

# OpenEPC: A Technical Infrastructure for Early Prototyping of NGMN Testbeds

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**Abstract.** The challenging and ever increasing requirements of future applications demand new concepts for better control and management of network resources. The Third Generation Partnership Project (3GPP) introduced in their latest specifications the Evolved Packet Core (EPC) architecture for transparently unifying the parameters of different technologies, like the UMTS, WLAN, non-3GPP access technologies and a future Evolved Radio Access Network, called Long Term Evolution (LTE), with the use of multiple application platforms such as IP Multimedia Subsystem (IMS) and the Internet. This paper describes a tested implementation of the Evolved Packet Core named OpenEPC which provides a reference implementation of 3GPP's EPC developed by the Fraunhofer Institute FOKUS. OpenEPC is a set of software components offering advanced IP mobility schemes, policy-based QoS control, and integration with different application platforms in converging network environments. This initiative, in addition to fostering research and development, enables academic and industry researchers to rapidly realize state-of-the-art NGMN infrastructures and application testbeds.

**Keywords:** Open EPC, Testing, Testbeds, Next Generation Mobile Network, Operator core network, EPC.

## 1 Introduction

The Evolved Packet Core (EPC) ([1], [2]), formally known as Service Architecture Evolution (SAE), was developed from the necessity to converge different types of networks for the different services which are provided on top, thus having as main goal the transparency of access technology features to the core network of the service provider. In the next years, not only the integration of these accesses and services networks is envisaged, but also the adoption of a new wireless access technology: the UMTS Long Term Evolution (LTE). LTE brings new requirements, and therefore enhancements to the current architectures should also take place in order to achieve better performance. Following these principles, EPC is designed to fully support and seamlessly integrate in the core network LTE and other future technologies. EPC is a converged network architecture that enables the efficient connection of

the mobile devices to the network and their communication with different service platforms like IMS or Internet. It guarantees the required resources are delivered with seamless service continuity among accesses. This functionality offers to the service platforms an independent management of the various wired and wireless networks following the indications for the Next Generation Mobile Networks (NGMN) Alliance [3].

This paper describes the OpenEPC testbed that is being developed by the Fraunhofer Institute FOKUS. OpenEPC aims to facilitate research and development of EPC, such as new access network integration, handover optimizations, EPC functional extensions, and new NGMN service prototyping. The implementation of the OpenEPC takes advantage of the previous successful implementation of the Open IMS Core ([11], [12]) as a prototypical open source implementation of the IMS core elements that started out as an internal project at the Fraunhofer Institute FOKUS in Berlin. Since the launch of that testbed, the solution has successfully worked as a reference implementation in the Open IMS Playground [7], a vendor and operator independent IMS test-bed providing coaching, consulting and proof of concept implementations as well as performance and interoperability tests for major vendors and fixed and mobile network operators.

## 2 OpenEPC

In comparison with the above related initiatives on the EPC/LTE, the OpenEPC [6] initiative targets not only trials and research on this topic, but also offers the platform for an easy integration of various research use cases. One of the main advantages of the OpenEPC, derived directly from the goals of EPC standards, is that it represents a simplified flat-IP architecture, with a single core network, able to integrate multiple access networks, with a clear separation between the data and the control plane, which offers an easy interaction with various service platforms and network independence to the services themselves. OpenEPC implements a set of standard components permitting the cost-efficient creation of NGMN testbeds. These testbeds are then used to prototype, measure, monitor, test, and perform research and development for NGMNs. It enables a quick start on the heart of emerging NGMNs, namely the EPC architecture, because of its standards conformance and of its configurability to match different needs for testing and extensibility. Open EPC aims to provide its users with a basic understanding and practical hands on experience with EPC, as well as conformance testing and proof-of-concept studies. With OpenEPC it is possible to develop functional extensions of individual and/or multiple EPC components and new NGMN showcases. In addition, OpenEPC supports research and development into challenging aspects of upcoming NGMN infrastructures and services, like the integration of new fixed and wireless access technologies, new approaches to mobility, QoS and security, optimizations of the architecture, design of new seamless wireless applications and the investigation of new business models in the NGMN world.

Having as basis the standards of 3GPP and containing already different optimizations to the available standards which follow the NGMN requirements, OpenEPC addresses to:

- Operators are using OpenEPC to prepare for the upcoming all-IP NGN and NGMN world and have an open and vendor independent testbed infrastructure.
- Manufacturers of individual EPC components are using OpenEPC to test their products in concert with a standards based NGMN environment.
- Manufacturers of full EPC platforms are using OpenEPC for practical research on new concepts and protocols in an easier to maintain platform.
- Application developers are using OpenEPC to certify that their applications work in NGMNs and take advantage of the functional capabilities offered by EPC to the applications domains.

Research institutions and universities are using OpenEPC for practical NGMN research, including usage of OpenEPC as black box for applications prototyping, or extending individual or multiple EPC components and/or developing new EPC components and protocols to provide new capabilities for integrating new networks or enabling new applications.

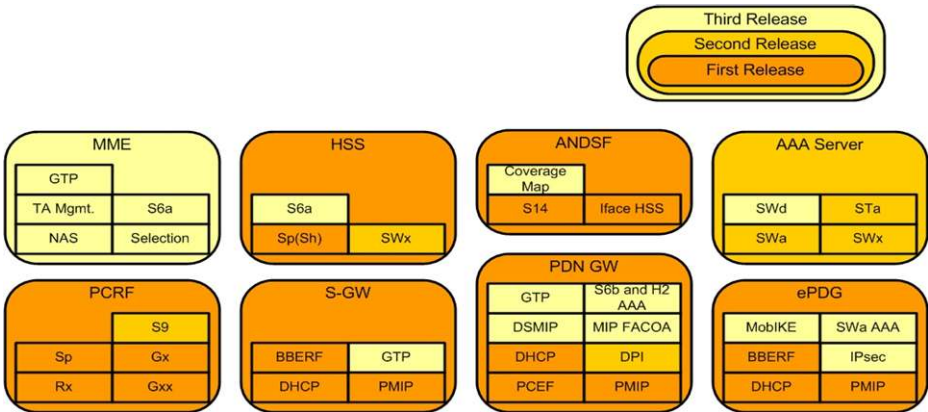


Fig. 1. OpenEPC Architecture

The current version of the OpenEPC is based on the 3GPP Release 8 standards offering the bases for research in the area of integrating different access technologies and different service platforms. Its features provide a policy based implementation for access network discovery and selection, attachment to different access networks, mobility and QoS management based on the network configuration and subscriber profiles. OpenEPC has been successfully tested for IPv4 and IPv6; the remaining heterogeneous IPv4/IPv6 scenarios will be added in the future. All the central software components of OpenEPC have been developed in C, based on a new high modular and configurable software framework, designed especially for the required EPC protocols and architectures (internal code-name Wharf). This allows the easy configuration and customization of components by selecting the functionality

required from a set of modules. With this approach, OpenEPC supports customized components which can dynamically include/exclude or combine functionality and interfaces. For instance, a deployment could include an S-Gw which performs BBERF functionality of the Policy and Charging Control architecture or a PCRF which does not include S9 interface for roaming scenarios. Such customizations are supported by simply modifying the configuration file and enabling or disabling such modules, each module being also capable of self-configuration by detecting what additional functionality it can employ. The components that require dynamic configuration or provisioning of parameters (like PCRF, HSS or ANDSF) offer a web-based front-end, while the state information is stored in a database back-end. In complete configurations a common front-end can be used to configure all components.

## 2.1 OpenEPC Components

The current first version contains the following entities, as depicted in Figure 1: HSS, ANDSF, PCRF, PDN-GW including PCEF and PMIP mobility, S-Gw and ePDG including BBERF functionality and PMIP functionality.

**OpenEPC HSS.** It provides storage and provisioning enablers for the subscriber profile, as defined in the EPC specification, by extending the IMS subscriber profiles already supported. It also performs the non-standard Subscriber Profile Repository (SPR) functionality which sends upon request the subscriber profile to the PCRF, ANDSF or any other authorized EPC component which requires subscription data to function. For this part it offers the not yet standardized interface Sp, which permits the support of personalization through subscriber profile of the policy and charging control functionality, included in the specifications, but still not developed. Added to that, through the same interface, the HSS is connected to the ANDSF to provide personalization for the mobility policies transmitted to the UE. The definition of the OpenEPC interface has been developed based on the Open IMS Core Sh interface, used between HSS and an IMS Application Server, with the addition of specific Data References and Attribute Value Pairs (AVPs). Concretely, the Data-Reference AVP has been extended to include parameters which are fetched from HSS and are used for policy control and for access network discovery and selection.

**OpenEPC PCRF.** It allows the application functions to request resources and priority treatment from the core network for one or more data flows which pertain to the application exchanged between the UE and the network. The Rx interface is used to convey the information received from the applications as part of the active profile of the UE. Also it connects to the HSS using the Sp interface, as to make the policy decisions according to the subscription profile of the users. These decisions are then pushed to be enforced on the gateways of the specific accesses using the Gxx interface and to the PDN Gw using the Gx interface. In order to receive notifications for events, the PCRF subscribes to profile modifications to the HSS (over the Sp interface) and to bearer modifications to the PDN GW and the access network gateways (using Gx and Gxx interfaces). The behavior of the OpenEPC PCRF is controlled through policies which can be provided dynamically through the provisioning

front-end. The policy language used complies with OMA Policy Expression Language extended with the specific PCRF tags. The interfaces of the OpenEPC PCRF are separated into different modules without a very tight interconnection, which makes them separately or all-together deployable depending on the specific requirements of an OpenEPC testbed. In practice, modules like the PCRF can detect which other modules are available and as such deploy a less or more complex set-up.

**OpenEPC PDN GW.** It includes a Proxy Mobile IP (PMIP) stack, capable of acting on both IPv4 and IPv6 and configured as Local Mobility Anchor (LMA). It allocates the IP address of the UE at the initial attachment from the provisioned client IP address pools. For all the subsequent attachments, the same IP address is transmitted. It also maintains the mobility tunnels and enforces the forwarding of the data packets to the access network specific gateway for download traffic and to the correspondent addresses of the other entities involved in the data sessions for the upload traffic. It also supports the Policy and Charging Enforcement Function (PCEF) as a module. This enables the allocation of the default QoS values (upon attachment of a new subscriber to the packed data network) and service and subscriber specific QoS (when a UE accesses a service). The enforcement of these rules is done through fully configurable and already established Linux network tools.

**OpenEPC Serving GW.** It includes the PMIP Mobility Access Gateway (MAG) functionality. It is also integrated with a modified version of the ISC-DHCP server, which offers support for both IPv4 and IPv6. The attachment of the UE to the EPC is detected at network level through a request for an IP address received by the DHCP server. During the tunnel establishment with the PDN GW the IP address to be allocated to the UE is received and it is then forwarded as the address to be transmitted by the DHCP server to the UE. The S-GW includes also a Bearer Binding and Event Reporting Function (BBERF) module for policy enforcement and event notifications related to the data traffic. It connects to the PCRF through the Gxx interface and receives QoS rules which are then enforced using standard Linux tools like iptables, traffic control etc.

**OpenEPC ePDG.** It includes the same functionality as the OpenEPC Serving Gateway, but with a special interest into non-3GPP access. For further releases IPsec connection to the UE will be deployed together with the EAP-AKA authentication interfaces, as to completely discriminate between the trusted and the un-trusted non 3GPP accesses [9].

**OpenEPC ANDSF.** It is based on several not yet standardized functions necessary to provide the demonstrative role of this entity in the EPC: the interface to the HSS for subscription profile fetching and the enabler to make decisions not only based on the location of the UE, but also on its required parameters as well as on the network's operational requirements. As standardized, it communicates to the UE to provide access networks available in the vicinity of the mobile device using the OMA DM communication mechanism and the Management Objects format of 3GPP [8].

**Mobility Manager.** For the UE, a minimal Mobility Manager was implemented which is able to retrieve data from the ANDSF in both PUSH and PULL modes, to make decisions on which access network to select for an initial and

subsequent attachment and to execute the afferent procedures, including handovers. The client platforms which are currently enjoying the largest deployments, like Windows™ and Linux for laptops/netbooks, or Android, Maemo 5 and Windows Mobile for smart-phones, are supported, with support for more extensible based on requirements. For deeper integration and more advanced demonstration of the EPC features, the Mobility Manager features an open interface, demonstrated for example by the integration with the MONSTER [10] client platform.

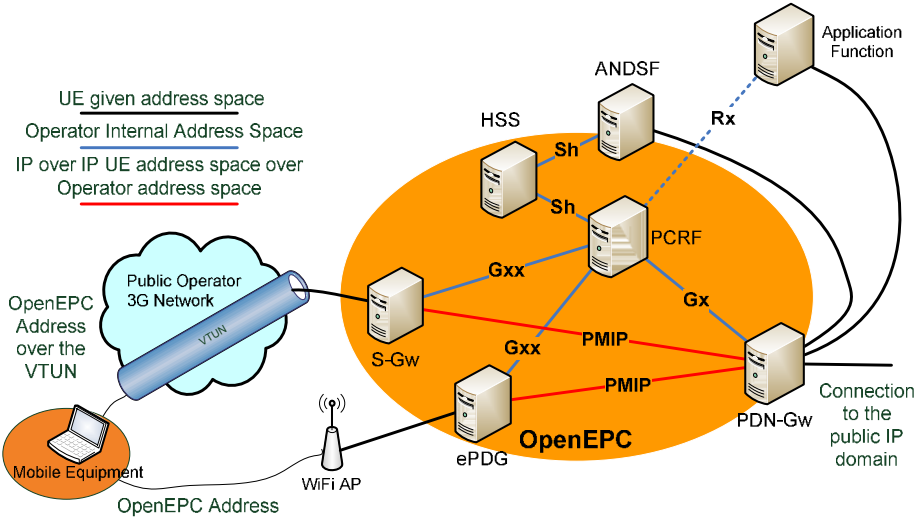


Fig. 2. OpenEPC Testbed

## 2.2 Interconnection with the Access Networks and Applications

As depicted in Figure 2, for the interconnection with the access networks, the OpenEPC uses the functionality described for the S-GW and the ePDG. Currently, the communication is sustained over a public 3G access network. A direct link layer connection is simulated through a Layer 2 tunnel (VTUN) which encapsulates all the link and network layer packets (e.g. DHCP, IP etc.) in UDP over IP packets. This special setup gives the opportunity to test the EPC procedures on a realistic environment, without interacting with the real access network provider and as such practically circumventing the high-costs usually associated with such testbeds. A local WiFi access network can also be easily deployed and connected to the OpenEPC ePDG, making the scenarios that can be demonstrated as realistic as possible for the testbed. This brings the total cost and complexity of running an EPC testbed to the minimum, while, of course, more realistic setups can be employed in case direct access to the SGSN/GGSN or eNodeB components is feasible.

OpenEPC provides inter-connection between the applications and services layer and the network layer. It provides IP connectivity far beyond the concept of an IP pipe by supporting extended features like QoS resource reservation, prioritization and information on events happening at the link and network level (e.g. the UE

lost connectivity or a handover to another access network occurred) upon request of the applications. These features are realized through two interfaces. The SGi interface is the IP interface from PDN-Gw to applications layer through which user data is sent. The Rx interface from PCRF to application layer is the signaling interface based on Diameter that allows the application layer to request special treatment to certain service flows and to get notifications upon events occurring in the access network. OpenEPC provides both interfaces and example functionality to demonstrate the interconnection to both Internet and the 3GPP IMS. The OpenEPC can be also used in conjunction with the IMS, providing for the IMS services QoS, IP mobility and security. The OpenIMSCore [11] provides the perfect extension to the OpenEPC in this area. IMS can be used for Voice over IP (VoIP) or other multimedia services. Independent of the implemented services, the P-CSCF of OpenIMSCore supports the Rx interface towards the PCRF and requests service authorization and resource reservation from IP connectivity layer. Moreover the OpenEPC platform can also be used to connect to **plain Internet**, in order to make use of the advantages of the communication between the applications and the EPC, providing a better control of network usage.

### 3 Proof of Concept Implementation

For showing the capabilities of the OpenEPC in the area of seamless mobility between heterogeneous access networks, advanced triggers for mobility, QoS decisions and enforcement, interconnection with the service delivery platforms and personalization of services multiple testing scenarios were implemented, from which the following were selected as the most representative. These are presented here as validation proofs of the OpenEPC platform, as they can be demonstrated in the current state.

**Mobility Scenarios.** In EPC, a network provider is able to restrict the access of a UE to specific access networks by modifying the subscription profile. This scenario presents an initial connectivity case in which one subscriber attaches to one access network, as exemplified in Figure 3, to the 3G network. After the initial attachment, it connects to the ANDSF and requests the default attachment policy. For this purpose, the ANDSF fetches the client's subscription profile from the HSS, which was modified during the inactive time the UE as to restrict it to connect to the 3G networks. Then the ANDSF evaluates inter-system policy in conjunction with the subscriber profiles and makes a mobility policy decision in order to find another suitable access network to maintain the data traffic. It finds that a WiFi access is available in the vicinity of the mobile device and it sends as a response to the UE with a policy indicating that an immediate handover to the WiFi is required, which the UE executes. The modification of the subscription profile can happen also during the service of the mobile device. In that case, the ANDSF receives a notification from the HSS containing the modifications of the profile and upon this trigger it makes the decision for mobility. The ANDSF alerts the UE in this case, which practically triggers an immediate policy PULL between the UE and the ANDSF. Using the new policies, the UE executes the handover procedures. The mobility 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 transmitted by 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.

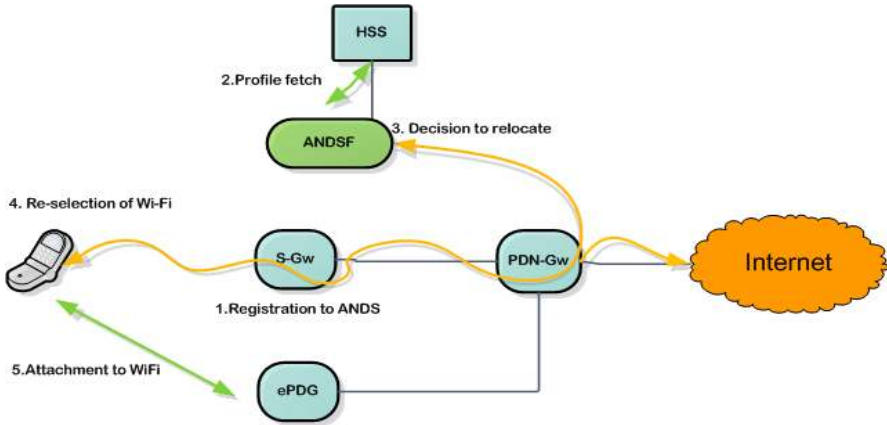


Fig. 3. Subscription Based Mobility

This scenario was tested with and without having a real-time video application established between the UE and a server providing the service. As specified by the PMIP standard, the same IP address was allocated to the two interfaces of the mobile device which made the service to be seamless to the user. This opens the possibility for the operators to deploy seamless services across multiple access technologies without having to extend the functionality of neither the mobile devices nor of the service platforms.

**QoS Control Scenarios.** In OpenEPC, the subscription profile can be used to provide different QoS levels for the same service. For instance a list of prioritized services is provisioned, or different QoS profiles can be provisioned for different users [4], [5]. This allows the OpenEPC network provider to offer differentiated service levels according to subscriptions which may be bound with different charging schemes. An UE connected to one access network, for example to the 3G network as depicted in, initiates the establishment procedures with the Application Function (AF). After the session parameters are negotiated, the preferred QoS levels are indicated by the application function to the PCRF which fetches the subscription profile from the HSS. Based on this subscription profile it makes the policy based decision whether the user is allowed to use the negotiated level of resources. Then the decision is enforced on the PDN GW and on the access network gateway. During the testing process, a SIP based video service was used as a stub for services. The PCRF offered the required level of resources for one subscriber, but a smaller level for another one. For the subscriber which received the required level of resources the



service was available at a good quality of experience while for the other it deteriorated fast. If other mechanisms of detecting the service are available, like Deep Packet Inspection ones, in which the EPC detects the service, then the network operator may increase or decrease the quality depending on the service, the service provider and the momentary conditions in the access networks.

**Service Adaptation to Network Context.** Different wireless access technologies offer different capabilities to which the services have to be adapted. OpenEPC provides the connection between the access networks and the service layer which allows to inform the applications when the characteristics of the access network through which a UE communicates change due to a vertical handover. This allows the services to adapt to the change and to transmit its data according to the requirements of the UE in the new access network. In this OpenEPC scenario, a UE is attached to one access network; as depicted in Figure 4, it may be the 3G network. A service is initiated with an Application Function (AF) having a negotiated level of resources. The AF in this case subscribes to an access network type event for the specific UE, as the service may be received with different qualities depending on the access technology. A handover is triggered by the ANDSF, in the case of the first version of the OpenEPC, manually by the operator of the testbed. A handover indication is transmitted to the UE, which requests a handover to a WiFi access network. The UE attaches to the WiFi access network and the event of the new attachment is received by the PCRF. The PCRF informs the subscribed application function that the UE has changed the access network and receives in return the new parameters which are to be enforced for the target access network. The new QoS level is enforced on the gateways and the AF changes its parameters too and continues to provide the service uninterrupted.

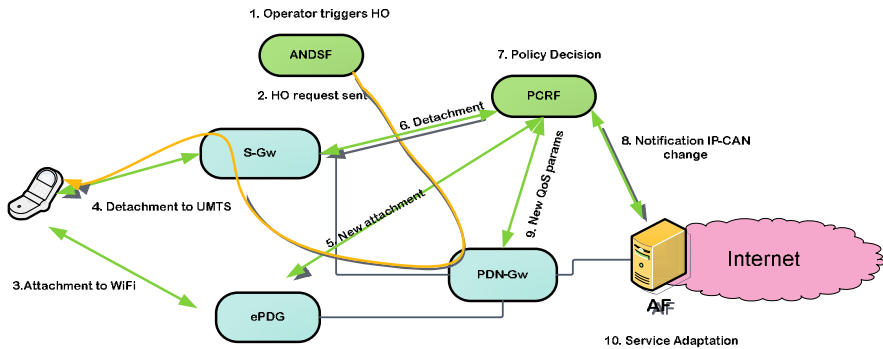


Fig. 4. Service Adaptation to the Network Environment

**Internet Services over OpenEPC.** OpenEPC is prepared to offer more than just best-effort IP pipes for any type of IP services. It can connect to any internet service delivery platform, exporting the same capabilities as given to IMS. As a testing scenario for the OpenEPC, an HTTP Proxy based on the Squid project and enabled with the Rx interface was used. Two mobile devices were used. One which uses the HTTP Proxy and one that does not. As a service, a public third party TV broadcast from the

Internet was used. For the user which connected over the HTTP proxy the service received the required quality while for the user which did not use the proxy, as the service remained transparent to the EPC, the resources usually allocated for the default communication were used. Then the PCRF makes the decision on which level of resources are to be allocated, based on the type of service, the subscription information and the momentary available resources in the access networks. This allows operators to dynamically discriminate between the different services which the UE are allowed to use depending also on the location which gives the possibility of introducing new charging schemes.

## 4 Conclusions and Further Work

The OpenEPC platform, here presented conforms on one side to the standards of 3GPP and it also provides different researched optimizations which enable the operators to easily test and to enhance their requirements for the device manufacturers. It offers also to the device manufacturers, the basis for further development of concepts and proof of concept demonstrations for a fast development of standards and new products. Continuing in these two directions, the OpenEPC will develop to further include more standards related to the Next Generation Mobile Network Core architecture with a high regard for new service platforms and access networks. It will also contain new concepts regarding Self Organizing Networks, more flat network architectures and Future Internet research activities.

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