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Transparent Network-Assisted Flow Mobility for Multimedia Applications in IMS Environments

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ABSTRACT

Cellular network operators are striving to solve the problem caused by the increasing volume of traffic over their networks. Given the proliferation of multi-interface devices, offloading part of the traffic to available access networks (e.g., WiFi or 3G access networks, even from other operators) seems to be a promising alternative. Here, we propose an IMS-compatible solution for flow mobility between access networks that exhibits two key features: flow mobility is transparent to both local applications at mobile nodes and their communication peers (e.g., multimedia content servers), and mobility operations are assisted by the network, so the home network supports the terminal in the process of access network discovery, and provides the terminal with policies that meet visited and home operators' roaming agreements while optimizing the use of their networks. The proposed solution has been validated using a real IMS testbed with Ethernet and WiFi access networks, where the mobility of UDP and TCP flows has been tested.

INTRODUCTION

With the widespread adoption of smart phones, the volume of data traffic and, in particular, video traffic over cellular networks has increased remarkably. Telecom operators are facing the challenge of keeping up with the resulting high traffic demands on their networks. The evolution of the technologies used in the air interface, new assignments of spectrum, and smaller cells provide more capacity in the radio access, which is the real bottleneck in wireless networks. Nevertheless, these developments do not seem to be enough to cope with the high bandwidth requirements, coming especially from video applications, and, in any case, they require high investments in infrastructure.

Operators are looking for alternative solutions to tackle this problem. The most promising one is the concept of offloading, the ability to move part of the user traffic to other access networks that could be available at the users' loca-

tions with enough resources to serve that traffic. This would allow operators to gain benefit from alternative networks that could help them to alleviate overload situations in their cellular access networks.

Thus, operators are studying with great interest mechanisms to be able to use alternative infrastructure (non-Third Generation Partnership Project, 3GPP, access technologies such as WiFi or WiMAX) to complement their 3GPP cellular networks (e.g., Universal Mobile Telecommunications System, UMTS, or Long Term Evolution, LTE), and even to take advantage of access networks from other operators if their own are overloaded (assuming corresponding roaming agreements are in place). In this way, operators can provide their users with a variety of access networks that are available at the users' current locations. Mobility support is needed to gain the advantage of these available access networks, so users can change access network without that movement breaking their open communications. Besides, mechanisms to control how to select the target access network are also needed. Operators are pushing the standardization of solutions in the 3GPP to address these challenges. In this article we propose a solution for transparent mobility support between access networks. Our solution has important properties that are not found together in other solutions in the literature or in the solutions initially being explored in the 3GPP:

- It is compatible with the signaling architecture defined by the 3GPP, the IP multimedia subsystem (IMS), and can be used with any IMS-enabled network independent of the access network technology.
- It is transparent for multimedia applications and communication peers of the mobile nodes.
- It supports flow mobility so that different communications (e.g., video traffic flows) in a mobile node can use different access networks, and each traffic flow can be moved independently.

The article also proposes a mechanism to enable an operator to guide their users in how to select the access network to serve the traffic of each of

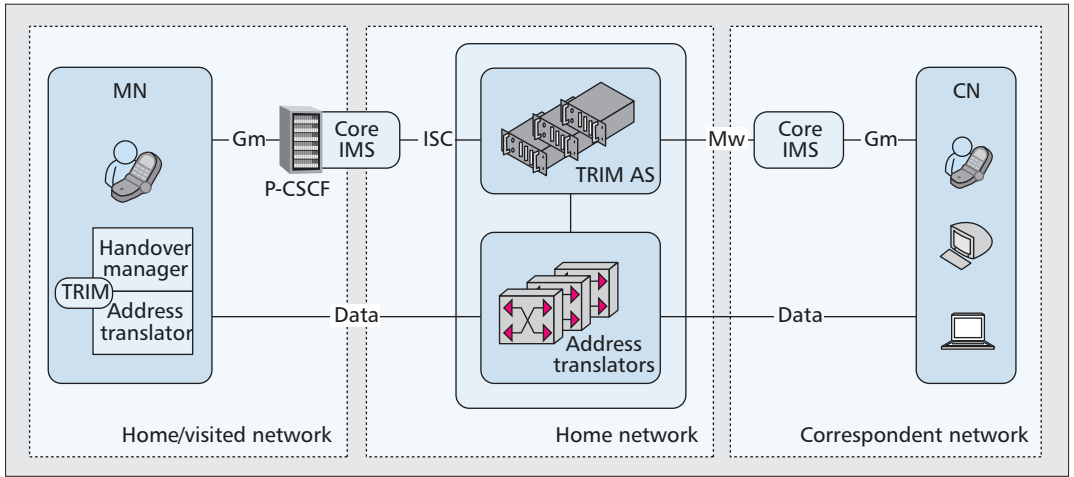


Figure 1. *TRIM architecture.*

their communications. The mechanism allows better control of the selection of access network by the home operator than in the model being developed by the 3GPP (described later), providing the means for visited and home operators to honor their roaming agreements while optimizing the use of their networks.

The rest of the article is organized as follows. First, we review the solutions being developed regarding mobility management and selection of access networks. Next, we propose our solution for transparent mobility management assisted by the network. We then dedicate a section to an experimental validation of our solution, and finally describe the conclusions of our work.

BACKGROUND

IMS AND MOBILITY MANAGEMENT

Two main trends in the current evolution of communication networks are convergence and mobility. Regarding convergence, operators have pushed the standardization of IMS [1], a control architecture that facilitates the provision of value-added multimedia services in IP networks. On the other hand, users want to access their services anytime, anywhere, and even while moving. Therefore, in converged IP networks we need mobility support.

The Internet Engineering Task Force (IETF) has standardized several solutions for mobility support that provide global mobility, but these solutions require specific mobility related functionality at the IP layer of the mobile nodes (MNs) [2, 3]. There are extensions [4] to these solutions to support not only terminal mobility (i.e., when the terminal moves to a new access network, all ongoing sessions are moved to the new access network) but also flow mobility (i.e., the MN can move each of its communication flows independently among its interfaces). 3GPP has adopted DSMIPv6 [3] and its extensions as a solution for providing flow mobility support in LTE networks [5]. Unfortunately these solutions do not work with IMS [6], [7] because the application layer, where IMS signaling is implemented, only sees the home address (the identifier address of the MN), and IMS would use that address to authorize traffic in the transport

plane when it should be configured using the MN's routing address (the care-of address) instead.

As IMS is based on Session Initiation Protocol (SIP) [8], another alternative is to use SIP-based mobility [9, 10]. SIP provides the identification of the endpoint of a communication using a SIP uniform resource identifier (URI), and a registrar server (S-CSCF in IMS) is used to find out the IP address currently associated with the URI [1]. SIP allows the change of IP address due to mobility by keeping the endpoints of the communication informed of the IP addresses currently in use, but the change of address is visible to applications, in both ends of the communication, which need to implement procedures to handle this change. Particularly, applications have to implement mechanisms to avoid breaking the communication upon an IP address change.

In [11] we proposed TRIM, a solution for providing transparent mobility in IMS-based networks using SIP (Fig. 1). This solution is compliant with IMS as defined by 3GPP [1]. In TRIM, mobility decisions are taken in the terminal without any support or information from the network. The key elements are the TRIM application server (AS), the address translator in the network, and the address translator in the MN. The TRIM AS is the anchor point for supporting the MN's mobility. The TRIM AS is located in the home network of the MN, and it is always kept in the signaling path of the MN. A communication between a TRIM MN and another node (the correspondent node, CN) creates two signaling sessions, one between the MN and the TRIM AS, and another one between the TRIM AS and the CN. The TRIM AS is responsible for configuring, during session establishment, the address translator in the network, which is kept in the data path. Once configured, the MN sends the data to an address belonging to the address translator. The address translator sits in the middle of the communication, changing the addresses of the data packets, so both the MN and CN receive packets with source addresses belonging to the network address translator. Regarding the destination address of the packet, the address translator sends the

packets to the respective addresses of the MN and CN. Note that the identification of the endpoints of the communication is through the SIP URIs, not the IP addresses that are acting just as locators. The association is done during the establishment of the session; the address of the network address translator is given as the address of the MN to the CN, and vice versa. Movement of the MN is completely transparent to the CN, which continues exchanging data traffic with the network address translator. Thus, only the MN leg of the communication has to be updated. This is done by the MN, by registering and sending an INVITE after obtaining connectivity in the new network. This message arrives at the TRIM AS that reconfigures the network address translator, so the MN starts receiving traffic from the CN in the new location.

Even then, the MN changes its address with each movement, and this would affect the applications running in the MN. Here is where the address translator in the MN comes into play. This address translator basically always presents the same address (an internal address) to user applications, and translates between this internal address and the address in use by the MN in the current access network. A handover manager in the MN takes care of keeping the MN address translator updated with the addressing information. Note that TRIM requires support in the network, but it adds elements that are IMS compliant (an IMS AS and an intermediate element in the data path). The important advantage of TRIM is that it requires changes to neither the CNs (they are standard IMS-enabled nodes) nor the user applications, which are kept unaware of the mobility.

In [12] the authors combine a multihoming protocol with the IMS to provide mobility support. Although this solution is transparent to applications, it requires modifications to CNs, which hinders deployment.

NETWORK DISCOVERY AND SELECTION ASSISTANCE

Nowadays, there is a proliferation of devices equipped with 3G and WiFi interfaces. But the procedure to use the different access networks is quite limited and managed by the user who, typically, switches interfaces on and off with a static configuration to prioritize Wi-Fi over 3G if both networks are available. Significant current limitations are that typically two accesses cannot be used simultaneously and that the operator cannot influence the decision of the access network chosen by the user device, nor even provide information to help in that decision considering also operator's needs. The 3GPP is specifying functionality in LTE networks to obtain a much more flexible and efficient use of the available access networks. Part of it is adding flow mobility support mechanisms as mentioned above [5]. The other key addition is a new network entity: the Access Network Discovery and Selection Function (ANDSF) [13, 14]. This entity has two main functions: providing MNs with information to support them in the process of access network discovery, and delivering policies to the MNs to help them to select an access network. These

policies basically define a set of network selection rules. They can be based on the restriction of using just one access network simultaneously, so the policies define rules on which one to use; or the policies can consider the use of several access networks simultaneously and then define rules on how to assign flows to the access networks. Using the received policies and applying user preferences, the MN chooses how to use the access networks to carry out its communications. If a MN is in roaming, the specification states that the MN must receive independently the policies of the home and the visited networks, and combine them with the user preferences to decide the access network to use.

The ANDSF has interfaces with the MN and with the management plane. The network management components may send triggers to the ANDSF indicating an event that requires moving traffic from one access network to another, for example an overload in a particular access network that cannot be solved internally. In [15] the authors explore the possibility of connecting the ANDSF entity with other network elements to enrich the knowledge that the ANDSF has about the current network status so that it may generate better policies.

These solutions are centered in the MN, which makes the final decision with information coming from the networks, home and visited. Better optimizations are possible with points of decision in the home network having information about roaming agreements and the current situation of MNs in home and visited networks.

TRANSPARENT NETWORK-ASSISTED MOBILITY MANAGEMENT

This section describes the architecture proposed in this article to enable network-assisted flow mobility in the IMS. To this end, we have extended TRIM, our solution to support transparent mobility management in IMS, to integrate it with ANDSF, which provides functionality for network-assisted mobility. Additionally, we propose some modifications to the operation model of 3GPP ANDSF to gain some advantages described below. Figure 2 shows a general overview of the proposed architecture.

In this architecture, TRIM is used to support mobility management procedures transparently to multimedia applications. Moreover, in this article we explore the potential of TRIM to handle mobility at flow-level granularity. To this end, the session description included in the INVITE can specify different IP addresses, corresponding to different access networks, for the media flows (UDP or TCP) forming the session. The information within the INVITE is used by the TRIM AS to appropriately configure the network address translator, so each flow in the session is forwarded to the corresponding access network of the MN. The address translator in the MN presents an internal address to applications, which does not change due to mobility,¹ so flow mobility is transparent to applications.

As the TRIM AS stays in the signaling path of each multimedia session of the MN, the application server receives every SIP signaling mes-

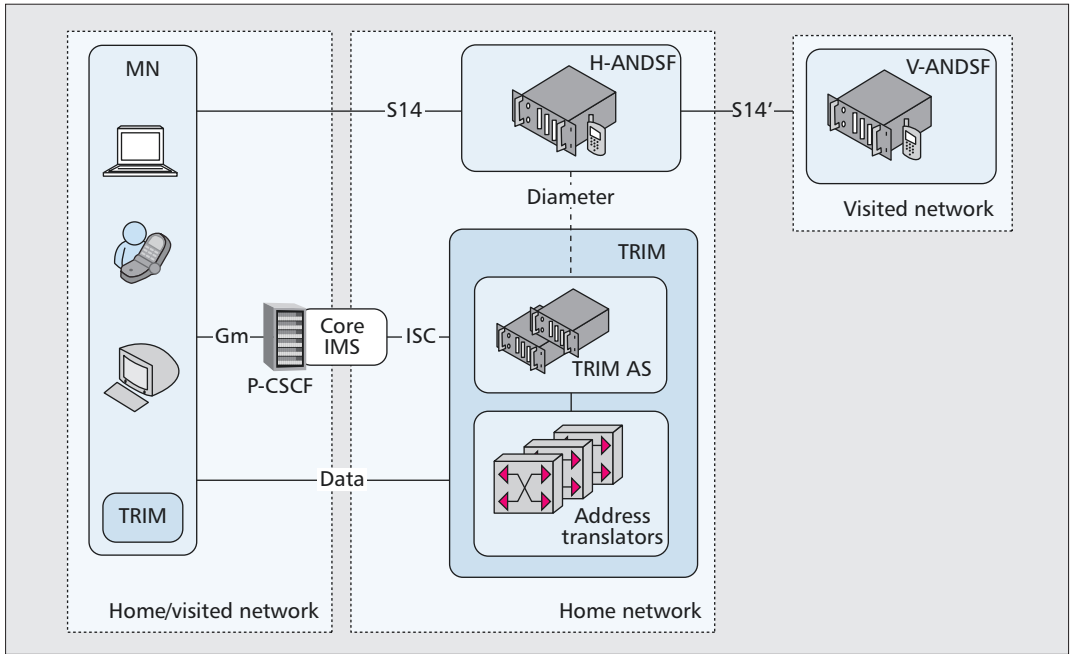


Figure 2. Overview of the proposed architecture.

sage exchanged by the MN. This way, the AS holds up-to-date information about every multimedia session established by the end user. For each media flow within the session, this information includes, although is not limited to, the media type (e.g., audio or video) and format (i.e., codec), the bandwidth that has been authorized by the network, and addressing information, such as the IP address of the access interface where the MN is receiving an incoming flow.

Network-assisted flow mobility is supported in our solution by introducing an ANDSF in the home network of an MN (i.e., H-ANDSF in Fig. 2). This functional entity implements the control functionality that is necessary to assist the MN in the access network discovery and selection procedures, according to the policies of the home operator. The ANDSF is a functional entity, but it could be physically distributed in several servers (e.g., according to a geographical area of influence) for load balancing and robustness purposes. The communication between the MN and the H-ANDSF takes place securely over the reference point S14 [13]. Using this interface, the MN can query the H-ANDSF for access network discovery information and policies (pull mode), and the H-ANDSF can autonomously initiate an update of the information at the MN (push mode).

In the proposed architecture, the TRIM AS can provide the H-ANDSF with all the information describing the multimedia sessions of the MN. This way, the H-ANDSF can have a global view of all the flows of the MNs belonging to the home operator. This view can then be used to build appropriate policies that guide the MNs in the assignment of flows to access networks, taking into account the availability of network resources and operator-defined rules. The exchange of information between the TRIM AS and the H-ANDSF requires a new reference point. This interface can easily be built by means

of a Diameter application, similar to the interface defined by 3GPP to provide the session-related information to the policy and charging rules function (PCRF) in IMS.

When an MN exchanges data traffic from a visited network, according to 3GPP specifications, it can independently receive policies from the H-ANDSF and an ANDSF located in the visited network (i.e., V-ANDSF in Fig. 2). Consequently, the MN must solve potential conflicts between the policies transferred by both ANDSFs. This approach presents several drawbacks because:

- The home operator has no control over the policies that are transferred by the visited network to the MN, and it is not aware of the events that legitimate the visited operator doing the policy update (e.g., overload in a particular access network).
- The current approach reduces the control of the home operator (i.e., the operator with which the user has a service contract) over the network selection procedures carried out by the MN.

To address these issues, our approach restricts the usage of the S14 interface of the MN to the H-ANDSF. Thus, in our solution, only the home operator implements the control functionality that is necessary to assist the MN in the access network discovery and selection procedures. However, this control functionality also considers preferences and policy rules reported from visited networks, which are securely communicated by means of a new reference point, S14'. The information provided by the V-ANDSF to the H-ANDSF via this new interface does not need to be restricted to simple policies affecting specific MNs. Instead, the S14' interface can be used by a visited operator to supply enriched policies that affect the global traffic of the home operator subscribers over the visited network. As an example, due to the overload of an access network in a visited domain, the V-

ANDSF can send a policy to the H-ANDSF of an operator to request reduction of the bandwidth consumed by the operator's subscribers over that access network.

Thus, in our architecture, the H-ANDSF becomes the single point of decision for network discovery and selection procedures. Decisions made by the H-ANDSF can be based on different types of information, such as the current situation of the MNs in home and visited networks, their location and capabilities (e.g., supported access technologies), the access bandwidth available in the home network, information about roaming agreements, and preferences and policy rules received from visited operators.

Therefore, our architecture presents a simple design that enables delivery to the H-ANDSF of all the information that may be needed for an appropriate operation. This design does not require the implementation of complex and demanding mechanisms to characterize the traffic flows, such as the real-time inspection of data packets at the transport level. Moreover, unlike [15], no extensions are needed to the 3GPP policy and charging control architecture. Our proposal requires a software modification in UE, but it is compatible with UE devices that do not have TRIM functionality. It also introduces elements in the network: address translators, TRIM ASs, and ANDSF nodes. From the point of view of performance, note that each of those elements can be distributed in several physical nodes, so the architecture is scalable to accommodate growth in the number of users or traffic.

In the next sections, we describe a set of scenarios that illustrate the different mechanisms involved in our solution.

IMS SESSION SETUP

The execution of a multimedia service or application at the MN, such as a video call or a video-on-demand service, typically requires the establishment of a multimedia session with a CN (e.g., a media function in the case of video on demand). Figure 3 illustrates the procedures executed by our architecture during an IMS session setup.

Prior to session establishment, we assume that the MN is pre-provisioned with an intersystem routing policy. This is an operator policy that allows the MN to build an initial set of preferences related with the selection of access networks. In addition, during an initialization phase (step 1), the MN discovers the IP address of the H-ANDSF, and a secure connection is established between them. It is important to note that this phase might also be executed during or after the session setup, although Fig. 3 depicts it as a first step for clarity.

Step 2 shows a typical example of the SIP signaling that is necessary between the MN and a CN to establish a multimedia session through the IMS. For simplicity, the figure only shows the signaling procedures at the originating side, assuming that the MN does not need to do resource reservation over its access networks. As the user is subscribed to the service provided by TRIM, a TRIM AS receives all the SIP signaling messages exchanged by the MN. Consequently, this application server maintains detailed infor-

mation about every multimedia session of the MN. Eventually, the IMS session setup completes, and the TRIM AS can provide the H-ANDSF all the information related to the different flows forming the multimedia session (step 3). Moreover, the TRIM AS detects any modification in the multimedia session, as it stays in the signaling path and keeps the H-ANDSF informed of those changes.

Therefore, our architecture provides a simple mechanism that allows the H-ANDSF to build a global view of the data traffic corresponding to the MNs of the home operator. This view enables the discrimination between the different traffic flows according to diverse parameters, such as the nature of the flows (e.g., audio or video) and their bandwidth demands. Thus, the operator is provided with all the information that may be necessary to generate the policies to be transferred to the MNs.

TRANSPARENT NETWORK-ASSISTED MOBILITY MANAGEMENT

This section presents a scenario that illustrates the network-assisted flow mobility procedures supported by our architecture. These procedures are executed transparently to the end-user multimedia applications, which can use TCP or UDP in the user plane. In this scenario, we assume that the home operator has a number of MNs, a subset of which exchange traffic through a visited network. Following the procedures described in the previous section, the H-ANDSF maintains a global and comprehensive view of all the user flows of the MNs. Figure 4 illustrates the procedures performed by the elements of our architecture due to a change in the network conditions of the visited domain.

In the scenario shown in Fig. 4, we assume that an access network in the visited domain is overloaded. As this situation cannot be solved internally within the access network, the ANDSF in the visited network is triggered (step 1). Based on this trigger, the V-ANDSF sends an interdomain policy update to the H-ANDSF, aiming to reduce the traffic in the overloaded access network caused by the MNs of the home operator (step 2).

Based on the global view of the data traffic maintained by the H-ANDSF, a policy decision is made on which user flows should be moved from the visited network. For this purpose, the nature of the different user flows (e.g., audio or video) and their bandwidth demands can be taken into account. As a result of this step, a set of candidate MNs (those holding the selected flows) is generated. Then the H-ANDSF sends an updated intersystem routing policy to each MN in this set (step 4), specifying that the overloaded access network is now restricted (for simplicity, only one of these MNs is shown in the figure). The policy provided by the home operator may also indicate which access networks types can be selected by the MN.

After evaluating the received policy (step 5), the MN sends a request to the H-ANDSF (step 6) to obtain information about access network discovery and selection. The request includes the capabilities of the MN, such as supported access network types, and its location.

The H-ANDSF can optionally contact the V-ANDSF (step 7) to request specific policies for any flows pertaining to the MN. This way, the home operator can consider preferences and policy rules provided by the visited operator. The request sent from the H-ANDSF includes the description of the user flows for which operator policies are requested, as well as the capabilities of the MN and its location. As a result of this request, the V-ANDSF generates an intersystem routing policy (step 8), indicating the preferences of the visited operator for the allocation of the indicated user flows to access networks. This policy is sent back to the H-ANDSF (step 9).

Next, the H-ANDSF makes a final decision on the intersystem routing policy to be provided to the MN (step 10). This policy expresses the preferences of the home operator with respect to the selection of access networks for the user traffic originated and terminated in the MN. The decision about the policy can be restricted by the capabilities of the MN and the access networks available in its vicinity. Moreover, the policy can be generated taking into account the current situation of the MN in the home and visited net-

works, the availability of access resources in the home network, the intersystem routing policy received from the visited operator, and roaming agreements with visited networks. Finally, the intersystem routing policy is transferred to the MN (step 11).

Based on the received intersystem routing policy and the user preferences, the MN selects the most preferable access networks (having coverage in its location) for the different traffic flows. Finally, the MN obtains IP connectivity to any new access networks (step 12).

As a result of the previous steps, the assignment of user flows to access networks may have changed in the MN. Consequently, the TRIM enabled MN executes the SIP signaling mechanisms necessary to update the multimedia sessions affected by flow mobility procedures (step 13). As a result of this, the TRIM address translator (in the home network) is updated to forward each user flow to the MN via the appropriate access network. Note that by using TRIM, this configuration is handled transparently to the end-user applications running at the MN and CN.

At this point, transparent network-assisted

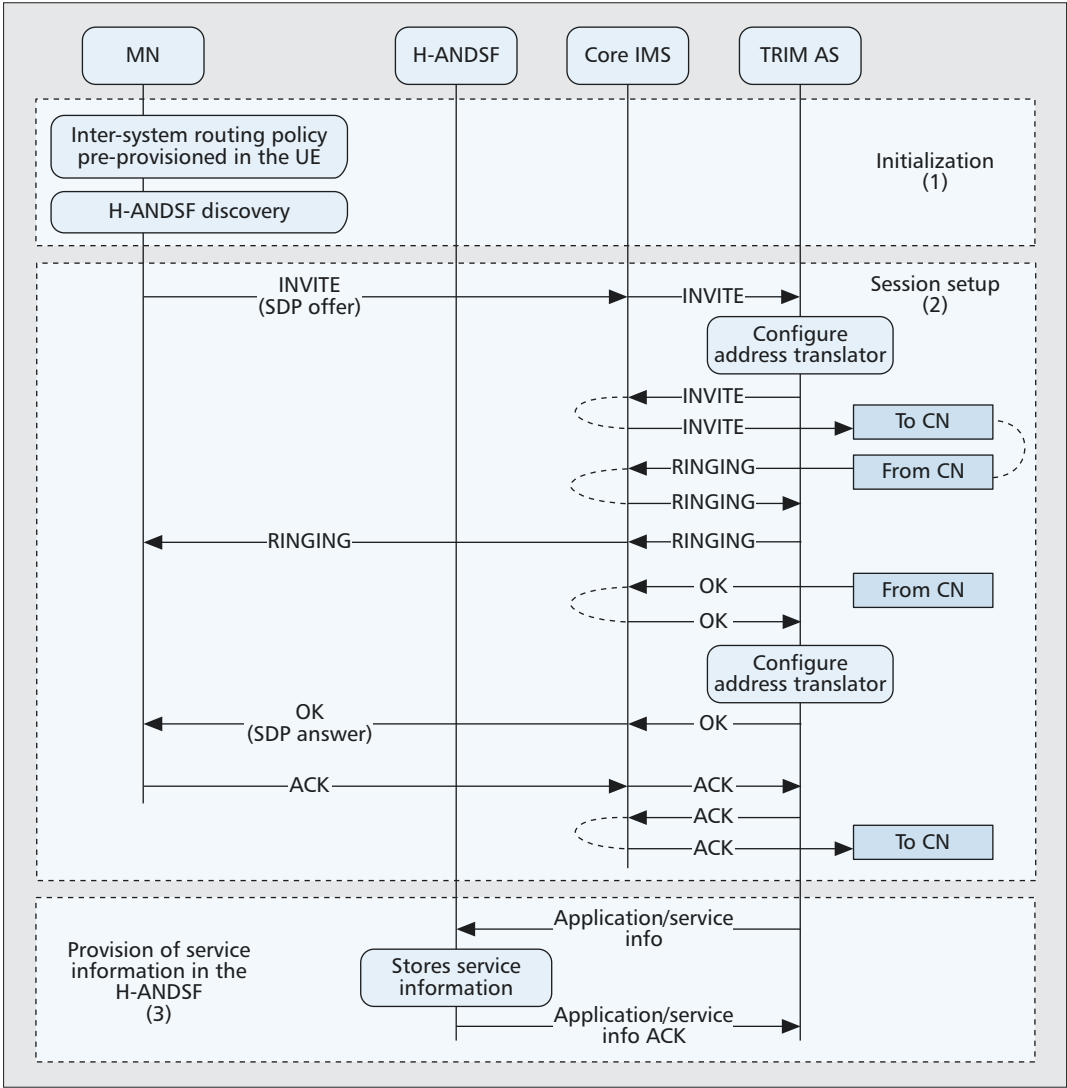


Figure 3. Session setup.

flow mobility has successfully been completed at the MN. Nevertheless, a last interaction is still needed between the TRIM AS and the H-ANDSF (step 14). The purpose of this communication is twofold: first, to provide the H-ANDSF with up-to-date information about the multimedia sessions established by the MN, which would allow effective operation; second, to serve as a confirmation to the H-ANDSF that flow mobility procedures have been made effective as a result of the intersystem routing policy provided to the MN.

ACCESS FROM NETWORKS WITHOUT IMS SUPPORT

In our proposal, mobility is an IMS service, and as such it is provided from the home network. Thus, MNs do not depend on the availability of an IMS framework in visited networks to benefit

from transparent mobility support and offloading of traffic to those networks. A V-ANDSF is not required either, although it enables the visited network to indicate preferences and policy rules, and to dynamically update requirements to the MN's home network. Static rules, part of the roaming agreement for using resources in the visited network, would be used if a visited network lacks a V-ANDSF and wants to define policies in the use of resources by visiting MNs.

EVALUATION

As a proof of concept, we have designed a testbed aimed at validating our proposal. The different elements depicted in Fig. 2 were implemented with the minimal functionalities necessary to perform a basic experiment, where two flows (UDP and TCP) are moved between the Ethernet and WiFi access networks that provide

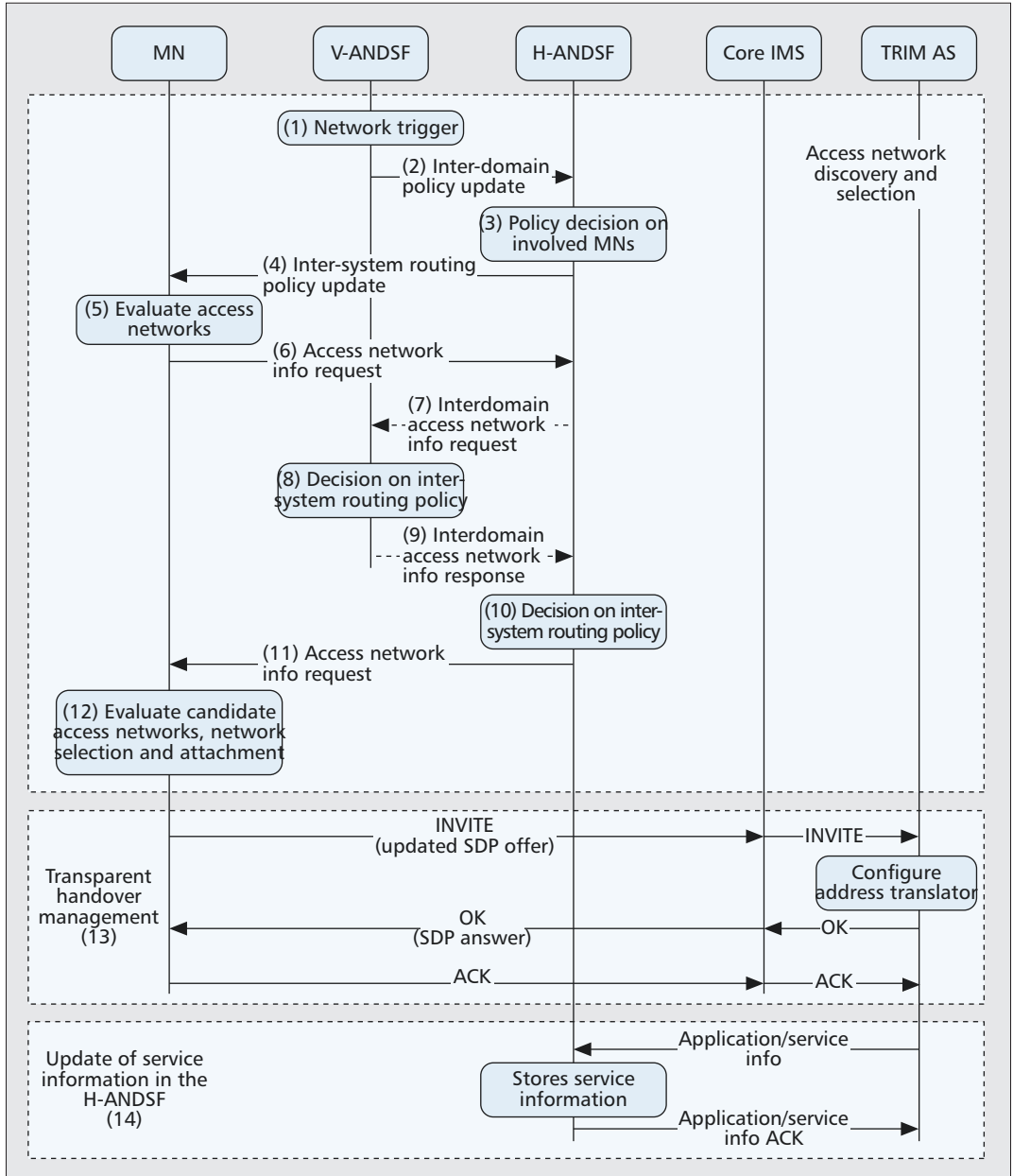


Figure 4. Transparent network-assisted mobility management.

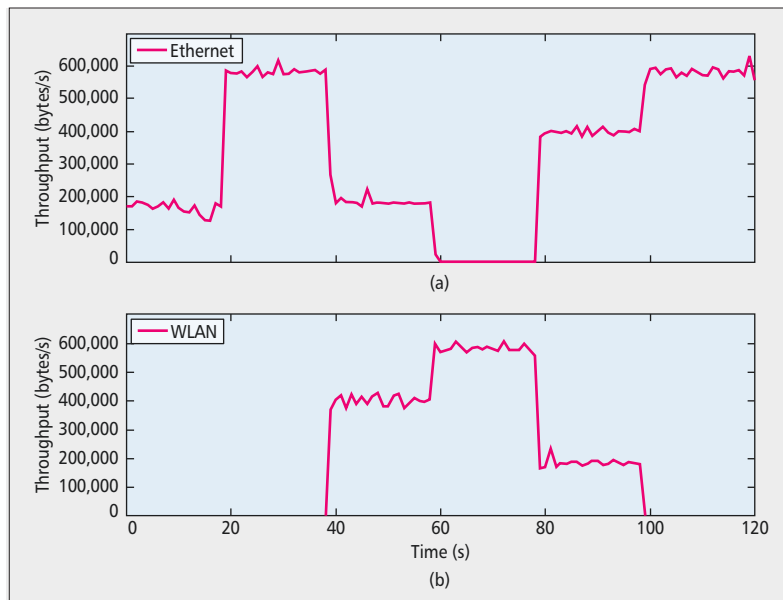


Figure 5. UDP/TCP throughput per access network.

connectivity to the MN. The Open IMS Core² is used as the IMS framework. The SIP elements (MN and TRIM AS) were built using the JAIN SIP stack. We use the Click! software router³ to implement the address translators located at the MN and the network. A simple ANDSF was programmed to push policies to the MN at certain time intervals. Figure 5 shows the results of our experiments.

After the MN is registered in the IMS, it establishes a multimedia session with a server to stream, using the VLC application,⁴ a variable bit rate video with a 160 Kbytes/s average rate over UDP. This session is established using the Ethernet interface available at the MN. After 20 seconds, the MN establishes another multimedia session through the Ethernet. This session is used to download a video from the server using TCP, with a maximum bandwidth of 3 Mb/s (we enforce this maximum bandwidth using the `tc` tool available in Linux). To test the proposed solution, the ANDSF interacts with the MN at time 40 s to change the allocation of the TCP flow from the Ethernet to the WiFi access network. This may happen because, according to operator policies, the traffic load exceeds a certain threshold in the Ethernet access network. Figure 5 shows how the UDP traffic is received from the Ethernet, while the TCP flow arrives via WiFi, in the time interval 40–60 s. Around time 60 s, the MN is contacted by the ANDSF, and the UDP traffic is transferred to the WiFi interface. Once the traffic load decreases in the Ethernet, the TCP flow is moved back to the wired interface, at time 80 s. Finally, the ANDSF communicates with the MN to move the UDP flow to the Ethernet at time 100 s.

Despite the movement of the UDP and TCP video flows, end-user applications do not have to do any operation related to the flow mobility procedures. In addition, the quality perceived during the video playback was not degraded during the experiments.

CONCLUSION

In this article, we present an architecture to support transparent network-assisted flow mobility in IMS networks. In our solution, access network discovery and selection is guided by operator policies, using a modification of the ANDSF model proposed by 3GPP. Additionally, our architecture provides a simple mechanism enabling the H-ANDSF to obtain detailed information about user traffic. In our solution, the H-ANDSF is a single point of decision for network discovery and selection procedures, building appropriate policies according to all the available information, including the operators' preferences and roaming agreements. Our future work includes studying different models of interaction between the H-ANDSF and the TRIM AS, as well as different algorithms to be deployed in the H-ANDSF, to support cost-effective distribution of flows to access networks. We are also working on developing a route optimization mechanism for TRIM to avoid the sub-optimal data path through the home network.

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NOTES

¹ TRIM could also support having one internal address per interface to allow applications to choose the initial interface for a flow. Once an internal address is assigned to a flow, it does not change even if the flow is moved to another interface.

² <http://www.openimscore.org/>

³ <http://www.read.cs.ucla.edu/click/click>

⁴ <http://www.videolan.org>

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