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Stateless overlay multicast with in-packet bloom filters

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Abstract

Due to the difficulty of deploying Internet protocol (IP) multicast on the Internet on a large scale, overlay multicast has been considered as a promising alternative to develop the multicast communication in recent years. However, the existing overlay multicast solutions suffer from high costs to maintain the state information of nodes in the multicast forwarding tree. A stateless overlay multicast scheme is proposed, in which the multicast routing information is encoded by a bloom filter (BF) and encapsulated into the packet header without any need for maintaining the multicast forwarding tree. Our scheme leverages the node heterogeneity and proximity information in the physical topology and hierarchically constructs the transit-stub overlay topology by assigning geometric coordinates to all overlay nodes. More importantly, the scheme uses BF technology to identify the nodes and links of the multicast forwarding tree, which improves the forwarding efficiency and decreases the false-positive forwarding loop. The analytical and simulation results show that the proposal can achieve high forwarding efficiency and good scalability.

Keywords overlay multicast, BF, Internet node coordinate, network awareness

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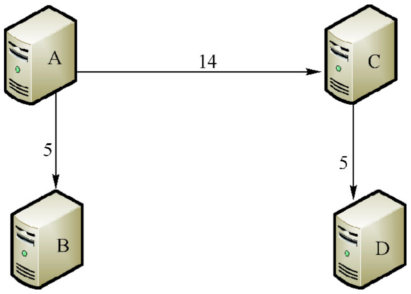
1 Introduction

With the increasing of group-oriented media streaming applications, such as video-on-demand, audio/video conference and on-line games, one-to-many or many-to-many multicast communication has attracted many attentions of researchers. However, limitations in the practical deployment have prevented IP multicast from becoming available on a global Internet level. Thus, overlay multicast has been considered as a promisingly efficient solution for ubiquitous multicast communication to overcome the IP multicast deployment hurdles [1–2].

Overlay multicast is implemented on the application layer by constructing an overlay topology on top of the underlying physical network. Overlay multicast consists of two key aspects: the overlay structure and the multicasting algorithm deployed on the structure. Participating nodes in overlay multicast are organized into an overlay topology (e.g., a tree or mesh) for data delivery. Each edge in this topology corresponds to a unicast path between two nodes in the underlying Internet. For the example in Fig. 1, an overlay multicast forwarding tree is built on the application layer, as shown in Fig. 1(a), while the multicast data is transmitted essentially in unicast mode, as shown in Fig. 1(b). Once the overlay topology is constructed, the data from the source node is delivered to all multicast recipients using the implemented multicasting algorithm. Note that all multicast-related functionality is implemented at the end-hosts in overlay multicast instead of at the routers in IP multicast.



(a) Multicast forwarding tree in overlay layer

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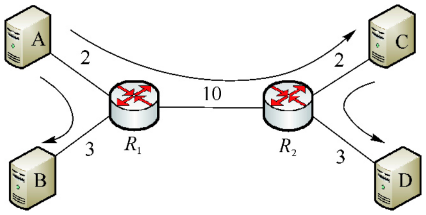

(b) Forwarding data in physical network

Fig. 1 Overlay multicast

In recent years, researches about overlay multicast have obtained many achievements [3–5]. However, due to the bandwidth limitation of end-nodes, these existing algorithms often suffer from high cost of maintaining the multicast forwarding tree, i.e., maintaining the node forwarding state in the process of forwarding multicast packets. To address this challenge, we present a stateless overlay multicast scheme by introducing the in-packet bloom filters (iBF). In our proposal, the information of nodes and interfaces that participate in the multicast forwarding is identified and encoded into two different BFs, and then encapsulated into a compact packet header. Our proposal moves the state information of nodes and interfaces to the packet header, which can alleviate the multicast system bottleneck (e.g. high maintenance cost) [6]. In the process of forwarding the multicast data, to decrease the false positive rate, a two-stage decomposition method is applied, including the node decomposition method and the interface decomposition. Moreover, the usage of fixed-size identifiers in the iBF enables line-speed execution of the forwarding operation, which can decrease the transmission delay.

In this paper, we also take node proximity information into consideration to construct the network-aware overlay multicast topology. Compared with IP multicast, the common limitation of overlay multicast is its long end-to-end delay. This is because nodes in overlay multicasts have little or no knowledge about the underlying network topology, which can cause a performance penalty in terms of longer end-to-end latency and lower efficiency. To alleviate this deficiency, we first assign a geometric coordinate to each overlay node according to the proximity relationship between nodes in the physical network, and then construct the overlay topology based on the geometric distance between overlay nodes.

In addition, the frequent join and departure of nodes in overlay networks can increase the topology maintenance costs. To improve the reliability of the overlay multicast topology, we construct the overlay topology hierarchically based on the heterogeneity of nodes. We select the powerful and relative stable nodes as transitpeers and construct the transitpeers layer using the Yao-Graph method [7]. It has been proved that Yao-Graph can exhibit the Euclidean minimum spanning tree; thus the transitpeers layer can provide a low delay and high bandwidth backbone infrastructure for multicast communication.

The rest of the paper is organized as follows. In Sect.2, we introduce the related work. Sect. 3 presents the method of constructing a network-aware overlay topology. Our proposed overlay multicast algorithm with the iBF is described in Sect. 4. In Sect.5, we present the simulation results and analyze the performance of our algorithm. Finally, the paper is concluded in Sect. 6.

2 Related work

From the network designers' perspective, overlay multicast can be classified into single-source multicast and multiple-source multicast. The single-source multicast uses the tree-based topology, whereas the multiple-source multicast applies the mesh-based topology [1–2]. The main advantage of tree-based approaches is its high resource efficiency. Unfortunately, tree-based approaches may cause some single points of failure. Mesh-based approaches provide the reliability guarantee, but they suffer from unnecessary redundancy in the dissemination process.

There has been a great amount of work in the area of overlay multicast. For example, Scribe [5] is a tree-based multicast algorithm, which builds the tree on top of the structured overlay named Pastry [8]. Layered degree-constrained overlay multicast (LDCOM) [9] builds the single-source multicast tree based on an unstructured overlay for live streaming applications. Min-sum delay overlay multicast/min-max delay overlay multicast (MSDOM/MMDOM) [10–11] constructs the mesh overlay multicast with delay minimization. FaReCast [12] designs a forest-based multiple parents-to-multiple children (M2M) overlay multicast to enhance reliability. However, these algorithms ignore the proximity relationship between nodes and suffer from the high cost of maintaining the overlay multicast tree. Although FPCast [13] builds a proximity-aware multi-source overlay multicast based on Chord [14] structure, it ignores the cost of maintaining the node states. Different from all the above-mentioned