Advantage of Solitons pulse in Fibre Loop Buffer Switch

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Abstract

Photonic all-optical switch is widely considered as one of the techniques to utilize the enormous optical bandwidth. This paper attempts to present a mathematical model for a loop buffer based switch and brings out the aspects of designing the of all optical switch. The important aspects discussed are length of the optical loop, effect of cross talk, and how the optical solitons benefits the switch performance. This paper also deals with the comparison of maximum number of circulations of the packet in the loop buffer for NRZ and Soliton pulses.

Introduction

The demand for higher bandwidth is ever increasing due to continuous evolution in the services. Broad acceptance of fiber optic and photonic technology in transmission systems has led to potential opportunities for using all-optical switching. The important aspects of photonic packet switching [1] are control, packet routing, packet synchronization, clock recovery, contention resolution, packet buffering and packet header replacement. This paper emphasizes the aspects of buffering.

Buffering in packet switching

Considering network shown in figure1 in which, A to E are end nodes, and 1 to 5 are switching nodes. If we suppose that node A has to sent a packet to node D.The packet may choose multiple path likeA-1-4-D, A-1-5-4-D, A-1-2-3-4-D etc, the selection of the path will depend on the switch traffic and the routing algorithm. The function of the routing node is to route the packet, on the basis of the information stored in the packet header. At each switching node the payload of the packet has to be buffered until control module can decides on which path the packet has to be sent. Limited access speed of electronic RAMs constraints it uses in packet buffering.

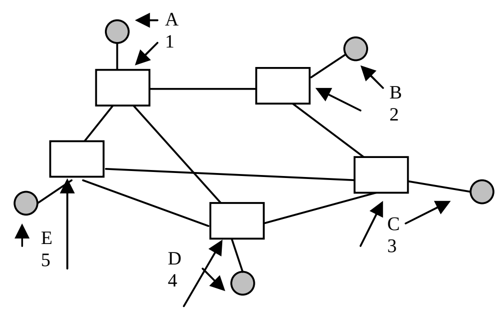

Figure 1 Schematic of the switched network

In addition this approach requires optical to electrical (O/E) conversion and vice- versa when packets are written into and read out of electronic RAMs and hence adds to the complexity and delay.

All-optical RAM suitable for photonic packet switching has not yet been found. The alternative is to use optical fiber delay lines incorporating other components such as optical gate switches, optical couplers, optical amplifiers, and wavelength converters to realize photonic buffering. A number of photonic packet buffers based on optical fiber delay lines have been proposed and demonstrated [2]. In general these optical fiber delay lines based buffers can be classified into two basic categories: travelling-type and recirculating type. A travelling type buffer generally consist of multiple optical fiber delay lines whose lengths are equivalent to multiples of a packet duration T, and optical switches to select delay lines [3]. The recirculating type buffer is more flexible than the travelling type buffer because the packet storage time is adjustable by changing the number of circulations. In principle recirculating type buffer offer a kind of random access where storage time depends on the number of circulations.

Working of all optical loop buffer

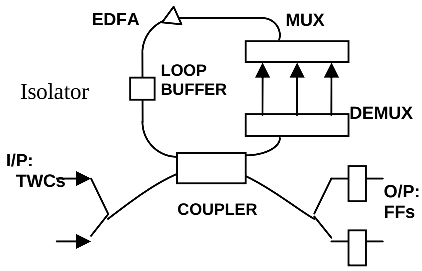

Figure 2 All Optical Loop Buffer Switch

This architecture [4,5] consists of N tunable wavelength converters, one at each input, a recirculating loop buffer, and N fixed filters, one at each output. Packets from all the inputs use WDM technology to share the recirculating loop buffer. The number of buffer wavelengths depends on the switch design, desired traffic throughput, packet loss probability and size of the switch. The allocation of the packets to the loop buffer depends on the routing and priority algorithm for the switch. The packets to be buffered are converted to the wavelengths available in the buffer; if buffer is full then packets are dropped.

When a packet is selected for buffering, the respective TWC in the buffer is tuned to the buffer wavelength to accept the packet. As long as a packet is in buffer, the selected TWC will remain transparent, till it is desired to read out the packet or to have dynamic wavelength re-allocation. The TWCs are tuned at every cell slot either to place a packet in the loop buffer to avoid contention or to direct them to output. For reading a packet, when output contention is resolved, buffer TWC is tuned to the wavelength of appropriate output port fixed filters (FF), the packet is broadcasted to all output ports.

Mathematical Model

Let loss in signal power in a single circulation from entry port to before reaching EDFA be A_1 and that after the EDFA be A_2. Hence A_1 and A_2 are given by

$$A_1 = L_{3dB} + L_{DMUX} + L_{TWC} + L_{MUX} + 5L_s + L_F \quad (1)$$

$$A_2 = L_{ISO} + L_{BPF} + 3L_S + L_F \quad (2)$$

Where L_{3dB} is loss due to 3dB coupler, L_{DMUX}, L_{MUX}, L_{TWC} and L_{BPF} are losses due to Demultiplexer, Multiplexer, Tunable Wavelength Convertor and Band Pass Filter respectively. L_s is the splice loss, L_F is the fiber loss and L_{ISO} is the isolator loss. Let $A = A_1 A_2$ also let the input signal power be P. Then the output power of EDFA after one circulation is given by:

$$APG + (G-1)n_{sp} h\upsilon B_o \quad (3)$$

Where A is the loss and G is the gain of EDFA in one circulation, the first term represents the signal power, and second term represents Amplified Spontaneous Noise Power [6]. Similarly output power of the signal after K circulations is:

$$P_K = A^K PG^K + (G-1)A_2 n_{sp} h\upsilon B_o F$$

Where $$F = \frac{1-(AG)^K}{1-AG} \quad (4)$$

Crosstalk Calculation

The above calculation assumes that components in the loop do not produces any cross talk, if crosstalk is incorporated then total output power of the signal after K circulations is

$$(P_k)_T = P_K + P_{crosstalk}$$

$$P_{crosstalk} = \{P_{DEMUX} + P_{MUX} + P_{TWC}\}AGF \quad (5)$$

Where the crosstalk power at demux and mux and TWC is P_{DEMUX}, P_{MUX} and P_{TWC} respectively. Other components in the loop like 3dB coupler and EDFA do not produce any significant crosstalk.

The major assumptions in the above model are:

- There is no gain saturation, i.e. the signal power after K circulation is less than the saturation power level of the EDFA.
- In each circulation gain remains constant.
- The change in wavelength when the packet is read out of the buffer does not cause any variation in gain of the last circulation.

Noise Analysis

For NRZ pulses

Due to square law detection by the photo detector in the receiver, various noise components are generated. These noise components are shot noise, ASE-ASE beat noise, sig-ASE beat noise, shot-ASE beat noise and thermal noise denoted by $\sigma_s^2, \sigma_{sp-sp}^2, \sigma_{sig-sp}^2, \sigma_{s-sp}^2$ and σ_{th}^2 respectively [6]. These terms after K circulations are given by:

$$\sigma_s^2 = 2qRP_{sig}(K)B_e$$

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

$$\sigma_{sig-sp}^2 = 4R^2 P_{sig}(K)\frac{P_{sp}(K)B_e}{B_0}$$

$$\sigma_{s-sp}^2 = 2qRP_{sp}(K)B_e$$
$$\sigma_{th}^2 = \frac{4kTB_e}{R_L} \quad (6)$$
Where $P_{sig}(K)$ is the signal power when packet passes through the 3dB coupler after K circulations and $P_{sp}(K)$ is the ASE noise power when packet passes through the 3dB coupler after K circulations. They are given by:
$$P_{sig}(K) = \frac{(AG)^K P}{2}$$
$$P_{sp}(K) = A_2(G-1)n_{sp}h\upsilon\frac{B_o F}{2}$$
Now when crosstalk is present then the term $P_{sig}(K)$ will be modified as
$$P_{sig}(K_c) = \left[\frac{(AG)^K P + \{P_{DEMUX} + P_{MUX} + P_{TWC}\}AGF}{2}\right] \quad (7)$$
The total noise power is
$$\sigma^2 = \sigma_s^2 + \sigma_{sp-sp}^2 + \sigma_{sp-sig}^2 + \sigma_{s-sp}^2 + \sigma_{th}^2 \quad (8)$$
The SNR after K circulations can be written as
$$SNR = \frac{\left[R(AG)^K P_{sig}\right]^2}{\sigma^2} \quad (9)$$
The BER in terms of SNR can be written as [7]
$$BER = \frac{1}{2}erfc\left(\frac{\sqrt{SNR}}{2\sqrt{2}}\right) \quad (10)$$

Optical Solitons

A solitons is a very narrow pulse with high peak power. The soliton pulses are so stable that its shape and velocity is preserved while travelling along the medium. This means that solitons pulses do not spread in optical fiber after thousands of kilometres. In an optical fiber solitons pulses are generated by counter balancing the effect of the dispersion by the self-phase modulation [8]

The shape of the Solitons pulse is secant hyperbolic in nature, and is of the form
$$u(\tau) = N_0 \sec h(\tau) \text{ where } \tau = \frac{t - \frac{z}{v_g}}{T_0} \quad (11)$$
For $N_0 = 1$ the pulse is called fundamental Soliton, and the peak power of the pulse is related to N_0 as
$$N_0{}^2 = \gamma P_0 L_D = \frac{\gamma P_0 T_0^2}{|\beta_2|} \quad \text{where} \quad \gamma = \frac{2\pi n_2}{\lambda A_{eff}}$$
and $$T_0 = \frac{Full\ \ width\ half\ \max ima}{1.763} \quad (12)$$
In the above expression t is time, z is propagation distance and v_g is group velocity of the pulse β_2 is second order dispersion effect.

The stability of the solitons make them very good candidate for optical communication. The solitons pulses are superior to NRZ pulses in the following manner.

1) Soliton can be generated in the loss minimum region at around 1550 nm

2). Soliton pulse transmission is possible over long distance. Soliton can be both time and polarized multiplexed.

3). There is no waveform distortion over long distances, which are useful for long distance communication.

4). Solitons are dispersion free, and the collision of the solitons are elastic in nature, after collision their amplitude and frequency remain unchanged, only position and phase changes.

5). Two counter propagating solitons pass each other without affecting each other's motion

The main difference between encoded digital signals with solitons and with NRZ is that in NRZ if two ones are close together then the signal intensity does not falls to zero between individual bits but it does fall in solitons. For NRZ the nonlinearity in optical fiber is a problem that can distort the signal. So we can employ solitons in high-speed WDM networks.

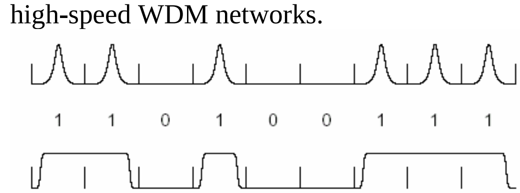

Figure 3 Comparison of NRZ versus Solitons

The number of circulations can be further increased by employing soliton pulses. As like other pulses, when solitons pulse propagate their peak power decreases and this reduction the power of the soliton pulse will mismatch the counter balancing condition of group velocity dispersion with self phase modulation. To overcome this difficulty amplifier are used. Optical amplifiers amplify the soliton power, but unfortunately add ASE noise and due to this noise the amplitude, frequency, position and phase of the optical pulse varies. But the variation in the amplitude is small and does not have detrimental effect on the soliton based communication, but fluctuation the frequency, effect the system performance drastically by inducing time jitter

In term of the design rule [9]

$$BL_T < [\frac{9 f_b^2 L_A f_{LM}}{h\nu_0 F_n (G-1) q_0 \gamma |\beta_2|}]^{\frac{1}{3}} \quad (13)$$

Where B is the bit rate, L_T is transmission length, L_A is the distance between amplifiers, $f_{LM} = \frac{G \ln G}{G-1}$ where G is the gain of the amplifier, n_{sp} is the spontaneous emission factor, ν is the frequency q_0 is the normalized frequency between two solitons, and f_b is a important term which describe the fraction of the bit period occupied by the soliton pulse.

For the loop buffer the design rule can be modified as $L_T = L \times N$ where L is the length of the lop buffer and N is the number of circulations, under the condition *AG=1*

$$BLN < [\frac{9 f_b^2 L f_{LM}}{h\nu_0 F_n A_2 (G-1) q_0 \gamma |\beta_2|}]^{\frac{1}{3}} \quad (14)$$

$$(BNL)^3 < [\frac{9 f_b^2 L f_{LM}}{h\nu_0 F_n A_2 (G-1) q_0 \gamma |\beta_2|}] \quad (15)$$

Calculation and result

The length of the loop is taken equal to the packet duration and is given by $L = cb/nB$. In the calculation we have assumed equal length packets of 53 bytes and 1byte period on each side taken as guard period the length is found to be 8.52m. In the calculation the peak signal power for the NRZ pulses assumed to be 1mW, and for solitons pulse the peak signal power is 4mW. The maximum number of circulations of the packet in the loop buffer can be calculated by under the condition *AG=1* there is no crosstalk present in any component this number is found to be 40 for all four wavelengths.

Table-1

Para-meter	Value	Para-meter	Value	Para-meter	Value
L_{3dB}	3.4dB	L_{DMUX}	1.5dB	L_{TWC}	2dB
L_{MUX}	6.8dB	L_s	2.0 dB	L_F	0.2 dB/km
L_{ISO}	0.15 dB	L_{BPF}	1 dB	A_1	15.10dB
n_{sp}	1.2	B_e	10GHz	B_o	$2B_e$=20 GHz
A_2	1.75 dB	A_{eff}	50μm^2	n_2	3×10^{-20} m^2/W
f_b	0.1	q_0	6	β_2	1ps^2/km

In the architecture combiner is used to multiplex the wavelength. Combiner can be designed using 3-dB couplers. These 3-dB couplers are wavelength-flattened coupler, so does not produce any crosstalk. Considering four-wavelength demux, for the cross talk calculation the shape of the pulse assumed to be gaussian and the isolation between two channels at the demux is –25dB. This value comes out to be 0.016 mW.

For NRZ pulses

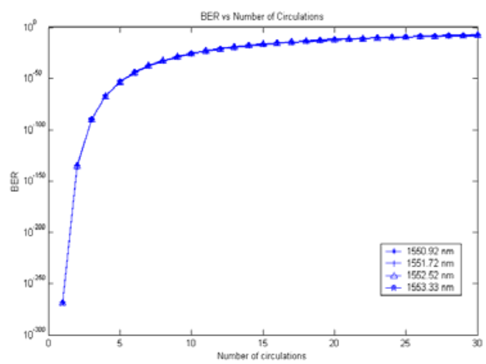

Figure 4 BER vs. Number of Circulations

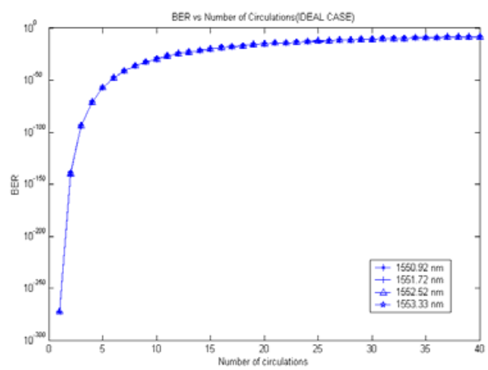

Figure 5 BER vs. Number of Circulations (Ideal Case**)**

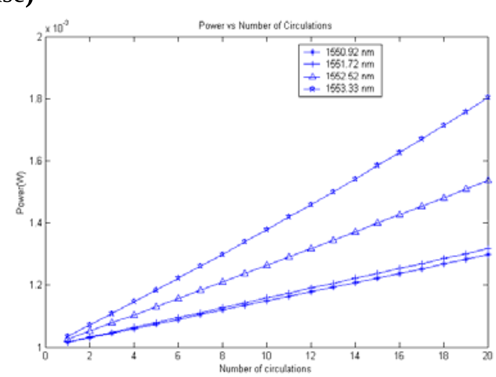

Figure 6 Power vs. Number of Circulations

For Solitons pulses

After plugging the values of the different parameter we can find the value of N, which describe the maximum number of the circulation of the data in the loop buffer.

N=7421 at 1550.92 nm
N=7421 at 1551.72 nm
N=7418 at 1552.52 nm
N=7418 at 1553.33 nm

Conclusion

This paper briefly discussed the aspects of Optical Loop Buffer design. In the graphs BER, and Power plotted against number of circulations for NRZ pulses. It was found out that for a BER $<10^{-9}$ for ideal case the packet can remain in the loop for up to 40 circulations and for non-ideal case the packet can remain in the loop for up to 27 circulations (this figure varies slightly with wavelength). With soliton pulse this number increases drastically to 7421 circulations. This result emphasis that soliton pulses are better choice in loop buffer switch.

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