# A Loopless Deflection Routing Algorithm For Photonic Packet Switched Networks

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## ABSTRACT:

In this paper, an improved deflection routing method for loopless deflection in photonic packet switched networks and its performance is analyzed. This algorithm guarantees that no closed loops are formed and thereby assures that no packets are lost. This algorithm was tested on different networks and the important performance measures like average throughput, average blocking probability, average delay and average cost of the network have been obtained. Based on the results, it can be concluded that under heavy traffic conditions, contention can be greatly reduced by using the loopless deflection algorithm particularly for larger networks. This analysis is verified through simulation.

## I.INTRODUCTION:

As telecommunications networks gradually evolve towards data-centric architectures, packet-based networks will be required to provide increasingly stringent quality of service requirements in order to support a growing number of high-speed multimedia applications. A significant issue in photonic packet switching is contention resolution. Contention occurs when two or more packets contend for the same output port at the same time [1],[2],[3].

An approach for resolving contention is to route the contending packets to an output port other than the intended output port. This approach is referred to as deflection routing or hot potato routing [2]. While deflection routing is generally not favored in electronic packet-switched networks due to potential looping and out-of-sequence delivery of packets, it may be necessary to implement deflection in photonic packet-switched networks, where buffer capacity is limited, in order to maintain a low level of packet losses [7].

When deflection is implemented, a potential problem that may arise is the introduction of routing loops. If no action is taken to prevent loops, then a packet may return to nodes, which it has already visited and may remain in the network for an indefinite amount of time [3]. The looping of packets contributes to increased delays and degraded signal quality for the looping packets, as well as increased load for the entire network. Standard approaches for eliminating looping, such as maintaining a hop counter for each packet, can lead to increased complexity when processing packets headers. An alternative approach to resolving routing loops is to define the deflection alternatives at each note in a manner, which eliminates all possibility of routing loops.

In this work, approaches for implementing deflection in a manner, which eliminates looping was investigated, and an analytical model for evaluating deflection schemes in arbitrary mesh networks was presented. Section II describes the basic network architecture and the deflection algorithm. Section III presents the analytical model for evaluating packet losses. Section IV provides numerical results for specific network topologies, and Section V concludes the paper.

## II. DEFLECTION ROUTING ALGORITHM

In this work, assume that deflection is implemented within a label-switched environment. Each node maintains a label database with a number of label entries. Each label entry indicates, for a given input port and outgoing label. Deflection options are defined by adding additional output-port/label pair to each entry in the label database. When a packet arrives to the node, the corresponding entry in the label database is referenced, the packet's label is updated to the new outgoing label, and the packet is sent to the appropriate output port. If the primary output port is occupied, then the packet will be deflected to the alternate output port after updating the packet's label to the alternate outgoing label.

Fig.1.illustrates the label-switched paths for a given destination node 8 and Fig.2.shows the corresponding label entry at node 2. Note that, in destination-based labeling, the label of a packet will remain the same throughout the network. Furthermore, the primary label-switched paths specified for a given destination will define a spanning tree on the network, with the destination node at the root of the tree. By examining the spanning tree for a given destination, we note that deflection alternative links may be added to the tree in manner, which avoids routing loops. The process of defining the label entries at each node can be divided into two sub-problems is to determine the primary outgoing link for each destination at each node. In this paper, assume that the link, which is on the shortest path to the destination, is chosen as primary outgoing link at a node for that destination. These links may be found by running Dijkstra's shortest-path routes[4], [5]. The Physical distance of each link determines the link weights in the shortest-path algorithm.

The second problem is to find the set of deflection alternatives for each destination at each node, given the set of primary links defined in the previous problem. The deflection alternative at each node must be defined in a way, which eliminates the possibility of routing loops [3],[6]. The deflection-finding problem can be formulated in graph theoretic terms. Given a graph G (V, E), and a directed spanning tree, $T_V$, rooted at vertex v, and with edges, $ET_v$, directed towards the root, the problem is to find set of edges $E_{DV} \subset E$ such that the directed graph $R_v = (V, E_{Tv} \cup E_{Dv})$ is acyclic. The following loopless deflection algorithm [3] is proposed to find a feasible set of deflection edges. We define $\delta(v)$ to be the nodal degree of a vertex v, and dist(u,v) to be the hop distance from node u to node v.

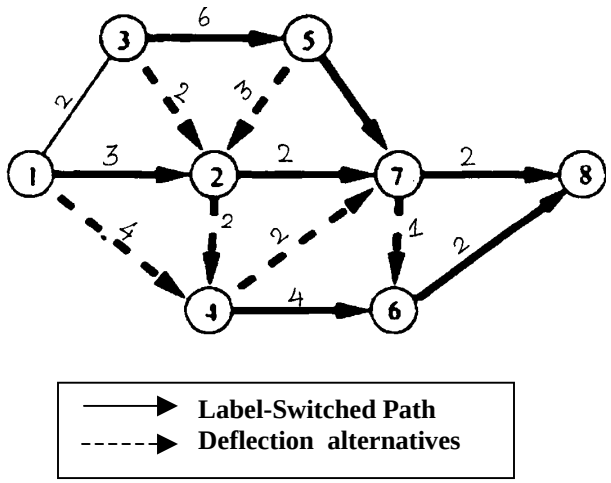


Fig. 1. Label switched paths and deflection alternatives for destination node 8.

| NODES | INPUT PATHS TO THE NODE | LABEL | OUTPUT PATHS FROM THE NODE | LABEL | DEFLECTION PATHS FROM THE NODE | LABEL |
|---|---|---|---|---|---|---|
| 1 | - | 8 | 2 | 8 | 4 | 8 |
| 2 | Any | 8 | 7 | 8 | 4 | 8 |
| . . . | . . . | . . . | . . . | . . . | . . . | . . . |

Fig. 2. Label entry at each node from source to destination for 8 node network

## LOOPLESS DEFLECTION ALGORITHM:

### Given:

A graph G=(V, E).

|V| spanning trees, Tv = (VTv, ETv) each with a unique root vertex,v is element of V

### Find:

EDv, the set of deflection edges.

Directed routing graphs, $R_v = (V, ER_v)$, for all v is element of V.

### Step 0:

Set V* = V.

Set $ED_v = \{\varphi\}$, for all v is element of V.

### Step 1:

Select a vertex v is element of V*

Set $E^* = \{E-ET_v\}$.

Let $d_v$ be the depth of tree $T_v$.

Let Si, i is element of $\{1,2,\ldots.d_v\}$ be the set of vertices, which are, distance i from the root node v.

Set $k = d_v$.

### Step 2:

Select vertex u is element of $S_k$, such that $\delta(u) = \min_{u`\text{is element of Sk}\ \delta(u`)}$ and the cost factor is C( i, j) is minimum.

### Step 3:

Select a directed edge, e(u,w), such that $\text{dist}(w,v)=\min_{w`:e(u,w`)\text{is element of E*}} \text{dist}(w`,v)$, if such an edge exists.

Set $ED_v = ED_v \cup e(u,w)$.

### Step 4:

Remove all edges e(i,u), for all i and e(u,j), for all j from E*.

Remove node u from $S_k$.

If Sk = {φ}, then k=k-1.

If k not equal to 0 then go to Step 2, otherwise, go to Step 5.

**Step 5:**

D (v)=min (D (v), D (w) + c(w,v))
Remove node v from V*.
If V* not equal to {φ}, then go to Step 1,
otherwise, stop.
Set $R_v$=(V, ETv U EDv).

The loopless-deflection algorithm selects nodes one at a time, [3] and attempts to find a deflection output port at the selected node. By selecting leaf nodes which are furthest from the root, and by deleting the node after its deflection output port has been selected, the algorithm ensures that no deflection are made to nodes which are further from the destination that the selected node, and that packets, upon departing from the selected node, can never return to that node. In step3, the algorithm attempts to choose the deflection edge, which results in the shortest path to the destination. The algorithm can be further customized in step 3 by choosing the deflection edges based on estimated link loads, or by allowing multiple deflections options for each destination. If multiple deflection options are allowed, the options may be prioritized based on distance or load considerations.

Since the proposed algorithm does not allow loops, it is possible that a node will not have any deflection alternatives for a given destination. In particular, those nodes, which are closer to the destination, are less likely to have deflection alternatives than nodes, which are further form the destination. By restricting deflection at these nodes, the packet losses may increase.

# III.ANALYTICAL MODEL

In this section, an analytical model for evaluating the packet loss probabilities of the proposed deflection scheme was developed. The model is general, and can be applied to any irregular mesh topology. The analysis can also be used to evaluate any deflection scheme in which the deflection alternatives at each node are ordered and pre-defined.

The model assumes that the network is asynchronous, and that packet have a fixed length of L seconds. Packets arrive to the network according to a Poisson process. Each link in he network is modeled as an M/D/1/1 queue with no buffers. The arrival rates will also depend on the probability of contention, $P_{ij}$, on each link in the network, and the deflection policy.

To find the contention probabilities, the time between packet departure instants was examined and calculate the fraction of time that a link is busy. The expected cycle time, T, between two consecutive packet departures is found by adding the expected time until the next packet arrival to the expected packet transmission time: $E[T] = 1/\lambda_{ij}+L$

The probability that a packet arriving to link ij encounters contention is equal to the probability that the link is busy: $P_{ij} = L/E[T]$.

The analysis may also be applied to deflection schemes in which looping is present; however, the analysis must be modified slightly in order to avoid infinite path lengths. When evaluating the packet loss probabilities, the analysis will stop evaluating a path once it reaches a certain number of hops.

# IV. NUMERICAL RESULTS

In this section, we evaluate the deflection algorithm in the 18-node network topology illustrated in Fig.3, and in a bi-directional Manhattan Street network topology in which the nodal degree at each node is equal to 4. Packets are fixed in length, consisting of 10,000 bits each, and the transmission rate is assumed to be 10Gb/s. Packets arrive to the network according to Poisson process, and traffic is uniformly distributed over all source-destination pairs.

The network parameters measured are the throughput & blocking probality at a node where the packets are generated. For a given arrival rate, the random number is generated for a given number of times which is the input packets generated to a particular node. These input packets may go to destination through shortest path and other input packets will go to destination through defection path. The remaining packets will be discarded. Throughput will be calculated by the total path (sum of the shortest-path routing and deflection path routing) and the sum of the input packets generated. The relation between the arrival rate Vs throughput is made for shortest path routing and deflection routing.

The network considered in the paper is 8 and 18 node network. The network shortest path is found by using the Dijkstra's algorithm and deflection route is found by the loopless deflection algorithm. For those networks the performance measures like throughput, delay and loss are analyzed. The cost analysis for those nodes are found the graphs are plotted.

The throughput and delay probability analysis of 18 node network is analysed in this form. Let the probabilities P1 and P2 be the transition probabilities from one node to another node. The routing of the shortest path and deflection is shown below.

**Shortest path routing:**

0-2-12-17

**Deflection path routing:**

0-2-12-15-17
0-2-12-12-16-17
0-2-15-17
0-2-15-16-17
0-1-3-11-10-9-8-12-17
0-1-3-11-10-9-8-12-15-17
0-1-3-11-10-9-8-12-15-16-17
0-1-3-11-10-9-12-17
0-1-3-11-10-9-12-15-17
0-1-3-11-10-9-12-15-16-17
0-1-3-11-12-17
0-1-3-11-12-15-16-17
0-1-3-8-12-17
0-1-3-8-12-15-17
0-1-3-8-12-15-16-17

**Probabilities of a 18 node:**

- P (first node=0)=1

- P(second node=2)=5/17
- P(second node=1)=12/17
- P(third node=3)=12/17
- P(third node=12)=3/17
- P(third node=15)=2/17
- P(fourth node=8)=3/17
- P(fourth node=11)=9/17
- P(fourth node=15)=2/17
- P(fourth node=16)=1/17
- P(fourth node=17)=2/17
- P(fifth node=10)=6/15
- P(fifth node=12)=6/15
- P(fifth node=16)=1/1
- P(fifth node=17)=2/15
- P(sixth node=9)=16/3
- P(sixth node=15)=4/13
- P(sixth node=17)=3/13
- P(seventh node=8)=3/10
- P(seventh node=12)=3/10
- P(seventh node=16)=2/10
- P(seventh node=17)=2/10
- P(eight node=12)=3/8
- P(eight node=12)=3/8
- P(eight node=15)=2/8

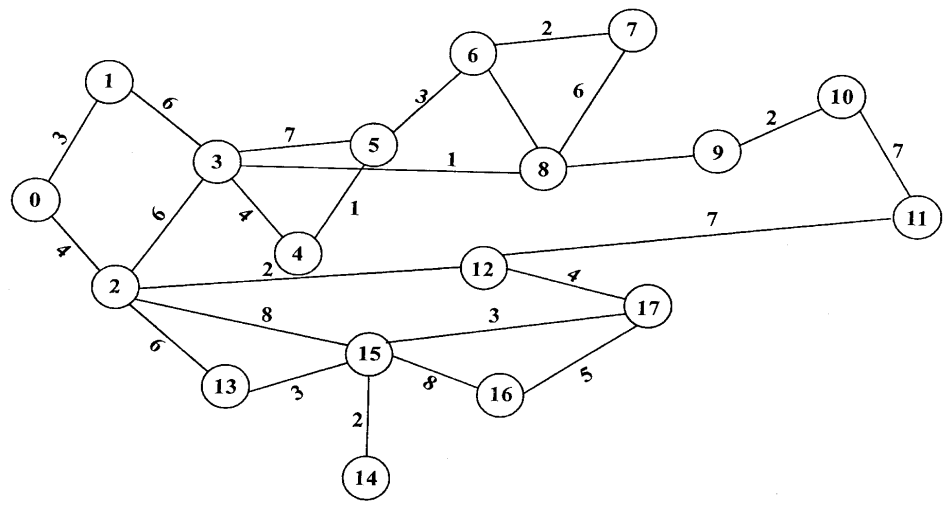


**Fig.3. 18 node network topology**

- P(eight node=17)=3/8
- P(ninth node=15)=2/5
- P(ninth node=16)=1/4
- P(ninth node=17)=2/5
- P(tenth node=16)=1/3
- P(tenth node=17)=2/3
- P(eleventh node=17)=1

The average throughput and packet loss probability analysis of 18 node networks is shown in Fig. 4 & 5. Fig 4 shows that in the larger network the average throughput for shortest path routing is low compared to throughput for deflection path routing if the packet arrival rate is increases. After the arrival of the first packet itself shortest path routing get the maximum throughput whereas after the arrival of more than 1 packet only deflection path routing get the maximum throughput.

Similarly, the average loss probability for the larger networks is zero in the deflection path routing but it is smaller in the shortest path routing. The throughput and loss is very much better in the larger network compared to smaller network.

The average delay and cost analysis of 18 node network is shown in Fig. 6 & 7.The average delay is smaller in both the paths and it is better in larger node network compared to smaller node network.

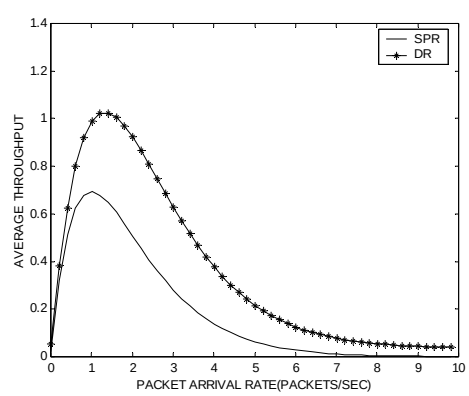


**Fig.4. Average throughput analysis for 18 node network.**

The Cost analysis of 18 node networks is shown

in the Fig.7. From the Fig7, it is inferred that the average cost of a shortest path routing is low whereas the average cost of a deflection path routing is high for larger network. And also the number of packets increases to one, then only the shortest path routing deflection path routing get the maximum cost. Thus in the smaller network the average cost is high through deflection routing.

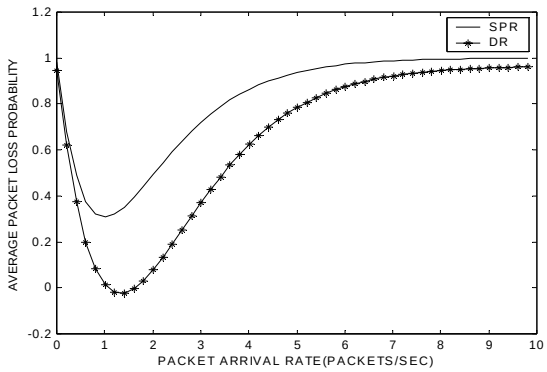


**Fig.5. Average packet loss Probability for 18-node network**

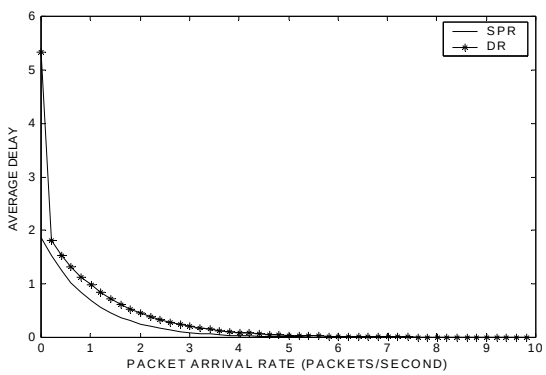


**Fig.6. Average delay analysis in 18 node network**

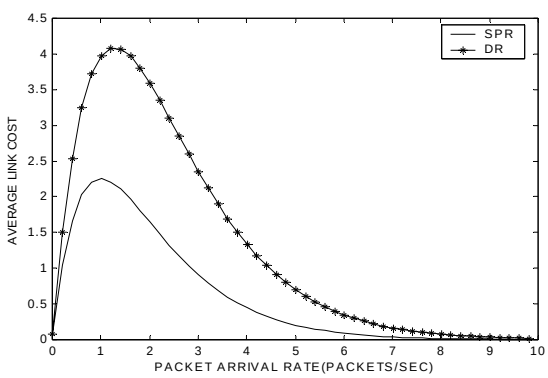


**Fig.7. Average cost analysis of 18-node network.**

From the figures it inferred that in the larger networks the performance measures like throughput and delay is better when compared to the smaller networks. The throughput is increased from 15% to 50% for larger networks compared to smaller networks. Also the delay is less for larger networks compared to smaller networks. The packet loss probability is also reduced for large networks, when traffic is heavy.

The increase in average cost when deflection routing is adopted also gets reduced for larger networks at heavy loads. So for larger networks, under heavy load conditions the loopless deflections routing algorithm gives better results.

# V. CONCLUSION:

In this work, it has been observed that the packet loss probability due to contention can be reduced by adopting deflection routing. Further reduction in packet losses can be obtained by increasing the number of deflection alternatives. However, there will be a corresponding increase in delay, which may not be acceptable. Therefore a multiple deflection algorithm needs to be designed with delay minimization as the main design criteria.

In this paper, analysis of improved deflection routing method called loopless deflection routing algorithm is carried out. It is proved that under heavy traffic conditions, contention can be greatly reduced by using the loopless deflection algorithm, particularly for larger networks. It has been shown that with the packet arrival rate increased, the better performance of throughput for larger network compared to smaller network. The delay decreases for larger network compared to smaller network. By these analysis, it has been shown that deflection routing gives better performance in larger networks compared to smaller networks.

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