Multicasting in Differentiated Service Domains

Baijian Yang
Department of Computer Science and Engineering
Michigan State University
East Lansing, MI 48824

Prasant Mohapatra
Department of Computer Science
University of California at Davis
Davis, CA 95616

***Abstract*— Advances in the areas of QoS and IP multicasting have necessitated the need of integration of these two important features of Internet. Differentiated services (DiffServ) has been proposed as a scalable solution for supporting QoS in the Internet. Coexistence of multicasting and DiffServ is promising since the DiffServ model can provide a scalable framework and may reduce the computational complexity to locate a QoS-satisfied multicast tree. In this paper, we first identify the problems of provisioning multicasting in DiffServ domains. Next, we propose an efficient DiffServ-Aware Multicasting (DAM) scheme which has three novel features: weighted traffic conditioning (WTC), receiver-initiated marking (RIM) scheme, and Heterogeneous DSCP Headers encapsulation (HDE). The proposed technique solves many problems with the integration of DiffServ and multicasting while accommodating heterogeneous QoS requirements. The framework is scalable, flexible, and feasible. Performance evaluation through analyses and simulations demonstrate conformance of the QoS requirements and the potential benefits of DAM.**

I. Introduction

The next generation Internet needs the support of two important aspects in addition to all the features of the current generation Internet. These aspects are: additional capacity and the support for Quality of Service (QoS). Capacity of the current generation Internet is likely to get outgrown by the bandwidth-consuming network traffic such as transmission of continuous media, interactive games, and the evolving peer-to-peer information sharing applications. The other issue is QoS support, which includes requirements of minimum bandwidth, delay, loss rate, jitter etc., which are being aggressively demanded by the evolving applications, and the transformation of Internet into a commercial infrastructure. Simply increasing the network capacity through advanced technology is not the solution of the capacity problem. Historically, the users have always managed to consume the entire system capacity soon after it was enlarged [1]. IP Multicasting techniques [2], [3], [4] are attractive solutions for this capacity shortage problem since they can reduce the bandwidth consumption by sharing network resources.

Several approaches have been proposed to provide QoS in the Internet. Among them, Differentiated Service (DiffServ) [5] model has received more attention because of its scalability and implementation simplicity. In DiffServ model, traffic entering a network are classified and conditioned at the boundaries of the network and assigned to a set of behavior aggregates. Each traffic aggregate is assigned a DiffServ Code Point (DSCP). Within the core of the network, packets are forwarded based on the per hop behaviors (PHBs) associated with the DSCP. A DiffServ domain is defined as a contiguous set of DiffServ-aware nodes with common service provisioning policy and a set of PHB groups implemented at each node. In order to support differentiated services, Service Level Agreements (SLAs) must be set up between the DiffServ domains, which specifies a negotiated service profile between two adjacent DiffServ domains. The resource allocation and management are handled by dedicated nodes, called Bandwidth Brokers (BBs), in each of the domains. Current proposal of DiffServ has two basic classes of services: Assured Forwarding (AF) and Expedited Forwarding (EF). AF assigns a higher drop probability to out-of-profile (in excess of the SLA) traffic. It is used to support services in which the customers are likely to get the negotiated SLA without any guarantees. EF exercises strict admission control and drop all out-of-profile traffic. Since EF guarantees a minimum service rate and has the highest priority, it is used to support premium services.

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IP Multicasting and QoS are closely related since most applications that are suited for multicasting normally desire QoS support. It is thus essential to design techniques to support QoS-aware multicasting in the Internet [6], [7], [8]. Two major problems need to be addressed to support DiffServ multicasting. One of them is the Neglected Reservation Sub-tree Problem (NRS-Problem) [9], and the other is associated with marking/remarking schemes. We have proposed a DiffServ-aware multicasting technique that provides solutions for both the problems. The proposed DiffServ-Aware Multicasting (DAM) framework has two main components. First, a Weighted Traffic Conditioning (WTC) table is located in every DiffServ edge router with a goal to maintain SLA integrity. The second component is the Receiver-Initiated Marking (RIM) scheme to support heterogeneous QoS requirements within a multicast group. The performance and impacts of DAM on various classes of traffic (unicast, multicast, AF, and EF) have been analyzed through simulations. In summary, DAM can support QoS-enabled multicasting in DiffServ domain without violating the SLAs of a heterogeneous and dynamically changing group.

The rest of the paper is organized as following. In Section II, DiffServ multicasting problems are discussed. DAM and its building blocks are proposed in Section III. The implementation details are summarized is illustrated in Section IV. Simulation results are presented in Section V, followed by the concluding remarks in Section VI.

II. DiffServ Multicasting Problems

A DiffServ domain consists of Edge Routers (ERs) and Core Routers (CRs). The main idea behind the DiffServ architecture is to push the complexity of traffic conditioning and policing to the ERs. The core routers just take care of forwarding packets based on their per-hop behavior (PHB), thus retaining the simplicity of implementation. Details of the DiffServ architecture are described in [12].

A. NRS Problem

In DiffServ domains, network resources are consumed based on the pre-negotiated SLA. However, in a DiffServ-aware multicasting environment, it is possible that the actual resources consumed exceed the pre-negotiated SLA. Since the multicast tree could branch at any node, the amount of outgoing traffic from a domain may exceed the incoming traffic rate to the domain and thus consume additional resources. This problem is termed as Neglected Reserved Sub-tree (NRS) problem [9], which violates the SLAs and adversely affects any existing traffic flows.

NRS problem can be solved by assigning a Lower than Best Effort (LBE) PHB to the newly branched multicast traffic [10]. In this approach, the resources and processing of existing traffic are protected while maintaining the simplicity of the DiffServ model. In order to get higher level of services, the joining node has to explicitly negotiate with the bandwidth brokers (BBs). Upon succeeding, the BBs will reconfigure the routers accordingly. However, this approach did not address how networking resource management should be done in DiffServ multicasting environment.

B. DiffServ Multicasting Marking Problems

In the DiffServ network, packets are marked as ‘In’ or ‘Out’ on the basis of the profile negotiated through the SLA. In unicast communication, the marking of the packets is usually done on the aggregate basis of bandwidth requirements. As DiffServ is uni-directional, the current marking scheme is normally sender-based, which do not consider the QoS requirements of the receivers. Such a marking would not be adequate in multicast communications. Packet marking in DiffServ multicasting environment differs from that of the unicast case in the following three aspects:

1) Receivers in a multicast group may have different QoS requirements. When multicast packets are duplicated in a router, every outgoing branch may have to be marked differently. It also implies that the marking should be based on the requirements and the capabilities of the receivers.
2) Group membership in multicast operation is dynamic. When a new host joins a multicast group, a new branch may be generated. Simply coping the DSCP code from existing branch may lead to SLA violations.

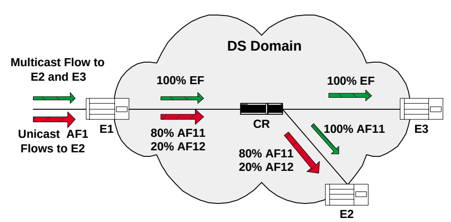

Fig. 1. Illustration of the Unfair Marking Problem.

3) When heterogeneous marking are allowed in a DiffServ domain, marking of the lower level of services to the subtrees that branch after admission control will bring unfairness between multicast flows and unicast flows. Consider the scenario in Figure 1, a multicast flow enters a DiffServ domain at ingress router E1, and is destined to E3 and E2 requesting *EF* and *AF1*, respectively. At the incoming interface of E1, assume that 80% of the *AF1* packets are in-profile and marked with lower drop probability of DSCP *AF11*, while the remaining *AF1* packets are marked with higher drop probability of DSCP *AF12*. Further assume that network congestion only happens on the link from core router CR to edge router E2. Marking the multicast packets as *AF11* DSCP at the multicast branching node CR is not fair because this new subtree originating from the core router is unaffected by the traffic conditioning that the unicast message encounters at E1. In this example, unicast *AF1* class packets traveling from E1 to E2 will be dropped more severely than that of multicast packets, since 20% of the unicast *AF1* packets are marked with a higher drop probability *AF12*, but all the *AF1* multicast packets are granted *AF11* DSCP. Thus it is unfair to the existing unicast flows if markings at the branching points are not handled properly.

In this paper, we have proposed a fair marking scheme, which accommodates heterogeneous QoS requirements of the receivers without violating the SLAs or affecting the quality of the existing flows.

III. DiffServ Aware Multicasting (DAM)

We propose a DiffServ-Aware Multicasting (DAM) technique, which is composed of three novel components: Weighted Traffic Conditioning (WTC) model, Receiver-Initiated Marking (RIM) scheme, and Heterogeneous DSCP Header Encapsulation (HDHE). In this section, we outline these components and the algorithm for DAM in detail. The WTC model aims to maintain the negotiated SLAs in DiffServ multicasting environment, and the RIM scheme is proposed primarily to accommodate heterogeneous QoS requirements of the receivers in multicast groups, while HDHE provides a mean to ensure the fairness among multicast flows and non-multicast flows.

A. Weighted Traffic Conditioning (WTC) Model

The WTC scheme can be illustrated with the example shown in Figure 2. If one multicast flow with premium service enters domain A and is replicated twice within this domain, the amount of that flow should be counted three times as many as the original amount at the boundary of the domain. Using this approach, there will not be any SLA violations since the amount of traffic counted at the ingress point of a DiffServ domain equals to the actual amount of traffic flowing out of that domain. It must also be noted here that the proposed counting approach overestimates the bandwidth requirements within each domain for each of the multicast flows. However, such overestimation helps in maintaining the SLAs.

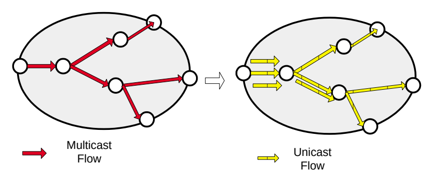

Fig. 2. Counting a multicast flow as multiple unicast flows.

The fundamental idea of WTC is to ***count*** the admitted multicast traffic as multiple unicast traffic while conditioning the traffic aggregate at the edge routers. This approach is different from some of the unicast based multicasting schemes, such as [11], where one multicast flow is replaced by multiple unicast flows and each intermediate multicast receiver acts as a proxy server by sending multiple unicast flows to its downstream receivers. In our approach, however, it is not necessary to convert a multicast flow into multiple unicast flows (although it can also be applied to the unicast based multicast techniques). The counting is done only on a logical basis. Thus, the WTC model retains the bandwidth saving feature of multicasting.

B. Receiver-Initiated Marking (RIM) Scheme

Inherently QoS-aware multicasting is a receiver-based approach. Receivers join and leave at their own will and many have heterogeneous QoS needs. In the context of DiffServ-aware multicasting, packets should be marked according to receivers’ QoS requirements. This concept is quite different from the popular DiffServ model which is unidirectional (usually sender-based) in nature. The QoS specification is made only in one direction; from the sender to the receiver. When a new receiver joins a multicast group, its QoS requirement could belong to one of the following four levels:

1) It has no QoS requirements.
2) It requests for whatever is the highest level of the available QoS at the node at which the new member joins.
3) It explicitly specifies a QoS requirement that is lower than or equal to the highest available QoS at the node at which it joins.
4) It explicitly specifies a QoS requirement that is higher than the available QoS at the node at which it joins.

Among these four types, level 1 and level 2 define relative QoS requirements, i.e., a new receiver only needs to indicate whether it has QoS requirements or not when it seeks to join a multicast group. If a receiver specifies QoS requirements explicitly, it indicates that the receiver wants absolute QoS requirements, which can be further classified as level 3 and level 4. Different levels of QoS requirements demand the packet marking scheme to appropriately handle them. To meet end-to-end QoS requirements, packet marking should be done in a consistent manner. In other words, a multicast sub-tree should be grafted at a node where its upper stream is marked at a level equal to or higher than the markings of the sub-tree.

The basic rules of this RIM scheme are described as follows, where the DSCP 'DEFAULT' can be either BE or LBE.

- *Level 1:* Mark the new branch as DEFAULT.
- *Level 2:* If the highest available QoS is DEFAULT, do the same as in the case of level 1. Otherwise signal network management entities (e.g. BB or the ingress router) for admission control. If successful, copy the 'highest' available DSCP at the joining node, otherwise, mark it as DEFAULT.
- *Level 3:* Signal network management entities for admission control. If successful, update the WTC look-up table, and mark the new branch with a DSCP that corresponds to the best available QoS, otherwise, mark it as DEFAULT.
- *Level 4:* Traverse retracing path toward the a root of the multicast tree until an on-tree node having a DSCP equal to or higher than the requested QoS requirement is found. Signal network management entities for admission control. If successful, mark the new branch with a DSCP that corresponds to the best available QoS and remark intermediate path with this new DSCP. If unsuccessful, either try selecting a new path or simply mark it as DEFAULT.

C. Heterogeneous DSCP Encapsulation (HDE)

In HDE, when a multicast flow enters a DiffServ domain and is supposed to be branched with heterogeneous QoS requirements at a core router, the markings for each of these branches are encapsulated in the packet header at the ingress router of the domain. Thus the traffic conditioning done at the edge routers will be equally applicable to all the multicast branches that will egress out of the DiffServ domains with different QoS requirements. Thus all of these branches encounter the same traffic conditioning as that of any existing unicast message. As the number of branchings within any DiffServ domain is not expected to be too high (or a limit could be imposed), the HDE scheme will not pose significant overheads in terms of the header length. Furthermore, we need to capture the markings of only the heterogeneous AF traffic. The out-of-profile EF traffic will get dropped at the ingress router.

Consider Figure 3 as an example. A multicast flow enters a DiffServ domain at edge router E1. One branch that leaves through E4 is marked as *EF*, another branch that flows out from E3 is marked as *AF1*, and the last branch exiting from E2 is marked as *AF2*. Suppose at E1, this flow is marked *AF12* for *AF1* class, and *AF21* for *AF2* class, this information is inserted in the packet. When this packet is duplicated at the branching node CR, the DSCP stored in CR indicates the class of service, and the actual DSCP code should be either copied or calculated from the the information stored in the header. In our example, the branch from CR to E3 belongs to class *AF1*, and ingress *AF1* marking for this packet is *AF12*, thus this branch will be marked as *AF12*. For the same reason, the branch from CR to E2 will be marked as *AF21*.

D. DiffServ Aware Multicasting (DAM) technique

The primary goal of this technique is to quantify the amount of each multicast traffic flow at its ingress node and have the packets appropriately marked. It is clear that the WTC scheme demands

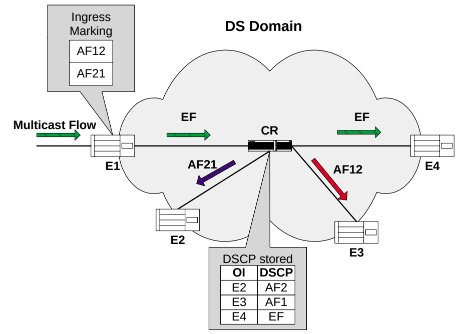

Fig. 3. Heterogeneous DSCP Encapsulation (OI: Outgoing Interface).

edge routers to maintain and update flow-specific information. The proposed protocol, by taking receivers' QoS requirements into account, can reduce the load of updating WTC look-up table.

In DAM, receivers' QoS requirements will be piggybacked on the multicast JOIN packet. If a receiver requests no QoS requirements or the network fails to allocate the requested resources, the new branch will be marked as DEFAULT. In such cases, there is no need to update the WTC look-up table. The weighted multicast flow traffic conditioning is needed only when the new branch needs to be marked higher than the DEFAULT. So for the rest of this section, we only consider QoS requirements at levels 2, 3 and 4 (as defined earlier in Section III-B).

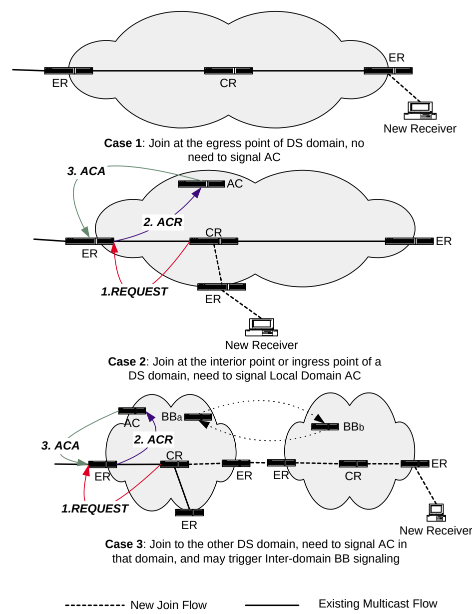

Fig. 4. Three cases of joining multicast tree in a DiffServ domain.

When a receiver wants to join a multicast group, the existing multicast delivery tree may or may not exist in its DiffServ domain. There may be three possible cases that need to be considered, as shown in the Figure 4. The 'join router' in the discussion refers to the nearest on-tree node whose highest DSCP is either higher than or equal to the receivers' QoS requirements.

- **Case 1**: Join at the egress node of the DiffServ domain. In this scenario, the first hop of the receiver, which is also the egress point of the DiffServ domain, is already in the multicast delivery tree. Without further ado, the new receiver can join directly. The extra traffic generated on the output link by the multicast replication will not affect other hosts, subnets or domains. Therefore, it is the responsibility of Subnet Bandwidth Manager (SBM) or hosts to ensure that their QoS requirements do not exceed what they subscribed to in conformance with the SLA. Therefore, the Admission

Controller (AC) will not be signaled and the multicast flow weight will not be updated.

- **Case 2**: Join at the ingress or interior node of the same DiffServ domain. When the edge routers get a 'JOIN' message and find out that it is not in the multicast delivery tree, it will then forward this JOIN request back toward a root of the multicast tree. When it finally reaches a join point, which could be either an ingress node or an interior node of the same DiffServ domain, multicast flow weight may need to be updated at the WTC look-up table. The procedures that should be followed can be enumerated as:

1) Mark the new branch as DEFAULT. If the branching router is a core router, it sends a REQUEST message to the upstream ER in its domain.
2) ER sends an Admission Control Request (ACR) to the BB similar to the case when a unicast flow wants to send packets to this DiffServ domain.
3) Upon receiving ACR, the AC validate the request based on the SLA and resource availability. AC will send Admission Control Answer (ACA) message to the requesting ER. The ACR message will be positive if it is successful, otherwise it will be negative.
4) If the response from the AC is positive, the ER marks this new branch with the DSCP that corresponds to the best available QoS and sends an UPDATE message to the downstream routers in the path from this edge router down to the new receiver. All the inter-domain ingress routers on this path should also update their WTC look-up table.

- **Case 3**: Join at another DiffServ Domain. In this case, the JOIN message will be forwarded to other DiffServ domains. Basically routers in the joining DiffServ domain will perform the same actions as described in case 2.

For the cases of 'LEAVE' or 'PRUNE', the same approach is adopted with minor differences, such as, decreasing the counter or removing the entry rather than increasing or generating the corresponding elements.

IV. Implementation Issues

In this section, we describe the implementation details of the proposed DAM technique.

A. WTC

In order to perform weighted traffic conditioning, ERs should maintain a look-up table and they should be informed of the number of replications of each multicast flow. The look-up table would contain the following fields: multicast group ID, DSCP, and the number of replications.

The architecture of traffic conditioners at the edge routers should be thus changed to facilitate weighted multicast metering as illustrated in Figure 5. When packets enter the edge router, based on their destination address, they will enter at either the unicast classifier component or the multicast classifier component. In the unicast case, the traffic conditioning structure remains unchanged. If a multicast flow *f* enters a domain, since its destination IP address is a class D address, it goes to the multicast classifier unit and then checks the look-up table for the weight. As shown in the example of Figure 6, the look-up results indicate that this flow has two DSCP codes: *D1* and *D2*, with weight, *w1* and *w2*, respectively. It means that the flow has *w1+1* branches marked as *D1* and *w2+1* branches marked as *D2* leaving this domain. Thus packets of flow *f* should be shaped and conditioned based on the look-up weight results. The other entries in the Table corresponds to AF and EF packets as indicated.

B. Marking

Figure 7 illustrates a token bucket implementation scheme of DAM marking at the edge routers. For simplicity, we assume that the DiffServ domain supports two classes of forwarding schemes, EF and AF, respectively. Further, we assume that each packet consumes only one token. To facilitate the receiver initiated marking scheme, every multicast-capable router needs to have one more DSCP field setup for the multicast flow. This extra field was also suggested in [9].

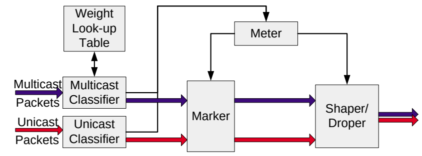

Fig. 5. Logical View of Traffic Conditioner with WTC Component.

Destination Address	DSCP	Weight
226.35.7.28	EF	1
226.35.7.28	AF1	3
226.35.7.28	AF2	2
IP of flow f	D1	w1
IP of flow f	D2	w2
...	...	...

Fig. 6. An Example of Multicast Flow Weight Look-up Table.

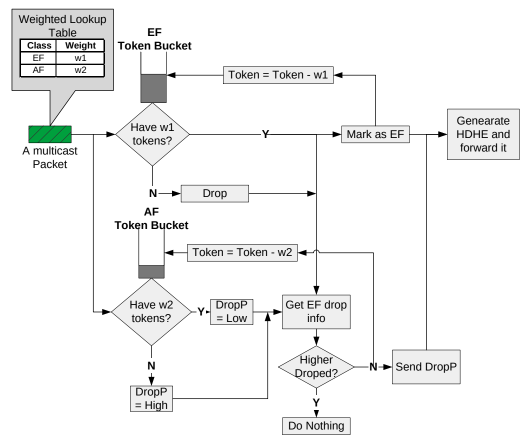

Fig. 7. Token Bucket Marking Implementation at the Edge Routers.

V. Simulations Results

We have implemented the normal DiffServ multicasting, and DAM on the NS simulator [13]. The goal of the simulation is to evaluate the above approaches by comparing the packets transmission ratio, which is defined as the ratio of the number of packets transmitted to the total number of packets. This study is focused on a single DiffServ domain. In the simulation, we assume that the multicast traffic is based on UDP. For each scenario, unicast UDP and TCP traffic are studied. The network topology of the simulation is illustrated in Figure 8. The bandwidth of each link is 10Mb. Consider that S1 is delivering multicast packets at a rate of 1Mb per second through ER1, CR and ER3 to a multicast receiver R1. Host R2 wants to join the multicast group. Existing unicast traffic flow aggregations are: ER1 to ER4 – 4Mb BE; ER3 to ER4 – 2Mb EF; and ER2 to ER4 – 6Mb AF.

If the multicast flow is EF traffic and the maximum rate of EF traffic which are allowed to enter the domain at ER1 is 2Mb, then DAM produces the same results as the normal DiffServ approach. EF traffic has the highest priority level, and no packets are dropped unless the amount of EF traffic exceeds the link capacity. Thus for the EF multicast flow, we mainly study its impact on other traffic classes, such as AF traffic and BE traffic.

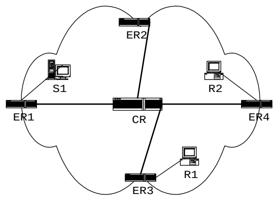

Fig. 8. Network topology of the simulation environment.

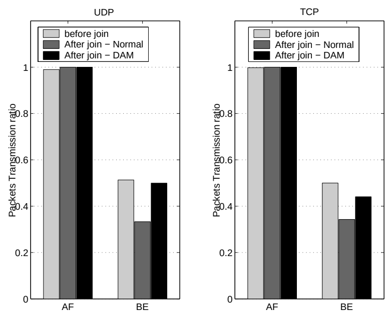

Fig. 9. EF multicast results.

Figure 9 illustrated the EF traffic simulation results. For AF class traffic in this domain, we have studied both UDP traffic and TCP traffic. Both results indicate that normal DiffServ multicasting noticeably reduces the packet transmission ratio of BE traffic, while DAM approach has little impact on the existing traffic.

If the multicast flow belongs to AF traffic and the maximum rate of AF traffic that is allowed to enter the domain at the edge router ER1 is 5Mb, then a part of the AF traffic will be marked down to BE if DAM technique is adopted.

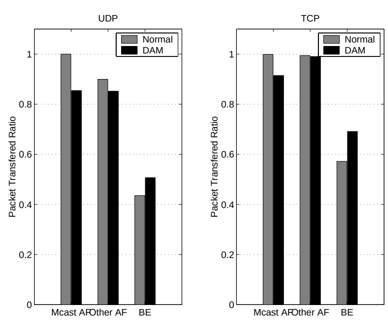

Fig. 10. AF multicast results.

The simulation results of AF multicast traffic are shown in Figure 10. When the existing AF traffic is UDP based, the normal DiffServ multicasting approach produces better results for the new AF multicast flow at the cost of severely dropping the BE traffic. While DAM forms a compromise between the new multicast traffic and the existing BE flows. The packet transmission ratio of the multicast flow is about 0.9 with DAM without any significant impact on the BE traffic. When other AF traffic belongs to TCP, the results demonstrate the same trends except that unicast TCP AF traffic remain unchanged in terms of packet transferred ratio. This behavior is due to the TCP congestion control mechanism.

Both EF and AF simulation results indicate that WTC is necessary when applying per-aggregation-based resource management schemes in DiffServ domains. SLA violation problems can be avoided in DAM without per-flow resource management approaches like RSVP.

As discussed in Section III-C, HDE approach is adopted in DAM to improve fairness. For the same network topology, we assume one EF multicast flow which originates from ER1 is remarked to AF at CR for a sub-tree through ER4. Comparisons have been made with unicast AF flows traveling through ER1 to ER4 to study the packets transfered ratio. Traffic distribution on link CR to ER4 is: 2Mb EF, 1Mb AF multicast, 6Mb unicast AF and 6Mb unicast BE. Figure 11 clearly illustrated that the multicast AF traffic presented nearly the same performance as that of unicast UDP AF traffic when HDE is used. For unicast TCP AF traffic case, around 10% of the multicast AF packets are dropped with HDE, while nearly no multicast AF packets get dropped without HDE. Packet transferred ratio is not affected for TCP AF traffic. But the average transmission rate increases about 4% with HDE. Both the results show that HDE scheme ensures fairness between AF multicast flows and AF unicast flows.

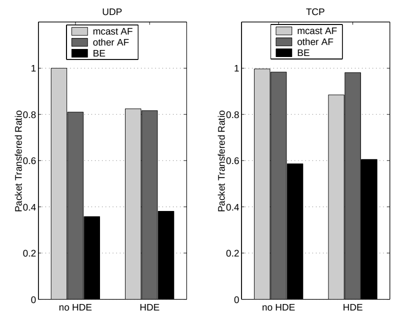

Fig. 11. AF Fairness results.

In short, DAM technique avoids the SLA violation problem and unfairness issue introduced in DiffServ multicasting environments.

VI. Conclusions

In this paper, we proposed a DiffServ-aware multicasting (DAM) technique to provide QoS in multicasting. In DAM, the NRS problem is solved by Weighted Traffic Conditioning (WTC) at the edge routers, and the heterogeneity in QoS requirements of the receivers are handled by receiver-initiated marking (RIM). Fairness is achieved with Heterogeneous DSCP Headers Encapsulation (HDHE). Through simulations, we have shown that DAM conforms to the SLAs between DiffServ domains while requiring a simple and scalable resource management scheme.

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