Network and Control Platforms

Marius Corici[2], Julius Müller[1], Dragos Vingarzan[2], and Thomas Magedanz[1]

[1] Technische Universität Berlin, Straße des 17. Juni 135, 10623 Berlin, Germany
julius.mueller@tu-berlin.de
[2] Fraunhofer Institute FOKUS, Kaiserin-Augusta-Allee 31, 10589 Berlin, Germany
{marius-iulian.corici,dragos.vingarzan}@fokus.fraunhofer.de

Abstract. The Internet as the largest global recognized communication system is in constant change and evolves in dimensions of technology, capacity, availability and size continuously since its beginnings in the late 1960's. The openness and its continuous change became characteristics of the Internet nowadays, but were no available in its origins. This chapter presents an overview about the telecommunication network and control platform evolution from classic fixed Circuit-Switched (CS) on to current fixed and mobile Next-Generation-Networks (NGN) towards future networks trends. Furthermore the Fixed-Mobile-Covergence (FMC) is presented and technology specific details are presented exemplarily.

1 Introduction

The Internet is the largest global recognized communication system, which evolved in dimensions of technology, capacity, availability and size continuously since its beginnings in the late 1960's. Information is transported via packets without differentiating between individual application characteristics over manifold access and core network technologies. The openness and its continuous change became characteristics of the Internet nowadays.

This chapter presents a chronological overview on the evolution of telecommunication networks and control platforms in the last decades, transition from closed to open networks, the fixed and mobile convergence and finally outlines trends of future networks. This chapter focuses on connectivity and builds the fundament for the following chapters especially for the Application Layer Evolution chapter, which outlines the application layer evolution, which is aligned on network layer evolution. Both presented trends influence each other.

The structure of this chapter is as follow. An introduction, which positions the presented work and provides the historical background, is followed by section 2, which introduces the concept of Intelligent Networks (IN) as a classical closed telecommunication system initially designed for fixed networks with a limited set of functionalities. Intelligent Networks or its mobile variant Customized Applications for Mobile Enhanced Logic (CAMEL) are introduced as classic telecommunication systems circuit-switched networks. Section 3 presents the concept, architecture and key functionalities of the IP Multimedia Subsystem (IMS) standardized by 3GPP. IMS is presented as network layer abstraction for 3GPP GPRS and UMTS or non-3GPP, cable,

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digital-subscriber-line (DSL) networks with the goal of providing unified interfaces for SIP based services. Section 4 presents the architecture, main protocols and key functionalities of the 3GPP All-IP Evolved Packet Core (EPC). The need for standardizing the Evolved Packet Core System (EPS) consisting of the radio part LTE and the core network part EPC is motivated and outlined. Section 5 discusses the role of Over-The-Top (OTT) applications and their growing impact on the application diversification, which directly influences the classic telecommunication value chain. Section 6 presents the trend of Machine-Type-Communication (MTC) in form of standardization activities. Section 7 outlines the trend of Open Networks by motivating the concept of network virtualization and presenting ongoing research and development activities. Section 8 summarizes and concludes the chapter. A list of acronyms and references are attached to the end of this chapter.

2 Intelligent Networks

The term Intelligent Network (IN) describes a framework, which provides an open platform support for uniform creation, introduction, control and management of services in an abstract way. The concept of Intelligent Networks separates control and switching logic what in turn introduces flexibility in static telecommunication networks. Logic is pulled out of the network switches (SSP) into dedicated network nodes (SCP), what accelerates the overall performance to real-time signaling and eases the deployment of new service features for the whole network. One main benefit is the reusability of basic services to shorten the time-to-market duration of introducing novel and complex services on top of existing standardized simple services (enabler), without changing the deployed switches. The other benefit is the achieved network and service independence.

Global System for Mobile Communications (GSM) networks were deployed in parallel to fixed line IN. The concept of IN was applied on GSM networks with regards to mobility of the subscriber over network provider boarders. The ETSI standard for IN in mobile networks is called Customized Applications for Mobile Enhanced Logic (CAMEL). The CAMEL architecture supports Operator specific services (OSS) to mobile subscribers even when roaming in another network (international roaming).

IN for fixed CS networks did never support service interoperability, but in mobile networks we are confronted with roaming users and have strong heterogeneity of service platforms, which require seamless and transparent interoperability.

CAMEL evolved within four phases, in which basic call control functions for GSM calls, charging of services in visited network domains, enhanced mobility management and interworking with IMS were introduced step by step.

2.1 Network Elements

Service Switching Points (SSP) connects subscribers' telephones and terminal equipment with the network. SSPs contain large switching matrices in order to switch the high volumes of traffic from the interconnected subscribers. A finite state machine, namely the Basic Call State Machine (BCSM), represents an abstract two-party-call containing all stages. Trigger hook between two adjacent states and invokes further services after reaching this state.

Service Control Functions (SCF) request SSF/CCF to perform certain call and connection processing functions (routing, charging, etc.) and requests Service Data Functions (SDF) to receive/update service data information.

Service Switching Functions (SSF) determine when IN service logic should be invoked. The SSP represents the point of subscription for the service user, which is responsible for detecting special conditions during call processing that cause a query for instructions to be issued to the SCP.

Signaling Transfer Points (STP) act as SS7 routers and give alternate paths to destinations when one possible route to a destination fails.

Signaling Control Points (SCP) provide database and data processing functions within the network, such as billing, maintenance, subscriber control and number translation. The SCP validates and authenticates information from the service user (such as PIN information), processes requests from the SSP and issuing responses.

The Intelligent Peripheral (IP) or Specialized Resource Function (SRF) provides additional interaction functions, which provides additional voice resources to the SSP for playing back standard announcements. Therefore DTMF tones are detected when gathering information from the user.

Service Management System / Operations System (SMS) deploy, manage and configure services. Monitoring data is collected to charge service usage and to provide statistics to the service operator.

Service Creation Environment (SCE) provides to service designer capabilities to construct chains realizing services (service features).

CAMEL and IN have share the same concept, therefore the components of them are quite similar and displayed in the same Fig. 1.

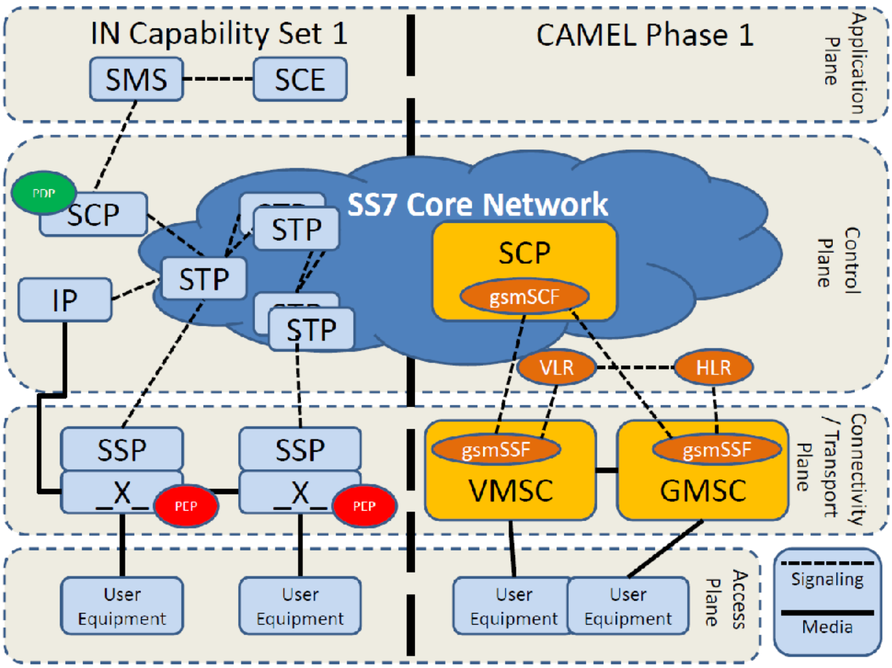

Fig. 1. Intelligent Network and CAMEL Architecture Overview

The Home Subscriber Register (HLR) stores the information relevant to the current CAMEL subscription (CSI). Its counterpart in the visiting domain, the Visitor Location Register (VLR) stores the O-CSI and T-CSI as a part of the subscriber data for subscribers roaming in the VLR area.

The Gateway or Visitor MSC (GMSC/VMSC) receive an O/T-CSI from the HLR, indicating the GMSC to request instructions from the gsmSSF, in case the processing of a subscribe call requires CAMEL support. The MSCs monitor on request the call states (events) and inform the gsmSSF of these states during processing, enabling the gsmSSF to control the execution of the call in the specific MSC.

The gsmSCF functional entity contains the CAMEL service logic to implement OSS. It interfaces with the gsmSSF and the HLR.

The gsmSSF functional entity interfaces the MSC/GMSC to the gsmSCF. The concept of the gsmSSF is derived from the IN SSF, but uses different triggering mechanisms because of the nature of the mobile network.

2.2 IN Key Protocols

Common Channel Signaling System No. 7 (i.e., SS7 or C7) is a global standard for telecommunications defined by the International Telecommunication Union (ITU) Telecommunication Standardization Sector (ITU-T) used in IN. The SS7 network and protocol are used for basic call setup, management, and tear down. Signaling links are logically organized by link type ("A" through "F") according to their use in the SS7 signaling network, depending on the connected network components.

INAP (Intelligent Network Application Part) is used between a wire line Service Switching Point (SSP), network media resources (Intelligent Peripherals), and Service Control Points (SCPs). It supports IN services such as enhanced call routing, VPN, number portability, etc.

CAMEL Application Part (CAP) [1] is used for interactions between the SSF and SCF. Mobile Application Part (MAP) queries the HLR.

Switches are complex, powerful, efficient and expensive network components. Once deployed in the telco network, it is difficult to apply changes on them. Switches of the IN were designed to work simple without having much logic. A Basic Call State Machine instance is instantiated for every incoming call reaching a switch. Trigger Points (TP) are located between these individual Call States, to perform blocking or non-blocking actions to control call establishment and call management.

It was assumed that the idea of the Basic Call Model has a longer duration than service logic deployed on each switch, therefore the intelligence in form of logic was moved from the switch into SCP (high availability server cluster) nodes.

3 IP Multimedia Subsystem

The IP Multimedia Subsystem (IMS) [2] was originally designed to merge the Internet and the carrier grade operator telecommunication worlds with the purpose of creating a platform able to enhance and diversify the process of service provisioning and service delivery. Subsequently, IMS has evolved as a middleware layer between the different access networks and their afferent core network functionality including 3GPP architecture for GPRS and UMTS as well as WiFi and WiMAX from the mobile telecommunication and NGN fixed networks interoperating with legacy PSTN fixed and mobile communication. With the fast deployment and gradual adoption of the LTE access network which offers only packet based communication, IMS is foreseen as the feasible support for voice and other telecommunication services support in the future mobile broadband communications.

IMS represents a generic service provisioning platform widely adopted in the design of Next Generation Networks (NGN) as operator mediation of the service control between the various fixed and mobile devices and the specific application servers enabling the support of the services through the various NGN transport architectures including the 3GPP architecture for 2G and 3G access networks and later for LTE as well as the integration with third party and operator controlled WLAN accesses, the 3GPP2 architecture for the CDMA technologies and ETSI/TISPAN NGN architecture for fixed communication.

Over these multiple accesses, IMS is able to provide a unified QoS and charging mechanisms. Independent of the various access networks, IMS is able to provide service personalization and localization as well as flexible charging schemes based on content and an integrated authentication and authorization.

This brings, as shown in Fig. 2, a large number of benefits including:

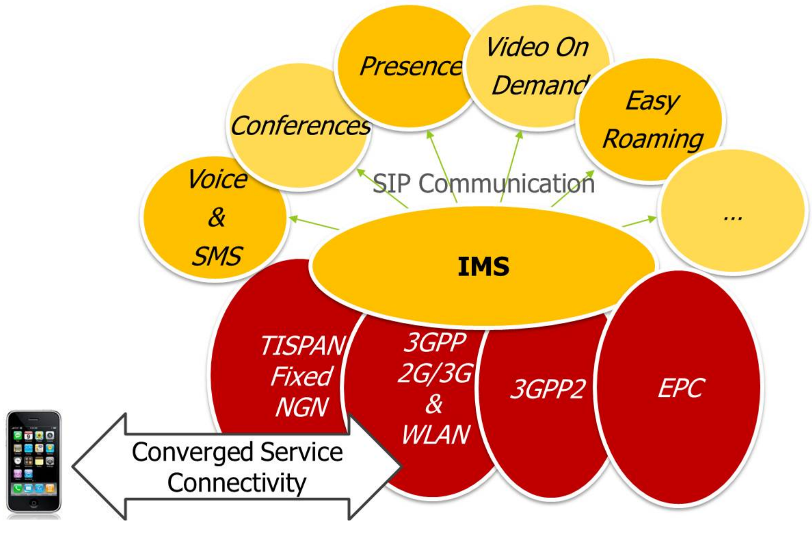

Fig. 2. 3GPP IP Multimedia Subsystem: The Multimedia Service Convergence

- Rapid service creation and system integration – part of the functionality usually required for a specific service is maintained by the service provisioning platform, therefore it does not have to be developed for the specific services such as presence, conferencing, push-to-talk, content sharing etc.
- High degree of interoperability is achieved through the usage of standard interfaces. Same functions are shared among several applications and a more complex service logic can be achieved. This enables service providers to build and customize their own multimedia services.

- The system was design to be highly scalable with build in redundancy mechanism, enabling the easy support of the carrier-grade multimedia communication needs of the fixed and mobile operators.

3.1 IMS Architecture

IMS follows an approach called functional decomposition, which is superior to the traditional vertical integration models in which common functions are replicated for each application. By contrast, IMS offers a layered architecture consisting of an access network, a transport layer, a control and an application/services layer.

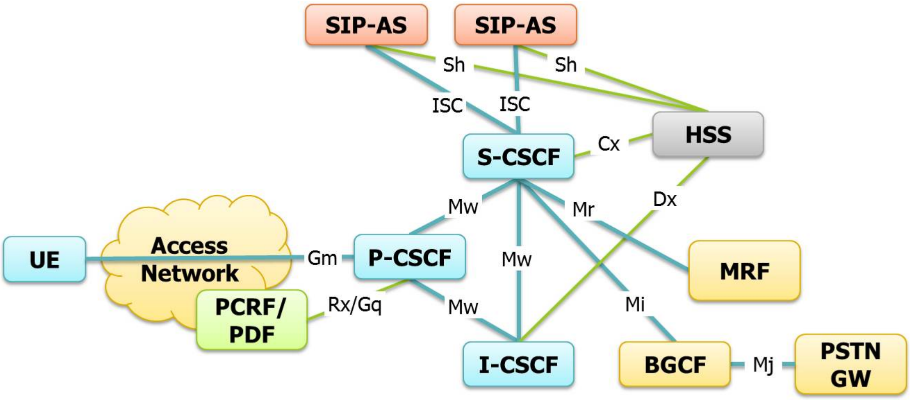

Fig. 3. 3GPP IMS Architecture

Fig. 3 depicts the main functions of a typical IMS infrastructure in a single operator. Each of these functions may be present multiple times in the architecture, ensuring the scalability of the operations of the system. The functions can be collocated or split between multiple physical components. Common practice of the vendors shows that co-location can be used in specific reduced deployment environments; however the most vendors implement each function as a component.

An IMS infrastructure is composed from a set of databases containing user related information, one or more SIP servers named Call Session Control Functions (CSCFs), one or more Application Servers (AS) and other multimedia and interoperability functions.

As main database, IMS includes the Home Subscriber Server (HSS) which contains the subscription profile of the user enabling the handling of the multimedia services as well as IMS platform information such as location, security, authentication and authorization, permissions and current network entities handling the device. If more than one HSS is used in a specific deployment, then a static Service Location Function (SLF) database enables the redirection of the subscription information exchange to the appropriate HSS.

The Call Session Control Functions (CSCFs) are SIP servers which are handling the subscriber signaling in the IMS. There are three types of CSCFs depending on the functionality they provide:

- P-CSCF (Proxy-CSCF) – the P-CSCF terminates the IMS domain towards the user endpoint acting as an inbound/outbound SIP proxy. The P-CSCF includes authentication and authorization functionality related to the usage of IMS services for the mobile device. Additionally, it enables the encryption and the compression of the communication of the mobile device. In relationship with the access networks, it makes resource reservation and charging requests towards the specific transport networks.
- I-CSCF (Interrogating-CSCF) – the I-CSCF is a static SIP proxy located at the border of an administrative domain. Its main function is to determine the service SIP proxy for a specific subscriber. For this it communicates with the HSS to determine the current node serving the subscriber.
- S-CSCF(Serving-CSCF) – the S-CSCF is the central node in the user signaling acting as a SIP registrar, maintaining the binding between the current contact address of the device and its public identity. Additionally, the S-CSCF routes the SIP messages to the appropriate Application Servers, PSTN interoperation nodes, other S-CSCF or the P-CSCF representing the User Endpoint.

A SIP Application Server (AS) hosts and executes a service such as presence, location, conferencing etc. Depending on the type of service, the AS can have multiple SIP functions. As the SIP AS may require information related to the subscription profile, an interface to the HSS is included.

An IMS infrastructure may include additional functions such as a Media Resource Function (MRF) providing the media content addressed to the user endpoint. For interconnection to the PSTN network, a supplementary Border Gateway Control Function (BGCF) and a gateway to the PSTN domain may be deployed enabling the location of the device in the PSTN network and the translation of the communication signaling and data information.

In order to be able to reserve resources and to transmit charging differentiation information towards the specific access networks, the IMS architecture is communicating with the policy decision entities for the specific transport network architectures such as Policy and Charging Rules Function (PCRF) for the Evolved Packet Core, the Policy Decision Function (PDF) for the UMTS and for the fixed network transport infrastructure. Through this interface data path resource requirements are transmitted enabling the appropriate QoS reservations and notifications related to the connectivity of the devices are received.

3.2 IMS Key Protocols

The Session Initiation Protocol (SIP) [3] is used for the signaling and the control of the communication between the User Endpoints or between a User Endpoint and the IMS CSCFs or one or more Application Servers. SIP enables the provisioning of information in the correspondent parties required for establishment and termination of specific services. Specifically for multimedia services such as voice or video calls SIP is transporting in the body of the messages the information in the form of the Session Description Protocol (SDP). SDP is a text based protocol which contains information on the multimedia end points, codec information and optionally indicates the communication data rates.

In case of SIP based sessions, the IMS infrastructure plays an intermediary role enabling the reachability of the correspondent parties, the transport of the resource negotiation and charging information as well as the communication of the different messages through the application servers which are involved in the specific service establishment. The basic SIP protocol was extended for enabling carrier grade communication as well as for supporting the required scalability features of the multimedia signaling.

The actual multimedia data is carried through protocols such as the Real-Time Transport Protocol (RTP) [4] which provides end-to-end real-time transmission. The data encoded with a specific codec is encapsulated into RTP data packets which include additional timestamp and order information enabling the receiver to decode and to render the information at the appropriate time interval from the previous message.

For specific services such as Instant Messaging and Presence, the SIP protocol was extended to transport other type of information such as plain text messages, subscriptions and notifications for specific events and XML formatted information related to the subscribed devices. The extension of the SIP protocol enables the IMS infrastructure to support additional services apart from the classic multimedia.

For the communication with the transport networks the IETF DIAMETER protocol [5] is used, extended for the specific purpose of resource reservations and event notifications. Diameter is additionally used as signaling protocol between the different control entities of the transport layer and it is further described in the next subsections.

3.3 The Role of IMS in the Future Internet Networks

Driven by the deployment of LTE access network, the current carrier grade network providers are also deploying all-IP based infrastructures in the mobile networks, similar to the evolution towards NGN in the fixed communication. In this context IMS plays a major role as the only standardized and highly flexible network architecture.

In order to be able to provide basic Voice Sevices in the all-IP infrastructure, the Next Generation Mobile Alliance (NGMA) adopted and further developed a set of IMS specification under the umberella of VoLTE which enable the basic call setup using IMS, roaming and voice call continuity to Circuit Switched communication through this simplifying the IMS standard to a level where inter-operability can be received with minimal costs.

Additionally, carrier grade operators are planning the deployment of rich communication suite services addressed to smartphone communication and extending the current telecommunication services towards high data exchanges and other user and community services. These services are currently standardized by the NGMA requiring an IMS infrastructure.

IMS can be deployed also independent of the various access networks acting as an Over-The-Top multimedia platform. From this perspective, the carrier grade operator networks are able to offer the services not only to their own subscribers, but also to other subscribers which are bale to communicate via IP. In this case an IMS infrastructure is not limited only to the specific operator, enabling it to act on a larger market targeted to specific users and not bound to a specific geographic region. This use case is addressing especially other industries than the telecommunications such as automated communication with consumer devices, sensors and actuators of automotive industry etc.

4 Evolved Packet Core

With the progress towards high data rate wireless access technologies, a complimentary evolution was required from the side of the core network architecture. As observed from the evolution of the fixed communication, the services that the user requires over broadband access are not any more limited to voice and reduced data exchange such as email over 3G networks. Instead, they are using all of the resources available which transforms the mass broadband wireless environment into an IP data dominant one. In order to face this challenge, the novel architecture is considered to rely on IP communication only and to use a similar forwarding mechanism as the Internet, adapted to the wireless environment and more efficient due to the increased deployment and operational costs compared to the fixed infrastructures.

Following the indications of the NGMN Alliance[11], the 3rd Generation Partnership Project (3GPP) initiated the standardization procedures for the Evolved Packet Core (EPC)[6][7], an all-IP core network architecture specifically designed for the communication requirements of the LTE access and offering IP convergence for the heterogeneous access networks in a transparent manner to the applications as depicted in Fig. 4.

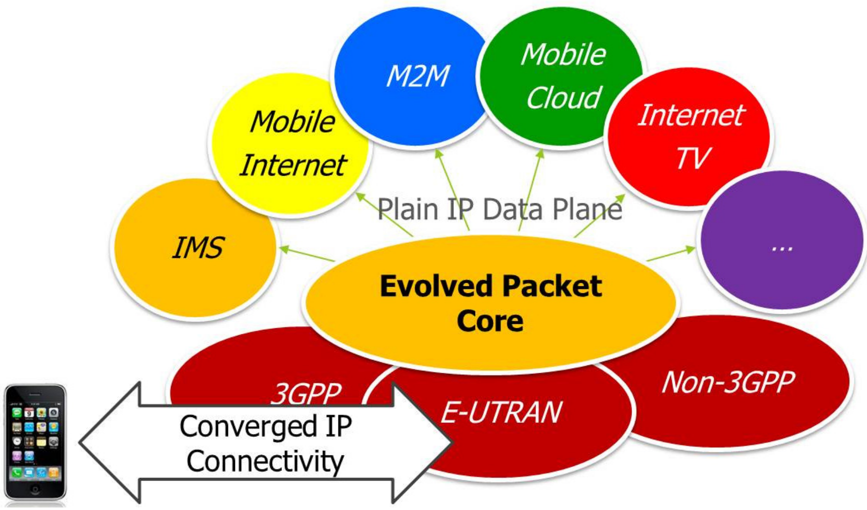

Fig. 4. 3GPP Evolved Packet Core: All-IP Access and Core Network Convergence

As the EPC is the only core network architecture supporting the LTE access technology and as the LTE is gradually deployed with a time horizon of more than ten years until complete deployment, the EPC architecture represents a technology landmark for the core network development. Furthermore, the further scientific development of the EPC core network will most probably be integrated in the next generations of the core network architecture as it was until now done throughout the evolution of the mobile core networks.

Other architectures are available from other standardization organizations such as the NGN architecture from ITU [16]. These architectures exhibit the same functional features as they offer the same type of connectivity support to the devices. However, either their standardization status is still in very early stages or the specific access technologies for which they are developed are not having a global momentum similar to LTE. Therefore, they will not be further presented here.

As LTE is still in its first releases in standardization, it is foreseen that the architecture is not yet completed. Major requirements are expected to be further received from the first deployments as well as with the increase in scale of the number of connected subscribers and of the number of applications especially tailored for the mobile environment[12]. Because of this a large space for novel concepts and innovation is envisaged.

Additionally, the EPC sustains also in an integrated manner the other heterogeneous accesses such as 3GPP e.g. UMTS, EDGE, GPRS and non-3GPP e.g. WiMAX, CDMA etc., being able to interconnect with any available or future wireless technologies including fixed communication [3],[4]. EPC provides for the mobile devices connected to these accesses full convergence at IP connectivity level including the support for identity, authentication and authorization, policy and charging control and mobility management.

Through the convergence at network level, the EPC is enabling efficient connection of the mobile devices to the network and their communication with the different service platforms such as the IP Multimedia Subsystem (IMS) [8] or the Internet, being able to control the resources allocated to the various devices and offering transparent service continuity across the same or different access technologies and by this offering to the service platforms an independent connection over the wireless accesses. From the service platform perspective, EPC manages event oriented policy based access control, resource management and mobility in single carrier grade operator core network together with accounting and charging functionality based on the subscription profile and the active services of the mobile device. These characteristics make EPC the next generation transport level for signaled services.

4.1 EPC Architecture

EPC is designed based on the concepts of previous 3GPP architectures ([12][16][8][9]). It represents a long term evolution of the UMTS architecture which was designed for voice and data transport [10]. Additionally, it maintains the subscriber differentiation based resource reservation and mobility concepts from the IMS architecture.

EPC contains a clear delineation between the control and the data path through the core network. Its main components are depicted Fig. 5. A correspondent mobile device is also considered, named User Endpoint (UE). They are classified based on their functionality as follows:

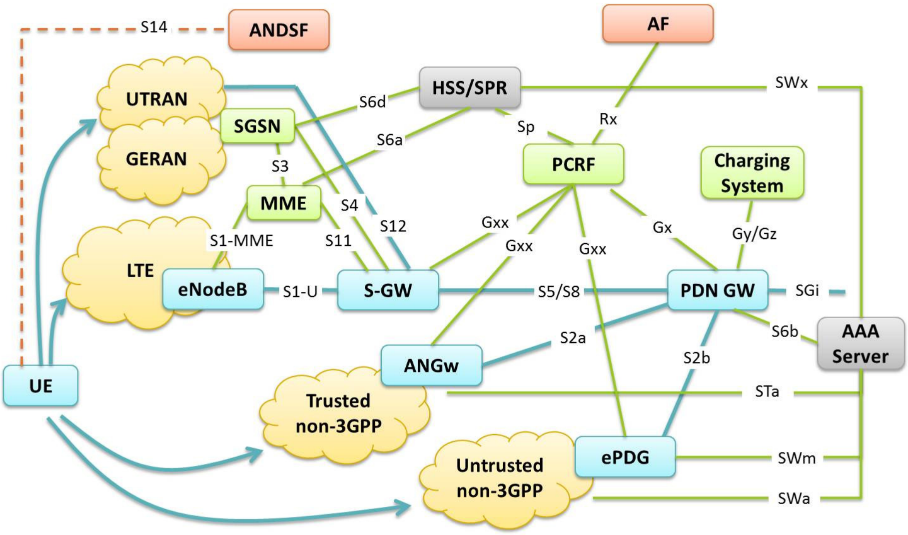

Fig. 5. 3GPP Evolved Packet Core Architecture

- Subscription Data Entities (e.g. HSS, AAA Server etc.) - These entities store, update and are able to transmit notifications on the subscription profile of the users and to perform authentication and authorization procedures. Additionally, they contain dynamic user information such as current allocated IP addresses.
- Control Entities (e.g. PCRF, MME, ANDSF) - These entities make policy based decisions regarding the connectivity, the access control and the resources required by a UE. Based on various subscriber related triggers, they make the decisions which are afterwards installed on the UE and on the various data path components.
- Gateways (e.g. Serving GW, PDN GW etc.) - These data path entities are forwarding the data traffic of the UE and ensure the access control, QoS and mobility support according to the decisions made by the control entities. They are also able to transmit subscriber related events to the control entities in order to adapt the policy decisions accordingly.

Together these entities enable that the IP Connectivity is provisioned and the resources are allocated according to the profile of the user and based on the requirements of each application. The applications are considered external to the EPC architecture and they are generically named Application Functions (AFs). The role of the AF can be taken by an IMS architecture, by a service broker, by an intermediary node of the operator on the application path or directly by infrastructures of third party service providers. Additionally, the operator may deploy traffic detection tools which can also transmit events which generate policy decisions modifying the IP Connectivity.

Furthermore, EPC contains accounting functions enabling the charging services for the IP connectivity. The charging is based on the data path sessions and can be executed synchronous or asynchronous to the data sessions.

The control functionality of the EPC is based on the subscriber information and does not consider that during the policy decisions information on the status of the network is available. Because of this, even though the decisions are taken considering the highest level of resources which may be allocated to each subscriber, they might not be available in the radio and on the data path. Because of this, the policy decisions are taken faster as they lack the complexity of the input parameters. However, in exception cases, which are more frequent due to the missing information during decision taking, the procedures are highly extended.

4.1.1 Subscription Data Entities

The Subscription Data Entities store and are able to send notifications for the subscription profile of the UE. They perform the authentication and the authorization upon the attachment of the mobile device to an access network.

The Home Subscriber Server (HSS) is imported from the previous 3GPP IMS architecture. In EPC, it maintains the subscription information for each user, including restrictions for the attachment and the resources that can be allocated over the different access networks. It also maintains dynamic information on the location of the UE and the network entities which serve it in the control and in the data path.

Another repository with similar functionality is the Subscription Profile Repository (SPR). It is a logical function which maintains the subscription related information necessary for the policy based decisions for access control and resource reservation. As the current standards do not specify the internal data structure of this repository and following the standardization direction in 3GPP to unify the different subscription data entities, the SPR is associated in this paper with the HSS, because of their similarities.

The AAA Server was initially defined for the inter-working between the 3GPP and WiFi and it was extended in the EPC for supporting authentication and authorization in non-3GPP accesses ([22][23]). It retrieves and updates the subscriber profile information from the HSS allowing also report generation for charging based on the authentication requests received from the non-3GPP trusted network or from the ePDG. In the roaming case, an AAA Proxy is located in the visited domain for forwarding the requests related to the user to the home domain.

4.1.2 Control Entities

The control functions of EPC manage the access control, the mobility and the resource reservations. The control mechanisms of EPC are triggered by events. When the user profile from the repositories, the attachment of the UE or its resources required change or the access network context is modified then policy based decisions are made which are further enforced in the gateways.

The Mobility Management Entity (MME) is the central management entity for the LTE accesses [21]. It is responsible for the connection of the UE by selecting the gateway through which messages are to be exchanged and a level of resources for the UE in cases of attachment and handover. It provides also authentication and authorization and location tracking using the HSS and intra-3GPP mobility (e.g. between 2G/3G and LTE).

The Policy and Charging Rules Function (PCRF) is the control entity making policy based decisions for service data flow detection, admission control, QoS and flow based charging [25][26][27][28]. It maintains a complete subscription state for each UE with decisions made on a per-user base. PCRF cannot be associated with a management entity as it does not maintain information on the resources available in the different access networks. Instead for each decision an enforcement procedure is to be executed in order to determine whether the requirements can be fulfilled by the gateways.

The Access Network Discovery and Selection Function (ANDSF) makes subscription based decisions and transmits to the UE information on the preferences of the operator for the discovery of accesses in specific locations and handover decisions of the UE [29]. The ANDSF uses the location of the UE, a Coverage Map and the subscription information, to make these decisions. As inside 3GPP accesses the preference of the operator is controlled by the MME, the ANDSF addresses only handovers with non-3GPP accesses.

4.1.3 Gateways

In EPC, the gateways ensure the forwarding of the data packets between the UE and the network core within the parameters enforced by the control entities. They also support the execution of different mobility protocols and transmit notifications for data related events for each subscriber to the control entities.

The Packet Data Network Gateway (PDN GW) is the entrance and the exit point for data traffic in the EPC. It provides connectivity from the user devices to the external packet data networks. Additionally, it acts as central mobility anchor. The PDN GW performs policy enforcement and packet filtering for each data flow of each subscriber. For this, it maintains the context for each connection of the mobile device, the traffic flow templates for the active services, the QoS profile and the charging characteristics.

The EPC is able to offer a unified enforcing of the policies for the different access networks. For each class of access networks, a different gateway is defined. For the 3GPP accesses a Serving GW (S-GW) is used. Additionally, a Serving GPRS Support Node (SGSN) is used for the 2G/3G access technologies. The non-3GPP technologies are separated based on the security the operator is able to provide over the access network in trusted and un-trusted non-3GPP accesses. In the untrusted non-3GPP accesses additional security levels are to be established. As gateways, for the untrusted non-3GPP accesses an evolved Packet Data Gateway (ePDG) is used while for the trusted non-3GPP a generic Access Network Gateway (ANGw) is deployed, differing in the specific requirements and parameters of the different accesses.

All the gateways, they include the Bearer Binding and Event Rules Function (BBERF) which provides policy based enforcement and event notifications from the wireless link to the PCRF and gating functionality for the data traffic. They also include the attachment and mobility related functionality for both the control and the data path.

4.2 EPC Key Protocols

EPC bases on IP protocols, as standardized by IETF and OMA, enhanced by the 3GPP specifications. It is able to communicate over IPv4 or over IPv6 or over a mixture of the both. Three main categories of protocols are considered, depending on their goal in the EPC: active management protocols, mobility protocols and mobile device management from the network.

Diameter is used as a singular management protocol[5]. The basic IETF standard was enhanced by 3GPP for supporting not only authentication and authorization, but also policy based decisions and event notifications related to the connectivity and the different data flows of the subscribers. Diameter is deployed on the interfaces between the subscription repositories, the control entities and the data path entities supporting the operations required for access control, QoS and events.

As mobility protocols, multiple options are available like GPRS Tunneling Protocol (GTP), Mobile IPv4 (MIPv4)[31], Dual Stack Mobile IP (DSMIP) [32] and/or Proxy Mobile IP (PMIP) [33][34]. Each of these protocols has different capabilities and is in a different development stage. Although they may function independent of the architecture itself directly on the data path, as specified by IETF, in EPC, the entities defined in these protocols are interconnected with the Diameter control interfaces which supply parameters and through which different events and operations are to be triggered. All these mobility protocols have some similar characteristics. First, they are transparent to the correspondent nodes, enabling the communication to any IP based service which may or may not pertain to the carrier grade operator which deploys the EPC. Secondly, the mobility protocols rely on a centralized anchor node which enable the mobility of the all the devices in all the accesses and in all the locations of the EPC.

In EPC, the access network discovery and selection functionality was included as part of the operator con-trolled management of the mobile device. Thus OMA Device Management (DM) protocol was chosen as transport protocol because it is already integrated in the existing mobile network architectures [35]. A novel Management Object was defined specifically for the access network discovery and selection for conveying the in-formation from the network to the mobile devices [21].

4.3 EPC Functional Features

EPC is designed to provide a number of key capabilities over the IP basis required for the support of the seamless and efficient service delivery. The main functionality includes network access control functions, resource control and mobility support.

4.3.1 Network Access Control Functions

The network access control functions enable the UE to connect to the EPC and then over the EPC to the different service providers. They include the authentication and authorization, admission control, selection of the entities which will serve the UE (e.g. the PCRF, the PDN GW etc.) and the establishment of a minimal context which enables the UE to be reachable in the IP domain and its basic communication with the service platforms.

The authentication and authorization procedures are dependent on the access network selected by the UE for attachment. In the case of LTE, the MME retrieves the profile of the subscriber directly from the HSS during the attachment, while in the case of non-3GPP accesses, the ANGw or the ePDG request the information through the AAA Server from the HSS after the UE attached to the wireless environment when it requests an attachment to the EPC [36]. In case of the other 3GPP accesses, the standard procedure is executed, considering that the role of the GGSN is taken by the Serving GW.

Then, the IP reachability context is created for the UE. In case of GTP or PMIPv6, upon an address request from the UE, a data tunnel is established between the gateway of the specific access and the PDN GW. In case of MIP or DSMIP, an address is allocated locally and the tunnel is established directly between the UE and the PDN GW.

During the tunnel establishment procedures, the PDN GW initiates the procedures for the basic resources which allow the UE to communicate with the service platforms. In this procedure, the PCRF makes a policy based decision whether the UE is allowed to communicate over the access network and which default level of resources is to be allocated for the basic communication.

After this decision is enforced and the mobile device receives the IP address over which it is able to communicate, the attachment procedure is completed and it may exchange data over the access network and the EPC - it has a Packed Data Network (PDN) connection.

The network access control functions allow the EPC to coherently apply policies during the attachment and detachment of the mobile devices according to the subscription profile of the user in the SPR/HSS.

4.3.2 Resource Control

The EPC has a central notion for resource reservations the IP Bearer, an aggregation of IP data flows that receive a common QoS treatment (forwarding, scheduling, queuing, shaping etc.) established between the UE and the PDN GW.

In EPC there is a clear distinction between the access network and the core network resource reservation. The access resource reservation is technology specific and does not influence directly the EPC operations. On the other hand, EPC was designed as support architecture for LTE, thus the MME is managing the resources inside this access technology.

For all the access technologies, the core network resource reservation can be triggered by the UE or by the service platform. The UE trigger is received by the gateway of the specific access which forwards the request to the PCRF. The service platform trigger is transmitted directly to the PCRF. By this centralization into the PCRF, the consistency of the QoS rules enforced for an UE is maintained. Then the PCRF makes the subscription based policy decision whether the UE is allowed to reserve the required resources. The decision is enforced to the PDN GW and to the gateways of the specific access networks and from here using specific mechanisms to the wireless access network.

As PCRF does not manage the resources available on the different wireless accesses and gateways, this enforcement may fail. From this perspective, PCRF is not a resource control entity as it is not able to consider the context in the different accesses, but as a user control entity because it sustains its decisions on input regarding the UE and its applications. This allows the concentration of the functionality on the UE itself and not as much on the momentary context of the accesses, enabling a scalable flat decision mechanism.

In order to reduce the complexity, EPC considers that the default bearer established at the attachment to the EPC and the subsequent bearers, requested by the UE or the service platform, are reserved using the same procedures. This allows, from the perspective of the EPC to regard the network access control functions as resource management functions.

4.3.3 Mobility Support

EPC integrates multiple access technologies. In order to be able to support mobility between the different access networks a set of mechanisms was defined which include the access network discovery and selection and the correlated attachment to the target access and detachment from the source access relying on the existing mobility protocols like GTP, Proxy MIP and Classic MIP.

LTE was designed to be a direct extension of the other 3GPP accesses, as UMTS was an extension for the GPRS architecture. The Intra-3GPP mobility management bases on the MME to select the next attachment cell and to initiate a preparation procedure. When it is completed, the MME transmits a handover command to the mobile device.

In case of non-3GPP technologies, 3GPP cannot influence directly the handover procedures, due to the various standardization groups involved for access networks specifications. Thus a complete network controlled handover cannot be realized. In order to limit the effect of the UE independent selection of the target access which leads to congestion of some accesses while others are capable to sustain seamlessly the communication, the ANDSF was introduced in the architecture. Based on the location information, it transmits to the UE the preferences of the operator for target accesses in case a handover becomes necessary. The functionality of the ANDSF restrains to this general indication. The UE has to consider the policies received and decide independently when a handover is to be executed.

The effective handover procedures are separated logically in the attachment to the target access network and the detachment from the source access network. In the handover with optimization case, like in the intra-3GPP handovers, a preparation phase is executed which creates the user context on the target access network. However this is not possible in handovers from and to non-3GPP accesses, as the decision on the handover is taken by the UE. In this case, the mobility relies on the mobility protocol deployed, e.g. GTP, PMIP, classic MIP. It presumes that at the moment when the UE attaches to the target access network, the data traffic is forwarded to the new access even though the source access network connection is still available. From this perspective EPC is able to execute soft intra-3GPP handovers and hard handovers with the non-3GPP accesses.

As all the mobility protocols deployed in the EPC rely on a centralized anchor node and as the handover procedures are triggered by the changes of the location of the device in the network, currently the EPC does not provide any mechanism in which the data path can be adapted for each subscriber depending on the current network status and according to the applications delay requirements.

4.3.4 Interconnection with Application Platforms

EPC provides a transparent convergent network layer for the IP applications. From the perspective of a service provider without a modification of the application, it enables a degree of satisfaction similar to the fixed IP applications, by transparently supporting features like access control, QoS insurance, seamless mobility between the different access networks, prioritization and security. Based on this it is foreseen that the mobile application environment will adapt and integrate the ones previously deployed on the fixed Internet.

Also due to the resource reservation mechanisms, the services have a guarantee of the quality of the communication which is an addition to the typical IP communication and a high added value for broadband communication on mobile devices with reduced processing power.

EPC Support for Applications	EPC Independent Applications	EPC Aware Applications	Applications using extensively EPC Enablers
Access Control	•	•	•
QoS Insurance	•	•	•
Seamless Mobility	•	•	•
Prioritization	•	•	•
Security	•	•	•
QoS adaptation		•	•
Access Network Information		•	•
Location Information			•
Ambient Information			•
Identity Insurance			•

Fig. 6. Application support in EPC

EPC provides also a control interface between the service platform and the network core [26]. Through this inter-face, the EPC aware applications can transmit indications on the resources that have to be reserved for the specific users. They can also receive upon request information on events happening at the link and network layers e.g. the UE lost connectivity or a handover to another access net-work occurred. By these mechanisms, the applications can be adapted to the momentary context of the mobile device and to offer services customized not only based on the service level user profile, but also to the mobile device in use and to the surrounding network context. In this class of applications may enter the services offered by the operator or by third parties having an agreement with the operator, like IMS services, mobile cloud computing etc.

Although not yet standardized, EPC is able to export a set of enablers to the applications which offer even more flexibility in the service delivered to the mobile user. For example, services may use the location of the UE or even ambient information on the vicinity of the UE and the subscriber identity of the mobile device, in order to further more adapt to the environment conditions and to ensure a more secure communication. In this category fall the future mobile applications adapted to the subscriber and to his surrounding environment.

With the development of the mass broadband environment offering data dominant broadband communication, a novel evolution of the applications that the mobile users will be using is foreseen. This is due to the complete personalization of the mobile device as communication instrument which allows the specific user to exchange data anytime and anywhere. In order to face this challenge the novel architecture is limiting its goal in offering added value at the level of network connectivity and of different enablers for the service platforms which enhance the communication (e.g. resource reservation enabler). This increases the acceptance of the overall system and of the novel mobile applications and thus the acceptance of the mass broadband wireless environment.

5 Over-The-Top

Over-The-Top (OTT) applications gain huge interest due to its competitive service offers towards the telecommunication provider and operator. Network (cloud) storage, news, social networks as well as classic telco provider services as voice, video and messaging are offered alternatively and partially for free.

The huge success of OTT can be measured in number downloads of apps, active users and generated data traffic. All of these numbers positively influences the acceptance and grows of the mobile domain, but challenges the telecommunication business in the domain voice, video and messages and finally reduces the operator business to a pure IP connectivity provider. The number of Short-Message-Services (SMS) and voice minutes is decreasing continuously since years.

The deployment of all-IP network infrastructures such as the 3GPP Evolved Packet Core enables the network operators to reserve resources and to differentiate the data traffic for charging reasons based on the requirements received from the service platforms.

At this point in time, OTT services mainly rely on best-effort data transport and do not consider resource reservation for specific applications or traffic classes. Current state-of-the-art research is presented in the 'Network Layer Evolution' chapter under Cross-Layer-Composition.

OTT services mainly rely on proprietary solutions, without taking interoperability into consideration. Usually the communication offered to subscriber of a OTT services (Skype, Facebook, Google, WhatsApp, etc.) is limited to other subscriber of the same system, but not includes subscribers of other OTT services.

GSMA as an alliance over 900 companies (including over 700 operators) facing the challenge of interoperability, by standardizing a generic interface specification (Rich-Communication-Suite/RCS) for a basic set of services (RCS-enhanced/RCS-e) such as voice, video, messaging, presence and enhanced phonebook. The main idea of RCS(-e) is to provide services over network operator domain boarders, being device independent and providing native interfaces in the device operating system in order to provide high quality communication.

6 Machine-Type-Communication

The term Internet-Of-Things (IOT) is a hot topic for academia and industry and is also referred as one view on the Future Internet. Machine-2-Machine (M2M) – as one single aspect of IOT - is a paradigm in which the end-to-end communication is executed without human intervention. In general, M2M is not a direct subscriber service.

IOT in general and M2M in particular gain importance through the global forecasted numbers in term of connected devices and expected data traffic. Network operators are facing a huge increase in data traffic in orders of magnitudes caused only by M2M [38][39].

The range of bandwidth varies huge given the different M2M scenarios. A humidity sensor in a museum may signal only 4bytes from time to time, whereas a surveillance system may stream multiple MB/s High Definition (HD) multimedia content continuously. Efficient concepts, mechanisms and technologies are required to transport M2M data traffic with large variations in capacity. Standardization activities address these challenges. The work of ETSI is briefly described in the following.

M2M ecosystem mainly consists of standardization bodys (IETF WG Constraint RESTful Environments (CORE), ETSI TS M2M, 3GPP Machine Type Communication[40], ISO, ITU-T, ZigBee, etc.) together with vendors, network operator and service provider.

The standardization within ETSI on MTC is ongoing. A current state is presented in the following. ETSI identifies three main components: device, gateway and server as depicted in Fig. 7. ETSI defines a set of standardized Service Capabilities (SC) [40] in M2M Core and M2M Device/Gateway, to provide functions that are to be shared by different M2M Applications

Currently ETSI defined 11 M2M Service Capabilities to

- Provide recommendations of logical grouping of functions
- Expose functionalities through a set of open interfaces
- Use Core Network functionalities
- Simplified, optimized application development and deployment through hiding of network specificities from applications

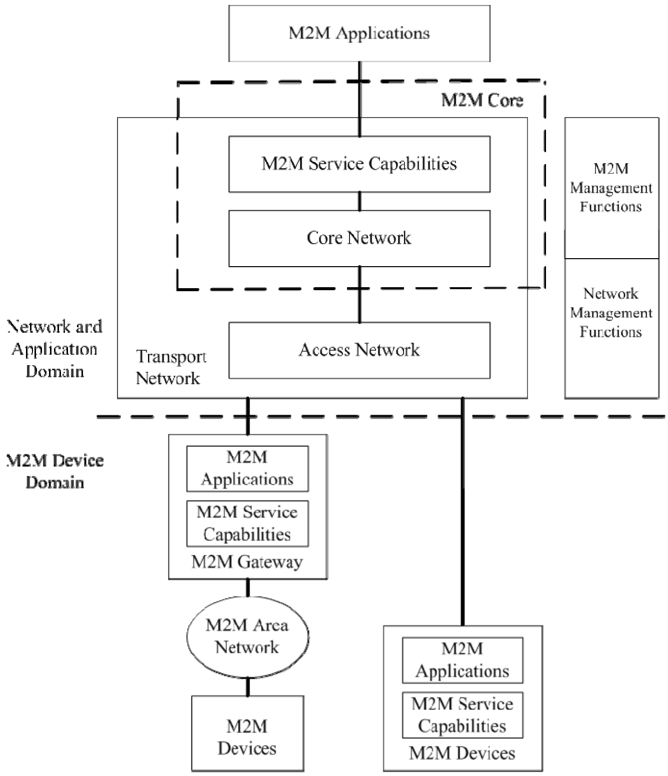

Fig. 7. ETSI General M2M Architecture

The ETSI M2M Release 1 fully specifies the 3 interfaces: mIa, mId, and dIa, which are specified to ensure interoperability towards operator domain boarders.

7 Open Networks

Resource sharing enables more efficient resource utilization and might result in cost savings. Virtualizing a network enables the operation of multiple protocols in parallel and independent of each other, providing a smaller closed partition of a larger network, or enables security by providing access control by separating network entities.

Network virtualization exists in manifold variations and can be applied on different layer in the network and on various technologies. Network virtualization mainly refers to network resources such as switches or routers from a hard- and software perspective.

Virtual local area networks or VLAN is the concept of grouping different hosts to a virtual topology, which is independent of the underlying hardware. The VLAN membership is software defined and not realized over physical links. Traffic related to one specific VLAN is marked with the same VLAN-tag or 802.1Q header within the header of an Ethernet frame.

The OpenFlow technology [41] is a famous representative for virtualizing networks, in order to run independent experiments on the same hardware environment by separating switching from control. OpenFlow enables networks to support traffic isolation, creates an open environment and flexible flow definition by individual flows, aggregated flows or post-IP protocol support.

OpenFlow defines itself as ‘open standard to deploy innovative protocols in production networks‘ [42] and is Open Source available. Commercial internet switches, routers and wireless access points are supported what eases the setup of test infrastructures.

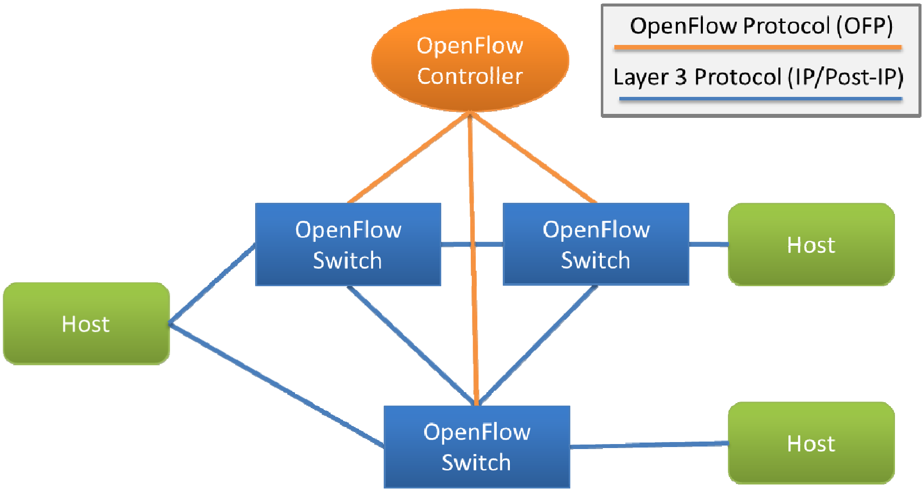

Fig. 8. Basic OpenFlow Architecture

Network packet routing consists first of routing decision followed by packet forwarding, what is done in the same entity (switch/router) in classic networks. OpenFlow separates routing and packet forwarding by extracting the routing decision in a separate box namely OpenFlow Controller (e.g. NOX [43]) from the switch, which functionalities are limited to packet forwarding as depicted in Fig. 6. The SSL secured OpenFlow Protocol (OFP) is used for communication between controller and switch to request and signal routing decisions.

8 Summary

The Internet is the largest global recognized communication system, which evolved in dimensions of technology, capacity, availability and size continuously since its beginnings in the 1960's. Information is transported via packets without differentiating between individual application characteristics over manifold access and core network technologies. The openness and its continuous change became characteristics of the Internet nowadays. Classical telecommunication networks transport voice over circuit-switched network initially, before adapting packet transport to the underlying network in order to increase the overall network performance.

This chapter presents a chronological overview on the evolution of telecommunication networks and control platforms in the last decades, transition from closed to open networks, the fixed and mobile convergence and finally outlines trends of future networks. The introduction chapter focuses on connectivity and builds the fundament for the following chapters especially for the Application Layer Evolution chapter, which outlines the application layer evolution, which is aligned on network layer evolution. Both presented trends influence each other.

The structure of this chapter is as followed. An introduction, which positions the presented work and provides the historical background, is followed by section 2, which introduces the concept of Intelligent Networks (IN) as a classical closed telecommunication system initially designed for fixed networks with a limited set of functionalities. Classic telecommunication systems as Intelligent Networks or its mobile variant Customized Applications for Mobile Enhanced Logic (CAMEL) rely on circuit-switched networks. Section 3 presents the concept, architecture and key functionalities of the IP Multimedia Subsystem (IMS) standardized by 3GPP. IMS is presented as network layer abstraction for 3GPP GPRS and UMTS or non-3GPP, cable, digital-subscriber-line (DSL) networks with the goal of providing unified interfaces for SIP based services. Section 4 presents the architecture, main protocols and key functionalities of the 3GPP All-IP Evolved Packet Core (EPC). The need for standardizing the Evolved Packet Core System (EPS) consisting of the radio part LTE and the core network part EPC is motivated and outlined. Section 5 discusses the role of Over-The-Top (OTT) applications and their growing impact on the application diversification, which directly influences the classic telecommunication value chain. Section 6 presents the trend of Machine-Type-Communication (MTC) in form of standardization activities. Section 7 outlines the trend of Open Networks by motivating the concept of network virtualization and presenting ongoing research and development activities. Section 8 summarizes and concludes the chapter. A list of acronyms and references is attached to the end of this chapter.

9 Acronyms

3GPP	3rd Generation Partnership Project
ANDSF	Access Network Discovery Selection Function
API	Application Programming Interface
AS	Application Server
EPC	Evolved Packet Core
EPS	Evolved Packet System
ETSI	European Telecommunications Standards Institute
HSS	Home Subscriber Server
IMS	IP Multimedia Subsystem
IN	Intelligent Network
INA	Information Networking Architecture
INAP	IN Application Protocol
IoS	Internet of Services
IoT	Internet of Things
IP	Internet Protocol
IPTV	Internet Protocol Television
ISC	IMS Service Control
ISUP	ISDN User Protocol
IT	Information Technology
ITU-T	International Telecommunication Union-Telecommunication
JAIN	Java APIs for Integrated Networks
JCP	Java Community Process
M2M	Machine 2 Machine
MTC	Machine Type Comminucation
NIST	National Institute of Standards and Technology
NGN	Next Generation Networks
NGSI	Next Generation Service Interface
OCCI	Open Cloud Computing Interface
ONA	Open Network Access
OND	Open Network Doctrine
ONP	Open Network Provision
OSA	Open Service Access
OTT	Over The Top
PBX	Private Branch Exchanges
PES	PSTN Emulation System
PGW	Packet Data Gateway
POTS	Plain Old Telephony Service
PS	Packet Switched
PSTN	Public Switched Telephone Network
QoS	Quality of Service
SaaS	Software as a Service
SCIM	Service Capability Interaction Manager
SCP	Service Control Points
S-CSCF	Serving Call Session Control Function
SDP	Service Delivery Platform
SGW	Serving Gateway
SIP	Session Initiation Protocol
SLEE	Service Logic Execution Environment
SMS	Short Message Service
SOA	Service Oriented Architectures
TMN	Telecommunication Management Network

TINA	Telecommunications Information Networking Architecture
TINA-C	Telecommunications Information Networking Architecture Consortium
TISPAN	Telecoms & Internet converged Services & Protocols for Advanced Networks
VAS	Value Added Services
VPN	Virtual Private Network
VoIP	Voice over IP
WWW	World Wide Web

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