Research Article

Optimum Design Analysis of Arrayed Waveguide Grating Based Optical Switches

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Abstract

Nowadays, in telecommunication industry, the effective bandwidth utilization and high-speed data transfer rate are the two basic requirements. For achieving these requirements, the optical network is the best option available in the market through which the data transfer is achieved nearly with the speed of light. For realizing the concept of optical network, the numbers of optical switches are available. In this paper, four arrayed waveguide grating (AWG) based optical switches are investigated heavily and a performance comparison is conducted between the switches in terms of loss, cost, and scalability analysis. The obtained results clearly set the guidelines for the optimum design of the switch.

Introduction

Data communications are the exchange of data between two devices via some form of the transmission medium; the transmission medium can be of any type which is capable of receiving or sending the data between device. In telecommunication industry, the fast speed communication is highly desirable, and for this purpose, the optical network is the best available option in which data communication network is built with optical fiber technology. In optical communication network, the optical fiber cables are used as the primary communication medium for converting data and passing as light pulses between sender and receiver nodes. For realizing optical communication system the optical packet switching systems are used frequently in which data is divided into small size packets and each packet is further divided into two parts—header and pay load. The payload contains the actual information which is to be transmitted from one node to other node and header contains the actual addressing information. During data transmission process the optical-electrical conversion exists, the header of each packet is converted from optical to electrical domain through

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Optical/Electrical convertors while on the other hand, the payload part of the packet remains in the optical domain throughout the communication(Pleros et al., 2008). There are different types of optical packet switch architecturesthat are available in the market; some of them are wavelength routed switch (Zhong & Tucker, 1998; Hunter et al., 1999; Sasayama et al., 1997; Shimazu &Tsukada, 1992), broadcast and select switch (Bendelli et al.,1995; Verma, et al., 2002; Singh et al., 2003) and AWG-based switch (Guillernot et al., 1998; Chia et al.,2001; Singh, 2007; Pattavina, 2005; Hunter et al., 1998). In this paper, four AWG-based optical routers are discussed and a detailed comparative analysis has been presented in terms of loss, cost, and scalability analysis. The whole paper provides the brief description about switches, loss analysis of switches, and the scalability and cost of each switch.Finally, the major conclusions of the paper are discussed.

Architecture Descriptions

In this paper four AWG-based optical packet switches are discussed. The switch presented in Fig. 1 is proposed by D.K.Hunter which is a wavelength selective switch in which the tunable wavelength convertors (TWC) are used at each input port of the switch. ThisTWC converts the wavelength of each packet according to the routing pattern of first AWG router(Hunter et al., 1999). Each of the packets has two available options; either packetis directed towards the appropriate output port or on the other hand, if the situation of contention arises then packets are forwarded towards the appropriate buffer. Here the fiber delay lines are used for buffering of contending packets. In the buffer section, there are set of TWC, Mux, and Demux at each of the fiber delay lines. Finally,at the output port of switch, another AWG is placed which is used to forward the packets towards appropriate output ports.

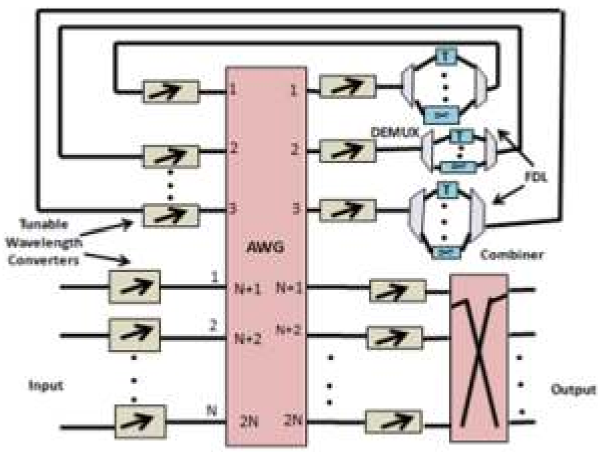

Fig.1.Switch proposed by WASPANET project (A1)
Source. Hunter et. al., 1999.

In Fig. 2 another AWG-based optical switch is presented which is a feedback optical switch. In this optical switch the shared feedback delay lines are used for buffering of contending packets(Chiaet. al., 2001). At the input of switch,tunable wavelength convertors are present. These TWC converts the wavelengths of incoming packets and the packets which feels contention are forwarded towards the appropriate buffer where fiber delay lines are used to store the contending packets while on the other hand, direct through packets are forwarded towards the appropriate output port of the switch. The switch consists of "N" modules one for each output port. For a tagged output at most "m" packets can be stored. Hence, in all the modules, at most N packets can have the same delay varying from 1 to m slots, and in all the modules all together at most mN number of packets can be stored. The problems associated with this architecture are as follows:
1.In the architecture exit time, contention may occur.

2. Control unit complexity is high.

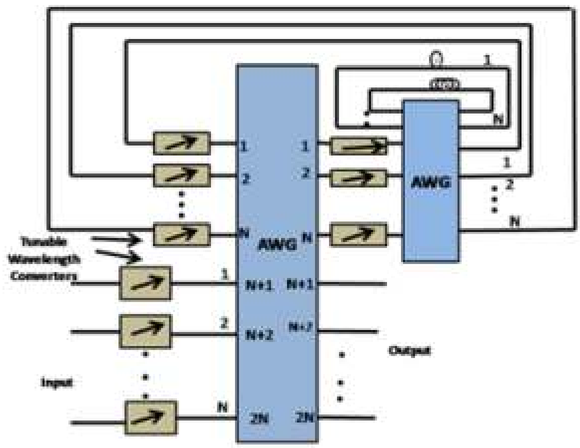

Fig. 2.Feedback optical packet switch (A2)
Source. Chiaet. al., 2001.

Figure 3 shows hybrid optical packet switch architecture (Lin et. al., 2003). The switch has two AWGs and a set of TWC as the core of optical switch. The architecture uses both techniques (feed forward and feedback buffering) for storing the contended packets. Here at the input of switch, the TWC is used to convert the wavelength of incoming packets according to the routing pattern of first AWG router. The noise performance of wavelength routing switch is improved as the wavelength converter can help and regenerate the signal. Due to the static configuration of AWG the complexity of switching stage reduces. The switch shown in Fig.3 has single wavelength input/output (I/O)ports. Thiscan be upgradedto a WDM version by using Mux, combines and multiple of the switch fabric plane.

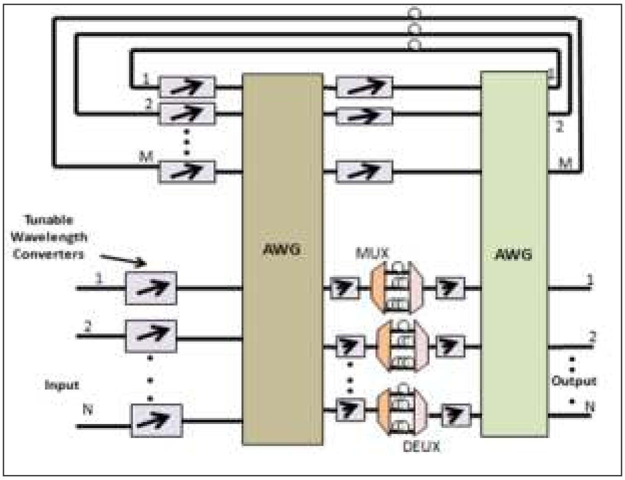

Fig. 3.Hybrid FDL based switch
Source. Linet al., 2003.

Finally, in Fig. 4 an AWG based switch is discussed the switch is proposed by R.Srivastava and further some modifications were proposed by V. Shukla in 2014. The designs structure is very simple and control operations are very less in comparison to other optical switches. At the input port of switch, the tunable wavelength convertors are present which are used to convert the wavelength of incoming "g" packets according to the routing pattern of first AWG-based optical router(Rastegarfar, et. al., 2013; Srivastava& Singh, 2010; Shukla et. al., 2016). Here the first N port of AWG is connected with the fiber delay lines while on the other hand, the lower N ports of AWG is connected with the switching section AWG through a set of TWC. When the situation of contention between packets arises then packets are forwarded towards appropriate fiber delay lines for buffering purpose.

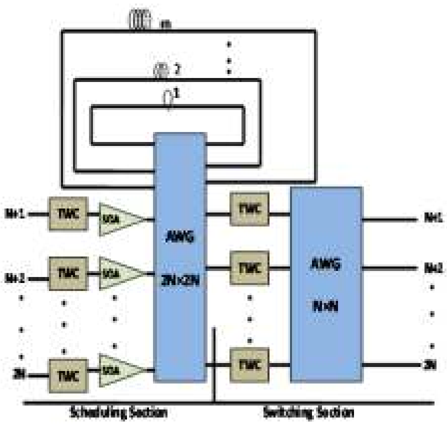

Fig. 4. Proposed switch
Source. Srivastava, & Singh, 2010; Shukla et al., 2016.

Analysis of Switches

In this section, the detailed analysis of each switch is presented and performance comparisons between switches are performed in terms of loss, cost, and scalability analysis.

Loss Analysis

Each of the devices present in the switch is a loss device and each device has its own insertion loss, so the loss of each switch is an important parameter in the case of analysis of switches. In this analysis, the loss equations of each switch are presented. The loss values of various devices are chosen from Table 1.

Table1.Value of different loss parameters

Symbol	Parameter	Value
N	Size of the Switch	4
L_{TWC}	TWC insertion loss	2.0 dB
$L_{AWG}^{2N\times N}$ $L_{AWG}^{N\times N}$	Loss of Scheduling and Switching AWG (32 channels)	3.0 dB
L_{FDL}	Loss of the fiber loop	0.2 dB/km
L_{SOA}	Loss of SOA	1dB
$L_{Demux}^{N\times 1}$	Demux Loss	$1.5(\log_2 N - 1)dB$
$L_{Mux}^{N\times 1}$	Mux Loss	$1.5(\log_2 N - 1)dB$
L_{TF}	Tunable Filter Loss	2dB

Source. Shukla et. al., 2014

Loss analysis of switch A1 is as follows:

$$A_T^{A1} = L_{TWC}^{in} L_{AWG}^{2N\times 2N} L_{TWC}^{b} L_{Demux} L_{Mux} L_{TWC}^{b} L_{TWC} L_{AWG}^{N\times N} \quad \text{(Eq. 1)}$$

After inserting various loss values the total loss of switch A1 is calculated as follows:

Loss analysis of switch A2 is as follows:

$$A_T^{A1} = 17\,dB \quad \text{(Eq. 2)}$$

After inserting various loss values the total loss of switch A2 is calculated as follows:

Loss analysis of switch A3 is as follows:

$$A_T^{A2} = L_{TWC}^{in} L_{AWG}^{2N\times 2N} L_{TWC}^{b} L_{TWC}^{b} L_{AWG}^{N\times N} \quad \text{(Eq. 3)}$$

After putting the various loss values the total loss of each switch is given by:

Loss analysis of switch A4 is mentioned next:

$$A_T^{A2} = 12dB \quad \text{(Eq. 4)}$$

In this analysis the total loss of each switch is calculated and the obtained results clearly reveal that the loss of switch A4 is in lowest category while on the other hand, the loss of switch A3 is highest while the loss of switch A1 is almost equal to the A3 and for the switch A2 the loss values are almost equivalent to A4.

Scalability Analysis

Each of the switches presented in this paper uses different components and as we all know, more the number of components means more complexity in the functioning of the switch. Since we all know that cost of each componentis too high so the switch having fewer component counts are preferable because as less the components means less the cost and loss of switch. Table 2 represents the total number of components in the switch.

Table2. List of various components

Components	A1	A2	A3	A4
SOA	×	×	×	N
TWC	4N	3N	5N	2N
AWG	2	2	2	2
Demux	N	×	N	×
Mux	N	×	N	×

Cost Analysis

As we all know that the cost of optical components are too high so more number of components means more cost of the switch. In this section of the paper, the detailed cost analysis of each AWG-based switch is presented in detail. This analysis is performed with the help of Fiberto Chip Coupling (FCC) model. This model for the optical components are based on FCC which is the number interconnections to the outer world through the components; the cost of the device is measured by counting the number of FCC (Shukla, & Jain, <2016> ; Shukla et. al., 2016; Shukla & Srivastava, <2015> ; Caenegem et. al., 2006). The wavelength conversion range is not considered by FCC model so further a more generalized cost model came into existence which incorporated the effect of wavelength conversion. In this generalized model, the cost of TWC is represented by:

$$C_{TWC} = ad^{b} \quad \text{(Eq. 5)}$$

In Eq. 5 the value of "a" is considered to be 1 while on the other hand, the value of "b" lies between the range 0.5 and 5.

Table 3.Cost values of various components

Symbol	**Representations**	**Cost**
C_{TWC}	Cost of TWC	4
C_{Demux}	Cost of Demux	N+1
C_{Mux}	Cost of Mux	N+1
C_{SOA}	Cost of SOA	2
C_{AWG}	Cost of AWG	2N

Now for calculating the cost of each switch presented in figures 1 to 4 the equations are represented as follows:

Cost of switch A1

$$C_T^{A_1} = NC_{TWC} + NC_{TWC} + C_{AWG}^{2N'\,2N} + NC_{DMUX} + NC_{MUX} + NC_{TWC} + NC_{TWC} + C_{N'\,N}^{AWG} \quad \text{(Eq. 6)}$$

Substituting the cost values of different components, and considering a=1 we get

$$C_{A_1} = 2N\left(2N\right)^b + 2N\left(N\right)^b + 9N + 2 \quad \text{(Eq. 7)}$$

Cost of switch A2 is as follows:

$$C_T^{A2} = NC_{TWC}^{in} + C_{AWG\,1}^{2N'\,2N} + N\left[C_{TWC\,1}^{b} + C_{TWC\,2}^{b}\right] + C_{AWG\,2}^{N'\,N} \quad \text{(Eq. 8)}$$

Substituting the various cost values from Table 3 and after putting the value of a=1the total cost of the switch is as follows:

$$C_{A2} = N\left[12\left(2N\right)^b + 8\right] \quad \text{(Eq. 9)}$$

Cost of switch A3 is:

$$C_{A3} = NC_{TWC} + C_{AWG} + NC_{SOA} + NC_{TF} + NC_{TWC} + NC_{SOA} + NC_{TF} + NC_{TWC} \quad \text{(Eq. 10)}$$

Now after inserting the cost value and substituting the value of a=1, we get the total cost of the switch as follows:

$$C_{A3} = N\left[(2N)^b + (N)^b + (N+1)^b\right] + 14N \quad \text{(Eq. 11)}$$

Cost of switch A4 is as follows:

$$C_{A4} = NC_{TWC} + C_{AWG}^{1} + NC_{SOA} + NC_{TWC} + C_{AWG}^{2} \quad \text{(Eq. 12)}$$

Now the final cost equation after inserting cost values of each device and the value of a=1 is as follows:

$$C_{A4} = N\left[(2N)^b + (N)^b\right] + 9N \quad \text{(Eq. 13)}$$

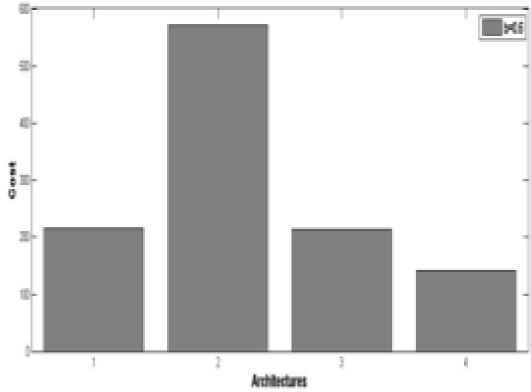

Fig. 5. Cost of the switch when b =0.6

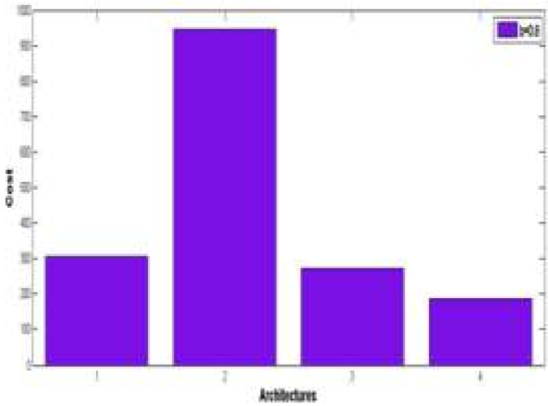

Fig. 6.Cost of the switch when b=0.8

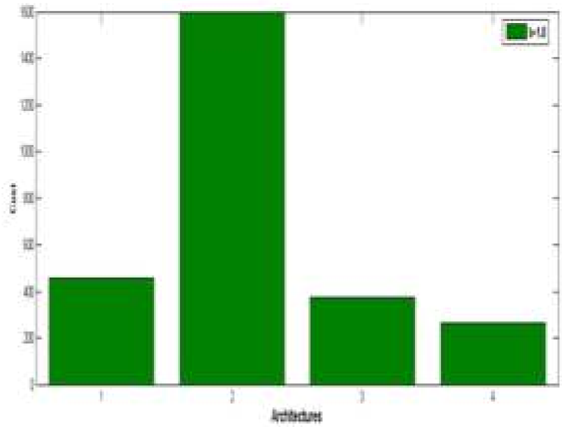

Fig. 7.Cost of the switch when b=1.0

The figure 5,6 and 7 shows the cost analysis of each switch from these graphs the cost of switch A4 is very less in comparison to other switches so the performance of switch D4 is much better in terms of cost parameter.

Conclusion

Nowadays, the telecommunication industry is one of the fastest growing industries; where bandwidth utilization and speed of light is the important parameter. As of now, the optical network is the best available option that provides fastest data transfer speed and effective bandwidth utilization. For realization purpose the concept of optical packet switching and optical burst switching came into existence; many of the researchers are focused on the design of switch. There isa number of optical switches available in the market, which has its own pros and cons. In this paper, four AWG-based optical packet switches are presented and a detailed analysis is shown. The obtained result clearly reveals that the TWC is a dominating device and if more number of TWC are used, it increases the cost of switch exponentially. On the other hand, if less number of components is used in the design of switch then it makes the switch more perfect because less the components mean lesser loss and less power requirement in the operation of the switch.

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