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Performance evaluation of shufflenet multihop network for different routing algorithms

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Abstract

To share the optical medium vast bandwidth potential among many users is necessary that a multitude of messages concurrently reside on the optical medium.

Concurrency may be achieved assigning to each user a unique wavelength on which each packet may be transmitted through the network. Each receiver must be tuned to the wavelength of interest within a given time interval.

In this paper we have considered a network with Perfect Shuffle as connectivity graph where the number of transmitters and receivers associated to each Network Interface Unit (NIU) is p and NIU are arranged in k columns.

In particular we have considered the 8-NIU and the network performances are evaluated under the assumption of a passive star as physical topology, uniform traffic and finite buffers capacity.

The network throughput, the network mean time delay as well as the loss probability for input packets and the loss probability for recirculating packets are evaluated using the classical minimum hop algorithm.

Through simulations it has been highlighted that the minimum hop algorithm causes unbalanced traffic in the network.

In order to obtain a better channel utilization, a simple adaptive routing algorithm is proposed.

An important result shown in this paper is that the adaptive routing algorithm allows to obtain better performance without increasing the routing complexity.

1. Introduction

Optical fiber has emerged in the last decade as the premiere medium for high-speed communication systems. Its initial application in point-to-point transmission facilities is now being supplemented with applications to multiuser local and metropolitan area networks where many users couple onto and share the transmission capabilities of a single fibre. Until the advent of optical processing, the speed will be limited by electronics.

Time and wavelength multiplexing are the most common methods for sharing a communication channel among multiple users.

Considering Wavelength-Division-Multiplexing (WDM), multiple users can transmit simultaneously on different wavelengths. Using direct detection we can reach about 10-20 wavelengths per fiber, but with coherent techniques this limit will be largely increased.

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The availability of many wavelengths will allow to share the same optical channel simply assigning to each user a unique wavelength on which each packet may be transmitted in the network. Each receiver then tunes to the wavelength of interest for a given time interval. In such a way two kinds of problems must be solved:

- pretransmission is needed in order to coordinate the establishment of the links between transmitters and receivers;
- each receiver must tune over the entire optical band, in the prescribed interconnection sequence, at speed comparable with the packet transmission rate. Such optical receivers are beyond the current state of the art.

The ShuffleNet multihop network avoids the previously reported disadvantages using fixed-wavelength transmitters and receivers assigned to each user [1].

After receiving a message, the user determine if it is intended for a different user or not. In the first case the message must be retransmitted. In such a way simultaneous transmissions among the user are allowed.

This paper deals with a network based on the Perfect Shuffle connectivity graph where the number of transmitters and receivers associated to each Network Interface Unit (NIU) is p and NIU are arranged in k columns [3].

The network performances are evaluated under the assumption of a passive star as physical topology, uniform traffic and a finite capacity of the buffers in each NIU.

The normalized network throughput, defined as the total amount of packets arrived to destination per time slot, the network mean time delay defined as the mean time needed to each packet to reach his destination NIU, the first offered packet-loss probability (i.e. the probability that a new generated packet is not allowed to input into the network) and the recirculating packet-loss probability (i.e. the probability that a packet already present into the network is discarded) are evaluated using the minimum hop algorithm.

Through simulations it has been possible to highlight that the minimum hop algorithm causes unbalanced traffic in the network.

To solve this problem, in Section 3, a simple adaptive routing algorithm is proposed.

The same parameters considered for the minimum hops algorithm have been evaluated using this routing algorithm under the same conditions to show a better behavior.

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2. Performance evaluation of ShuffleNet for minimum hops fixed routing

The (p,k) ShuffleNet consists of $N=kp^k$ (k=1,2,3,...) (p=1,2,3,...) NIU (Network Interface Unit) arranged in k columns of p^k NIU each. The connectivity graph can be considered as wrapped around a cylinder, as shown in Fig.1 for an 8-NIU with $p=2$ and $k=2$. If we associate a WDM channel with each arc (dedicated channels), then the network would require a total of kp^{k+1} channels with p transmitters and p receivers per NIU.

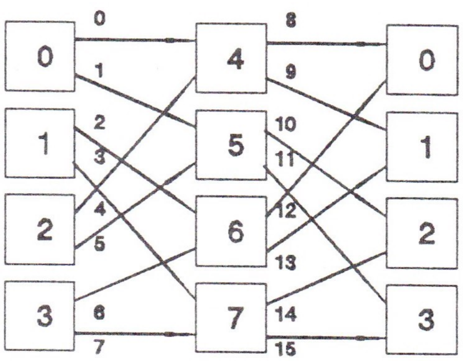

Figure 1 The 8-NIU connectivity graph

Considering any NIU to be identified by the couple (c,r) [2] where $c \in \{0,1,\ldots,k-1\}$ and $r \in \{0,1,\ldots,p^k-1\}$, we express r as p-ary digit:
$r=(r_{k-1},r_{k-2},\ldots,r_0)$.

Routing any packet from a source (c^s,r^s) to a destination (c^d,r^d), the decision at each intermediate NIU is based on one of the p-ary digits of the destination address contained in the packet header. For example, when an intermediate NIU (c^i,r^i) receive a packet with destination address $(c^d,r^d) \neq (c^i,r^i)$, the intermediate NIU must forward the packet using the routing algorithm described below.

Let us denote X as the number of columns between the current NIU and the destination NIU, we have:

$$X=\begin{cases}(k+c^d-c^i)\bmod k & \text{if } c^d \neq c^i\\ k & \text{if } c^d=c^i\end{cases} \tag{1}$$

Considering that a packet hops toward his destination one column at a time, and using the p-ary digit r^d_{X-1} [3], then the packet is routed to:

$$[(c^i+1)\bmod k,(r^i_{k-2},r^i_{k-3},\ldots,r^i_0,r^d_{X-1})] \tag{2}$$

Simulations have been based on the 8-NIU ShuffleNet with dedicated channels and have been made under the assumption of uniform loading of the NIU when the source-destination traffic pattern is uniform and assuming the size of the buffers at each NIU equal to 100 packets.

The parameters to be evaluated are:

- normalized network throughput (pkt/timeslot) as a function of the external input traffic λ (pkt/timeslot);
- network mean time delay (timeslot) as a function of λ (pkt/timeslot);
- the loss probability for input packets as a function of the buffer size, for fixed values of λ;
- the loss probability for recirculating packets as a function of the buffer size, for fixed values of the external input traffic λ;

Under the aforesaid conditions the routing algorithm produce a traffic imbalance in the network links. Therefore it is possible to verify that for each NIU one of the outgoing links results overloaded with respect to the other.

For the 8-NIU, showed in Fig.1, the links 1,3,9,11,4,6,12 and 14 are the high loaded traffic links. For those links it can be shown that the rate (λ_{HL}) of the input traffic for the associated buffers is:

$$\lambda_{HL}=\frac{8}{7}\lambda \tag{3}$$

In the same way we have that the rate (λ_{LL}) of the input traffic for the associated buffers is:

$$\lambda_{LL}=\frac{6}{7}\lambda \tag{4}$$

For this reason when the external input traffic (λ) exceeds 7/8=0.875 (pkt/timeslot) the buffer associated to the high traffic link tends to saturation. Reaching this situation some packets are lost and the throughput curve discosts from the throughput defined in [3], where the maximum achievable throughput per NIU (C) is derived by assuming buffers of infinite size (ideal case) as:

$$C=\frac{2p(p-1)(kp^k-1)}{kp^k(p-1)(3k-1)-2k(p^k-1)}\lambda \tag{5}$$

Moreover we have assumed in our model a light form of flow control.

After arriving a packet, any NIU selects the next NIU to which the packet must be forwarded and then stores it into the related buffer if the buffer is not empty. Before storing the new packet into the buffer a control is made in order to diminish the loss probability for packets already present into the network (recirculating packets).

In our case if the buffer does not have enough space to store almost two packets, the external input packet to be stored is discarded.

Due to the strategy assumed, the effective input traffic is less than the external input traffic (i.e. the generated one). The Figs.2 and 3 are expressed as a function of the external input traffic, but after the saturation value the effective input traffic differs from the generated one. For values of the external input traffic of 0.9, 0.95 and 1.0 (pkt/timeslot) it correspond values of the effective input traffic of 0.882, 0.897 and 0.911 (pkt/timeslot).

If we increase the capacity reserved for recirculating packets into each buffer before storing a new arriving external packet, we can reduce the input traffic λ_{HL} under the saturation value 1 even if the external input traffic to high traffic links λ is 1.

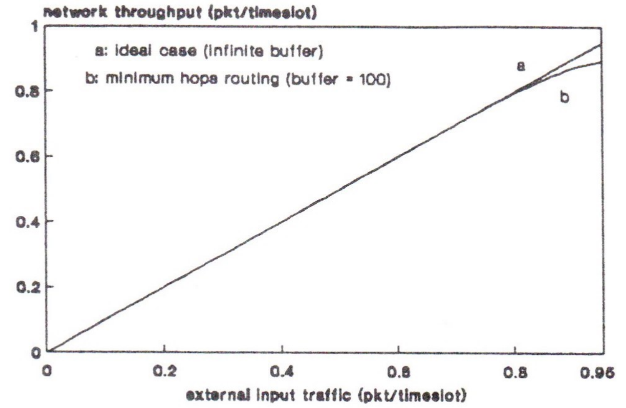

Figure 2 The normalized network throughput for the 8-NIU ShuffleNet

In Fig.2 is reported the normalized network throughput with respect to that obtained in the ideal case for a ShuffleNet with $(p,k)=(2,2)$.

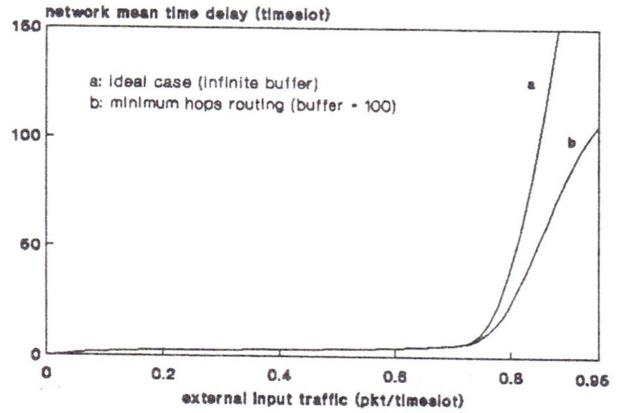

Figure 3 The network mean time delay for the 8-NIU ShuffleNet

Fig.3 shows the network mean time delay as a function of λ.

In the simulated case, until buffers related to the high traffic links are not full, increasing the external input traffic we obtain an increase of the mean time delay. When the network reach the congestion (i.e. saturation of the buffers for the high traffic links), also recirculating packets may be discarded and the mean time delay begin approximatively constant.

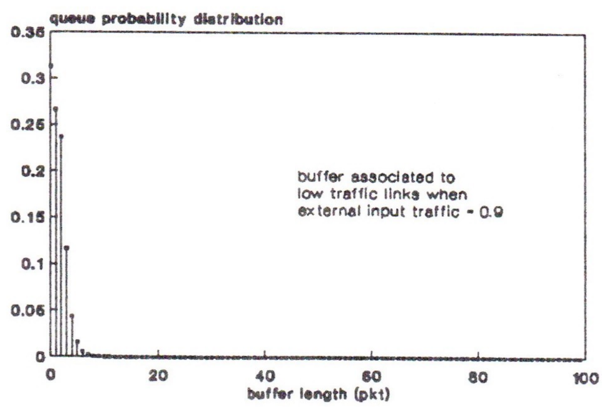

Figure 4 The queue probability distribution for low traffic links

Referring to queue distribution we consider a buffer capacity equal to 100 packets and external input traffic at rate λ = 0.9 .

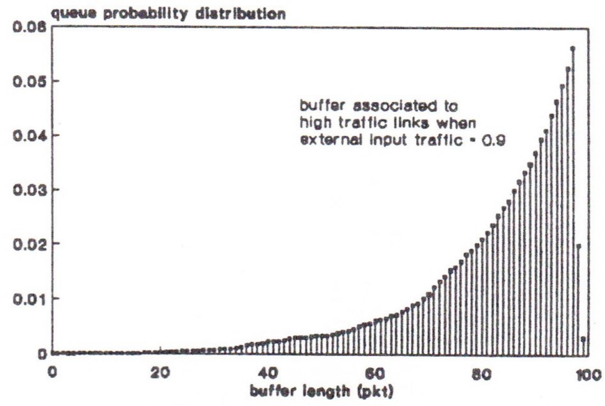

Figure 5 The queue probability distribution for high traffic links

Figs.4 and 5 show the queue distribution for any NIU when the external input traffic λ is 0.9 . From these figures the links load imbalance is evidenced. Note that in any buffer two packets are always reserved according to the assumed flow control technique.

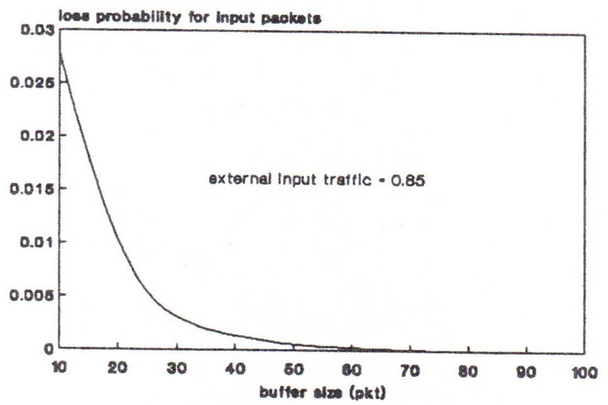

Figure 6 The loss probability for input packets for the 8-NIU ShuffleNet

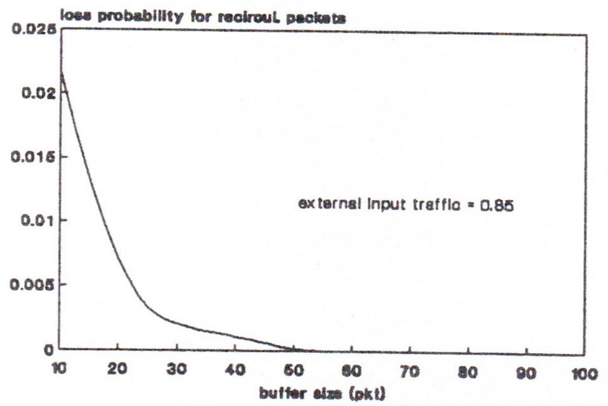

Figure 7 The loss probability for recirculating packets for the 8_NIU ShuffleNet

The input packet-loss probability and the recirculating packet-loss probability are shown in Figs.6 and 7 respectively as a function of the buffer size for $\lambda = 0.85$ (pkt/timeslot).

3. Performance evaluation of ShuffleNet for a adaptive routing algorithm with reduced complexity

In any NIU, packets wait to be routed to the next NIU in appropriate buffers. The resulting waiting time may be sometimes long, in particular under high external traffic load conditions.

With the proposed adaptive routing algorithm, a packet is deflected with respect to the buffer destination derived according to the minimum hops algorithm, whenever the following relation is verified:

$$\max_{\forall i \neq min\,hop} (n_{min\,hop} - n_i) \geq \overline{H}_{mean} \qquad (6)$$

where $n_{min\,hop}$ denotes the number of packets in the buffer where the packet should be stored according to the minimum hop path, n_i is the number of packets stored in the i_th buffer of the same NIU and where $\overline{H}_{mean}$ represents the mean number of hops between two any couple of source-destination NIU attained in the case of the minimum hops algorithm. This parameter can be derived as [3]:

$$\overline{H}_{mean} = \frac{kp^k(p-1)(3k-1)-2k(p^k-1)}{2(p-1)(kp^k-1)} \qquad (7)$$

According to the adaptive routing algorithm, the relation (6) is evaluated whenever a packet arrives at a NIU.

Adopting this algorithm in the case of the 8-NIU ShuffleNet, it has been possible to highlight that a more balanced loading for the two buffers at each NIU is attained independently of the input traffic providing jointly a reduced mean time delay with respect to the minimum hop algorithm.

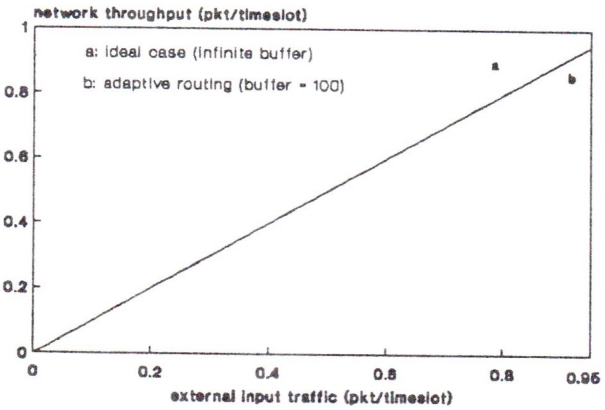

Figure 8 The normalized network throughput for the 8-NIU ShuffleNet using the adaptive routing algorithm

Fig.8 shows the normalized network throughput achieved by mean of the adaptive routing algorithm considered in comparison with the ideal case. It is important to outline that the simulations are performed under the same hypothesis of the minimum hop routing algorithm (i.e. under the assumption of uniform loading of the NIU when the source-destination traffic pattern is uniform and assuming the size of the buffers at each NIU equal to 100 packets).

We can see no difference between the two curves until the input rate is near 1 .

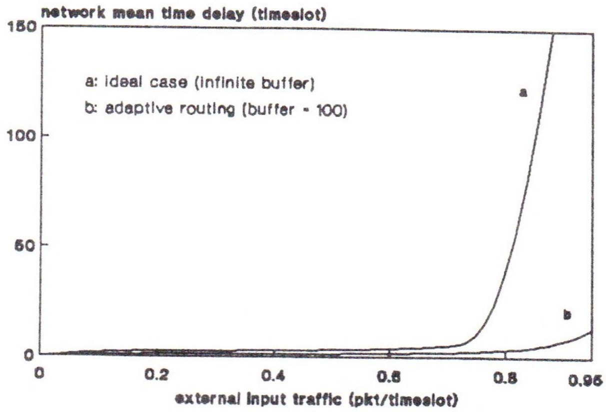

Figure 9 The network mean time delay for the 8-NIU ShuffleNet using the adaptive routing algorithm

In Fig.9 a function of the mean time delay in the case of the adaptive routing algorithm is reported. In the same figure the mean time delay achieved in the ideal case is also shown for comparison purposes. Performance closes to the optimum ones are highlighted in this figure.

4. Conclusions

In this paper we have considered an 8-NIU ShuffleNet where the network performance are evaluated under two different routing algorithms: the minimum hops one and an adaptive one.

Referring to the minimum hops routing algorithm we have stressed the traffic imbalance between the network links of each NIU. This imbalance is more evident under high input traffic.

This problem can be relaxed by using the proposed adaptive routing algorithm. Moreover in this case better performance is achieved. In particular the network throughput approaches 1 as the external input traffic approaches 1. In conclusion we can say that adaptive routing the proposed algorithm is suitable for use in a 8-NIU ShuffleNet; an investigation is still in progress for considering the ShuffleNet performances with increased number of NIU.

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