Design of a Control Algorithm for a 2x3 Optical Switch

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Abstract--In this paper, a control algorithm is proposed for a 2x3 nonblocking photonic switch. The switch is a space division multistage network using 2x2 optical switching elements which can serve as basic element for larger size networks. The idea behind the proposed algorithm is presented. The wide-sense nonblocking property of the switch under this control algorithm is tested and discussed. The results indicate that the algorithm is capable to maintain the wide-sense nonblocking property for all possible switch configurations.

Keywords- photonic switch; multistage network; wide-sense nonblocking; control algorithm

I. INTRODUCTION

Photonic switching architectures based on 2 x 2 optical switching elements (SEs) are attractive, since they can be constructed from directional couplers. The directional coupler switch is a device with two inputs and two outputs, both of which are optical signals [1]. The state of the device, as shown in Fig. 1, is controlled electrically by applying different levels of voltage on the electrodes.

Although other materials can be used as a substrate, lithium niobate is the most mature technology for directional coupler-based optical switch fabrication. A feature of these switches is their ability to route optical information regardless of its bit rate or coding format [1]. Several directional coupler-based architectures had been proposed in the literature [2][4][6][8]. This hybrid device will be the SE of the 2x3 network proposed in this paper.

For a good switching architecture from system considerations, the number of SEs for a given switch size, N, should be as small as possible [2]. When the number is large, implementation is expensive and the optical path is subject to large power loss and crosstalk. When designed to reduce the SE number in total and in each path, a switch can have a large internal blocking probability. The internal blocking should be avoided or reduced. It can be reduced to zero by using a good switching control or by rearranging the current switching configuration. These cases are called wide-sense nonblocking and rearrangeably nonblocking, respectively [3]. If a blocking condition never arises in a switch, it is said to be strictly nonblocking [3][4].

In this paper, a control algorithm for a 2x3 nonblocking photonic switch which is derived based on 2x2 SEs is proposed. The idea behind the proposed algorithm is presented. The wide-sense nonblocking property of the switch under this control algorithm is tested and discussed.

The paper is organized as follows; Section II provides an overview of the 2x3 architecture. We explain how to design it using planar switches. In Section III, the development of the control algorithm is explained. The wide-sense nonblocking property of the switch under this control algorithm is tested and discussed in Section IV. Section V concludes the discussion.

II. THE 2x3 SWITCH

The N-stage planar switch has $N/2$ odd stages and $N/2$ even stages. The odd stages are of $N/2$ SEs each, while the even stages are of $N/2 - 1$ SEs each [5]. In general an N x N network requires N stages, where N may be even or odd. The total number of SEs is:

$$SE_S = N/2(N/2 + N/2 - 1) = N/2(N - 1) \qquad (1)$$

The maximum number of SEs in a connection path is obtained when the optical signal crosses a SE in every stage of the switching system, that is, when it crosses N SEs. Fig. 2 illustrates a 3x3 N-stage planar switch.

An algorithm for deciding whether a given network is nonblocking or not is described in [7]. Using this algorithm the 3x3 switch of Fig. 2 was proved to be blocking unless rearranged [5][7].

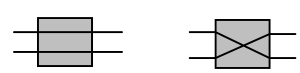

Figure 1. The states of a 2 x 2 switch element

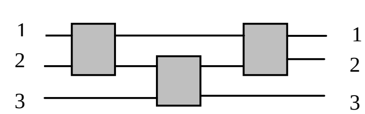

Figure 2. A 3 x 3 planar switch

Now, if only inputs 1 and 3 of Fig. 2 are used, instead of using all its three inputs, this will give the 2x3 planar switch shown in Fig. 3. Again, the same algorithm described in [7] can be used to decide if this switch network is nonblocking.

Because the switch network is simple and small, all its possible states can be manually studied on paper. However, both methods lead to the same outcome. That is, the network is nonblocking in the wide sense if all the states in which SE A is cross (x) and SE B is bar (=) are avoided. In other words, if SE A is in the cross state, SE B should not be allowed to get into a bar state, and vice versa. Such a state, which can cause blocking for a network, is said to be a forbidden state. The set of states of a network, that allow any required switching without bringing the network into a forbidden state, was called preservable by Benes [3].

If the 2x3 switch is flipped horizontally, as shown in Fig. 4, the network will be a 3x2 switch with the same nonblocking rule still applicable.

The preservable state of the 2x3 network is given in Fig. 5a. The state of the last SE does not affect the state of the network and this is the reason why it is left blank. The preservable state of the 3x2 switch is shown in Fig. 5b from which it is clear that neither input 1 nor input 2 should be connected to output 1 through SE B. The elements of Fig. 3 and Fig. 4 will be called 2W3 and 3W2, respectively. If these elements follow the algorithms given in Fig. 5, any future connection can always be made without blocking or additional rearrangement of the existing paths.

The 2W3 and 3W2 elements can be used to build a 4x4 wide-sense nonblocking network. The 4x4 network will consist of two 2W3 switches, three 2x2 switches, and two 3W2 switches as shown in Fig. 6.

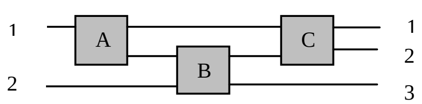

Figure 3. A 2 x 3 planar switch

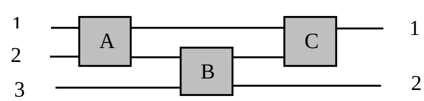

Figure 4. A 3 x 2 planar switch

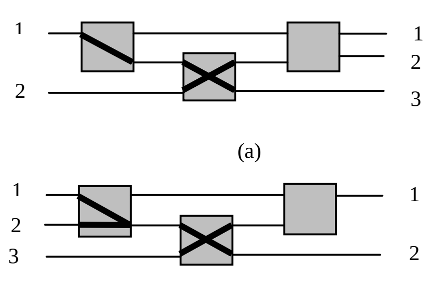

Figure 5. The preservable states for: (a) the 2x3 switch and (b) the 3x2 switch

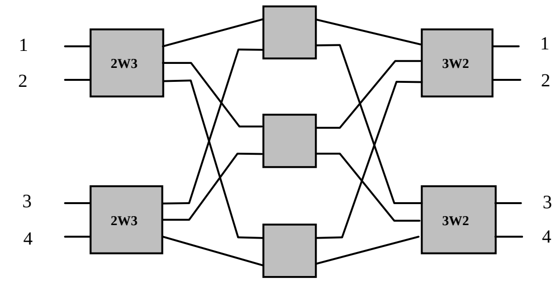

Figure 6. A 4 x 4 wide-sense nonblocking network

The 2W3 and 3W2 elements can also be used, recursively, to build larger wide-sense nonblocking networks with the basic 2x2 SE, always, representing the smallest possible subnetwork.

III. THE CONTROL ALGORITHM DESIGN

The 2W3 switch, and all the switches designed, recursively, based on it, will need a control algorithm to maintain their wide-sense nonblocking property explained in the previous section. In this section, a control algorithm is developed to control the 2W3 switch keeping in mind that algorithms for controlling larger sizes of switches based on the 2W3 and 3W2 elements should be addressed separately, and that the recursive approach is not applicable here.

The number of possible configurations of a switch, of size N, is given by $N!$. Thus, the 2x3 switch has 3! = 6 different configurations as shown in Fig. 7 denoted by S_1, S_2, S_3, S_4, S_5, and S_6. The state of each SE for obtaining these six configurations is shown in table 1 with “0” used to represent the bar state and “1” used to represent the cross state.

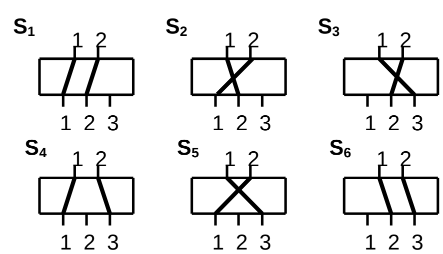

Figure 7. Possible configurations of the 3x2 switch

Observing Table 1, it can be noted that the highlighted states, i.e., state number 5 and state number 6, are the forbidden ones. These states can be compensated for by state number 2 and state number 1, respectively, since they give the same switch configuration for each case.

TABLE 1. THE DETAILED SE STATES OF THE POSSIBLE 6 CONFIGURATIONS

NO	SE A	SE B	SE C	Configuration
1	0	0	0	S_4
2	0	0	1	S_6
3	0	1	0	S_1
4	0	1	1	S_2
5	1	0	0	S_6'
6	1	0	1	S_4'
7	1	1	0	S_3
8	1	1	1	S_5

An algorithm code was written using Visual Basic tool to control the switch and maintain its nonblocking property. This tool is event-driven and is governed by an event processor. When an event is detected, the event procedure will then be executed [9]. The flow chart of the algorithm code is shown in Fig. 8. A Graphical User Interface (GUI) was also developed using Visual Basic.

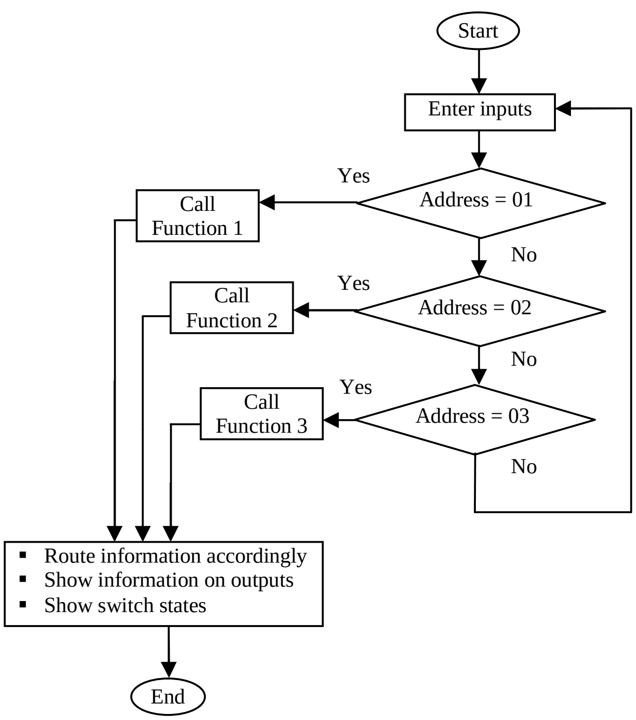

Figure 8. The flow chart of the algorithm code

As illustrated in the flowchart, one of the routing functions 1, 2, or 3 is called depending on the destination targeted by each input. Function 1, function 2, and function 3 are algorithm codes designed to control the state of SE A, SE B, and SE C, respectively. Each function contains tow subfunctions, one for the bar state, and the other for the cross state, of the corresponding switch. In each subfunction, all possible relations between the inputs and outputs of the SE are examined and, then, the route established if, and only if, it maintains the preservable states of the 2x3 switch as shown in Fig. 5a.

IV. PERFORMANCE ANALYSIS AND DISCUSSIONS

In this section, some results obtained after running the code will be presented and discussed. The following simulate window which appears when the start button of the start window is pressed is shown in Fig. 9. Here, the switches A, B, and C, are shown as Switch1, Switch2, and Switch3, respectively. These switches are shown without their current state which will change accordingly when the simulate button is pressed after a user inputs the destination output followed by the data as illustrated in Fig. 10, Fig. 11, Fig. 12, Fig. 13, Fig. 14, and Fig. 15 for different switching configurations.

In Fig. 10, the data at input data_1 is routed to output out_3 through switch 1 and switch 2 which both must be in the cross state to establish the configuration. If the data from the same input is to be routed to output out_1 or output out_2, the switch configuration will look as illustrated in Fig. 11 and Fig. 12, respectively. Note how the forbidden state, in which switch 2 should be brought into a bar state, was avoided in the configuration set to establish the new connection.

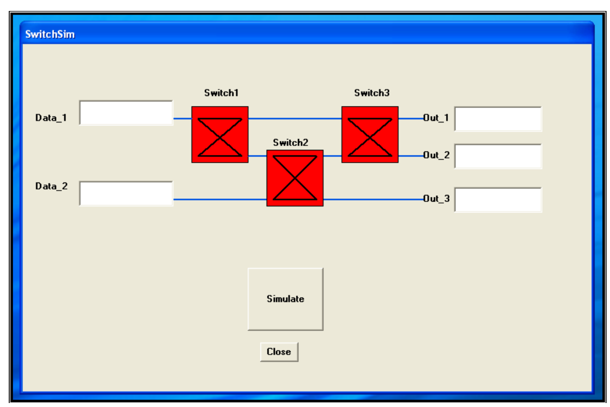

Figure 9. The simulate window of the designed GUI

Figures 13, 14, and 15 present simulation results obtained when the algorithm was tested for two inputs applied at parallel to the 2x3 switch. From these figures, of special consideration is the transition of the switch configuration from Fig. 14 to Fig. 15. From a control point of view, it was easier just to change switch 2 into a bar state to reconfigure Fig. 14 to establish the configuration shown in Fig. 15. If switch 2 was changed into a bar state, input data_2, would

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have been blocked from reaching output out_1, as long as input data_1 is connected to output out_2 through switch 2. That is the reason why the control algorithm instead changed the states of all the switches to avoid the easy, but yet, forbidden reconfiguration.

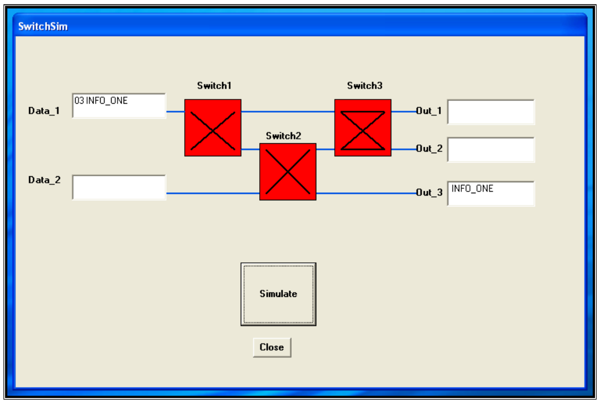

Figure 10. Input data_1 to output out_3 switch configuration

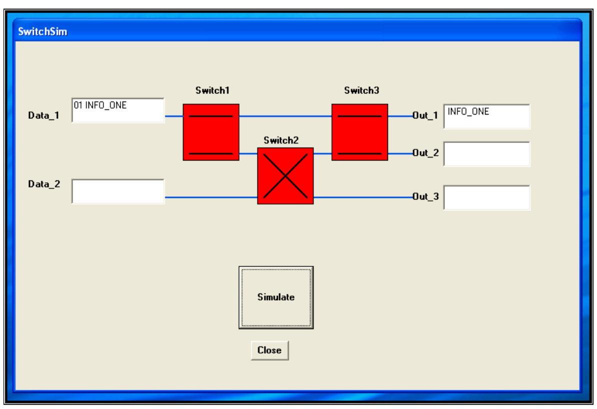

Figure 11. Input data_1 to output out_1 switch configuration

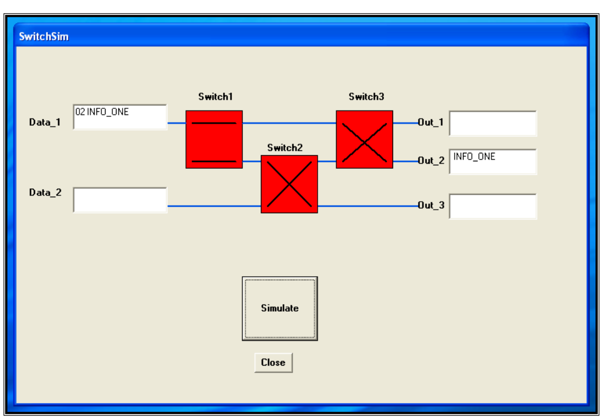

Figure 12. Input data_1 to output out_2 switch configuration

V. CONCLUSION AND FUTURE WORK

A control algorithm for a 2x3 wide-sense nonblocking photonic switching network has been proposed, designed, and simulated. Some simulation results of the proposed control algorithm are presented and discussed.

The results indicate that the designed algorithm is capable to maintain the wide-sense nonblocking property for all possible switch configurations. Algorithms for controlling larger sizes of switches based on the 2W3 and 3W2 elements should be addressed separately since the recursive approach can not be applied. Authors are now working on designing a control algorithm for the 4x4 optical switch mentioned in section II.

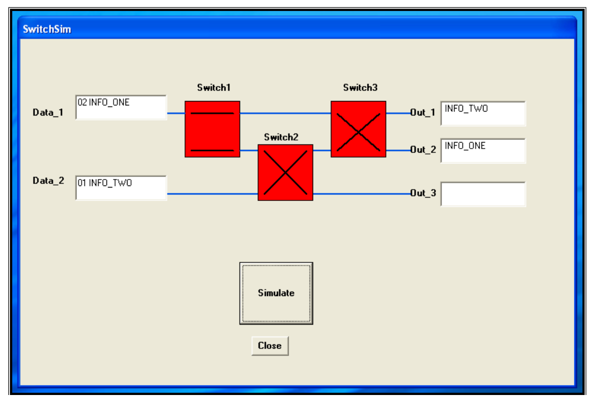

Figure 13. Input data_1 to output out_2 and input data_2 to output out_1 switch configuration

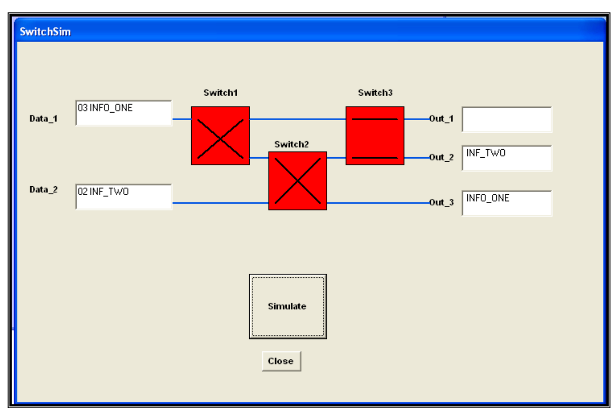

Figure 14. Input data_1 to output out_3 and input data_2 to output out_2 switch configuration

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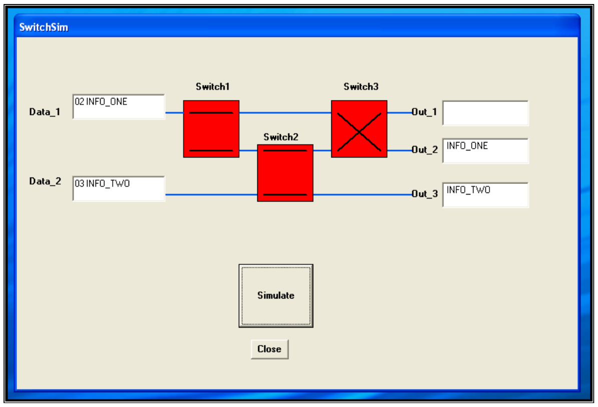

Figure 15. Input data_1 to output out_2 and input data_2 to output out_3 switch configuration

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