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# DEVELOPMENT OF AN OPEN SOURCE IMS CORE FOR EMERGING IMS TESTBEDS, THE ACADEMIA AND BEYOND

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The IP Multimedia Subsystem (IMS) as defined by the 3GPP emerges as blueprint for a central architecture to provide Next Generation Network (NGN) services. As an overlay architecture for IP based access networks, it provides standardized interfaces to services which will merge the advantages of traditional telephony networks with the benefits of Internet services.

The *Open IMS Core*[1] project of the Fraunhofer Institute FOKUS which is described in this article started in 2006 as an Open Source initiative targeted at all parties interested in the research development of NGN services and IMS testbeds. The Open IMS Core consists of Call Session Control Functions and a Home Subscriber Server and aims to fill the void in the Open Source software landscape with flexible solutions that have proved their conformance and performance in several national and international R& D projects.

This article highlights the challenges in the development of the components and provides insights on major implementation details as well as for their performance. Examples of the usage of the Open IMS Core will illustrate how IMS Open Source software helps not only rapid, but also efficient, flexible and powerful design, development and testing of NGN components and services.

*Keywords*: Diameter, CSCF, HSS, IMS, NGN, Open Source, OpenIMSCore SIP

*Communicated by*: A. Hafid, P. Dini & K. Liu

## 1 Introduction

The NGN study group of the ITU-T defined NGNs in [2] (amongst other criteria) to be packet-based networks which are capable of providing services (including telephony services) over multiple Quality of Service (QoS) enabled access technologies in a manner where services are decoupled from the underlying technologies used to serve them. The IMS as currently specified in Release 7 by the 3rd Generation Partnership Project (3GPP) works towards becoming a crucial part for the realization of the NGN vision of the ITU-T. Features like the dedicated support of QoS in the access network are addressed as well as the creation of a unified abstraction layer for services. IMS is standardized based on specifications and protocols of the Internet world. It is structured in a way that will provide almost unlimited multimedia capabilities for customers plus a very flexible service layer while offering appealing service creation and delivery possibilities for the operators.

The core of IMS signaling is based upon the Session Initiation Protocol (SIP) [3], a general dialog initiation protocol between two or more peers. From the technical point of view, SIP is a HTTP-like protocol based on requests and responses between nodes, capable of carrying the signaling of arbitrary contents. It emerged in the Voice over IP (VoIP) world (but it is not limited to it) as a response to the complicated stacks of H.323 [4] solutions. Besides SIP, the IMS uses other IP-based protocols like Diameter [5] or H.248 [6] to provide a core network architecture which supports the integration of existing Intelligent Network (IN) services with new SIP-based ones.

Since mobile devices are becoming smarter and are constantly gaining processing power, the SIP and IMS specifications moved a part of the signaling load from the core, as in a SS7 environment, to the edge of the network. The shift of a mobile network setup from a model where a rather dumb client communicates with an intelligent network towards the model of the Internet where a smart client communicates through a network that merely ensures routing[a] towards smart services is what makes the IMS a catalyst for convergent services.

While many vendors of core telephony network technology are currently performing research on concepts around the IMS and its components in a closed and company-internal manner, there were practically no core elements implementations existing previously in the Open Source field that would help to foster the widespread research of additional concepts around IMS in the R&D community as it has been established within the VoIP domain.

This article begins with a review of the standardization bodies and technical specifications. Then the IMS architecture is outlined and Chapter 4 contains a motivation for continuing the institute's VoIP efforts towards IMS. Chapter 5 discusses the challenges presented by an IMS core network and Chapter 6 is an overview of the current implementation efforts and status. At the end the Open IMS Core is validated and a brief summary closes the article.

## 2 IMS as core platform for Next Generation Networks (NGN) and Fixed/Mobile Convergence (FMC)

For long time voice communication was synonym with fixed telephony. This was the main source of revenue for the telecommunication industry, an industry that has seen major developments once Intelligent Network (IN) services were provided, or with the introduction and large adoption of mobile communication.

The Internet is continuously the scene for major breaktroughs in communication. E-Mail, World-Wide-Web, Instant-Messaging and other new paradigms generated growth for the telecommunication industry, but voice communication remained out of the Internet world until the introduction of Voice over Internet Protocol (VoIP). On the other side, the vast range of new IP services did not make a major breaktrough in classical telephony, although signs like E-Mail-to-Phone appeared. Clearly, both the telephony and the Internet worlds had serious issues into converging.

But the market drive at this point makes it clear that convergence is unavoidable. The Internet industry made important steps with the adoption of two standards that made VoIP

[a] and in case of IMS adds quality of service on top of it

a viable solution: H.323 and SIP. On the other side, the need for future networks to converge is materializing into the NGN concepts. The basic requirement for these future architectures is to offer an unified service delivery platform over reliable Internet standards.

### *2.1 Review of related NGN standards bodies*

The Third Generation Partnership Project (3GPP) is a collaboration agreement that currently has the following organizational partners: ARIB[b], CCSA[c], ETSI[d], ATIS[e], TTA[f] and TTC[g]. Established in December 1998 it has the scope of defining a globally applicable (3G) mobile phone system. The specifications are based on evolving Global System for Mobile communication (GSM) standards, currently known as the Universal Mobile Telecommunications System (UMTS). Inside this organization, the IMS concepts were defined as a solution for an universal all-IP telecommunication network.

Also in December 1998, a parallel collaboration agreement was created. The Third Generation Partnership Project 2 (3GPP2) was born out of the International Telecommunication Union's (ITU) International Mobile Telecommunications "IMT-2000" initiative and it is constituted by the following partners: ARIB, CCSA, TIA[h], TTA and TTC. 3GPP2 also embraces the IMS concepts. However, the focus of 3GPP2 is on CDMA2000[i] technologies, while 3GPP is concentrated on the W-CDMA[j] set of technologies.

Furthermore, recognizing the value of IMS, a third organization also embraced its concepts. The Telecoms and Internet converged Services and Protocols for Advanced Networks (TISPAN), formerly Telecommunications and Internet Protocol Harmonization Over Networks (TIPHON) is a body of ETSI having the scope of converging fixed and Internet networks. By adopting and reusing IMS components with additions to the xDSL technologies, TISPAN NGN standards are aiming directly at an universal fixed-mobile convergence. Its first release, based on 3GPP's Release 6 and 3GPP2 Revision A, proposes an architecture that shares common resources, mostly based on IMS components. This will ensure a maximal user and terminal mobility.

With three different standardization bodies accepting the same core technologies it is highly probable that NGNs will share the same core components with some additions for specific access networks. With respect to IMS component standardization the 3GPP is leading the efforts and enables a form of standardized NGN.

### *2.2 IMS for ubiquitous communication*

Taking the pulse of the industry, it becomes clear that the telecommunication markets are more than comfortable in using different products, like mobile communication, fixed telephony, broadband Internet access, wireless broadband, video-on-demand etc. However, more and more customers demand that these services are provided into an ubiquitous manner. Delivery

[b] Association of Radio Industries and Businesses (Japan)
[c] China Communications Standards Association (China)
[d] European Telecommunications Standard Institute(Europe)
[e] Alliance for Telecommunications Industry Solutions(U.S.)
[f] Telecommunications Technology Association (Korea)
[g] Telecommunications Technology Committee (Japan)
[h] Telecommunications Industry Association (North America)
[i] Code Division Multiple Access 2000
[j] Wideband Code Division Multiple Access

of any services should take place over any network and at the same time the switch must be seamless.

From this we can draw 2 planes: the access plane and the services plane. On the access plane, customers demand that the communication networks converge into a common layer which allows usage of any such networks in similar manner. Wired or wireless networks need to be accessed in the same way. On the second plane, the services need to be decoupled from the access network. Of course, there are certain dependencies between them, but the overall architecture must enable any service to work over a generalized access plane.

Here IMS comes into play as a broker between the access networks and the services. The access network is supposed to enable an IP network on top and the services must be deliverable over such IP networks. In the middle, IMS enables services by offering and ubiquitous platform to control the network parameters and to transport the data.

The Fixed/Mobile Convergence (FMC) is an essential topic for cable, mobile and fixed operators and with it also for any Telecom Equipment Manufacturer (TEM) or Service Provider (SP). Starting from 2005, this became a key marketing trend for the telecommunication industry. IMS plays also in this area a key role since it promises a well-defined platform for enabling FMC.

## 3 IMS Architecture

As a broker between access network and services, the IMS architecture can be split into three layers: transport, IMS and services/application. While the transport layer offers the adaption required for each underlying communication network, the IMS layer enables basic functionality and brokerage for the 3rd layer, where services and applications are executed.

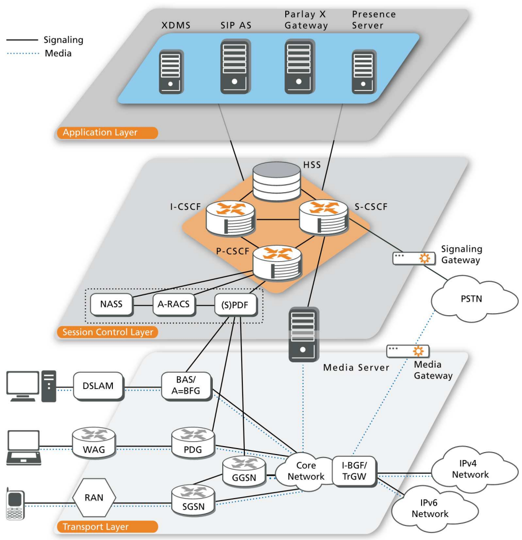


Fig. 1. IMS Architecture Overview.

As seen in Figure 1, the core components of the IMS layer are the Call Session Control Functions (CSCF). We are considering this to be essential components for any IMS network and such we are including them in our Open IMS Core concepts. Because even basic signaling routing functionality requires information lookup in a Home SubscriberServer (HSS), normal usage of such a core network is not possible without it, therefore a HSS is also part of the Open IMS Core project.

The idea of the entire project is to enable the development of IMS components around the core elements based upon pure Open Source software. The application layer development of IMS can be done for various platforms, be it pure SIP Application Servers, an OSA/Parlay respectively Parlay X Gateway or even an IN service that is connected to the IMS via an IMS Service Switching Function. Through the Open IMS Core project all of those platforms should have a fully 3GPP IMS compliant IMS Service Control interface at hand that allows them to make use of IMS routing features for converged services. But also towards the access network layer, the Open IMS Core enables the development of components and concepts that come with the attachment of various access networks to the overlay architecture IMS. One central point for stimulating as many development efforts in both areas was the idea to make the core routing functions available to the public in order to extend and to make the functionality of the IMS core elements adjustable to various needs and requirements.

## 4 Extending the VoIP Experience - From SIP Express Router (SER) to Open IMS CSCF

The CSCFs are represented by SIP agents with various specific requirements. For example, the Serving-CSCF (S-CSCF) is a SIP registrar for a part of the home domain. As the classical SIP agents specifications are extended for IMS with processing indications, it makes sense to build such CSCFs on top of existing SIP agents. Fraunhofer Institute FOKUS already had the experience of a very successful agent, the SIP Express Router[7], and extending this into powerfull CSCFs came natural.

### *4.1 SIP Express Router*

By driving the development of SER and its eventual release as Open Source software within the last years, the Fraunhofer Institute FOKUS enabled through its Open Source initiative iptel.org numerous R&D efforts around the SIP standard and VoIP concepts.

The SIP Express Router is a high-performance, configurable, Open Source SIP[3] server licensed under the GNU Public License. It enables functionality as SIP registrar, proxy, redirect server and more. With a modular structure several modules are bundled, implementing features like authentication, authorization, accounting, application-server interface, presence support, database interfaces, accounting, SMS gateway, SIMPLE2Jabber gateway, server status monitoring, etc. This functionality can be further extended with new modules implementing satisfying future requirements.

As the primary concern was performance, SER distinguishes itself as a very fast SIP router, able to deal with operational burdens, such as broken network components, attacks, power-up reboots and rapidly growing user population. To enable full flexibility in any usage scenario, the processing of SIP messages is performed through a user configurable routing & processing script which also takes advantage of the powerful extensibility through modules. This configuration ability meets needs of a whole range of scenarios including small-office use, enterprise PBX[k]replacements and carrier services.

In the past years SER positioned itself as a well known SIP router. Most of the VoIP networks in Germany and Europe are using it at the core of the network for the most resource-hungry tasks. Achieving such a large deployment and bringing together a wide community, SER as an Open Source project achieved an important recognition in the SIP world.

### *4.2 Design Requirements for IMS*

While IMS relies upon IETF specifications like the SIP standard [3], the SIP protocol requires certain extensions for IMS. The primary requirement for the Open IMS Core project therefore was to provide a set of IMS compliant components that will enable the development of the other layers around them. Accordingly, the main scope was to obtain compliant CSCFs and HSS. This means that all required functionality, as indicated by 3GPP in its Release 6 has to be implemented by this components.

Another requirement to the CSCFs was to maintain as much as possible SER's performance. As SER obtained a wide adoption in the SIP world, becoming almost a standard for performance, it is assumable that the CSCFs, sharing such a large base with SIP routers, would have similar performance standards. To conclude, it was important for us to maintain this high-performance grade, especially as the Open IMS Core should be able to produce first time answers for IMS scalability, distribution and performance questions.

Third, the 3GPP specifications represent a set of basic requirements, but around them many actual implementations will probably cut corners to achieve better running conditions, while still compliant with the specifications. For this reason, the Open IMS Core had to maintain SER's user scripting facilities, which enables full flexibility in exploitation. The IMS features are to be exported but how they will be orchestrated must be easily configurable.

Of course goals like achieving carrier-grade performance, certain security and availability requirements must be taken into account for the long run. Yet, since our main interest in developing these components was towards enabling an open community around the IMS core network, that will help development of IMS components and NGN services and adoption of IMS paradigms, these were not primary goals. Commercial implementations will certainly provide those features and the Open IMS Core project is not set to compete with such implementations, rather help the industry into R&D efforts to overcome challenges with setting up IMS networks and enabling the development of services that make use of the IMS core.

## 5 Challenges

The actual realization of an IMS core network proved to be a difficult task [8]. The main challenge was that it had to perform very well in terms of speed and in functionality. It had to reduce the processing to the minimum while it implements all functionalities required in the IMS specifications. The scope is to have a reference implementation by closely following the specifications and not compromising conformity for performance. For all interfaces related to the Open IMS Core we followed the specifications for Release 6 of the 3GPP IMS.

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[k]Private Branch eXchange

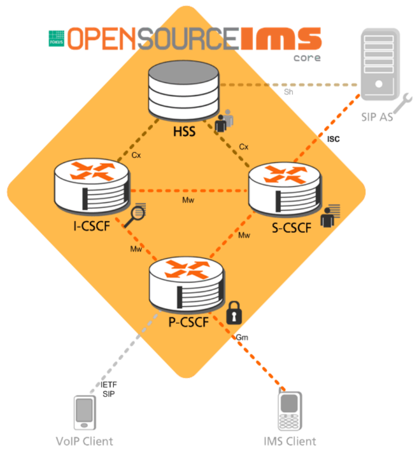


Fig. 2. IMS network components with Open Source IMS Core components emphasized.

### 5.1 *The Call Session Control Functions*

At the functional-core, the CSCFs are SIP proxies. This main functionality is complemented by registrar and B2B UA[l] capabilities. As all three entities share a lot of functionality, it makes sense for them to use a common base system, just configured differently.

As noted, the CSCFs are built upon the SER which can act as SIP registrar, proxy or redirect server and is capable of handling many thousands of calls per second. It has a modular structure that permits to make functionality additions. Each CSCF entity of the Open IMS Core is implemented as a SER dynamically loadable module that adds the required operations to the SER so that it can act according to the specific 3GPP technical specifications. The modules are capable of parallel processing and can keep supplementary state information. There is a special focus towards scalability for both load distribution and data quantity.

#### *5.1.1 SER IMS extensions*

As SER was designed to be a powerful SIP proxy/server and it also achieved a large deployment, it qualifies as the first candidate for enabling the SIP functionality. To be usable in an IMS environment it must also feature Diameter capabilities. This has proved to be not as easy as integrating RADIUS,[m] since a Diameter node must have both client and server capabilities at the same time. With special concerns towards speed, using an external stack would have not yielded good results because of numerous context changes and data exchanges. However, the target was to have a low latency of just a few milliseconds for SIP transactions and so the Diameter requests must be processed with even lower delays.

The obvious solution is to add Diameter as a SER module. As SER is open source, this could bring many benefits from the community while keeping the core unchanged and compatible with all the current and future modules. However, this solution is only usable for SER acting as a Diameter synchronous client. Asynchronous or server functionality will suffer from serious lack of performance.

[l] Back-to-Back User Agent
[m] RFC 2865 Remote Authentication Dial In User Service (RADIUS)

Core integration of a custom built Diameter stack is the best performance-wise solution. The Open IMS Core CSCFs run on an Diameter enhanced SER. Diameter peer processes run alongside SIP processes, providing cross access to each-others capabilities while still offering best performance. Due to its high parallelism grade, it is best to run these in a multi-processor environment.

Another problem arises from the new and evolved user profile employed in an IMS environment. While existing user location, registrar and authentication SER modules were already available, the data structures employed in IMS are more elaborated. Again, going for the simple solution of introducing this as generic additions to the above existing modules would have not allowed for the best performance.

The user location module required additions for keeping the extra user information employed in IMS, like the private/public identities, Proxy-CSCF (P-CSCF) path information, Initial Filter Criteria, etc. Replicating data into a database is not necessarily required as mechanisms for orderly moving users from a CSCF to another are specified in IMS. The registrar must also implement the "reg" event subscriptions and notifications [9]. The P-CSCF employs a reversed-registrar that must synchronize itself with the registrars on S-CSCFs. Regarding authentication, Authentication and Key Agreement (AKA) [10] mechanisms are mandatory in order to generate key material for the signaling security tunnels (IPSec) towards an IMS user.

Combining the registrar with the user location into a common user data storage module offers better performance, but it is breaking compatibility with existent modules that were basing their functionality on the replaced modules.

### *5.1.2 Proxy-CSCF*

In the current implementation of the Open IMS Core, the P-CSCF component is able to firewall the core network at the application level: only registered endpoints are allowed to insert messages inside the IMS network and the P-CSCF asserts the identity of the users. For this, upon registration, the P-CSCF establishes secured channels individually for each User Endpoint (UE) that it services.

To keep track of the registered users, it has an internal reversed-registrar that is updated by intercepting the registration process and later by subscribing in User Agent Client (UAC) mode to the registration package at the S-CSCF and receiving notifications. The actual data is kept in a hash-table to allow fast retrieval.

For originating call signaling it generates unique charging vectors and inserts network and path identifiers that are needed for the correct further processing of the SIP messages. UE forged information that might lead to an attack is removed and/or corrected. After a successful registration process to an IMS home network, subsequent user messages are forwarded based on DNS information towards the requested IMS home network.

Regarding NAT[n] issues for the SIP signaling, in the outgoing direction, towards the user endpoints, it can act as a router by simply being active in both networks. Also, NAT traversal modules were adapted for the specific user location storage mechanisms. After user-specific security data (like cypher keys) has been eliminated, the SIP messages are forwarded directly to their destination. Filtering in this direction is needed since cipher material must not be

[n] Network Address Translation

sent over the potentially untrusted connection between the UE and P-CSCF.

#### *5.1.3 Interrogating-CSCF*

The Interrogating-CSCF (I-CSCF) has the role of a stateless proxy that, by using the indicated public identities of the caller or the callee, queries the Home Subscriber Server (HSS) and based on responses routes the message to the correct S-CSCF. It implements the Cx [11] interface of an I-CSCF to the HSS. Therefore it supports the required Diameter commands to locate the user-assigned S-CSCF or to select, based on capabilities, a new S-CSCF and check identities, roaming authorizations as specified in [11].

After receiving a successful answer for the Diameter query the I-CSCF forwards the SIP messages in a transactional mode. It is optimized for speed and minimalistic state information is kept. To protect the home network, it has a firewalling capacity that only allows signaling messages coming from trusted networks through Network Domain Security (NDS).

#### *5.1.4 Serving-CSCF*

The S-CSCF implementation also communicates with the HSS using Diameter (over the Cx interface) to retrieve authentication vectors, update registration information and download the user profiles as specified in [11]. The S-CSCF can apply the user profile based initial Filter Criteria (iFC) to enforce specific SIP routing rules. It implements support for carrying out the IMS Digest AKA version 1 [10]. Rather than generating authentication vectors it relies on the HSS for this task and compares these values to the ones calculated in the UE. For fast response times with minimal locking, the registrar of the S-CSCF has a complex structure based on hash-tables. The information that is required to relate a user identity to a physical UE is stored here and used further on for call routing. It also accepts subscriptions to registration state events and notifies the subscribers about changes in the registrar.

### ***5.2 Home Subscriber Server***

The Open IMS Core would be incomplete without a Home Subscriber Server. FOKUS developed an own prototype HSS, the FOKUS HSS (FHoSS) which is entirely written in Java and based upon Open Source software. The user data is kept inside an external MySQL database. As its purpose in the Open IMS Core is that of a database, the FHoSS is targeted mainly towards conformance keeping in mind performance. It is mostly a glue between a DataBase Management System (DBMS) and the Diameter interfaces with the CSCFs and IMS application layer. Protocol checks and Diameter command logic are implemented in the HSS. Additionally, it allows the generation of authentication vectors, notification of IMS based events to subscribed IMS application servers via the Sh reference point [12] and it provides a HTTP-based management interface for easy management of user profiles and associated iFC.

As we found in the work on [13], one of the main performance bottlenecks seems to be related to the HSS and database access. Implementation of replication, distribution, caching or other optimization methods at the HSS are not efficient as the DBMS is already implementing those. For evaluating the mere performance of the CSCFs, a very performant HSS is required. Therefore a light-weight stateless HSS emulator which allows specific operations over the Cx interface [11] was implemented in C for carrying out some performance related measurements. It runs on a multi-threaded architecture and is capable of handling many clients and processing the requests through parallel workers. It does not keep any IMS state in memory but uses a MySQL database for this purpose.

## 6 Implementation Issues & Status

A full implementation of the whole features usually takes a long time. However, certain core features are to be implemented first as the rest of the implementations depend very much on that functionality. Problems identified at early stages must be fixed early to avoid future redesigns.

The implementation started with the first operation required for IMS, registration. For a successful Digest-AKAv1-MD5 authentication a HSS is needed to provide authentication vectors. The functions for Milenage key generation were implemented and the Cx link between S-CSCF and HSS. Because at first Diameter was not available as part of SER and it was developed on a parallel track, another very simple protocol was employed. This was designed by us as a very simple transport protocol for Diameter messages. Pretty-Simple-Diameter-Like (PSDL) was implemented on both sides and at the network level the traces were almost identical with those employed in normal operations. Later, when the Diameter extensions for SER were ready, PSDL was easily replaced with these extensions. In this first authorization step the Multimedia-Authentication-Request/Answer (MAR/A) Diameter commands were implemented.

Next an I-CSCF was started. Using the same PSDL libraries at the beginning and then Diameter, the User-Authorization-Request/Answer (UAR/A) Diameter commands were implemented, along with capability selection and Network Domain Security (NDS). To complete the authentication a Proxy-CSCF (P-CSCF) was started, enabling basic roaming functionalities.

To complete the registration process, the S-CSCF was then extended with a rebuilt registrar, adapted to IMS user profile requirements. To download the user profiles, the Server-Assignment-Request/Answer (SAR/A) Diameter commands was added with additions to the ongoing HSS development for full user profile.

The P-CSCF was also extended with a reversed-registrar, as compared to the S-CSCF, and signaling firewalling capabilities were introduced.

Once registration was completed, to enable message exchange and session set-up/tear-down, the I-CSCF needed to be extended with the Location-Information-Request/Answer Diameter command. At this point the Open IMS Core was capable of handling registration and basic SIP functionality.

Next, to enable the service plane, the S-CSCF was extended with iFC triggering capabilities and IMS Service Control (ISC) interface support. This enables triggering and use of services, as required per each individual user and as specified in the service profiles on the HSS.

In the next sub-chapters each component has its functional architecture described.

### *6.1 The Proxy-CSCF*

The P-CSCF, presented in Figure 3, is realized as SIP firewalling proxy. It spies on registration signaling and then keeps its internal reversed-registrar updated by subscribing to the "reg" event package at the S-CSCF assigned for each respective user. This registrar is referred to as reversed, because the Contact details are pointing to the user identities (Address of Record), as opposed to a normal registrar where the user identities are pointing to Contact details.

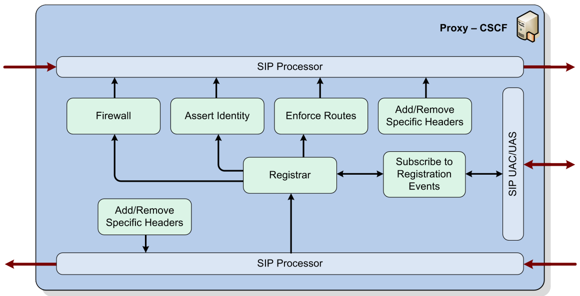


Fig. 3. The Proxy-CSCF functional schema.

Additionally, the P-CSCF prevents attacks by being able to deny further access from UEs that are not registered. After messages pass through this initial firewall, they are asserted with the real identity of the UE so that other components would be able to trust them. To force normal behavior, certain signaling routes are enforced here and specific headers, like Visited Network ID or Charging Vectors, are inserted.

### *6.2 The Interrogating-CSCF*

The I-CSCF, presented in Figure 4, is a SIP transparent redirect server. Because this also is an entry point in the domain network, NDS security is applied and messages comming from untrusted hosts are discarded. For registration signaling it performs the look-up in the HSS for S-CSCFs to redirect to and it is also performing capability selection. For the terminating leg, the I-CSCF is capable of Location Information Queries to the HSS and then forwarding to the respective S-CSCF. Whenever the I-CSCF is redirecting a message, if the first S-CSCF fails to respond and alternatives are available, serial forks are performed.

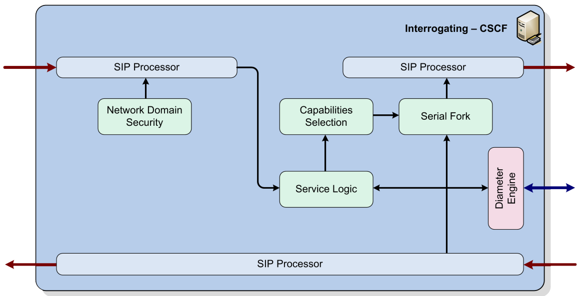


Fig. 4. The Interrogating-CSCF functional schema.

### *6.3 The Serving-CSCF*

The S-CSCF, presented in Figure 5, mainly acts as a registrar for a part of the home domain. This registrar also acts as an event pusher and other components can get informed about changes by subscribing to notifications.

By communicating with the HSS, it updates global information related to the user location and it also downloads into the registrar the user profile. Based on this user profile, the S-CSCF

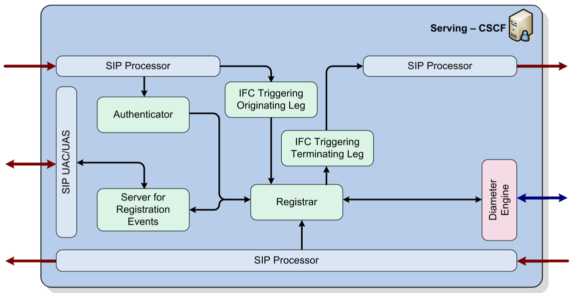


Fig. 5. The Serving-CSCF functional schema.

is capable of performing iFC triggering and exchange messages with the Application Servers through the ISC interface. The triggering is applied up to two times, for the originating leg and then for the terminating leg, checks being applied for the respective user profiles of the originating and terminating users. Of course, multiple triggers may match subsequently.

### *6.4 The Home Subscriber Server*

The HSS stores the user profile information of all IMS users in MySQL Database. The Java-based Diameter stack is used to validate the correctness of all incoming Diameter requests and answers. It is acting as a Diameter peer and in case of changes of user profile information for currently served users or for notifications of subscribed application serves, it sends out Diameter messages.

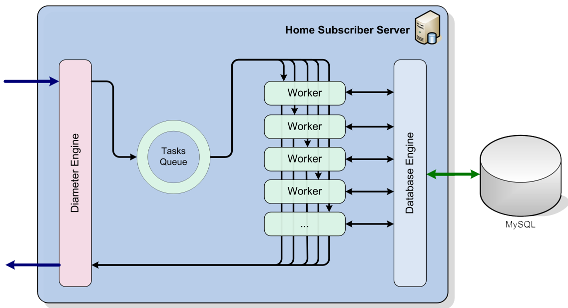


Fig. 6. The Home Subscriber Server functional schema.

The architecture is centered around parallel workers which translate the Diameter requests into SQL queries and perform a logic on top. It supports both Diameter interfaces required for the IMS ([11, 12]) and allows therefore notifications to subscriptions from application servers on changes in the user profile (e.g. changes in the user status) via entries in the database.

### *6.5 The SIP-to-IMS Gateway*

To accelerate testing and to integrate with SIP UEs and test tools, a gateway that helps SIP traffic to work in an IMS environment was required. Presented in Figure 7, the SIP-to-IMS gateway performs this adaption tasks. At the moment it translates between MD5 and AKAv1-MD5 authentications and helps with special headers. For future developments, it will add IPSec support and perform the rest of functionality from SIP to a compliant IMS UE.

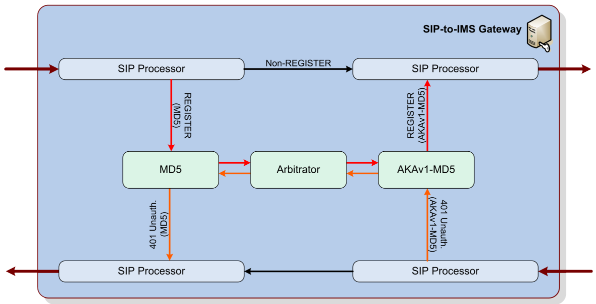


Fig. 7. The SIP-to-IMS Gateway functional schema.

## 7 Validation

The functionality and performance of the Open IMS Core was validated in the FOKUS Open IMS Playground within the last year. The following sections should allow to put the Open IMS Core in perspective to current VoIP installations since they outline the functionality of the Open IMS Core in the deployment of a simple service.

### *7.1 The Open IMS Playground*

The FOKUS Open IMS Playground [14, 15] is a unique open and vendor-independent IMS test environment which allows to experience the realization of IMS concepts and first IMS services based on prototypes of IMS components of the Fraunhofer Institute FOKUS as well as on carrier-grade IMS equipment of commercial vendors. FOKUS provides with the Open IMS Playground an open IMS platform where all IMS key components (x-CSCFs, Media Gateways, SIP Application Servers, IMS Clients etc.) are enabled. Interconnection to other IMS testbeds is currently under development.

Figure 8 shows that the Open IMS core forms the heart of the Open IMS Playground around which several IMS components were developed. Besides a Java-based Open IMS client [17] that allows to do IMS registration, signaling and supports features like presence or grouplist management, there is also a SIP application server the SIP Servlet Execution Environment (SIPSEE) [18] that allows the development of converged HTTP and SIP servlets and the Parlay and Parlay X Gateway (Open Communication Server (OCS) resp. (OCS-X)) that make also use of the ISC interface to map services to an IMS network.

Besides providing an ideal environment for developing NGN applications, application platform extensions as well as for IMS mobility, high-availability, performance evaluation, QoS and security research, the Open IMS Playground plays a key role in various national and international research projects as a technology hub.

### *7.2 Deploying services on the Open IMS Core*

As an example of deployment of a service with the help of the Open IMS Core, we will highlight the steps that are needed for the realization of a MESSAGE-2-SMS Service. The simple messaging service allows users with an associated service profile to trigger the sending of an SMS into a circuit switched network from an IMS network by simply sending a SIP MESSAGE to the MSISDN of a recipient. It illustrates the few steps that were necessary to trigger a service hosted on an IMS application server while using the Open IMS core to route

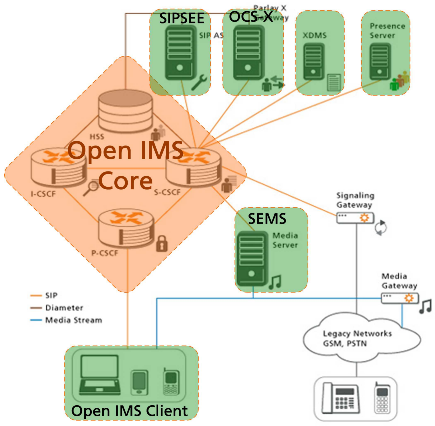


Fig. 8. The Open IMS Playground.


Fig. 9. FHoSS Screenshort of the Trigger Point for the MESSAGE-2-SMS service.

SIP messages.

The first step was to build a simple SIP servlet application, which on receiving a SIP message with the method MESSAGE, would take information from the Request-URI and send the content-body in the content-type text/plain through a SMS gateway.

The second step was to write an iFC for the HSS that will trigger on such specific messages and route them towards the SIP servlet Application Server implementing the MESSAGE-2-SMS gateway. As part of the user profile of an IMS user, service profiles are assigned to an IMS Public Identity (e.g. sip:sampleuser@open-ims.org) which carry the iFC for triggering specific actions in the user's S-CSCF. The iFC is set to match on every initial request with the SIP method field set to "MESSAGE" and with a "To" header matching a regular expression value. This regular expression was set to all SIP URIs that are composed as following: "sip:[0-9]+@open-ims\.org". This filter criteria was attached to the service profile of the test originator user.

The last step before sending the request was to register the originator user to the home domain. In this operation, the S-CSCF downloads the user profile through the Cx interface from the HSS.

Testing the service, the UE sent the MESSAGE request, as in the originating part of a call, through the P-CSCF and the S-CSCF. When at the S-CSCF, the originating party's filter were evaluated and the request was forwarded to the Application Server, which processed it as indicated in the first step and responded with a final response to the UE (through the S-CSCF and the P-CSCF), ending the transaction with success.

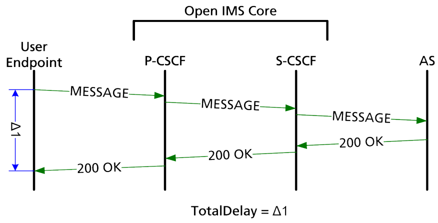


Fig. 10. MESSAGE-to-SMS Application Signaling flow

The actual implementation of the MESSAGE-2-SMS service took no more than one day and its deployment in the network was an update of the user profile information and the installation of the service on the SIP Application Server. The MESSAGE-2-SMS service illustrates the application of iFC in the S-CSCF of the Open IMS Core and its value for prototyping and testing NGN services.

### *7.3 Service latency in basic scenarios*

To have an evaluation of the performance of the components several intermediate tests were performed. Because it is usually hard to simulate individual benchmark for each component and then to also combine results in a relevant manner, testing the whole network together makes more sense. Several scenarios were evaluated and the results are presented in Table 1. During the tests there was no background traffic and the rate of message arrival was low. The SIP messages were almost identical to those indicated in [16] as signaling flow examples, containing all the necessary headers plus the SDP[o] bodies (there was no media traffic though). The hardware platform was a dual-CPU average x86 server.

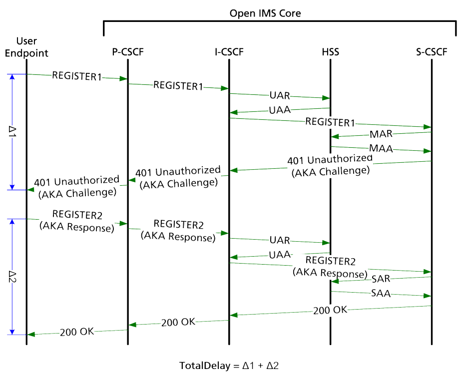


Fig. 11. Registration Signaling Flow

The following scenarios were simulated:

[o]Session Description Protocol

- Registration - Figure 11 - as the process by which an UE authenticates itself to the network, then the network saves the contact information and the user profile is downloaded. The core network latency is regarded as the sum of delays between the time that the first message was sent out and the first final response was received.
- De-Registration - Figure 11 - similar to registration, but the network drops the contact information for that user and possibly discards the user profile.
- IMS 2-party call - Figure 12 - a complete session set-up plus tear-down including signaling required for QoS reservations. As this scenario involves 2 UEs, the latency induced by the network and the Open IMS Core components is calculated as the difference between the total transactional delays on one side minus the total UE processing delays on the other side.

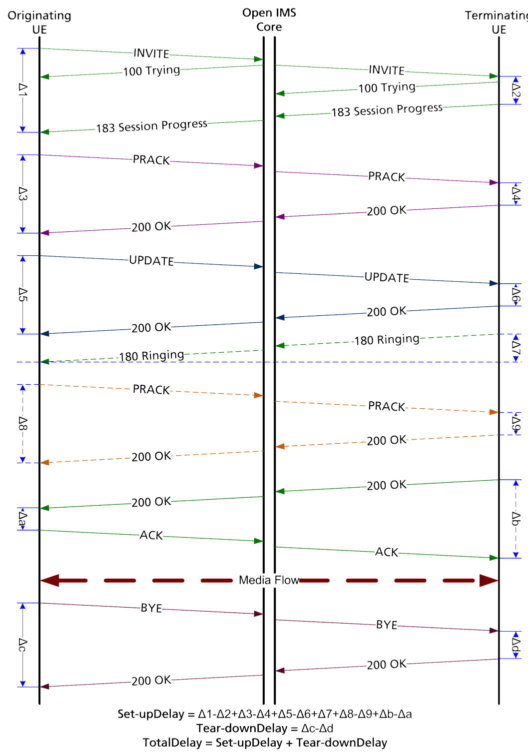


Fig. 12. IMS 2-party Call Signaling Flow

- IMS 2-party messaging - Figure 13 - a simple message exchange between 2 peers. Again, the processing delay on the terminating UE are subsctracted from the measured delay on the originating UE.
- MESSAGE-to-SMS Application - Figure 10 - a scenario in which an Application Server is involved. The request is filtered by the S-CSCF according to an iFC and it is forwarded to an Application Server. This Application Server is simulated with an ideal response time as a gateway from SIP MESSAGE to SMS.

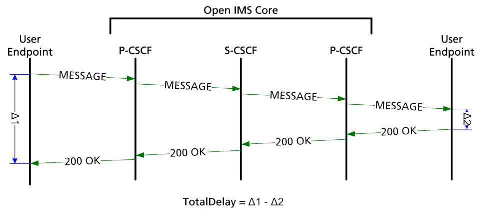


Fig. 13. IMS 2-party Messaging Signaling Flow

From Table 1 we can conclude that the Open IMS Core has a good performance. A registration process involving 12 SIP Messages and 8 Diameter messages is completed in around 20 milliseconds, a low delay considering that many queries and updates were performed during this process to the MySQL database.

For the IMS Call scenario, many more SIP messages were involved and no Diameter messages as the network was configured with only one S-CSCF and both users were registered there. Although the number of messages is high, the latency was under 20 milliseconds. For simple messaging the delays were very low and under 3 milliseconds. Filtering the messages in the last scenario also happened very fast and still under 3 seconds. The reason why application messaging is slightly faster than 2-party messaging is that the ideal Application Server simulation performed better than the P-CSCF and also the number of exchanged messages was lower by 2.

From the results and considering that the whole Open IMS Core has a parallel-processing architecture we can assume that these components will be able to handle many hundreds of dialogs per second on an average dual-CPU server.

## 8 Addressing the IMS skepticism

In the IMS community there is a very strong skepticism around the IMS standards mainly concerning the practicality of such systems or the weaknesses of the standards. During the implementation we were often frustrated by such open issues and we would've certainly enjoyed if the standards would detail all the aspects and the possible scenarios. However, we also understand that IMS represents an abstract platform for service delivery and because of that, it is nearly impossible to cover all aspects in the specifications. In this regards we are choosing to design our components open and flexible to future additions and modifications. For example when considering the transition to 3GPP IMS Release 7 there are some upgrades that need to be operated in the code, but most of the changes are simply configuration scripts ones.

Table 1. Latency

| | Measurements | Processing Time (avg) | Standard Deviation |
|---|---|---|---|
| Registration | 17.460 ms | 100 | 3.600 ms |
| DeRegistration | 21.590 ms | 100 | 6.500 ms |
| IMS 2-party call | 18.850 ms | 100 | 3.620 ms |
| IMS 2-party messaging | 2.730 ms | 100 | 0.770 ms |
| MESSAGE-to-SMS | 2.703 ms | 1000 | 0.870 ms |

Other IMS issues regard various features on which there is no clear conclusion on which options are the best to be used. The discussions here never ends as even the service providers can't converge on a common platform configuration. This is understandable as there is no complete and fully available platform to test, nor test tools are available. As the [14] aims to offer the first open source IMS core system, a second project is set to fill this need for practical evaluation. The IMS Benchmarking SIG[19] is an effort started also by FOKUS together with important industry partners. The work is taking place under ETSI/TISPAN premises in WorkGroup 6 as Work Item 06024.

For interoperability we did not had the chance to test with other CSCFs. Our plug-in test with HSSs were successful. After initial fix-up of trivial Diameter connectivity issues, the components successfully inter-operated. As the standards are relatively young and there are no conformance tests, we do not consider this small issues to raise an alarm on the openness of the interfaces.

The complexity of the SIP signaling also was something that troubled us. This was mainly because our proxies, for performance reasons, are not committing their changes immediately on the SIP messages. As the procedures at this nodes is specified in steps to be operated, there were cases when we had to hack certain steps in order to fit our running environment and our performance demands. This does not mean that the standards are bad, just that different implementations might choose to tweak them for efficiency. A standards change would not be practical until we will have evaluations from different systems to support it.

Comparing the system latency with that of current legacy networks, we have achieved good results so far. However, when complex applications servers are involved there is a noticeable deficiency. Real deployments will have to be very careful in choosing the running platforms for their applications and then the response times will have to be evaluated. This evaluation has to be performed as part of the entire system because the interactions between components play a major role in the overall performance.

## 9 Summary and Outlook

This article introduced the Open IMS Core project of the Fraunhofer Institute FOKUS as an enabler for the R & D community and parties interested in developing concepts and applications for IMS. After outlining the role of the IMS as central part of coming NGN networks and also for converging networks, the article showed the general IMS architecture and the important part that the CSCFs and an HSS, the constituting parts of the Open IMS Core, play in this architecture. Further, it highlighted the main requirements that were posed to develop it and gave insights into the structure of the implementation. It was outlined how extensions and changes to the SIP Express Router led to the development of 3GPP IMS compliant CSCF components and how they are used in addition with an HSS prototype in a unique vendor-independent IMS testbed, the Open IMS Playground. It gave details on the functional setup of all four IMS components and introduced also a gateway that allows to test the features of the Open IMS Core with current SIP clients.

A sample of the functionality of the Open IMS Core was given for a simple service that was deployed in the Open IMS Playground. This service was also used in some simple performance measurements that produced results for the latency of registration and call setup scenarios carried out over the developed CSCFs.

Since IMS is today already in trial phases with operators worldwide, R&D efforts with respect to NGNs are likely to gain support within a broader audience soon, especially for developing services. While there are already many Open Source projects established in the plain VoIP area for SIP clients, proxies, stacks and tools around the standard, there are currently practically no Open Source projects with specific focus on the IMS. This leaves the R&D community to extend existing VoIP implementations for SIP routing towards the 3GPP IMS standards in order to get started with signaling in the NGN context. The Open IMS Core project introduced in this article aims to fill this void since it made the central routing elements of an IMS available to interested parties licensed under the GPL since the end of 2006.

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