Evaluation of Policy Based Admission Control Mechanisms in NGN

Pedro Gonçalves[1], Ricardo Azevedo[3], Diogo Gomes[2], José Luís Oliveira[2], and Rui L. Aguiar[2]

[1]University of Aveiro, ESTGA/IT, Portugal
[2]University of Aveiro, DETI/IT, Portugal
[3]Portugal Telecom Inovação, Portugal

Abstract— **The 3GPP consortium proposed in the release 7 of the IP Multimedia Subsystem (IMS) a Diameter interface for the resource admission communication process replacing the previous COPS solution. Although both academic and industry communities have deeply debate the advantages and disadvantages of each protocol, its impact in NGN may have not been thoroughly quantified.**

This paper compares both protocols in terms of messages exchanged between network entities, and of bandwidth requirements during the admission control process. Based on general network operator environment characteristics, we present several exploitation scenarios where it is analyzed the scalability and adequacy of each protocol.

Index Terms— **Network management, 3GPP IMS, COPS, Diameter**

I. INTRODUCTION

One of the Next Generation Networks (NGN) characteristics has been the drive towards IP-based protocols. This aspect is present not only in research projects but also in 3GPP and ETSI-TISPAN standards, where the IP Multimedia Subsystem (IMS) is one of the most relevant trends. The move to IP-based networks, coupled with the need to support reliable voice communications, has also lead to the need for policy mechanisms that efficiently controls QoS provisioning.

IETF standards, namely COPS [1] and Diameter [2], have played an important role in the transition from 3GPP release 6 (3GPP R6) [3] to 3GPP release 7 (3GPP R7) [4]. In this transitions Diameter has replaced COPS without a clearly convincing set of advantages that justify the change.

In a previous work [5] the authors evaluated several management protocols from a view point of configuration efficiency but have not performed any analysis under a dynamic environment. This paper intends to discuss the transition made by 3GPP from COPS to DIAMETER and will make a parallel to a similar transition that occurred in the research project IST-Daidalos [11]. Section 2 of the paper refers the relevant state of art; section 3 explains the used methodology and section 4 summarizes the prototypes used, and section 5 discusses the attained results.

II. EVOLUTION OF THE POLICY BASED ADMISSION CONTROL MECHANISMS

IMS was proposed by the Third Generation Partnership Project (3GPP) as an overlay framework to deliver multimedia services in mobile IP networks [6]. Other standardization bodies, such as ITU and ETSI, have adopted this framework for their NGN proposals.

IMS is a layered architecture that separates the service, the control and the transport planes, offering significant benefits in terms of service creation and maintenance savings. Its framework is agnostic in terms of access network technology and it has been receiving a great attention from the ESTI TISPAN in order to achieve the fixed mobile convergence.

A simplified 3GPP IMS layered architecture is presented in Figure **1**.

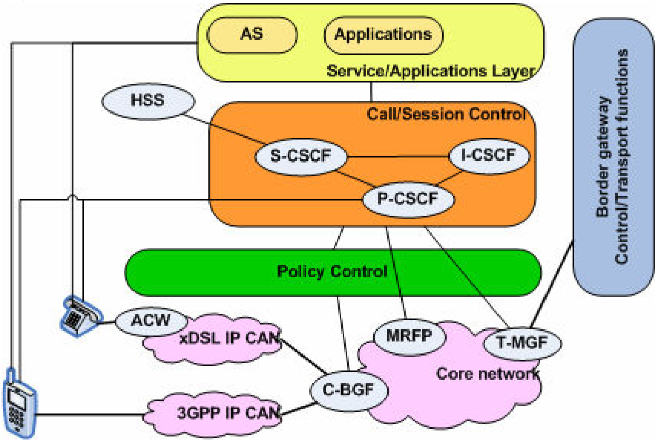

Figure 1 – 3GPP IMS simplified architecture.

The call/session control layer is composed by three entities that process SIP signaling packets in the IMS world. Those entities are collectively called *Call Session Control Function* (CSCF). The *Proxy*-CSCF is the initial interface between the terminal and the IMS core functions. Among others features, the P-CSCF is responsible for forwarding QoS requests to the policy control layer. *Interrogating*-CSCF is the function within the home network that is able to determine the *Serving*-CSCF with which a user should register. *Serving*-CSCF is the function that registers the user and provides him with the service. It performs routing and translation, provides billing information, maintains session timers, and interrogates the

HSS (*Home Subscriber Server*) to retrieve authorization, service triggering information and user profile.

A session experiences two different authorization processes: i) based on service user's profile (*Call/Session Control layer*) and ii) based on network status and policies (*Network Control layer*). The first one is based on user-specific information(for instance the user may not be allowed to establish video sessions). The second is based on current network status and network policies, which apply to all the users in the network.

The *Policy Control* framework – where the second authentication process takes place – and its protocols, changed significantly between 3GPP Release 6 and Release 7. New features have been introduced in the latter version to provide advanced core capabilities in terms of the policy control and charging architecture. The next two sub-sections further details the main differences between both releases, concerning policy control model and protocols.

1) *3GPP Release 6*

In 3GPP R6 the policy control layer contains the element responsible for the enforcement of network and QoS policies. This entity is called PDF (*Policy Decision Function*) and it provides interfaces to the P-CSCF (*Gq* interface [7]) and to the Gateway GPRS Support Node (GGSN) (*Go* interface [8]).

To transfer policy-related information, the *Go* interface can use the two well-known COPS models – outsourcing [1] and provisioning (COPS-PR) [8]. In R6 media authorization process [9], the PDF is seen as the COPS PDP and the GGSN holds the COPS PEP (Policy Enforcement Point) functionality.

When a user starts a SIP call, the P-CSCF requests the PDF to generate a media authorization token. This token is added, by the P-CSCF, to the INVITE request and sent to the callee UE (User Equipment). The caller UE will receive the token in the SIP 183 (*Session in Progress*) response. After this, the GGSN receives the request for a new PDF context from the user, the received token and session parameters are sent to the PDF in a COPS Request. The PDF checks the resource reservation request against network policies and sends back a COPS decision message to the GGSN. If the session is accepted, the GGSN establishes the requested PDF context with the UE and, finally, media can flow between both terminals.

2) *3GPP Release 7*

3GPP R7 [10] is considerably different from R6 in the policy control layer, where a new entity, called PCRF (*Policy and Charging Rules Function*), is responsible for control procedures. Policy control is supported without the use of an authorization token, which optimizes the real-time interactions with the IP transport gateways (e.g. GGSN).

When a user starts a SIP call, the P-CSCF sends an authorization request to the PCRF with service flow information and associated QoS parameters. Based on the received information, network policies and status, the PCRF authorizes or denies the session and configures the transport element PCEF (*Policy Control Enforcement Function*) with several charging and QoS rules in order to accommodate the requested session. After the conclusion of this process, the P-CSCF receives the answer from the PCRF and SIP messages are forwarded to the destination UE. The described process is repeated every time the P-CSCF receives a SIP message that contains information about the session.

It is also possible a different approach for session establishment, where the IMS Core is not involved. In this case the session establishment is requested directly from the user, via the IP Connectivity Access Network (IP-CAN). In this scenario, the IP transport gateway (PCEF) asks directly the PCRF for authorization and after that PCC rules (QoS and charging – online and/or offline) are enforced in the PCEF. PCEF finally acknowledges the IP-CAN bearer session establishment request.

B. *The Projects Daidalos and Daidalos II*

In November 2003, the Daidalos IST project [11] set forward the objective of researching an architecture for NGN. By that time, the 3GPP R5 was the main proposal and R6 was still a working document. As such Daidalos set forward to develop a QoS-aware packet-based network [12] using what it was believed would be the best protocols according to the industry direction. This meant the use of COPS as it perfectly fitted the needs of the Daidalos architecture and would be in accordance with 3GPP. The fact that Daidalos focused in a heterogeneous environment meant that the architecture was fully IP-oriented and technology specific issues would be treated using localized abstraction layers. Therefore COPS messages would only need to handle IP parameters, making the overall signaling less complicated than in 3GPP.

The Daidalos QoS architecture [13] is mainly composed of 3 entities: the QoS Broker, the Access Router and the A4C server [14] .The QoS Broker acts as the network PDP. To setup a distributed network that can scale to millions of customers and a maintain a centralized mechanism to coordinate the network, several QoS Brokers can co-exist with a Core QoS Broker that centrally manage all the others in the same operational domain.

The A4C server organizes user information in a so-called NVUP (*Network View of the User Profile*). The NVUP contains all policy rules that can be applied to a given user according to his commercial contract. The NVUP can be retrieved by the QoS Broker to manage user's sessions. These control procedures are done using SAML (*Security Assertion Markup Language*) tokens generated in the terminal on the bootstrap phase and later on exchanged by the QoS Broker.

The Access Router (AR) provides PEP functionality and each flow that transverse this element must be controlled by the QoS Broker, on request or through provisioned rules. This assures that the QoS Broker is fully aware of all network flows. In the Daidalos I architecture there are 3 signaling flows for the reservation of resources: Legacy, RSVP and Multimedia. The Legacy and RSVP signaling flows are very similar: on detection of a new flow either through a RSVP PATH message or policing of the first packet of the new flow, the AR (PEP) issues a COPS REQ to the QoS Broker (PDP) which, based on the NVUP, sends a COPS decision to the PEP. The PEP enforces the decision by both accepting the packet and configuring the QoS rules or by dropping the packet and the respective flow.

In 2006 Daidalos faced a second phase in which many signaling flows were revised and the following question was rised: "*Should we continue to use COPS or should we change to Diameter?"*. The draft version of 3GPP R7 already pointed the move towards a Diameter based *Gx*, as well as ETSI TI-SPAN documents [15, 16]. Therefore it was decided to follow the main standardization bodies and use Diameter in Daidalos II [17], replacing COPS. The architecture was quite modified from Daidalos I to Daidalos-II, but for our purposes the most relevant changes were simply the move from COPS to Diameter and of also the move from RSVP to NSIS, which this did not change the signaling between the PEP and the PDP.

III. COMPARING *GO* AND *GX* INTERFACES

The *Gx* is the result of the evolution that the *Go* interface suffered from R6 to R7. The policy control information was merged with the charging information in the messages exchanged through the *Gx* interface. The architectural evolution of the *Go* interface increased considerably the message sizes of the *Gx* messages, but it also added an extra functionality not present in the *Go* interface. That extra functionality is the reason why comparing COPS and Diameter performance using prototypes of the 3GPP IMS proposals would not produce a fair comparison. Most of the differences are not related with efficiency but simply with the way different functionalities are handled in each 3GPP release.

On the other hand, Daidalos project messages are much simpler than those of 3GPP. Daidalos proposes simpler functionality distribution than 3GPP, and as such both COPS (in Daidalos I) and Diameter (in Daidalos II) interfaces exchange only admission control information. This provides a basis for a fair comparison between both protocols, for assessing their usage in admission control aspects.

The following section detail some functional differences between both protocols and between *Go* and *Gx* interfaces.

A. COPS Vs Diameter

Although both COPS and Diameter protocols are used in the admission control mechanisms they strongly differ.

COPS was proposed within the IETF as a query/response protocol for policy information exchange. It is a binary protocol that transports messages, using TCP, between the manager – the PDP (*Policy Definition Point*) – and its managed entities – the PEPs (*Policy Enforcement Points*). Client and server maintain a COPS connection identifying all the messages with a unique handle. Two models of the protocol were proposed: the outsourcing - COPS-RSVP [18] and the provision model - COPS for Policy Provisioning (COPS-PR) [8].

The Diameter protocol was proposed within the Authentication, Authorization and Accounting (AAA) framework [2] as the successor for the RADIUS AAA protocol, enabling a modular and distributed AAA mechanism.. The Diameter Base Protocol is the core model and several extensions, tailored for specific applications were also proposed, such as the Diameter Network Access Server Application (NASREQ), the Diameter mobile IPv4 Application (MobileIP) [19] and the Diameter Session Initiation Protocol [20]. As a result Diameter messages offer a much complete information base than that of the COPS messages. On the other hand COPS messages are much more efficient; they have a common header, a client handle and all the remaining information is added accordingly with the application needs.

The Figure **2** illustrates the content of a typical Diameter message. The illustration represents a CCR request sent from the QoS Broker to the access router in the Daidalos-II project

```
<CCR > ::= < Diameter Header: 272, REQ, PXY >
          < Session-Id >
          < Hop-by-Hop Identifier >
          < End-to-End Identifier >
          < Session-Id>
          < Auth-Application-Id >
          < Origin-Host >
          < Origin-Realm >
          < Destination-Realm >
          < Flow Filter >
```

Figure 2 – Daidalos II CCR message information

B. The evolution from Go to Gx IMS interfaces

In the 3GPP R6 IMS architecture the PDF performs the policy based admission control and communicates its decisions to a policy enforcer element in the GGSN thought a COPS based interface named *Go*. *Go* interface implements a unique set of messages between the PDF and the PEP present in the GGSN.

A closer look in the message content illustrated in the Figure 3 shows that the message structure is very similar to the Daidalos I COPS Request. There are however some differences in the Clients object as well as in its size.

```
<Request Message > ::= < Common Header>
          < Client Handle >
          < Context >
          < ClientSI >
```

Figure 3 – Go REQ message information

As said in 3GPP R7 the *Go* interface was renamed as *Gx* and the communication protocol for the interface changed to Diameter. Furthermore, the enforcement element that existed inside of GGSN became an independent functional element and was named Policy Enforcement Control Function (PCEF).

Gx applications implement a dual resource reservation communication mechanism. The PCRF sends a RAR message to the PCEF in order to create a resource reservation for a request received from the CSCF. The Re-Auth-Request (RAR) message is responded by the PCEF with a Re-Auth-Answer (RAA) message reporting the success of the resource reservation process. The second mechanism for the resource reservation communication consists in a CC-Request (CCR) message sent by the PCEF once a new traffic flow is detected. The PCRF responds the request with a CC-Answer (CCA) message accepting or denying the request. Figure 5 illustrates the structure of a Gx CCR message.

```
<CC-Request> ::= < Diameter Header: 272, REQ, PXY >
           < Session-Id >
           { Auth-Application-Id }
           { Origin-Host }
           { Origin-Realm }
           { Destination-Realm }
           { CC-Request-Type }
           { CC-Request-Number }
           [ Destination-Host ]
           [ Origin-State-Id ]
          *[ Subscription-Id ]
           [ Bearer-Control-Mode ]
           [ Network-Request-Support ]
           [ Bearer-Identifier ]
           [ Bearer-Operation ]
           [ Framed-IP-Address ]
           [ Framed-IPv6-Prefix ]
           [ IP-CAN-Type ]
           [ RAT-Type ]
           [ QoS-Information ]
           [ QoS-Negotiation ]
           [ QoS-Upgrade ]
           [ 3GPP-SGSN-MCC-MNC ]
           [ 3GPP-SGSN-IPv6-Address ]
           [ RAI ]
           [ Bearer-Usage ]
           [ Online ]
           [ Offline ]
          *[ TFT-Packet-Filter-Information ]
          *[ Charging-Rule-Report]
          *[ Event-Trigger]
           [ Access-Network-Charging-Address ]
          *[ Access-Network-Charging-Identifier-Gx ]
```

Figure 4 – Gx CCR message information

Gx messages include a strong charging component and shown to be much bigger than the *Go* counterparts.

C. *From Daidalos I to Daidalos II*

As previously stated the Daidalos project followed 3GPP in the transition from COPS to DIAMETER. This transition was nonetheless much smother then the one that occurred in 3GPP as entities did not suffer any major evolution in terms of functionality. That said, in Daidalos it is easier to evaluate the impact of the change of protocol for admission control issues, as other control functions are more or less independent of these mechanisms.

In the first phase of the Daidalos project, its COPS specification did not follow very closely the 3GPP specification as entities were distinct and requirements were at that stage a bit different, 3GPP was still not defining an All-IP network and Daidalos was considering a pure All-IP NGN. In the second phase of the project and due to developments in 3GPP towards an IP based network the project decided to align its signaling specifications with 3GPP/TI-SPAN therefore taking Gq' as the base for its own specification. Since Daidalos had a separate architecture for accounting and charging [21] the integration of such interfaces together with QoS was redundanct in our implementation. The overall result is that the Daidalos I COPS interface is very similar to 3GPP *Go* interface, but with different Client Specific Objects. Nevertheless it remains 100% RFC compliant. As for Daidalos II, its DIAMETER interface resembles 3GPP Gq' interface but lacks the Accounting and Charging AVP's.

IV. EVALUATION USING DAIDALOS PROTOTYPES

Our evaluation methodology was based on the development of a prototype for each of the management technologies. Later on we performed a set of tests with the prototyped applications involving real traffic and correspondent analysis. The messages were examined and their sizes were measured in order to evaluate the traffic amount generated for each of the technologies.

The prototypes were composed of an access network QoSBroker and an AR. In Daidalos I, a Mobile Terminal (MT) used network resources in order to generate COPS admission control requests from the AR to QoSBroker. The QoSBroker took admission control decisions and answered to the AR with the decisions it took. After installing the decisions the AR sent a RPT message to the QoSBroker. In Daidalos II, the MT was used to generate network traffic which caused admission control requests in the form of Diameter RAR messages from the AR to the QoSBroker, which answered with Diameter RAA message.

The 3GPP IMS prototypes were developed from scratch as a simple client/server pair. In the case of the 3GPP *Go* prototype it was necessary to extend an existing COPS API [22] and there was the need to implement the messages standardized by 3GPP [23].

The Diameter API used in the *Gx* prototypes was based on the Daidalos II Diameter API. The API was extended with the messages defined by the 3GPP consortium in 3GPP TS 29.212 [24]. The CC-Request (CCR) message is send by the PCEF to the PCRF requesting for PCC rules for a given bearer in the legacy scenarios. The PCRF answers the CCR message with a CC-Answer message (CCA) providing the requested PCC rules to the PCEF. The PCRF performs provisioning of the PCC rules to the PCEF using a RAR message. The PCEF answers the RAR message with a RAA message to the PCRF.

V. RESULTS AND DISCUSSION

The tests were repeated a set of times with each of the prototypes. We made use of the captured traffic to conduct our study. Signaling comparison

The first result of our tests (see Table 1) shows that COPS protocol is much more efficient that Diameter protocol. There was no meaningful difference in the admission control information exchanged between the Daidalos prototypes, although the signaling information differs by more than 39%.

Table 1 - Signaling test results

PROTOCOL	PROTOTYPE	MESSAGE	SIZE	TOTAL
COPS	Daidalos I	REQ	184	512
		DEC	168	
		RPT	160	
	Go	REQ	182	546
		DEC	206	
		RPT	158	
Diameter	Daidalos II	CCR	374	712
		CCA	338	
	Gx	CCR	810	1504
		CCA	694	

The difference is mostly due to: the encoding efficiency of the Diameter protocol, which is smaller than in COPS, and to the fact that the Diameter protocol is more verbose than

COPS. Diameter messages include information like Hop-by-Hop Identifier, End-to-End Identifier, the Origin-Realm and Destination-Realm not present in the COPS messages. COPS disadvantage in terms of efficiency has to do with reporting messages. Sending a report message after the executing the PDP decision COPS wastes about 160 bytes. That mechanism is not used in Diameter and could increase even more the performance difference between the protocols.

The differences between the Daidalos I messages and the *Go* COPS messages can be neglected since this represent less that 7%. The communication protocol is the same for both prototypes and the information transferred by the prototypes is almost the same. The comparison between the Daidalos II and the *Gx* results shows that the merging of the policy provisioning information with the charging information doubled the message size. Considering that the results of Daidalos I and the *Go* prototypes are very similar and taking in consideration as well that the Daidalos prototypes transfer the same information we must conclude that IMS *Gx* interface is much more complex than IMS *Go*. The signaling exchanged by the *Gx* prototype exceeded *Go* prototype signaling in 175%. Figure **5** illustrates the signaling volume of each of the prototypes when compared with IMS *Gx* signaling volume.

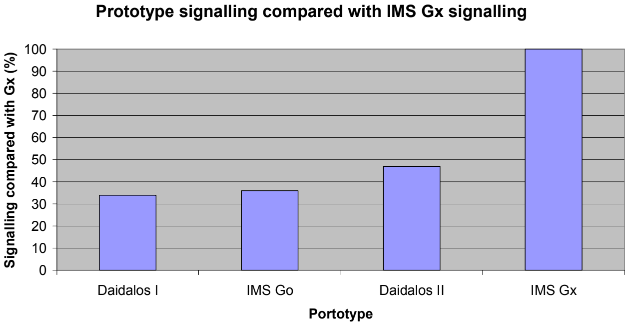

Figure 5 – Signaling size comparison

A. *Scalability extrapolation*

The scalability issues have a major importance for the interfaces evolved in the resource reservation process. The current section presents an operator scenario, illustrated in Table 2, that we used to perform a scalability study of the technologies under evaluation. The scenario represents a 6 Million users operator that use 3 network services simultaneously. It was considered that 30% of the users were simultaneously registered in the network and that the operator resource reservations validity last 30 seconds.

Table 2 – Scenario dimension

Item	Scenario	Comment
Clients	6M	Number of clients
Simultaneity (%).	30%	Simultaneity coefficient
Simult. services	3	Number of services simultaneously used by a client
Reservation	30s	Reservation validity

It was calculated the number of resource request messages sent from the admission control enforcer to the admission control decision maker, and the corresponding answering messages. We then calculated the generated signaling for each of the technologies accordingly with signaling information produced for the technology interfaces. The results are presented in Figure 6.

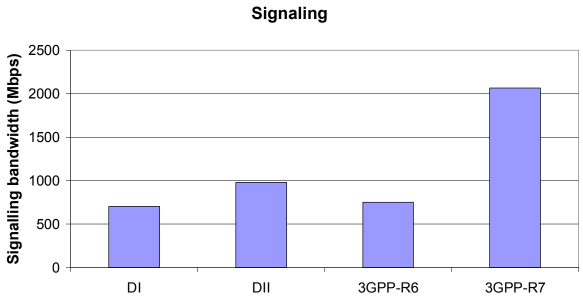

Figure 6 - Signaling results for the scenario from Table 2.

The best performance was achieved by the Daidalos I implementation with 700 Mbps followed by the 3GPP-R6 implementation with 750Mbps of signaling. The Diameter based implementations performed worst with 978 Mbps of signaling for the Daidalos II implementation and more than 2Gbps for the 3GPP-R7 implementation.

These results are important in the sense that they indicate a limit for the amount of signaling a server machine can generate based on the bandwidth available for that same machine.

Since the interface scalability highly depends on the number of messages generated by the admission control pair, we decided to study the effect of the variation of some related values: the number of the operator clients, the number of the services simultaneously used by the operator clients and the resource reservation period. Based on our initial scenario we performed a variation on each of the referred values and we analyzed the signaling effect.

With respect to the number of the clients we performed our analysis based on the operator dimensions referred on [25]. The results from the simulation are presented in Figure **7**.

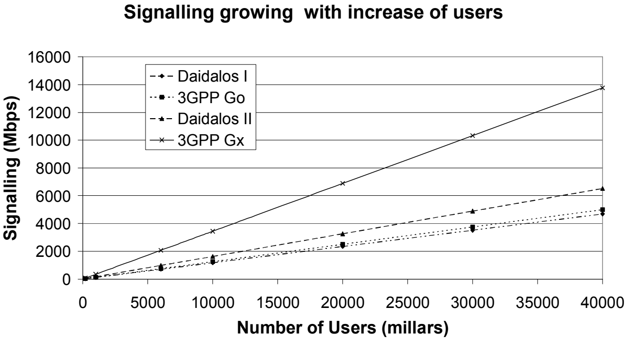

Figure 7 - Client number increase effect

The signaling bandwidth increases linearly with the increase of the number of the clients as well as with the technology performance. The 3GPP-*Gx* interface signaling reaches the 13.8 Gbps while the Daidalos I interface is bellow the 4.7 Gbps of signaling.

The reduction of the resource reservation period increases the number of the resource requests performed. The admission control enforcer performs a new resource request before the reservation timeout happens. On the other hand, short resource reservation periods allows an efficient resource management as well as they allow the creation of more flexible accounting methods.

In our simulation we varied the values of the resource reservation periods from 5 to 50 seconds in intervals of 5. The Figure 8 shows the resource reservation results.

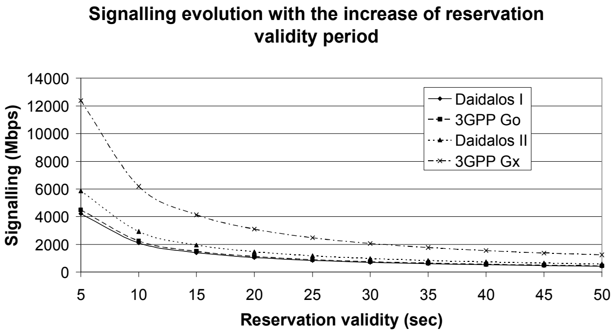

Figure 8 – Reservation period effect

These results show a logarithmic variation due to an increase in the validity of the reservation. Although these results show that for reservations that are valid for long periods such as multimedia services (VoIP, IPTV) the system performs well, smaller grain services such as web services will have a detrimental impact on the amount of signaling exchanged.

VI. CONCLUSION

In this paper we performed an efficiency analysis of the communication protocols used in the IMS *Go* and *Gx* interfaces for admission control aspects, as well as those used for similar purposes in the Daidalos I and Daidalos II project.

We concluded that COPS is more efficient that Diameter protocol mainly because of the verbose nature of Diameter, and quantified this difference to be around a factor of 3-4. In the scalability extrapolation study we verified that for a 40M users operator they would generate 14Gbps of signaling through an IMS *Gx* interface whereas they would generate 4,9 Gbps of signaling for an IMS *Go* interface.

The COPS based implementations used in IMS *Go* and in the Daidalos I prototypes did not shown significantly different results, since the results varied in less than 7% which can be attributed to specificities of each of the projects.

In the comparison between the Daidalos II and IMS *Gx* results we concluded that the IMS *Gx* is a much more complex interface. The reason has to do with the fact that IMS *Gx* implements an accounting communication mechanism whereas the Daidalos II this was kept a separated accounting mechanism. As such, the results obtained need to be carefully assessed, without forgetting this aspect. Our study did not perform a functional analysis of the COPS and Diameter solutions and of course the Diameter extra functionalities could justify the extra cost caused by the Diameter communication.

As future work it would be interesting to compare the effect of these technologies in terms of memory usage on the PEPs since they typically are very loaded machines and the memory requirements of the used technology will have a strong impact in their performance.

REFERENCES

[1]. D. Durham, J. Boyle, R. Cohen, S. Herzog, R. Rajan, and A. Sastry, "*RFC 2748 - The COPS (Common Open Policy Service) Protocol*", January 2000.

[2]. P. Calhoun, J. Loughney, E. Guttman, G. Zorn, and J. Arkko, "*RFC 3588 - Diameter Base Protocol*", Sep. 2003.

[3]. E.M.C. Centre, "*Overview of 3GPP Release 6 - Summary of all Release 6 Features*", Sep. 2006.

[4]. 3GPP, "*Overview of 3GPP Release 7 - V0.9.3*", Nov. 2008.

[5]. P. Gonçalves, J.L. Oliveira, and R.L. Aguiar, "An evaluation of network management protocols," *11th IFIP/IEEE International Symposium on Integrated Network Management* IEEE.

[6]. 3GPP, "TS 23.228-*IP Multimedia Subsystem (IMS) Stage 2*", Jan 2008.

[7]. 3GPP, "3GPP TS 29.209-*Policy control over Gq interface - version 6.7.0*", July 2007.

[8]. K.H. Chan, D. Durham, S. Gai, S. Herzog, K. McCloghrie, F. Reichmeyer, J. Seligson, R. Yavatkar, and A. Smith, "*RFC 3084 - COPS Usage for Policy Provisioning (COPS-PR)*", March 2001.

[9]. TISPAN, "ETSI TS 129 208-*End-to-end Quality of Service (QoS) signaling flows - version 6.7.0* ", Jun. 2007.

[10]. 3GPP, "3GPP TS 23.203-*Policy and charging control architecture*", Jun 2007.

[11]. "Designing Advanced network Interfaces for the Delivery and Administration of Location independent, Optimised personal Services", www.ist-daidalos.org, 16/10/2008.

[12]. R.L. Aguiar, A. Sarma, D. Bijwaard, L. Marchetti, and P. Pacyna, "Pervasiveness in a competitive multi-operator environment:the daidalos project," *Communications Magazine, IEEE*, vol. 45, no. 10, 2007, pp. 22-26.

[13]. R.L. Aguiar, S. Sargento, A. Banchs, C.J. Bernardo, M. Calderon, I. Soto, M. Liebsch, T. Melia, and P. Pacyna, "Scalable qos-aware mobility for future mobile operators," *Communications Magazine, IEEE*, vol. 44, no. 6, 2006, pp. 95-102.

[14]. R. Azevedo, A. Oliveira, F. Fontes, D. Guerra, P. Esteves, and T. Mota, "End-to-end QoS implementation in a B3G network," *Telecommunications, 2005. Advanced Industrial Conference on Telecommunications/Service Assurance with Partial and Intermittent Resources Conference/ E-Learning on Telecommunications Workshop. AICT/SAPIR/ELETE 2005. Proceedings*, pp. 122-127.

[15]. ETSI, "ETSI TS 183 048-*RACS; Protocol Signalling flows specification; RACS Stage 3*", June 2008.

[16]. ETSI, "ETSI ES 283 026-*Protocol for QoS reservation information exchange between the Service Policy Decision Function (SPDF) and the Access-Resource and Admission Control Function (A-RACF) in the Resource and Protocol specification*", Nov 2008.

[17]. S. Sargento, V. Jesus, F. Sousa, F. Mitrano, T. Strauf, C. Schmoll, J. Gozdecki, G. Lemos, M. Almeida, and D. Corujo, "Context-Aware End-to-End QoS Architecture in Multi-technology, Multi-interface Environments," *Mobile and Wireless Communications Summit, 2007. 16th IST*, pp. 1-6.

[18]. J. Boyle, R. Cohen, D. Durham, R. Rajan, S. Herzog, and A. Sastry, "*RFC 2749 - COPS usage for RSVP*", January 2000.

[19]. P. Calhoun, T. Johansson, C.E. Perkins, T. Hiller, and P.J. McCann, "*RFC 4004 - Diameter Mobile IPv4 Application*", August 2005.

[20]. M.A. Garcia-Martin, M.-C. Belinchon, M.A. Pallares-Lopez, C. Canales-Valenzuela, and K. Tammi, "*RFC 4740 - Diameter Session Initiation Protocol (SIP) Application*", November 2006.

[21]. R.L. Aguiar, J. Jaehnert, A.F.G. Skarmeta, and C. Hauser, "Identity Management in Federated Telecommunications Systems," *Workshop on Standards for Privacy in User-Centric Identity Management*.

[22]. D. Gomes, "COPS++," http://hng.av.it.pt/~copspp/.

[23]. 3GPP, "3GPP TS 29.207-*Policy control over Go interface*", Set 2005.

[24]. 3GPP, "3GPP TS 29.212-*Policy and charging control over Gx reference point*", May 2008.

[25]. Wikipedia, "List of mobile operators of Europe", http://en.wikipedia.org/wiki/List_of_mobile_network_operators_of_Europe.