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An Integrated Two-Tier Multicast-Agent Architecture for All-IP Multicast Transport Services

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***Abstract*- Current group communication applications need to overcome inter-domain and heterogeneous multicast transport challenges. All-IP multicast over Internet is proposed to achieve the efficiency and transparency on IP multicast packet delivery not only for native IP multicast domains, but also for non-IP multicast supported domains. To guarantee the efficient IP multicast packet delivery over heterogeneous networks, therefore application level multicast (ALM) and overlay multicast (OM) were introduced for the connectivity of inter-domain coordination and local heterogeneous access. In this paper, we propose two-tier multicast agent (MA) mechanism to integrate ALM with overlay tunnel connections to inter-domain multicast and network level connections to local heterogeneous multicast access. In our experimental results, the proposed MA mechanism can achieve all-IP multicast transport services with multicast packet transmission over inter-domain and heterogeneous local wired/wireless access networks.**

***Keywords*-** All-IP multicast, inter-domain multicast, heterogeneous multicast, multicast agent.

I. INTRODUCTION

With the advance of multimedia streaming technology, the group communication based applications are increasing growth rapidly in current Internet. In additions, heterogeneous multicast services become popular trend for various end-users' devices driven by mobile and wireless requirements. To consider the transmission cost and efficiency, therefore, tremendous efforts have been made to provide inter-domain and local access domain for effective multicast transport services. Many related approaches for point-to-multipoint delivery are proposed, such as IP multicast, application level multicast (ALM), overlay multicast (OM) and automatic IP multicast without explicit tunnels (AMT) [1-3]. Nevertheless, IP multicast is considered as an efficient packet delivery method without duplicating large amount of unicast packets through tree based multicast connections.

IP multicast tree is constructed by IP multicast routing protocol via multicast-capable routers to replicate and forward multicast packets. By using multicast tree delivery structure in single-domain, IP multicast can achieve network efficiency and scalability to large group size, since data packets are only replicated at branching routers and no redundant packets are delivered over each link. However, the disadvantage of inter-domain IP multicast protocol is still complicated to deploy globally over Internet. Therefore, we focus on IP multicast packet delivery in coordination of inter-domain and local access domain.

To resolve the deployment issues of IP multicast, application layer multicast (ALM) and overlay multicast (OM) have been proposed as alternative solutions to realize multicast over Internet. In both approaches, a virtual network is formed by specific nodes, which are to construct multicast delivery tree on top of this virtual network. The multicast data packets are only replicated at these participating nodes, and delivered through tunnel by unicast connection. The main differences among above three multicast architectures, namely, IP multicast, ALM and OM, depend on whether the group management and data delivery control are implemented in network routers, end hosts, or intermediate overlay proxy nodes.

The advantage of application-level multicast (ALM) approach is scalable for multicast-related features to implement at end hosts. Data packets are replicated and transmitted between end hosts via unicast. The ALM does not require multicast-capable routers support, therefore, can be applied for inter-domain multicast connectivity. However, the lack of knowledge about underlying network topology usually results in performance penalty compared with IP multicast, such as low efficiency in group management and heavy control overhead for tree maintenance that caused by unpredictable random behavior at end hosts [4] From the point of node stablility, ALM cannot be suitable to support all-IP multicast transport services.

Overlay multicast (OM) has been investigated with low deployment cost by combining the merits of IP multicast and ALM. In overlay multicast, unicast tunnel is used for inter-domain multicast transport. Based on multicast proxy function, the delegation of overlay nodes in multicast domains can construct a flexible and reliable transport tree as backbone for inter-domain connectivity. Recently, the universal multicast [5], and island multicast [6] are proposed to perform overlay multicast. Besides the backbone overlay connectivity, the proxies need to deliver data packets to end hosts via IP multicast or ALM in local network. Because the overlay multicast tree do not completely match with groups, heterogeneous group members cannot well identified by proxy overlay node to deliver multicast packet. As the disadvantage of heterogeneity, OM cannot perform well for all-IP multicast transport service.

To realize the all-IP multicast transport service, we propose an integrated two-tier multicast network architecture with cross-layer design for multicast agent (MA) installing in each domain to couple the inter-domain overlay multicast forwarding and

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heterogeneous local multicast transmission for wired / wireless access networks.

The rest of this paper is organized as follows. In Section II, we introduce the all-IP multicast transport service model. Section III exploits the overlay inter-domain connection by type-1 MA approach. Section IV presents the heterogeneous multicast transmission by type-2 MA approach. In section V, the functionality of MA system implementation are evaluated and discussed. Finally, we make conclusion in section VI.

II. ALL-IP MULTICAST TRANSPORT SERVICE MODEL

The all-IP multicast concept is introduced by transparent connectivity to support both native IP multicast domains and non-IP multicast-capable domains over Internet. To address the challenge of all-IP multicast transport service, the multicast transparent connectivity between backbone domain and heterogeneous access domains needs to be tightly coupled. Therefore, we propose a two-tier hierarchical multicast transport network architecture. The one upper-tier multicast transport is used for inter-domain multicast IP packet transparent delivery via overlay tunnel transportation. And, the other lower-tier multicast transport is provided for local-domain multicast transmission via encapsulated unicast layer2_MAC overhead for wireless IP multicast over heterogeneous multicast access networks. In additions, all-IP multicast transport properties are satisfied by following two conditions: 1) The native IP multicast packet delivery is followed by tree based transmission only once along each link; 2) The overlay multicast packet delivery is transmitted through point-to-point tunnel connection, but not required by multicast-capable router in-between.

We will explain the *all-IP multicasting by two-tier multicast integrated service* model as illustrated by the example of Fig. 1. The two-tier multicast transport network consists of one multicast backbone overlay network and three interconnected heterogeneous access domains which is supported by IP multicast routers (MR) and non-IP multicast capable router (AR). We describe the multicast relationship of media server (MS) and those group members (i.e., end host labeled as H1 through H6) distributed over three different access network domains. In all-IP multicasting service model, the properties of those components are functioned as followings. First, those end hosts (labeled as H1 through H6) are wired or wireless receiver nodes distributed in three local multicast domains to access streaming service form media server (MS) which is located in domain 1. Second, super hosts, labeled as SH1, SH2, and SH3 are powerful processing nodes to perform as multicast proxy or media cache in each network domain. Third, multicast agents MA1, MA2, and MA3 are the best equipped nodes installed within super hosts to perform as multicast designated node to transmit IP multicast packet and connect two access network domains via unicast tunnel throughout overlay multicasting network. Note that, the physical network routers (labeled as MR, AR, and BR) within each domain may not fully support IP related multicast protocols; and the group-member information is managed by multicast agent and local multicast designated router for local multicast delivery. That is, the global group information for inter-domain multicasting

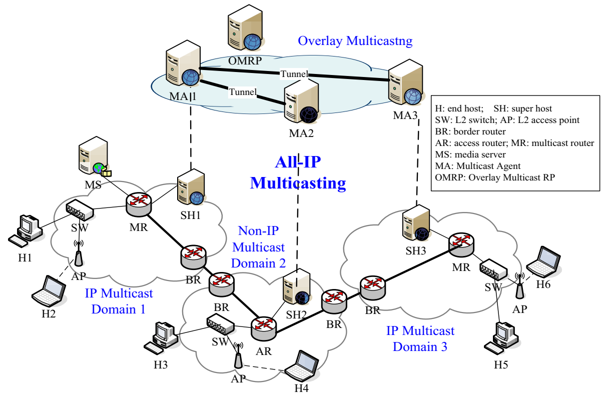


Fig.1 The example for all-IP multicast transport service

cannot be shared by the adjacent overlay nodes MA1, MA2, and MA3.

The cross-layer functionality of two-tier MA is featured by two types of multicast network service entity. The upper tier of service entity is defined as *type-1 MA*, which provides scalable and efficient inter-domain multicast for large scale multicast groups disseminating over backbone network. And, the lower tier of service entity is defined as *type-2 MA*, which can support local group member management and heterogeneous multicast transmission for various multicast access services. The multiple roles of MA can be regarded as proxy node executing the multicast packet delivery task by type-1 MA for inter-domain multicast via overlay tunnel tunnel, and type-2 MA for local heterogeneous multicast via hybrid packet overhead encapsulation with layer3 IP multicast and layer2 unicast header.

In following sections, we will introduce two types of multicast hierarchical architecture by multicast agent (MA) for inter-domain and local multicast transport services.

III. TYPE-1 MULTICAST AGENT APPROACH

The type-1 multicast agent considered as proxy node in backbone network utilizes overlay multicast connectivity approach for inter-domain multicast packet relay. In this section, we design the overlay multicast join heuristic algorithm for MA nodes to construct overlay delivery tree.

A. *Overlay Control and Data Group*

In order to setup inter-domain connections, type-1 MA is installed in each network domain as a unique leader. The overlay multicast tree is constructed on top of leaders around all network domains. Given a pair of neighboring network domains, MA is designated as relay-node in each domain and two MA nodes form a pair of relay-nodes. The connection link between two MA nodes is used to transfer multicast data packet across network domains. For efficiency in inter-domain packet delivery, the function of type-1 MA utilizes two address structures to support each DATA group for multicast overlay network and one CONTROL group for overlay tree construction. When MA joins both groups, the events of overlay tree setup and inter-domain multicast packet forwarding are activated by the current node state and role as described in next subsection.

The source node delivers multicast packets to its DATA group. Then, type-1 MA relays packets along its inter-domain connection to next MA entity in downstream network domain. And, type-2 MA will start to forward multicast packets to end hosts, only if there are members joining to DATA group in its local multicast domain. Note that each MA may update their states and roles which are operated by control message dissemination in control group. Thus, the MA is a permanent super-node with reliable service entity to work as a multicast overlay node. At the same time, MA also performs local cross-layer multicast forwarder for multicast packet transmission. The leader node MA in each network domain, need to periodically broadcast control messages (e.g., Hello or keep-alive message) to update the overlay node state, group membership and link state within the CONTROL group for overlay tree maintenance.

B. *Overlay Tree and Node Joining Algorithm*

To efficiently set up inter-domain connections, we need to develop a fast joining overlay multicast tree mechanism for MA, based on the joining heuristic algorithm as shown in Fig.2. For selection to the nearest overlay node, RTT (round-trip time) measurement between overlay links (i.e., each pair of relay-nodes) is detected by MA. In initial phase, a *new-member-node* MA is trying to join one overlay multicast tree. Initially, the specific address of OMRP (overlay multicast rendezvous point) is queried to obtain the *root-node* address as bootstrapping the joining process. In phase 2, the status of the *root-node* is determined, and the root node has been considered as a *potential-parent-node*. Then, the available degree of its *child-node* number will be checked to decide whether to accept the joining *new-member-node*. Otherwise, the joining new member MA node will repeat above step to visit next potential parent nodes. In phase 3, upon receiving the children-list as requested, new joining MA node will send ICMP (Internet Control Message Protocol) packets to ping the children nodes in the list to compare RTT values between each overlay links. After the comparison with the measurement results of RTT, the potential parent node with smaller RTT value will be accepted and become the parent node as joining success in phase 4.

C. *Overlay Tree Construction*

The Fig 3 is illustrated by example that the overlay tree is constructed as one new member node MA joining from any network domain using above heuristic algorithm (see Fig. 2). The MA proceeds fast joining mechanism as below. It first discovers the root MA of the group by querying the OMRP. A new member MA (192.168.200.1) who knows root address (192.168.100.1) indicate root as a potential parent, and send child-list request (CLR) to root. If root node MA receives CLR, it investigates whether there is available degree. And if there is no available degree, the root node delivers its child-list (192.168.103.1 and 192.168.104.1) to new member MA. Then, new member MA sends ping to all child nodes of the list it receives. The nearest node indicates a potential parent with smallest RTT value among the nodes. And, the new member sends CLR to the nearest MA (e.g., 192.168.103.1). Repeat above process. If the nearest overlay node MA that receives CLR has available degree, the node sends Join-accept to new member, and then set itself from potential parent to parent. Therefore, new member MA (192.168.200.1) joins as the child node of MA node (192.168.103.1).

Algorithm: Overlay MA node joining heuristic

```
// Overlay Node States: New_Member- initial node; Root- first join
   success node; Join- trying to join; Connect- join success node
// Overlay Node Role: Server- potential_parent
   & parent; Client-children
//(State, Role) action-list
//(New_Member, *): Query OMRP for Root IPAddress
//(Root, Server): Root wait for join request
//(Join, Client): New_Member join request
//(Connect, Server): Potential_parent wait for join request
Initial node state New_Member try to join overlay tree T {
//1. Initial joining phase
 (New_Member , *) Send Query to OMRP; // To get Root_IPAddress
If (OMRP responses) {
     If (Root_IPAddress = Null)
 // 2. Root determining phase
          Set action-list State = Root & Role = Server;
      Else  Set action-list State = Join & role = Client;  }
       While-do (CLR receiving) {    // Receive child-list request CLR
        If (Child_Num Degree == 2)  //Default children number = 2
 // 3. Potential parent selection phase
          Send CLR (all_Children_IPAddress);
          Send Ping (CLR (all_Children_IPAddress));
          Nearest_Node=Small_RTT (CLR(all_Children_IPAddress));
           Set Potential_parent = Nearest_Node;
        Else Return join_accept request;
 // 4. Joining success phase
           Update child-list;
           Set action-list State = Connect & Role = Server;
           Set Potential_parent = Parent; }
```

Fig.2 Overlay MA node joining heuristic algorithm

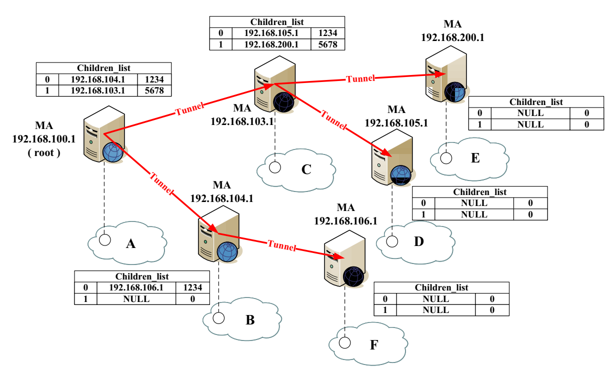


Fig.3 Overlay tree setup by type-1 MA

IV. TYPE-2 MULTICAST AGENT APPROACH

The type-2 multicast agent acting as local multicast proxy node provides heterogeneous multicast access from group members. In this section, we introduce the group management and multicast routing decision for local multicast with cross-layer multicast transmission over hybrid wired and wireless access network.

A. *Group Management for Member Joining*

Each session has a unique class-D group address for IP multicast identified by each end user. A new host first detects the existence of the multicast session by sending joining control message to type-2 MA in local network domain. While obtaining the specific session group address, end host can explicitly subscribe to a service by sending a Join_session request with this group address. After MA accepting the joining request via IGMP (Internet Group Management Protocol), the MA then replies with a Join_session_reply message which contains the session-ID for joining host. The multicast table of type-2 MA is updated by group/member membership information. We summarize the group member management process while local hosts joining to type-2 MA as shown in Fig. 4. When MA (192.168.103.1) receiving IGMP report from the joining host (192.168.103.28), MA will store the pair of group and host address (224.100.100.100→192.168.103.28) in multicast table. MA will lookup the multicast table to forward multicast packet to local IP multicast domain.

B. *Multicast Routing and Forwarding Control*

The leader node MA use type-1 MA function within its network domain to setup inter-domain connections between MAs for overlay multicast network. Firstly, leaders joining the overlay tree are to relay multicast packet from source or parent overlay node. Generally, when a multicast application starts, host first request for its session service entity and try to join multicast group in designated router or multicast agent, within its own network domain. Then, MA acts as type-2 MA function to forwards multicast data to group members within its local network domain.

In two-tier multicast routing and forwarding, the source sends multicast data packets to root node MA of overlay tree, and then MA relays and forwards multicast data to its destined domains. However, it is a problem for global multicast group to route and forward multicast packet; that is how to efficiently deliver multicast packets through matched overlay nodes MA with multicast group members joining in local network. The two-tier layer-3 address format is used for cross multicast network domains. Hence, IP-IP encapsulated packet address structure is designed by utilizing the combination of IP unicast tunnel address and IP multicast address.

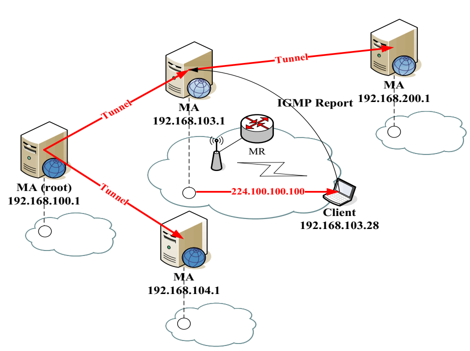


Fig.4 Local group management by type-2 MA with member joining

In Fig 5, the two-tier multicast routing and forwarding control procedure is proposed to determine tier-2 multicast address to control native IP multicast forwarding; and relay multicast packet by assigning tier-1 tunnel address for downstream overlay MA node. While receiving tunnel packets, the protocol type of IP packet is checked. Then the multicast address is extracted and matched by group address in multicast table. After completing local multicast forwarding, the original multicast data will be relayed between overlay MA nodes using type-1 MA function.

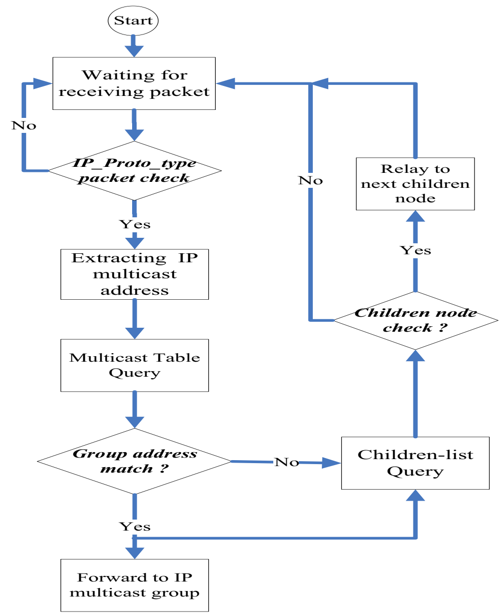


Fig.5 Two-tier multicast routing and forwarding control procedure

Based on overlay child-list query, the unicast tunnel address is assigned to outbound the data packets to next downstream overlay MA node till the leave node of MA.

C. *Cross-layer transmission for Heterogeneous Multicast*

The local multicast transmission is performed by cross-layer multicast agent for heterogeneous access users over hybrid wired / wireless network [7]. The type-2 MA uses the multi-channel MAC mechanism to separate the transmission operations between IP multicast layer and layer-2 MAC layer. By utilizing cross-layer overhead encapsulation, we select unicast MAC transmission channel for multi-rate service to increase the multicast throughput.

V. EXPERIMENTAL RESULTS

In this section, we demonstrate the implementation of MA network deployment and valid functional test results of multicast control and management, on the aspects of overlay tree joining, multicast table update in local group management, and multicast packet relaying and forwarding through inter-domain overlay tree.

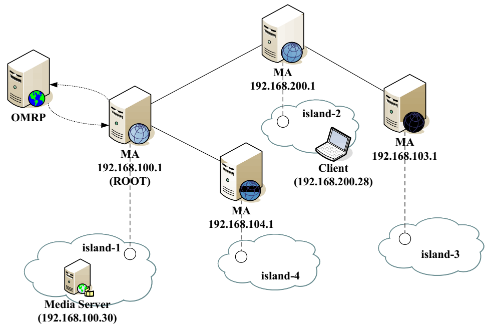
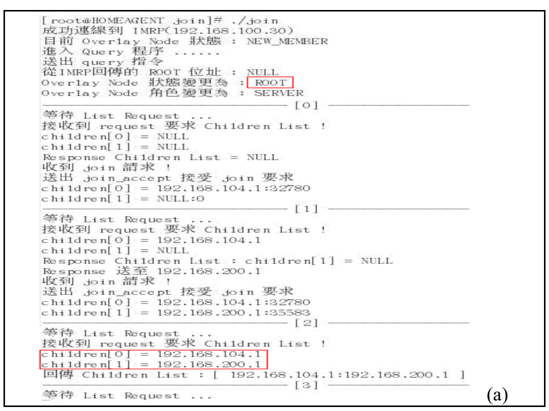


Fig.6 Integrated MA network test environment

All experiments are performed by four integrated MA nodes running Fedora Linux with core 5 version in each local domain called island, and the inter-island multicast manager, i.e., OMRP node is used to initiate overlay tree construction as shown in Fig. 6. By querying the OMRP node, the address of island-1 MA is assigned as root node of overlay multicast tree for media server and the other MAs are trying to join multicast tree as members. The degree of overlay tree is set to 2 for joining child-list.

A. *Overlay tree joining experiment*

In joining sequence, island-1 MA, island-4 MA, island-2 MA, and island-3 MA, we observe the joining process of island-1 MA and island-3 MA and verify the connection status is in success state. In Fig. 7 (a), island-1 MA is a root node to accept two child nodes joining request. And, in Fig. 7 (b), island-3 MA is a leaf node to choose island-2 MA as parent node by RTT measurement between island-2 and island-4 MA.



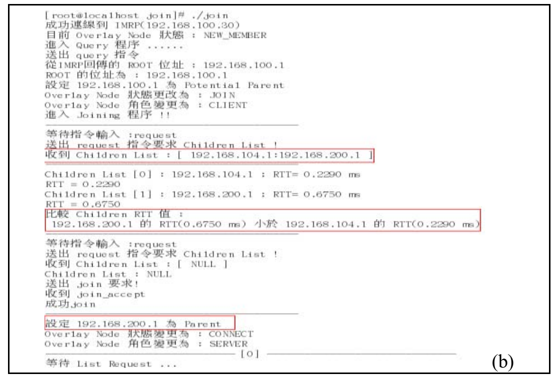


Fig.7. Overlay tree joining results: (a) island-1 MA as root node; (b) island-3 MA as leaf node

B. *Multicast table update experiment*

When group members request a multicast stream, IGMP report is sent to MA for joining the specified multicast group. Thus, MA will forward the multicast stream to subscribed member in local domain by multicast table lookup. The Fig. 8 shows the multicast table update by adding the entry of member (192.168.200.28) joining group 224.100.100.100 in island-2.

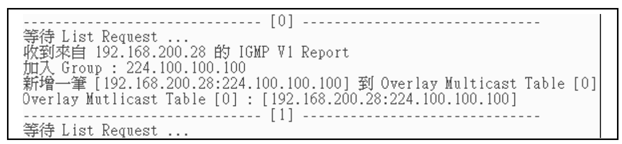


Fig. 8. Multicast table update in island-2 MA

C. *Multicast packet relay and forward experiment*

In multicast packet relay and forward experiment, the media server in island-1 starts to send multicast packet via overlay root MA throughout overlay tree (see Fig. 6). When island-2 MA receiving the multicast packets from root tunnel, the multicast address is extracted to check with multicast table for multicast packet forwarding to local group member (192.168.200.28: 224.100.100. 100). Then, MA will query the child-list to relay multicast packet to next overlay child node (192.168.103.1) via overlay tunnel as shown in Fig. 9.

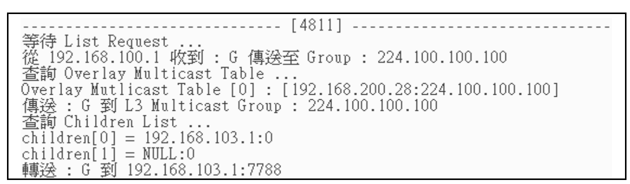


Fig. 9. Multicast packet relay and forward

VI. CONCLUSION

In this paper, we propose an integrated two-tier multicast network with cross-layer multicast agent (MA) framework to support inter-domain multicast via overlay tunnel connections and heterogeneous multicast access for various receiving end users' devices. To consider the deployed cost and efficiency, we focus on IP multicast packet delivery and coordination of inter-domain and local access domain to support all-IP multicast transparent connectivity for future multicast wired/wireless Internet. In our experimental results, the proposed MA framework can achieve all-IP multicast transmission over inter-domain connectivity and heterogeneous multicast access services

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