Scalable Multicasting over Application-Oriented Networks

1. Introduction

This research develops an efficient and scalable multicast scheme over application-oriented networks, where the networking routers incorporate application-layer intelligence. The traditional IP multicast, a pure network-layer solution, is bandwidth efficient in data delivery but not scalable in managing the multicast tree. The more recent overlay multicast establishes the data-dissemination structure at the application layer; however, it induces redundant traffic at the network layer. We propose an application-oriented multicast (AOM) protocol, which exploits the application-network cross-layer design. With AOM, each packet carries explicit destinations information, instead of an implicit group address, to facilitate the multicast data delivery; each router leverages the unicast IP routing table to determine necessary multicast copies and next-hop interfaces. In our design, all the multicast membership and addressing information traversing the network is encoded with bloom filters for low storage and bandwidth overhead. We theoretically prove that the AOM service model is loop-free and incurs no redundant traffic. The false positive performance of the bloom filter implementation is also analyzed. Moreover, we show that the AOM protocol is a generic design, applicable for both intra-domain and inter-domain scenarios with either symmetric or asymmetric routing.

2. Research Description

Background - Provisioning high-quality multimedia services (e.g., on-line multiplayer games, IPTV, and video conferencing) to a large number of subscribers, possibly located in a vast geographic area, requires a scalable and efficient multicast scheme to disseminate the shared data to a group of destinations. In this paper, we propose a protocol-independent multicast scheme based on an application-network cross-layer design, which is scalable in routing, forwarding and address allocating.

The traditional multicast solutions are implemented at the network layer, where the IP routers need to communicate with each other to construct and maintain a tree structure according to a distributed multicast routing algorithm. Although various multicast protocols, e.g., dense mode protocols, sparse mode protocols, and inter-domain protocols have been proposed to reduce the messaging overhead and the amount of states at routers for enabling a single group, the messaging overhead and the memory cost grow linearly with the number of multicast groups being supported by the router, leading to the scalability issue. The unscalable implementation hinders IP multicast to be an efficient transport scheme for delivering multimedia applications over the Internet, where a huge number of groups need to be supported. The
emergence of overlay networks provides another alternative multicasting approach, where trees or other delivery structures are constructed at the application layer. Each link in the overlay network is an end-to-end logic connection between two end hosts. Overlay multicast is increasingly popular as the underlying unicast infrastructure needs no modification. Nevertheless, overlay multicast performs much less efficient than IP multicast in bandwidth utilization, as it is not a rare case that separate overlay links pass through common physical links in the underlying transport network.

**Application-Oriented Multicast (AOM)** - The long-lasting issue that neither the network-layer nor the application-layer approach itself can achieve a generic scalable multicast solution reveals that multicasting by nature incurs an application-network cross-layer design problem. Specifically, identifying the users associated with a multicast group requires application-layer membership management, while delivering data to the proper destinations needs network-layer support according to the application-layer membership information.

In this research, we interpret the application-network cross-layer design as incorporating application intelligence into the network. The network with the enhanced application intelligence is termed as the application-oriented network, based on which we propose an application-oriented multicast (AOM) protocol. The basic idea of AOM is to make the packet carry the explicit destination addresses in its header, so that the routers (with application intelligence) can retrieve the addresses and leverage the unicast IP routing table to determine necessary multicast copies and the corresponding forwarding interface for each copy, without establishing and maintaining any separate multicast tree. However, the fundamental issue is that we must limit the bandwidth overhead for such explicit addressing; it is impractical to attach all the destination addresses to each packet. In this research, we develop a bloom filter based design to make the AOM practical. We further prove theoretically that the AOM service model is loop-free and incurs no redundant traffic. The false positive performance of the bloom filter implementation is also analyzed. Moreover, the AOM protocol is a generic design, applicable for both intra-domain and inter-domain scenarios with either symmetric or asymmetric routing.

AOM readily supports a flexible and scalable group ID allocation in the form of a two-tuple (source node address, source-specific channel ID), which breaks the address space limitation of IPv4 and brings significant management flexibility. It even allows a logical local channel ID rather than an IP-address based channel ID. Furthermore, the AOM decouples the membership management component from the multicast forwarding component. Group IDs are only used for labeling groups at the service provider (SP) and receivers to establish the service relationship. In case that a SP updates its channel list or wants to upgrade the services of existing channels, it just sends related service information to each receiver over the established data delivery tree. As long as the receivers tune to the new channel list, service starts immediately. In other words, the service upgrading or rearrangement could be implemented seamlessly, where the established multicast infrastructure does not need any extra operation. This unique property of AOM is especially suitable for multimedia applications such as IPTV over the Internet.
3. Contribution

Our research has the following technical contribution:

(1) AOM does not need the group based tree construction, which eliminates the cause of the scalability issue in IP multicast.

(2) We enable AOM to accommodate the longest-prefix matching and route aggregation in the practical Internet, which is achieved by maintaining group-independent forwarding states at related routers.

(3) We propose to apply the Border Gateway Protocol (BGP) routing information in the reverse path forwarding (RPF) scheme to address the asymmetric inter-domain routing issue, which avoids the cost of deploying/configuring the Multiprotocol Extensions to BGP-4 (MBGP).

(4) We develop a fast group joining scheme for AOM by leveraging the forwarding states installed at the AOM-aware router.

(5) We analyzes the effect of the forwarding loop caused by the bloom-filter false positive on the network performance, and theoretically proves that the AOM can automatically eliminate the forwarding loop caused by the false positive forwarding incurred by the bloom filter.

(6) We could deploy AOM in a backward compatible manner over a network, in which AOM works with even only a small fraction of routers have AOM-aware intelligence while others are legacy routers.

(7) We develop a generic simulation platform to facilitate the application-network cross-layer design research, which can be embedded into a widely accepted networking simulator. We have implemented AOM and FRM (a recently proposed multicast protocol) based on the platform.

We have summarized the above contribution in several papers:


1. The submitted papers focus on different properties of the proposed multicast protocol; therefore the protocol may be differently termed in titles of those papers.