Home Circuit Sharing for Dynamic Wavelength Assignment in LOBS-Based Datacenter Networks

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SUMMARY According to the match-degree between lightpaths, an HC-sharing approach is proposed to assign wavelength for an arriving transmission request for dynamic traffic in LOBS-based datacenter networks. The simulation results demonstrate that the proposed approach can provide lower block probability than other approaches for both unicast and multicast transmissions.

key words: label optical burst switching (LOBS), datacenter network, wavelength assignment, HC-sharing

1. Introduction

Internet of things (IoT) following the cloud model connects all the tiny devices through central nodes - datacenters [1]. The datacenter network (DCN) based on optical switching can provide high-bandwidth guarantee and fast switching for the exponentially growing data traffic in various applications of cloud computing [2]. Lightpaths are built to connect network devices in a DCN (i.e., intra-DCN) or DCNs in different geographical locations (i.e., inter-DCN) for end-to-end communications.

An enhanced label optical burst switching (LOBS), named label optical burst switching with home circuit (LOBS-HC), is applied to provide a high bisection bandwidth with low cost and energy consumption for the intra-DCNs [3]. However, the home circuit (HC) routing and wavelength assignment schemes proposed in [3] are only valid for all-to-all communication in ring and hypercube intra-DCNs. Furthermore, it is different from the real dynamic DCN traffic that the sustained bandwidths of all HCs should be fixed and the same. Based on integer linear programming (ILP), an optimal solution will be found for rings under both all-to-all uniform traffic and arbitrary traffic demands [4]. ILP-based and heuristic methods are designed to build lightpaths and light-trees for optical inter-DCNs, however, they are only feasible for small-size networks under static traffic [5].

The schemes of routing and wavelength assignment can be generally classified into static and dynamic ones. In the dynamic case, a unicast or multicast session arrives at and departs from the network dynamically, and the objective is to minimize the blocking probability.

The main character of LOBS-HC, which allows HCs with the same source to share the same wavelength(s), is to provide the same bandwidth guarantee service to traffic flows as in optical circuit switching (OCS), while still keeping a fast switching speed and high resource utilization capability as in optical burst switching (OBS) [3].

In this work, with the absence of wavelength conversion, we proposed a max-matching method for HC-sharing to find the most appropriate sharable wavelength and establish a lightpath or light-tree (here in after to be referred as HC and HC-tree, respectively) for a dynamically arriving unicast or multicast request. The assigned wavelength maybe has been occupied by some existing HCs or HC-trees with the same source/root as the new request, and its remainder bandwidth is enough for the traffic demand of the request. To the best of our knowledge, this is the first work to assign wavelength in consideration of HC-sharing in LOBS-based networks under dynamic traffic.

Different from some other dynamic wavelength assignment methods [6], e.g., first-fit and random, the proposed method requires the dynamic information of all existing HCs/HC-trees, such as the bandwidths, the status of links and wavelengths. Fortunately, there is a network interface – OpenFlow – can provide a centralized control plane for developing the dynamic and global wavelength assignment [7].

The paper makes the following three major contributions. First, it defines match-degree as a metric to measure the availability of one wavelength which is being occupied by a same-root HC/HC-tree to a routing path/tree. Secondly, the paper proposes a dynamic wavelength assignment scheme with max-matching (MM) HC-sharing according to match-degree. Thirdly, the paper shows that, comparing with other HC-sharing approaches such as random, min-remainder, and max-spare by simulation, the proposed MM HC-sharing can establish HCs and HC-trees considering wavelength utilization to provide lower blocking probability.

2. Max-Matching HC-Sharing

2.1 Max-Matching (MM)

To facilitate the presentation, the HC is here in after treated as a special HC-tree with only one destination. The network is denoted by a graph G consisting of N nodes (i.e., vertices). An edge in G corresponds to a bidirectional link in the network, e.g., the existence of an edge e(v, u) from node
$v$ to $u$ implies the existence of an edge $e(u,v)$ from node $u$ to $v$. In addition, a tree is denoted by $T$, $V(T)$ is the node set of $T$, and $E(T)$ is the edge set of $T$. The tree rooted at node $s$ is denoted by $T_s$. Note that, in this paper, the path is treated as a special tree with only one destination node.

In MM HC-sharing, match-degree is a metric used to measure the availability of one wavelength. A wavelength, which is available and being used by one existing HC-tree, measures the availability of one wavelength. A wavelength, as a special tree with only one destination node.

A wavelength is available for an arriving unicast or multicast request with source $s$ if it can be assigned to all the edges required by the routing tree $T_s$. There are two types of available wavelengths. The Case1 wavelength is being occupied by an existing HC-tree with the same source/root $s$ and its remainder bandwidth is enough for the traffic demand. A Case2 wavelength means it hasn’t been assigned for any existing HC-tree which occupies some edges in $T_s$.

Before describe how to calculate the match-degree, we give following definitions.

**Definition 1:** $\gamma_e(T,e)$, the number of nodes in tree $T$ which is reachable via edge $e(v_1,v_2)$. So it is equal to the number of nodes of tree $T_{v_2}$, the largest sub-tree of $T$ rooted at $v_2$. The edge with higher $\gamma_e$ is more important to the communication request with routing tree $T$.

**Definition 2:** $\gamma_{hc}(T,H)$, the number of nodes in tree $T$ which is reachable via HC-tree $H$. $H$ is source-same with tree $T$, and $\lambda$ (the wavelength of $H$) is available to tree $T$. $\gamma_{hc}(T,H)$ can be calculated by (1):

$$\gamma_{hc}(T,H) = \sum_{i=1}^{n} \gamma_e(T,e_i),$$  

where $n_e = |E(T) \cap E(H)|$, and $\forall \gamma_i \in E(T) \cap E(H)$.

**Definition 3:** $Degree_m(\lambda, T, H)$, the match-degree between tree $T$ and HC-tree $H$. It is calculated as in (2).

$$Degree_m(\lambda, T, H) = \frac{\gamma_{hc}(T,H)}{\gamma_{hc}(T,T)}$$

2.2 Wavelength Assignment Based on MM-Sharing

We omit how to construct the routing path or tree for a connection request here. In addition, the match-degree of the wavelength should not be less than a given threshold in specific applications. Use $Q$ to denote the arriving connection request. How the wavelength assignment based on MM HC-Sharing works for $Q$ is presented as follows:

**Step 1:** find an available Case1 wavelength based on MM HC-Sharing:
If (available Case1 wavelength(s) exist)
Find out an HC-tree $H'$ that has the highest match-degree with the routing tree $T$ of $Q$ and $Degree_m(\lambda, T, H')$ is not less than the given threshold $D_m$. Assign the wavelength $\lambda$ to $Q$, and exit.

**Step 2:** find an available Case2 wavelength in increasing wavelength index order:
If (an available Case2 wavelength $\lambda'$ exists)
Assign the wavelength $\lambda'$ to the communication session of $Q$, and exit.

**Step 3:** the assignment is fail and the session is handled according to a given approach, e.g., dropping, re-assignment, or postponing.

Note that the wavelength assigned to a flow in a link will be released when all the bursts of the flow have passed the reserved link.

The complexity of calculating the match-degree between tree $T$ and any HC-tree is $O(|E(T)|)$. The number of existing HC-trees from source $s$, denoted by $N_{hc}$, is $\rho_s/(\rho_s\rho_f)$, where $\rho_s$, $\rho_f$, and $t_f$ are the probability of a node to be a source, the flow arriving rate, and the average duration time of flows, respectively. Therefore, the overall complexity of the wavelength assignment for a new session based on MM HC-Sharing is $O(N_{hc}|E(T)|)$. If $N_{hc}$ is constant, the complexity is only $O(|E(T)|)$.

In this work, the light-tree construction does not discriminate between unicast and multicast communications, because a path is considered as a tree having only one destination. Therefore, the proposed approach can be applied seamlessly in both unicast and multicast sessions.

3. Performance Evaluation

We run the simulation on a 4-dimension hypercube intra-DCN and a 16-node inter-DCN, each node of which is an LOBS-HC node integrating the function of edge and core nodes. The inter-DCN topology is given in Fig. 1, and the distance unit is 10,000 m. The number of wavelengths per physical link is 16, and the capability of each wavelength is 40 Gbps. The source and destination node(s) of flows are randomly picked up from all nodes in the network, and the size of the destination set in each multicast request is in uniform distribution between 4 to 10.

Connection requests of flows arrive at and depart from the network one by one in a random manner. The reserved bandwidths of flows are uniformly distributed between 10 and 40 Gbps. The average size and the ratio of actual required bandwidth to the reserved bandwidth of each flow are 100 Mbits and 1.2, respectively. In a flow, the packets are generated in ON-OFF model with Hurst $= 0.9$. In addition, the maximum burst size is 200 Kbits. $p_m$ denotes the
multicast ratio. If all the flows are unicast, $\rho_m = 0$. The match-degree threshold $D_m$ used in the proposed approach is 0.6.

In this section, the performance of the proposed wavelength assignment scheme based on four HC sharing methods, including (a) Max-Matching, (b) Random, (c) Min remainder bandwidth, and (d) Max remainder bandwidth, is compared in terms of the block probability and resource utilization.

The blocking probability is measured in terms of the flow loss rate and the in-profile burst ratio. If the HC-tree of a flow cannot be established, the flow will be discarded at the source. The bursts launched from the source node are classified into in-profile and out-of-profile bursts. Due to the lack of optical buffer at either edge or core nodes in our network model, a burst can be delivered from source node via its HC-tree when the bandwidth of the first light-link has not been occupied by unexpected burst(s) arriving from other nodes. In this situation, the burst is in-profile.

Light-link is corresponding to a directed link with certain wavelength. In this work, light-link utilization rate $\rho_\lambda$ is calculated by (3):

$$\rho_\lambda = \frac{n_{\text{used},\lambda}}{2|E(G)|W}$$ (3)

where $n_{\text{used},\lambda}$, $|E(G)|$, and $W$ are the number of used light links, the number of physical links in the network, and the number of wavelengths per physical link, respectively.

The results shown in Fig.2 and Fig.3 demonstrate that wavelength assignment based on MM HC-Sharing can achieve lower blocking probability comparing with other three cases in different multicast ratios. There are more flows are transmitted due to more HC-trees constructed in the NSFNet network. Additionally, more bursts are in-profile and can almost be delivered losslessly in the MM case. No flow is discarded at the source in the 4-cube DCN.

From the results presented in Fig.4, we can see that the MM HC-Sharing can make more light links used for burst transmission. As the offered load increasing, the MM case is much better than the others. Due to the larger number of links, the light-link utilization rate in the 4-cube network is lower than in the NSFNet with 25 links.

4. Conclusion

In this work, we have considered to addressing the dynamic wavelength assignment for the LOBS-based DCNs, and an approach based on Max-Matching HC sharing was proposed. We have shown through simulation results that the proposed approach can provide better network performance comparing with some other approaches in terms of blocking probability and wavelength utilization. Given the increasing maturity of wavelength sharing technology in the near future, the proposed approach is a promising solution to reduce the cost and blocking probability in both intra- and inter-DCNs under dynamic traffic.

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