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**LTE Data Roaming over IPX Service Schedule
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May 11 th 2014	1.0	First release of the LTE Data Roaming over IPX Service Schedule – First version

EXECUTIVE SUMMARY

A rapid increase of mobile data usage and rise of new IP-based applications have been the main pushes for the 3GPP and GSMA to specify Long-Term Evolution (LTE) as the 4th generation of Mobile Systems. LTE provides end-users with high data rates, low latency and packet optimized radio access so to increase quality of experience and enable new applications.

In order to allow end-users roaming abroad to access 4G data service over the visited networks, LTE Data Roaming service is required, which is handled over the 3GPP defined Evolved Packet Core (EPC) network as a part of the Evolved Packet System (EPS). At international level, the use of the global IPX technical and commercial framework, consisting of IPX Providers' interconnected networks and service capabilities, is an efficient way to interconnect the home and visited networks.

In order to ensure LTE Data Roaming service, there are technical and business implications for both SPs and IPX-Ps. Roaming Partners (SPs) have to sign new roaming agreements or amend existing ones to enable Signalling and 4G Data exchange. At the same time, both Service Providers and IPX Providers must enhance their own network environments to support standard interfaces (e.g. Diameter based) and new criteria in existing protocols for Data Roaming (GTP-c, GTP-u and DNS). The transport of such Data traffic will be efficiently provided by IPX framework capabilities, thus ensuring the proper QoS levels required by SPs.

The objective of this document is to provide a technical network architecture and features, as well as relevant service descriptions and business models that Carriers implement in the global IPX ecosystem to allow Service Providers to offer Data Service for their LTE end-users roaming abroad. This document encompasses the 3GPP reference architecture for LTE Roaming and implementations of Diameter Signalling and LTE Data Transport capabilities in the IPX network environment. In addition, the topic of interworking between 2G/3G and rising 4G mobile networks is described, as it ensures the required interoperability in the coexistence stage.

A section of this document is devoted to security matters and recommendations, in order to provide common IPX security mechanisms together with specific Diameter application layer screening and hiding functionalities. Furthermore, QoS aspects are explored with reference to how the IPX can fulfil SPs' quality requirements.

For the provisioning of the Diameter signalling and LTE data transport services various business models are identified covering the relationships between IPX Providers and Service Providers, as well as between interconnected IPX Providers. The commercial relationships with Service Providers consist of models with fixed or variable fees as options. The models amongst IPX Providers range from settlement-free peerings to paid peerings. Regardless of which business model is applied, the objective is to promote broad interconnection between IPX Providers for both Diameter signalling and LTE Data Transport (and GRX) fostered by a free and open market. Furthermore, it is recommended that arrangements between IPX Providers, including SLAs, are set into contractual arrangements to ensure end-to-end quality of the services.

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1. Scope of the document

The objective of this document is to provide a technical network architecture and features, as well as relevant service description and business models that Carriers implement in the global IPX ecosystem to allow Service Providers to offer Data Service for their LTE end-users roaming abroad.

It encompasses the 3GPP reference architecture for LTE Roaming and implementations of Diameter Signalling and LTE Data Transport capabilities in the IPX network environment. In addition, the topic of interworking between 2G/3G and rising 4G mobile networks is described, as it ensures the required interoperability in the coexistence stage. A section of this document is devoted to security matters and recommendations, in order to provide common IPX security mechanisms together with specific Diameter application layer screening and hiding functionalities.

The ultimate purpose is to promote broad interconnection between IPX-Ps for Diameter signalling, and LTE Data Transport (and GRX) fostered by a free and open market.

In a roaming scenario, services over LTE different from basic Data service (e.g. Voice over LTE, SMS) although making use of IP bearers similarly to the Data service, are out of scope of this document.

2. Acronyms

3GPP	3rd Generation Partnership Project
AAA	Authentication Authorization Accounting
ACL	Access Control List
APN	Access Point Name
AVP	Attribute Value Pair
CAMEL	Customised Applications for Mobile networks Enhanced Logic
CgPA	Calling Party Address
CdPA	Called Party Address
CS-FB	Circuit Switched – Fall Back
DEA	Diameter Edge Agent
DNS	Domain Name System
DRA	Diameter Routing Agent
DSCP	Differentiated Services Code Point
EIR	Equipment Identity Register
EPC	Evolved Packet Core
EPS	Evolved Packet System
E-UTRAN	Evolved – UMTS Terrestrial Radio Access Network
FQDN	Fully Qualified Domain Name
GGSN	Gateway GPRS Support Node
GPRS	General Packet Radio Service
GRX	GPRS Roaming eXchange
GT	Global Title
GTP	GPRS Tunnelling Protocol
HSS	Home Subscriber Server
IMS	IP Multimedia Subsystem
IMSI	International Mobile Subscriber Identity
IP	Internet Protocol
IPSec	IP Security
IPv4	Internet Protocol Version 4
IPv6	Internet Protocol Version 6
IPX	IP eXchange
IPX-P	IPX Provider
IWF	InterWorking Function
KASME	Key Access Security Management Entity
LTE	Long Term Evolution
MAP	Mobile Application Part

MME	Mobility Management Entity
MNO	Mobile Network Operator
MPLS	Multi Protocol Label Switching
NAPTR	Name Authority Pointer
NNI	Network-to-Network Interface
OCS	Online Charging System
P-GW	Packet Data Network - Gateway
PCC	Policy and Charging Control
PCEF	Policy and Charging Enforcement Function
PCRF	Policy and Charging Rules Function
PDN	Packet Data Network
PLMN	Public Land Mobile Network
PMIP	Proxy Mobile IP
RTD	Round Trip Delay
RTT	Round Trip Time
S-GW	Serving-Gateway
SCCP	Signalling Connection Control Part
SCTP	Stream Control Transmission Protocol
SGSN	Serving GPRS Support Node
SLA	Service Level Agreement
SLF	Subscriber Location Function
SP	Service Provider
TCP	Transmission Control Protocol
TDR	Transaction Data Record
UDP	User Datagram Protocol
UE	User Equipment
VLAN	Virtual Local Area Network
VRF	VPN Routing and Forwarding

3. References

- [1] 3GPP, TS 23.401 “General Packet Radio Service (GPRS) enhancements for Evolved Universal Terrestrial Radio Access Network (E-UTRAN) access”.
- [2] GSMA, IR.88 “LTE and EPC Roaming Guidelines”, Version 11.0, Jan 21st 2014.
- [3] GSMA, IR.34 “Guidelines for IPX Provider networks”, Version 9.1, May 13th 2013.
- [4] GSMA, IR.67 “DNS/ENUM Guidelines for Service Providers & GRX/IPX Providers”, Version 8.0, Nov. 23rd 2012.
- [5] i3Forum, “Common functionalities and capabilities of an IPX platform”, Release 2.0, May 2014.
- [6] IETF, RFC 6733 "Diameter Base Protocol", Oct. 2012.
- [7] 3GPP, TS 29.213 “Policy and Charging Control signalling flows and Quality of Service (QoS) parameter mapping”.
- [8] 3GPP, TS 29.272 “Mobility Management Entity (MME) and Serving GPRS Support Node (SGSN) related interfaces based on Diameter protocol”.
- [9] 3GPP, TS 29.215 “Policy and Charging Control (PCC) over S9 reference point; Stage 3”.
- [10] 3GPP, TS 29.305 “InterWorking Function (IWF) between MAP based and Diameter based interfaces”.
- [11] 3GPP, TS 33.401 “3GPP System Architecture Evolution (SAE); Security architecture”.

4. LTE Roaming Reference Framework

Having been designed to support packet-switched services, LTE results in a full-IP technology in the Radio Access and Core Network, and in IP-capable User Equipment (UE).

In principle, 4G end-users can simultaneously access several applications and services, with specific quality levels, by means of different IP bearers towards heterogeneous Packet Data Networks (PDN). To make it technically feasible, 3GPP specified a number of new logical nodes and interfaces, starting from Rel.8, in both Radio Access and Packet Core frameworks.

A fundamental aspect of this process is related to signalling. While 2G/3G system strongly rely on protocols belonging to the SS7 system, such as MAP and CAMEL, to support the Control Plane necessary to access to services, LTE as a technology makes use of new IP-based protocols, like Diameter, while taking advantage of existing protocols and services like GTP and DNS.

4.1 Reference Model for LTE Roaming

3GPP TS 23.401 [1] describes the standard Roaming Architecture for LTE access to services, showing the subset of main 3GPP standardized interfaces which interconnect H-PLMN to V-PLMN.

These interfaces cover two main areas, which can be referred to as sub-services of LTE Data Roaming, cfr. Figure 4.1:

- Signalling service for Control Plane (e.g. S6a and S9 interfaces, among others)
- Data transport service, related to end-users' payload, for the User Plane (S8 interface) and supported by its Control Plane including DNS. .

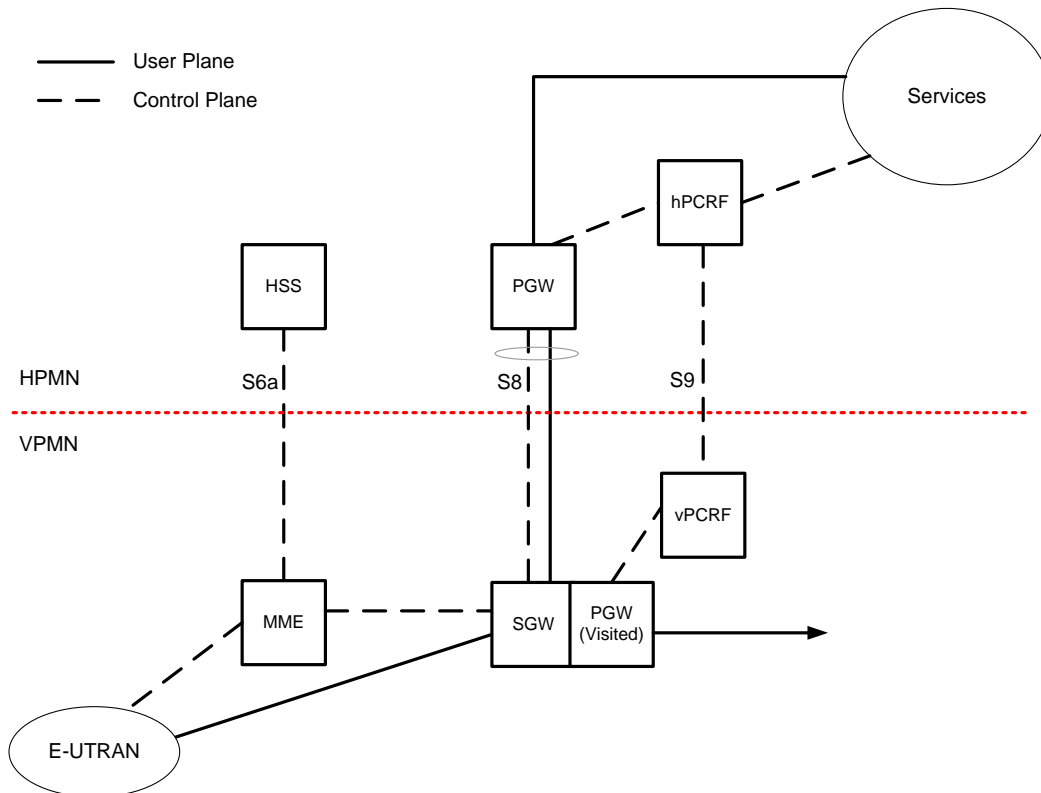


Figure 4.1 LTE Roaming Architecture

Following 3GPP and GSMA specifications and recommendations, covering technical requirements to offer services for LTE end-users, in the most general case two main scenarios are expected, which are Home Routing and Local Breakout.

The first one occurs when the Home Network chooses to bring users' data back to their H-PLMN to autonomously handle users' access to PDNs and services, applying own policy and charging criteria.

The latter is in place when the Visited Operator is allowed, on a per APN base, to offer breakout access to networks and services, on behalf of the Home MNO; such scenario requires additional signalling interfaces so that H-PLMN is able to give instructions on policy and charging criteria for each single user and session.

In general, the two described scenarios can be applied to all services deployed over the IP Multimedia Subsystem (IMS) framework, with specific requirements and exceptions.

4.2 Home Routing

In Home Routing mode the end-user's access to services is provided by the H-PLMN. As a first evident implication, this requires the payload data to be carried from the V-PLMN, where the user is located, to the Home Network, where the breakout to relevant PDNs and external networks is provided: this transport mechanism makes use of S8 interface (cfr. Figure 4.2). Furthermore, a signalling connection between Roaming Partners' networks has to be in place for authentication and mobility management, by means of S6a/S6d interface, which allows the end-user to authenticate and register under the Visited network.

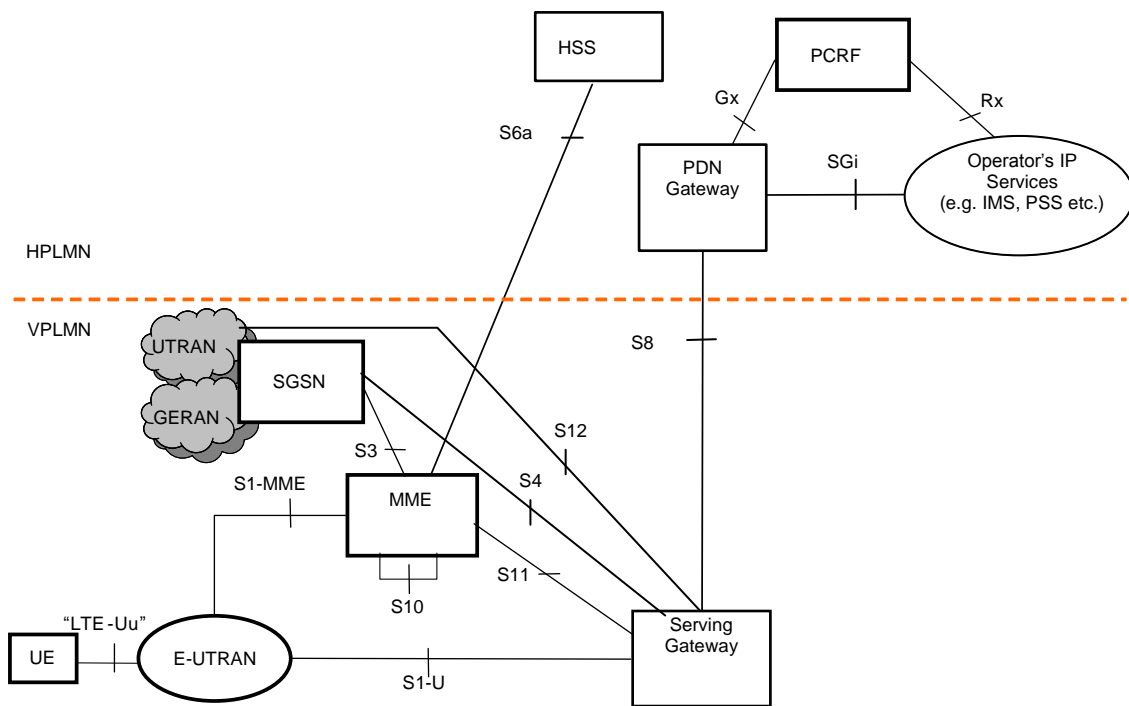


Figure 4.2 LTE Roaming Home Routing Architecture

4.3 Local Breakout

When Local Breakout mode is allowed by the Home Operator, the V-PLMN can provide the end-user a direct access to PDNs and external networks from its own P-GW. Besides mobility management procedures, which are required in Local Breakout as well, the H-PLMN gives instructions about end-user traffic policy and charging criteria, by means of S9 interface (cfr. Figure 4.3).

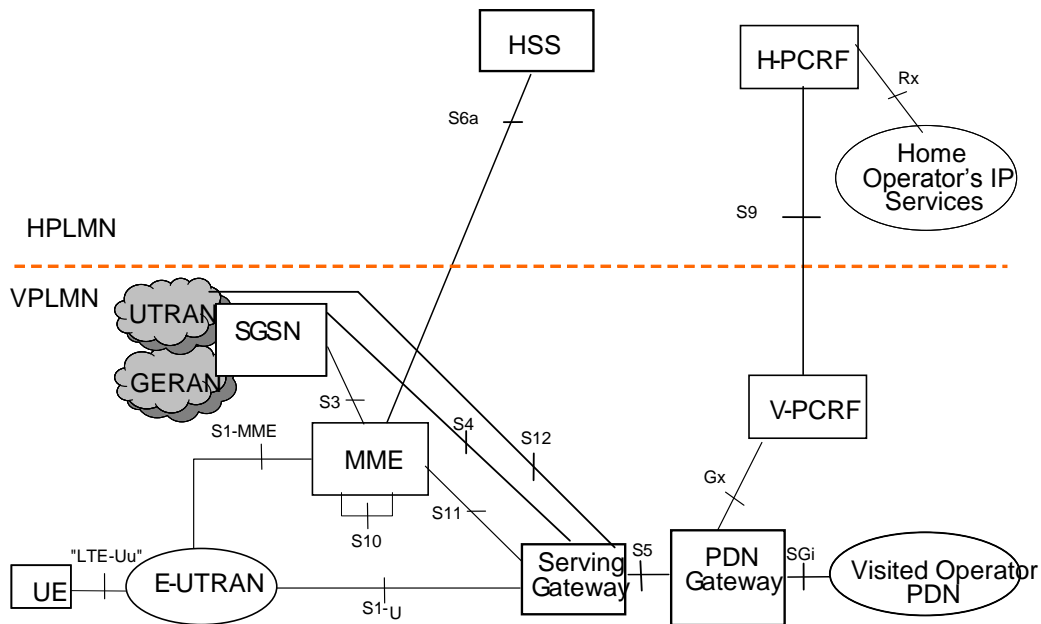


Figure 4.3 LTE Roaming Local Breakout Architecture

In addition, in the case of Online Charging being required and provided by the Home Operator, a separate interface called Gy could be required, depending on SPs' implementation, connecting the PCEF function of the V-PLMN (usually hosted in the P-GW) to the Online Charging System (OCS) of the H-PLMN.

4.4 Role of Carriers

In the described framework, in line with GPRS Data Roaming consisting of SS7 Signalling Relay and 2G/3G Data Transport (GRX), the Carriers' role is important in LTE Data Roaming, leveraging the IPX ecosystem strengths, such as global reach, QoS, security and reliability.

With regards to the Signalling Service (Diameter), Carriers can provide efficient technical and commercial Hubbing or Service Transit models by means of Diameter routing and relay/proxy capabilities. This approach reduces the number of signalling interconnections and guarantees the overall scalability. Furthermore it makes the setup and maintenance of routing rules easier for SPs, thus speeding up network implementations of the increasing number of 4G bilateral agreements between Roaming Partners. In addition, Carriers are able to provide signalling interworking in case SPs implement specific Diameter capabilities and/or different dialects and can ensure that 4G and 2G/3G networks can coexist with regard to roaming services..

In addition to Diameter Signalling, exploiting IPX Providers technical transport capabilities and relevant business models, SPs are able to exchange LTE end-users' home-routed data information, choosing either to combine it with 2G/3G Data (GRX over IPX) or to setup dedicated logical interfaces and commercial criteria (LTE Data over IPX).

5. LTE Data Roaming within IPX Environment

The challenging demands of 4G end-users' applications, which result in an enhanced Data Roaming service that MNOs are interested to offer, can be effectively addressed under the IPX framework's capabilities and services set.

Not only necessary QoS and Security requirements are taken into account, also a Capex and Opex reduction is expected for MNOs when they can exploit the IPX commercial and technical capabilities to access several services, like Voice or GRX, besides LTE Data Roaming.

Consistently with the GRX service, according to the reference documents [2], [3] and [4], which represent the main documents by GSMA about the deployment of LTE Data Roaming, it is assumed that this service is implemented over the global IPX ecosystem. As an example, it is specified that end-users traffic is encapsulated (e.g. by means of GTP) in the network portion between Visited and Home PLMNs, so that UE addressing is meaningless in the network(s) providing the transport capability.

5.1 Use of IPX Core capabilities

A detailed reference for the IPX technical architecture can be found in Sec. 5.2 of "Common functionalities and capabilities of an IPX platform" [5], in here also referred to as the IPX Core document. Figure 5.1 summarizes the reference model of the IPX domain, including general interconnection criteria.

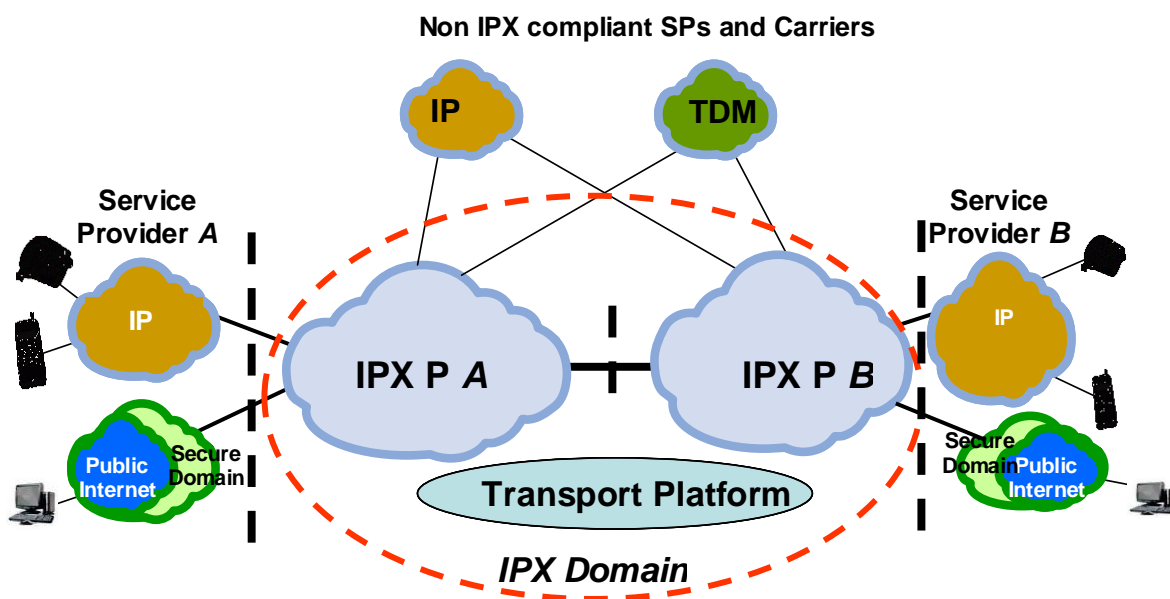


Figure 5.1 IPX Domain Network Reference Model

It is worth underlining that the Signalling service (based on Diameter protocol) and LTE Roaming Data transport (based e.g. on GTP) are addressed as separated services by IPX Providers and, consequently, SPs may choose different IPX Providers to obtain access to these services. In this regard the technical and commercial models are similar to that providing 2G/3G users' mobility management and GPRS Data in Roaming, where for each given MNO the Signalling Provider (or SCCP Provider) may be different from the GRX Provider.

5.2 Connectivity Modes for LTE Data Roaming

Limited to the scope of this Service Schedule and, with reference to IPX Core document [5], possible service connectivity options are:

- Signalling service (Diameter):
 - Bilateral - Service Transit
 - Multilateral – Hubbing
- Data Transport service (S8 Interface + DNS):
 - Bilateral – Transport Only
 - Multilateral – Hubbing

5.3 Break-in / Break-out

Although it is generically possible within the IPX domain, ref. Sec. 5.1.1 [5], no break-in or break-out modes should be allowed with regards to LTE Data Roaming over IPX, for both Signalling and Data Transport services. Both services are expected to be delimited within the IPX boundaries. End-users' access to the Public Internet or to other public / exposed PDNs should be provided outside the IPX domain by the Visited or Home PLMN, depending on whether respectively Local Breakout or Home Routing is applied, and it is out of scope of this document.

Although there is no specific requirement for LTE Data Roaming service (which means that general recommendations described in Sec. 5.2 of the IPX Core document [5] apply), it is generally assumed that 2 hops are sufficient to guarantee the reachability between Roaming Partners' networks.

5.4 Diameter Network Functions

5.4.1 Diameter Agents

IETF RFC 6733 [6] defines Diameter Agents as nodes that are able to treat Diameter messages in 4 different manners: Relay, Proxy, Redirect and Translation. In the generic case a node presents itself in the network as a Diameter Host belonging to a Diameter Realm. RFC 6733, which obsoletes the most known RFC 3588, also defines basic routing mechanisms for Diameter Agents.

As indicated in IR.88 [2], only Relay and Proxy modes are relevant to LTE Roaming procedures. In particular, a Relay node is able to find the relevant information inside the content of Diameter messages for routing them to the proper outgoing interface and peer/host; this means that a Relay node does not actually inspect the meaning of the message that needs to be routed. On the other hand, when a node acts in Proxy mode, not only it is able to provide routing functionality as in the Relay mode, it can also inspect the message and parameters in order to perform actions like screening, policy control, manipulation of content, etc.

On top of these definitions, respectively 3GPP and GSMA have specified two further roles for Diameter Agents, Diameter Routing Agent (DRA) and Diameter Edge Agent (DEA), with relevance to signalling nodes implementations for LTE Roaming.

5.4.2 Diameter Routing Agent (DRA)

Diameter Routing Agents' role and features are specified in 3GPP TS 29.213 [6], specifically as a node providing routing functions of Diameter messages inside a PLMN, addressing reachability and session balancing among different internal Realms. DRAs are therefore expected to be deployed in the first place inside PLMNs, but since such role does not specifically apply to International Roaming this is out of scope of this document.

Furthermore it is recognized that, at International level, the same routing criteria and functionalities are required by IPX Providers in order to provide connectivity in hubbing mode between SPs / Roaming Partners, which is expected to be the common scenario to exchange signalling related to LTE Data Roaming. In particular, IPX Providers need to address and connect different Service Providers' PLMNs meaning one or more Diameter Realms related to them.

In this context technology vendors addressed such needs deploying DRA capabilities and other functionalities, in the IPX Agents described in IR.88 [2].

Other features of the DRA include protocol adaption for different flavours of Diameter, due to the current state of the market by which interoperability of Diameter implementations has not completely reached maturity.

5.4.3 Diameter Edge Agent (DEA)

Diameter Edge Agent as a logical node is defined and described in GSMA IR.88 [2], as the border element of a Mobile Operator LTE/EPC network, with regard to Diameter signalling. It is strongly recommended for SPs not to expose EPC elements to any external network for security reasons.

Among other features, DEAs are able to hide the EPC topology, thus preventing external networks to get information about Core elements such as MME and HSS, and let SPs perform screening on the content of messages (Diameter AVPs).

An important feature that DEAs and DRAs are able to cover is to balance Diameter messages towards resources in pools, where applicable. This can be exploited for all interfaces where transactions do not represent sessions (e.g. S6a/S6d) and the best choice is to efficiently use network resources, while at the same time DEAs are generally capable to bind session-based signalling (e.g. Gy interface) so that messages belonging to the same session follow the same route towards specific nodes.

5.4.3.1 DEA Hosting

An IPX Agent providing DRA capabilities can be partitioned to act as a DEA on behalf of the SP, so providing connectivity and security for international roaming transactions, in all cases when the SP is not able or willing to deploy own DEA nodes (e.g. during the start-up of its LTE/EPC network).

This scenario is described in IR.88 [2] Fig. B-6, and is given in Figure 5.2 below for reader's convenience.

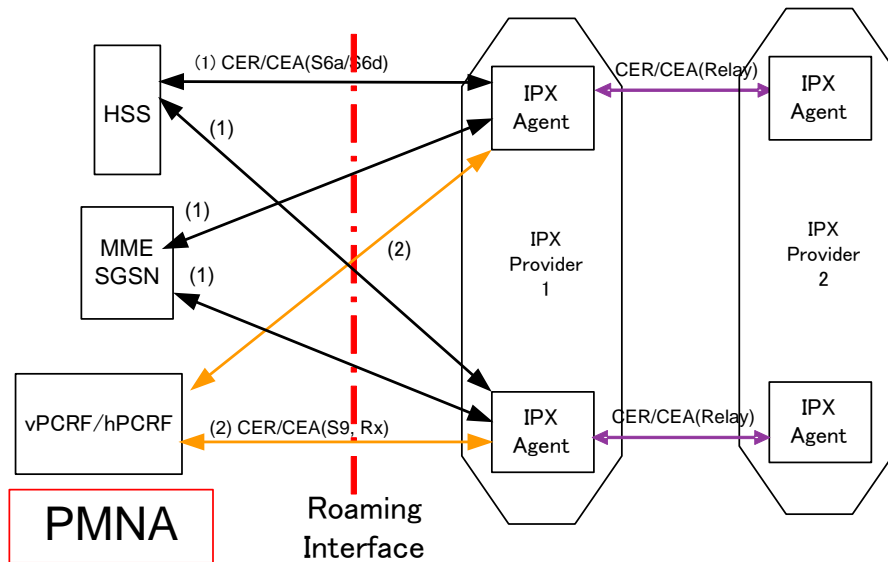


Figure 5.2 IPX Agent hosting DEA capability

5.5 Data Transport Network Functions

5.5.1 S-GW and P-GW

Serving Gateway (S-GW) and PDN Gateway (P-GW) are nodes deployed by LTE-capable MNOs within their LTE/EPC network to provide end-users with IP connectivity and access to services, in both Home Routing and Local Breakout modes.

The S-GW acts as a mobility anchor for terminals handovers between e-nodeB and is able to route and forward IP packets towards the proper P-GW. In this way it prevents UE to change IP address when doing handovers from an e-nodeB to another (mobility), so keeping the connections up.

The P-GW provides connectivity from the UE to external Packet Data Networks (e.g. Internet or IMS), being the entry or exit point for the UE payload traffic. Comparable with GGSN in 3G environments, the P-GW is responsible for IP address allocation to the UEs for each bearer it wants to setup. Other capabilities include policy enforcement, packet filtering and screening and anchoring for mobility between 3GPP and non-3GPP networks.

For LTE Roaming and in case of Home Routing, the transport of the S8 interface between S-GW in the V-PLMN and P-GW in the H-PLMN is addressed by SP and Carriers within IPX technical capabilities, coherently with commercial settlements between Service Providers and IPX Providers. At NNI between SP - IPX-P, and between IPX-P networks, the S8 interface traffic is segregated from Diameter signalling and does not involve any IPX Agent.

Figure 5.3 shows the overall LTE Roaming architecture in the most general case covering main interfaces with regards to both signalling and payload. As it can be seen IPX-P providing Diameter connectivity may be different from those providing LTE Data connectivity; at the same time, for both aspects, peerings between IPX Providers are needed to enable global reachability.

Note that Figure 5.3 is intended to provide basic functionalities for LTE Roaming at IPX level and as such it is not complete with regard to MNOs' internal networks; any other elements (e.g. internal DRA, SLF, Firewall, etc.) and interfaces not provided there are not in the scope of this document.

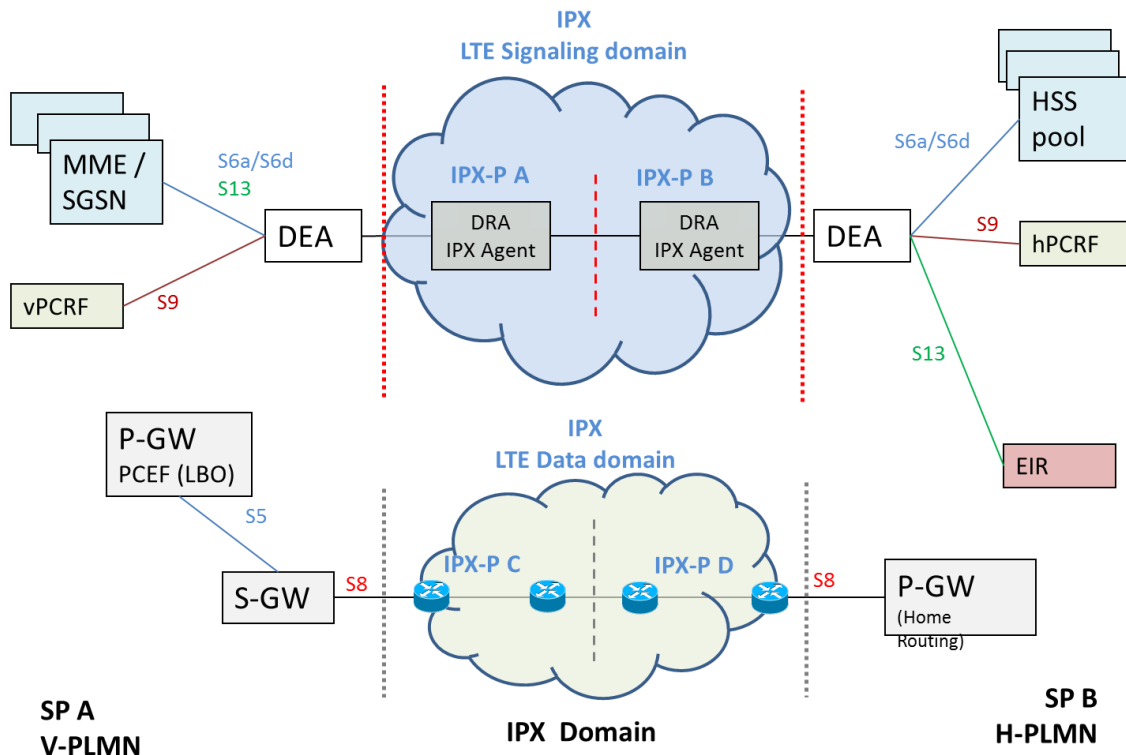


Figure 5.3 LTE Data Roaming – Entities at the edge of the networks

6. Signalling Functions for LTE Roaming

All 3GPP specified interfaces for International LTE Roaming signalling are based on the Diameter protocol, specified by IETF RFC 6733 [7].

The Diameter applications for S6a/S6d and S13 interfaces are specified in 3GPP TS 29.272 [8]. Details about the application for S9 interface can be found in 3GPP TS 29.215 [9].

6.1 Transport Capabilities

6.1.1 Dedicated VLAN

According to the i3F IPX Core document [5] Par. 7.3, it is recommended that Diameter Signalling traffic is logically segregated, by means of a dedicated VLAN on both the interconnection between an SP and an IPX-P and the interconnections between IPX Providers. If SS7 signalling over IP (SIGTRAN) is exchanged on the same physical IPX interconnection as used for Diameter, the compliance with this recommendation may be requested e.g. to accommodate different business models and charging criteria.

6.1.2 IP Packet Marking

Following IP Packet Marking in the i3F IPX Core document [5] Par. 7.4.3, and in compliance with GSMA IR.34 [3] Par. 6.2 Table 5 and 6, it is recommended that Diameter Signalling end to end makes use of a specific Class of Service and DSCP, as reported below in Table 6.1 and Table 6.2 as an extract for readers' convenience:

Traffic Type	GSMA Traffic Class
Signalling (including capability discovery and Presence)	Interactive

Table 6.1

Traffic Type	DSCP Marking	IP Precedence	802.1Q VLAN
Signalling	DSCP 26/AF31 (011010)	3	3

Table 6.2

6.1.3 SCTP

SCTP is the default transport protocol for all Diameter applications supporting LTE Roaming procedures. By means of Multihoming functionality SCTP provides reliable layer-4 connectivity for the transport of Diameter messages. In particular it means that each Diameter Agent is implemented to use 2 IP addresses, the first one as primary IP, the latter as backup. This mechanism provides logical redundancy and interface redundancy on the Agent.

Differentiating IP paths connecting primary and secondary IP addresses of each multihomed agent can guarantee a further reliability, that is the capability to withstand any issue on IP nodes and paths (e.g. route unavailable condition).

If an SCTP implementation for the transport of Diameter does not support multihoming capability, then unihomed SCTP is still preferable over TCP, since it provides mechanisms to enhance reliability such as keep-alive and message boundaries preservation.

IR.88 [2] Par. 3.1.2.2 gives recommendations on how to define SCTP parameters based especially on engineered Round Trip Time (RTT) over the IP path connecting two SCTP peers. It is suggested to follow such recommendations unless different bilateral agreements between peers or specific requirements need to be fulfilled.

6.1.4 TCP

In the case where SCTP is not supported (neither multi-homed nor uni-homed) by an SP or an IPX-P, TCP is an alternative for Layer-4 transport of Diameter signalling. The use of TCP must be agreed by the interconnecting parties.

6.1.5 Redundant interconnection topology

In addition to the Multihoming capability, it is suggested to deploy a Diameter Proxy architecture in a reliable configuration, so that link redundancy can be provided. A suggested topology for an IPX-P consists of 2 geographically distributed nodes, acting as Diameter Proxy/Relay, having different IP addresses and Diameter Host names, which directly connect SPs or IPX-Ps with similar architecture in full meshed mode, as shown in Figure 6.1.

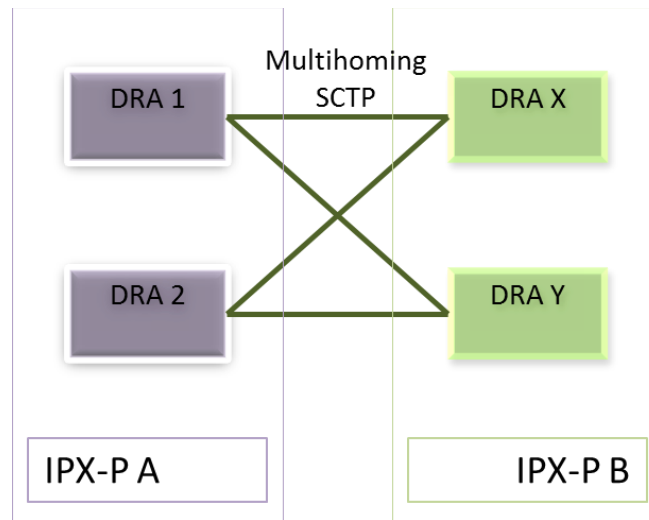


Figure 6.1 Multihomed meshed architecture for Diameter peering

6.2 Diameter Protocol

6.2.1 Main Diameter features and parameters

Diameter is an IETF-specified [7] peer-to-peer protocol, at first among protocols of Internet, to address Authentication, Authorization and Accounting (AAA) purposes in extension to RADIUS protocol, with respect to which it introduces enhanced capabilities and reliability. Among all improvements, Diameter as specified:

- can be transported by TCP and SCTP, not only on UDP
- supports larger AVP fields (32 bits)
- supports both stateless and stateful sessions
- provides the possibility to define new or custom applications, commands and attributes

Diameter protocol has a basic structure, on top of which a set of applications have been created for different use cases, not limited to 3GPP-defined procedures. The basic structure provides peerings setup, state control and disconnection, nevertheless one or more applications have to be declared for the transactions related to Roaming procedures, as well as others defined by 3GPP.

A set of standard headers allow the Diameter peer to peer connections and, among them, natively each session between two endpoints is uniquely identified by two types of ID: End-to-End Identifier and Hop-by-Hop Identifier.

The content of Diameter messages for all type of applications is structured in a variable number of data units called Attribute Value Pairs (AVP). Any AVP is made up of the following structures: Code, Length, Flag and Data.

Diameter messages are defined in couples “Request” / “Answer” and identified by Command Codes. Every peer sending forward a “Request” with given Command Code expects back an “Answer” on the same

transaction, meaning same Command Code as well as other parameters. The application outcome in the “Answer”, be it successful or not, is expressed in the AVP *Result-Code*, or in the AVP *Experimental-Result-Code* within the grouped AVP *Experimental-Result* (the first used in basic Diameter protocol, the latter specifically for S6a/S6d). The list of IETF and 3GPP roaming-meaningful result codes can be found in [7] and [8].

Diameter is not only based on peer to peer connections, it also supports peer self-discovery, capabilities exchange and keepalive between interconnected peers. In details, as described in Figure 6.2, one of the two peers acts as the Client; in this way as soon as a SCTP or TCP connection is up, the Client peer is in charge of initiating “Capability Exchange Request” (CER), in order to share network information and negotiate supported Diameter applications with the Server peer which replies with a “Capability Exchange Answer” (CEA). Afterwards both peers will exchange Device Watchdog messages (DWR/DWA) in order to keep the Diameter connection up in case no further Diameter application-related messages are exchanged in a predefined timeframe. Both Capability Exchange and Device Watchdog are basic protocol mechanisms not linked to specific applications.

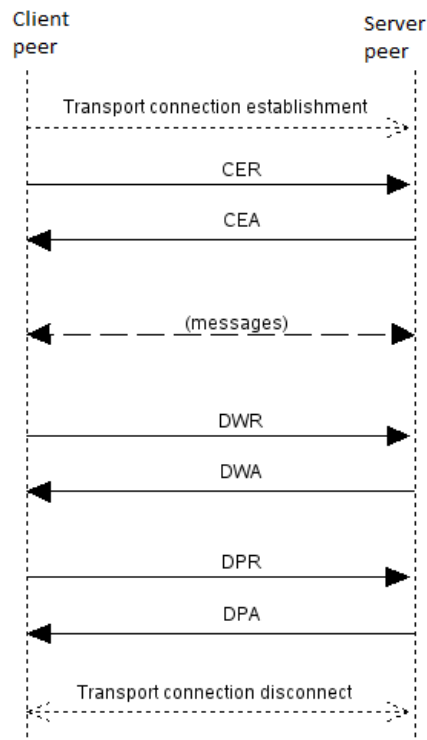


Figure 6.2 Diameter Client-Server peer handling

As another capability, the Diameter protocol also exploits an AVP called Route-Record to prevent loops in the signalling exchange. Based on this, each Diameter Agent can insert its own identity as a Route-Record entry when relaying or proxying messages.

6.2.2 3GPP specified nodes and interfaces

As described in the previous Sections, a set of Diameter-capable logical nodes have been specified by 3GPP within the IMS environment to cover functionalities supporting network signalling, policy, charging, credit control, etc. Among them, the logical nodes relevant to LTE/EPC for LTE Data Roaming service constitute a subset, of which the main ones are:

- MME
- HSS
- PCRF
- EIR

On top of that, in order to guarantee a scalable and effective environment for global exchange of signalling supporting LTE Roaming, two further nodes (DEA and DRA) are defined, which are described in Sec. **Errore. L'origine riferimento non è stata trovata.** Both DEA and DRA can work in Relay or Proxy modes, with regards to the possibility to manipulate messages content (AVPs) to cover different network scenarios.

The 3GPP interfaces connecting Diameter-capable nodes are identified as Diameter Application together with their own Application-ID. Below are the main 3GPP interfaces and Diameter Application-IDs for LTE Roaming purposes:

- S6a/S6d: 16777251
- S9: 16777267
- S13: 16777252

6.2.3 Diameter Routing

In LTE Roaming, Diameter transaction Requests generated at Visited PLMN's EPC (e.g. MME), are addressed towards the Home PLMN (or viceversa, according to different scenarios), by means of Destination Host and Destination Realm AVPs. Those messages are expected to be delivered to destination node by intermediate agents in the IPX environment (Diameter Relays/Proxies) and possibly inspected by the border nodes of the destination network, typically a DEA hiding node information inside the EPC network.

Among all information included in each "Request", Destination Host and Destination Realm are of particular importance. Destination Host is optional in first requests of 3GPP procedures and this AVP can be used when the actual node to be reached is known, typically belonging to a pool of resources (e.g. HSS pool). Conversely, Destination Realm is in any case mandatory within the "Request", since it identifies the 4G destination network to which the message has to be delivered.

On this basis, the most common routing criteria at DEA and DRA nodes would be based on Destination Realm analysis, by which the SP or IPX-P can retrieve relevant information to find the proper outgoing route; it could be a Diameter peer connecting to the terminating SP or an interconnection with an IPX-P serving it.

Other possible routing criteria may involve different AVPs such as *Origin-Host* and/or *Origin-Realm*, *Application-ID* (i.e. 3GPP interface), *User-Name* (i.e. IMSI), and others. Such criteria can match any SP's or IPX-P's requirements for routing optimization, load balancing or redundancy, or different specific routing rules which may be applied based on bilateral agreements between the parties.

Differently from SS7 routing criteria, the delivery of a Diameter "Answer" by specification does not require any further routing analysis, since the "Answer" follows the same path used to deliver the related "Request". Such mechanism ensures that every peer in the chain receives the relevant "Answer" for a "Request" it has generated or relayed, so helping understanding of the signalling state and troubleshooting as well. See an example in Figure 6.3.

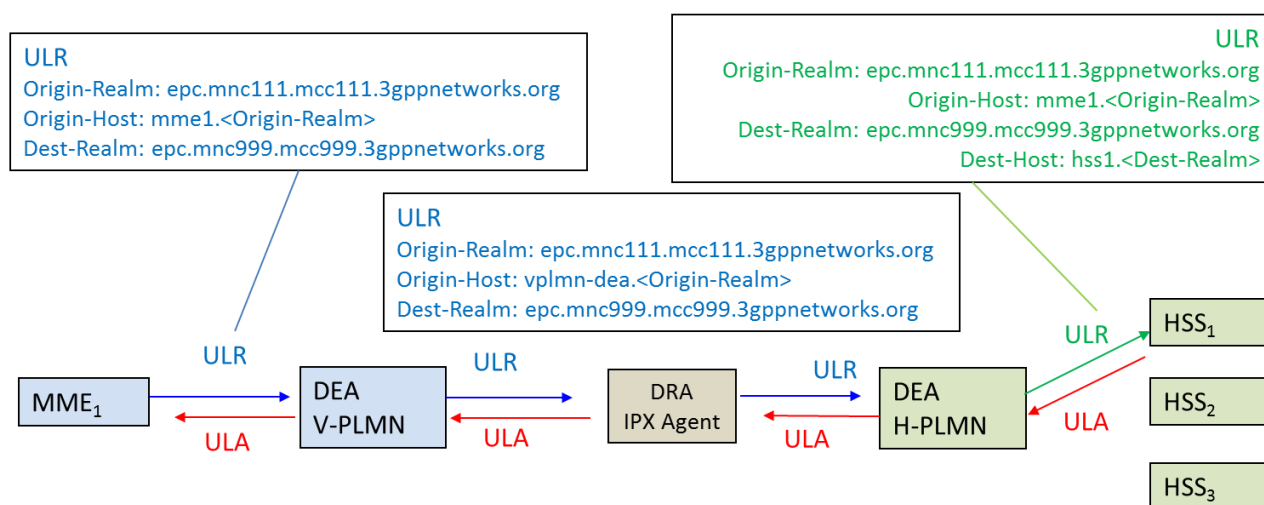


Figure 6.3 Routing of a Diameter Update Location Request

6.3 Mobility Management: S6a/S6d

On top of the basic Diameter structure and procedures, 3GPP TS 29.272 [8] Sec. 5 defines the procedures related to S6a/S6d interface, listing the relevant supported AVPs which can be mandatory, optional or conditional with regards to roaming mobility management procedures:

- Mobility Services: Update Location (ULR/ULA), Cancel Location (CLR/CLA), Purge-UE (PUR/PUA),
- Subscriber Data Handling: Insert Subscriber Data (IDR/IDA), Delete Subscriber Data (DSR/DSA)
- Authentication Procedures: Authentication Information Retrieval (AIR/AIA)
- Fault Recovery Procedures: Reset (RSR/RSA)
- Notification Procedures: Notification (NOR/NOA)

7. Data Transport in LTE Roaming

Concerning the implementations of the Data Roaming service, although 3GPP specifications allow for both Home Routing and Local Breakout, i3Forum recognizes and underlines that the Home Routing mode is currently the de facto unique scenario and LTE Data Roaming implementations at this first stage are expected to be consistent with the 2G/3G technical model (GRX). Such approach allows the Home MNO to apply a direct control on the end-users' traffic, mostly regarding dynamic policy and charging control. To provide an example, the Home MNO might be interested in applying specific QoS level and charging policy to a given end-user for a specific application, which may not be adequately guaranteed by Visited Operator's technical or commercial bearer management capabilities and charging criteria.

Therefore, in the Home Routing scheme the end-users' data sessions towards relevant PDNs and external networks will be provided by the H-PLMN, by means of a specific interface (S8) interconnecting Visited and Home packet networks. This transport mechanism can be setup when the end-user is already located and registered under the V-PLMN, following S6a/S6d related procedures described in Sec. 6, in order to allocate a proper bearer to the end-user by the V-PLMN itself.

For the sake of completeness, in the Local Breakout scheme the interface between the S-GW and the P-GW is confined within the V-PLMN boundaries and is named S5. The S5 interface is in any case not implemented on the IPX framework, so it remains out of the scope of this document.

7.1 Transport capabilities

7.1.1 Use of VLANs

The Data Transport service over an IPX interconnection interface, either supported by an SP – IPX-P interconnection or an IPX-P – IPX-P peering, may be implemented on a dedicated VLAN or sharing the same VLAN used to carry GRX traffic, if any.

The choice between the two approaches is driven by joint technical and business considerations. For instance, two distinct business models that an IPX-P intends to apply for its GRX and LTE Data Transport may lead, as a constraint, to the need of separated VLANs with regards to the two mentioned services.

In accordance with the naming convention used in i3f, the LTE Data Transport is recognized as an instance of the *IPX Transport* set of services. However, since Mobile Data (GRX and LTE Data) have in general different properties and in general different business models with respect to the other services in the *IPX Transport* set, the LTE Data Transport will require a dedicated VLAN.

7.1.2 IP Packet Marking

Following IP Packet Marking described in GSMA IR.34 [3] Par. 6.2 including Table 5 and 6, it is expected that the SPs are able to apply marking of the traffic before forwarding it on the interface to the IPX. This applies to EPC traffic that includes LTE Data as well as potentially to 2G/3G Data that SPs collect from the Radio Access network including its QoS levels (QCI).

To enable the correct management of traffic in the IPX backbone, the IPX-Ps are requested to enable the proper CoS levels (i.e. Traffic Class) in their backbone and apply the proper mapping of all DSCP values of the IP packets, received on IPX compliant interconnections, to the corresponding Traffic Class. This behaviour is in line with IR.34 [3] and endorsed by the i3F IPX Core document [5] Par. 7.4.3.

7.2 S8 Interface

The 3GPP-specified S8 interface interconnects the S-GW of the V-PLMN to the P-GW of the H-PLMN, whose role and capabilities are described in Par. 5.5.1. The supported protocols underlying the S8 interface are the GPRS Tunnelling Protocol (GTP) and the Proxy Mobile IP (PMIP).

GTP in its Control Plane represents an enhancement to the same protocol used for 3G Data Roaming (Gp interface). In particular, LTE Data requires the support of GTP-v2 for Control Plane, which implies that both S-GW and P-GW should support this protocol as a minimum requirement. Furthermore, if an MNO chooses to implement 4G Data for inbound roamers on a Rel.8-compliant GGSN (i.e. as a Visited Network), it can fulfil the same requirement or keep using the Gp interface.

For hybrid 3G-4G networks it's worth underlining that fallback to GTP-v0 is not supported within LTE procedures. If such hybrid network is forced by network or coverage circumstances to use GTP-v0 within its SGSN or remote GGSN, the service connection will be provided as GPRS Data Roaming (GRX) which is out of the scope of this document.

As an alternative to GTP, PMIP can be used to implement the S8 interface for Data Roaming, covering user data layer and providing similar capabilities to GTP with different features. Differently from GTP, roaming partners using PMIP would require the support of Diameter-based S9 interface in order to apply Policy and Charging Control (PCC), in both Home Routing and Local Breakout schemes.

7.2.1 Coexistence with Gp interface

GSMA IR.88 [2] provides a set of interworking scenarios involving legacy network elements: in each of those scenarios either the Home or the Visited network have to choose between S8 interface or legacy Gp interface for the setup of proper bearers and the transport of end-users' data, based on several criteria:

- network nodes capabilities
- support of dedicated APN for services under LTE or, alternatively, use of a unique APN for the 2G/3G/4G data roaming service
- whether the UE is LTE-capable or not

None of those scenarios requires interworking between Gp and S8 (that is, an interworking between GTPv2-C and GTPv1-C) and this topic isn't addressed in 3GPP standards. At the same time it is understood that, regardless whether the mobility management is performed using MAP or Diameter, the Gp interface is used when the roamer is registered under the 2G/3G radio access network, so this does not specifically represent LTE Data Roaming.

7.3 DNS

Within LTE Data Roaming scenarios and in compliance with 2G/3G procedures, DNS resolution is required in order to provide mandatory addressing and routing information for Home and Visited networks to involve the relevant network elements, to make end-users' access to PDNs possible. The DNS is used in this perspective to support all required procedures.

In one of the first tasks of bearer setup procedures in a roaming scenario, DNS is used by MME/SGSN to select the relevant S-GW within the V-PLMN, however this procedures is confined within Visited MNO boundaries and does not involve the interface between SPs and IPX-Ps.

In the following or in parallel, V-PLMN must discover the proper P-GW and its IP address based on the APN-FQDN. From 3GPP Rel.8 on, this mechanism requires the support of particular DNS entries named S-NAPTR (Straightforward-Name Authority Pointer) which can also identify specific P-GW in terms of S8 protocol support (GTP or PMIP).

In general, as for GPRS Data Roaming, the Authoritative DNS Servers for a given APN may be located on the same network as the P-GW, or may be provided by the IPX-P serving the Home network; the DNS procedures may also involve the Root DNS for GRX/IPX, as described in IR.67 [4].

The DNS function in IPX domain can be used for different services (GRX, LTE data roaming, MMS, Diameter, RCS, others) and for different type of Service Providers (MNOs, FNOs, Online Service Providers). The DNS access can be common and accessible to all services and all SPs, or for security reasons it can be restricted per service and type of SPs (MNOs, FNOs, OSPs etc..). This security policy and technical architecture must still be defined and agreed by GSMA.

8. Security for LTE Data Roaming

The i3F IPX Core Document [5] Sec. 11 provides the generic recommendations for the security of interconnections to and within the IPX global environment. In particular, in line with other Services over IPX, three requirements are recommended for the IPX interconnections ensuring LTE Data Roaming service:

- Isolation from the Public Internet
- Segmentation of Traffic related to different services by IP Addressing
- Use of Proxy

8.1 IP/IPX Layer Security

General security requirements, as provided by [5], are applicable for all interconnections in the IPX environment, regardless the service offered over the IPX.

All services provided over the IPX framework are transported over an isolated IP environment through the use of physical separation (e.g. dedicated routers' interfaces) or logical L2 / L3 isolation (e.g. VRF on IP-MPLS networks). The IP addresses of any node involved in such interfaces are not advertised over the Public Internet nor are reachable from any, with regards to the IPX, untrusted external network.

Specifically for the Signalling Service (Diameter), IPX-P and SP should ensure that their IP connectivity and visibility is limited to the exchange of Diameter signalling between the two of them. No other L3 reachability should be provided by an IPX-P than to his own different SPs or to other IPX-Ps offering the Diameter Signalling Service.

For Diameter Signalling, the security requirements are applicable for the interconnections between the relevant nodes in the SP network (DEA or, if no DEA has been deployed, other EPC nodes like HSS, MME, etc.) and the Routing Agent in the IPX-P network, as well as between the Routing Agents of two interconnected IPX-Ps.

At the interconnection level the security can be enforced by one or more of the following methods:

1. a direct physical connection
2. an IPSec tunnel
3. a logical connection via an MPLS network.

Such enforcement ensures that Diameter Proxies are not visible in the full GRX/IPX routing table and thus cannot be reached by those SPs who are only allowed to access other IPX services. In addition, when IP-MPLS is used, a proper VRF configuration (e.g. route targets and import/export) and/or Access Control Lists (ACL) are recommended on interconnect routers and Diameter IPX Agents.

For the Diameter Signalling Service, as well as other IPX services, IPX-Ps are also recommended to apply logical IP screening at the edge of their network e.g. IP packets sent to or received from an SP, should belong to the IP-range assigned to that SP.

8.2 Application Layer Security

8.2.1 Screening of AVP and parameters

Also at the application level the IPX-P could apply some Diameter message filtering. More specifically, an IPX-P should only allow supported Application IDs, Command Codes and AVPs, verify consistency between all related AVPs that identify origin and destination, and apply anti-spoofing mechanisms.

When the SP has outsourced the DEA functionality to its IPX-P, the IPX-P should also carry out additional Diameter message screening that would normally be done by the SP e.g. only allow Diameter transactions from 3rd Party SP with which the involved SP has an LTE roaming agreement.

As outlined in section **Errore. L'origine riferimento non è stata trovata.** two types of Diameter Agents, Relay and Proxy, are relevant for the IPX domain. A Relay Agent routes messages based on Application ID and/or Destination Realm, without modifying any AVP not related to routing. With regards to security matters an IPX Diameter Agent, acting as a relay node and in line with [2], can then inspect the content of each AVP related to routing and, based on that, take any proper action, such as dropping or modifying the AVP. As a

result, the IPX-P Agent has the possibility to screen on relevant fields, such as IMSI ranges or Application-ID, to ensure that no unexpected or fraud traffic is routed. Optionally, a Diameter Agent can act as a proxy if it needs to inspect or take any action on the content of non-routing related AVPs.

Figure 8.1 gives an example of such a screening action.

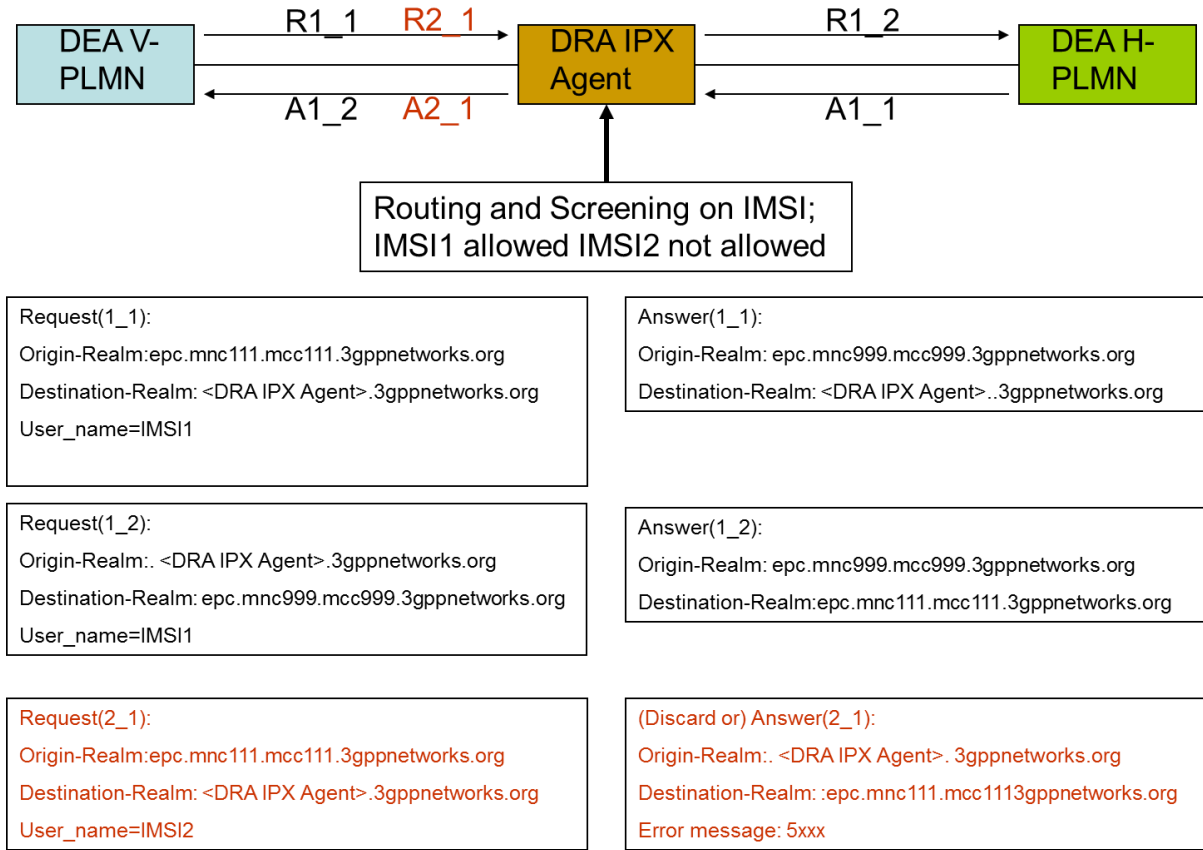


Figure 8.1 Screening of AVP User-Name

8.2.2 Topology Hiding

With topology hiding enabled, the IP addresses and host names of the Diameter core network elements in the EPC are hidden to external parties, thus preventing that any information about MMEs, HSSs, PCRFs etc. can be retrieved by unauthorized parties. Also the number of certain types of network elements (e.g. HSSs) and the routing within an SP network are hidden.

Topology hiding is normally performed e.g. by using aliases for Diameter names in Route-Record AVPs and hiding Diameter host names in other AVPs. Topology hiding is a function typically carried out by the SPs' DEA towards its external networks, however in the case where the SP hasn't deployed a DEA or makes use of a hosted DEA, as outlined in section 5.4.3, this feature can be carried out by the serving IPX-P.

9. Quality of Service

The general principles about Quality of Service definitions and measurements in an IPX framework are defined in Section 11 of i3Forum “Common functionalities and capabilities of an IPX platform” [5].

Since the Diameter Signalling and the LTE Data Transport service show different technical nature and business models, it is recognized that they imply distinct QoS requirements and measurements criteria.

9.1 QoS approach for Diameter Signalling

As the IPX Provider acts as a Relay or Proxy Agent for Diameter messages exchanged between SPs, at the application layer the IPX Provider is responsible to ensure the delivery of Diameter messages that are part of transactions for Roaming procedures, as explained in Sec. 6.

For this reason an IPX-P is suggested to provide its Diameter Signalling customers (SPs) with the measurements provided in the following subsections.

9.1.1 Delivery Success Ratio for incoming transactions.

It is defined as the ratio between the number of correctly delivered transactions whose Requests are raised by a given interconnected SP and the total received transaction Requests from such SP over a time period.

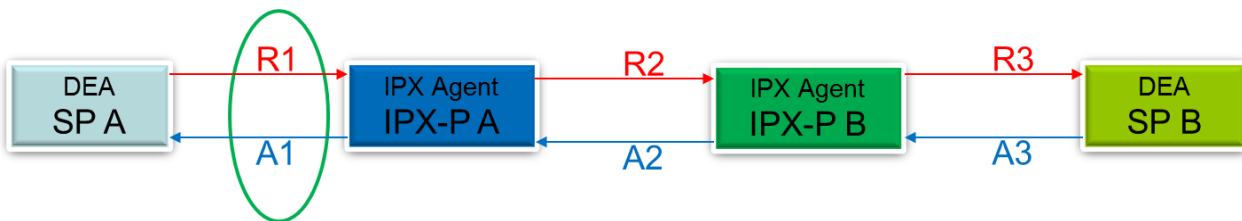


Figure 9.1 Measurement interface of IPX-P A for Delivery Success Ratio for incoming transactions

With reference to **Errore. L'origine riferimento non è stata trovata.**, the measurement interface for the IPX-P A can be found in the green circle; thus the relevant measurement is provided by the IPX-P A to the SP A as:

$$\text{Delivery Success Ratio for incoming transactions} = \left(\frac{A1}{R1} \right) * 100\%$$

This measurement can be generalized for every Agent in the Signalling chain, by setting the measuring point at the interface with its upstream peer.

As shown, a precondition for a transaction to be considered correctly delivered is that the IPX Provider delivers a corresponding Answer to the SP or IPX-P that sent the Request message. In some cases this precondition is sufficient to increase the Success Ratio, while other cases require a deeper analysis of the transaction outcome. Some known scenarios are here below provided.

- Case 1: with respect to the IPX Agent, if the Answer is generated by a downstream Diameter Agent (e.g. in an interconnected IPX-P network or in the other-end PLMN), the transaction is considered correctly delivered regardless the Diameter application outcome found in the AVP (*Experimental-Result-Code*). **Errore. L'origine riferimento non è stata trovata.** shows an Answer provided by the H-PLMN, leading to an increase in the Success Ratio, where yet the end-to-end roaming procedure has failed.

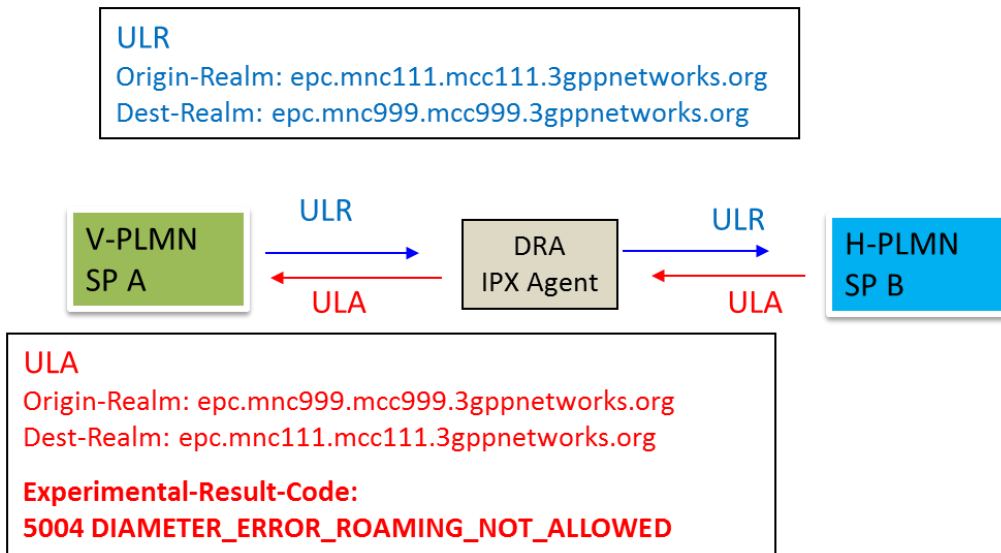


Figure 9.2 Answer provided by H-PLMN

- Case 2: if the Answer is generated by the IPX Agent, it implies a failure in the end-to-end roaming procedure and a negative impact on the Success Ratio measured by that IPX-P. An example is provided in Figure 9.3 where the IPX Agent faces an internal fault, leading to a failure in the end-to-end roaming procedure.

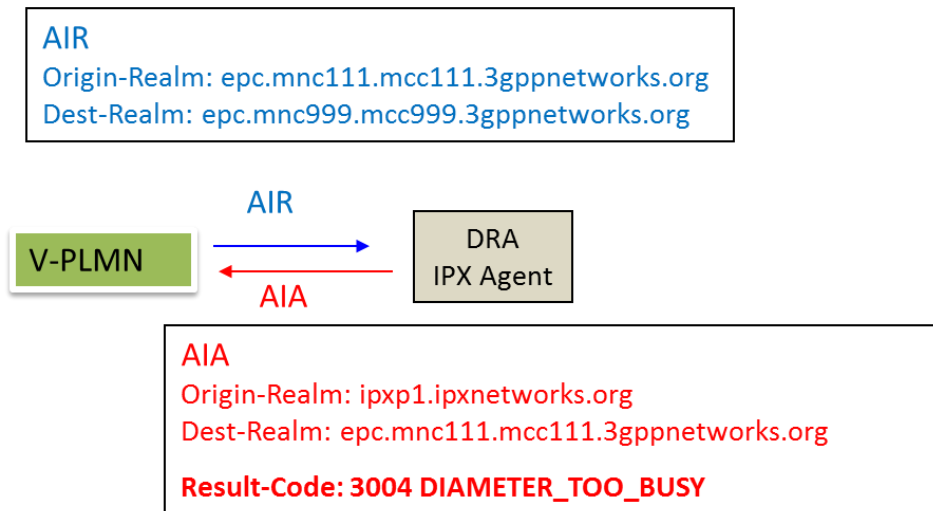


Figure 9.3 Answer provided by the IPX Agent - Internal failure

- Case 3: there are situations where the IPX Agent would be capable to fulfil the delivery of a transaction but it is forced to reject/discard the Request e.g. due to signalling errors or screening actions. In principle, it is recognized that these scenarios should not have a negative impact on the Success Ratio that the IPX Provider provides to the SP originating the Request.
Example 1: In Figure 9.4 the case is depicted where the *Destination-Realm* in the original incoming Request is malformed, so that the IPX Agent has no possibility to deliver the Request to a downstream network, due to an error of the V-PLMN. Therefore it would be wrong in principle to consider the transaction not delivered and let the Success Ratio decrease.

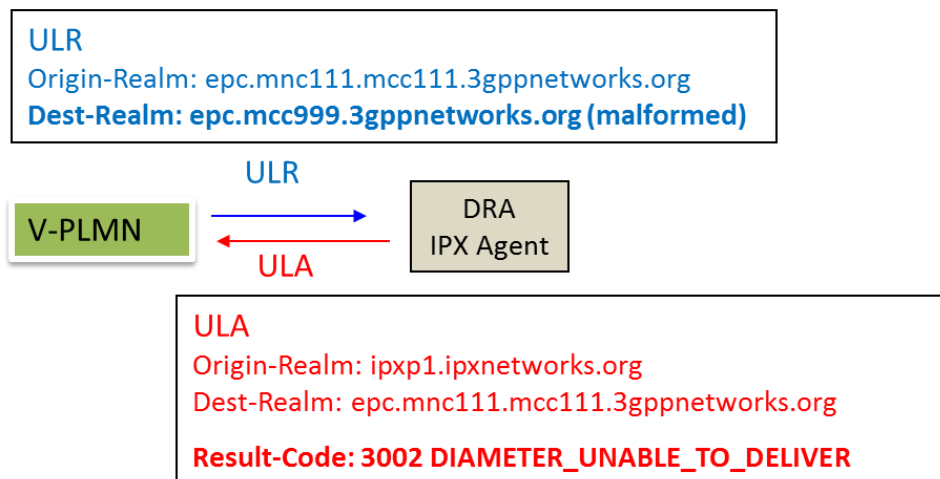


Figure 9.4 Answer provided by the IPX Agent - Malformed Dest-Realm

9.1.2 Delivery Success Ratio for outgoing transactions.

It is defined as the ratio between the number of correctly delivered transactions to a given SP among the total amount of transaction requests addressed to a given interconnected SP, received from any network, over a time period.

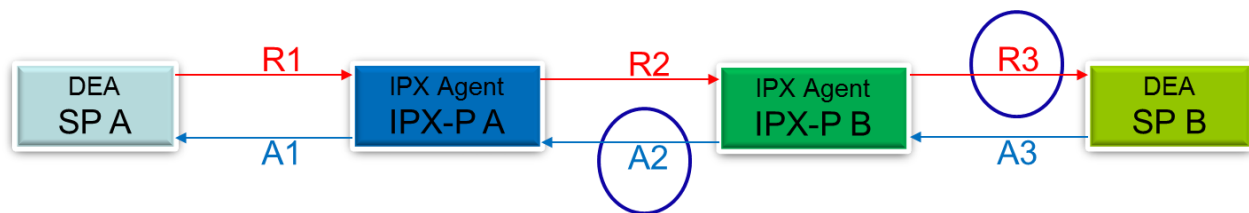


Figure 9.5 Measurement interfaces of IPX-P B for Delivery Success Ratio for outgoing transactions

With reference to Figure 9.5 the measuring interfaces for the IPX-P B can be found in the blue circles; thus the relevant measurement is provided by the IPX-P B to the SP B as:

$$\text{Delivery Success Ratio for outgoing transactions} = \left(\frac{A2}{R3} \right) * 100\%$$

This measurement can be generalized for every Agent in the Signalling chain, by setting the measuring points of Requests and Answers, respectively at the interface with its downstream network and the interface with its upstream network.

A correctly delivered transaction is one where the IPX Provider delivers the Request to such SP and forward to the backward network chain the corresponding Answer, regardless the outcome expressed in the AVP (*Experimental-Result-Code*). As shown in Figure 9.5 a precondition for a transaction to contribute to this measurement is that the Request is delivered to the destination SP, thus it is ensured that routing and screening/policy criteria were previously successfully met and they do not affect the Success Ratio measurement, as in the originating case instead.

9.1.3 Considerations on the QoS control for Diameter Signalling

From the observation of live networks, it is recognized that a reliable Delivery Success Ratio computation which takes into account the approach and exceptions above described, can be achieved from the analysis of Transaction Data Records (TDR) generated by DRAs / IPX Agents. However, being the DRA implementation vendor / technology dependant, it is outlined that other methodologies (e.g. external probes) are possible.

In addition to the two suggested Success Ratio measurements, IPX Providers may also provide their customers with more detailed reports of Diameter Transactions, based on criteria like: roaming interface (i.e. "LTE Data Roaming over IPX Service Schedule", Release 1.0, 2013-2014

Application-ID), *Command-Code*, Origin/Destination network (e.g. Realms or IMSI range), *Result-Code*, etc.. For example, an IPX-P might measure the amount of successful Update Location procedures exchanged in a time frame between an SP and each origin or destination PLMN (i.e. for outbound / inbound roamers), in a similar manner to what is usually done for 2G/3G roaming signalling.

It is worth noticing that a deeper analysis, based on the Diameter (*Experimental-Result-Codes*) list and their match with success/failure conditions, should be addressed by all involved parties, aimed to provide a rigorous definition of a KPI (or list of KPIs) for the Diameter Signalling service. This activity has not yet been addressed by standardisation bodies and i3 forum calls for an extensive study on this topic together with other industry stakeholders.

9.2 QoS approach for LTE Data Transport

As LTE Data Transport from a technical standpoint makes use of IPX networks' transport capabilities, the QoS approach defined in Section 12 of IPX Core document [5] applies. Consequently, the reference points for quality measurements are described in Figure 9.6.

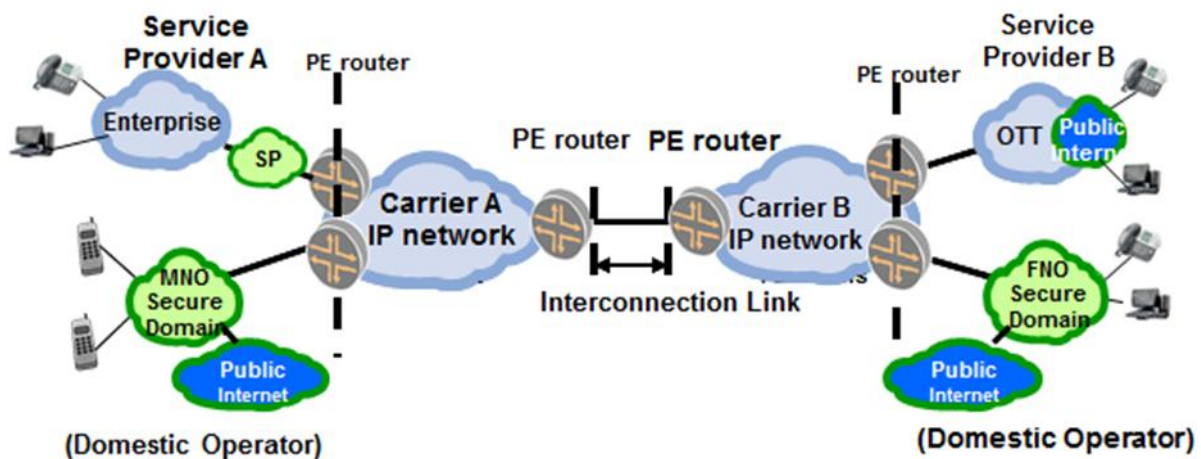


Figure 9.6 Reference configuration for QoS measurements

In line with [5], the parameters to be taken into account are the following:

- **Transport parameters**
 - **Round-Trip Delay (RTD):** RTD is defined as the time it takes for a packet to go from one point to another and return
 - **Jitter:** Jitter is the absolute value of differences between the one-way delays of consecutive packets
 - **Packet Loss:** Packet loss is the ratio between the total lost packets (= total sent – total received) and the total sent packets over a given time period
- **Service Availability:** is defined as the percentage of the time the IPX Core platform is available for the service. This encompasses the routers' availability as well as all service platform involved in the service delivery. Assuming the access link between the SP and the IPX Provider is under the responsibility of the IPX Provider, the availability of this link maybe part of the overall service availability. Service unavailability will be confirmed with a ticket opening by the SP to its IPX-P.

The details of minimum performance and measurements for the IPX transport layer KPIs are covered in i3forum IPX Core document [5].

10. Addressing Schemes

10.1 IP Address

Since the EPC is natively a full IP environment, all network elements within the EPC and IPX Agents (e.g. DEA, DRA) will have one or more IP addresses. In case SCTP multihoming is used as a transport protocol for Diameter, each Agent will be assigned two IP addresses, as primary and secondary address.

To be reachable by external IPX agents, e.g. for Diameter messages exchanged between interconnected SPs and/or IPX Ps, all border nodes should have one or more public IP addresses in the IPX address space perimeter, while being not accessible from the Public Internet.

For security and screening purposes, during the setup of the SCTP association (INIT / INIT_ACK) and Diameter peering (CER/CEA), it is recommended that each Diameter Agent advertises only own IP addresses that are agreed and shared offline between the interconnecting parties, including own virtual IPs.

As described in Sec. 11.1, the IPX Diameter Agents providing the IWF for Diameter-MAP interworking support SS7 addressing scheme (Point Codes and/or Global Titles) to allow the relevant procedures described in [10].

10.2 Diameter Realms and Diameter Hosts

Every Diameter Agent is recognizable in the global LTE Signalling network by an own Diameter Host name and belonging to a Diameter Realm. Both Host and Realm appear in the format of a FQDN, although in typical scenarios it is not expected them to be resolved with DNS; however, every border node is well known by the interconnecting party. The choice of Realms domain names should be in line with the recommendations in IR.67 [4] Table 1, for both SPs and IPX Ps.

The Destination Realm is always mandatory in Diameter Requests, as it identifies the mobile network to reach. In roaming procedures, the originating network may also use the Destination Realm in the Request messages as the unique addressing criteria, when the exact Agent (Host) in the destination network which will process the Request is not known at that stage. A DRA/DEA in the destination network is then in charge of adding the known Destination Host when proxying the Request to the known available resource(s).

Typically DEAs or DRAs in an SP's or IPX Provider's network share the same Realm, unless more than one network belong to the same SP or IPX-P with different traffic / service treatment expected. Conversely, different nodes/agents should not have the same Host name. It is common that Host names be a sub-domain of those used for Realms (e.g. *host-name.epc.mnc111.mcc111.3gppnetwork.org*).

11. Interworking with 2G/3G Networks

In the upcoming years 2G/3G networks and 4G networks will coexist. Therefore scenarios will appear in such networks where end-users belonging to 2G/3G-capable MNOs will be roaming in 4G networks' coverage and viceversa.

For some of those scenarios there is a need for an Interworking Function (IWF) which is capable to translate SS7 MAP messages into Diameter messages and viceversa. As recommended in GSMA IR.88 [2], the IWF capability, when needed, should be carried out by the 4G EPC PLMN, but could also be delegated to a third party, typically an IPX-P providing Diameter Signalling service to that MNO. In this section, the focus is on the latter case that is where the IWF is provided by an IPX-P.

When an IPX-P offers an Interworking Function capability between 4G and 2G/3G networks, the IPX-P needs to deliver SS7 messages to an SP directly or via an interconnection with a different IPX-P. So far, a service schedule for SS7 over IP (SIGTRAN) on IPX framework has not been defined by the i3Forum, such service schedule is FFS. The IPX Agent providing the IWF must be interconnected to the SS7 environment ensuring incoming and outgoing routes from/towards 2G/3G networks and, as such, must support the proper SS7 addressing schemes, in terms of Point Codes and/or Global Titles.

11.1 Interworking Function in IPX networks

The two relevant cases (H-PLMN is 4G, V-PLMN is 2G/3G and viceversa) are described in the following subsections. The IWF is located in the IPX-P network serving the 4G MNO.

11.1.1 H-PLMN has implemented 4G, V-PLMN is 2G/3G only

As anticipated in this case it is normally assumed that the H-PLMN carries out the IWF between MAP and Diameter, in the first place for conversion between MAP-based Gr interface and Diameter-based S6a/S6d. However it could also be the case that the IWF is performed by an IPX provider. For the sake of simplicity in Figure 11.1 only a single IPX provider is depicted in the Diameter signalling path. The Gp interface can, but not necessarily needs to, flow via the same IPX Provider that provides Diameter signalling and IWF to SS7.

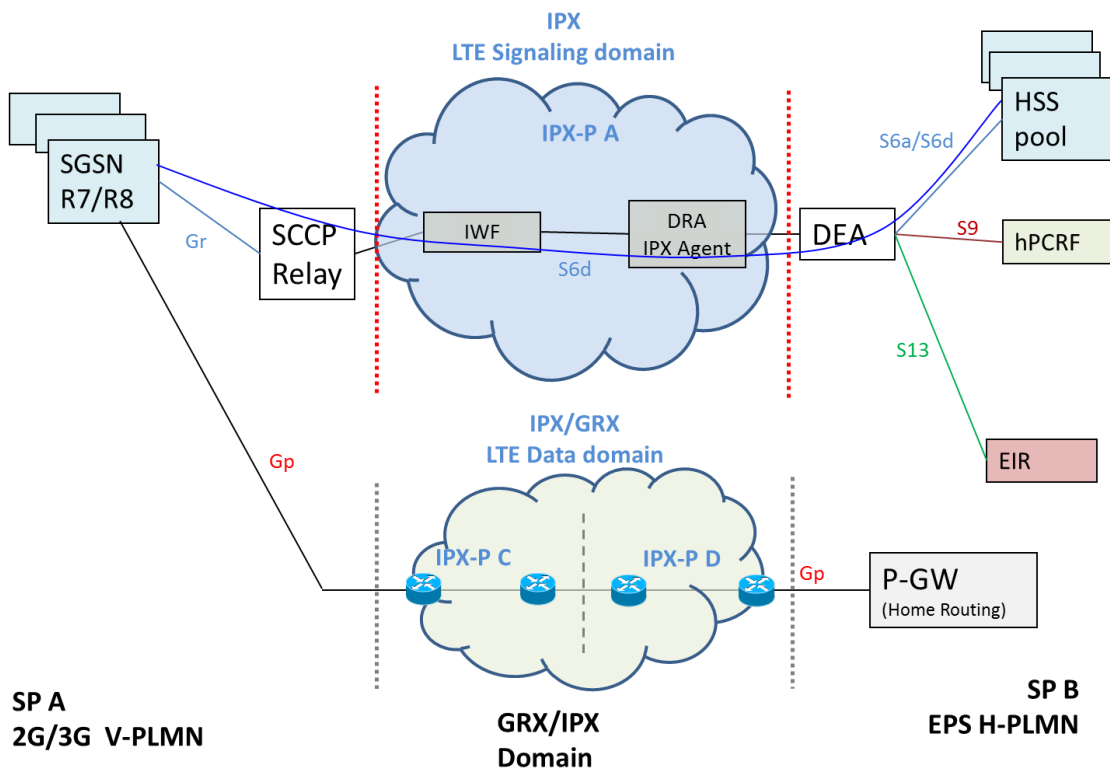


Figure 11.1 H-PLMN is 4G, V-PLMN is 2G/3G

11.1.2 H-PLMN is 2G/3G only V-PLMN has implemented 4G

This case can typically occur when the Visited MNO only has an *ex novo* EPC network, with no 3G capabilities, or instead in the case of the MNO willing to exploit 4G access network to broaden the radio access coverage for inbound roamers as well as own end-users.

In this case the IWF could be carried out by H-PLMN, V-PLMN or a third party. The conversion explicitly refers to Gr+ interface into S6a. Figure 11.2 depicts the case, where the IWF is located in the IPX domain. It is noted that 3GPP has not defined an IWF between S8 and Gp, therefore the specified basic scenario only supports Local Breakout in the V-PLMN, as depicted in Figure 11.2.

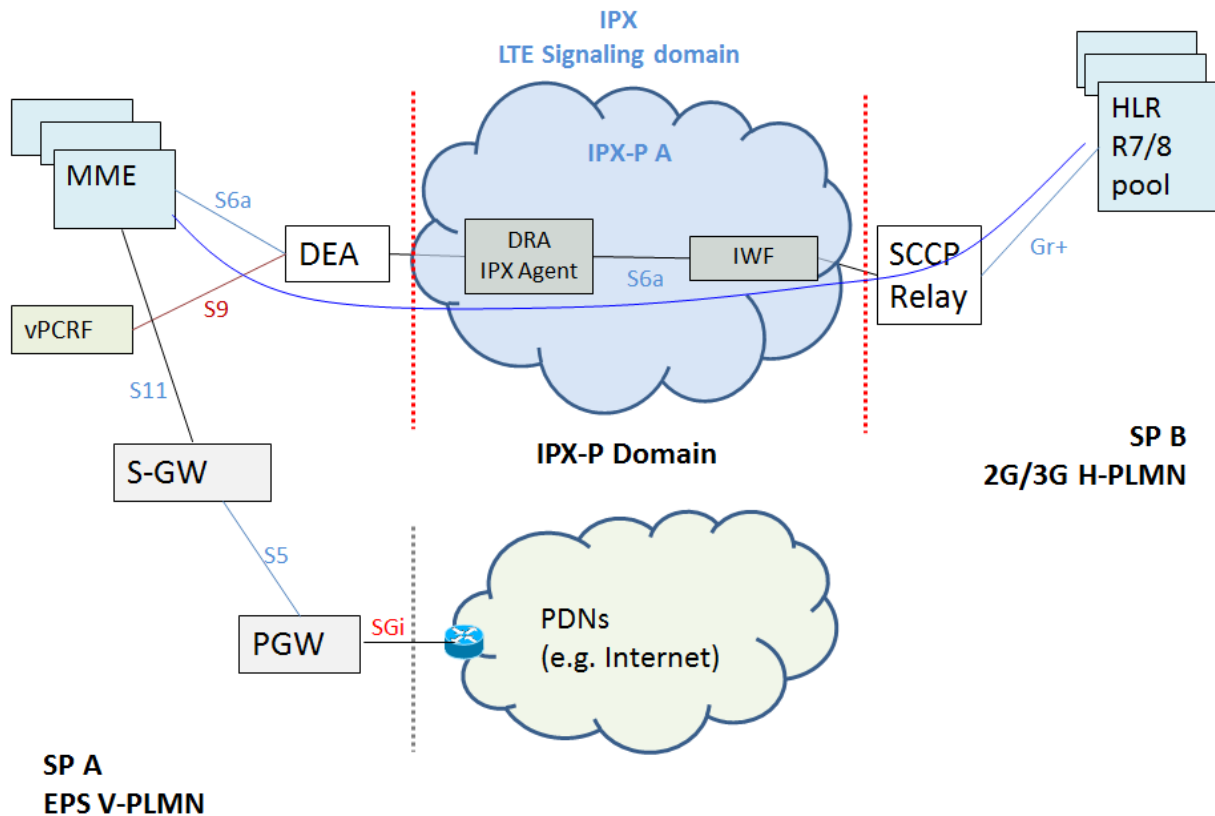


Figure 11.2 H-PLMN is 2G/3G, V-PLMN is 4G

In the case when the H-PLMN has upgraded its GGSN to support procedures of 3GPP Rel. 8 or higher, with support of GTPv2 for the Control Plane of S8 interface, then Home Routing scenario is technically feasible. However, in order to fully guarantee the correct procedures for AAA and mobility management, two additional conditions have to be met in the 2G/3G H-PLMN:

- the HLR must support Gr+ interface, being able to manage the specific EPS authentication vector (e.g. KASME) and EPS subscription data
- the H-PLMN DNS must support NAPTR records, which are required to provision APN FQDNs pointing to own Data Gateways

User Data could, but again not necessarily, be transported via the same IPX Provider offering Diameter signalling service and its conversion to MAP Gr+ (IWF).

It is recognized from the market that, though H-PLMNs support 2G/3G radio access, some networks might have also implemented some EPC functionalities, such as P-GW.

11.2 Interworking between Diameter and MAP

The Interworking function and procedures have been defined in 3GPP TS 29.305 [10]. The specification describes scenarios with 1 or 2 IWFs. A scenario with 2 IWFs is not very common, but theoretically might occur e.g. when the two PLMNs would want to reuse their existing SS7 roaming agreement.

Here it is assumed that one of the two IPX-PS in a connection between 2 SPs could both provide an IWF. This type of scenarios is out of scope here. Also out of scope is intra-PLMN (i.e. within 1 Service Provider domain) interworking between Diameter and MAP.

The 3GPP specification distinguishes between pre-Rel.8 HLR/ Gr interface and Rel.8 HLR/ Gr interface. The pre-Rel.8 scenario requires an upgrade of the HLR to support release 8 security mechanisms and upgrade of the Gr interface to support the transfer of the security parameters. Details related to these security mechanism can be found in 3GPP TS 33.401 [11].

In section 11.2.2, the message mapping for the interworking between S6a/S6d and Gr is summarized. Detailed parameter mapping, also for different MAP versions, can again be found in 3GPP TS 29.305 [10].

11.2.1 Interworking and routing principles

The main message routing principles in case of Diameter-MAP Interworking are:

- for the complete duration of a MAP dialog, all messages should go through the same IWF
- the IWF shall assign an SS7 number for the Diameter-capable MME/SGSN and shall assign a Diameter identity (Host and Realm) for the MAP-based HSS/HLR and be able to map between them one-on-one
- the IWF shall be able to map the MAP Dialogue Id and Diameter Session ID one-on-one.

In order to allow the two roaming partners to exchange relevant messages and information for mobility management, it is required that a proper interworking and mapping is performed within addressing parameters:

- Diameter Host and Diameter Realm
- SCCP CgPA and CdPA (full GT or GT ranges)
- IMSI (i.e. AVP User-Name)

Talking about mobility management procedures, typically, when the first message is originated by the 2G/3G network towards the IWF (e.g. SGSN to HSS via IWF), CgPA and CdPA GT ranges will be used to map Diameter Host and/or Realm out of the IWF towards the 4G network. This information of both sides should be kept in the IWF state machine to all transactions belonging to the same nodes and IMSI, as for Gr and S6a/S6d procedures.

In the reverse direction, when the first message is sent by an LTE network (e.g. MME to HLR via IWF), Diameter Host and/or Realms plus the User-Name are mapped to CgPA and CdPA GT ranges to address 2G/3G networks and/or nodes. This information of both sides should be kept in the IWF state machine to all transactions belonging to the same nodes and IMSI, as for Gr and S6a/S6d procedures.

11.2.2 Interworking S6a/S6d – Gr

The one-on-one message mapping between S6a/S6d Diameter and Gr MAPv3 messages is as listed below:

S6a/S6d	Gr
Authentication Retrieval (AIR/AIA)	SendAuthenticationInfo
Update Location (ULR/ULA)	UpdateGprsLocation
Cancel Location (CLR/CLA)	CancelLocation
Purge (PUR/PUA)	PurgeMS
Insert Subscriber Data (IDR/IDA)	InsertSubscriberData

Delete Subscriber Data (DSR/DSA)	DeleteSubscriberData
Reset (RSR/RSA)	Reset
Notification (NOR/NOA)	UpdateGPRSLocation
Trace Activation (IDR/IDA)	Activate TraceMode
Trace DeActivation (DSR/DSA)	Deactivate TraceMode

Table 11.1 Summary of message mapping S6a/S6d - Gr

Other details can be found in 3GPP TS 29.305 [10].

11.3 Impact on LTE Data Service in 2G/3G fallback scenario

In the Interworking scenarios the roaming subscriber in the 4G V-PLMN could fall back to 3G, e.g. due to lack of 4G coverage or due to access to those services which can only be offered in the 2G/3G roaming framework.

In this scenario Data services can still be offered with the 2G/3G capabilities and limitations of GRX service, which are out of scope of this document.

12. Business Aspects

To ensure Diameter signalling and transport of LTE data roaming services, the parties involved need to agree with each other on the business aspects of these services. Service Providers have to sign new roaming agreements or amend existing ones to enable signalling and data exchange. Service Providers also need to agree with IPX Providers on the commercials of the services.

12.1 Signalling Service (Diameter)

Options for signalling service between SP and IPX-P:

- flat fee (with tiered levels based on usage)
- per-transaction fee.

Options for signalling service between IPX-Ps:

- settlement-free peerings (sustainable if both SPs exchanging traffic are billed for the signalling service)
- paid peerings, e.g.
 - flat fee for a given capacity level
 - transit per outgoing or incoming transaction based on bilateral negotiations between the two IPX-Ps.

The objective is to promote broad interconnection between IPX-Ps for Diameter Signalling fostered by a sustainable and open market.

12.2 LTE Data Transport

Options for LTE Data transport between SP and IPX-P are:

- flat fee per installed/provisioned bandwidth
- used bandwidth based fee

In the above list, bandwidth is measured in Mbit/s and shall not be confused with traffic volumes (typically measured in MBytes).

Options for LTE Data transport between IPX-Ps:

- settlement-free peerings
- paid peerings, e.g. based on destination, destination.

In all above models a different pricing per Class of Service can also be used.

The objective is to promote broad interconnection between IPX-Ps for LTE Data Transport (and GRX) fostered by a free and open market. For both signalling and LTE data roaming it is recommended for IPX-Ps to have a contractual agreement in place, including SLAs for enabling end-to-end quality of the services. In case of paid peering penalties can be agreed in SLAs. Even in case of free peering SLAs make sense as they typically rule notice times for service suspension, response and reaction times in case of failures, escalation procedures, etc. If no financial penalties are agreed in case of free peering there is still the option to agree some form of escalation if the agreed SLA is violated too often.

i3Forum Recommendations

In the following some technical recommendations for the implementation of the two presented services are listed. They are a summary of what has been discussed in the previous sections and apply to the IPX Providers that are interested in offering a full LTE Data Roaming solution to their customers.

Regarding the Diameter Signalling service, IPX Providers are recommended to:

- adopt a fully redundant solution for the deployment of IPX Agents and inter-Providers peerings
- setup IPX-compliant interconnections for the transport layer of Signalling in compliance with the recommended configuration in the IPX Core document [5] and isolate the Signalling from the rest of IPX traffic via a dedicated VLAN
- apply specific SCTP parameters preferably for each interconnection or as a minimum on a geographical basis, computed from the estimated RTT with the counterparties
- apply appropriate routing and screening criteria of Diameter interfaces and messages in the proper way so to allow the exchange of the signalling to authorized parties only
- address QoS control matters in order to provide the SP with the proper visibility on the service performance

IPX Providers should also promote when possible a meshed architecture with regards to the interconnections between all IPX Providers, in order to speed up the technical implementation of LTE Roaming between all SPs.

With regards to QoS control for the Diameter Signalling service, examined in Sec. 9.1, i3 forum recognizes this topic as a novelty in the industry in early 2014. As a result, i3 forum calls for an extensive study, with the final objective of defining a set of KPIs, in conjunction with relevant industry members and supports any possible work on the subject by standardization bodies .

With regards to the LTE Data Transport service, IPX Providers are recommended to follow the guidelines described in the i3f Core document [5] in order to setup a proper IPX solution and configuration that fits for the transport of 4G Data, as well as 2G/3G, thus including connectivity options, networking, security, QoS measurements and enforcement.

Considering the rapid growth of the number of 4G end users, and consequently of the related roaming traffic, it is suggested that the level of occupancy of the bandwidth allocated on the NNI to this service is constantly monitored in order to meet the QoS sold to and expected by SPs.

As far as business aspects are concerned, this document provides an objective standpoint with regards to the commercial options for both SPs and IPX-Ps, listing the available options for the Service Provider – IPX Provider relationship and between IPX Providers.

By keeping different commercial options available in the market, the target is to encourage a rapid implementation of the interconnections between IPX Providers, offering both Diameter and Data Transport capabilities, in order to ease the growth of 4G Data services in roaming scenarios.