International Journal of Academic Research and Development
ISSN: 2455-4197
Impact Factor: RJIF 5.22
www.academicsjournal.com
Volume 3; Issue 1; January 2018; Page No. 520-524

A review on optical time division multiplexing (OTDM)

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Abstract
Electrical multiplexing has limited channel capacity as the Ethernet switches can only run at most 10 Gbps. To increase this channel capacity optical multiplexing is required. The OTDM path network has the ability for 100 Gbps Ethernet switching, however more modulators need to be equipped in the transmitters, and only connections from the source node to its downstream nodes in a super light path can be referred to be used. The recent advances in optical time division multiplexing (OTDM) shows the technique to be highly suited to the generation and transmission of high capacity data on a single optical carrier. This approach uses a single wavelength to carry capacities of at least 40 Gbps. Such systems are based on a clock frequency and tributary data rates which are easily accessible using electronic components. In this system or methodology the short optical pulses are used in a return-to-zero data transmission format with temporal interleaving to map a number of optical data channels into a single electronic clock cycle. It is an approach that can be used to achieve extremely high data-rate bit interleaved systems. This article summarizes the basic uses of optical time division multiplexing and outlines a possible methodology to evolve transport networks to encompass the potential that OTDM has to offer.

Keywords: time division multiplexing, optical devices data communication multiplexing and de multiplexing light paths

Introduction
Optical time division multiplexing (OTDM) is a very powerful and scalable technique to investigate high-speed data transmission systems, related signal processing and monitoring technologies at serial data rates beyond the bandwidth limitation of (optic) electronics. The OTDM technique is basically compatible with modern multi-level quadrature-amplitude modulation (QAM) formats and digital coherent detection. In contrast to wavelength division multiplexing (WDM), only one wavelength (one/single color) of light is used in optical time division multiplexing.

The operation principle of OTDM is as follows
The different optical pulse streams called tributaries originating from the same laser (same central wavelength) are firstly separately encoded by electrically generated data signals. Due to the low duty cycle of their pulses the tributaries are serially bit interleaved in order to form the high speed serial OTDM data signal. At the receiver end, an ultra-fast optical clock and data recovery extracts the individual time-domain tributaries, which are subsequently processed by conventional (optic) electronics [7]. The basic principle of this technology is to multiplex a number of low bit rate optical channels in time domain. The overall OTDM system can be viewed as three big blocks i.e. transmitter block, line system, and receiver block. The basic transmitter block consists of laser sources, modulators, channel alignment systems, and multiplexer. Further the line system contains optical amplifiers and transmission fibers. And the receiver block further has synchronization circuit and a channel demultiplexer. Channel allocation by time division multiplexing is dependent on the fundamental electrical data rate and the optical pulse width. With a fixed electrical clock we need to shorten the optical pulse width in order to multiplex more channels within the same clock period. In addition to it, the shortened pulse width can help reduce the crosstalk between channels because of more room left in bit slot. However, short optical pulses are subjected to heavy dispersion penalty as traveling distance increases. The use of transform-limited pulse and dispersion slope compensation technique can reduce the dispersion effect on OTDM. Transform-limited pulse has a property which reduces the optical spectral width for a given pulse width. This ensures the pulse broadening due to dispersion is minimized. Adding negative slope dispersion fiber can actually minimize the pulse broadening effect over a long distance. This is basically dependent on the choice of dispersion slope factor and length of the dispersion compensated fiber, which in turn depends on the fiber fabrication technology. Polarization mode dispersion is also a main concern as traveling distance increases over 100km.Accurate control on the channel alignment is also critical as transmission speed increases because more channels are multiplexed in a fix clock period. Any misalignment can cause a problem in the performance of the OTDM system because of crosstalk and dispersion. The use of electro-optic switching technique or all-optical switching technique can be used in demultiplexing at the receiver end. The electro-optic technique is great for transmission speed at less than 40 GB/s. It is more difficult to achieve for speed over 40Gb/s due to restraint on electrical drive power. All-optical switching is based on third order nonlinear effect of the optical fiber.

Methodology
The basic principle of OTDM is as follows:

Optical time division multiplexing is more powerful optical multiplexing technique as it can combine multiple low bit rate channel in to single high bit rate channel in time basis. Each channel can be multiplexed in to multiplexer for given period of time.

In OTDM, only one wavelength of light is used instead of different wavelength of light in WDM.

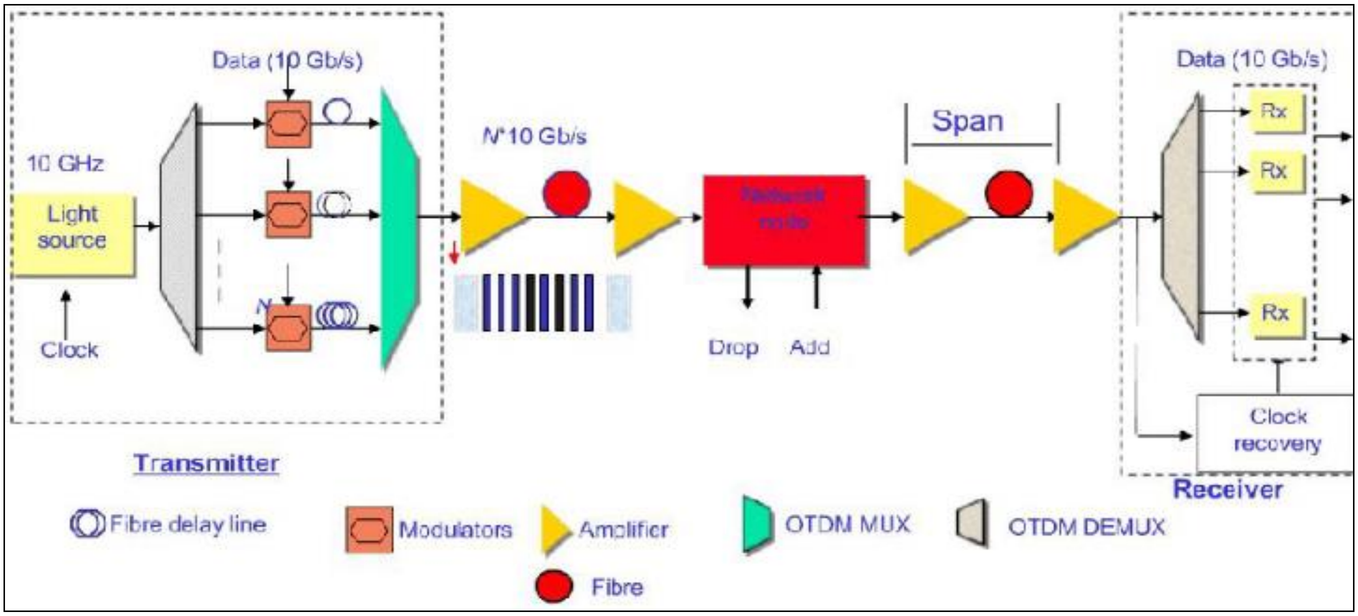

Fig 1

The above figure shows the schematic block diagram of an optical time division multiplexing system.

Description

A Simple OTDM consists of the following three main stages

1. Transmitter
2. Inline system
3. Receiver

The transmitter consists of optical source, modulator, channel alignment and multiplexer. Optical signal can be modulated using Return to Zero (RZ), Non Return to Zero (NRZ), Manchester and various length of fiber can be used for the channel alignment or for delay signal, the multiplexer is used to combine the various optical data stream. The line system consists of optical amplifier, add-drop multiplexer and transmission fiber. Semiconductor Optical Amplifier (SOA) and Erbium dropped fiber Amplifier (EDFA) is used for optical amplifier to amplify the optical signal in between into the network while the receiver consists of a demultiplexer and synchnoronous clock. The synchronous clock is used to extract framing pulse or clock signal. The demultiplexer is then used to separate out the multiplexed optical signal [7].

Figure shows the design of optical time division multiplexing.

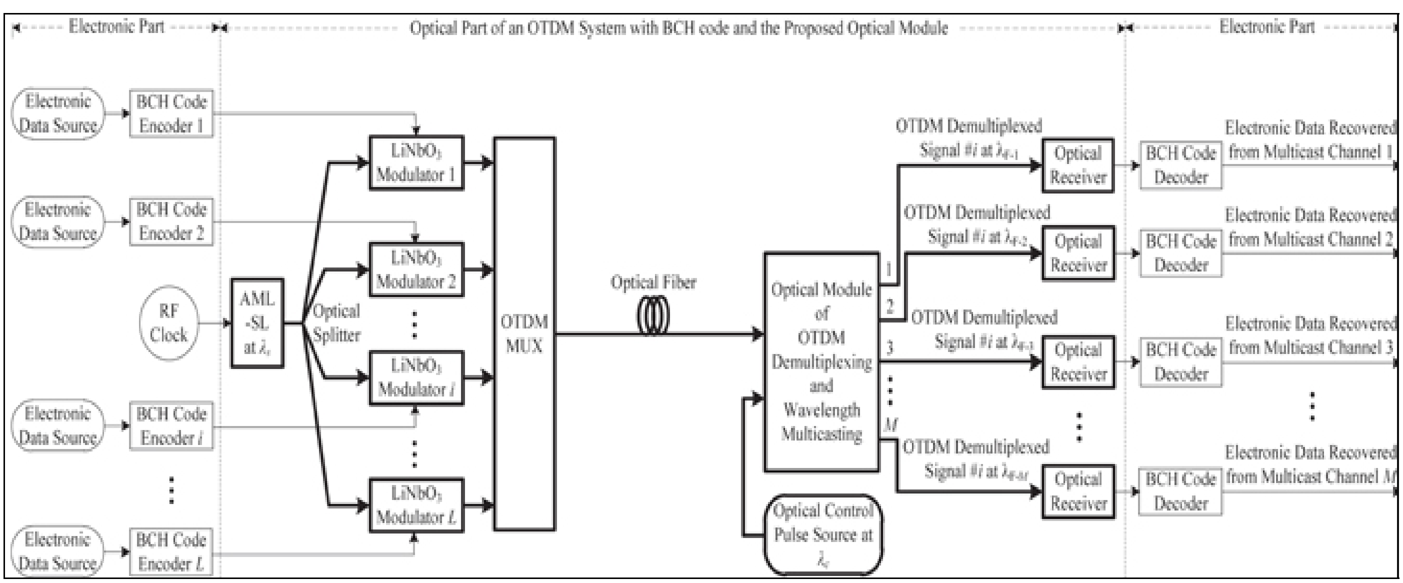

Fig 2

Literature Review

The authors Cada, Habara, Tucker *et al.* in their study of Optical Time Division Multiplexing concluded that

1. A time-division optical multiplexer system, having a plurality of multiplexer elements the optical multiplexer elements comprising:

A first optical waveguide for receiving and transmitting a first optical signal having a first optical carrier wavelength;

A second optical waveguide for receiving and transmitting a second optical signal having a second optical carrier wavelength; and

A third optical waveguide for alternately receiving the first and second optical signals and providing an optical output signal;

Said first and second optical waveguides being joined together at a junction;

said third optical waveguide being coupled to said junction by switchable filter means for alternately passing one of the first and second optical signals;

where in:

The plurality of multiplexer elements are arranged in a plurality of cascaded groups, each group having twice the elements of a following group;

Inputs of the elements in each respective group are connected to outputs of the elements in a respective preceding group;

The switchable filter means of the elements of a respective group are controlled in synchronism by respective control signals; and

The switchable filter means of the elements in each respective group are controlled by a control signal having a frequency twice the frequency of a following group

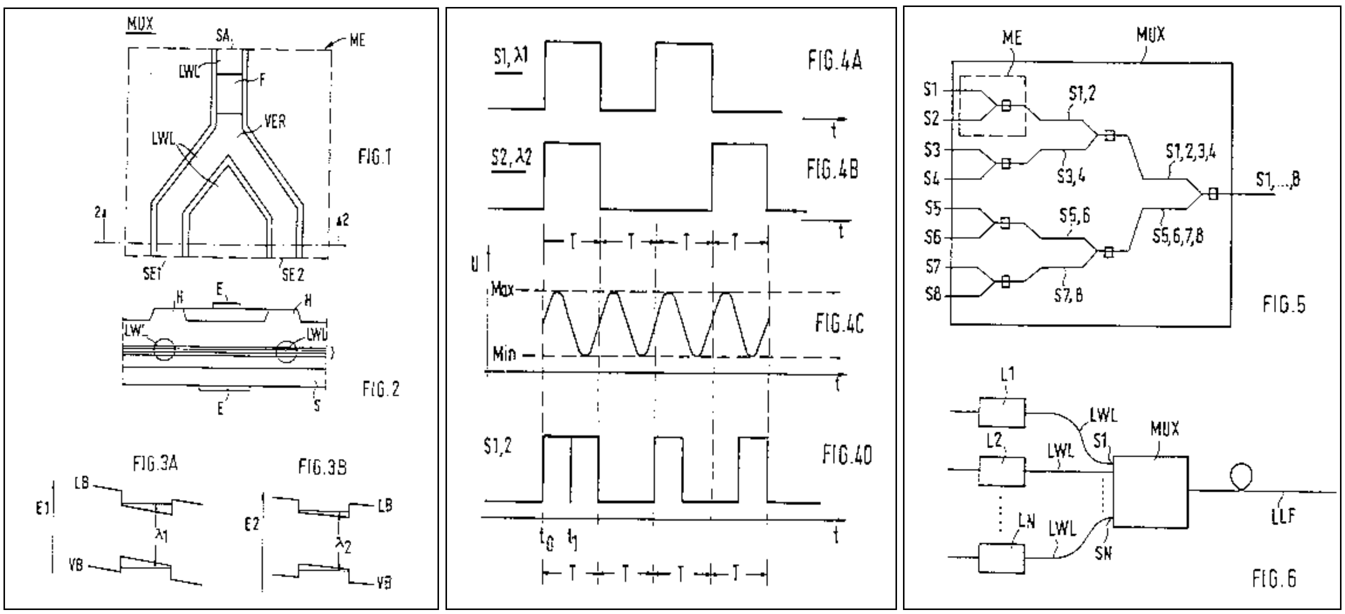

Fig 1: is a plan view of a multiplex element according to the invention; **Fig 2:** is a sectional view along line AB of the multiplex element of FIG. 1 according to the invention; **Fig 3A and 3B:** show possible band transitions of a filter with a multiple quantum well layer sequence; **Fig 4A-4D:** show the combining of the entering signal streams by an applied, sine-wave electrical field, to make one outgoing signal stream; **Fig 5:** shows an exemplary embodiment of a time-division multiplexer; and **Fig 6:** shows a transmission unit having a time-division multiplexer according to the invention [1]

2. An optical time-division multiplexer comprising:

At least one multiplex element having inputs for receiving at least two optical signals, the signals having carriers of different wavelengths, the inputs being connected to an optical signal output via a junction, the element further having switchable filter means for switching the signals applied to the inputs to the signal output in alternation, wherein the multiplex element is controlled so that a switching time interval is shorter than a pulse duration of the input signals.

3. The optical time-division multiplexer of claim 2, wherein the pulse duration of the optical input signals is less than 50 ps.
4. The optical time-division multiplexer of claim 2, wherein for each multiplex element, the at least two optical signals are two digital optical signals, a switching signal period is equal to the input signals' pulse duration during multiplexing, and a pulse duration of the output of the multiplexer is halved during multiplexing.
5. The optical time-division multiplexer of claim 2, wherein the switchable filter means is disposed between the junction and the signal output.
6. The optical time-division multiplexer of claim 2, wherein the input signals to be multiplexed are digital signals, and the switchable filter means is controlled by a periodic alternating voltage of frequency f=1/T, where T represents the duration of one bit-clock period of the input signals to be multiplexed.
7. The optical time-division multiplexer of claim 2, wherein the multiplex element has two signal inputs for receiving respective signals, the respective signals each having a different respective carrier wavelength, and wherein the switchable filter means alternatingly blocks a respective one of the carrier wavelengths.
8. The optical time-division multiplexer of claim 2, wherein

a plurality of multiplex elements are disposed in a cascade, and wherein one signal output of each multiplex element is connected to one signal input of a following multiplex element.

9. The optical time-division multiplexer of claim 2, further comprising a plurality of optical wave guides for transmitting the optical signals, wherein the optical waveguides are planar optical wave guides.
10. The optical time-division multiplexer of claim 2, wherein the switchable filter means has a multiple-quantum-well structure, and has a pass band switchable by the application of an electrical field.
11. The optical time-division multiplexer of claim 2, further comprising optical wave guides for transmitting the optical signals, the optical waveguides substantially comprising semiconductor layers.
12. An optical transmitter having an optical time-division multiplexer of claim 2, wherein individual integrated semiconductor elements are provided [2].
13. An optical multiplexer element comprising:

A first optical waveguide for receiving and transmitting a first optical signal having a first optical carrier wavelength;

a second optical waveguide for receiving and transmitting a second optical signal having a second optical carrier wavelength; and a third optical waveguide for alternately receiving the first and second optical signals and providing an optical output signal; and

Switchable filter means for alternately passing one of the first and second optical signals;

wherein said first and second optical waveguides are joined together at a junction, and wherein said third optical waveguide is coupled to said junction by said switchable filter means for alternately passing one of the first and second optical signals, wherein the multiplexer element is controlled so that a switching time interval is shorter than a pulse duration of the first and second optical signals.

14. The optical multiplexer element according to claim 13, wherein said optical multiplexer, including said first, second and third optical waveguides, said junction, and said switchable filter means, is formed as an integrated optics layer structure on a substrate.
15. The optical multiplexer element according to claim 14, wherein at least said switchable filter means is formed as a multiple-quantum-well layer sequence, said switchable filter means including electrodes encompassing the multiple-quantum-well layer sequence, for connection to an external source of control signals whereby the alternate passing of the first and second optical signals by said switchable filter means is controlled [3].
16. The optical multiplexer element according to claim 14, wherein at least said first, second and third optical waveguides are formed of layers of at least one of PLZT, $LiNbO_3$, and optical polymers.
17. An optical multiplexer system, having a plurality of multiplexer elements according to claim 13, wherein the plurality of multiplexer elements are arranged in a plurality of groups, outputs of the multiplexer elements of one group being connected to inputs of the multiplexer elements of a succeeding group.
18. A time-division optical multiplexer system, having a plurality of multiplexer elements according to claim 13, wherein:

The plurality of multiplexer elements are arranged in three cascaded groups, a first group having four elements, a second group having two elements, and a third group having one element;

Inputs of the element in the third group are connected to outputs of the elements in the second group, and inputs of the elements in the second group are connected to outputs of the elements in the first group;

The switchable filter means of the elements of a respective group are controlled in synchronism by respective control signals;

The switchable filter means of the elements in the first group are controlled by a control signal having a first frequency, the switchable filter means of the elements in the second group are controlled by a control signal having a frequency twice the first frequency, and the switchable filter means of the element in the third group are controlled by a control signal having a frequency four times the first frequency [4].

Channel allocation by time division multiplexing is dependent on the fundamental electrical data rate and the optical pulse width. With fixed electrical clock, one must shorten the optical pulse width in order to multiplex more channels within the clock period. In addition, the shortened pulse width can help reduce the crosstalk between channels because of more room left in bit slot. However, short optical pulses are subjected to heavy dispersion penalty as traveling distance increases.

The use of transform-limited pulse and dispersion slope compensation technique can reduce the dispersion effect on OTDM. Transform-limited pulse has the property that minimizes the optical spectral width for a given pulse width. This ensures the pulse broadening due to dispersion is minimized. Adding negative slope dispersion fiber can actually reduce the pulse broadening effect over long distance. This is dependent on the choice of dispersion slope factor and length of the dispersion compensated fiber, which in turn depends on the fiber fabrication technology. Polarization mode dispersion is also a main concern as traveling distance increases over 100km.

Accurate control on the channel alignment is also critical as transmission speed increases because more channels are multiplexed in a fix clock period. Any misalignment can affect the performance of the OTDM system because of crosstalk and dispersion.

Electro-optic switching technique or all-optical switching technique can achieve de multiplexing at receiver end. The electro-optic technique is great for transmission speed at less than 40 Gb/s. It is more difficult to achieve for speed over 40Gb/s due to restraint on electrical drive power. All-optical switching is based on third order non-linear effect of the optical fiber. It is highly suitable for ultra-fast speed transmission because the non-linear response is in fs range. It is also allowing add/drop of an individual channel or a number of channels, which is great feature for network operation.

Although, the all-optical switch is very bulky and expensive to made. Nevertheless, successful de- multiplexing can only be accomplished with accurate timing extraction. The timing jitter from the extraction circuit can directly affect the BER performance of the OTDM system [5].

After studying this Optical Multiplex Techniques I, conclude that channel capacity will be increased and we transmit more data thorough single fiber.

- Till date in Commercial application we can Transmit 1Tb/s through single fiber.
- Berlin's Fraunhofer Heinrich Hertz Institute in collaboration with the Technical University of Denmark in Copenhagen have succeeded in generating a serial data rate of 10.2 Terabit per second and transmitting it over a 29 km long fiber optic link.
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- Further, Increased Data rate by using Combination of OTDM + WDM optically Multiplexing Techniques [6].

Different optical pulse streams, called tributaries, originating from the same laser (same central wavelength), are separately encoded by electrically generated data signals. Due to the low duty cycle of their pulses (1.5 ps at 10 GHz) the tributaries are serially bit interleaved in order to form the high speed serial OTDM data signal. At the receiver end, an ultra-fast optical clock and data recovery extracts the individual time-domain tributaries, which are subsequently processed by conventional (opto) electronics.

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