DIFFSERV EXTENSIONS FOR QOS PROVISIONING IN IP MOBILITY ENVIRONMENTS

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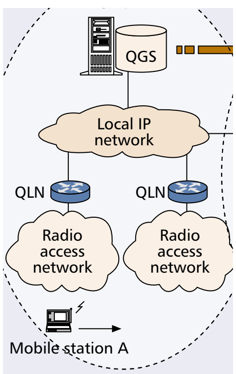

DiffServ itself lacks a simple and scalable bandwidth resource management scheme for a dynamic environment as an IP-based RAN. It is, therefore, necessary to extend DiffServ model for admission control and on-demand resource reservation under IP mobility environments.

ABSTRACT

In this article we focus on DiffServ for QoS provisioning in RANs. We first give short explanations of the DiffServ model. We then investigate the problems of DiffServ under IP mobility environments. We also present several DiffServ proposals in IP-based access networks. We finally propose a mobility-aware drop precedence scheme for flows experiencing handover events.

INTRODUCTION

A radio access network (RAN) typically provides the radio access — Global System for Mobile Communications (GSM), code-division multiple access (CDMA), or wideband CDMA (WCDMA) — to mobile stations in a cellular network. In an IP-based RAN, several wireless cells need to be interconnected at the IP level since mobility is basically a routing problem at the network layer. As a result, all network nodes in all-IP access networks need to be integrated with Mobile IP [1] or an IP micromobility protocol [2] in order to keep seamless interoperability with the wired Internet. In addition, quality of service (QoS) management should be tightly coupled with IP mobility management.

Two different Internet QoS models have been proposed by the Internet Engineering Task Force (IETF): integrated services (IntServ) and differentiated services (DiffServ) [3]. In IntServ, network nodes classify incoming packets, and network resources are explicitly identified and reserved. In DiffServ, instead of explicit reservation, traffic is differentiated into a set of classes for scalability, and network nodes provide priority-based treatment according to these classes. In this article we focus on DiffServ in order to provide consistent end-to-end QoS behavior. However, DiffServ itself lacks a simple and scalable bandwidth resource management scheme for a dynamic environment such as an IP-based RAN. It is therefore necessary to extend DiffServ for admission control and on-demand resource reservation under IP mobility environments.

We first give short explanations of the DiffServ model. We then investigate the problems of DiffServ in IP mobility environments. We also present several DiffServ proposals in IP-based access networks. We finally propose a mobility-aware drop precedence scheme for flows experiencing handover events.

DIFFERENTIATED SERVICES

Differentiated services [3] is a policy-based approach to QoS support in the Internet, where traffic entering a particular network is classified into different classes, and classes are assigned to different behavior aggregates. DiffServ uses the DiffServ code point (DSCP) field in an IP packet header, which determines the service type of the data traffic by specifying a per-hop behavior (PHB) for that packet [3]. Packets marked into the same PHB class experience similar forwarding behavior in the core nodes. PHBs are actually implemented by means of buffer management and packet scheduling mechanisms in the core nodes. For service differentiation for individual or aggregated flows, a meter measures the sending rate of a flow, and a marker sets the DSCP fields of packets in the flow at the edges of the network. A dropper discards packets of different flows according to the DSCP fields and the current load with various dropping precedence policies [4] in the core of the network.

Several PHB group approaches have been introduced, but expedited forwarding (EF) and assured forwarding (AF) PHBs are currently considered to allow delay and bandwidth differentiation. An EF flow, which has high priority and needs bandwidth and delay assurances, is based on User Datagram Protocol (UDP) traffic and is nonadaptive. EF service thus requires admission control to prevent resource starvation of lower-priority traffic classes. Meanwhile, an AF flow, which is based on TCP traffic, would be to consume a fraction of the available bandwidth. AF service also requires buffer management mechanisms to control its effect on TCP traffic under congestion.

DIFFSERV PROBLEMS IN IP MOBILITY ENVIRONMENTS

DiffServ is typically expected to provide better QoS than existing services with a set of policies and rules that are predetermined between the user and Internet service provider (ISP) through a service level agreement (SLA). In this section, however, we investigate the problems of DiffServ under IP mobility environments.

Dynamic SLS Configuration

The service level apecification (SLS) is a translation of an SLA into appropriate information necessary for provisioning and allocating QoS resources within network devices at the edges of the domain [5]. A mobile host (MH) at its home network typically depends on the SLAs that have been negotiated between its home network and its correspondent host's (CH's) networks. When an MH visits several RANs managed by different ISPs, additional SLAs are required between the MH's visited network and the CH's network. Those SLAs may be negotiated between the bandwidth brokers (BBs) of the different networks.

However, the admission control of BBs based on static SLAs is not suitable in highly dynamic mobile environments since the location and QoS requirements of users may change very frequently. Therefore, for dynamically changing wireless networks, dynamic SLA renegotiations are essential. In other words, the current QoS requests of each mobile host need to be delivered to the BB more accurately using the signaling information. Dynamic SLA negotiation requires significant QoS signaling exchanges between the MH and routers in DiffServ networks.

Meanwhile, when the routing path is changed due to mobility in the DiffServ domain, the protocol flows necessary to reestablish QoS in a new subnet may be very time consuming for Mobile IP and other mobility protocols. Therefore, in order to reestablish the specific service without having to perform the entire SLA negotiation between the MH and the CH, a QoS context such as an SLS at the MH's home network has to be transferred to the MH's visited network. The BB in the visited network then configures the network according to the MH's SLS. Typically, a mechanism to transfer the MH's QoS context to the newly visited network could guarantee faster reestablishment of the MH's current service.

Dynamic Routing for SLA Setup

Typically, the BB in a DiffServ domain should identify the path of the flow for the user's request and check whether there are enough available resources in the DiffServ routers along this path. Thus, interior routers or BBs should be able to be dynamically configured for admission control and resource scheduling in a DiffServ network. In a RAN, when transferring QoS context to the visited network, in addition to the MH's visited network or subnets, some additional routers in the path between the visited network and the CH's network might be involved. Therefore, when all the DiffServ routers on the data path of the user's request have enough available resources, the request could be accepted. In order to identify the data path satisfying a mobile user's QoS request for SLA setup, some scenarios could be considered from the QoS routing mechanisms for the fixed Internet. First, the BB might obtain the topology information of its domain by indirectly communicating with the domain's routing protocol, such as Mobile IP-enabled Open Shortest Path First (OSPF), Cellular IP, or HAWAII. Second, a BB may calculate the QoS path by investigating routing tables from all routers of the domain using the signaling protocol. The third method is to find the QoS path by using a hop-by-hop route discovery mechanism that depends on a specific routing protocol.

Transparent Flow Identification

In IP-based RANs, the first and border routers identify microflows associated with mobile users. The source or destination IP address fields in the header of IP packets, which an MH generates, might change when the MH roams between different subnets. That is, the original IP address in an IPv4 packet is changed when it is encapsulated by an IP tunneling mechanism. Moreover, the home address in an IPv6 packet is moved to its destination option header, and instead the care-of address is put into the source address field. For multifield (MF) classification, therefore, the first-hop router has to check the inner IPv4 header or IPv6 destination option header in order to identify the flow information of a mobile sender. This requires additional time or many modifications to router functions.

In IP micromobility protocols [2] such as HAWAII or Cellular IP, the home address of an MH does not change within a domain even though the MH moves to a different network domain. Instead, the home address of an MH is replaced with the gateway node's address when the packets are forwarded to Mobile IP-enabled Internet. That is, the care-of address of an MH known by a home agent (HA) becomes the gateway node's address. Typically, when an MH moves from one DiffServ first-hop router to another within the same domain, no additional SLAs are required. For MF classification based on home IP address, however, the new first-hop router to which the MH connects must be able to identify the packets sent from the MH by its home address in order to provide the same service to the MH as the previous first-hop router. In addition, the new first-hop router must consult a BB in the same domain in order to get information about the service the MH has received.

RAN Resource Provisioning

In order to provide an end-to-end QoS guarantee across a RAN, the air interface must be able to support the various kinds of traffic an MH generates. Typically, the different types of traffic with different SLSs might be mapped into wireless QoS service classes in a RAN. The AF service class is well suited for a RAN since it only gives assurances on the delivered service. The service level of this class could be degraded for dynamic resource availability in the RAN. The only difference between AF services in a fixed network and a RAN will be in the level of assurance. However, it may not be possible to allocate resources at every base station in support of an SLA that offers EF service in a RAN because radio resources in a heavily crowded area may no longer be available after a handoff. Instead, it is necessary to give a statistical guarantee on the

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SLA in a RAN has to be negotiated mainly based on the available radio resource. It is also necessary to use any mechanism to limit the usage of the radio resources, which is based on QoS service classes. This kind of mechanism might prevent network congestion or sudden degradation in network performance.

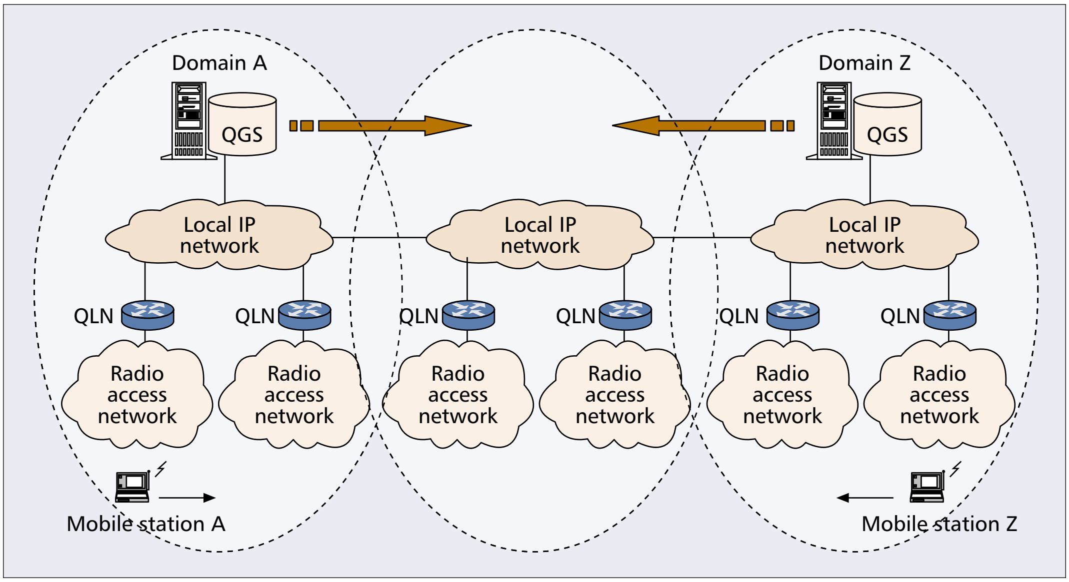


Figure 1. *QoS architecture for a wireless DiffServ-capable IP network.*

handoff success in a RAN.

During a handoff event, the resource management scheme should be very fast, and able to be invoked frequently and on demand. When a resource is reserved for AF and EF service classes at a handoff event in a RAN, typically the wireless link becomes the main bottleneck. Therefore, an SLA in a RAN has to be negotiated mainly based on the available radio resources. It is also necessary to use any mechanism to limit usage of the radio resources, which is based on QoS service classes. This kind of mechanism might prevent network congestion or sudden degradation in network performance. Moreover, priority can be given to a QoS service class, which is based on the resource availability in the cell. If an MH that uses high-priority service moves to a network in which enough resources are not available, the service of other MHs that use low-priority service in the same network may be downgraded.

DiffServ Proposals in IP Mobility Environments

It is necessary to extend the DiffServ model for admission control and on-demand resource reservation under IP mobility environments. In this section we present several DiffServ extensions under IP mobility environments. These schemes under IP mobility are the ITSUMO architecture [6], MIR/HMIP/DiffServ architecture [7], SLS transfer mechanism for Mobile IP [8], hierarchical QoS architecture, and resource management in DiffServ (RMD) framework [9–11].

ITSUMO Architecture

Chen *et al.* [6] proposed a QoS architecture for wireless DiffServ-capable IP networks. This architecture shows that the DiffServ domain can be extended into the wireless mobile network by defining a set of QoS service classes and adding DiffServ-enabling network components: the QoS global server (QGS) and QoS local node (QLN). Figure 1 shows the QoS architecture for a wireless DiffServ-capable IP network. A QGS is added in the core network to provide QoS negotiation with the MN, while a QLN is added near the RAN to act as a DS domain ingress node that shapes and conditions traffic to and from the MN. The aim of this architecture and protocols is to provide an efficient and flexible way to support QoS in the mobile environment. The architecture separates control and transport so that the QGS handles QoS signaling and the QLN deals with transporting actual traffic. The QLN provides local information to the central QGS, and the QGS retains the global information of the domain. The merit of the architecture includes flexibility, less QoS signaling messaging, integration with other protocols, ease of adjusting the reservation bandwidth, and provisioning bandwidth in each local domain.

MIR/HMIP/DiffServ Architecture

Grand *et al.* [7] proposed a Mobile IP Reservation Protocol (MIR), which is an extension of Control Load Ethernet Protocol (CLEP) [4] to mobile environments; it is intended to provide statistical QoS guarantees to mobile nodes (MNs). MIR addresses the problem of bandwidth allocation and reservation in order to provide users of a shared medium with guaranteed bandwidth. MIR is also integrated with Hierarchical Mobile IP (HMIP) and DiffServ in order to provide end-to-end QoS. In this architecture there are two assumptions: only wireless cells need to run MIR, and MIR cannot be used all along the path for scalability reasons. In HMIP, an MN roams within a domain without updating the SLAs between the CN, the HA, and the visited domain. Figure 2 shows the visited domain with a GFA, and a home network with an HA, which can be described as follows: MIR operates only on the wireless part of the network between the foreign agent (FA) and the MN. In addition, CLEP and HMIP are used within a domain, and DiffServ operates between domains. When an

MN is roaming within a domain, the GFA with which it is registered is responsible for negotiating an SLA dynamically with the neighbor domains through a BB. When an MN is roaming within a visited network, it wishes to benefit from the same service it has in its home network.

SLS Transfer Mechanism under Mobile IP

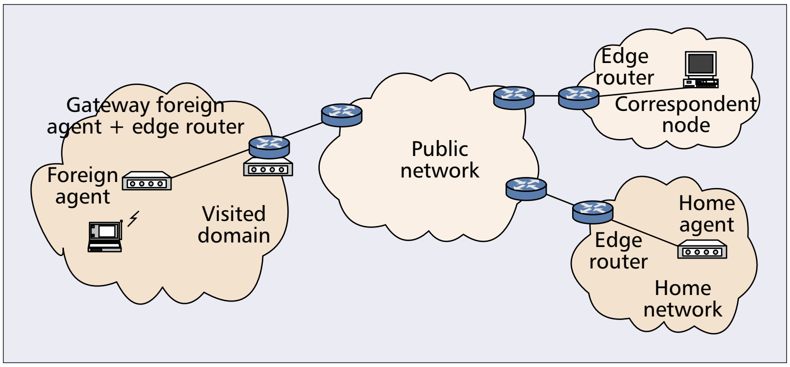
Stattenberger *et al.* [8] proposed a QoS provisioning scheme for Mobile IP users using BBs. In this scheme the SLS negotiation starts when an MN sends the desired SLS information to the BB in the home domain after registering at the HA in Mobile IP. The BB then sets up the routers in a way that best fits the current network topology according to the user's requirements. When an MN moves to a foreign domain, in order to transfer the MN's home SLS to the BB in the foreign domain, it signals the request message containing the MN's home IP address. The BB in the foreign domain then contacts the home domain's BB through the MN's home IP address to obtain the MN's SLS. The home BB then transmits the SLS to the foreign BB using the signaling message, and the foreign BB configures the routers in its network. The home BB then reconfigures the routers in the home network in order to release the resources occupied by the MN, and the foreign BB informs the MN of success or failure of the SLS transfer. Failure can be caused by errors during the configuration or unavailable bandwidth.

Hierarchical QoS Architecture

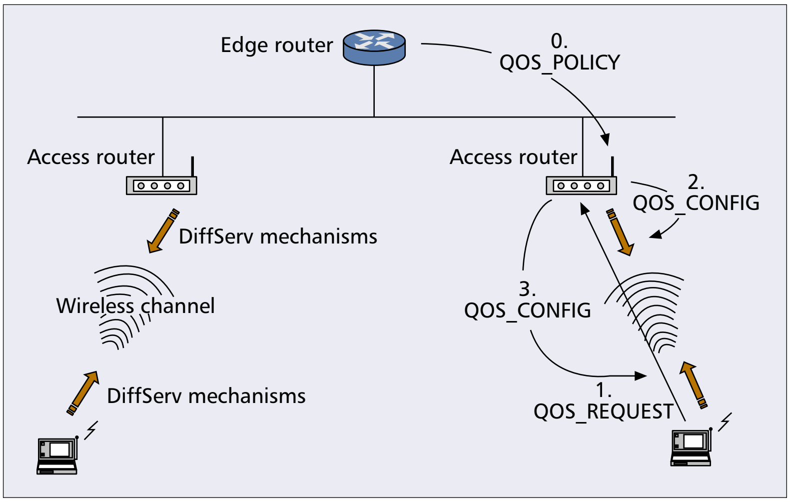
Garcia-Macias *et al.* [12] proposed a hierarchical QoS architecture for the DiffServ model on wireless LANs. In Fig. 3, each wireless cell is managed by an access route (AR) that forwards packets between MNs in a cell and connects it to an edge router (ER). This architecture has two levels of management: intracell and intercell. Intracell QoS management is local to one cell and performed by the AR that manages fast changing local situations. MNs inform the AR of the required bandwidth, and the AR in turn configures their QoS mechanisms. Intercell QoS management concerns a set of wireless cells connected to an ER. The ER acts as a long-term global QoS manager for ARs managing cells. It sets policies followed by ARs, such as admission control and resource reservation (QOS_POLICY). Bandwidth allocation follows the soft-state principle. The AR interprets requests for QoS allocation (QOS_REQUEST) and satisfies them if possible by appropriate configuration of DiffServ mechanisms (QOS_CONFIG). The QoS management module in the MN configures the output rate of the EF and AF/best effort (BE) classes, and fixes the proportion between the AF and BE classes.

Resource Management in a DiffServ (RMD) Framework

Heijenk *et al.* [9–11] proposed a resource management in a DiffServ (RMD) framework. This RMD framework extends the DiffServ architecture with new reservation concepts and features of the IP-based RAN. It provides per-domain



■ Figure 2. *The visited domain with a GFA, and a home network with an HA.*

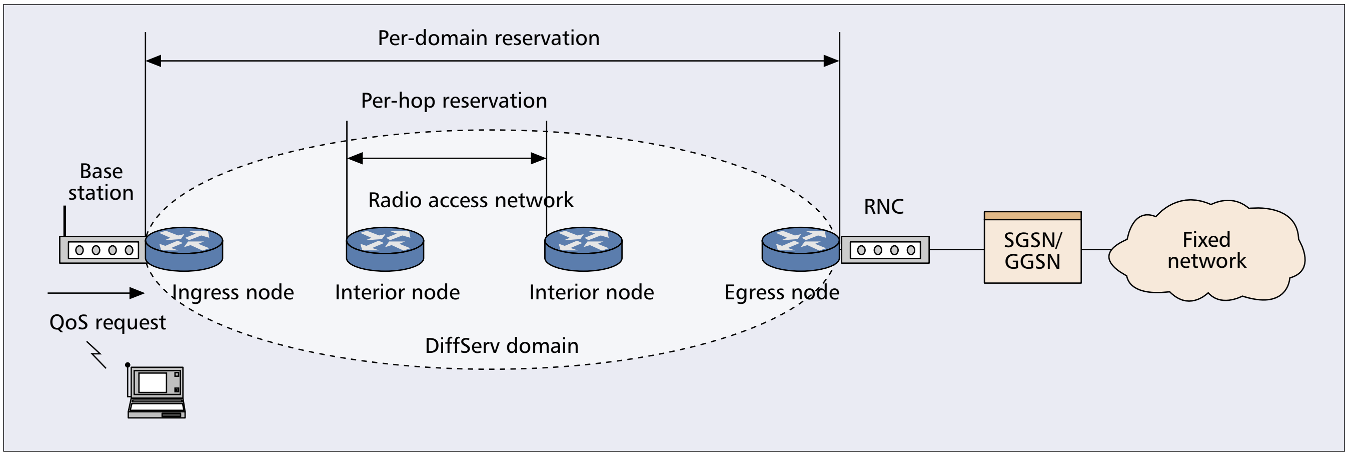


■ Figure 3. *A hierarchical QoS architecture for wireless access networks on the DiffServ model.*

reservation (PDR) and per-hop reservation (PHR) [10]. The PHR protocol extends DiffServ PHB with resource reservation, and thus enables reservation of resources per PHB in each node within a DiffServ domain. The PDR protocol extends DiffServ per-domain behavior (PDB) with resource reservation, which describes the behavior experienced by a particular set of packets over a DiffServ domain. Figure 4 shows the PDR and PHR protocols in the radio access network (RAN). RMD On Demand (RODA) PHR [11] is a unicast edge-to-edge protocol designed for a single DiffServ domain. It operates on a hop-by-hop basis on all nodes, both edge and interior, located in an edge-to-edge DiffServ domain. In the figure the PDR protocol links the external "QoS request" and the PHR protocol. Once a QoS request arrives at the ingress node, PDR classifies it into an appropriate DSCP and calculates the associated resource unit for this QoS request (e.g., bandwidth parameter). The admission or rejection of QoS requests depends on the results of the PHR in the DiffServ domain.

Mobility-Aware Drop Precedence

Random Early Detection (RED) with In and Out (RIO) [13] starts to drop incoming OUT packets randomly with a certain probability in



■ **Figure 4.** *PDR and PHR protocols in the radio access network.*

order to inform TCP sources of congestion after the average queue length of the buffer reaches the lower minimum threshold. It also starts to probabilistically drop IN packets when the average queue length exceeds the upper minimum threshold. However, due to the sawtooth variation of the TCP window, a flow has to transmit a certain amount of OUT packets in order to realize its reservation.

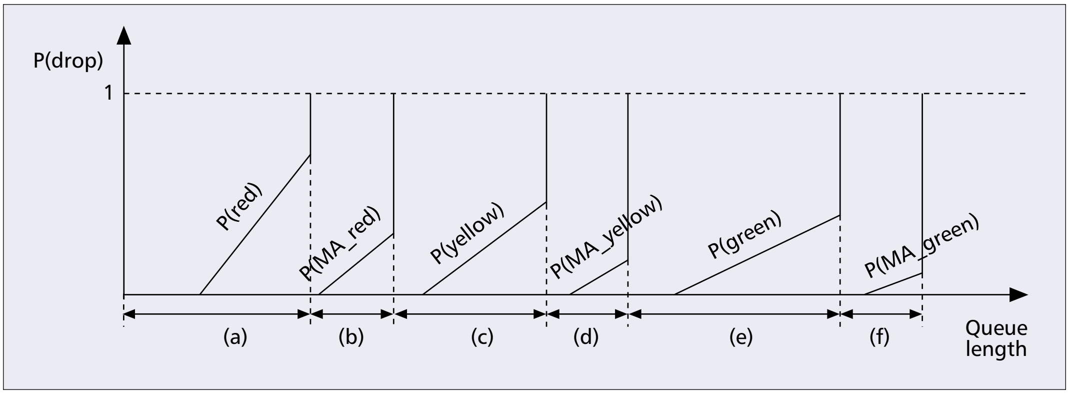
Heinanen *et al.* [14] proposed a marking scheme with three priority levels instead of two. The idea is to protect the OUT packets of a connection transmitting less than its fair share by giving medium priority to them while giving low priority to the OUT packets of a connection exceeding its fair share. Meanwhile, during temporally scarce resources or handover periods in a RAN, an MH should be able to prioritize the important packets of its flow in order to realize reservations. This could be special DSCP marking or specific flow prioritization. If the packets of a flow experiencing handover events could be delivered without dropping when crossing over the interior routers in a RAN, the packet sending rate of the flow would naturally grow by increasing congestion window size. Giving temporal priority to the packets of a handover flow can naturally improve the packet sending rate of a flow for bandwidth fair share after handover in a RAN.

In a RAN the handover packets that belong to a flow that has lost their reservation due to path change after handover are routed through interior nodes without information about reservation. In addition, during the time required to renegotiate an SLS or a BB's admission control along the path via a new access router, a TCP sender might time out and reduce its congestion window. Thus, an MN has to send packets in BE style, and the efficiency of the connection is greatly reduced. During this period, therefore, the packet sending rate an MN generates may not be enough to keep its contract service rate. In particular, in streaming audio or video service disruption might occur.

Packet Marking and Dropping Policy

In this section we propose a mobility-aware drop precedence policy. We assume that an MN is able to mark the DSCPs of packets it creates when it is a sender. Therefore, the different types of traffic an MN generates with different SLSs can be shaped and conditioned with mobility-aware service classes. That is, the packets an MN generates during a handoff period can be marked with a new mobility-aware (MA) tag with higher priority than each color in three-drop precedence. Thus, these packets could be further separated with handover characteristics combined with MA marking.

When traffic exits from a RAN to a core network via a DiffServ boundary node (e.g., a gateway router), the packets with MA drop precedence are mapped to the standard three-drop precedence. Meanwhile, when an MN is a receiver, it informs the gateway node of its new



■ **Figure 5.** *Drop probabilities of mobility-aware drop precedence.*

location during handover in a RAN. After that, the gateway node remarks the incoming packets, which are from the core network, with MA tags to give priority to a handover flow.

Inside a class in three-drop precedence, one of *green*, *yellow*, and *red* can be assigned to the packets of a flow based on predefined service rates. In an MA drop precedence scheme, the source makes two reservations like three-drop precedence. Packets are basically marked with three colors, but depending on the handover characteristics of a flow, the MA tag combined with each color is marked in each packet of handover flow. In MA drop precedence in a RAN, therefore, there may be six possible subscription levels:

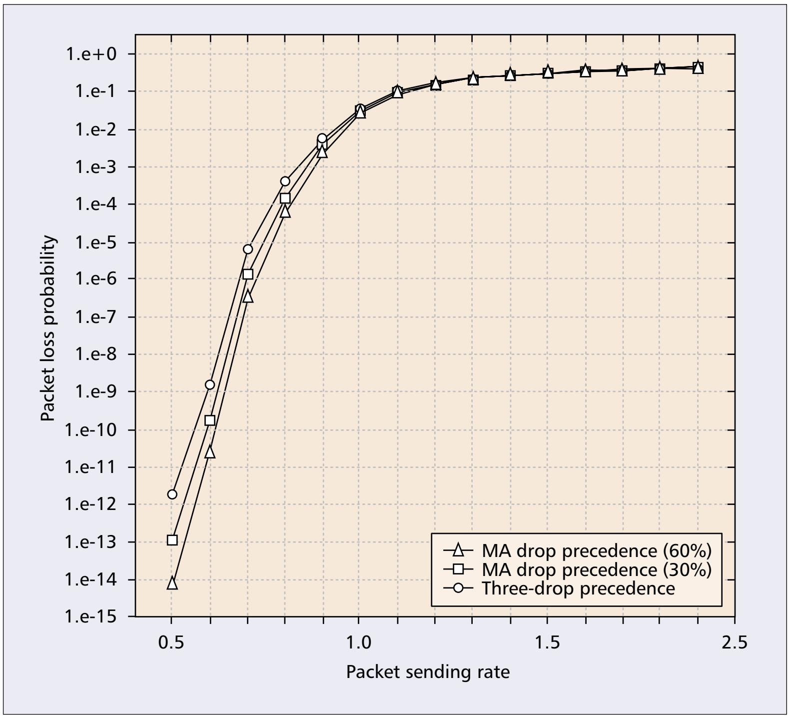
- Only *red* packets are dropped (Fig. 5a).
- Every red packet is dropped, and some *MA_red* packets are dropped (Fig. 5b).
- Every red (*MA_red*) packet is dropped, and some *yellow* packets are dropped (Fig. 5c).
- Every red (*MA_red*) and *yellow* packet is dropped, and some *MA_yellow* packets are dropped (Fig. 5d).
- Every red (*MA_red*), and yellow (*MA_yellow*) packet is dropped, and some *green* packets are dropped (Fig. 5e).
- Every red (*MA_red*), yellow (*MA_yellow*), and green packet is dropped, and some *MA_green* packets are dropped (Fig. 5f).

AF PHB Buffer Modeling

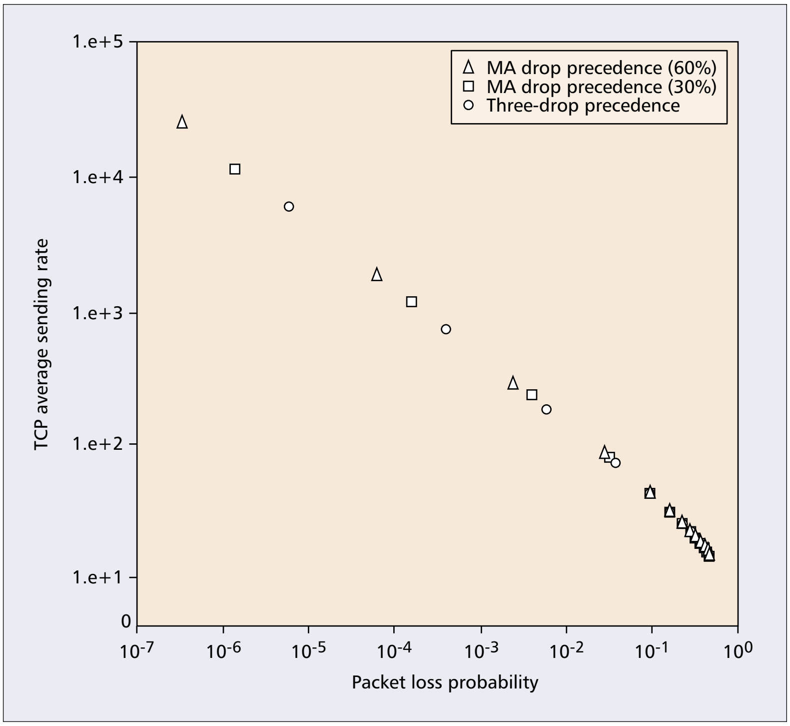
The packet classifier is modeled with a flow conditioner mechanism that splits a flow into several subflows according to levels of drop precedence. The subflows are marked with different levels of drop precedence depending on handover characteristics and traffic intensity (packet sending rate) of a flow. An AF PHB node can be implemented with four buffer queues. The packets in each AF class are buffered (in one of four queues) based on the AF class marking. That is, this buffering mechanism can give equal treatment to flows that belong to the same AF class. Each AF class buffer has its own certain congestion thresholds for the levels of drop precedence. Thus, RED packet dropping depends on the instant values of buffer occupancy levels. For simplicity of modeling, we assume that packets arrive according to a Poisson process and the packet service times are exponentially distributed. The detailed analysis model will be published at a later date.

One AF PHB class buffer model is used in evaluating how packet loss probability and average sending rate between the normal TCP flow and handover flow is achieved with the AF PHB mechanism. The buffer size is set to $K = 39$ and the drop precedence limits for the buffer are $K3 = 13$, $K2 = 26$, and $K1 = 39$. The buffer service intensity $\mu = 1$ and round-trip time (RTT) = 0.1. The reservation rates of both 30 and 60 percent are used for handover flow packets in the buffer model. Figure 6 shows the packet loss probability of handover flow in an AF PHB node as a function of packet sending rate. In this figure MA drop precedence with reservation rate (e.g., 30 and 60 percent) for handover flow has smaller packet loss than three-drop precedence when the load ratio (packet sending rate/buffer service intensity μ) is less than 1.2. This is because three-drop precedence does not provide any priority mechanism for handover flow. However, when the load ratio becomes considerably greater than 1.0, there is little difference in packet loss probability. This means that MA drop precedence does not give better results when network congestion is high.

Figure 7 shows the average sending rate (throughput rate) of TCP handover flow as a



■ Figure 6. *Packet loss probability of a handover flow in an AF PHB node.*



■ Figure 7. *Average sending rate of a TCP handover flow.*

The reservation rate of 60 percent makes better throughput rates than that of 30 percent. This result can compensate for the reduction of TCP window size due to frequent mobility of host under wireless environments. However, high rate of reservation can make unused buffer wasted in the case of non-handover flows.

function of packet loss probability. This figure shows that the TCP handover flows using MA drop precedence can achieve higher throughput than normal flows using three-drop precedence when packet loss probability is less than or equal to 0.1. Moreover, a reservation rate of 60 percent makes better throughput rates than one of 30 percent. This result can compensate for the reduction of TCP window size due to frequent mobility of a host in wireless environments. However, a high rate of reservation can waste unused buffer in non-handover flows.

Conclusions

In this article we have investigated the problems of the standard DiffServ model for IP-based access networks. We have then identified several proposals to solve these problems under IP mobility environments. We finally propose an MA drop precedence scheme that gives priority to handover packets to reduce service disruption of real-time applications under frequent host mobility.

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