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PERFORMANCE OF INLINE SWITCH IN OPTICAL NETWORK

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ABSTRACT

Optical packet switching is a new emerging technology for next generation data transfer. Optical Packet Switching (OPS) utilizes the very large bandwidth of the optical fiber along with Wavelength Division Multiplexing (WDM) for high speed data transfer. In OPS, contention among the packets is a major problem, which can be solved by using the buffering of contending packets. The need of the buffering of contending packets gave birth to optical switches designs. This paper presents analysis of an optical switch in different configurations. Analysis is presented for four different switch configurations. It has been found that there is tremendous increase in switch operating power when switches are placed in the network.

Keywords: Optical packet switch, wavelength division multiplexing, power and noise analysis.

INTRODUCTION

In the last few years, explosive growth has been seen in the internet traffic, due to emergence of data centric applications. On the other hand, massive data centers (Google, Yahoo etc.) are also generating lot of heat and their expansion is not possible. This growth/limitation has necessitated new technologies which can handle enormous data. It is well known that the optical fiber provides very high speed transmission and a single piece of fiber has enormous bandwidth. Thus optical communication can provide a possible solution. The development of optical communication took place with very slow pace, however now most of the optical components are commercially available, thus making optical communication as feasible solution. The only two components Tunable Wavelength Converter (TWC) and Optical 3R-(Re-amplification, Re-shaping and Re-timing) are not commercially available. TWCs are expected to be

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commercialized by the end of this year. But the use of 3R in optical communication is very limited, as 2R re-amplification and re-timing is possible with optical amplifier and with dispersion compensated fibers and re-timing is not that much critical issue in optical communication.

In this paper, we have shown that an isolated switch analysis is deceptive as it does not provide insight into the switch when placed in the network. Therefore, a careful design analysis is necessary when switches are placed in the core network.

OPTICAL NETWOROKS

The generic layout of OPS network is shown in Figure 1. Here, the edge nodes have E/O and O/E conversion capability, while in OPS nodes data propagates optically. However, clients generate data electronically. As electronic data is aggregated and edge nodes, the size of packets is generally larger. These aggregated larger size packets traverse in the core networks and passes through OPS nodes [1-4]. Therefore, design of these core switches is very critical and integral part of the network design. In optical core networks optical switches play very important role in the over-all performance in terms of both physical and network layer parameters [5-7]. In past, many design have emerged with their pros and cons [5-12]. In this paper, we have selected a switch which has very simple buffer design.

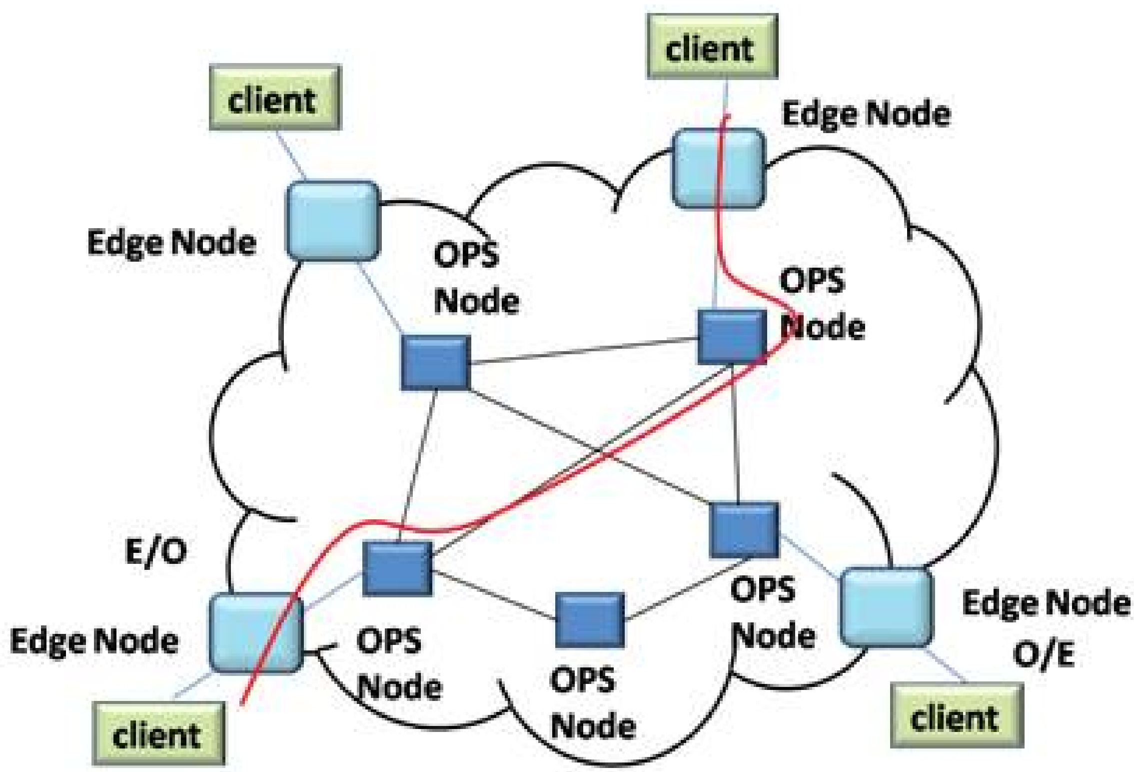


Figure 1: Generic Layout of Optical Network

SWITCH ARCHITECURE

A recently published switch design has been selected for analysis. In this switch design, packets are directly transmitted to output by tuning their wavelengths appropriately through input TWCs and at the output, corresponding TF tunes its wavelength to accept the packet. Buffer is created using multi-wavelength FBGs. Each FBG reflects a set of wavelengths which are distinct for each FBG. Each FBG reflects one wavelength for each output.

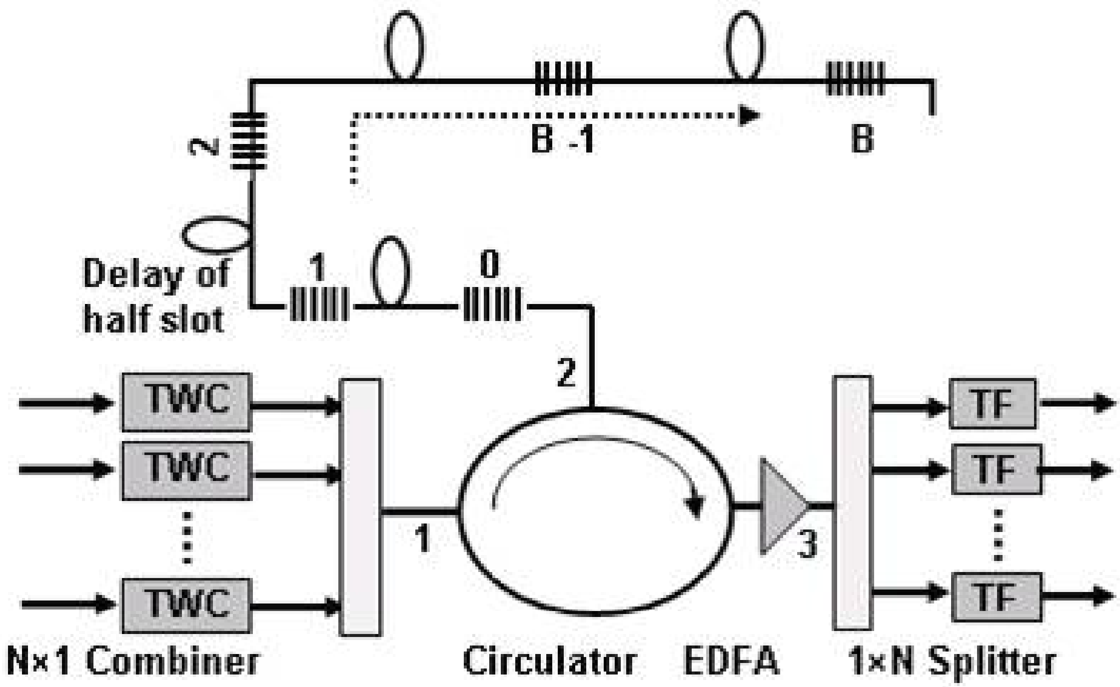


Figure 2: Switch Design Under Consideration

As per the required amount of delay, different FBGs can be selected. For detailed description on the architecture reader can refer to Srivastava *et al.* [8].

ARCHITECURE MODIFIATIONS

When such switches are placed in the networks, at the input of the switch splitter and at the output of the switch, combiners are required. As in the network, data propagates using WDM technology. So at the input of the switch, first data needs to be split and then will be routed within the switch and again at the output of the switch, data has to be multiplexed using combiner.

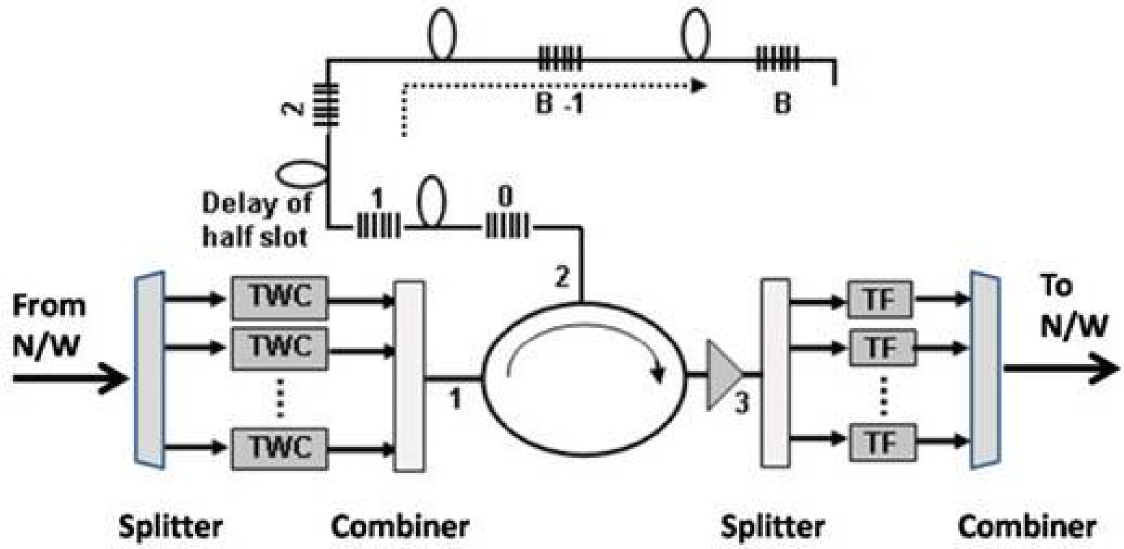


Figure 3: Modified Switch Design

PHYSICAL LAYER ANALYSIS

The power budget analysis is necessary to identify the minimum power of the signal which passes through the switch and correctly identified at the switch outputs. In the power budget analysis, following steps are to be followed:

1. Calculation of accumulated losses when signal passes through different components of the switch.
2. Gain calculation of EDFA, which is numerically equal to the total loss of the switch.
3. Total signal power received at the output using additive noise.
4. Noises accumulation within the switch and at the receiver.
5. Bit Error Rate analysis at different power levels.
6. At a fix BER of $\leq 10^{-9}$, identification of minimum power required for correct operation of the switch.

Loss Analysis

The loss of the input which consists of TWC and combiner is $A_{TWC}A_{Com}^{N\times 1}$, the loss of output unit which consists of splitter and TF is $A_{FBG}A_{Cir}A_{Spt}^{1\times N}A_{TF}$, and the loss of buffer unit is BA_{FBG}.

Thus the maximum possible loss when a packet passes through the switch is

$$A = A_{TWC}A_{Com}^{N\times 1}(B+1)A_{FBG}A_{Cir}A_{Spt}^{1\times N}A_{TF} \quad (1)$$

This loss is compensated by EDGA, and it is found that the condition $AG=1$, a condition which maximizes the SNR [1].

When switch placed in the network, the new loss can be formulated as

$$A = A_{Spt}^{1\times N} A_{TWC} A_{Com}^{N\times 1} (B+1) A_{FBG} A_{Cir} A_{Spt}^{1\times N} A_{TF} A_{Com}^{N\times 1} \tag{2}$$

Additional loses is encountered due to the splitter and combiner.

Power Analysis

Again, power entering the switch is

$$P_s \quad bP_{in} \quad b \quad [0,1] \tag{3}$$

The extinction ratio ($\varepsilon = P_0/P_1$) is assumed to be zero.

Power at the output of the switch is

$$P_{out} = P_s + P_{sp}$$

$$P_{out} = bP_{in} + n_{sp}(G-1)h\nu B_0 A_{Spt}^{1\times N} A_{TF} \tag{4}$$

The term $n_{sp}(G \quad 1)h\nu B_0$ represents the ASE noise of the EDFA amplifier. In case of network the power of bit leaving the switch is

$$P_{out} = bP_{in} + n_{sp}(G-1)h\nu B_0 A_{Spt}^{1\times N} A_{TF} A_{Com}^{N\times 1} \tag{5}$$

Noise analysis

Noise components generated at the receiver are shot noise, ASE-ASE beat noise, sig-ASE beat noise, shot-ASE beat noise and thermal noise. Variances are denoted by σ_s^2, σ_{sp-sp}^2, σ_{sig-sp}^2, σ_{s-sp}^2, and σ_{th}^2, respectively [9]. For the bit b, the different noise components in the receiver area are:

$$\sigma_s^2 = 2qRP_sB_e$$

$$\sigma_{sp-sp}^2 = 2R^2P_{sp}(2B_o - B_e)\frac{B_e}{B_0^2}$$

$$\sigma_{sig-sp}^2 = 4R^2P_s\frac{P_{sp}B_e}{B_0} \tag{6}$$

$$\sigma_{s-sp}^2 = 2qRP_{sp}B_e$$

$$_{th} \quad \frac{K_BTB_e}{\;}$$

The total noise variance for bit b is

$$\sigma^2(b) = \sigma_s^2 + \sigma_{sp-sp}^2 + \sigma_{sp-sig}^2 + \sigma_{s-sp}^2 + \sigma_{th}^2 \tag{7}$$

$$BER = Q\left(\frac{I(1) - I(0)}{\sigma(1) + \sigma(0)}\right) \tag{8}$$

$$Q(z) = \frac{1}{\sqrt{2\pi}} \int_z^{\infty} e^{-\frac{z^2}{2}} dz \tag{9}$$

Where I(1) =*RP*(1) and *I*(0) =*RP* (0) are photocurrent sampled by receiver during bit 1 and bit 0 respectively, and *R* is *responsivity* of the receiver.

CALCULATION AND RESULTS

Table 1: List of Parameters and Their Value [9].

Parameters	Value
Size of the switch	4
Population inversion factor	1.2
Loss of Circulator	1 dB
Speed of light	$3\times10^{8} m/s$
Refractive index of fiber	1.55
Loss of FBG	1 dB
Responsivity	1.28 A/W
Electronic charge	$1.6\ \ 10^{-19} C$
Electrical bandwidth	10GHz
Optical bandwidth	20GHz
TWC insertion loss	2.0 dB
Loss of TF	1.0 dB

The typical values of the parameters used in the calculation are shown in Table 1. Using the above formulation and the values of the parameters as given in Table 1, the results obtained in terms of BER at different power levels is shown in Table 2. It is clear from the Table 2 that as the power increases, the BER performance of switch improves significantly. For the acceptable BER$\leq 10^{-9}$, the minimum power level is nearly 3 micro-watts. When such switch make compatible with network placement then the required amount of power increases to 17 micro-watts (Table 2), which is nearly 6 times in comparison to isolated switch.

Table 2: Switch Size 4×4, and Buffer 4.

Power in micro-watts	BER
1	2.08×10^{-4}
2	1.55×10^{-7}
3	1.3×10^{-10}
4	1.12×10^{-13}
5	9.94×10^{-17}
6	8.90×10^{-20}
7	8.03×10^{-23}
8	7.26×10^{-26}
9	8.89×10^{-29}
10	6.01×10^{-32}

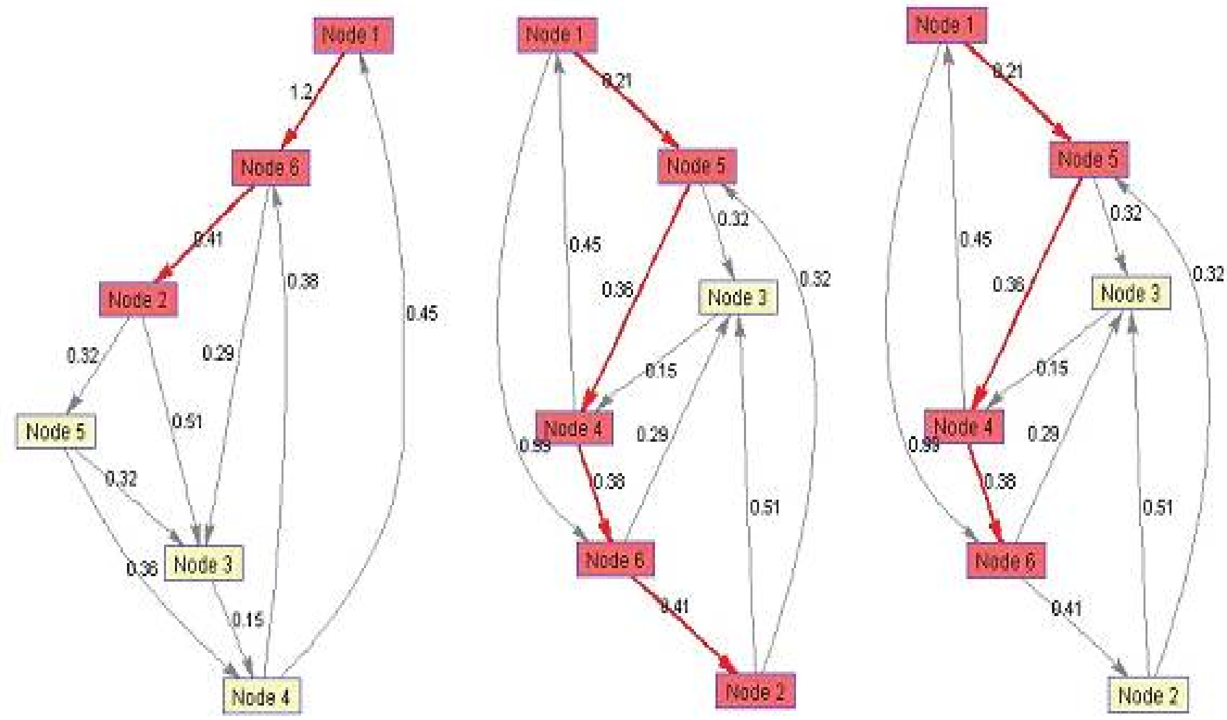
Table 3: Switch Size 4×4, and Buffer 4 in network

Power in micro-watts	BER
10	1.95×10^{-6}
11	6.13×10^{-7}
12	1.93×10^{-7}
13	6.10×10^{-8}
14	1.92×10^{-8}
15	6.12×10^{-9}
16	1.94×10^{-9}
17	6.20×10^{-10}
18	1.97×10^{-10}
19	6.31×10^{-11}
20	2.02×10^{-11}

NETWORK ANALYSIS

Finally these switches are placed in the network. In the network, two more parameters need to be considered in the analysis:

1. Number of switches between a pair of source and destination,
2. Distance between the nodes though which data propagates form source to destination.



(a) **(b)** **(c)**

Figure 4: Network Bio-graph

For example, we have considered 6 nodes and 11 edges network. Distances among different nodes are different in Bio-graph 1, however similar distances have been considered in Bio-graph 2 and Bio-graph 3. In Bio-graph 1and 2, source node is 1 and destination node as 2, while in Bio-graph 3, destination node is 6.

In Bio-graph 1, the shortest path is 1-6-2 and distance is 1.61 units.

In Bio-graph 2, the shortest path is 1-5-4-6-2 and distance is 1.36 units.

In Bio-graph 3, the shortest path is 1-5-4-6 and distance is 0.95 units.

In general, distances among adjacent nodes in optical core networks are in some hundreds to some thousands of kilometers (considering 1unit=1000km).

Therefore, travelled distance in Bio-graphs 1-2-3 is 1610 km, 1360 km and 950 km, respectively. The loss of the fiber is 0.2 dB/km. Therefore losses are 322, 272 and 170 dB, respectively. Considering EDFA of gain 30dB each, which are placed in the links of the network. Therefore, to compensate losses of 322 and 170 dB, the required numbers of amplifiers are 11 (10 of 30 dB and one of 22 dB) and 6 (5 of 30 dB and one of 20 dB), respectively.

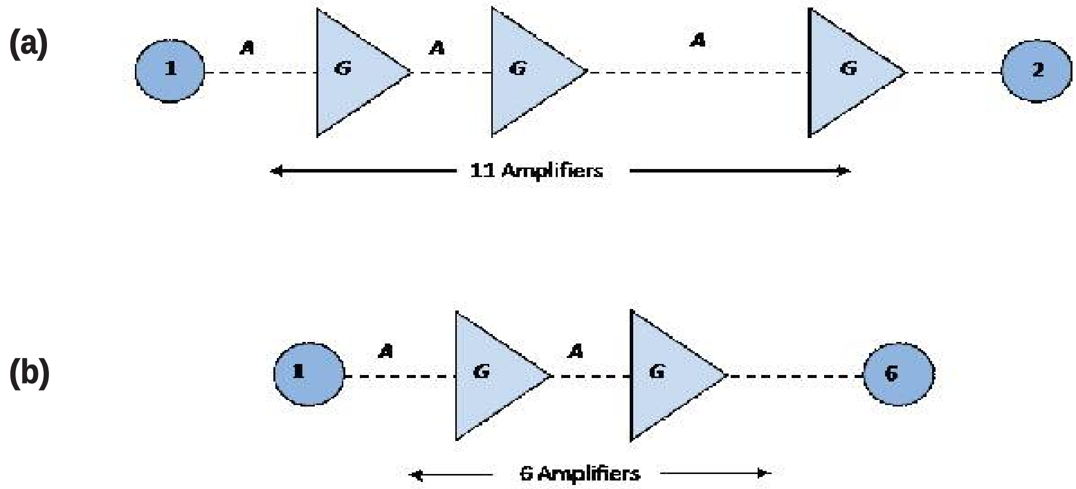


Figure 5: (a) Inline amplifier for longest path (b) Inline amplifier for shortest path

In network, the new equation for power calculation would be

$$P_{out} = P_{in}(A_{in}G_{in})^{K} + N_{sd}\, n_{sp}(G-1)h\nu B_0 A_{spl}^{1\times N} A_{TF} A_{Com}^{N\times 1} + K n_{sp}(G_{in}-1)h\nu B_0 \qquad (10)$$

Where, A_{in} and G_{in} is the loss and gain of the inline amplifier, and 'K' is the number of inline amplifiers and N_{sd} is the numbers of switch through which data moves between source to destination.

Again using equation (6)-(9), BER can be re-evaluated at different power levels.

Table 4: Performance in Network with Longest path.

Power in milli-watts	BER
1.0	2.75×10^{-8}
1.1	5.77×10^{-9}
1.2	1.21×10^{-9}
1.3	2.56×10^{-10}
1.4	5.43×10^{-11}
1.5	1.51×10^{-11}
1.6	2.42×10^{-12}
1.7	5.23×10^{-13}
1.8	1.11×10^{-13}
1.9	2.38×10^{-14}
2.0	5.11×10^{-15}

Table 5: Performance in Network with Shortest path.

Power in milli-watts	BER
0.10	0.0115
0.20	3.98×10^{-4}
0.30	1.59×10^{-5}
0.40	6.75×10^{-7}
0.50	2.95×10^{-8}
0.60	1.31×10^{-9}
0.65	2.79×10^{-10}
0.70	5.95×10^{-11}
0.80	2.72×10^{-12}
0.90	1.25×10^{-13}
1.00	5.80×10^{-15}

In Table 4, Power vs. BER is shown. Here minimum power level is 1.3 mW, and for the shortest path, the minimum power level is 0.65 mW.

Table 6: Comparative Analysis of Switch.

Switch Design	Power
Isolated Switch	3 micro-watts
Switch in Network	17 micro-watts
Switch in Longest Path	1.3 milli-watts
Switch in shortest Path	0.65 milli-watts

In Table 6, comparison between different configurations of the switch and required amount of power for successful operation of the switch has been done. It is evident that isolated switch analysis is very deceptive as it shows much lesser power requirement in comparison to when placed in the network. When whole network is considered, power increases from micro-watts to milli-watts. This is a tremendous rise in power.

CONCLUSIONS

This paper presents analysis of an optical switch in different configurations. Analysis is presented for four different switch configurations while assuming a six nodes and 11 edges network. It has been found that power requirement in isolated switch is very less- 3 micro-watts. When such switch is made compatible with network placement, power increases six-fold and becomes 17 micro-watts. The power requirement also depends on the physical distance between source and destination pair and number of hops data traverse before it reaches its destination. In the future work, how network layers parameters will be affected by different configurations is required to be explored.

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