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Energy Efficient Waveband Translucent Optical Burst Switching Network

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Abstract

The fast development of translucent Optical Burst Switching (OBS) technology, which employs multiple wavelengths per fiber, increases the size (i.e., the number of ports) as well as the cost and power consumption of Optic Cross-Connects (OXCs). This paper studies the impact of OBS network parameter settings, where switching is performed at the Waveband Switching (WS) granularity using an end-to-end grouping method to reduce the number of lightpaths and switch ports. The simulation results illustrate that using OBS networks with WS by the suitable parameter settings, namely the Burstification Time (BT) and waveband granularity, offers considerable energy savings in the core network compared to using an OBS network without WS, where overall power consumption is decreased by maximizing BT values and waveband granularity.

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Keywords: Optical Burst Switched (OBS); Energy Efficient; Waveband Switching (WS).

1. Introduction

Optical networks utilizing WDM have been considered a favorable candidate for the Internet backbone. WDM technology allows multiple signals to be transmitted concurrently and worked individually on a single optical fiber, which is considered the only way to keep up with the massive increase in data traffic [1]. Therefore, such advances in transport techniques also lead to a significant increase in the number of ports (which is the main contributor to power consumption) in optic cross-connects (OXCs), in addition to the complexity and difficulty of controlling and managing this large-scale OXC [2]. In this situation, Waveband Switched (WS) has been suggested to minimize the number of ports and lower OXC cost [3].

WS has lately garnered the attention of the optic networks industry for its practical relevance in decreasing port count, associated control complexity, and the cost of OXCs. The major concept of WS is to group several wavelengths as a waveband and switch the waveband optically using a single input and a single output port instead of multiple input/output ports, one for each of the individual wavelengths of the waveband. As a result, the size of OXCs that traditionally switch at the wavelength granularity can be reduced [4]. However, despite the translucent OBS network's use of WDM technology for data transfer (all-optical) of different wavelengths, translucent OBS networks have an energy-efficient switch strategy that can minimize the switch processing, which occurs only once each burst when the burst aggregates from many IP packets. Subsequently, the burst-switching strategy can reduce power consumption by decreasing the amount of header processing in core switching significantly [5, 6]. In addition, the translucent OBS network is considered a technique that keeps wide bandwidth, allowing high transport data and various types of traffic [7]. Thus, to achieve a delicate balance between lower energy usage in transparent OBS networks and data transmission quality, it needs to be put in place innovative approaches. Studying energy-efficient methods for translucent OBS networks is critical since they are backbone networks for the present-day Internet. Therefore, several researchers are interested in studying strategies and methods to improve energy efficiency in OBS networks. Therefore, we present some methods that are used in former studies. Bathula, et al. [8] proposed an energy-effective system to close wavelength-routed nodes (WRNS) using anycasting routing ways. Callegari, et al. [9] proposed using wavelength converters in optical packet switching architecture, exploiting the time and wavelength domains for contention resolution. Significant energy savings are possible if wavelength converters are switched off when not used to send packets. Zaiter, et al.[10] the author recommends increasing the size of the data burst in the OBS network for further energy efficiency in the optical network. Kang, et al.[11] proposed a strategy to improve energy provision efficiency by reducing the number of unnecessary transitions. Zaiter, et al. [12] proposed a new strategy for Energy improvement known as Parallel Optical Burst Switching (POBS) networks. Hautegem, et al. [13] proposed a scheduling algorithm to reduce the up-time of the wavelength converters by applying both in a void-filling and non-void-filling setting. However, all the above researches aim to get more network performance with low energy.

Nomenclature

OBS	Optical Burst Switching	SCU	Switch Control Unit
WDM	Wavelength division multiplexer	FTB	Fabre-To-Band
WS	Waveband Switching	MUX	Multiplexer
OXCs	Optical cross-connects	DEMUX	Demultiplexer
BXC	Band Cross-Connect	I/O	Input/output
DB	Data Burst	BL	Burst Length
BCP	Burst Control packet	BT	Burstifcation Time
NSFNET	National Science Foundation Network	PC	Personal computers

In this paper, we present a Waveband Switching (WS) approach for OBS that reduces the number of core node ports to improve energy efficiency. The primary objective of WS with OBS is to combine several wavelengths inside a waveband and optically switched the waveband through one port. Through the grouping of lightpaths into wavebands, the size of OXCs (such as the number of ports and switching) is reduced.

2. Architecture of OBS

The OBS network consists of an edge and core nodes associated via WDM fiber links, as shown in Fig. 1. To fully use the WDM links, the designers have to face several challenges, such as reduction of the nodal size, the cost, and power consumption incurred by the network and providing efficient bandwidth utilization [5]. The OBS network is based on a one-way reservation mechanism (known as "Tell-and-Go"). In this mechanism, a BCP setup is sent in advance to precede the arrival of a DB of BCP by an offset time to reserve the transmission of the required resource for the corresponding DB. Several Tell and Go (TAG) techniques, including Just in Time (JIT) Just Enough Time (JET), and Just In Time (JIT), have been suggested for OBS networks [14, 15].

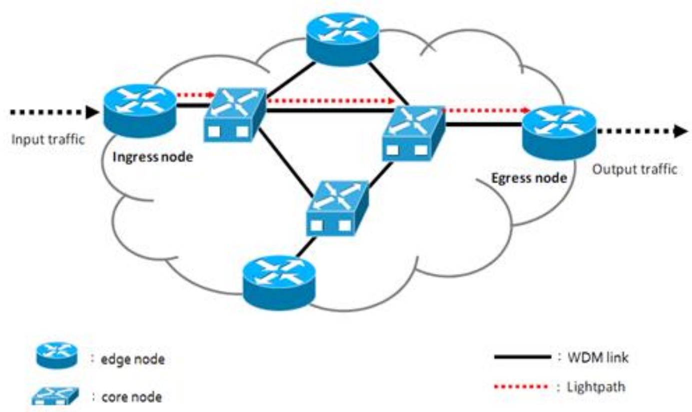

Fig. 1. Structural OBS Network

2.1. Edge OBS Node

The edge node consists mainly founded on two parts referred to as the ingress and egress nodes; an ingress node is responsible for the assembly of the packets (IP packets, ATMcells, Frame Relay, etc.) to a larger frame called DB that transfer optically on a waveband to the core node. When bursts are generated, A BCP is created for each burst, and BCPs are sent to the core node before the burst. After an offset time, the bursts are directed to the intended egress node through the core node. Hence, the egress node is responsible for burst disassembly, recovering IP packets from the incoming DB, and forwarding packets to the destination terminals[16]. Fig. 2 shows the assembly DB and transmitted via waveband.

2.2. Core OBS Node

A core node consists of Band Cross-Connect (BXC) and a Switch Control Unit (SCU), as shown in Fig. 3. The optic signal in the input fibre is demultiplexed into wavebands utilizing the Fibre-To-Band (FTB-DEMUX) Demultiplexer. The BCP is transmitted separately via the control channel to the input of SCU, which initially converts BCP to the electrical domain, then extracts the control field. The SCU uses the information extracted from the BCP to configure BXC to determine the outgoing waveband port. While, on the side output BXC, the wavebands are multiplexed to the same fibre utilizing Band-To-Fibre (BTF-MUX) Multiplexer.

2.3. Fiber Link

OBS networks use WDM fiber links to interconnect between edge and core nodes. The WDM transport system has multiple wavelengths; each represents a separate channel for the Gb/s data rate, where such transport systems provide a data rate of up to 50 Tb/s[17]. However, to decrease the number of lightpaths and switching ports, WS is implemented with WDM, where many wavelengths are switched into a single waveband that can be switched via a single port [18]. Hence, a fiber consists of a waveband; a waveband consists of different wavelengths, shown as in Fig. 4.

In addition, multiple wavelengths operating on different fibers are combined into one fiber by an FTB multiplexer at the transmitter. At the same time, an FTB demultiplexer separates all the wavelengths into individual fibers at the receiver. Devices multiplexer (MUX)/demultiplexer (DEMUX) be Optical, where component signals are MUX and DEMUX optically, not electronically; thus, no external power source is required. However, when sending optical signals long distances via a fiber link, the signs are distorted because of noise accumulation and chromatic dispersal[16]. Consequently, translucent OBS networks use all-optical Reamplification and Reshaping (2R) regenerators to mitigate end-to-end BER of the channel and increase optical signal quality[19], as shown in Fig. 5.

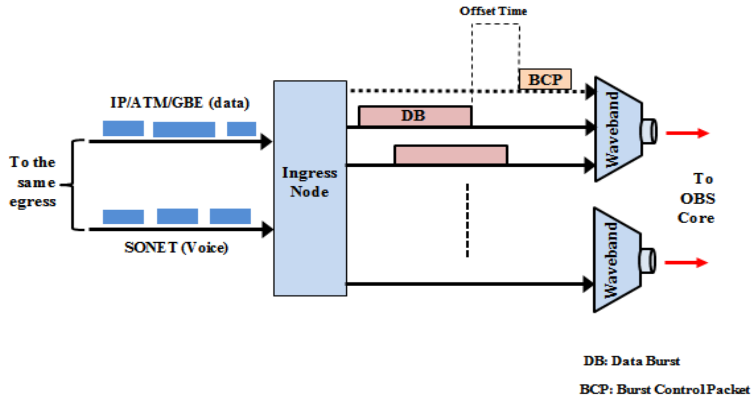

Fig. 2. Burst Assembly of OBS Edge Node with Waveband

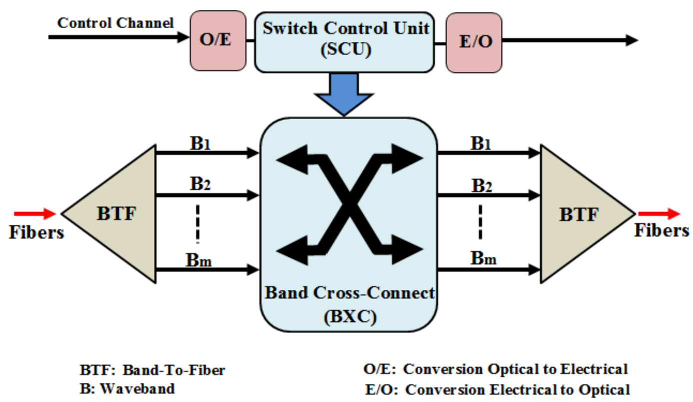

Fig. 3. Structure of a Core Node

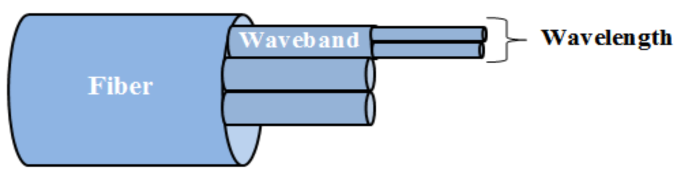

Fig. 4. Fiber Link

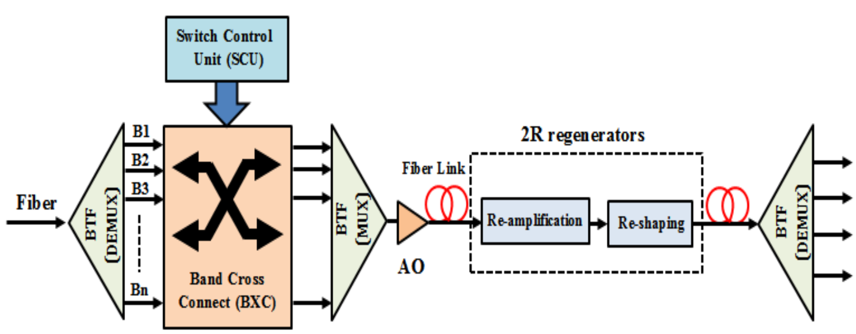

Fig 5. Translucent OBS optical link

3. Proposed Model Calculation of Energy

In this section, energy consumption is expressed in terms of the unit Joules per bit (J/ b). The amount of energy consumption is used to evaluate the energy efficiency of the OBS network equipment. Generally, two main operations require energy consumption in optical networks. The first operation involves the transmission of bits over an optical fiber link, and the second operation involves switching bits in a node. A power model intended to capture the energy consumption of commercially available subsystems is used to calculate power consumption in an OBS network[20, 21]. The proposed power model is based on Cisco 12816 single-chassis router and the Cisco CRS-1 multi-chassis router, which are utilized as edge and core nodes, respectively. Fig. 6 illustrates the subsystem's power consumption for such two routers.

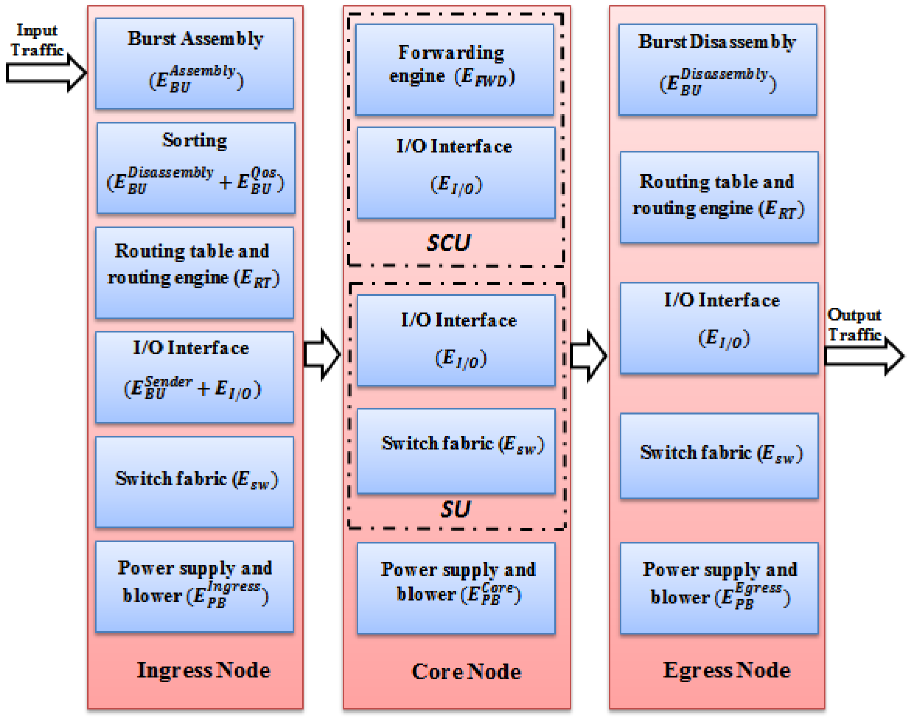

Fig. 6. Blocks of Functions of Nodes in OBS Networks

In the edge nodes, the calculation for ingress and egress node energy consumption in nJ/b is as follows:

$$E_{bit}^{(Ingress)} = E_{I/O} + E_{BU}^{(Assembly)} + E_{BU}^{(Destination)} + E_{BU}^{(QoS)} + E_{BU}^{(Sender)} + E_{SW} + E_{RT} \quad + E_{PB}^{(Ingress)} \tag{1}$$

$$E_{bit}^{(Egress)} = E_{I/O} + E_{BU}^{(Diassemply)} + E_{SW} + E_{RT} + E_{PB}^{(Egress)} \tag{2}$$

In OBS networks, wavelengths emerging from the ingress node with the same source-destination nodes are aggregated into a single waveband allowing the switching of many wavelengths utilizing one port [18, 22]. The total energy consumed at the core OBS node is dependent on the energy consumption of its components, specifically, the I/O interface, the switch fabric of BXC and SCU, in addition to the power supply and blower, as shown in Fig 6. Therefore, the computation of total energy consumption in the core OBS node, defined in nJ/b, is shown in the below equation:

$$E_{bit}^{Core} = E_{I/O}^{BXC} + (E_{SW}^{BXC} + (E_{I/O}^{SCU} + E_{FWD}^{SCU} + E_{BU}^{SCU}))/(S_d/m_P) + E_{PB}^{(Core)} \tag{3}$$

Where S_b, represents the length of the burst (in bytes) and m_p represents the mean packet size (in bytes).

For this end-to-end grouping in the WS technique, where each port on the BXC of the core node represents a waveband port, switching is performed at the granularity of a WS to transfer DB concurrently to the egress edge node, as shown in Fig 3. In such a context, the number of needed ports in the OBS core node is reduced; thus, the energy consumption of the I/O interface is decreased by the ratio (x), as indicated in Equation (5). Equation (4) seeks to describe the relationship between the energy consumption of the I/O interface in the OBS network with and without the WS technique, which is reflected by the number of ports in both cases:

$$x = \frac{E_{I/O}^{BXC}}{E_{I/O}^{SU}} = \frac{F \times M}{F \times W} = \frac{M}{W} \tag{4}$$

Where F, M, and W indicate the number of fibres at a single link, the number of wavebands at a single fibre, and the number of wavelengths at a single fibre respectively. Therefore, the ratio(x) reduces the energy consumption of the I/O interface of BXC for core OBS nodes, reducing the overall energy consumption of the core node. The value of $E_{I/O}^{BXC}$ at Equation (4) can be replaced with Equation (3) to generate Equation (5):

$$E_{bit}^{(Core)} = x \times E_{I/O}^{SU} + (E_{SW}^{BXC} + (E_{\frac{I}{O}}^{SCU} + E_{FWD}^{SCU} + E_{BU}^{SCU}))/(S_d + m_p) + E_{PB}^{(Core)} \tag{5}$$

The overall power consumption in the core OBS nodes is as follows:

$$P^{(Core\ nodes\ )} = \sum_{j=1}^{C} E_{bit}^{(Core)} \times t_j \quad (6)$$

Where t_j indicates the average bit rate in Mb/s in core OBS node j. The total energy consumption in edge OBS nodes can be calculated in the following Equation:

$$P^{(Edge\ nodes\ )} = \sum_{n=1}^{E} [E_{bit}^{(Ingress)} \times t_n^i + E_{bit}^{(Egress)} \times t_n^o] \quad (7)$$

Where t_n^i and t_n^o indicate I/O average bit rate in Mb/s respectively in the edge OBS node. Lastly, the overall power consumption in the translucent OBS network is computed by Equation (8):

$$P^{(Total)} = P^{(Edge\ nodes)} + P^{(Core\ nodes)} + (N_r)P^{(regenerators\ )} \quad (8)$$

Where N_r represents the total number of regenerators and $P^{(regenerator)}$ indicates the power consumption (watts) of 2R regenerators. The power consumption of 2R regenerators is 10 W [23]. The total number of 2R regenerators in the network is computed in the equation below:

$$N_r = \sum_{i=1}^{L} F_i \times \frac{l_i}{d} - 1 \quad (9)$$

Where F_i represents the number of fibres in the link and l_i represents distance among two bordering nodes on link i, while d is the span distance among regenerators. Hence, the 2R regenerators put a distance of 100 km [24].

4. Configuration Parameters of OBS Networks

Fig. 7 shows the topology of the National Science Foundation Network (NSFNET) utilized in the simulation. The NSFNET topology consists of 10 edge nodes, 14 core nodes, 10 PC, and 21 bi-directional links between core nodes. Where each link consists of as many as 62 channels (60 channels for DB and 2 channels for BCP) are used to investigate the effects of wave-band size (granularity) on the power consumption of the OBS network. Table 1 shows the configuration parameters of the OBS network in the NCTUns 0.6 simulator.

Table 1. Configuring Simulation Parameters

Parameters	Values
Bit Rate (BR)	100 Gb/s
Burstifcation Time (BT)	2 μ sec
BCP processed time	2 n s
Reservation Protocol	JET
Bandwidth-channel	1Gb/s
Burst length (BL)	5 KB,1000KB
No. of edge nodes	10
No.of core nodes	14
No.of channels (wavelength)	60
No.of wavebands	3,6

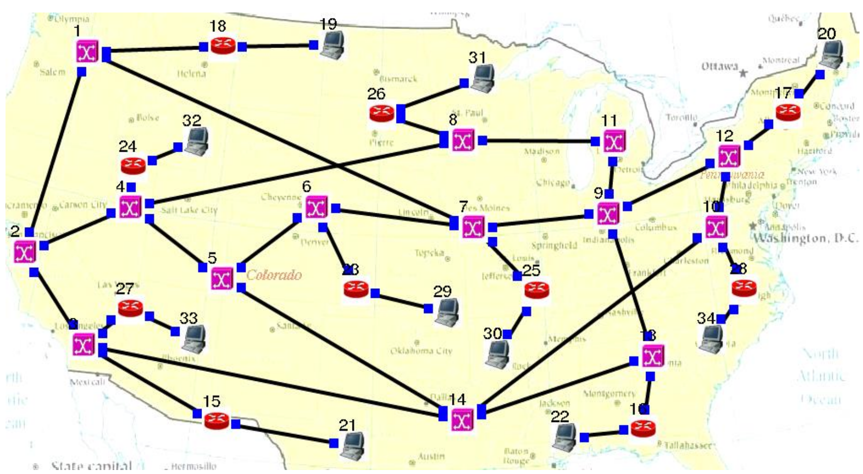

Fig. 7. NCTUns 0.6 Screenshot of NSFNET

The OBS networks use one-way reservation mechanisms through Just-Enough- Time (JET) signaling technique. Hence, the traffic load of the simulation uses UDP of 10 dyads of source-destination nodes, where each node is represented with PC, and offered load can be calculated as follows[25]:

$$Offered\ Load\ (Erlang) = \frac{a \times m_p}{R} \quad (10)$$

Where a, $m_{p,}$ and R represent the average appearance rate of packets (packets/sec), the average packet length (bits), and the transmission rate (bits/sec) independently.

5. Results and Discussion

In the NSFNET topology for the OBS network, the power consumption is calculated using the parameters shown in Table 1, with the number of wavebands per fibre set to three (M=3). This indicates that wave-band granularity (K) is 20 wavelengths for each wave-band (K =60/3=20). Fig. 8 illustrates the simulation results. It is found that at zero-traffic load, the power consumption of traffic-independent components for OBS with WS technique and OBS without WS technique is 3576 W. In addition, in high-traffic load, the power consumption of the OBS without the WS technique is almost 18% more than that of the OBS with the WS technique.

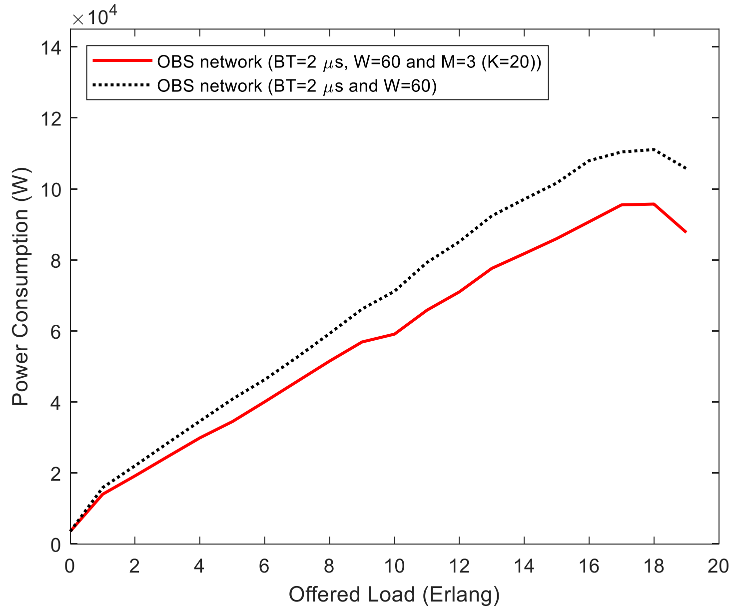

Fig. 8. Comparison of Energy Dissipation

The simulation experiment is recurred in three cases to calculate the power consumption of the OBS network. Each case combines one BT value (2 μ *sec* or 4 μ sec) with a set waveband granularity (K) value and ten channels in a single waveband. Fig. 9 illustrates the effect of K and BT on energy consumption for OBS topology as traffic load increases.

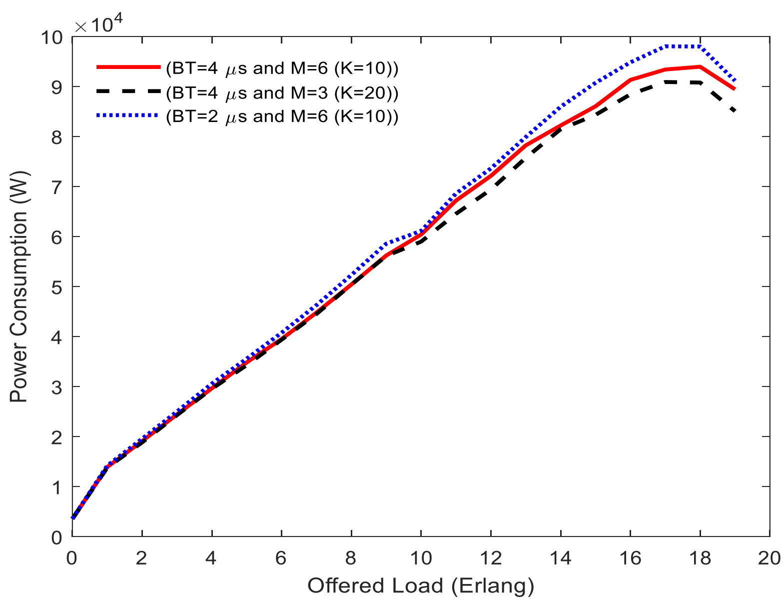

Fig. 9. Network OBS Load vs. Power Consumption in NSFNET

Based on Equation 8, the total energy consumption of translucent OBS networks of data inflow in the shortest path from node1 (ingress edge) into node14 (egress edge) for throughputs of 60 Tb/s, as shown in Fig. 10. This is based on the assumption that a short Burst Length (BL) has the size of 5 Kbyte while a long BL has the size of 1000 Kbyte.

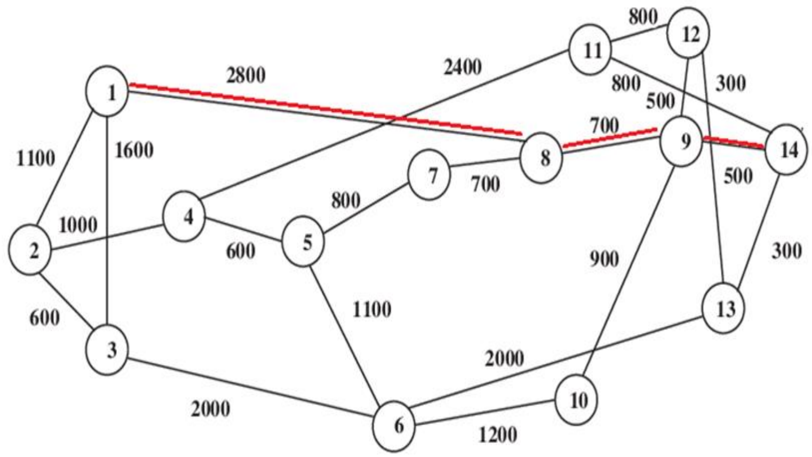

Fig. 10. The NSFNET Network, which has (14) Nodes and (20) didirectional Links

Fig. 11 illustrates the effect of various burst lengths (5KB – 1000KB) for data flow with a throughput of 60 Tb/s from node 1 to node 14 on the power consumption of the OBS network. The simulation results indicate that the OBS without WS technique consumes approximately 13% more power than the OBS with WS. In addition, the results obtained from these two ways for two switching techniques indicate a marginal decrease in power consumption and energy each bit when the BL is larger than 60 KB.

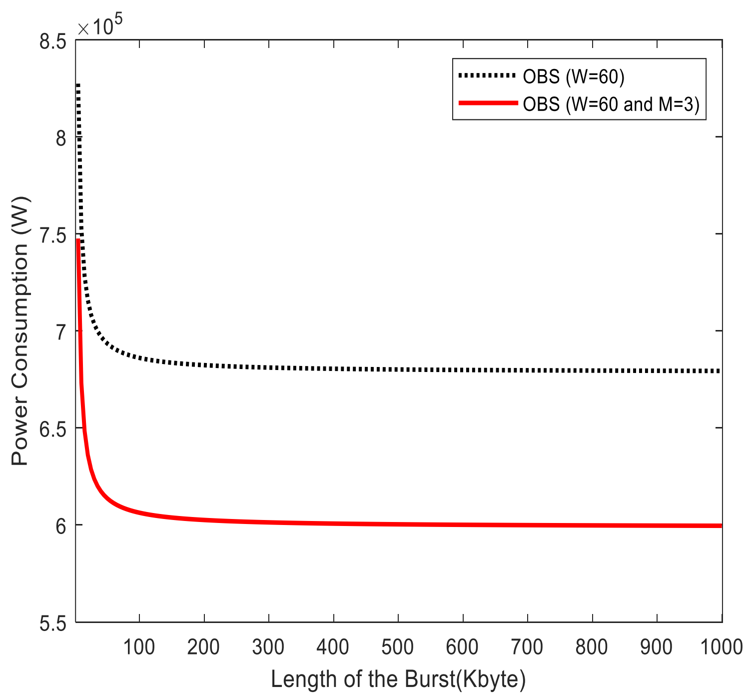

Fig. 11. Required Energy Consumption for Transmission of One Bit

Table 2 compares the proposed strategy results with some published works. Hence, all researches aim to get more network performance with low energy. Hence, researchers try to get a result from the simulation of the network models, network architecture, and algorithms that are implemented in the network. Therefore, WS Technique is implemented with a translucent OBS network to reduce the number of ports to improve the energy efficiency of the network.

Table 2.A comparison between the proposed strategy in some previously published research

references	Energy Saving Technique	Energy Saving	pros and cons
[9]	Turn off the wavelength converters.	50%	Low energy, burst loss but expensive technology
[8]	Turn off the underutilized core nodes.	40%	The network's connectivity decreases due to the sleep modes of the core node. This increases the average request loss and a larger number of burst drops.

[13]	scheduling algorithms	28% for non-void-filling algorithms and 37% for void-filling algorithms	The scheduling algorithms are complex in implementation but attractive for switch design.
[11]	Transition Decision Algorithm	20%	Energy saving and packet delay were preserved within an acceptable level.
[10]	Increase Data Burst	10%	An advantage of increased data burst is header processing reduction with effective switching.
This work	Use the WS technique.	18%	Provided more energy efficiency.

6. Conclusion

The major object of this paper is to improve the energy performance of translucent OBS using the Waveband Switching (WS) technique. The simulation results show that the WS technique with a translucent OBS network is more energy-efficient when compared with a translucent OBS network without WS. Where WS based on switching strategy has significantly reduced the number of ports where only one port of waveband switching (group of wavelengths) is used. This has also reduced the power consumption of the I/O interface in core OBS nodes. As well as, simulation results for BL increase lead to decreasing the power consumption of the OBS network. Finally, it can be deduced that utilizing a BT with a high value and granularity in waveband can reduce the overall power consumption of an OBS network.

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