Research Article

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Evaluating OADM network simulation and an overview based metropolitan application

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Abstract: Using optical add-drop multiplexer/remover multiplexer (OADM), it is possible to add or remove wavelengths and change or route them through the various nodes and networks. At this moment, key problems in add-drop multiplexer (ADM) are the bandwidth, modulation format, and reuse wavelength. In this article, the Optisystem software simulation is used as a platform to design, test, and verify the method applied to the current work; the OADM is proposed based on the metro network to get distribution between nodes over a transmission link; OADM analysis was presented with four channels (193.1, 193.2, 193.3, and 193.4 THz) at total bandwidth of 1.6 Tb/s, none-return-to-zero (NRZ), and return to zero coding types. Experiment one shows that the average output power is -17.997 dBm, the average drop power is −17.997 dBm, and the average add power is −18.338 dBm, the average gain is −0.0429 dB, the average noise figure is 0 dB, the average power input signal is 10.679 dBm, the average of power output signal is 10.633 dBm, and the average output optical signal-to-noise ratio (OSNR) is 0 dB, However, the second experiment shows that the average output power is -24.238 dBm, the average drop power is -24.288 dBm, and the average add power is -24.753 dBm, the average gain is -0.0417 dB, the average noise figure is 0 dB, average power input signal is 7.691 dBm, average of power output signal is 7.677 dBm, and the average output OSNR 0 dB. The system supports four input channels, four add channels, four output channels, and four drop channels. The results are acceptable after three spans of Solitons fiber with 600 km length, 200 km for each span. Nonetheless, it is believed that it is well justified to adopt these schemes in the current optical network with a low cost for overall expenditure.

Keywords: simulation, ADM, RZ, metro network, soliton fiber

1 Motivation

Nowadays, the Internet as an industry is based mainly on fiber. This leads to a vast range of misunder-standings, misconceptions, and errors when working with fiber-optic networks. Definitely, several attempts have been made to assist a large number of individuals using the same transmission medium. This term refers to the different multiplexing techniques used by hackers. Wave division multiplexing allows the use of the fibers' broad bandwidth [1]. Due to the recent development of dense wavelength division multiplexing (DWDM) systems, it is now possible to transmit hundreds of channels at a total capacity of more than terabits per second. Another technique has been attempted in conjunction with wavelength division

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multiplexing the best performers on a multiprocessor and being one of the multiprocessor's top weapons (optical add–drop multiplexer/remover multiplexer [OADM]) [2]. ADM is the most critical component of a fiber-optic communication network. If the traffic is ascending, it may be bidirectional or unidirectional. In OADM, the wavelength modulation may be reduced or increased selectively. Wavelength coexists within a fiber, resulting in channel concurrence. It then applies the same wavelength but in a different direction to the same signal but an additional input, this time with the same signal but a different input [3].

An optical multiplexer's primary purpose is to integrate multiple wavelengths into a single fiber. When used in conjunction with a multiplexer, it is evident that the spectrum contains two distinct wavelengths (or channels). This enables the separation and addition of wavelengths separately. It is colloquially referred to as an add–drop demultiplexer, but when an optical wavelength is defined, it is referred to as a multiplexer. Although these units are small, monolithic integration will undoubtedly play a significant role in future designs of smaller, lighter, and more affordable devices [4].

The discussion of an all-fiber unidirectional ring in the article is almost entirely confined to ring WDM networks. Each node in OADM subtracts a distinct wavelength, allowing for stage-by-stage wavelength selection. The transmission uses longer data wavelengths, while reception uses shorter data wavelengths. Each OADM converts the data from the ring to an optical signal. Infrastructures are being strained to the breaking point as bandwidth demands grow. Metros have been fitted with this capability to fulfil this requirement. Optical add/drop multiplexers are well suited for wavelength handling due to their ability to connect and remove optical channels. Due to the OADM's low-loss, low-cost passive systems, low-cost, and scalable technology enables a highly stable network with very little electricity consumption [5–7]. The article is divided into four sections: one devoted to prior research on the topic, one to the proposal itself, one to a comparison, conclusion, and discussion, and one to two experiments.

2 OADM architecture

A conventional OADM comprises three components: an optical (multiplexer (MUX)/De-MUX) system for reconfiguring the paths between the (MUX/De-MUX) and a series of add—drop ports. A multiplexer is a device that couples two or more wavelengths into a single fiber. A fiber patch panel or optical switches that guide wavelengths to the optical (MUX) or drop ports can then reconfigure the system. The De-MUXs reverse the multiplexer's behavior. They divide a fiber's multiple wavelengths and send them to multiple fibers. "Add" refers to an OADM's ability to adding one or more new wavelength channels to an existing multi-wavelength WDM signal. Although "delete" refers to dropping or removing one or more channels and routing those signals to a different network direction. OADM eliminates (drops) a wavelength from a group of wavelengths in fiber, thus from traffic on that channel. It then adds a wavelength in the same direction as the data flow but with different data materials [1].

3 Related studies

Many previous studies were conducted by many researchers in relation to OADM including Lee and Koh [8]; they discuss a proposal of the hybrid ring-mesh network in survivable network communication by specifying a location for traffic demands. The difficulty lies in assigning each traffic demand to rings and mesh such that the cost of ADM and DCS equipment's required is minimized. Fishman et al. [9] state that this OADM has shown to have a unique asymmetric bandwidth that could be used to optimally support 50 GHz DWDM transmissions with 10 Gb/s and 40 Gb/s DWDM spacing. Numerous OADMs accept 10 Gb/s RZ-OOK and 40 Gb/s DPSK signals with a reasonable penalty. Konishi et al. [10] propose and demonstrate a wavelength- and time-selective reconfigurable optical add–drop multiplexer (ROADM) using time-frequency domain processing with equivalent 3.2 Tb/s (0.64 Tb/s five channels) and reconfigurability through

the MEMS optical switch switching operation. Chung and Mo [11] consider the routing and wavelength assignment problem on synchronous optical network over WDM ring networks. To deal with the complexity of the problem, Udalcovs et al. [12] develop a combined system model that can be considered under the next-generation optical network as a model for the future design of backbone networks. Zabir et al. [13] propose a novel method for dealing with crosstalk using an optical add-drop multiplexer based on fiber Bragg gratings. The authors demonstrate through an analytical model that various parameters improve when their proposed OADM is used. Mahiuddin and Islam [14] develop an investigative model for low crosstalk in an OADM with a fiber Bragg grating and isolator. Syuhaimi Ab-Rahman [15] develop a design to combine the operational concepts of (OADM) and an optical cross-connect (OXC). It is developed by analyzing the shortcomings of existing devices and adding some superior features. Optical cross-connect add drop multiplexer is introduced to increase the ring network's survivability. Ibrahim Essa et al. [16] demonstrate the simulation of an architecture enabled by an optical coaster wavelength division multiplexer that satisfies reconfiguration requirements and enhances network security. Their architecture is truly scalable in terms of efficiently handling additional wavelengths or nodes. Mohan and Anisha [17] demonstrate how to achieve full-duplex transmission of RoF using WDM and OADM, where WDM enables the transmission of multiple signals over a long distance via a single-mode fiber and OADM enables the transmission of both downlink and uplink data via the same SMF. El-Naser et al. [18] have numerically and parametrically modelled the high and best performance functions of optical add-drop multiplexers (OADMs) for ultrawide wavelength division multiplexing technique processed to handle bit rate either per link or per channel for multilink cables (20-120 links/core). According to Udalcovs and Bobrovs [19], energy-consuming per transmitted bit could increase more than twofold when WDM channels are added at the OADM/OXC station, compared to wavelengths transmitted over point-to-point fiber-optical links and then reduced at the receiving node. Bajaj and colleagues [20] propose a work-based OADM that consists of three parts: initially, the DWDM network is modeled in OptiSystem (an optical simulating tool), and parameters such as optical signal-to-noise ratio (OSNR), jittering, chromatic dispersion, and bit error rate are obtained. These parameters are used to train the feed-forward artificial neural network in the second phase. Bala and Dewra [21] investigate the presence of a ring-star-tree hybrid topology using OADM. They discover that at a transmission power of -17 dBm, the hybrid network supports 32 and 128 users for the star and tree topologies, respectively. Miladic et al. [22] demonstrate the optical technologies that will help smart cities use sensors and reliable optical infrastructure. Boubakri et al. [23] figure the relation between the 5 G networks based on the optical networks to applications in smart cities.

The work contributions fall into many considerations like:

- (i) Overcoming group velocity dispersion (GVD) and self-phase modulation (SPM) phenomena using solitons fiber as transmission link.
- (ii) Overcoming the reuse of wavelength in the optical network by using WDM systems.
- (iii) Applying this work to the metro optical network currently used by the Ministry of Communication in the Republic of Iraq by designing two experiments with two different modulation codings.

4 Proposal methodology

There are several possible implementations of OADMs depending on the physical concept and the deployed optical components. Besides the general use of (passive/active) optical components, this work presents an attempt to design and simulate a ring optical network based on OADM with some different fiber lengths, additional bandwidth, and advanced modulation format for overcoming some problems mentioned by the Ministry of Communication in the Republic of Iraq including the reuse wavelengths, bandwidth amount, network monitoring, and the addition of new nodes over fiber. Therefore, the current study aims at finding solutions for these problems without re-changing the current infrastructure. It also attempts to add a unique wavelength and drop it from another node. Figure 1 shows the current work's block diagram.

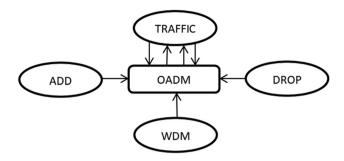


Figure 1: The block diagram of the OADM node.

This project will be simulated, tested, verified, and performed with a series of loops by the Optisystem package. It presents a software simulation funded by the Optiwave Canadian company [24].

4.1 Proposal experiment OADM @200 km solitons fiber, 40 Gbps, and NRZ modulation format

The main layout for our design consists of many properties, namely, the bitrate is 40 Gbps, the total bitrate is $1.6 \, \text{Tb/s} = 40 \times 4$, the sample rate is $64 \times 10^{10} \, \text{Hz}$, the sample length is 64 bit, the sample per bit is 256, and the number of pieces is 16,384. There are four frequencies (193.1, 193.2, 193.3, and 193.4 THz) for Frequency 1 through Frequency 4. The control is 0, and the project builds up from four stages (optical transmitter, optical link, ADM system, and optical receiver). The first one consists of two WDM transmitters; each produces four channels (four frequencies F1–F4). The input power is 8 dBm, the frequency is 193.1 THz, the frequency spacing is 100 GHz, and the modulation type is set to NRZ. Figure 2 shows the main four stages of proposal architecture.

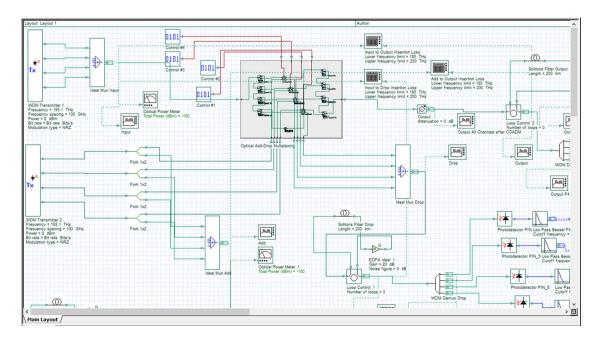


Figure 2: Demonstrate the four main stages for proposal architecture.

The second stage is the wavelength division multiplexer WDM as three Ideal Mux (4×1) (one for input, second for drop, and third for add) that is, four inputs and one output multiplexers a user-defined number of input WDM signal channels. When signal added is immediately attenuated, there is no power splitting and filtering in this component because the user defines parameter, and three demultiplexers (1×4) with a bandwidth of 40 GHz, insertion loss of 0 dB, depth of 100 dB, filter of Bessel type, and filter order as 2. The ADM techniques are organized as reconfigurable optical add-drop multiplexer with four WDMs add, four WDMs drop, and four digital optical switches. The properties of it are as follows: F1-F4 is 193.1-193.4 THz, respectively; bandwidth is 40 GHz; insertion loss is 0 dB; depth is 40 dB; filter type is Bessel; filter order is 2; noise threshold is -100 dB; and noise dynamic is 3 dB. The bandwidth, ripple, and depth of the filter are important parameters to determine the crosstalk amount. The digital optical switch is responsible for managing the optical switch processing. It has five optical ports, that is, three as input ports and two as output ports. The optical switch directs the optical signals at input ports 1 and 2 to the two output ports, according to the control signal as in so far as when the control signal is 1, optical signals from both inputs are combined. This component operates similarly to the optical switch component; when the control signal is 0, the phase shift is set to π ; and when the control signal is 1, the phase shift is set to 0, as shown in Figure 3.

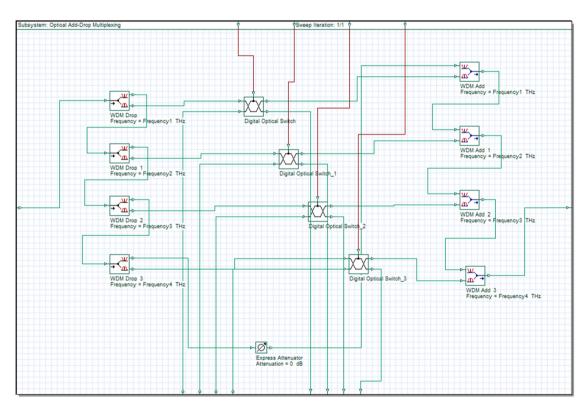


Figure 3: The subsystem of optical add-drop multiplexing components.

The third part is the transmission link. Here, the three spans are used with a length of 200 km for each, the total is 600 km of Solitons fiber of certain balance of nonlinear and dispersive effects with properties of reference wavelength of 1,300 nm, attenuation of 0.4 dB/km, dispersion of 1.67 ps/nm/km, dispersion slope of 0.08 ps/nm²/km, Beta 2 of 20 ps²/km, Beta 3 of 0 ps²/km, effective area of 62.8 μ m², n² of 2.6⁻²⁰ m²/W, and the fraction Raman contribution is 0.8. The optical amplification was processed by the erbium-doped fiber amplifier (EDFA) with the following properties: gain = 20 dB, power = 10 dB, saturation

power = 10 dB, noise figure = 0 dB, noise center frequency = 193.4 THz, noise bandwidth = 13 THz, and noise bins spacing = 125 GHz.

Finally, part four consists of 12 photodiodes of positive intensive negative (PIN) type with properties of responsivity of 1 A/W, the dark current of 10 mA, the sample rate of 3.2×10^{12} , and the thermal noise of 1×10^{-22} W/Hz, and 12 low-pass Bessel filters with properties of cutoff frequency of 7.5×10^9 Hz, insertion loss of 0 dB, depth of 100 dB, and order as (4). The mathematical model for the low-pass Bessel filter is shown in equations (1)–(6). The system behaviors are monitored by oscilloscopes, optical spectrum analyzer, optical power meters, dual-port analyzer, and radio frequency spectrum analyzer.

$$H(s) = \alpha \frac{d_0}{B_N(s)},\tag{1}$$

$$d_0 = \frac{(2N)!}{2^N \cdot N!},\tag{2}$$

$$B_N(s) = \sum_{N}^{k=0} d_k s^k, \tag{3}$$

$$d_k = \frac{(2N - k)!}{2^{N - k} \cdot k!(N - k)!},\tag{4}$$

$$s = j \left(\frac{f \cdot w_b}{f_c} \right), \tag{5}$$

$$w_b \approx \sqrt{(2N-1)\cdot \ln 2} \quad \text{for } N \ge 10,$$
 (6)

where insertion loss is α , the *n*th-order Bessel polynomial is the BN, it is the frequency that is set by the filter cutoff parameter, and w_b is the 3 dB bandwidth, which can be estimated by using equation (6). For values of N less than 10, a separate table is used to calculate the actual bandwidth.

4.2 Proposal experiment OADM @200 km solitons fiber, 40 Gbps, and return-to-zero (RZ) modulation format

In this experiment, the same components that were used in previous experiment, except the modulation type in the WDM transmitter is set to RZ modulation format as a coding technique.

5 Output results and discussion

After simulating our designed proposal and performing a series of tests, the following results are obtained and summarized in the following subsections.

5.1 Results of proposal experiment OADM @200 km solitons fiber, 40 Gbps, and NRZ modulation format

(1) Figure 4 illustrates the power vs frequency for the drop signals for all four channels, that is, after multiplexer directly. It is clear that the signals do not have any degradation because the span link = 0 km.

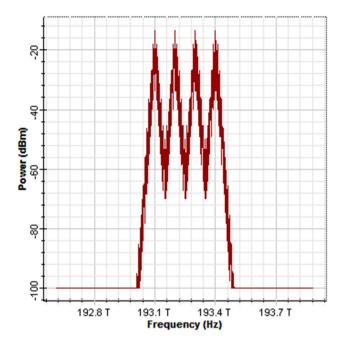


Figure 4: The power vs frequency of the drop signals for all channels directly after the ideal multiplexer before the transmission link.

(2) In Figure 5, from the oscilloscope visualizer, the comparison of amplitude vs time is shown as add channel_1 (193.1 THz) to channel_4 (193.4 THz) after 200 km of fiber optic transmission link directly of Solitons type after photodiode and filter at the receiver side, which are good in the figure.

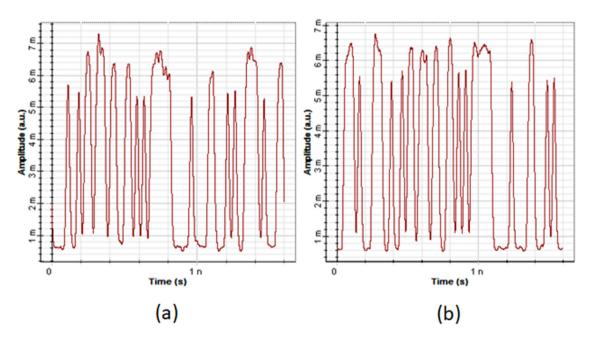


Figure 5: Amplitude vs time directly after photodetector (PIN) at the side receiver for add: (a) signal_1 = 193.1 THz and (b) $signal_4 = 193.4 \text{ THz } @span = 200 \text{ km}$, and bitrate = 40 Gbps.

(3) In Figure 6, from the oscilloscope visualizer, the comparison of amplitude vs time is shown as drop channel_1 (193.1 THz) to channel_4 (193.4 THz) after 200 km of fiber optic transmission link of Solitons type directly after photodiode and filter at the receiver side, which have a good quality in the figure.

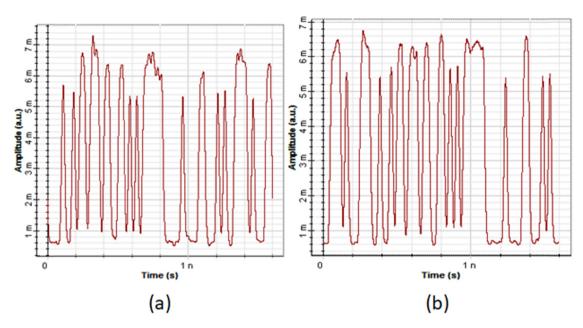


Figure 6: Amplitude vs time directly after Photodetector (PIN) at the side receiver for drop: (a) signal_1 = 193.1 THz and (b) signal_4 = 193.4 THz @span = 200 km, and bitrate = 40 Gbps.

(4) In Figure 7, from the oscilloscope visualizer, the comparison of amplitude vs time is shown as output channel_1 (193.1 THz) to channel_4 (193.4 THz) after 200 km of fiber optic transmission link of Solitons type directly after photodiode and filter at the receiver side, which have a good quality in the figure.

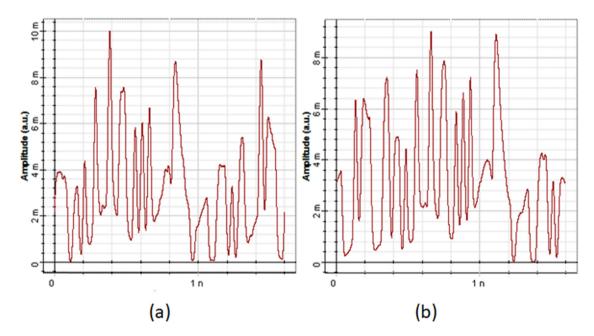


Figure 7: Amplitude vs time directly after Photodetector (PIN) at the side receiver for output: (a) signal_1 = 193.1 THz and (b) signal_4 = 193.4 THz @span = 200 km, and bitrate = 40 Gbps.

From the optical power meter at the wide receiver, in Table 1, the total output power (dBm) is summarized for three nodes for four channels as the output, drop, and input.

Table 1: Output, drop, and add power obtained from the electrical power n	neter visualizer at the receiver side
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Channel frequency (THz)	Output power (dBm)	Drop power (dBm)	Add power (dBm)
193.1	-18.352	-18.005	-18.005
193.2	-18.31	-18.0033	-18.0033
193.3	-18.285	-17.9707	-17.9707
193.4	-18.4048	-18.0063	-18.0063
Average	-17.997	-17.997	-18.338

From the dual-port WDM analyzer between multiplexer and demultiplexer, the signals are monitored from end to end; Table 2 summarizes these values.

Table 2: The ratio of the total parameter related to the input, output, add, and drop calculated by dual-port WDM analyzer

Parameters	Total input-output	Total add-output	Total input-drop	Average
Gain (dB)	-0.0595	-0.0643	0.00492	-0.0429
Noise figure (dB)	0	0	0	0
Power input signal (dBm)	10.6777	10.682	10.6777	10.679
Power output signal (dBm)	10.618	10.618	10.682	10.633
Output OSNR (dB)	0	0	0	0

5.2 Results of proposal experiment OADM @200 km solitons fiber, 40 Gbps, and RZ modulation format

Many series of the software simulations are performed to test this experiment as OADM at 600 km of Solitons fiber, 1.6 Tbps, four channels WDM based on RZ modulation format to the coded input data. The following results are obtained:

(1) Figure 8 shows the power vs frequency as output add channel 1 (193.1 THz) and channel 4 (193.4 THz) after 200 km of fiber optic transmission link directly after demultiplexer at the receiver side. They have a good shape.

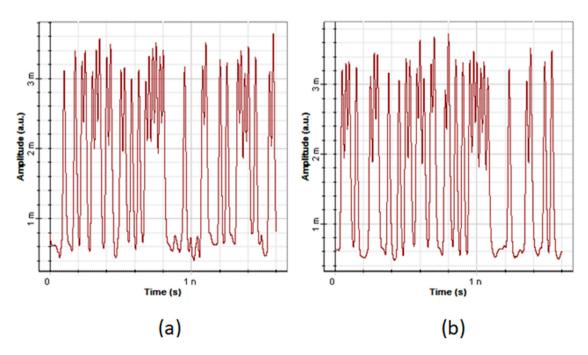


Figure 8: Amplitude vs time directly after Photodetector (PIN) at the side receiver for output add: (a) signal_1 = 193.1 THz and (b) signal_4 = 193.4 THz @span = 200 km, and bitrate = 40 Gbps.

(2) In Figure 9, from the oscilloscope visualizer, the comparison of amplitude vs time shows the output drop channel_1 (193.1 THz) to channel_4 (193.4 THz) after 200 km of fiber optic transmission link Solitons type directly after photodiode and filter at the receiver side. They have a good shape.

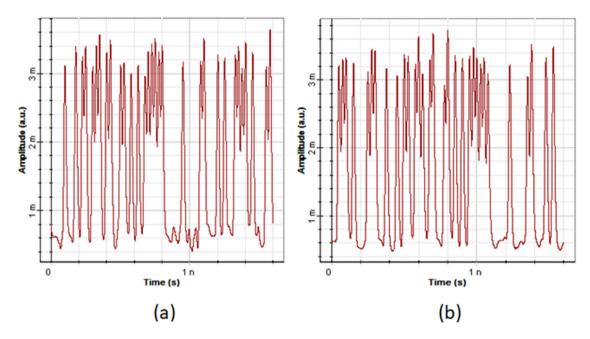


Figure 9: Amplitude vs time directly after Photodetector (PIN) at the side receiver for output drop: (a) signal_1 = 193.1 THz and (b) signal_4 = 193.4 THz @span = 200 km, and bitrate = 40 Gbps.

(3) In Figure 10, from the oscilloscope visualizer, the comparison of amplitude vs time shows the output channel_1 (193.1 THz) to channel_4 (193.4 THz) after 200 km of fiber optic transmission link Solitons type directly after photodiode and filter at the receiver side. They have a good quality in shape, but there are some noise and inter-symbol interference (ISI) caused by the unwanted contributions from other symbols.

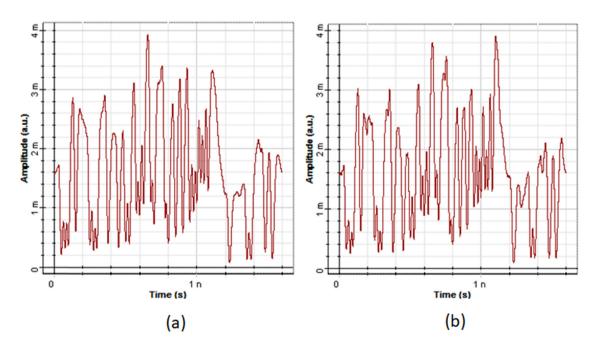


Figure 10: Amplitude vs time directly after Photodetector (PIN) at the side receiver for output: (a) signal_1 = 193.1 THz and (b) signal_4 = 193.4 THz @span = 200 km, and bitrate = 40 Gbps.

From the dual-port WDM analyzer between multiplexer and demultiplexer, the signals are monitored from end to end. Tables 3 and 4 summarize these values.

Table 3: The output power for add, drop, and output calculated by the electrical power meter analyzer

Channel frequency (THz)	Output power (dBm)	Drop power (dBm)	Add power (dBm)
193.1	-24.7997	-24.4556	-24.2556
193.2	-24.6989	-24.146	-24.146
193.3	-24.6996	-24.2539	-24.2539
193.4	-24.8116	-24.2944	-24.2944
Average	-24.238	-24.288	-24.753

Table 4: The total ratio for the input, output, and drop signals calculated by dual port WDM analyzer

Parameter	Total input-output	Total add-output	Total input-drop	Average
Gain (dB)	-0.0359	-0.0625	-0.0266	-0.0417
Noise figure (dB)	0	0	0	0
Power input signal (dBm)	7.683	7.7098	7.683	7.691
Power output signal (dBm)	7.647	7.647	7.709	7.677
Output OSNR (dB)	0	0	0	0

Table 5 summarizes the average parameters concluded from the two proposals with different modulation formats.

Table 5: The average parameters obtained from two proposals

Parameter	NRZ	RZ
Output power (dBm)	-17.997	-24.238
Drop power (dBm)	-17.997	-24.288
Add power (dBm)	-18.338	-24.753
Gain (dB)	-0.0429	-0.0417
Noise figure (dB)	0	0
Power input signal (dBm)	10.679	7.691
Power output signal (dBm)	10.633	7.677
Output OSNR (dB)	0	0

As shown in Table 5, the average values for the evaluation parameters for the two types of modulation format are acceptable for this software simulation due to choosing suitable elements with their properties.

The applicability of these new results is tested for the current infrastructure used by the Ministry of Communications in the Republic of Iraq. In spite of being widely accepted, it suffers from some limitations due to polarization mode dispersion management. This is particularly important when investigating the third-order dispersion. In contrast, this makes it possible to implement this work in smart cities. There are reasons to doubt these networks to overcome the nonlinearities problem and high bandwidth. As discussed, this is because the Solitons fiber is an attractive selection in the OADM networks.

6 Conclusion

The findings of this article can have the way for adopting the upgrading current optical infrastructure with low cost of the overall system by eliminating the conversions of optical-to-electrical-to-optical and perform these conversions as optical-optical-optical. This is an important finding in the understanding of the switching processes. The bandwidth, distance, and monitoring are important issues in the optical infrastructure. In this article, the evaluation of OADM-based metro network is evaluated. The presentation of OADM is analyzed with four input channels (193.1, 193.2, 193.3, and 193.4 THz) at a total bandwidth of 1.6 Tb/s of NRZ and RZ coding types. Experiment reveals the values of the average output power (-17.997 dBm), the average drop power (-17.997 dBm), and the average add power (-18.338 dBm), the average gain (-0.0429 dB), the average noise figure (0 dB), the average power input signal (10.679 dBm), the average of power output signal (10.633 dBm), the average output OSNR (0 dB). While the second experiment shows the average output power (-24.238 dBm), the average drop power (-24.288 dBm), the average add power (-24.753 dBm), the average gain (-0.0417 dB), the average noise figure (0 dB), the average power input signal (7.691 dBm), the average of power output signal (7.677 dBm), the average output OSNR (0 dB). As the bandwidth and the transmission link increase, the monitoring nodes are used to monitor the network using add-drop. So far, to overcome the GVD and SPM phenomena, we use EDFA is used with Solitons fiber. The system supports four add channels, four output channels, and four drop channels. The results are acceptable and significant after three spans of Solitons fiber with 600 km length, 200 km for each span.

Conflict of interest: Authors state no conflict of interest.

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