Access Network Discovery and Selection in the Future Broadband Wireless Environment

Marius Corici, Jens Fiedler, Thomas Magedanz, and Dragos Vingarzan

Fraunhofer FOKUS Institute
Kaiserin Augusta Allee 31, 13589, Berlin, Germany
{marius-iulian.corici,jens.fiedler,thomas.magedanz,
dragos.vingarzan}@fokus.fraunhofer.de

Abstract. The Future Broadband Wireless environment is characterized by the co-existence of a multitude of wireless networks e.g. LTE, UMTS, WiMAX, WiFi etc. In order to be able to offer the best connectivity, according to the requirements of the user and to the preferences of the operator, a novel functionality was introduced in the network and in the mobile devices for access network discovery and selection. This paper introduces this functionality as standardized in the 3GPP Evolved Packet Core (EPC), highlighting its main concepts and technical scenarios. Further a set of novel optimizations are evaluated, followed by the description of the Fraunhofer FOKUS OpenEPC implementation.

Keywords: Access Network Discovery and Selection, Wireless Broadband Networks, 3GPP Evolved Packet Core, heterogeneous wireless access.

1 Introduction

With the deployment of multiple access networks of various technologies, the mobile communication system is evolving towards a dense wireless environment where multiple access networks overlap and complement each other in terms of bandwidth, transmission delay and operational costs.

On the other side, the mobile users demand an increasing and diverse amount of resources for their mobile applications (like video, conferencing, streaming) in addition to the classic voice communication. To fulfill the requirements of this evolution, in which the telecommunication environment is transformed into a data dominant one, the network operators have to deploy a novel, more cost efficient network infrastructure.

The current access network selection mechanism presumes that the user of the mobile device decides independently the access through which it communicates. However, the mobile device is not aware of the momentary context in the network, so this mechanism does not offer any guarantee that the selected access is able to sustain the communication at a satisfying operational cost. Also it relies on multiple scans of the wireless environment, power consuming operation performed by the mobile device for the discovery of the available accesses. As it is foreseen that a multitude of accesses will be available at the same location delivering wireless broadband services

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to a multitude of devices, a novel mechanism for network discovery and selection has to be deployed, considering the information available in the core network e.g. the momentary preferences of the operator, the momentary operational costs of the accesses etc.

In order to solve this issue, the NGMN Forum [1] indicated that the novel wireless network environment will include a mechanism to provide services cost-efficiently by balancing the performance requested by the mobile users and the resources available in the different access networks.

To fulfill the requirements of the operators for the heterogeneous wireless broadband environment, the 3rd Generation Partnership Project (3GPP) initiated the standardization process for the Evolved Packet Core (EPC) as an all-IP based multi-access core network which integrates both 3GPP i.e. LTE, LTE-A, UMTS, GSM and non-3GPP i.e. cdma2000, WiFi, WiMAX wireless technologies. In the EPC, the balancing mechanism recommended by the NGMN Forum is separated into intra-3GPP and with non-3GPP accesses load balancing.

From the perspective of the operator, the 3GPP accesses are seen as a single integrated access network, which implies that the discovery and selection procedures are supported by the inter- and intra-access technology mobility management. The non-3GPP accesses are seen as an extension of the resources offered by the 3GPP accesses, which makes the discovery and selection functionality a generic enabler loosely coupled with the existing architecture. In this case, the functionality limits its goal to offering operator policies to the mobile device that optimize its handover decision.

This paper presents the access network discovery and selection functionality in the 3GPP EPC. The challenges cover several possible enhancements for the ANDSF, like the rapid handovers, caused by Femto-Cells, or the missing links between the ANDSF and service platforms (e.g. for location based services) and the ANDSF and subscriber profiles for access-network pre-selection or dynamic discovery of access network in the area of a mobile terminal. Furthermore its novel concepts and possible solutions are presented according to the standardization direction in the 3GPP and to the NGMN Forum recommendations. The Fraunhofer FOKUS OpenEPC proof-of concept implementation of the functionality is described together with the already implemented enhancements.

The remainder of this paper is organized as follows: Section II provides an analysis of the current status for the access network discovery and selection in 3GPP. In section III a set of novel concepts which enhanced the functionality are presented followed in Section IV by the proof-of concept implementation of the FOKUS OpenEPC platform. A set of conclusions are provided in Section V.

2 Access Network Discovery and Selection in 3GPP

Recognizing the need for the integration into a converged wireless environment of 3GPP and non-3GPP access technologies, 3GPP initiated the standardization of the Evolved Packet Core [2], [3] as an all-IP architecture which is able to support access control, subscription based resource reservations, security and seamless mobility between the different access networks.

As depicted in Fig. 1, the functionality is supported by a set of gateways which enable the exchange of data traffic with the mobile devices, named User Endpoints (UEs). The gateways are managed by a central policy based control entity – the Policy and Charging Rules Function (PCRF) which makes the subscription based decisions on the access control and on the resources to be reserved for each data flow of the UE. Completing the architecture, a Subscription Profile Repository (SPR) maintains the information related to the user profile. As in the current stage of standardization the SPR is not clearly defined as functionality, during this paper, it will be associated with the Home Subscriber Service (HSS) – the user profile repository imported from the IP Multimedia Subsystem (IMS) present also in EPC for storage of authentication and authorization of the UE and of its location information in the 3GPP wireless environment.

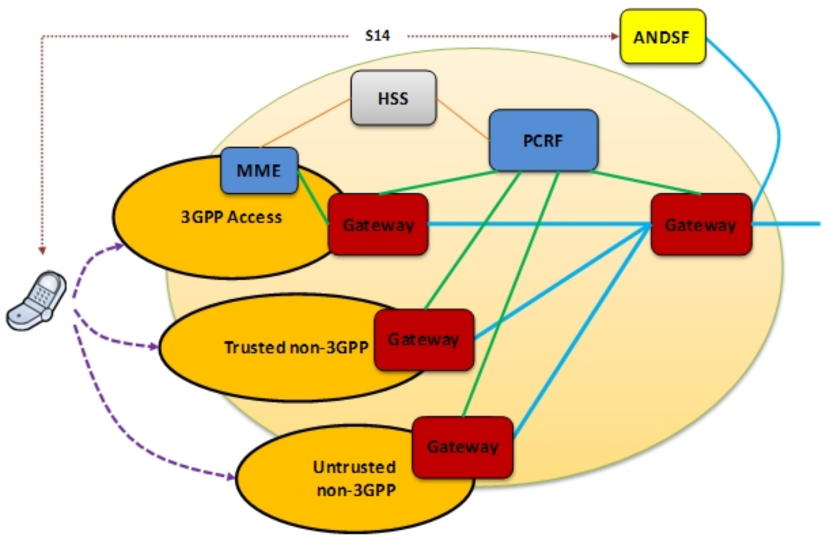

Fig. 1. EPC Simplified Architecture

For the mobility management inside the LTE and between the 3GPP access technologies, EPC contains a Mobility Management Entity (MME) which maintains local to the specified accesses the network discovery and selection. Due to the control of 3GPP on the standardization of the access technologies, the MME is able to select the target access cell and to prepare and command a handover of the UE.

For the interconnection with or between the other non-3GPP access technologies (e.g. WiMAX, WiFi etc.), a network discovery and selection functionality is introduced on top of the EPC architecture as an enabler. It presumes that two functional entities are deployed, one in the network – denominated as Access Network Discovery and Selection Function [4] and one in the UE – denominated in this document as Client Mobility Manager (CliMM).

The UE is able to receive discovery information and selection policies from the ANDSF using a logical interface. On this interface, OMA Device Management (DM) [5] protocol is deployed, which supports dynamic updating mechanisms, but it is not suitable for real-time communication. The OMA DM protocol was initially standardized as PULL mode protocol. At specific moments, the UE updates the device management information. As this did not provide enough dynamicity to the information refreshing, an out of band mechanism for triggering the fetching of data from the network was developed as a rudimentary PUSH mode. Currently it relies on OMA DM specific mechanism which use a trigger based on exterior services like SMS [6] which may not be suitable considering the new all-IP communication environment [4].

A Management Object (MO) [7] for the network discovery and selection functionality was specified by 3GPP. The MO describes the information exchanged between the UE and the ANDSF.

The UE transmits to the ANDSF the momentary location as geo-location or as information on the accesses to which it is currently connected to. For example, for a UE connected to an LTE access network, the location information may contain the operator domain, the Tracking Area Code and the cell identification.

The ANDSF responds to the UE with a set of policies separated for different physical areas which contain information on the operators deploying access networks, on the access networks (e.g. for WiFi the ESSID and the BSSID), a time interval when they are available and a prioritization between them. This information enables the UE to select the target access network restricted to a specific location and time interval and ordered by the operator preference.

The ANDSF maintains a Coverage Map database, which contains static information on the accesses available at specific locations. For example, a query to this repository with a specific location – geo-location or 3GPP cell-ID – will return a set of operators deploying WiMAX and WiFi accesses in the area and the Access Point information – NAP_ID, ESSID etc.

Although this solution provides the operators with a minimal mechanism for access network discovery and selection control, the information transmitted from the ANDSF to the UE does not state any information on the availability of the resources that are required for a seamless communication.

Also, the information is static; the UE does not have any guarantee that the access networks received are available in the area. For example, a WiFi access network may be available in the vicinity of the UE, but because of various external factors (interference, environmental conditions, operational failure etc.) it may not sustain the communication.

Due to the minimal coupling to the core network of the operator (the communication is executed on an application level protocol and the functionality does not interact with any other functionality deployed in the network), the access network discovery and selection can be deployed as a stand-alone 3rd party enabler which enables the mobile device to select the most appropriate access network and the services to be adapted to its environment.

3 Beyond 3GPP ANDSF

Although the functional goals of the ANDSF are already set, due to the incipient phase of standardization, several optimizations can be brought to the access network discovery and selection functionality. In this paper a set of these optimizations are analyzed and their suitability and possible integration into the 3GPP architecture are evaluated.

3.1 Subscription Profile Based ANDSF

As described in the previous section, currently the ANDSF is connected only to the mobile device, as the recipient of the access network discovery and selection decisions. In this context, the ANDSF has no interaction with the subscription profile which is already present in the network core for the access control and resource reservation procedures.

A first optimization proposed by this paper is to introduce a trigger into the ANDSF with the subscriber profile as a decision parameter. Using this enhancement, when a request for access discovery and selection policies is received, the ANDSF is able to select from the access networks which are located in the vicinity of the mobile device only those to which the UE can and is allowed to connect to.

For example, if a request is received from a mobile device which is not able to connect to WiMAX access networks because it does not include the required device interface or it is not allowed from the agreement with the network operator, then these accesses can be safely removed from the further ANDSF decision and thus from the information transmitted to the mobile device.

Also if the subscription profile is modified, due to an administrative change, then a notification may be transmitted to the ANDSF which in turn generates new policies and pushes them to the mobile device.

This optimization allows the ANDSF to reduce its processing for individual mobile devices to the set of access networks to which they can connect to and also the information exchanged over the network.

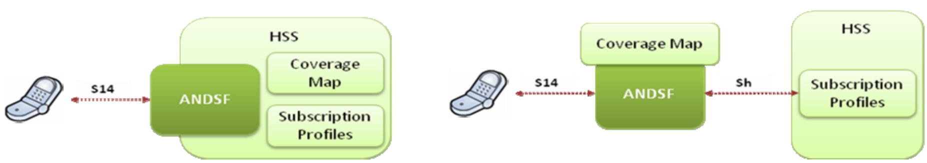

Fig. 2. Subscription Profile Architectures - ANDSF integrated into HSS (*left*) and ANDSF interfaced with HSS (*right*)

As depicted in Fig. 2, from an architectural perspective, this optimization can be implemented by using two mechanisms:

- ANDSF is integrated into the subscription repository
- A new interface between the ANDSF and the subscription repository

ANDSF already stores the Coverage Map containing the access networks which are available at specific locations. From this perspective, the repository can be integrated with the subscription profile repository, which using our convention is the HSS. In this case, the ANDSF becomes a communication entity of the HSS which is able to respond to the requests of the mobile device.

The ANDSF-HSS integration allows faster responses to the UEs as there is no other communication necessary. However, in this case the HSS has to be extended with more complex decisions related to the UEs by matching the information of the Coverage Map with the one of the subscription profile and the ability to push information to the mobile devices.

Also the direct connection between the operator storage and the mobile device is not advisable due to security. Various attacks can be performed on the storage itself if the UEs can transmit queries directly to the HSS.

In order to circumvent these disadvantages, the same functionality can be obtained by maintaining the ANDSF as a separate entity in the core network and introducing a new interface between it and the HSS. A similar interface is already standardized: the Sh interface between the IMS Application Servers (ASs) and the HSS [11]. The Sh interface allows for the same functionality as the interface here proposed: subscription profile fetching upon request and its modification notifications. In order not to modify the HSS side of the communication and to introduce only the ANDSF endpoint, it is beneficial if the same reference point would be deployed.

Compared with the integration of the ANDSF in the HSS, the novel interface has the advantage of isolating the database from the direct communication with the mobile device. Also it allows that the access discovery and selection functionality to be maintained as a separate enabler, who may be further integrated with other functionality of the core network to provide other optimizations.

3.2 Dynamic Discovery

The ANDSF maintains static information on the access networks available in specific areas. Currently, it is introduced through administrative means and due to the external factors (e.g. the control on the availability and mobility of a WiFi access point, the weather conditions etc.) their availability in the exact location of the UE may not be determined.

In this case, even if the UE receives the discovery and selection criteria for a specific area, it has first to discover that the accesses are available. This presumes that a scan of the wireless environment is to be performed. Only after determining the presence of the access network, it is possible for it to select the one which offers the best service continuity.

So, a handover is executed in two steps, one in which the access network is discovered and one in which it is selected as target access network, which increases the delay of the handover procedures and the power consumption of the device.

In order to reduce this delay and to make the ANDSF decisions more accurate and also to be able to introduce dynamically information in the Coverage Map, a novel Dynamic Discovery Enabler independent of the selection one may be considered. It presumes two different operations:

- Dynamic information is introduced in the Coverage Map
- The dynamic discovery information is transmitted to the UE.

In order to introduce dynamic information in the Coverage Map, the UEs should be able to scan the wireless environment upon request and based on the criteria received from the ANDSF. For example, if the ANDSF requires receiving information on the

Fig. 3. Dynamic Discovery Procedures: (A) PUSH of information from the UE to the Coverage Map, (B) PULL of information to the UE through the ANDSF decisions

WiFi access networks available at a specific location, it transmits to the UE a scan request for the WiFi frequencies. The UE powers-up the WiFi device interface and scans the environment. The list of the discovered access networks together with the momentary location of the UE are transmitted to the ANDSF which in its turn introduces the information in the Coverage Map.

This information allows the ANDSF to have a degree of certitude on the momentary availability of the access networks at the specific locations. Using this procedure the ANDSF is enabled to make decisions having different levels of probability that the various access networks are available. The level of probability should be transmitted also to the mobile devices requesting discovery and selection information. When the probability that one access network is available in a specific location, it enables the UE to directly select the access network, without passing through the discovery phase.

Using the Dynamic Discovery Enabler, the ANDSF does not require anymore that the Coverage Map information is introduced through administrative means. It can receive information directly from the various UEs and to compute a momentary level of probability that the access network is available for other or the same mobile devices.

From this perspective, the ANDSF can be deployed as a third party enabler, completely decoupled from an operator network. It can maintain in its Coverage Map information on all the access networks available at specific locations, from more than one operator. The service provided by ANDSF to the mobile devices consists of offering dynamic discovery information, independent of operators, which may be beneficial to the UEs especially in roaming cases in which the UE has to choose a different operator than the one to which it has an agreement to in order to sustain its communication.

3.3 Location Enabler

ANDSF maintains the location of the UE and the access network to which it is currently connected to as main parameter of the discovery and selection decision. Several ambient aware applications may use this information in order to transmit context aware information to the mobile devices.

Currently in the EPC, there is no interface to transmit ambient information from the core network to the service platforms, thus the services have to use other exterior means to determine the location of the mobile devices. These mechanisms presume that an application on the mobile device determines and transmits the location directly to the service platform. The two operations, the one executed for the service platform and the one executed for the access network discovery and selection enabler are similar.

In order to reduce this redundancy, the ANDSF can expose the location information to the service platforms through a Location Enabler (Fig. 4). Using this information, the applications use not only the service profile of the user, but also its momentary vicinity. The usage of the ANDSF as a central location enabler for the various platforms reduces the communication over the wireless link – as only once the location of the mobile device is determined, compared to the state of the art solution in which all the services determine independently the location.

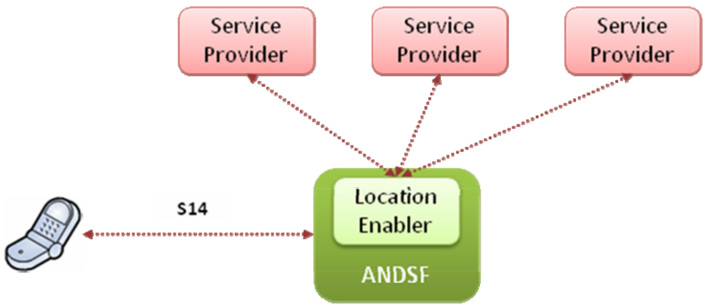

Fig. 4. Novel Location Enabler Functionality for the ANDSF

In order to be able to deploy the location enabler, a novel interface has to be considered between the ANDSF and the service providers. Currently only one similar interface is considered in the EPC – the Rx interface which allows the services to notify the PCRF on the resources that have to be reserved for specific data flows [10]. It also allows the PCRF to notify the services on specific events related to the data flows e.g. loss of communication etc. The same high level interface may be deployed between the ANDSF and the Service Providers. As the location enabler has a different functionality then the PCRF, a further evaluation of the operations and of the information exchanged is to be further considered.

3.4 Femto Cells Discovery and Selection

With the foreseen deployment of 3GPP accesses femto-cells the wireless environment is highly modified [9]. A femto is located at the user premises, has only a small coverage and is able to offer the same amount of resources as an operator controlled base station.

From the network discovery and selection perspective, they are introduced in the network as on top extensions of the existing infrastructure having the same advantages and limitations as the non-3GPP accesses: increased throughput at specific locations, parallel access to the existing wide coverage networks, reduced assurance of availability and limited coverage which translates into fast loss of signal during mobility. Also only a limited number of subscribers are allowed to use a specific femto cell, which if maintained as part of the 3GPP mobility management would make the MME decisions more complicated (e.g. the list of accepted users to the femto and the information on which femto cells the user is allowed to use).

Because of this, the ANDSF is a better candidate for Femto Cell Discovery and Selection. As seen for the non-3GPP accesses, there is no need for a complete mobility management scheme for the wireless accesses which come as extensions to the wide are wireless infrastructure and the ANDSF already provides the functionality for integrating non-3GPP hotspots and enterprise accesses.

For this only minor changes are to be introduced in the architecture. The femtocells are considered as a novel type of access networks with similar characteristics as the WiFi access networks. The discovery and selection information send by the ANDSF to the UE will include this new category.

From the perspective of the handover procedures, they can be executed as in the current state of the art for the handovers with non-3GPP accesses ensuring the same seamless quality.

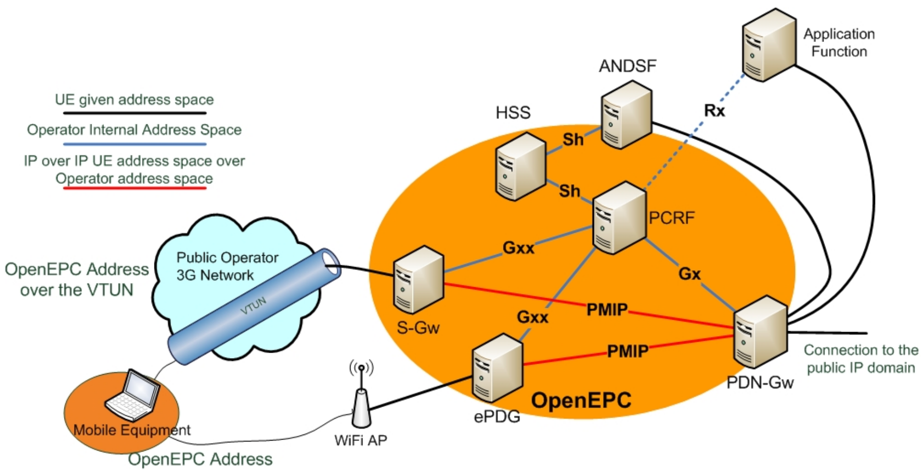

Fig. 5. OpenEPC Testbed

4 OpenEPC ANDSF Realizations

Fraunhofer FOKUS OpenEPC [8] platform implements a set of components according to the 3GPP EPC specification. By its highly modularized structure, it enables easy integration of access technologies and wireless broadband applications. Also, fast innovation in the challenging areas of mobile broadband networks research like new approaches to mobility, QoS, security and optimizations of the architecture are addressed.

As depicted in Fig. 5 currently it is able to provide subscription based access control, resource reservation and seamless mobility between UMTS and WiFi using as support IPv4, IPv6 or a mixture of the both. Other access technologies will be shortly integrated i.e. LTE, femto and fixed access.

OpenEPC implements the 3GPP standard for the access network discovery and selection functionality several own additions, including the connection with the subscription profile described in Subsection 3. As depicted in Fig. 6, it contains a CliMM in the UE, a separate ANDSF entity in the network which is connected to the HSS representing the repository maintaining the user profiles.

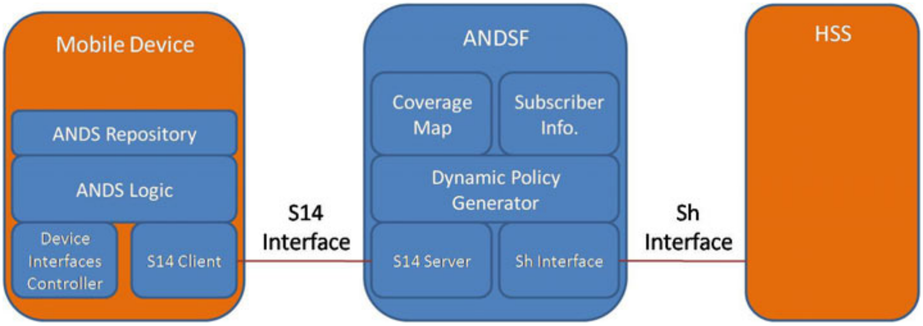

Fig. 6. OpenEPC Access Network Discovery and Selection Realization

The CliMM integrates a client for the interface to the ANDSF named S14 in the 3GPP specifications. Through this, it is able to communicate with the ANDSF in either PUSH or PULL mode. The functionality in the mobile device is separated into ANDS Logic which makes the discovery and selection decisions and an ANDS Repository storing the policies received from the network. The result of the decisions taken by the ANDS Logic is enforced on a Device Interface Controller which enables attachment and detachment from specific access networks and the forwarding of the data traffic accordingly.

The simple structure of CliMM and its complete independence on the applications enables its easy deployment on various mobile platforms. Currently Linux and Windows operating systems are sustained, shortly followed by Android, Symbian and other.

The OpenEPC ANDSF maintains Coverage Map and subscriber information repositories. The Coverage Map is indexed by areas, enabling a fast determination of the access networks that may be located in the vicinity of the mobile device. ANDSF maintains subscription information for the mobile devices which are registered through the S14 server. This way, there is no need for further queries on the profile, enabling a fast response customized on the capabilities of the mobile device and on its access rights e.g. the access networks to which a mobile device is capable and allowed to connect to.

The interface introduced in Subsection 3.1 between the ANDSF and the HSS was implemented, based on the FOKUS OpenIMS Core Sh interface. It allows the ANDSF to fetch subscription information for newly attached UEs and to receive notifications in case it is modified.

A central Dynamic Policy Generator makes decisions on the information which is to be then transmitted to the mobile device in either PUSH or PULL mode over the S14 interface. Compared to the specifications, the decisions are made not only based on the location of the mobile device, but also dynamically customized based on the subscription profile. Through this mechanism, the redundancy of the discovery and selection information is reduced, thus reducing the processing power consumed by the mobile devices. For example, if a mobile device is not allowed to connect to WiMAX in a specific area or it is not capable of connected to LTE accesses, the correspondent information is eliminated from the ANDSF decision and thus from the one transmitted to the mobile device.

For demonstrating the proof of concepts of the access network discovery and selection, the OpenEPC discovery and selection functionality is capable not only on the transmission of indications to the UE on the different access networks which can be considered in case it decides a handover, but it is also capable of transmitting handover commands. This enables a fast adaptation of the UE to the modifications from the subscription profile than in the real deployment scenarios. For example, if the subscription profile is modified and the UE is not allowed anymore to connect to the WiMAX access to which it is already connected to, then a handover command is transmitted from the ANDSF on which the UE makes the decision to select another access. Because of this feature, the OpenEPC ANDSF is able to present in real-time its integration with the subscription profile information compared to the real deployment scenarios in which the UE executes the handover procedures only when they are triggered by other mobile device internal mechanisms like loss of signal in a specific access network.

4.1 OpenEPC ANDSF - Evaluation Scenario

For showing the capabilities of the OpenEPC in the area of access network discovery and selection multiple testing scenarios had been implemented, from which the following was selected as the most representative.

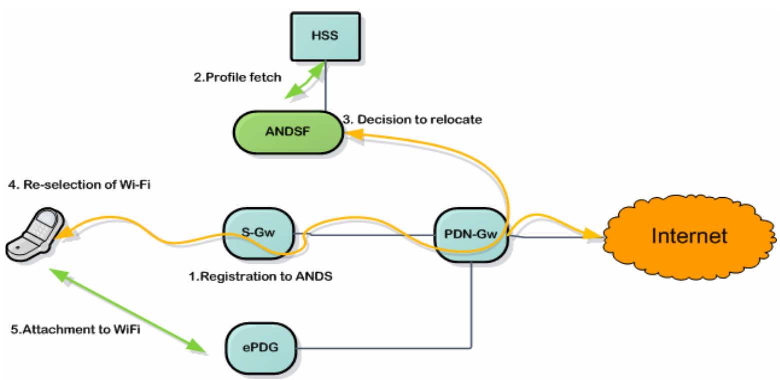

Fig. 7. Subscription Based Access Network Discovery and Selection

It is presented here as validation proof of the ANDSF functionality of the OpenEPC. As the goal of the OpenEPC is to provide a platform open for innovation and as the access network discovery and selection functionality is not very time constraint in the 3GPP EPC, the experimental measurements do not truthfully provide a view on the efficiency of the functionality, thus they were not included in this paper.

The OpenEPC operator can restrict the access of a UE to specific access networks by modifying the subscription profile. For brevity, the scenario selected here presents an initial connectivity case, although it was tested also during the active connectivity of the mobile device. As exemplified in Fig. 7, the mobile device initially attaches to the UMTS network.

After the initial attachment, it connects over the S14 interface to the ANDSF and requests the default discovery and selection policies for a newly attached UE. The ANDSF fetches the subscription profile from the HSS, which was modified during the inactive time of the UE, as to restrict it to connect to the UMTS networks. Then, the ANDSF makes a policy decision in order to find another suitable access network to which the UE can handover to. It finds that a WiFi access is available in the vicinity of the mobile device and it sends a response to the UE containing a policy which indicates that a handover to the WiFi access is required. As to shorten the duration of the demonstration of the scenario, the policy also indicates that an immediate handover is required. The UE executes the handover to the WiFi access network.

The modification of the subscription profile can happen also during the service of the mobile device. In this case, the ANDSF receives a notification from the HSS containing the modifications of the subscription profile and upon this trigger it makes the decision that new access discovery and selection policies have to be transmitted to the UE. The ANDSF alerts the UE, which triggers an immediate policy fetching from the ANDSF to the UE. Using the new policies, the UE executes the handover procedures as in the previous initial connection case.

The access network discovery and selection functionality may be triggered also by the loss of signal to the access network to which the UE is connected to. In this case, the UE either uses the policies of handover as they were previously received from the ANDSF or requires new policies.

It is to be noted that in OpenEPC the policy transmission to the mobile device can be either synchronous with the handover trigger or asynchronous based on the location change of the UE. In the second case, when the network or the UE notices a change in location new policies are either pushed or pulled to the UE.

This scenario uses the non-standard interface between the HSS and the ANDSF as described in the previous sections. It is used to bring to the ANDSF from the subscription profile the information on which access networks the UE is momentarily allowed to connect to.

As the communication for access network discovery and selection was done as a background communication to the active applications of the mobile device and as the resources consumed by this communication can be easily supplied by the current and future access networks to all the mobile devices, no impediment was seen on the communication of the mobile device due to this novel enabler.

This scenario was tested with and without having a real-time video application established between the UE and a server providing the service. Due to the underlying mobility protocol deployed – Proxy Mobile IP, the same IP address was allocated to the two device interfaces of the UE which made the service to be seamless to the user. This scenario opens the possibility for the operators to deploy seamless services across the multiple access technologies without having to extend the mobility related functionality in the mobile devices and without any modification of the service platforms. Using the minimal CliMM application on the mobile device, the access network discovery and selection functionality can be easily deployed to real operator scenarios.

5 Summary and Conclusions

This paper presented the access network discovery and selection functionality in the 3GPP EPC including the general procedures and protocols already defined between the network-located function and the mobile device. From the perspective of 3GPP, the functionality is seen as an over the top enabler. The overall system can function without its deployment, but it provides its benefits when it is present. This allows a fast integration into the existing architecture, without requiring the modification of the other components.

Maintaining this general scope, a set of issues and potential improvements were further analyzed on how it can be extended without modifying the already existing functionality. Several options on how they can be integrated in the architecture were presented according to the directions of 3GPP standardization. These possibilities open new areas of research and optimization which may be further considered according to the different real operator deployments.

Furthermore, this paper presented the realization of the new concepts in the Fraunhofer FOKUS OpenEPC platform and the validation scenarios which were developed.

As proven by this article, the EPC access network discovery and selection functionality, by its clear separation from the other functions of the network core, can be further developed as a dynamic discovery or location enabler. Also its functionality may be extended with a correlation with the subscription profiles maintained by the operator and with femto-cell integration through which a better service is provided to the mobile devices. A further evaluation of these concepts and afferent architectures is required on a per-deployment basis in order to obtain an efficient operation of the EPC.

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