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MAC protocol with delay-aware adaptive round time for split light-trail

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ABSTRACT

Light-trail (LT) has been considered as an attractive solution for optical networks to support emerging services such as video-on-demand, pseudo-wires, and data-centers. The media access control (MAC) protocol is essential for LT networks because LT is a shared-medium. Recently, in order to enhance the throughput, a regular LT can be split into several sub-LTs at the split nodes where traffic undergoes optical-electronic-optical conversation. To deal with the split LT, a novel MAC protocol named Delay-aware adaptive round time for split LT (DAARTS) is developed on the basis of DAART MAC protocol and the schemes of splitting LT. To estimate the performance of the developed MAC protocol, ART, DAART and DAARTS protocols are simulated and compared in the scenarios of three different traffic patterns. Simulation results show that, for traffic 1 and traffic 2, DAARTS has stable throughput performance and can obtain almost 40.83% and 106.64% throughput improvement compared with DAART, respectively. In other words, DAARTS can further enhance the throughput of LT networks.

1. Introduction

Light-trail (LT) is a generalization of a light path [1], which supports dynamic bandwidth allocation, optical layer multicasting, sub-wavelength spatial grooming at a low price using contemporary technologies. LT has been considered as an attractive solution for optical networks to support emerging services such as video-on-demand, pseudo-wires, data-centers, etc. Extensive researches have been devoted to addressing the problems in LT networks, such as traffic grooming [2–4], node architecture [5,6] and media access control (MAC) protocol [7–13].

In this paper, we focus on the performance of MAC protocol in LT networks. Due to the fact that LT is a shared medium, the MAC protocol is essential to avoid collisions of packets sent by transmission nodes simultaneously. LT MAC [1] has been proposed to avoid collisions using carrier sensing, but it cannot guarantee fairness among transmission nodes. To address this problem, light trail fair (LT-FA) MAC [7] and adaptive round time (ART) MAC [8] have been proposed. Besides, ART MAC obtains more throughput than LT-FA MAC [9]. However, ART MAC has not provided a way to evaluate the actual token holding time of every transmission node. Hence, on the basis of ART, DAART MAC [15] which adopts the delay-aware idea [14] to evaluate the actual token holding time is developed to improve throughput in LT networks. However, DAART is not suitable for the case of split LT. Therefore, on the basis of DAART and the schemes of splitting LT, a novel MAC protocol named DAARTS is developed for split LT. Extensive simulations have been made to compare the performance of ART MAC, DAART MAC and DAARTS MAC.

The rest of this paper is organized as follows: Section 2 analyzes the schemes of splitting a LT once to obtain maximum capacity gain according to different traffic patterns. Section 3 introduces the implement details of DAARTS MAC, its LP formation and the corresponding algorithm. Section 4 gives the simulation results concerning the performance of ART MAC, DAART MAC and DAARTS MAC. The paper is concluded in Section 5.

2. Schemes of splitting a LT once according to three different traffic patterns

To keep the advantages provided by LTs in terms of time division multiple access, without suffering much loss in terms of space division multiple access, LTs can be split into multiple short segments [16]. To get more throughput of a LT, we consider splitting a LT once into two LTs to take full advantage of bandwidth resource. In this section we analyze how to split a LT once to obtain maximum capacity gain according to three different traffic patterns, the cost of splitting is also discussed.

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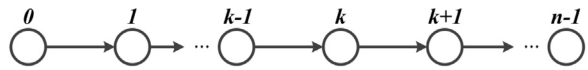

Fig. 1. A non-split light trail numbered from 0 to $n-1$.

2.1. Split a LT once for traffic pattern 1

Traffic pattern 1 here is a uniform traffic pattern where every node pair has a connection and every connection has the same traffic volume. Consider a LT with n nodes numbered from 0 to $n-1$ as shown in Fig. 1, there are $n(n-1)/2$ connections in this LT. If the bandwidth of this LT is B (Gbps), then every connection can get a bandwidth c theoretically as follows:

$$c = \frac{B}{C_n^2} \tag{1}$$

We split the LT once at node k ($0<k<n-1$), then this LT is split into two LTs. We call the LT from node 0 to node k as upstream LT and the LT from node k to node $n-1$ as downstream LT. Because the original LT is split, so the traffic started from upstream LT and terminated in downstream LT must undergo optical-electronic-optical conversion at node k, namely this kind of traffic must be downloaded from upstream LT to node k firstly and then uploaded into downstream LT. Traffic in upsteam LT can be denoted as $[k(k+1)/2+k(n-k-1)]c$ where $ck(k+1)/2$ is the traffic which is generated and consumed internally by node 0 to k and $ck(n-k-1)$ is the traffic started from upstream LT and terminated in downstream LT. In upstream LT the ideal bandwidth can get B theoretically, so it is a waste of bandwidth that every connection in upstream LT just gets a bandwidth c. Every connection in upstream LT can theoretically get a bandwidth denoted with c_1 as follows:

$$c_1 = \frac{B}{k(k+1)/2 + k(n-k-1)} \tag{2}$$

Traffic in downstream LT can been denoted as $[(n-k)(n-k-1)/2+k(n-k-1)]c$, where $c(n-k)(n-k-1)/2$ is the traffic which is generated and consumed internally by node k to $n-1$, and $ck(n-k-1)$ is the traffic started from upstream LT and terminated in downstream LT. In downstream LT, the ideal bandwidth can also get B theoretically, so it is a waste of bandwidth that every connection in downstream LT just gets a bandwidth c. Every connection in downstream LT can theoretically get a bandwidth denoted with c_2 as follows:

$$c_2 = \frac{B}{(n-k)(n-k-1)/2 + k(n-k-1)} \tag{3}$$

From Equations (2) and (3), we can see that c_1 and c_2 vary with k ($0<k<n-1$). If $c_1>c_2$, then capacity gain in upstream light-trai is more than that in downstream LT, as a consequence, traffic downloaded from upstream LT to node k for the optical-electronic-optical conversion is $k(n-k-1)c_1$, however, traffic uploaded at node k to downstream LT is just $k(n-k-1)c_2$, thus there is $k(n-k-1)(c_1-c_2)$ traffic cannot be accommodated, so the actual capacity gain of connections in upstream LT should be equal to c_2. More commonly, the actual capacity gain denoted as c' for both upstream and downstream LT should be equal to the less one of c_1 and c_2 as follows:

$$c' = \min(c_1, c_2) = \min\left(\frac{B}{k(k+1)/2 + k(n-k-1)}, \frac{B}{(n-k)(n-k-1)/2 + k(n-k-1)}\right) \; (0 < k < n-1) \tag{4}$$

As a result, the actual bandwidth used in upstream LT B_1 and actual bandwidth used in downstream light-trial B_2 should be described as follows:

$$B_1 = \left(\frac{k(k+1)}{2} + k(n-k-1)\right)c' \tag{5}$$

$$B_2 = \left(\frac{(n-k)(n-k-1)}{2} + k(n-k-1)\right)c' \tag{6}$$

Check the Equation (4), we can obtain the maximum capacity gain when $k=(n-1)/2$. If n is odd, then the two LTs will obtain the maximum capacity gain $c'=2B/n(n-1)$ and $B_1=B_2=B$, node k is selected to be the exact middle node. If n is even, then $k=(n-1)/2$ is not an integer and the possible solutions is $k=n/2$ or $k=(n-2)/2$. When $k=n/2$ we can get $c'=8B/n(3n-2)$, $B_1=B$ and $B_2=B(3n-6)/(3n-2)$ according to Equations (4)–(6), respectively. When $k=(n-2)/2$, we can get $c'=8B/n(3n-2)$, $B_1=B(3n-6)/(3n-2)$ and $B_2=B$ according to Equations (4)–(6), respectively. In this paper, we choose n as odd to simplify the problems.

In a word, for uniform traffic a LT must be split in the middle to maximize the capacity gain. Traffic started from upstream LT and terminated in downstream LT is $k(n-k-1)c'$. Therefore node k must be equipped with enough electronic buffering to store and forward this traffic.

2.2. Split a LT once for traffic pattern 2

Traffic pattern 2 here is the pattern where every node just sends traffic to its adjacent node. As Fig. 2 shows, node 0 just sends traffic to node 1 and node 1 just sends traffic to node 2 and so on, by the way, the volume of every connection is same. Because of this character, there is no need to undergo optical-electronic-optical conversion at split node k ($0<k<n-1$).

In a word, for traffic pattern 2 no matter which node is chose as the split node, the upstream and downstream LTs both can obtain the maximum capacity gain and get the bandwidth B, and there is no need to equip with extra electronic buffering to store and forward traffic at split node. Considering the throughput of this split LT, which is discussed below, we also choose the middle node of this LT as the split node for traffic pattern 2.

2.3. Split a LT once for traffic pattern 3

Traffic pattern 3 here is the pattern where every node just sends traffic to the terminate node and every connection has the same traffic volume. As Fig. 3 shows, nodes from 0 to 3 just send traffic to node 4, if we choose node 2 as the split node, thus the connection of node 0 to node 4 and node 1 to node 4 have to be downloaded from upstream LT into extra electronic buffering at node 2 and then uploaded into downstream LT.

More commonly, there are n nodes from node 0 to node $n-1$ in an original LT and node k is the split node. For this traffic pattern, we can get c_1 and c_2 according to Equations (2) and (3) as follows:

$$c_1 = \frac{B}{k} \quad c_2 = \frac{B}{n-1}$$

Because k is less than $n-1$, so c_2 is less than c_1, then we can get $c'=B/(n-1)$, thus the actual bandwidth used in upstream LT B_1 and actual bandwidth used in downstream light-trial B_2 can be described according to Equations (5) and (6) as follows:

$$B_1 = \frac{k}{n-1}B \quad B_2 = B$$

To maximize B_1 we must choose node $n-2$ as the split node and we can get $B_1=B(n-2)/(n-1)$.