Application Layer Signaling for Proactive Handoff Management in all-IP Wireless Networks

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Abstract—Recently, all-IP wireless systems have been standardized under the IP Multimedia Subsystem (IMS) framework to support next generation value added mobile services. In all-IP networks, multiple base stations connect to IMS policy servers through IP-based access gateways. As users move from one access gateway area into another, the corresponding access gateways initiate signaling flows for QoS authorization toward the IMS policy server. Depending on the service, the policy function may contact one or more application servers resulting in variable and prolonged signaling delays upon each handoff. Such delays can be of the order of seconds, depending on the specific system design and whether the user is roaming, which maybe critical to the quality of real time services. In this paper, we propose a novel proactive signaling method in the application layer that conveys authorization delay constraints from the IMS to the radio layer and thus mitigates the effects of variable signaling delay. Our method is practically relevant as it uses the already established mechanisms of authentication and authorization signaling via standardized interfaces and protocols. Using the OPNET simulator, we demonstrate that our scheme is also scalable, as its corresponding signaling overhead is upper bounded to approximately double the handoff rate.

I. INTRODUCTION

The recent evolution of wireless cellular systems towards the all-IP architectures has stimulated unprecedented standardization and research efforts to support new service offerings, most notably within the IP Multimedia Subsystem (IMS) framework [1]. In a typical IMS architecture, multiple radio cells are served by IP access gateways (AGWs); specific examples of standardized gateways are the GGSN in 3GPP networks, PDSN in 3GPP2, and ASN in WiMAX networks. The IMS services are authorized and their control of the offered QoS level is facilitated through interaction with the IMS policy function, which communicates the authorized QoS levels to the serving IP access gateway. When mobile nodes cross the boundaries of gateway areas, the IP layer signaling is triggered. Such signaling includes both MobileIP and IMS authorization signaling. While MobileIP is needed to preserve IP connectivity, the IMS signaling authorizes the service delivery in the new access gateway region. The IMS authorization time poses considerable challenges for mobile realtime services as it can vary considerably depending on several factors, such as service implementation, number of application servers hosting the service logic, and round trip delay between the IMS provider and the third party application provider [2][3][4].

In this paper, we address the access gateway handoff delay due to IMS authorization by introducing a simple, application-layer proactive signaling mechanism that adapts to each service and its authorization delay requirements. In our method, the delay requirements of a service are passed from the IMS to the radio layer to assist handoff prediction, by leveraging the existing signaling systems for authentication, authorization, and accounting (AAA) systems. To this end, we propose a method for the IMS authorization delay estimation and the corresponding handoff prediction. For the proactive signaling implementation, we introduce five new messages, based on established standard interfaces and protocols. We provide extensive simulation and performance results to quantify the impact of our mechanism on the signaling plane as well as on the data plane for various mobility patterns. Our results demonstrate the feasibility of the method as well as its ability to adapt to high application server loads and round trip delays while satisfying the realtime services requirements. We also show that the false alarms due to mispredicted handoffs are bounded to approximately double that of highly predictable handoffs, which is a promising result.

This paper is organized as follows. In Section II, we describe the state of the art and the proposed signaling mechanism. In Section III, we present the methods for signaling delay estimation and handoff prediction. In Section IV, we evaluate our mechanism via simulations. Section V concludes the paper.

II. SIGNALING MECHANISM

A. State of the Art

Figure 1.a illustrates a simplified architecture based on the 1xEVDO cellular system as standardized in [9]. In this architecture, groups of cells are served by a radio network controller (RNC) and one or more RNCs are served by an access gateway. Typically, a service is requested using Session Initiation Protocol (SIP) signaling between the mobile node and the IMS network. The serving call session control function (CSCF) is the first point of contact to the user and handles user registration and authentication by interacting with the home subscriber subsystem (HSS). The CSCF also routes SIP messages to application servers (AS) and to the called parties. In IMS, the home subscriber subsystem (HSS) contains the users’ profiles including their service subscriptions. 1

When users move between RNCs belonging to the same access gateway (i.e., case A in Fig.1.a), only radio layer handoff signaling is triggered and an optional authentication is required.

1 Due to space, we only focus on IMS components relevant to this paper and avoid details of a much richer IMS standard as in [1].
carried out at the AAA server, typically through the RADIUS-based A12 interface [10]. However, when a mobile node moves between RNCs belonging to two different gateways (i.e., case B and C in Fig. 1.a), the target gateway contacts the IMS policy control and charging function (PCRF) over the Diameter-based Ty interface [12]. In this way, the target gateway can obtain the QoS profile for the handoff session in progress using the so-called service based bearer control (SBBC) signaling standard, see [9]. Depending on the service logic, the policy function may contact the CSCF and one or more application servers for QoS authorization, which can easily result in an handoff delay in the order of seconds, unacceptable for realtime services. It is because only once a response is received from the application servers, the PCRF can respond to the target AGW over the Ty interface and authorize the handoff. The handoff delay is further aggravated when users roam into other networks, i.e., visited networks, as illustrated with Case C in Fig. 1.a.

Although considerable past research focused on predictive signaling for MobileIP based on testbed measurements [6], simulations [8] as well as pre-authentication at the radio layer for WiFi and UMTS [7], no detailed studies have addressed proactive schemes for IMS. For instance, in [2], the authors provide testbed measurements based on an emulated 3GPP2 1xEV-DO network and demonstrate that handoffs between proxy call session control functions, which are core IMS elements, can be intolerable (up to 5 secs) if no proactive mechanisms were employed. In addition, the IEEE 802.21 working group addresses issues of seamless mobility in heterogeneous environments by offering cross layer triggers to the higher layer protocols such as wireless link is down, up or going down [5]. However, none of the existing efforts addressed the handoff signaling delay variability due to the interaction between the IMS network and IMS services. In our preliminary work [3][4], we presented the first ideas for the proactive schemes in the application layer, but did not as in this paper provide detailed signaling, delay and handoff estimation mechanisms, as well as extensive OPNET-based simulations to demonstrate the feasibility of the method. We also emphasize the fact that our work only considers gateway handoffs, i.e., handoffs between two border base stations belonging to two different gateway areas.

B. The Proposed Proactive Signaling Mechanism

To alleviate the IMS authorization delay during handoffs, we propose a proactive mechanism that pre-authorizes the session at the target gateway prior to handoff. For this proactive mechanism to be feasible, the IMS layer estimates the service authorization delays and conveys it to the radio layer, which in turn uses this information to predict handoffs and then informs the IMS layer about the predicted handoffs to start the signaling proactively towards the target gateway. In this way, our mechanism is able to lower the impact of or potentially eliminate the handoff delay due to IMS authorization, while adapting to the service-specific authorization delays. To establish a communication path between the IMS and the radio layers, we benefit from the fact that the PCRF and the AAA support the Diameter protocol and that the AAA has an existing interface with the RNCs (i.e., the A12 interface) in the network. Hence, we only need to formally define a Diameter based interface between the AAA and the PCRF, which we call the Tz interface, akin to the SBBC parlance. We now present our protocol messages and the signaling flow. In the next section, we explain delay estimation and handoff prediction implementation details. For space limitations, we focus on a single operator environment. The signaling for the roaming case can be easily incorporated as discussed in [4] while using the handoff and signaling delay estimation techniques proposed in this paper.

1) The Protocol Messages: We propose that a new interface, referred to as Tz, is used between the policy function (PCRF) and the AAA system (see Fig. 1.a). The Tz interface is easy to introduce as it uses Diameter protocol signaling already supported by both the AAA and the PCRF systems [12]. It is implemented as a new authentication application and includes two primary messages: the Service Notification...
Request (SNRQ) and the Handoff Notification Request (HNR). The policy system uses the SNRQ message to inform the AAA about the service authorization. On the other hand, the HNR message is sent by the AAA to inform the policy system of a probable handoff as soon as it receives a trigger from the radio layer. Note that the PCRF and the AAA serve as checkpoints; the services and their delays are inspected at the PCRF, while handoff indications are inspected at the AAA. This minimizes the likelihood of instabilities due to misconfigurations.

We also use the already existing RADIUS based A12 interface[11] between the AAA and the radio controllers to communicate handoff prediction triggers and service delay requirements between the radio and IMS layers. Within the A12 interface, we define three new RADIUS messages, i.e., Service Authorization Latency Information (SALI), Handoff Imminent (HI), and Service Authorization for imminent Handoff (SAH). The implementation of our messages is based on RADIUS vendor specific attributes (VSAs)[10] carried in the authentication (access-request) messages. Since the SALI and SAH messages are server initiated, they are implemented similar to [13]. SALI messages are used to inform the border radio controllers within the gateway area about the delay requirements of the service authorization. SALI messages are only sent in case of a considerable change from the last delay measurement for a given service, or when the service is requested for the first time within an AGW region. The information the SALI message carries is used by the handoff prediction algorithm in the RNC to send the HI messages to the AAA server indicating an imminent handoff. The SAH message is used to proactively authorize radio sessions at the target RNC prior to handoffs to eliminate the current A12 authentication delay. Since users may possibly be moving for long periods in the border areas between AGW regions, a large number of HI messages can be incurred. To address this issue, the HI message authorizes the session at the target gateway for a predefined authorization interval. The authorization interval should be chosen based on a tradeoff between low signaling load and adaptive reservation of the radio layer and memory resources at the RNC.

2) The Signaling Flow: Figure 1b shows the corresponding signaling flow. In step 1, the policy system provides an estimate of the authorization delay to the AAA server (SNRQ), which is followed by a SALI notification to the RNCs (step 2). Notice that these messages are not sent on a per session basis but rather when an appreciable change in the service authorization delay is observed. When the RNC determines the likelihood of an imminent gateway handoff (step 3), it sends a HI message including the estimated handoff time to the AAA server (step 4). The AAA may prioritize the processing of HI messages based on service priorities and inform the policy system of the imminent handoff using the HNR message which carries the expected target AGW information (step 5). In step 6, the policy system requests QoS authorization information for the session from the application servers and the CSCF, and checks its local policies for the target access gateway. If successful, the policy system informs the target gateway about the imminent handoff using SBBC signaling [9]. The target AGW then requests authorization from the AAA setting a vendor specific pre-authentication attribute on (step 8). The AAA authorizes the request and optionally preauthorizes the request at the target RNC by sending the SAH message (step 10). In steps 10-13, the standard proactive MobileIP, radio flow reservation, and point-to-point (PPP) connection establishment are performed. Once MobileIP handoff completes, it is unnecessary to authenticate at the IMS layer and hence the media session resumes with minimal delay.

III. DELAY ESTIMATION AND HANDOFF PREDICTION

A. Authorization Delay Estimation

The policy system (PCRF) maintains an average estimate of the authorization delay per service (Ws). Since the Tx interfaces between PCRF and CSCF as well as between PCRF and AS are based on Diameter protocol, estimates of the signaling delay can be obtained from the time an authorization request is sent until an answer is received, or from the Diameter watchdog messages when the interfaces are idle. If the authorization delay Ws differs from the last estimate by a given margin, δ, an update is sent to the underlying radio network through the AAA framework (see Mechanism 1).

Mechanism 1 IMS Authorization Latency Update Mechanism

Input: Set of services, Set of border RNCs

Output: The authorization latency for each service

foreach update step n do
  foreach AGW i do
    foreach Service s do
      Measure Ds As the authorization delay to application servers and CSCFs.
      Measure Ds as the round trip delay from each AGW i to the PCRF.
      Calculate the moving average Ws as the round trip delay from each AGW i using Ds.
      if |Ws - Ws| > δ then
        Send a SNRQ to all AAA servers
        All AAA servers update all border RNCs using the SALI message
        All border RNCs use the new Ws for prediction
    end
end
end

The margin δ is a critical parameter to the stability of the system as it determines the frequency of the SALI messages and hence the stability of the handoff prediction. Since δ is highly dependent on the AS loading, it is important to select a margin such that the moving average, Ws, is stable and is barely affected by the server load fluctuations. To illustrate this effect, let us assume that all Ns ASes hosting the service logic incur similar loading and that the policy function forks its authorization requests to the application servers. Since each AS responds after a random delay d, the authorization latency Ds is determined by the latest responding server (i.e., Ds = max{d1, ..., dNs}). Assuming quasi-stationarity and by central limit theorem, Ws is normally distributed with mean E[Ds] and variance of Var[Ds]/(Window Size). Assuming M/M/1 application servers, typical values are obtained for δ...
as in Table I. We observe that the required margin grows approximately linearly with the AS load until loads of 80% and exponentially afterwards. Depending on the service time of the AS, one can select a suitable value for \( \delta \) (e.g., if the AS serves 50 req/s, then \( \delta = 3.84(20) = 76.8\) ms at 90% load).

### Table I

<table>
<thead>
<tr>
<th>Load</th>
<th>10%</th>
<th>25%</th>
<th>50%</th>
<th>75%</th>
<th>80%</th>
<th>85%</th>
<th>90%</th>
<th>95%</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \delta ) (1 AS)</td>
<td>0.37</td>
<td>0.44</td>
<td>0.66</td>
<td>1.32</td>
<td>1.65</td>
<td>2.19</td>
<td>3.29</td>
<td>6.58</td>
</tr>
<tr>
<td>( \delta ) (2 AS)</td>
<td>0.41</td>
<td>0.49</td>
<td>0.74</td>
<td>1.47</td>
<td>1.84</td>
<td>2.45</td>
<td>3.68</td>
<td>7.36</td>
</tr>
<tr>
<td>( \delta ) (3 AS)</td>
<td>0.43</td>
<td>0.51</td>
<td>0.77</td>
<td>1.54</td>
<td>1.92</td>
<td>2.56</td>
<td>3.84</td>
<td>7.68</td>
</tr>
</tbody>
</table>

#### B. Handoff Prediction

**Mechanism 2 Handoff Prediction Mechanism**

**Input:** The TrackedSet \( B_T \), the authorization delay \( W_{s_{(n,i)}}^{(n)} \)

**Output:** Handoff Imminent (HI) message

This logic runs at each time step, \( n \) (e.g., 100 ms)

1. foreach \( B_{TS} \) \( \in B_T \cap (B_{AS} \cup B_{BC}) \) do
   1. Compute the mean signal to interference ratio \( \Delta_j = \frac{E_0}{(N_o + I)} \)
   2. Estimate the rate \( R_j = d\Delta_j/dt \) using the last M samples
   3. if \( R_j < 0 \) AND \( E_0/(N_o + I) \leq \text{Threshold} \) then
      1. \( \Delta_0 = \Delta_H + \Delta_j \), \( T_j = |R_j|^{-1} \Delta_0 \)
   end
2. \( T_k = \min\{T_j\} \)
3. if NOT IsTriggered AND \( T_k \leq W_{s_{(n,i)}}^{(n)} \) then
   1. IsTriggered = true
   2. Start Timer = Authorization Interval
   3. Send HI message including \( T_k \) to the AAA system

The authorization delay estimate \( W_{s_{(n,i)}}^{(n)} \) for AGW\(_i\) is used by the border radio network controllers to predict handoff events and therefore attempt to trigger the proactive authorization process \( W_{s_{(n,i)}}^{(n)} \) seconds prior to the estimated handoff instant. In this paper, we use a simple linear prediction to estimate the handoff instant. By monitoring the candidate \( B_{BC} \) and the active sets \( B_{AS} \) of base stations for each mobile node, RNCs are able to predict handoffs moments; a candidate set includes base stations with received powers below a certain threshold, and once this threshold is exceeded they are added to the active set. Let us define the TrackedSet, \( B_T \), as the set of bordering base stations in a border RNC in an access gateway coverage area. This is needed because not all base stations in RNC regions are at the edge. The handoff moment can then be estimated by monitoring the power decay rate \( R \) from all base stations belonging to the TrackedSet that appear in the candidate or active sets (i.e., \( B_{TS} \in B_T \cap (B_{AS} \cup B_{BC}) \)) as shown in Mechanism2. Then, the handoff moments can be estimated by the product of the decay rate and the sum of the handoff hysteresis margin \( \Delta_H \) and the difference between the signal to interference ratios \( \Delta_j \) from the target and the current base stations (i.e., \( (E_0/(N_o + I))_{n,i} \) and \( (E_0/(N_o + I))_{j} \) respectively). Once estimates of the handoff moments are collected, the earliest predicted handoff event from base station \( k \), denoted as \( T_k \), is compared to the estimated authorization delay \( W_{s_{(n,i)}}^{(n)} \) and if \( T_k < W_{s_{(n,i)}}^{(n)} \), a handoff imminent (HI) message is sent to the AAA server reporting the possible source and target RNCs and the authorization lifetime is set to \( T_A \). During the authorization lifetime, no HI messages are sent by the source RNC to prevent continuous triggering of HI messages. The complexity of the prediction grows linearly with the number of base stations and services. Finally, note that our prediction approach is different from the 802.21 because we consider a variable prediction delay \( W_{s_{(n,i)}}^{(n)} \).

### IV. Simulation Model and Results

To simulate the proposed scheme, we developed C++ modules within the OPNET simulator. Our new modules handle the relevant signaling messages, users’ mobility, and radio signal attenuation. We simulate the signaling mechanism for two neighboring AGWs each supporting four RNCs. Each RNC serves \( N \times N \) cells. We assume a composed service running over three application servers and assume that authorization signaling from the PCRF is forked to all application servers at the same time. The application servers service time is modeled using M/M/1 behavior.

To study different mobility patterns, we modify the well-known Waypoint model by limiting the distance a node travels during each movement epoch. We refer to this distance as the span. In other words, after pausing the node picks a random destination that is utmost span distance units away. By controlling the span variable in our simulator we are able to simulate different mobility patterns during each session duration. For instance, long spans result in long straight movements or highly directional mobility, whereas short spans result in localized movement or highly random mobility. We also consider the corrections suggested by [14] by having the minimum speed > 0. Note that we do not incur the known issue that users in Waypoint simulations tend to go towards the center after a long time as in our simulations session durations are limited and new sessions are randomly placed in the coverage area and are removed once they finish.

To study the effect of our mechanism on both the signaling plane and the data plane, we generate a Poissonian load of sessions with Lognormally distributed durations and we randomly select one of the generated sessions to act as probe user. The probe user generates VoIP traffic and we measure the number of dropped packets. Table II lists the fixed parameters of the VoIP application, the wireless channel, and the topology used in our simulation. All simulation results are conducted within the confidence interval of 90%.

#### Table II Simulation Parameters

<table>
<thead>
<tr>
<th>Aspect</th>
<th>Parameters</th>
</tr>
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<tbody>
<tr>
<td>VoIP</td>
<td>Session duration: 10 min, Frame duration, Talk Spurt, Silence Period (ms): (20,6.3,5.6,5.3), Codec: EVRC, coding rate: 8.5kbps,</td>
</tr>
<tr>
<td>Wireless Channel</td>
<td>Mobile Node's Tx power 250 mW, Freq.: 1.9 GHz, channel rate = 38.4 kbps, channel power loss exponent = 3.7, LogNormal shadowing standard deviation = 4.1</td>
</tr>
<tr>
<td>Topology</td>
<td>2 A0G areas, 2 × 2 RNCs per AGW, 3 Application Servers</td>
</tr>
<tr>
<td>Link Delays</td>
<td>RNC-AAA: 40ms, RNC-AGW: 40ms, PCRF-AAA: 100ms, PCRF-AGW: 100ms, PCRF-AS: 200ms</td>
</tr>
</tbody>
</table>

Figure 2 summarizes our simulation results. We first study the effect of the cell radius on the mean triggering rates of our
proactive signaling as well as the standard IMS authorization schemes, as described in Section II. We simulate two session arrival rates (i.e., 1 and 5 sessions/cell/min). As shown in Fig.2(a), as the cell radius increases, the mean signaling rates for both schemes decrease. We also observe that the proactive signaling rate is larger than that of the standard IMS procedure. This is due to the fact that the standard IMS signaling is triggered per handoff while the proactive mechanism incur extra triggers due to the mis-predicted handoffs (i.e., false alarms). In Fig.2(b), we study the effect of the mobility pattern on the mean signaling rates. We perform simulations for various waypoint mobility spans ranging from highly random (0.2 km) and highly directional (8km) movement patterns. We observe that the triggering rates for both standard IMS and the proactive mechanism are very similar and differ the most for random movers. For random movers, the triggering rates are very low as they barely leave their initial access gateway due to the frequent changes in direction during their sessions. On the other hand, highly directional movers (i.e., high span) are more likely to leave their gateway resulting in larger signaling rates. Clearly, the mobility pattern highly affects the resulting signaling rate; for instance, the signaling
rate for a cell radius of 0.5km and a span of 8km is approx. 16 times that for spans of 0.2km. In Fig.2(c), we study the ratio of the proactive signaling mechanism to the handoff rate for random and highly directional movement patterns. We observe that for highly directional movers the proactive triggering mechanism is executed almost at the same rate as the handoff rate (i.e., the standard IMS mechanism). On the other hand, proactive signaling is triggered at approx. double the handoff rate for random movers. This is due to the fact that random movers result in a large number of false alarms and hence larger number of proactive signaling executions if they are near the border. As such, Fig.2(c) establishes performance bounds using the two extreme mobility patterns and hence we expect that in the worst case the triggering rate of our proactive mechanism is twice that of the standard IMS scheme. In Fig.2(d), we compare the signaling rate in relevant interfaces (i.e., AAA-RNC, PCRF-AAA, PCRF-AS, and PCRF-AGW) for the two sample mobility patterns. We observe that for highly directional movers, the signaling load of the proactive and the standard IMS mechanisms are almost the same on all interfaces except on the AAA-RNC interface. This is because of the newly introduced HI messages in our proactive scheme. Notice that since the SALI and the HNR messages are only triggered when there is a major change in the application server loading, they rarely result in any additional loading on the PCRF-AAA and the AAA-RNC interfaces. For random movers and due to the large likelihood of false alarms the signaling rate for the proactive mechanism relative to the standard IMS mechanism is approximately three-folds on the AAA-RNC interface due to the more frequent transmission of the HI messages and almost two-folds on rest of the interfaces.

In Fig.2(e), we study the effect of the authorization interval on the triggering rate of our proactive mechanism. We observe that mean triggering rate of our mechanism is barely affected for authorization intervals as low as 2 seconds below which the signaling rate increases rapidly. This means that mean residence time for a moving user in the triggering zone is approximately 2 sec and hence the mean authorization interval must be selected to be greater than 2 sec to avoid excessive transmission of HI messages (see Mechanism 2).

Now we turn our attention to the interplay of our signaling and the data plane traffic. We study an exemplary VoIP application and the number of dropped VoIP packets during gateway handoffs using our proactive signaling mechanism. To evaluate the handoff impairments due to the IMS signaling, we assume an ideal proactive MobileIP handoff delay of 140ms and a typical 70ms delay in the EVD0 layer. We monitor the mean number of dropped VoIP packets during handoff for various AS loads ranging from 40% to 95%. As in Fig.2(f), we see that our proactive mechanism is able to minimize the number of dropped packets even for a large round trip delay between the PCRF and the AS. We also observe that the number of dropped packets in the standard IMS mechanism is sensitive to the round trip time to the ASes as well as their load. When the AS load exceed the 90% limit, the authorization delay variance of the AS increases rapidly and our prediction mechanism is no longer able to correctly adapt resulting in a large number of packet drops. This effect is clear in Figs.2(g)-2(i) where we plot the probability density function of the time between the last HI message and the handoff trigger. Notice that due to the shape of the histograms in Fig.2(g) (i.e., 40% loading) and Fig.2(h) (i.e., 90% loading) are similar while the delays start to ‘spill out’ when the AS is increased to 95% due to the large variance in latency and hence resulting in improper prediction of the handoff time. We also observe that the largest component in the histograms shifts according to the AS load (i.e., 1.25 in Fig.2(g), 1.40 in Fig.2(h), and 1.75 in Fig.2(h)) and hence explains the flat shape of the number of packet drops in Fig.2(f).

Finally, we confirm that the signaling load of our scheme follows the same trends as the standard IMS signaling by varying the users concentrations in the border area between AGWs. For concentrations of 10%, 15%, and 25%, and at session arrival rate of 200 sessions/min in the whole network, the corresponding execution rates of the proactive mechanism are {0.65, 0.75, 0.93} and for the standard IMS mechanism are {0.60, 0.68, 0.87}. Similar consistent behavior was observed by varying the number of cells per RNC (not shown here).

V. CONCLUSION

In this paper, we proposed an application layer proactive signaling mechanism for efficient handoff management within the IMS and verified it with extensive OPNET-based simulations. Our results showed the feasibility of the proposed mechanism. We showed that even in worst case scenarios, such as when all users are random movers, the proactive mechanism is triggered only twice as much as the standard IMS mechanism, but the benefits on service quality are significant. We believe that our results are the first step towards the standardization and practical implementation of adaptive proactive schemes within the next generation application layer signaling systems and hence can provide a solid basis for future research.

REFERENCES