NETWORK AND SERVICE MANAGEMENT

Transparent Reallocation of Control Functions in IMS Deployments

Jaime Garcia-Reinoso, Ivan Vidal, Paolo Bellavista, Ignacio Soto, and Pedro A. Aranda Gutirrez

The authors present a novel solution to transfer users between IMS network elements. This solution enables a home operator to perform an appropriate redistribution of load among the call session control functions of the IMS, which can be deployed as virtualized network functions or over dedicated machines.

ABSTRACT

In this article we present a novel solution to transfer users between IMS network elements. This solution enables a home operator to perform an appropriate redistribution of load among the call session control functions of the IMS, which can be deployed as virtualized network functions or over dedicated machines. This way, the operator is enabled to adequately accommodate the instantaneous load generated by users to the available control resources, which may dynamically be activated or deactivated as necessary, as well as to enhance the resilient operation of the IMS deployment. Additionally, our solution does not require any change to the IMS specifications, and at the same time, the procedures are transparent to the end-user applications running at the IMS terminals. Finally, we describe some results obtained with a proof-of-concept implementation of the procedures presented in the article in order to show the viability and correctness of our proposal.

INTRODUCTION

Nowadays, telco operators own a huge and complex infrastructure to provide their services to their end users. To maximize the usage of such infrastructure, and to accommodate the instantaneous requirements of their customers, these network operators usually deploy load balancers to select the proper network device to serve incoming requests. On the other hand, the traffic load generated by end users is variable during the day, where the high differences between the peak and valley zones impose different network requirements. In such scenarios, a telco operator would like to add or remove active machines in order to reduce costs. This reduction of costs is even clearer when operators use virtual network functions of third-party providers. By using virtualization, telco operators could dynamically request the instantiation of virtual machines in order to adapt their network resources to the traffic load. However, even using load balancers to allocate the incoming end users' traffic to (possibly virtual) network element functions, the change in number of available active elements generates different loads on such devices. In that case, it would be desirable to transfer load between network elements to maximize their utilization while minimizing the number of active network devices.

The IP multimedia subsystem (IMS) framework defined by the Third Generation Partnership Project (3GPP) is a next generation network architecture to provide multimedia services over IP networks. This architecture is designed to be scalable throughout the redundant instantiation of these entities and the usage of load balancing mechanisms, such as those supported with the DNS. In this respect, the considerations described before about the transfer of the load between functional elements would be beneficial for the IMS core elements too. Additionally, with such mechanisms, it would be straightforward to add resilience to both virtual and physical IMS deployments, as they would enable transfer of the load of failing core elements to other existing elements without disrupting the service provided to the end users. IMS is playing a relevant role in 3G/4G telco support infrastructures, even more with the introduction of Voice over Long Term Evolution (VoLTE), with many general concepts that are going to influence and persist in future 5G networking. In particular, the elastic provisioning of virtualized IMS-based functions is still considered a challenging issue.

In this article, we propose a new architecture to transparently transfer users among the functional elements that implement the IMS call session control functions. With our approach, a network operator can better adapt its active control resources to the instantaneous load generated by users, also considering roaming users from other operators, with evident advantages in terms of efficiency and economic costs. It would also be possible to use this solution to add resilience to IMS after failures, transferring all the state of the failed control element to a new machine.

IMS AND RELATED WORK ON ITS EFFICIENT DEPLOYMENT

IMS is a standardization effort supported by the majority of relevant telco players' consortia and initiatives, such as 3GPP, 3GPP2, Internet Engineering Task Force (IETF), and Open Mobile Alliance (OMA), in order to create a common signaling framework for the provisioning of value-added services in operator networks. The IMS architecture incorporates a set of key functions

Jaime Garcia-Reinoso, Ivan Vidal, and Ignacio Soto are with Universidad Carlos III de Madrid; Paolo Bellavista is with the University of Bologna; Pedro A. Aranda Gutiérrez is with Telefónica I+D.

related to quality of service (QoS) provisioning, charging, integration, security, and roaming. The definition of the IMS network entities and interfaces can be found in [1]. A simplified overview of the IMS architecture is depicted in Fig. 1, the main functional entities of which are the proxy-/interrogating-/serving-call session control functions (P-/I-/S-CSCF), the application servers (ASs), the home subscriber server (HSS), and the IMS terminal or user equipment (UE).

The UE controls session setup and media transport via a specific Session Initiation Protocol (SIP) profile defined in IETF and 3GPP IMS-related standards [2]. Each UE is associated with an IMS user identified by a globally unique identifier in the form of a SIP URI [3]. CSCFs are the core entities for providing session control in the IMS. In particular, the P-CSCF is the entry point to the IMS infrastructure for the SIP messages of a UE. Each UE maintains a security association with its P-CSCF to exchange SIP messages with the IMS core in a secure way. If the UE is in a visited network (i.e. the UE is roaming), it can use a P-CSCF placed in its operator network (i.e. the home network) or in the visited network. The I-CSCF is the entry point in a network for incoming SIP session setup messages and for UE registration messages coming through a P-CSCF. It interacts with the HSS to locate the particular S-CSCF assigned to a UE (allocation is based on user profiles) and routes incoming messages to it by acting as a stateless SIP proxy. The S-CSCF performs functionalities related to user registration and session control. In particular, it registers users, interacting with the HSS to obtain authentication and user profile information, and routes SIP messages to different ASs depending on message type and filters/triggers specified in user profiles; these are IMS initial filter criteria. ASs implement the logic to provide services to end users, simplifying the introduction of new IMS-based services. Finally, IMS uses the standard procedures defined in [1] (e.g., based on Domain Name Service [DNS] or Dynamic Host Configuration Protocol [DHCP]) to obtain the IP addresses of SIP servers, such as CSCFs and ASs.

In the literature we can find some proposals to improve the efficiency of IMS deployments. In [4] the authors propose a mechanism by which new registration requests are distributed among available S-CSCF nodes considering their load. At the cost of more complexity, the proposal in [5] provides better load distribution because, in addition to new registration requests, registered users without open sessions can be moved to a different S-CSCF according to load balancing requirements. In [6, 7] the authors propose solutions to distribute the load among ASs, but in both cases this is only done for new sessions. In [8, 9] the authors propose solutions that consider load balancing and also node failure recovery for P-CSCF and I-CSCF nodes in IMS, allowing reallocation of control nodes for users with open sessions. Nevertheless, both proposals require modifications to the standardized behavior and interfaces of IMS nodes (i.e., a change in IMS specifications), which are not needed in our proposal. A paper focused on scalability problems of the IMS core is [10], which describes interesting solutions for effective load balancing, adaptive replication, and elastic quality provisioning via dynamically replicated IMS core components, but considering only new sessions and not the reallocation of active sessions our proposal enables.

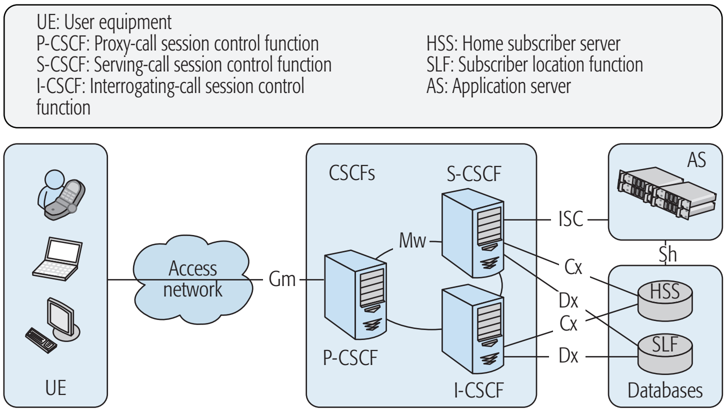

Figure 1. Simplified overview of the IMS architecture.

Finally, another interesting research direction (e.g., [11]) is the virtualization of IMS components to create flexible environments in which to add and remove those components to adapt to the load. The components can be deployed on public/private/hybrid cloud infrastructures. A requirement to maximize the benefit from this environment is effective management of the dynamic transfer of users, even with active sessions, among IMS functional elements, which is the key contribution of our article.

Transparent Reallocation of IMS Control Functions

This section describes the functional entities that are proposed in this article to enable an appropriate allocation of users to the available CSCFs in IMS deployments. These entities, interoperating with the IMS, allow a home operator to dynamically change the allocation of the P-CSCF or S-CSCF of any of its users, transparent to the end-user applications running at the UE. This way, our architecture enables the home operator to maintain an appropriate distribution of the load among the existing CSCFs. Figure 2 shows the new functional elements of our solution (highlighted in gray), as well as their relationship with the elements of the IMS architecture. It is important to remark that our solution does not add new interfaces or functionality to standard IMS elements, so it does not require modifications to the IMS specifications.

The *control function discovery* (CFD) is an application server acting as a SIP user agent. The SIP URI of this AS is configured in the user profile, in initial filter criteria that will be matched during the registration. This way, after successful registration or re-registration of the user in the IMS, and following the regular IMS procedures, the CFD AS will receive the information corresponding to this particular registration, which will include, among other things, the value of the registration expiration interval and the addresses

It is important to remark that our solution does not add new interfaces or functionality to standard IMS elements, so it does not require modifications to the IMS specifications.

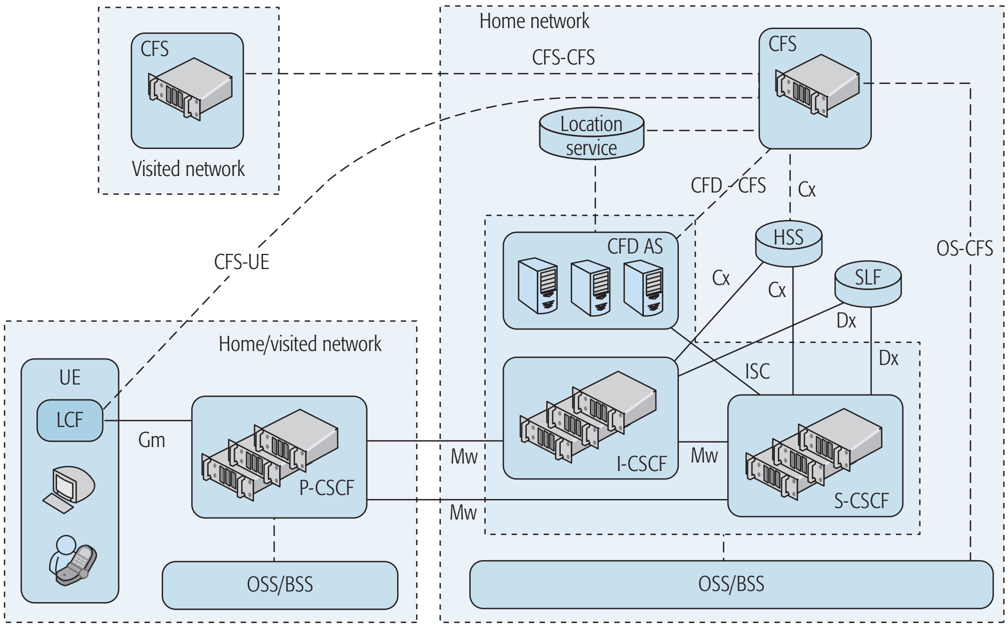

Figure 2. Overview of the proposed architecture.

of the P-CSCF and S-CSCF allocated to the user. The CFD AS stores this information in a *location service*, which is a new database in the home network domain that maintains all the information related to the IMS control functions serving the users of the home operator. For the sake of scalability, there may be several CFD AS entities in the home network to appropriately process the load of notifications about the registration status of users. However, we want to highlight that our solution only requires a reduced set of these entities with respect to the number of CSCFs, as CFD ASs are only contacted after successful registration and re-registration of a user, and are not involved in any other IMS signaling procedures (e.g., session setup, event subscription, and notification.).

The *control function selection* (CFS) is the key component of our solution that enables the change of the P-CSCFs and S-CSCFs allocated to the users of the home operator. This functional entity is the contact point of our solution with the operations support systems/business support systems (OSS/BSS) of the home network domain. The OSS/BSS can activate or deactivate control functions (P-CSCF, S-CSCF and I-CSCF entities) as needed to scale the IMS control resources to the instantaneous load generated by the users, and triggers the CFS when a redistribution of the load among the existing CSCFs is required. This may happen, for instance, to enforce a transfer of the load of an underutilized CSCF to other existing CSCFs prior to its deactivation, or to achieve the resilient operation of an IMS deployment under a failing or overloaded control node. To support the appropriate operation, the CFS implements a Cx interface, as defined for the IMS in [12], which enables the communication with the HSS. This interface will be used in S-CSCF reallocation procedures, as explained later.

The CFS has access to the information stored by the CFD AS in the location service of the home network domain. Thus, upon receiving an indication from the OSS/BSS, via the reference point os-cfs, to perform a load transfer from a P-CSCF (or S-CSCF) to other existing CSCF entities, it may retrieve the information about the users served by the former CSCF from this location service. With this information, the CFS can initiate a reallocation procedure to satisfy the request received from the OSS/BSS, transferring a subset of the users from the initial CSCF to the target CSCFs.

Our architecture includes a local control function (LCF) in the UE. This is integrated as an extension to the IMS stack of the terminal,[1] and maintains status information about the SIP dialogs established by the user. The LCF supports a new reference point cfs-ue, which can be used by the CFS to trigger the transfer of the user to a new CSCF. The LCF is in charge of executing the signaling procedures that are necessary to perform this transfer. Moreover, it carries out these procedures transparently to any end-user application running at the UE, which are kept unaware of the CSCF change.

In the following, we illustrate the procedures used in our solution to change the allocation of the P-CSCF or the S-CSCF for a given user of the home operator, and also to enable appropriate load balancing among I-CSCF and CFD AS entities.

Change of the P-CSCF Allocation

This section describes the procedures that are performed in our solution to change the P-CSCF allocated to a set of users. Prior to the execution of these procedures, we assume that the users have already registered to the IMS, and may have established a set of multimedia sessions by means of SIP dialogs. The procedures are outlined in Fig. 3.

In the scenario shown in this figure, the OSS/

---

[1] The required functionality can be implemented as software in the UE, and it can be delivered integrated with the required software to access the IMS services.

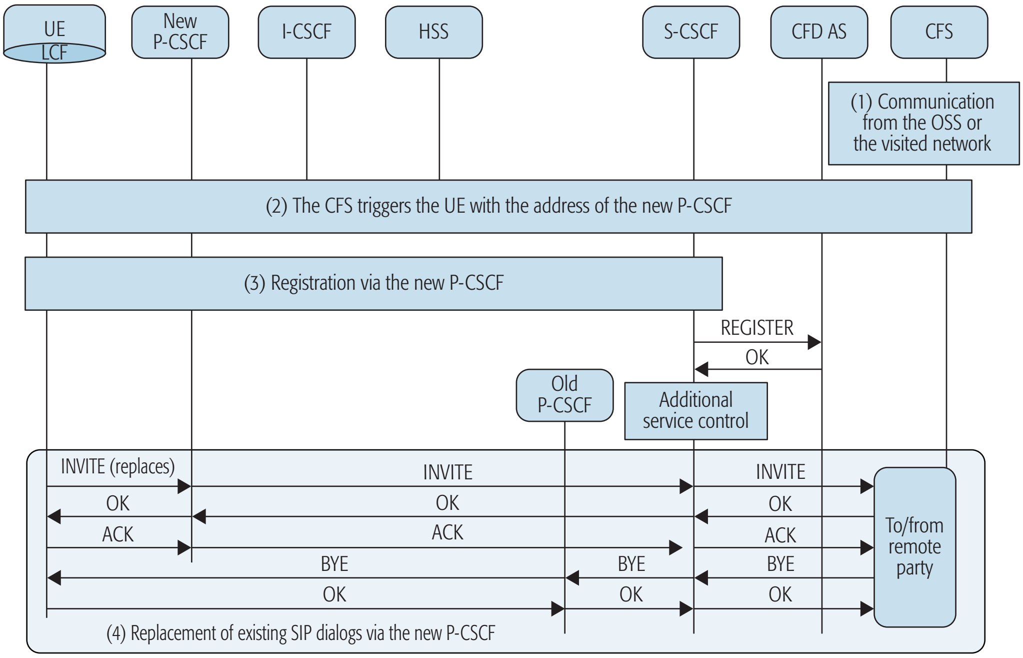

Figure 3. IMS procedures to change a P-CSCF allocation.

The operator may instruct the LCF to delay the replacement of each SIP dialog established by the terminal to a given deadline. This would allow distributing over time the signaling load corresponding to dialog replacement procedures, and even reducing this load by allowing the dialog to be terminated by the end user, via the old P-CSCF, before the deadline.

BSS in the home network contacts the CFS to perform a load transfer from a P-CSCF to other existing P-CSCFs (step 1). Next, the CFS retrieves from the location service the information about the users served by the affected P-CSCF, and determines the set of candidate users that will be transferred to each target P-CSCF. After defining the set of candidate users for each target P-CSCF, the CFS starts a reallocation procedure to transfer each identified user to its corresponding target P-CSCF. For this purpose, it communicates with the UE of each user to be transferred (step 2), using the reference point *cfs-ue*.[2] As a result of this communication, the LCF at each UE can independently initiate the IMS signaling procedures that are necessary to enforce the allocation of the new P-CSCF to the user. In particular, the LCF executes a new IMS-level registration using the address of the new P-CSCF (step 3). After successful registration of the user, and following the regular IMS procedures, the S-CSCF allocated to the user performs service control functionalities by sending a SIP REGISTER request to any AS specified in the user profile for the registration event. This way, a REGISTER request is received by a CFD AS, which updates the information contained in the location service to reflect the address of the new P-CSCF allocated to the user. Finally, to complete the transfer to the new P-CSCF, it is necessary to replace all the SIP dialogs established by the user via the old P-CSCF with new SIP dialogs through the new P-CSCF. This process is done by the LCF, according to the procedures defined in [13], using the status information corresponding to the SIP dialogs of the user. To clarify this concept, step 3 in Fig. 3 shows an example, where the LCF replaces a single SIP dialog established by the user.

Finally, our solution does not impose or recommend any specific mechanism to select which specific users will be reallocated to each target P-CSCF. Instead, the final decision is uniquely subject to the policy rules established by the home operator. Moreover, the proposed solution does not define the precise instant of time when each candidate user is to be contacted to carry out the reallocation. On the contrary, the time schedule of the reallocation procedures is dictated by the operator, who might contact all the candidate users simultaneously or spread the requests sent to UEs over time. Additionally, the operator might provide the LCF (through the *cfs-ue* interface) with diverse policies to govern user transfer. As an example, the operator may instruct the LCF to delay the replacement of each SIP dialog established by the terminal to a given deadline. This would allow distributing over time the signaling load corresponding to dialog replacement procedures, and even reducing this load by allowing the dialog to be terminated by the end user via the old P-CSCF before the deadline.

CHANGE OF THE S-CSCF ALLOCATION

The procedures to change the S-CSCFs allocated to users are similar to those described in the previous section, and are illustrated in Fig. 4. After receiving a trigger from the OSS/BSS to perform a redistribution of the load of a given S-CSCF to other existing S-CSCFs (step 1), the CFS retrieves the set of users served by the specified S-CSCF. Following the policy rules defined by the home operator, the CFS determines the set of candidate users that will be transferred to each target S-CSCF. Then, for each candidate user, the CFS contacts the HSS through the reference point Cx, and changes the S-CSCF assigned to the user (step 2). This can be done using a Multimedia-Authentication-Request (MAR) Diameter command, according to [12].

Next, the CFS communicates with the UE of

---

[2] The communication between the CFS and the LCF should be done out of the SIP signaling path, as this communication can be the result of a failed or overloaded P-CSCF, and could be implemented, for example, using HTTP.

each of the users, using the reference point cfs-ue, instructing the LCF to start the IMS procedures needed to enforce the allocation of the new S-CSCF to the user (step 3). Analogous to the previous case, the LCF first initiates an IMS-level registration using the new S-CSCF. Step 4 in Fig. 4 illustrates an example of the registration process, where the S-CSCF performs user authentication procedures. In the example, the registration proceeds in two phases. In the first phase, the UE generates a SIP REGISTER request, which is routed via the P-CSCF allocated to the user and an I-CSCF belonging to the home network. Then the I-CSCF contacts the HSS to discover if there is an S-CSCF allocated to the user. As the user has already been allocated the new S-CSCF in step 2, the HSS returns the address of the new S-CSCF to the I-CSCF. Consequently, the new S-CSCF receives the REGISTER request and contacts the HSS to download the data that is necessary to authenticate the user. Then the S-CSCF answers back the REGISTER request with a SIP Unauthorized response, containing a challenge to be satisfied by the UE. The response to this challenge requires a second REGISTER transaction between the UE and the S-CSCF, as shown in Fig. 4.

After successful registration of the user, the new S-CSCF performs the regular IMS service control functionalities, which result in the update

Analogous to the P-CSCF reallocation procedure, note that the actual decisions on which candidate users are to be transferred from a given S-CSCF to another, and the precise time schedule of the reallocation process, are controlled by the policy rules established by the operator.

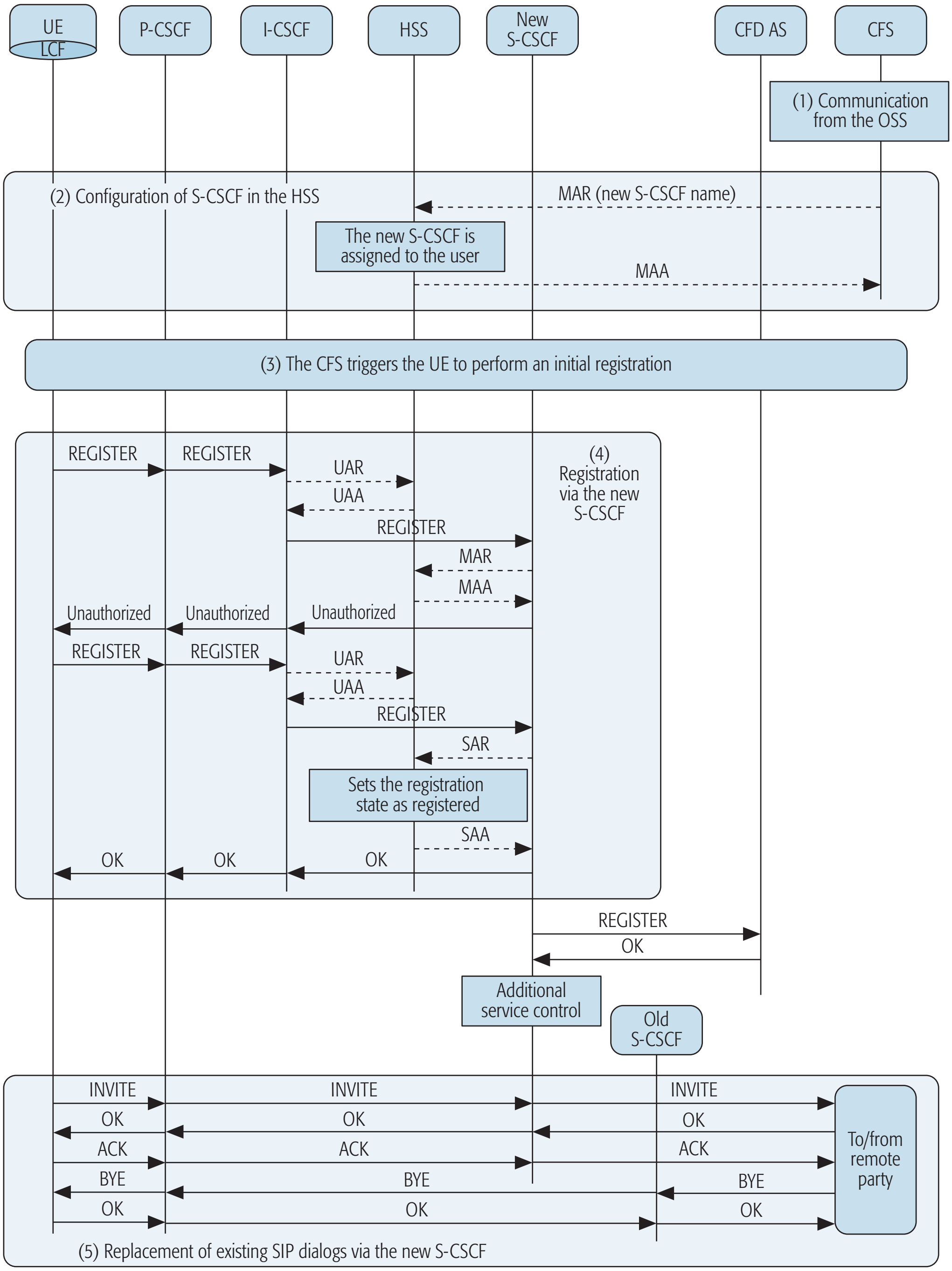

Figure 4. IMS procedures to change an S-CSCF allocation.

of the information stored in the location service by a CFD application server, to reflect the address of the new S-CSCF assigned to the user. Finally, the LCF initiates the signaling procedures to replace the SIP dialogs established by the user to use the new S-CSCF (step 5).

Analogous to the P-CSCF reallocation procedure, note that the actual decisions on which candidate users are to be transferred from a given S-CSCF to another, and the precise time schedule of the reallocation process, are controlled by the policy rules established by the operator.

MANAGEMENT OF CFD AS AND I-CSCF ENTITIES

The application servers of our solution, that is, the CFD AS entities, can also be activated or deactivated as necessary by the OSS/BSS for resilience and scalability purposes. In our proposal, the CFD service is identified by a SIP URI, containing a domain name that, according to the procedures specified in [14], can be resolved by the S-CSCF in the DNS to the different addresses of the application servers executing the CFD service. The OSS/BSS will trigger the CFS when a CFD AS is activated or deactivated, so that it can change the configuration of the DNS in the home network accordingly, this way enabling an appropriate load balancing among the existing CFD AS entities.

On the other hand, besides the IMS control functions that are allocated to the end users (i.e., P-CSCFs and S-CSCFs), an IMS deployment also includes a number of I-CSCFs for scalability reasons. The selection of an I-CSCF during the IMS registration and session setup follows the SIP procedures specified in [14], and is based on DNS usage. In a dynamic environment, the OSS/BSS could also activate or deactivate an I-CSCF entity as necessary. In this case, the OSS/BSS would trigger the CFS, which in turn would change the configuration of the DNS in the home network to reflect the addition or deletion of the I-CSCF address. This will enable an appropriate (for low-medium frequency updates such as the ones of interest for many application domains [10]) DNS load balancing among the available I-CSCFs.

CONSIDERATIONS ABOUT ROAMING USERS

According to the IMS specifications [1], there is the possibility that the P-CSCF allocated to a roaming user is located in the visited network. In that case, there may be users served by a P-CSCF that are not registered in the network of the operator owning the P-CSCF. Our solution covers this specific use case, by allowing communications between CFS entities in the home and visited networks through the inter-domain reference point *cfs-cfs*.

After the successful registration of a user who is roaming in a visited network, a CFD AS in the home network of the user stores the address of the visited P-CSCF in its location service. Additionally, when this CFD AS detects a new address of a visited P-CSCF, it contacts the CFS in the home network (hereafter referred to as home CFS) via the reference point *cfd-cfs*. If the visited network implements the solution presented in this article, the home CFS communicates with the CFS in the visited network (hereafter referred to as visited CFS), through the reference point *cfs-cfs*, and registers its desire to receive notifications about the state of the P-CSCF allocated to the user.

Now, if a P-CSCF is overloaded, fails, or needs to be removed, the operator owning the P-CSCF may contact any operator that has expressed its interest in receiving notifications on the P-CSCF status. To this end, the visited CFS (i.e., the CFS in the domain of the affected P-CSCF) communicates with the home CFS via the *cfs-cfs* interface. The visited CFS may explicitly indicate the reason for the communication, and request of the home CFS information about the visiting users that are served by the P-CSCF (e.g., the number of these users). Taking into account the information from the different CFS entities that have been contacted, and according to the policy rules established by the visited operator, the visited CFS can then request any home CFS entity to perform a reallocation process of its visiting users. The trigger from the visited CFS may include a set of alternative P-CSCFs and the assignment of load that should be transferred to each of these P-CSCFs. With this information, and attending to the policy rules defined by the home operator, the home CFS then executes the reallocation process following the procedures previously described.

Finally, we want to note that there is always the possibility of having roaming users assigned to a P-CSCF belonging to a network domain that does not implement the solution described in this article. In this case, the visited CFS would not have access to the information about the visiting users from their home network domain, and would not be able to request the execution of a reallocation process for these users. However, this issue can easily be prevented if the service level agreement established with other operators allows use of the set of P-CSCFs of the operator only by those operators that implement the control function discovery and selection procedures described in this article (users can still be provided service with a P-CSCF in their home networks).

EXPERIMENTAL RESULTS

To assess our proposed solution, we have deployed a testbed using the FOKUS OpenIMS core[3] and the SIPp open software.[4] The former includes the call session control functions of the IMS (i.e., P-CSCF, S-CSCF, and I-CSCF) and an HSS, while the latter is used to emulate an IMS UE. The OpenIMS core is deployed over three virtual machines: the first, including the HSS together with three CSCFs (P-CSCF1, S-CSCF1, and I-CSCF1); the second, executing P-CSCF2 and S-CSCF2; and the third, including P-CSCF3 and S-CSCF3. Two additional virtual machines are used to run the SIPp scripts corresponding to the UEs.

To illustrate the benefits that can be achieved reallocating users to CSCF entities, we designed a first experiment with 20 users. All these users are served by P/S-CSCF1 and are configured to generate a certain aggregate session setup rate. In the experiment, we measured the average session setup delay for different session setup rates. The results are shown in Table 1. As can

According to the IMS specifications [1], there is the possibility that the P-CSCF allocated to a roaming user is located in the visited network. In that case, there may be users served by a P-CSCF that are not registered in the network of the operator owning the P-CSCF. Our solution covers this specific use case.

---

[3] http://www.fokus.fraunhofer.de/en/fokus_testbeds/open_ims_playground/components/osims/index.html

[4] http://sipp.sourceforge.net

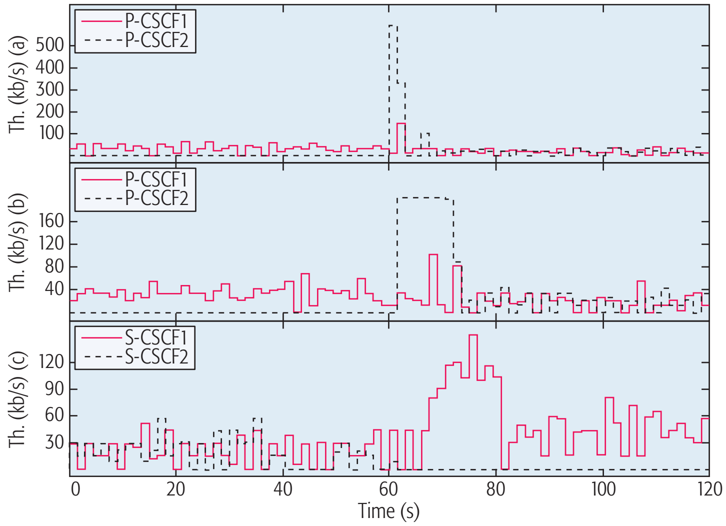

Figure 5. Results of the experiments.

be observed, in our particular testbed, when the session initiation rate is over 5 requests/s, the session setup delay is above the grade-of-service parameter for call setup delays recommended by the International Telecommunication Union — Telecommunication Standardization Sector (ITU-T) of 3 s [15]. This shows the benefits of distributing the rate of sessions established by users among CSCFs, as supported by our reallocation procedures.

In the second experiment, 20 registered users allocated to P-CSCF1 establish IMS sessions with 2 registered users using P-CSCF3. The aggregate session setup rate is 1 session/s. Using the SIPp scripts, we execute the procedures to change the allocation of 10 users from P-CSCF1 to P-CSCF2, as illustrated in Fig. 3. This change is triggered manually after approximately 60 s. In this particular setup, all the users are transferred in parallel, which imposes a high transitory load for both P-CSCFs. Figure 5a presents the result of this experiment in terms of total throughput at the two P-CSCFs, where we can observe that once the users are transferred to the new P-CSCF, the load is distributed between them. Note that the throughput shown corresponds to SIP signaling and is also a measurement of the load at the CSCFs to process those SIP messages. Although the specific policy to reallocate users between functional elements is under the control of the home operator, for the sake of completeness we also consider in this validation a simple algorithm to schedule the transfer of users between P-CSCFs. In such an algorithm, the users are contacted in sequence with a configurable transfer rate. In the third experiment, where we configure a transfer rate of 2 users/s, we are able to significantly reduce the peak throughput during the transfer stage, as shown in Fig. 5b.

In the fourth experiment, we show a scenario where the load of two S-CSCFs are below the minimum configured threshold, so all the users assigned to one of them can be transferred to the other. In this case, there are 10 users registered in S-CSCF1, while another 10 are registered in S-CSCF2. The 20 users generate an aggregate rate of 1 session/s, as in the previous experiment. After approximately 60 s, the users registered in S-CSCF2 are transferred to S-CSCF1 at a transfer rate of 2 users/s, using the mechanisms illustrated in Fig. 4. As can be seen in Fig. 5c, the users and their active sessions are transferred to the new S-CSCF between 60 s and 80 s, causing a higher load in S-CSCF1 during that period. After 80 s, the users have been successfully transferred to S-CSCF1, which receives a rate of 1 session setup per second.

Aggregate session setup rate (sessions/s)	Average delay of the session setup (s)
0.5	0.068
1	0.073
2.5	0.7
5	3.1
10	10.97

Table 1. Average delay of the session setup for different values of aggregate session setup rates.

CONCLUSIONS

In this article we have provided a solution to transparently transfer users between IMS control elements, which can be used to appropriately adapt the utilization of these elements to the instantaneous load generated by users as required by the operator, and add resilience to the IMS infrastructure at the same time. The results achieved with our proof-of-concept implementation show the viability and correctness of the proposed solution. The solution guidelines described in our article also have general validity and applicability to next generation telco support infrastructures, which, for example, will extensively exploit the opportunities of virtualization and dynamic re-allocation of their control functions. We plan to extend our proposal by including the possibility to manage other IMS functional elements like ASs.

ACKNOWLEDGMENTS

The work in this article has been partially supported by the European FP7 Trilogy 2 project (grant agreement CNECT-ICT-317756).

REFERENCES

[1] 3GPP, "IP Multimedia Subsystem (IMS); Stage 2," TS 23.228 v. 12.6.0 Release 12, Sept. 2014.
[2] 3GPP, "IP Multimedia Call Control Protocol Based on Session Initiation Protocol (SIP) and Session Description Protocol (SDP); Stage 3," TS 24.229 v. 12.6.0 Release 12, Oct. 2014.
[3] J. Rosenberg *et al.*, SIP: Session Initiation Protocol, RFC 3261, July 2002.
[4] I. Abdalla and S. Venkatesan, "Notification Based S-CSCF Load Balancing in IMS Networks," *Proc. Wireless Telecommun. Symp.*, 2011, pp. 1–5.
[5] L. Xu *et al.*, "De-Registration Based S-CSCF Load Balancing in IMS Core Network," *IEEE ICC '09*, 2009, pp. 1–5.
[6] Y-J. Yoo *et al.*, "Service Triggering Algorithm for Optimal Load Balancing In Heterogeneous Multiple AS (Application Server) System," *Proc. Int'l. Conf. Info. and Commun. Tech.. Convergence*, 2010, pp. 10–15.
[7] J. Zha *et al.*, "Research on Load Balance of Service Capability Interaction Management, *Proc. 3rd IEEE Int'l. Conf. Broadband Network and Multimedia Tech.*, 2010, pp. 212–17.
[8] C. Makaya *et al.*, "Service Continuity Support in Self-Organizing IMS Networks," *Proc. 2nd Int'l. Conf. Wireless Commun., Vehic. Tech., Info. Theory and Aerospace & Electronic Sys. Tech.*, 2011, pp. 1–5.

[9] A. Dutta *et al*., "Self Organizing IP Multimedia Subsystem," *IEEE Int'l. Conf. Internet Multimedia Services Architecture and Applications*, 2009, pp. 1–6.
[10] A. Corradi, P. Bellavista, and L. Foschini, "Enhancing Intra-Domain Scalability of IMS-Based Services," *IEEE Trans. Parallel Distrib. Sys*., vol. 24, no. 12, Dec. 2013, pp. 2386–95.
[11] P. Bellavista *et al*., "QoS-Aware Elastic Cloud Brokering for IMS Infrastructures," *Int'l. Symp. Computers and Commun.)*, 2012, pp. 157–62.
[12] 3GPP, "IP Multimedia (IM) Subsystem Cx and Dx Interfaces; Signalling Flows and Message Contents," TS 29.228 v. 12.3.0 Release 12. Oct. 2014.
[13] R. Mahy, B. Biggs, and R. Dean, "The Session Initiation Protocol (SIP) 'Replaces' Header," IETF RFC 3891, Sept. 2004.
[14] J. Rosenberg and H. Schulzrinne, "Session Initiation Protocol (SIP): Locating SIP Servers," IETF RFC 3263, June 2002.
[15] ITU-T Rec. E.721, "Network Grade of Service Parameters and Target Values for Circuit-Switched Services in the Evolving ISDN," May 1999.

BIOGRAPHIES

JAIME GARCIA-REINOSO (jgr@it.uc3m.es) received a telecommunications engineering degree in 2000 from the University of Vigo, Spain, and a Ph.D. in telecommunications in 2003 from the University Carlos III of Madrid, Spain. He is currently an associate professor at University Carlos III of Madrid, having joined in 2002, and has published over 50 papers in the field of broadband computer networks in top magazines and congresses. He has been involved in several international and national projects related to broadband access, peer-to-peer overlays, next generation networks, signaling protocols, and information-centric networking like EU IST MUSE, Trilogy 2, EU H2020 XHaul, and the Spanish MASSES project.

IVAN VIDAL (ividal@it.uc3m.es) received a telecommunication engineering degree in 2001 from the University of Vigo, and a Ph.D. in telematics engineering in 2008 from the University Carlos III of Madrid. He is currently working as a visiting professor at Universidad Carlos III de Madrid. His research interests include multimedia networking, unmanned aircraft vehicles, and information-centric networking. He has been involved in several international and national research projects related to these topics, including EU IST MUSE, the Spanish MEDIANET project, and the Spanish Ministry of Defense project DRONE. He has published several papers in magazines and conferences, lately in the areas of mobility support in IMS networks, UAVs, and ICN management.

PAOLO BELLAVISTA (paolo.bellavista@unibo.it) is an associate professor at the University of Bologna, Italy. His research activities span from mobile computing to pervasive ubiquitous middleware, from vehicular sensor networks to big data adaptive stream processing and adaptive scalable multimedia, from IoT middleware for cloud integration to resource management in SDN. He has published more than 60 magazine/journal articles and more than 80 conference/workshop papers in those fields, reporting results from several national- and EU-funded projects. He serves on the Editorial Boards of *IEEE TNSM*, *IEEE TSC*, *Elsevier PMC*, and *Springer JNSM*. See also http://lia.deis.unibo.it/Staff/PaoloBellavista/ for additional details and a complete publications list.

IGNACIO SOTO (isoto@it.uc3m.es) received a telecommunication engineering degree in 1993, and a Ph.D. in telecommunications in 2000, both from the University of Vigo, Spain. He was a research and teaching assistant in telematic engineering at the University of Valladolid from 1993 to 1999. He was an associate professor at the Universidad Politcnica de Madrid from 2010 to 2012. In 1999 he joined University Carlos III of Madrid, where he currently works as an associate professor in telematic engineering. His research activities focus on mobility support in packet networks, heterogeneous wireless access networks, and vehicular networks.

PEDRO A. ARANDA GUTIÉRREZ (pedroa.aranda@telefonica.com) obtained a Master's degree in telecommunications at the Universidad Politécnica de Madrid in 1989 and his Ph.D. in informatics at the Universität Paderborn in 2013. He currently works at the Technology Exploration unit at the Network Virtualisation and Innovation directorate at Telefónica, I+D/GCTO Unit. He has worked for Telefónica, I+D for the last 24 years and has participated in joint research projects of the EU starting at the RACE I Framework Programme until now. He is currently acting as technical manager of the NetIDE project of the 7th Framework Programme. His technical experience and interests range from IP networking with a foundation in IP routing and inter-domain routing architectures to the current SDN frameworks from a networking and programmer's point of view.