LETTER

Multicast Routing in GMPLS Networks with Unequal Branching Capability

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SUMMARY In this letter, we study dynamic multicasting in GMPLS networks with unequal branching capability. An overlapped multicasting tree is proposed to reduce blocking probability, which can utilize the branching capabilities more efficiently than the traditional Steiner tree. A nearest node branch first heuristic is developed to find such an overlapped tree.

key words: *routing, multicast, branching capability, overlapped tree*

1. Introduction

The services with multicasting demand such as content distribution (CD), interactive multimedia (IMM) and Virtual Private Network (VPN) multicast have become the most attractive ones in future broadband services. However, they require point-to-multipoint (P2MP) real-time communication with quality of service (QoS) guarantee or traffic engineering (TE), which may not be provided well by the existing best-effort IP multicast protocols. Recently, IETF has presented a set of requirements for P2MP TE extensions to Multi Protocol Label Switching (MPLS) [1]. A scalable multicast MPLS protocol is also proposed [2], [3], and the network framework is not limited to the packet switched networks, but also includes SDH/SONET, lambda and port switching networks managed by Generalized MPLS (GMPLS) protocols. In this architecture, multicast tree is achieved by source node calculating explicit route and without running a multicast routing protocol in the network core. Accordingly, an efficient source-based multicast routing is needed for good bandwidth performance and highly effective P2MP tree. In general, the only dynamic information in multicast routing is the link residual bandwidth. The problem is often referred as Steiner problem in networks (SPN). However, in practice, the branching capabilities of the nodes should also be considered as important information because some nodes may be incapable of replicating incoming signal due to evolutional and economical reasons. Furthermore, branching capabilities of multicast nodes may not be identical because of the trade-off between non-blocking and multicasting in the design of core switch fabric. Previously, sparse light splitting in wavelength division multiplexed (WDM) networks was studied where a *light-forest* multicast structure, consisting of one or more light-trees from the source node, was proposed to reduce the blocking due to insufficient branching capability [4]. But in some cases it is also less efficient because of inadequate utilization of the residual branching capabilities in the intermediate nodes of the trees.

In this letter, we consider the constrained dynamic multicasting problem in GMPLS networks with unequal branching capability, which is different from conventional Steiner tree problem. A new multicasting tree structure is proposed, called *overlapped tree*, where a child node has one or more ingress edges connected to its parents. Then a nearest node branch first heuristic is proposed to find such an *overlapped tree*. Finally, we evaluate its performance in a 14-node NSFNET. The results show that *overlapped tree* can significantly reduce the blocking probability in the case of light loads.

2. Problem Formulation and Algorithm

Conventional multicast routing problem always refers to construct a Steiner tree in the graph, which assumes unlimited branch capability in each node. In the network with unequal branching capability, Steiner tree algorithm can still be employed by pruning the edges connected to nodes without branching capability. However, the pruning may lead to insufficient utilization of limited branch capability. For example in Fig. 1(a), if we use Steiner tree, session A to F is blocked since G is branch incapable. To efficiently utilize the limited branch capability, we propose an overlapped tree in which a node or an edge can be used more than one time. In other words, a child node has one or more than one ingress edges connected to its parents and the parents could

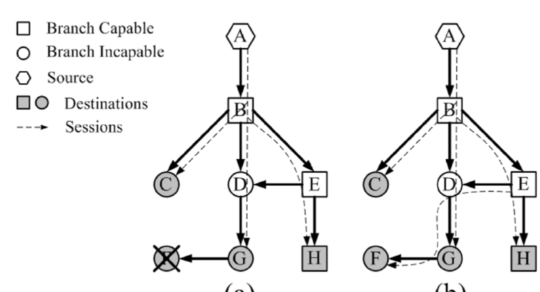

Fig. 1 Steiner tree vs. overlapped tree.

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be either the same or different nodes. These overlapped structures belong to different connecting sessions, so the interrelations between the nodes still form a tree. As shown in Fig. 1(b), session A to F can be setup through branch capable node E via G. Nodes D, G and edge (D, G) are used twice. G has two connecting sessions from its parent D. D has two parents B and E. Steiner tree is a special case of *overlapped tree*, where a child node has only one ingress edge connected to its parent. *Overlapped tree* is more efficient than Steiner tree because *overlapped tree* allows overlapped structure so that all the branching capabilities in a tree can be utilized, and meanwhile, the branching capability of the overlapped node is multiplied.

The multicast routing problem with unequal branching capability is formally stated as follows.

GIVEN:

a) A simple, directed and connected graph $G = (N, L)$ with nonnegative edge costs;

N is the set of the nodes, and L is the set of edges in the graph.

b) A set of bandwidth BW associated with each edge;

c) A set of maximum branching capability C associated with each node;

The maximum branching capability of node n is given by $c(n)$, which is an inherent attribute for each individual point-to-multipoint cross-connecting session in a node. To be practical, $c(n)$ is subject to $1 \leq c(n) \leq deg(n)$, where $deg(n)$ is the node degree, representing the number of neighbor nodes connected to node n. When a node without branching capability $c(n)$ is equal to one. And the upper limit of branching capability in a node usually is $deg(n)$ when, in addition to dropping locally, a node is supposed to branch an input signal to all the neighbour nodes except its incoming node. The limit in the number of connecting sessions which can be supported by a node is not considered here.

d) A multicasting request denoted by 5-tuple (a, T_e, s, R, b_r), where $a \in$ {add, remove} is request action; T_e is an existing multicasting tree; $s \in N$ is the source node; $R \subseteq N - \{s\}$ is the set of destination nodes; and b_r is the request bandwidth.

FIND:

A directed *overlapped tree* T with minimum cost in G connecting s and R subject to the constraints that the bandwidth of any edge in T is equal to b_r and the branching ratio of a node $flow^+(n)/flow^-(n)$ is less than or equal to its maximum branching capability $c(n)$. $flow^-(n)$ and $flow^+(n)$ are defined as the total bandwidth of incoming and outgoing flows of the node n in T. Local add and drop are also counted into incoming and outgoing flow respectively.

Three scenarios are considered in this letter: (1) Creating a new tree; (2) Grafting a tree; (3) Pruning a tree. Migrating tree structure and modifying tree bandwidth are beyond the scope of this letter.

Although the *overlapped tree* is different from Steiner tree, it can be proved that finding a minimum cost *overlapped tree* is also an NP-complete problem.

Lemma: Finding an *overlapped tree* with minimum cost is NP-Complete.

Proof: We prove the lemma by contradiction. Assume that the lemma is not true, thus there exists an algorithm which could solve the mini-cost *overlapped tree* problem in polynomial time. It has been mentioned above that Steiner tree is a special case of *overlapped tree*. So the algorithm also could solve the Steiner tree problem in polynomial time. It contradicts with the well-known theorem that finding a Steiner tree for a multicast session whose members are only a subset of the nodes in a network with arbitrary topology is an NP-complete problem [5]. The lemma is true.

Previously, an efficient nearest node first (NNF) heuristic has been developed for Steiner tree computation of online multicast routing [6]. This idea is convenient to be transformed to solve multicast routing problem with limited branching capability. We propose a nearest node branch first (NNBF) heuristic for the directed *overlapped tree* problem as outlined below:

1. Compute available branching capability $b(n)$ of all the nodes $\{n\}$ in T_e:

$$b(n) = \frac{flow^-(n)c(n) - flow^+(n)}{b_r}$$

2. Set the costs of the edges in G along T_e to zero from s until it reaches the most remote nodes with $b(n) > 0$;

3. Use Dijkstra's shortest path algorithm to find a path P in G from s to $r \in R$;

4. Retrogress along P from r to find the first node u with $b(u) > 0$;

5. Let branch P' denote the segment of P from u to r, $T_e = T_e + P'$;

6. Update bandwidth of edges and available branching capability of nodes along P';

7. Set the costs of the edges in G along P' to zero from u until it reaches the furthest node w with $b(w) > 0$ to u;

8. $R = R - \{r\}$;

9. Repeat 3-8 until R is empty.

In NNBF, a single member r could be rejected for two possible reasons: the first is insufficient link bandwidth so a path from s to r in step 3 cannot be established; the second is insufficient branching capability in path P as a result that cannot find a branch node u in step 4. If a member is rejected, it does not affect existed trees. Note that, to reduce the complexity of the algorithm, it does not search all the nodes with spare branching capability in the tree when finding a path to a receiver.

In order to compare *overlapped tree* with Steiner tree, we also modify NNF by using graph-pruning approach (NNFP). When a new member is added to an existing tree T_e, and if the out-degree of a node n in T_e is equal to its maximum branching capability $c(n)$, we delete all the edges connected to node n in G except those belonging to T_e. Then NNF is used in this pruning graph.

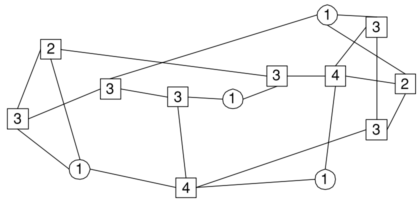

Fig. 2 NSFNET with unequal branching capability.

Considering distributed implementation regardless of NNBF or NNFP, the maximum branching capability information of each node has to be disseminated by extension of OSPF. Once an *overlapped tree* is obtained at the source, it is encoded one main point-to-point (P2P) path and several P2P secondary paths by depth-first-order algorithm. The P2MP *overlapped tree* can then be established by the extension of current GMPLS signaling protocols [2].

3. Performance

We compare the performance of our proposed algorithms by using discrete event simulation model. The simulation was performed in a 14-node NSFNET as shown in Fig. 2. In the network, the circular nodes are those legacy switches that can only provide P2P connections, while the square nodes are branching capable. The number inside a node denotes the maximum branching capability of a node. For simplicity, we assume that $b_r = 1$ and the bandwidth of all the links is equal to 16. The multicasting requests are randomly generated based on weights assigned in different scenarios and their conditions. All the requests are assumed to arrive under a Poisson process and to hold with an exponential distribution. We define a dynamic multicasting performance metric member rejection rate (MRR), which is the total number of rejected members divided by the total number of request members.

Figure 3 is the MRR under different loads. NNBF provides much better performance than NNFP when the load is light. This can be attributed to the fact that the *overlapped tree* is more efficient and flexible than Steiner tree when branching capability is insufficient. The performance of NNBF is similar to that of NNFP as the load increases to 120 erlang. To explain such a phenomenon, we also plot the rejection rate caused by insufficient branching capability (RCBI) in NNBF with dash line in Fig. 3. It is shown that RCBI does not change much with different loads. When the load increases, insufficient link bandwidth becomes the main factor causing rejection in both two algorithms.

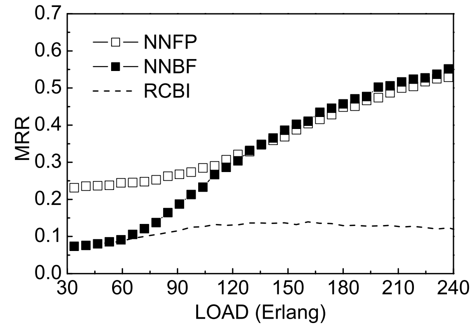

Fig. 3 Member rejection rate vs. network load.

4. Conclusions

Dynamic multicasting in GMPLS networks with unequal branching capability was studied. The proposed multicasting tree with overlay structure shows more efficient and flexible performance than Steiner tree in the networks. A nearest node branch first heuristic is proposed to find optimal *overlapped tree*.

Acknowledgements

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