T (UTP) to Single-Mode Optical Fiber converter interface card is connected between two different media; they are the copper unshielded twisted pair (UTP) cable and the single mode optical fiber cable as shown in Figure (1). The Ethernet to Single-Mode fiber optic converter takes 10Base-T Ethernet electrical signals and converts them to/from optical signals that are transmitted / received over single-mode optical fiber cables.

The main advantage of using the Ethernet/Fiber converter card is to extend the maximum distance of the Ethernet LANs to a distance greater than the 100m maximum limit.

The fibers used in the work are single mode fibers. Each with 10/125 µm core to cladding radius, 1.48 core refractive index, 0.11 – 0.14 µm numerical aperture, 0.2 and 0.6 dB/km attenuation for 1310 and 1550 nm wavelengths respectively and 100GHz bandwidth. The splices loss is about 0.03 dB measured using Optical Time Domain Range (OTDR) and connection loss of 1 dB for each connector.

The 2 computers are connected with each others by using the optical fiber as a transmission media. The maximum distance used in the work was 61.2 km, which consists of multi segments each with length of 5.1 km length. The splices that used for connecting these pieces with each others.

The BER of the system was monitored and it decreases as the distance of the transmission is increased as illustrated in Figure (2). In general, the BER in the case with adding the WDM components is less than that without WDM. This is due to the losses contribution resulted from increasing number of the connectors, crosstalk and insertion losses.

The bit rate of the optical link is the same bit rate (R) of the 10Base-T link, which is 10Mbps. Since 10Base-T uses the Manchester signal encoding scheme, therefore; BW = 2R = 20MH$_Z$. Since τ =1/BW=50ns, then the pulse rise time is equal to 0.35*50ns=17.5ns

For the 155nm link, the initial width of the optical pulse τ was 50 nsec which is used as a reference width. After propagation distance of a kilometer, the pulse width is 50.00075nsec. The measured pulse broadening after one kilometer propagation distance was 0.75 psec. The dispersion parameters D would be 17.626 psec/km.nm. Figure (3) shows how the overall rise time varies with distance. From the

Figure it can be noticed that the system is not limited by dispersion since overall rise time is less than 17.5 ns.

4- Conclusion

The implemented system worked correctly for transmission of information over a distance of 61.2 km in full duplex mode using the WDM components. The BER for different length and hence SNR was investigated. BER was about 10^{-8} for 62.1 km of distance. Also it is found that the overall system rise time was less than rise time which was 17.5 ns even for 62.1 km distance where it was about 7.5 ns. This indicates that the system was not limited by dispersion and there was no intersymbol interference ISI occurred.

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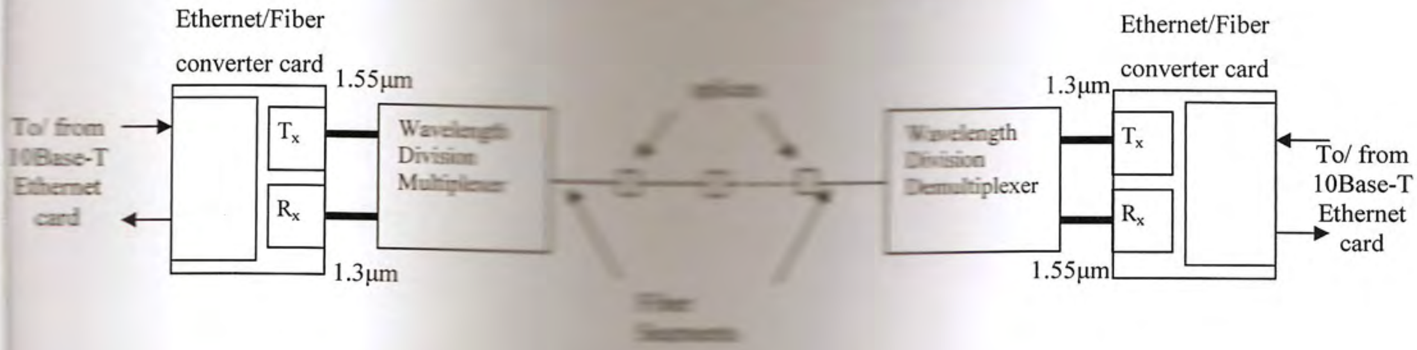

Figure 1: Block Diagram of the Implemented System

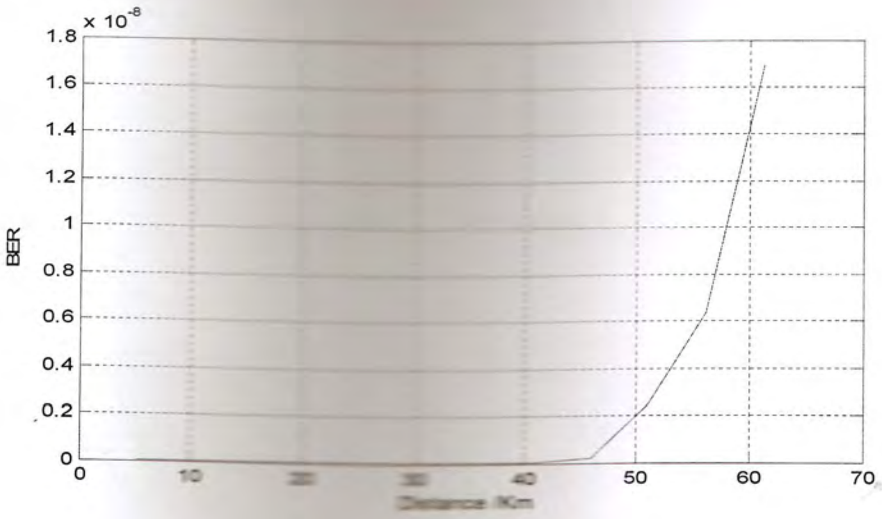

Figure 2: BER versus Distance of Transmission

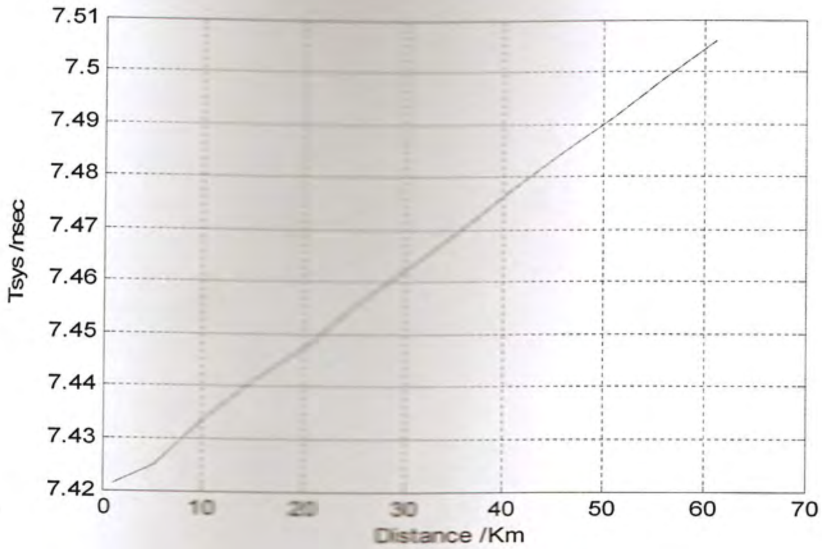

Figure 3: Overall Rise Time versus Distance of Transmission

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