Generalized recursive network: a new architecture for self-routing non-blocking optical switch networks

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Abstract

In this paper we present a new approach for building non-blocking optical MINs on building blocks of given size. The network constructed by our approach is self-routing and has $O(\log_2 N)$ propagation delay for size $N \times N$. The maximum signal loss and crosstalk are compared to those of the widely used crossbar network with the switch complexity of $O(N^2)$. The proposed approach is a good choice for constructing non-blocking optical switch networks with low signal loss and crosstalk. © 2002 Elsevier Science B.V. All rights reserved.

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1. Introduction

Non-blocking switch networks are useful in designing optical cross-connect to reduce the cell loss probability. For applications that require a high data transmission rate, low error rate and low delay, rearrangement of the states of switching elements in the optical network is not desirable, making non-blocking switching increasingly important for optical networks [1]. Besides, if traffic arrives at input ports asynchronously then a switching network is required to be non-blocking to handle the traffic efficiently. In such cases signals at each input port can be instantly delivered to their destination ports if the destination ports are free and rearrangement of states of internal switching elements will thus be minimized. So, non-blocking switching provides a promising technology for development of all optical networks.

Two major problems in designing optical switch networks are signal loss and crosstalk. There are two ways in which optical paths can interact in planar switching networks. First, two optical channels on different waveguides may cross each other in order to obtain a particular topology. We call this a channel crossover. Alternatively, two paths sharing a switching element will experience some undesired coupling from one path to the
other. This is called switch crossover [2]. Experimental results reported in [3] showed that it is possible to make crosstalk from passive intersections of optical waveguides negligible. So, many researchers studied how the crosstalk from switch crossover can be reduced [1–4,6–12]. Chikama et al. [12] pointed out that Crossbar networks suffer from huge signal loss and crosstalk, and therefore cannot be directly employed in the optical networks [4,5]. A double crossbar has been proposed for a strictly non-blocking and zero crosstalk network [10] with an increased loss \((2N)\) and number of switching elements \((2N^2)\). Spanke’s [11] network has zero crosstalk with reduced signal loss \((2\log_2 N)\), but at the cost of huge switching complexity \((2N^2 - 2N)\). Vaez and Lea in [7,8] proposed a multiplane banyan switch architecture that has much less crosstalk, signal loss and switch complexity. Papers [7,8] address the issue that how many planes of banyan type networks are required to construct a non-blocking and crosstalk-free optical switch network based on directional couplers. As the banyan type networks are self-routing, routing in a plane of a multiplane banyan network is not a problem. But how an input (output) is connected to planes and how a signal is routed to the right plane is not mentioned. Either the switches in the planes have to be able to decode the destination address along with a inter-plane coordination circuitry or the signal should be sent to the right plane by other switching elements \((N \times K)\) switches where \(K\) is the number of planes. Recently, Khandker et al. [18] proposed a recursive network architecture, \(\text{RN}(N, m)\) network, in which an \(N \times N\) strictly non-blocking switch network can be constructed with strictly non-blocking switches of given size \(m \times m\). They showed that even with \(2 \times 2\) optical switches as the building block the \(\text{RN}(N, 2)\) has \(O(\log_2 N)\) signal loss and constant crosstalk for switch crossover. Moreover, the crosstalk and loss can be customized by choosing an appropriate building block. They did not show how the network can be constructed in case when the building block is non-square, neither they gave a routing algorithm.

Self-routing has several advantages over global routing, as the routing time in a self-routing network is the same as the propagation delay in the network. Furthermore, if the address decoding logic at each switch can be kept simple then the hardware cost of a self-routing network will in general be less than that of a network with global routing scheme. Consequently, self-routing reduces the connection complexity for the control lines [13]. Again, as the control function is distributed among different switching modules, the network is less susceptible to faults of a switch. Most of the existing switch networks are not self-routing for all permutation. Banyan and its equivalent networks are self-routing, but they cannot route all \(N!\) permutations. Nassimi and Sahni established that many permutations frequently used in parallel computations, which they named class \(F\), can be self-routing through the Benes network [14]. Boppana and Raghevendra showed in [15] that many more permutations, which they called class \(L\), can also be self-routed by the same network. Barry and Yavu Oruç in [16] showed that Benes network with more than five inputs are not self-routing. They also showed that Clos network whose first stage contains more than two switches are not self-routing. Crossbar network is self-routing for all permutations but it requires the header of size \(O(N)\). Moreover, the network uses a global reset signal to all switches. That means, all of the packets must be buffered by the interfacing hardware, and simultaneously sourced into the network with their first bits synchronized with respect to one another [17]. Non-equal path lengths require extra circuitry to handle the variable signal loss and relative delay among paths.

In this paper we propose a recursive architecture for non-blocking optical switch networks which is more general than the \(\text{RN}(N, m)\) network. In this architecture, any \(M \times N\) non-blocking switch network can be built with building blocks of given size \(m \times n\), where \(M, N, m, n\) are all powers of integers. We show that the proposed network is self-routing for all \(N!\) permutations and the propagation delay is \(O(\log_2 N)\). We also show that both \(\text{RN}(N, m)\) and Spanke’s networks are special cases of this network.

This paper is organized as follows. In Section 2 we give some preliminaries of crossbar and Clos network. In Section 3, we propose the generalized
recursive network, GRN. In Section 4 we discuss two special cases of GRN. Section 5 explains how GRN can be self-routing. We discuss and compare GRN with crossbar network in Section 6 and conclude our paper in Section 7.

2. Preliminaries

We shall use the term switching element or SE (in short) for $1 \times 2$, $2 \times 2$ and $1 \times 1$ three types of optical switches. We consider a directional coupler or similar device as the switching elements. When a small $m \times n$ network is used as a building block of a large network, we use the term $m \times n$ switch rather than $m \times n$ network. We also use switch and switching element interchangeably. In this paper all the logarithmic expressions are of base 2 unless otherwise stated.

The total number of switches required, namely switch count, to build a network is a representative measure of the hardware complexity of the network [19]. The number of switching elements in a signal path is a measure of signal loss (or insertion loss). Clearly signal loss is proportional to the number of switches that has to be crossed by a signal before reaching the output. The number of crosstalk switches along a path of a signal from input to output is a representative measure of crosstalk of the switch architecture. We shall use these three measures for comparing our network with other networks, where for signal loss and crosstalk we consider the worst case, i.e., the maximum of each measure.

2.1. Crossbar and Clos networks

For an $N \times M$ optical switching network, where $N$ represents the number of inputs and $M$ represents the number of outputs. Let $T_N$ be the switch count, $S_N$ be the maximum signal loss and $C_N$ be the maximum crosstalk. Then these parameters of the crossbar network are given by

$$T_N = NM,$$
$$S_N = N + M - 1,$$
$$C_N = \min(N, M) - 1.$$  \hspace{1cm} (1)

For a square crossbar network (i.e. $N = M$), $C_N = N - 1$.

For an $N \times N$ non-blocking three stage Clos network, let $n$ be the number of inputs (outputs) of each input (output) switch, $m$ be the number of middle stage switches and $m = 2n - 1$ and $r$ be the number of input (output) switches. Then

$$T_N = (2n - 1)(2nr + r^2),$$
$$S_N = 6n + 2r - 5,$$
$$C_N = 2n + r - 3$$

are obtained from [18].

2.2. The RN$(N, m)$ network

A RN$(N, m)$ is defined to be a non-blocking network of size $N \times N$ constructed recursively with building blocks of $m \times m$ switches. Let $T_m$ be the switch count, $S_m$ be the maximum signal loss and $C_m$ the maximum crosstalk of the building block. Then from [19] we have:

**Theorem 1.** RN$(N, m)$ is a strictly non-blocking network and its total number of switches, maximum signal loss and maximum crosstalk are given by the following equations, respectively:

$$T_N = 4^{\log(N/m)}T_m + 2N(2^{\log(N/m)} - 1),$$
$$S_N = S_m + 2\log\left(\frac{N}{m}\right),$$
$$C_N = C_m.$$  \hspace{1cm} (3)

The proof is omitted here. All logarithms are of base 2.

In Eq. (3) the expression of total number of switching elements, $T_N$, has two parts. $4^{\log(N/m)}$ represents the total number of building blocks (of size $m \times m$) and $2N(2^{\log(N/m)} - 1)$ represents the total number of switching elements required for the $N \times N$ network.

3. The generalized recursive network (GRN)

Our objective is to construct a non-blocking network of size $M \times N$, where $M = 2^X$ is the number of inputs and $N = 2^Y$ is the number of outputs, with building blocks of size $m \times n$, where $m = 2^x$, $n = 2^y$, $X, x, Y$ and $y$ are integers.
Lemma 1. An $m \times N$ GRN is a non-blocking network consisting of 2 building blocks of $m \times (N/2)$ on-blocking switches connected in shuffle exchange fashion with $m \times 2$ switching elements. If the size of the building block is $m \times n$, then the number of building blocks required is $N/n$ and the number of switching elements required at the input side is $m((N/n) - 1)$.

Fig. 1 shows an example of $m \times N$ network.

Proof. If an input is free, both of its output links to output switches are free. So, a free input can always reach both the output switches. Since output switches are non-blocking, the free input can reach the free output without disturbing other connections.

If $T_{m\times N}$ is the switch count of the $m \times N$ network and $T_{m\times(N/2)}$ is the switch count of $m \times (N/2)$ network, then from Fig. 1 we can write

$$T_{m\times N} = m + 2T_{m\times(N/2)}$$
$$= m + 2(m + 2T_{m\times(N/2)})$$
$$= m + 2(m + 2m + \cdots + 2(m + 2T_{m\times N}) \cdots)$$
$$= m + 2m + 2^2m + \cdots + 2\log(N/n) - 1 + 2\log(N/n) T_{m\times N}$$
$$= m\left(1 + 2 + 4 + \cdots + \frac{N}{2^n}\right) + 2\log(N/n) T_{m\times N}$$
$$= m\left(\frac{N}{n} - 1\right) + \frac{N}{n} T_{m\times N}. \quad (4)$$

Here $T_{m\times N}$ is the switch count of the building block, $m((N/n) - 1)$ is the total number of switching elements and $N/n$ is the total number of building blocks required in the $m \times n$ network. □

It is clear that creating a network of size $m \times N$ from building blocks of size $m \times n$ can be done by simply increasing the number of outputs of the given building blocks from $n$ to $N$ by recursion. The number of recursions is $\log(N/n)$.

Lemma 2. An $M \times n$ GRN is a non-blocking network consisting of $n$ switching elements connected with 2 building blocks of $M/2 \times n$ non-blocking switches in a shuffle-exchange fashion. If the size of the building blocks is $m \times n$, then the number of building blocks required is $Mm$ and the number of switching elements required is $n((M/m) - 1)$.

Fig. 2 shows the construction of an $M \times n$ GRN with an example.

Proof. With the same argument as in Lemma 1, we can prove that this network is non-blocking. Let $T_{M\times n}$ be the switch count for $M \times n$ network and $T_{(M/2)\times n}$ be the same for $(M/2) \times n$ network. Then from the symmetry shown in Fig. 2 we can write

$$T_{M\times N} = n + 2T_{M\times(N/2)}$$
$$= n + 2(n + 2T_{(M/2)\times N})$$
$$= n + 2(n + \cdots + 2(n + 2T_{M\times(N/2)}) \cdots)$$
$$= n + 2n + 2^2n + \cdots + 2\log(M/m) - 1 + 2\log(M/m) T_{M\times N}$$
$$= n\left(1 + 2 + 4 + \cdots + \frac{M}{2^m}\right) + 2\log(M/m) T_{M\times N}$$
$$= n\left(\frac{M}{m} - 1\right) + \frac{M}{m} T_{M\times N}. \quad (5)$$

Here $T_{M\times N}$ is the switch count of the building block, $n((M/m) - 1)$ is the total number of switching elements and $M/n$ is the total number of building blocks required in the $m \times n$ network. □

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Fig. 1. (a) $m \times N$ GRN: two $m \times (N/2)$ switches connected with $m$ switching elements in shuffle-exchange fashion. (b) An example of $m \times N$ GRN, $m = 2$ and $N = 8$.

Fig. 2. (a) $M \times n$ GRN: two $M/2 \times n$ non-blocking switches connected with $n$ switching elements in shuffle-exchange fashion. (b) An example of $(M/2) \times n$ GRN, $M = 8$ and $n = 2$. 
To construct an $M \times N$ GRN with building blocks of $m \times n$ non-blocking switches, first we make an $m \times N$ GRN by Lemma 1, then we apply Lemma 2 considering this $m \times N$ network as the building block. The switch count, maximum signal loss and maximum crosstalk for such a generalized non-blocking network is given in Theorem 2.

**Theorem 2.** An $M \times N$ GRN constructed from $n \times n$ building blocks of strictly non-blocking switches is a strictly non-blocking network and the switch count ($T_N$), maximum signal loss ($S_N$) and maximum crosstalk ($C_N$) are given by the following equations, respectively:

(i) 
\[ T_{M \times N} = \left(\frac{MN}{m} + \frac{MN}{n} - N - M\right) + \frac{MN}{mn} T_{m \times n}, \]

where $MN/nn$ represents the total number of building blocks of size $m \times n$ and

\[ \left(\frac{MN}{m} + \frac{MN}{n} - N - M\right) \]

represents the total number of switching elements.

(ii) 
\[ S_{M \times N} = \log \left(\frac{M}{m}\right) + \log \left(\frac{N}{n}\right) + S_{m \times n}, \]

where $S_{m \times n}$ is the maximum signal loss of the building block.

(iii) 
$C_{M \times N} = C_{m \times n}$, where $C_{m \times n}$ is the maximum crosstalk of the building block.

**Proof.** To construct an $M \times N$ GRN, first we apply Lemma 1 to make an $m \times N$ GRN from $m \times n$ switches. Since $m \times n$ is strictly non-blocking, the resulting $m \times N$ GRN is also strictly non-blocking. Next we apply Lemma 2 taking the $m \times N$ network as the building block to construct the $M \times N$ GRN. Since the $m \times N$ network is strictly non-blocking, the resulting $M \times N$ network is also strictly non-blocking. So, from the symmetry of construction we have

\[ T_{M \times N} = N + 2T_{(M/2)} \quad = N + 2(N + 2T_{(M/4)} + N) \]

\[ = N + 2(N + \cdots + 2(N + 2T_{m \times n}) \cdots) \]

\[ = N(1 + 2 + 2^2 + \cdots + 2^{\log(M/m)-1}) + 2^{\log(M/m)} T_{m \times n} \]

\[ = N(2^{\log(M/m)} - 1) + 2^{\log(M/m)} T_{m \times n} \]

\[ = N \left(\frac{M}{m} - 1\right) + \frac{M}{m} T_{m \times n}. \]

Now replacing the value of $T_{m \times n}$ from Eq. (4) we get

\[ T_{M \times N} = N \left(\frac{M}{m} - 1\right) + M \left(\frac{N}{n} - 1\right) + \frac{MN}{mn} T_{m \times n} \]

\[ = \left(\frac{MN}{m} + \frac{MN}{n} - N - M\right) + \frac{MN}{mn} T_{m \times n}. \quad (6) \]

Here

\[ \frac{MN}{m} + \frac{MN}{n} - N - M \]

is the total number of SEs and $MN/mn$ is the total number of building blocks of size $m \times n$.

During the construction of the $m \times N$ GRN we add $\log(N/m)$ switching elements on the input side of building blocks. Similarly, while we apply Lemma 2 to construct the $M \times N$ network with this $m \times N$ network as the building block, we add $\log(M/m)$ stages on the output side of building blocks. So, a signal has to cross $\log(N/m)$ input stage switches, $\log(M/m)$ output stage switches in addition to one building block. If $S_{m \times n}$ is the maximum signal loss of the building block, then

\[ S_{M \times N} = \log(M/m) + \log(N/n) + S_{m} \]

Since the input stage switches are $1 \times 2$ switches, they do not contribute to crosstalk. Likewise, the output stage switches are $2 \times 1$ and they do not have to bear signals at both of their inputs at the same time. So, they do not contribute to crosstalk as well. The only possible elements that contribute to crosstalk are the building blocks. Thus, if $C_{m \times n}$ is the maximum crosstalk of the building block, then clearly $C_{M \times N} = C_{m \times n}$. \qed

4. Two special cases of GRN

In this section we show that RN(N,m) and Spanke’s network are two special cases of GRN.
The expression for the total number of switches in an RN\((N, m)\) network given in Eq. (3) can be rewritten as

\[ T_N = \frac{N^2}{m^2} T_m + 2N \left( \frac{N}{m} - 1 \right). \]

Let us consider a GRN for \(M = N\) and \(m = n\). With this consideration Eq. (6) becomes

\[ T_{N\times N} = \frac{N^2}{m} + \frac{N^2}{m} - N - N + \frac{N^2}{m^2} T_{m\times m} \]
\[ = \frac{N^2}{m^2} T_{m\times m} + 2N \left( \frac{N}{m} - 1 \right). \]

Since \(T_m\) and \(T_{m\times m}\) represent the same building block, GRN and RN\((N, m)\) have the same switch count when \(M = N\) and \(m = n\).

It is easy to check that the maximum signal loss and maximum crosstalk of the above GRN are the same as that of RN\((N, m)\).

Fig. 3(a) shows a \(4 \times 4\) GRN network with \(2 \times 2\) switch as the building block. According to Lemma 1, if \(m = 2\) and \(n = 2\), then an \(m \times n\) GRN can be constructed as shown in Fig. 3(b) using only \(1 \times 2\) and \(2 \times 1\) switches. Replacing each \(2 \times 2\) switch in Fig. 3(a) with such a \(2 \times 2\) GRN we get Fig. 3(c), which is a Spanke’s network. The total number of switching elements required for this network is \(2N^2 - 2N\) which is the same as Spanke’s network [20].

5. Self-routing in GRN

Fig. 4 shows an \(8 \times 8\) GRN with \(2 \times 2\) switch as the building block. The column of the building block switches (i.e. \(2 \times 2\) switches) is called **building-block-stage**. The switches at the left of the building-block-stage are called **input stage** switches. Similarly, the switches at the right of the building-block-stage are called **output stage** switches.

A signal from an input up to the building-block-stage has paths like a binary tree. Similarly if we track paths of a signal from an output to the building-block-stage, we see that they also form a binary tree. Both these trees have their leaves at the building blocks. Thus we can define following two terms:

**Input tree:** The binary tree formed by all possible paths of a signal from an input up to the building-block-stage with the root at the input switch and leaves at the building blocks.

**Output tree:** The binary tree formed by all possible paths of a signal from an output up to the building blocks.
building-block-stage with the root at the output switch and leaves at the building blocks.

In Fig. 4, both these trees have been shown in thick lines. A signal from an input of the GRN has to cross \( \log(N/n) \) switches of the input stage, one building block and \( \log(M/m) \) switches of the output stage. Therefore, we divide the whole routing mechanism from an input to an output into three steps:

(a) routing in the input stage;
(b) routing in the building-block-stage;
(c) routing in the output stage.

Switches at the input and output stages have the following properties (Fig. 5):

(i) Control_register = 0, input (output) is connected to output (input) 0.

This state of the switch is called Normal or stable state. The Normal state is decided at the time of manufacturing the optical device.

(ii) Control_register = 1, input (output) is connected to output (input) 1.

This state of the switch is called Biased or Quasi-stable state. The optical device remains in this state as long as there is a control potential at its control input.

Let \( S = s_{p-1}s_{p-2}\cdots s_0 \) be the source address where \( s_{p-1} \) is the most significant bit (MSB) and \( s_0 \) is the least significant bit (LSB), \( D = d_{q-1}d_{q-2}\cdots d_0 \) be the destination address where \( d_{q-1} = 1 \) is the MSB and \( d_0 \) is the LSB, and \( p = \log M \), \( q = \log N \). The format of the routing tag in the header is shown in Fig. 6.

\[
d_{q-1}d_{q-2}\cdots d_0\ s_0\ s_1\cdots s_{p-1}
\]

Fig. 6. Format of the routing tag in the packet header.

5.1. Routing mechanism

We assume that

- Each input and output switches uses 1 bit to decide its state.
- A building block has \( m \) inputs and \( n \) outputs. Each building block has its own routing strategy. It can route a signal properly with the given source and destination addresses (local to the building block).

**Routing in the input stage:** The input switch (the first switch along the signal path) uses the first tag bit arriving at the switch, sets the state of the switch accordingly and sends rest of the tag bits to the next switch along the path up to the building block. Starting from the left, the first \( \log(N/n) \) bits are used by the input stage switches, i.e. bit \( d_{q-1} \) by SE at input stage 0, bit \( d_{q-2} \) by SE at input stage 1 and so on. Bit \( d_{q-\log(N/n)} \) (i.e. bit \( d_{\log N} \)) is used by the last SE of the input stages. In this way the signal traverse across the input tree from the root to a leaf (the building block). Let RIS be the set of bits used for routing in the input stage, then RIS = \( \{d_{q-1}d_{q-2}\cdots d_{\log n}\} \).

**Routing in the building-block-stage:** Bits \( d_{\log n-1}\cdots d_0 \), \( s_0s_1\cdots s_{\log m-1} \) are used by the building block. Bit \( s_0s_1\cdots s_{\log m-1} \) is the source address at the building block, i.e. the signal from the input stage SE that appears at this input of the building block (i.e. leaf). The building block routes the signal to its output \( d_{\log n-1}\cdots d_0 \) by its own routing strategy. At this point the signal is at a leaf of the output tree. Let RBS be the set of bits used for routing in the building-block-stage. Then RBS = \( \{d_{\log n-1}\cdots d_0\ s_0s_1\cdots s_{\log m-1}\} \).

**Routing in the output stage:** In this stage the signal is routed from the leaf to the root of
the output tree. The last \( \log(M/m) \) bit is used by the output stage switches, i.e. bit \( s_{p-1} \) is used by the SE at output stage 0 (rightmost SE of the network), bit \( s_{p-2} \) is used by the SE at output stage 1 and so on. Bit \( s_{p-\log(M/N)} \) (i.e. bit \( s_{\log m} \)) is used by the last SE of the output stages. The signal from the building block (i.e. leaf) enters into this SE of the output stages. Let ROS be the set of bits used for routing in the output stages. Then \( \text{ROS} = \{s_{\log m}s_{\log m+1}\cdots s_{p-1}\} \).

5.2. An example of self-routing

Fig. 7 shows an \( 8 \times 8 \) GRN with \( 4 \times 4 \) non-blocking switch as the building block.

Suppose that the signal at input 001 requests to be connected with output 100. So, the header in the request message has \( \text{TAG} = 100100 \). Here \( m = n = 4 \), \( M = N = 8 \), thereby \( \log(N/n) = \log(M/m) = 1 \). That is, the first (from left) bit, 1, will be used by the SE at the only input stage and the last bit, 0, will be used by the SE at the only output stage. The leaf building block will use the middle 4 bits, 0010, for its internal routing. The thick line in Fig. 7 shows the route from input 001 to output 100.

5.3. Size of the routing tag

Let \( \text{TAG} \) be the set of bits used for routing a signal from an input to an output. Then the size of the \( \text{TAG} \) is

\[
|\text{TAG}| = |\text{RIS}| + |\text{RBS}| + |\text{ROS}|
\]

\[
= \log \left( \frac{N}{n} \right) + (\log m + \log n) + \log \left( \frac{M}{m} \right)
\]

\[
= \log(MN).
\]

For an \( N \times N \) network \( |\text{TAG}| = 2\log N \). Therefore, for an \( N \times N \) network the size of the routing tag is of the \( O(\log N) \).

Since every path can be routed independently, any permutation can be routed without any conflict in the switches. Even if the routing requests are asynchronous to each other it can be routed to the correct outputs without any conflict in switches. Furthermore, the length of the routing tag is considerably small, \( O(\log N) \). So the propagation delay is only \( O(\log N) \).

6. Discussion and comparison

Given the building blocks of size \( m \times m \), an \( N \times N \) switching network in crossbar architecture is as shown in Fig. 8. The building blocks may have the same or different structure consisting of \( T_m \) switching elements.

The optical crossbar network is a wide-sense non-blocking network unlike the electronic crossbar network, which is strictly non-blocking. We compare the switch count, maximum crosstalk and maximum signal loss of GRN with such a generalized crossbar network.

Fig. 9 shows the comparison of switch count of GRN and crossbar networks considering two different sizes of building blocks (\( 2 \times 4 \) and \( 4 \times 4 \)). ‘TN’ represents the ‘total number of switches’ – which counts both building blocks and switching elements. ‘BB’ represents the ‘total number of building blocks’ – which counts only the building blocks. The total number of switches required for \( N \times N \) GRN is larger than that of Crossbar. However, in both cases the switch count increases by the \( O(N^2) \). But the total
number of building blocks required for GRN is much more less than that required for Crossbar networks. For very large size networks we can use Clos network with GRN as building block to reduce the switch complexity. However, minimizing the switch count was never the goal of our research. The main advantage of GRN is that it has lower signal loss and crosstalk than that of crossbar networks, which is clear from Figs. 10 and 11. The building block approach let us customize the distribution of control circuitry in the network.

7. Conclusion

We have presented a new approach for constructing non-blocking optical multistage interconnection networks that are self-routing. Our proposed GRN network has been compared with the widely used crossbar network on switch count, maximum signal loss and maximum crosstalk. It is shown that GRN has much lower signal loss and crosstalk than crossbar networks. The routing in the GRN requires header information by the $O(\log N)$ compared to $O(N)$ for the same in the crossbar network.
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