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WDM–OTDM based spectral efficient hybrid multiplexing technique inherent with properties of bandwidth elasticity and scalability

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Abstract

In this paper a hybrid multiplexing technique has been presented that merges WDM and OTDM multiplexing technologies. The WDM–OTDM hybrid realizes wavelength parallel bus architecture and is inherent with features of high spectral efficiency, high scalability and bandwidth elasticity. Simulations and experiments were carried out to investigate the selection of most suitable modulation format, dispersion compensation technique and erbium doped fiber amplifier (EDFA) noise figure for WDM–OTDM hybrid, where link lengths exceeding 500 km at high Q-values was achieved.

Keywords: WDM; OTDM; EDFA; Multiplexing technique

1. Introduction

An increased channel capacity coupled with enhanced operational flexibility is the requirement of future high capacity optical transmission systems [1]. This calls for the selection of an efficient transmission technology that can be implemented in future systems [2]. A single fiber is sufficient to provide all services like voice, data, multimedia, cable TV and internet facilities to the end user. All these services have to be multiplexed and transmitted on a single fiber which will deliver the services at the doorsteps of the end user. The multiplexing approach based on electronic signal processing become increasingly complex and expensive with higher data rate and channel capacity. An all optical approach is aimed at transferring MUX/DEMUX operations into optical domain, to relieve the electronic speed bottle neck [3]. The achievable bit rate in electrical domain is about 40 Gbps as against that achievable in optical domain being of the order of 10–20 Tbps [2,4].

Among the various multiplexing techniques developed from time to time for utilization of the wide bandwidths of optical fibers, and for better exploitation of the existing transmission infrastructure are WDM and OTDM. On one hand WDM technology offers less complexity in signal generation and an improved system upgrade capability, and on other hand OTDM can be efficiently used for the generation of higher channel data rates exceeding 10 Gbps [2].

This paper has been focused on development of a unique WDM–OTDM hybrid technology that is based on parallel wavelength bus architecture [5,6]. The WDM–OTDM based technology is characterized by similar features as that of a wavelength bus and additionally offers advantages inherent of a WDM–OTDM hybrid combine. The paper is

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further aimed at investigating the technique that can improve the performance of the unique WDM–OTDM hybrid wavelength bus through an increase in the spectral efficiency and link length.

The rest of this paper is organized as follows: after introduction in Section 1, in Section 2 system description is discussed. Section 3 compares the results obtained by simulating the said technique by using different contending, spectral efficient modulation formats and dispersion compensation techniques and Section 4 concludes the paper.

2. Model description

In this proposed method the data sources are parallel bit interleaved and then the resulting interleaved group of bits is transmitted using WDM. The proposed WDM–OTDM based technology overcomes the limitations of the prior WDM systems by supporting sources more in number than the number of wavelengths, each at a different rate and each of different types.

It offers advantage of bandwidth elasticity, payload versatility, and bandwidth scalability. It utilizes the bandwidth efficiently by incorporating the increased channel capacity and high spectral efficiency feature of a WDM and OTDM combine. In this method the undesirable delays and latency are also reduced by providing a unique technique of parallel bit interleaving.

The WDM–OTDM hybrid-based wavelength-bus on transmitter side model is presented in Fig. 1. The data source Channel 1, 2, 3 and 4 represent the sources of serial data bit streams A, B, C and D, respectively, at the

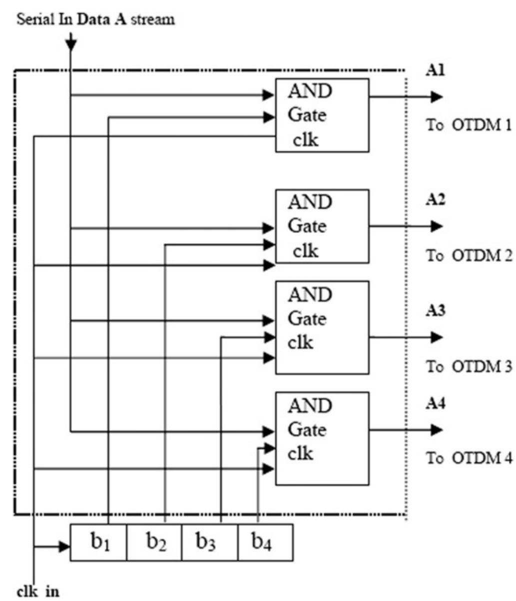

Fig. 2. Subsystem T1.

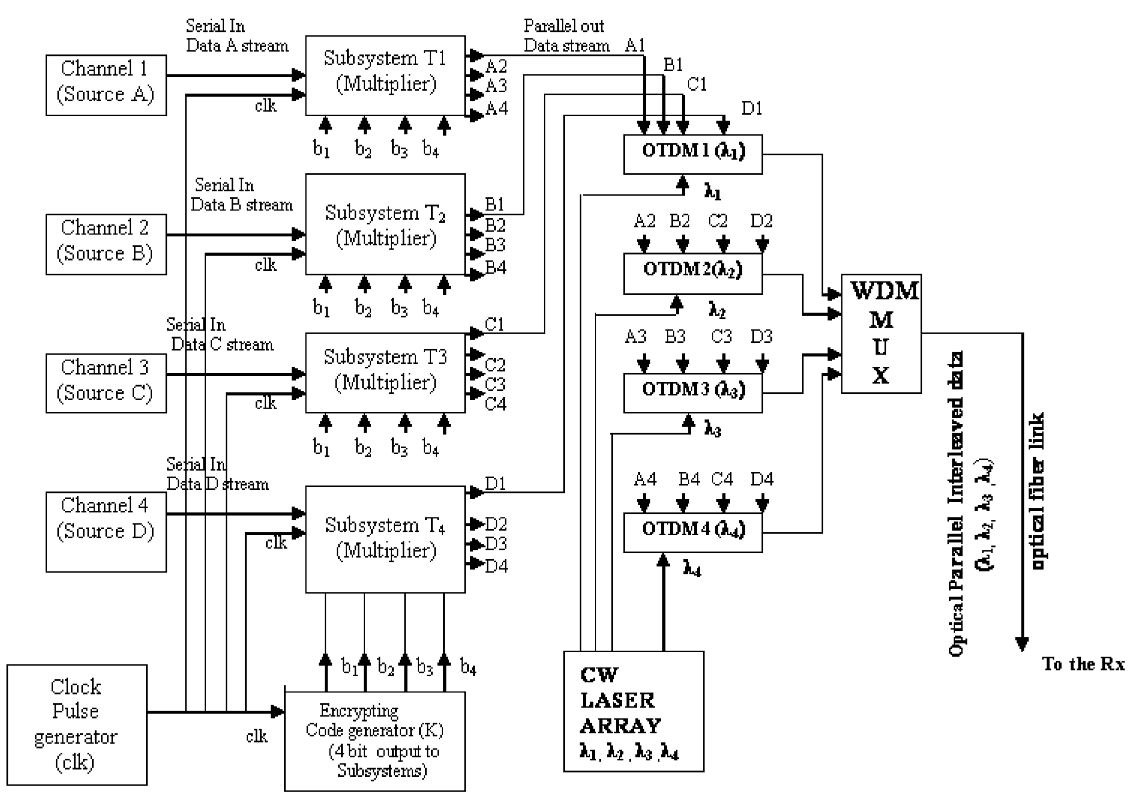

Fig. 1. WDM–OTDM hybrid wavelength-bus (transmitter side).

same bit rate. The binary data is converted to any desired modulation format e.g. NRZ, RZ, Gaussian or soliton pulses in this stage and then fed to their respective subsystems. The number of sources can exceed the number of wavelength rails for which the wavelength bus is designed without requiring much change in the structure of the rest of the hybrid system. This ensures a bandwidth elastic and scalable transportation technique. For example, for transmitting five sources over four rails, now five bits, each from different sources is made available to each OTDM.

The code generator comprises of four 1 bit registers or flips flops. Each will provide a high output successively by rotation thus separating out four successive bits on four different output lines. It has being ensured by the clock pulse input to these flip flops. The clock shifted, 4-bit binary code b_1 b_2 b_3 b_4 so generated is applied as one of the inputs to the logic AND gate within each subsystem besides the clock pulse and the respective serial data bit streams.

In general an N bit code will separate out N bits of an input data byte to be transmitted over an N-λ wavelength bus. The code generator can also be designed to generate a scrambling encoding pattern that will operate on the input data to secure the data at the physical layer.

The description of internal structure of subsystems is shown in Fig. 2. Each subsystem has four AND gates. Here serial data bit streams, clock pulse and the four bit code b_1 b_2 b_3 b_4 generated by the code generator are fed simultaneously to all the logic gates within a subsystem. For a code input of 1000 on first clock pulse, all first bits of data sources A, B, C and D are outputted. Similarly 0100 on second clock shift, 0010 on third clock shift and 0001 on fourth clock shift successfully output the second bits, third bits and the fourth bits, respectively, from each subsystem. The separated out bits from each subsystem available on each clock pulse is applied to the optical time division multiplexers.

The successive bits from each data source available on a clock pulse are time division multiplexed in optical domain using four wavelength CW laser source (λ_1, λ_2, λ_3, λ_4). The operation of optical time division multiplexer (OTDM) is presented in Fig. 3. The OTDM 1 multiplexes the incoming separated out data bits from different sources to produce an optically time division

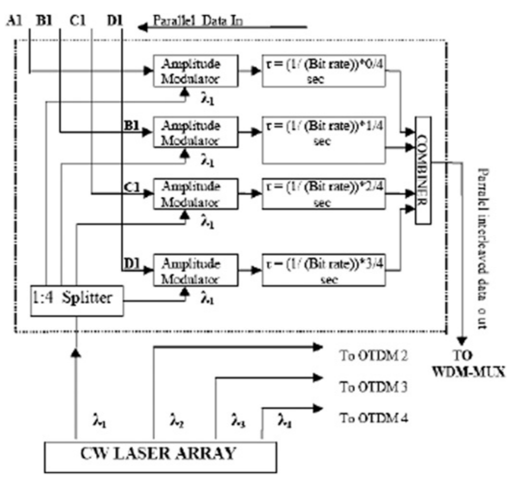

Fig. 3. OTDM 1.

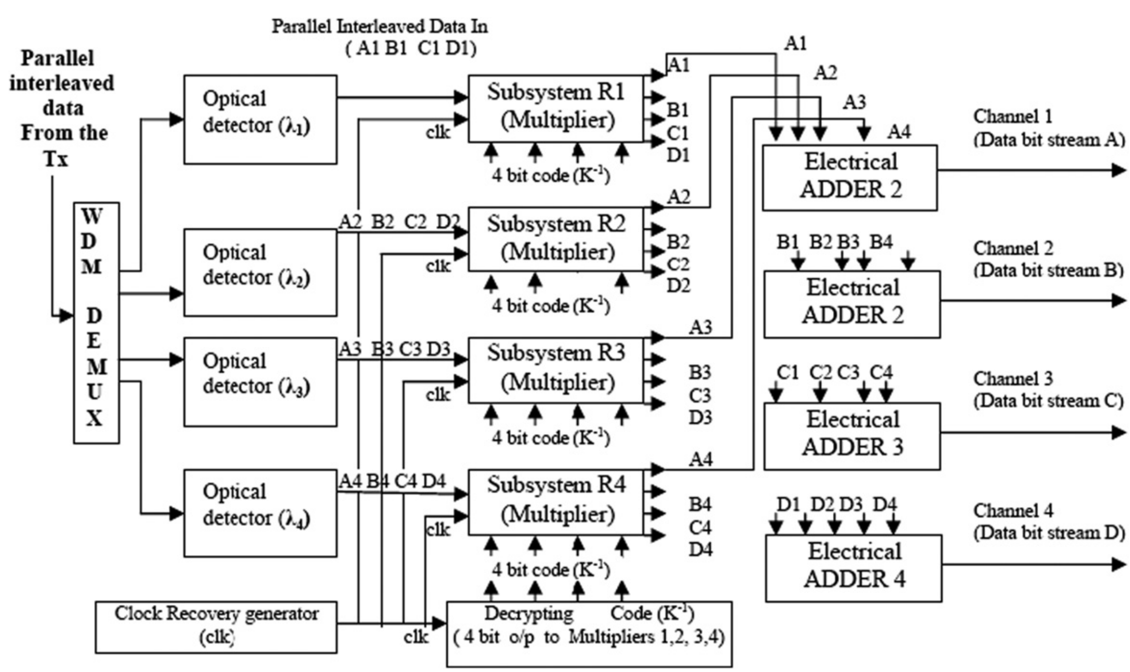

Fig. 4. WDM–OTDM hybrid wavelength-bus (receiver side).

parallel interleaved output at four times the bit rate using λ_1 wavelength rail of the wavelength bus. Similarly OTDM 2, OTDM 3 and OTDM 4 also produce the parallel interleaved data bits which are available at the next clock pulses, over the rails λ_2, λ_3, and λ_4, respectively. Scrambling of the data is also accomplished within the OTDM with ease by introducing a delay to each bit according to a predetermined pattern ensuring another level for securing the data. Here depending upon the value of the delay introduced the scrambling can be achieved to change the order of the bits transmitted.

The WDM–OTDM hybrid-based wavelength bus on receiver side is shown in Fig. 4. The output from each OTDM is combined by a WDM-multiplexer to be transmitted as parallel data over a 4-λ wavelength bus on an optical fiber link. The resulting bit rate is 4*B where B is the data rate of each individual data source. Also four optical detectors are used that are centered at λ_1, λ_2, λ_3 and λ_4, respectively. The resulting output of each optical detector is the parallel interleaved data in electrical domain.

Moreover, subsystem R1–R4 on the receiver side of the hybrid, functions in a similar manner and has an internal structure that is identical to that on the transmitter side. It also consists of four AND gate inputted with a serial bit stream that represents the parallel interleaved data at a bit rate of 4*B. Its operation will be initiated by a synchronous clock. Thus on multiplying with the same binary code pattern that was used at the transmitter subsystem, again four successive bits are separated out. Each of these is available on each output line of each subsystem. For example, the output of subsystem R1 will be A1, B1, C1 and D1 on the four output lines.

Each input line of an electrical adder is connected to four output lines, one from each subsystem, in order. The output of each adder is the recovered data bit stream that was transmitted from each source with the bits having retained their original positions in the time domain.

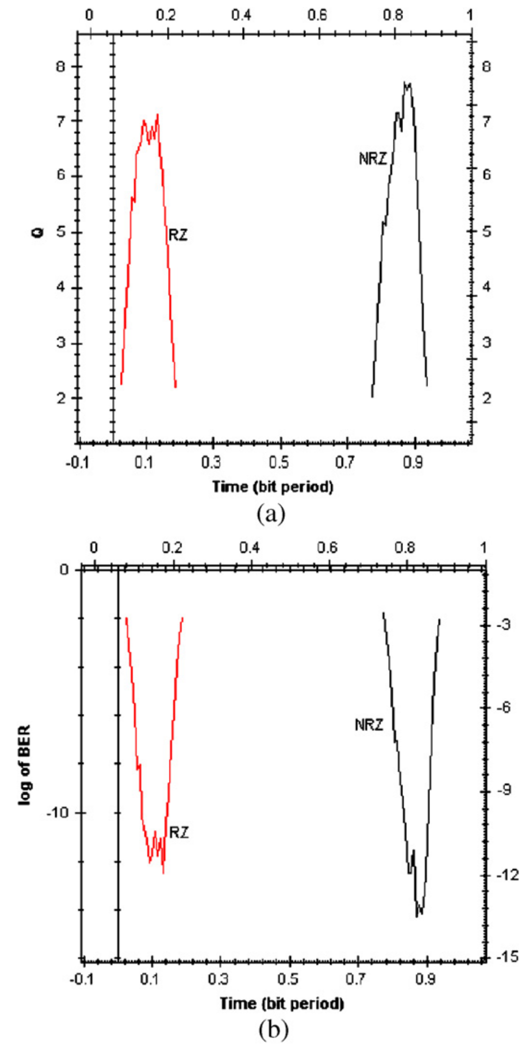

Fig. 5. (a) Quality factor (Q) and (b) bit error rate (BER) for channel 1 for RZ- and NRZ-based transmission system. (Using pre-compensation dispersion technique.)

3. Results and discussion

The performance of any optical fiber communication system is measured in terms of three parameters: spectral efficiency, maximum link length and usable system bandwidth.

The proposed transmission system was simulation using OptiSystem^{TM} and the results have been investigated for the selection of a modulation format which exhibit high spectral efficiency. The related results are given in Fig. 5. To increase the link length between the transmitter and the receiver, dispersion compensation techniques are used. The system was investigated by incorporating pre-, post- and symmetrical-dispersion compensation techniques. The results are presented in Fig. 6. Finally usable bandwidth is extended to accommodate more number of channels over the uniform gain characteristics of the EDFA used. The last sets of results are presented in Fig. 7 that were obtained by simulating the transmission system at different values of noise figure for the EDFA.

The WDM–OTDM hybrid transmission system was simulated using return-to-zero (RZ) and non-return-to-zero (NRZ) modulation. The results in Fig. 5 shows the quality factor achieved with RZ and NRZ modulation format in case of channel 1 (data bit stream A). It was observed that the NRZ-based systems show better performance over RZ-based systems in case of all channels (data bit stream A, B, C and D). The Q-value (quality factor) of NRZ-based transmission system is

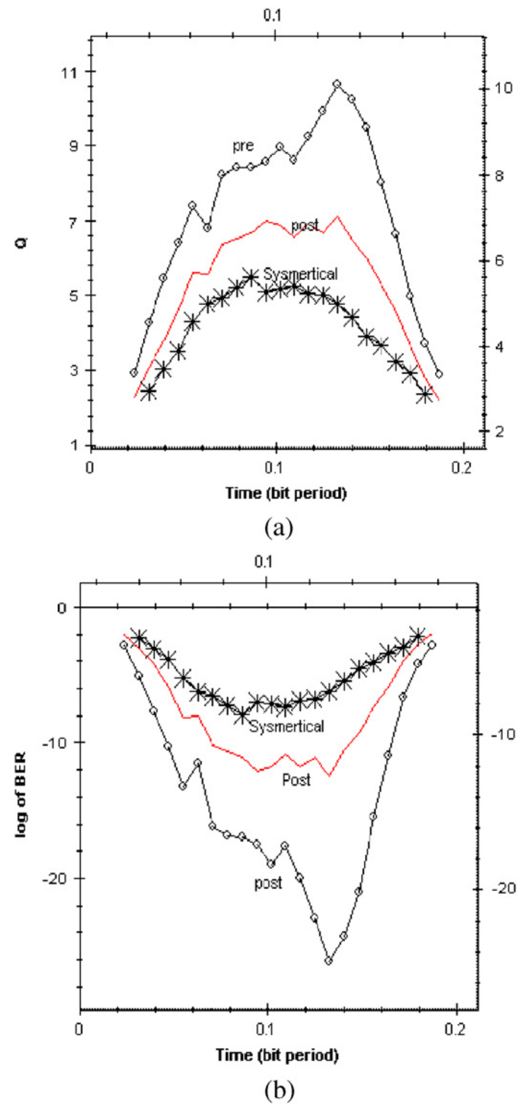

Fig. 6. (a) Quality factor (Q) and (b) bit error rate (BER) for channel 1 for pre- post- and -symmetrical compensated fiber link. (Using RZ modulation format.)

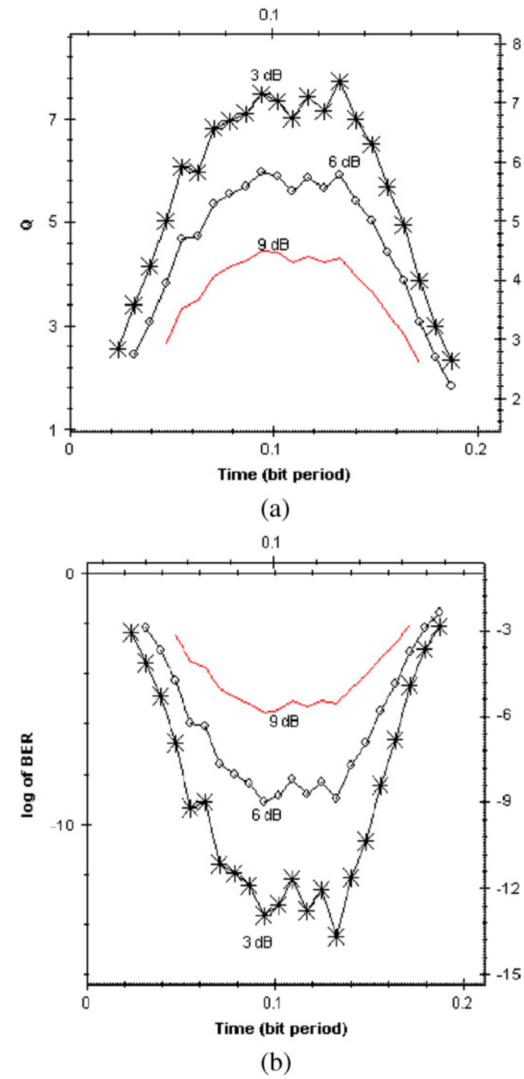

Fig. 7. (a) Quality factor (Q) and (b) bit error rate (BER) for channel 1 with values of the noise figure at 3, 6 and 9 dB, respectively. (Using RZ and pre-compensation dispersion technique.)

higher than RZ-based systems. The bit error rate also is least for the NRZ-based systems. Better performance of an NRZ-based transmission system is expected since RZ code has a broader signal spectrum in comparison to NRZ coding and RZ-based formats exhibit an increased sensitivity to dispersion and a significant nonlinear tolerance. On the other hand, although NRZ-based formats exhibit low nonlinear tolerance but exhibit high dispersion tolerance and are spectrally more efficient than RZ-based formats. However, where minimum bandwidth is needed with NRZ coding but it lacks any timing information which is essential for OTDM systems.

The graphs as shown in Fig. 6 were obtained by simulating the transmission systems using the three different dispersion compensating schemes i.e. pre-, post-, and symmetrical-dispersion compensation. The compensation techniques are used to compensate the accumulated dispersion in the fibers so that performance can be improved under reduced dispersion compensation conditions. Comparison of the Q-value and BER results showed that pre-compensated fibers perform better than post-compensated fibers. Symmetrical compensated fibers show least values of Q and high BER as compared to the other two compensation techniques.

The results presented in Fig. 7 were obtained by observing the change in the performance of the system for the noise figure of the EDFA at 3, 6 and 9 dB. As is expected the performance of the system is the best when an EDFA is used with noise figure of 3 dB. Observation of these plots also show a significant increase in Q values and significant reduction of BER as the noise figure was reduced from 9 to 6 dB and then to 3 dB.

4. Conclusions

The simulation results indicate that the growing demand for higher bandwidth requirements can be met by increasing the capacity and efficiency in fiber optical networks. Proposed WDM–OTDM hybrid technology can be implemented in the optical networks for tapping the transmission capacity of a fiber. The proposed method offers combined advantages of WDM and OTDM as well as overcomes their limitations. Further enhancement of the hybrid technology is possible by selecting a spectrally efficient modulation scheme and a suitable dispersion compensation technique. Link lengths achievable for transporting the interleaved data over the secure optical link exceeded 500 km when NRZ format, pre-compensation technique and EDFA with low noise figure has been used.

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