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LTE IP Address Allocation Schemes II: A Case for Two Cities

This document presents a specific case of IP address allocation – allocation in geographically-separated locations within an LTE network. In case of dynamic allocation, no matter where a user accesses, a dynamically selected P-GW dynamically allocates an IP address to the user for PDN connection. In case of static allocation, however, there is always one specific P-GW and one IP address for a user - the designated P-GW allocates a static IP address for the user's PDN connection. Here we will use an LTE network that serves two cities as an example to describe different ways and procedures of IP address allocation, and see how they are different from each other.

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Abbreviations

APN	Access Point Name
DNS	Domain Name System
EMM	EPS Mobility Management
ESM	EPS Session Management
eNB	Evolved Node B
EPS	Evolved Packet System
HSS	Home Subscriber Server
IMS	IP Multimedia Subsystem
IMSI	International Mobile Subscriber Identity
IP	Internet Protocol
LTE	Long Term Evolution
MME	Mobility Management Entity
PCO	Protocol Configuration Options
PDN	Packet Data Network
P-GW	Packet Data Network Gateway
S-GW	Serving Gateway
UE	User Equipment

I. Introduction

The previous document, IP Address Allocation Schemes I [1], has covered the basic allocation procedures, explaining how an LTE network allocates IP address to a user when the user attempts to access the network at different times (t=t1 and t=t2) while staying at one place. This document goes a little more specific, studying the allocation procedure where a user is accessing from two geographically-separated service locations (e.g. City 1 and City 2) within an LTE network. As in the previous document, two types of allocation methods (dynamic and static) will be discussed. Additionally, we will learn how a P-GW, the connecting point between UE and Packet Data Network (PDN), is selected, and how a default bearer route is set accordingly.

In case of dynamic allocation, the LTE network allocates a dynamic IP address (PDN address) to UE no matter which city the UE is accessing from, and the UE can connect to a PDN through a P-GW by using the IP address. The IP address allocation procedure is the same as in the previous document regardless the user's access location. However, in case of static allocation, the network allocates one permanent IP address, allowing UE to connect to a PDN through one designated P-GW, no matter where the UE is accessing from. The procedure is the same as in the previous document in that a permanent IP address is allocated according to the user's subscription profile. But, it is different in that a default bearer route can be set either within the city the UE accessed from or between two geographically-separated cities, now that there is one designated P-GW (connecting point to PDN).

This document is organized as follows: In Chapter II, different types of IP address allocation – dynamic and static - and their characteristics will be discussed. Chapters III and IV will provide the detailed explanation of the dynamic and static allocations, respectively.

II. Types of IP Address Allocation

Below, we will describe the allocation procedure using a two-city model in one of our EMM scenarios presented previously [2]. In this scenario, we assume there are MME, S-GW and P-GW in each city (City 1 and City 2). Each P-GW has its own IP pool(s), and only City 1 has HSS. UE uses only one PDN service (Internet). When requesting for a PDN connection, UE requests for DNS server IP addresses as well as a PDN address (IPv4 address). The scenario details are as follows:

① In City 1, a user turns on UE, accesses the LTE network, and uses a PDN (Internet) service.
② After using the Internet service, the user turns off UE, and moves to City 2.
③ Upon arriving at City 2, the user turns on UE again, accesses the LTE network, and uses a PDN (Internet) service.

During initial attach in City 1 or City 2, UE requests MME for PDN connection[1]. Upon the request, the MME selects a P-GW through which the UE can access the PDN, and the P-GW determines an IP address (i.e. PDN address) for the UE to use a PDN service. The P-GW forwards the IP address to the UE while a default bearer is being established, so that the UE can use the PDN service with the IP address.

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[1] UE provides the ID of PDN that it wants to use (i.e. APN). If not, MME performs procedure to connect to the PDN using the default PDN ID (i.e. default APN) stored in the subscription profile.

In this two-city model, IP addresses are allocated in two ways as seen in the previous document – dynamic and static IP allocation. Dynamic IP allocation will be explained in Chapter III and static IP allocation will be described in Chapter IV. IP address allocators and P-GW selection methods in each way are listed in Table 1.

Table 1. IP Address Allocation Methods

	Dynamic IP Address	Static IP Address
IP Address Allocator	**P-GW** (One from local IP pool is allocated)	**HSS** (The one provisioned at HSS is allocated**)**
P-GW Selection	**MME** (A P-GW is dynamically selected according to P-GW selection policies)	**HSS** (The one provisioned at HSS is selected**)**

III. Dynamic IP Address Allocation

In case of dynamic allocation, an IP address is dynamically allocated to a user whenever the user performs initial attach to the network. MME selects a P-GW through which the user can access a PDN, and asks it to establish an EPS session (i.e. PDN connection). The P-GW dynamically selects an IP address for the UE to use in accessing the PDN. Figure 1 illustrates how a dynamic IP address is allocated in the two-city model.
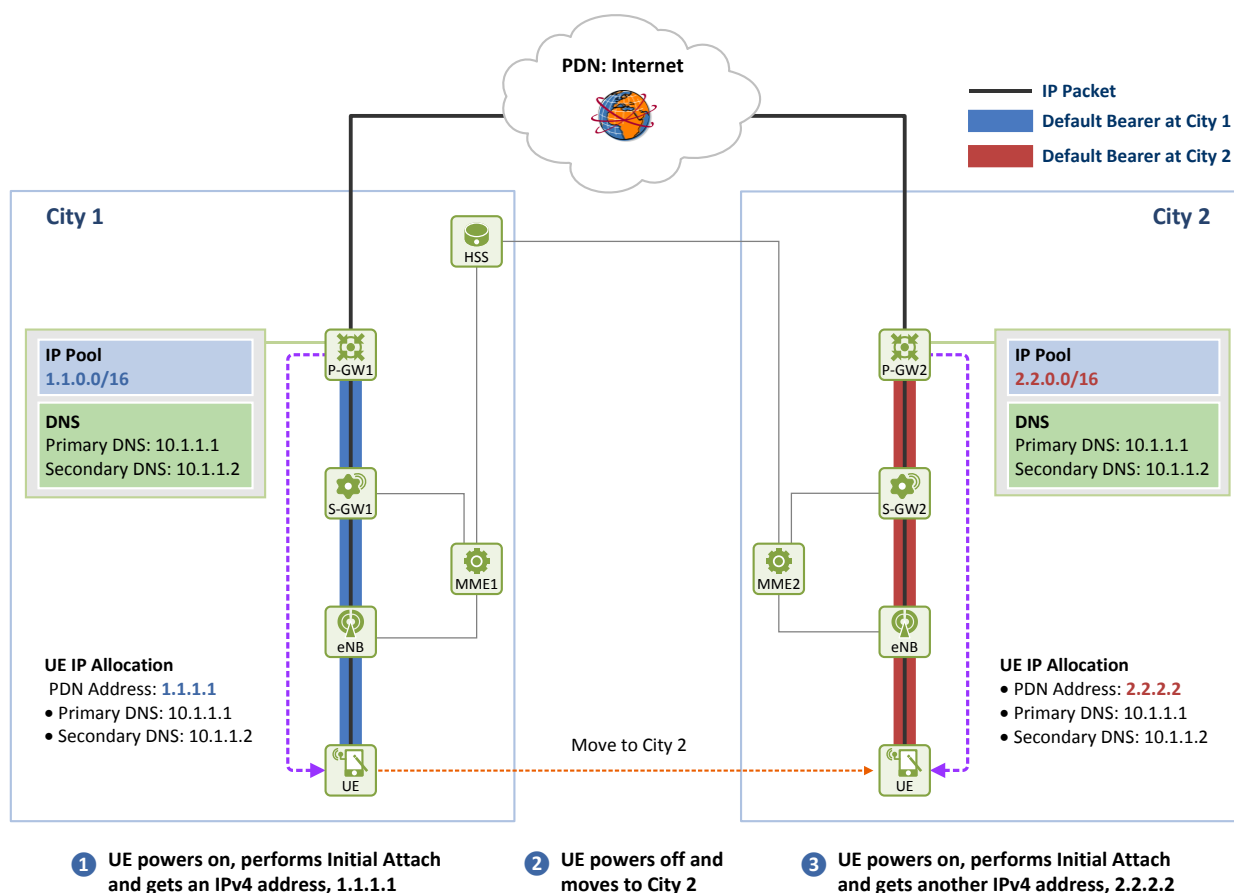
Figure 1. Dynamic IP Address Allocation

IP Provisioning at P-GW

At P-GW1 and P-GW2, an IP pool containing IP addresses to be allocated, and DNS server IP addresses are already provisioned by the network operator.

P-GW1
- IP Pool: 1.1.0.0/16 (1.1.1.1 ~ 1.1.255.254)
- DNS server IP addresses: Primary DNS: 10.1.1.1
                               Secondary DNS: 10.1.1.2

P-GW2
- IP Pool: 2.2.0.0/16 (2.2.1.1 ~ 2.2.255.254)
- DNS server IP addresses: Primary DNS: 10.1.1.1
                               Secondary DNS: 10.1.1.2

IP Address (PDN Address) Acquisition and PDN Connection

A user turns on his UE, requesting the local MME for a PDN connection. From the subscription profile downloaded from HHS, the MME learns the UE does not use a static IP address. Thus, it selects a local P-GW (P-GW1 or P-GW2), which then chooses an available IP address from its IP pool and allocates to the UE. While a default bearer is being established, the UE obtains DNS server IP addresses as well as a UE IP address from the local P-GW. Next, it connects to a PDN (Internet) through the local P-GW to use the Internet service.

Procedure for Dynamic IP Address Allocation

The procedure for dynamic IP address allocation in City 1 or City 2 will be the same as explained in the previous document (see [1] for details).

IV. Static IP Address Allocation

In static IP address allocation, i) the IP address (PDN address) to be used by UE for PDN, and ii) the ID of a P-GW through which the UE will be accessing the PDN are already provisioned at HSS as subscription profile. No matter where the user is accessing the LTE network from, MME selects the designated P-GW, and the P-GW allocates the static IP address stored in the user's subscription profile to the UE. Hence, the UE is always assigned the same permanent IP address regardless of its initial attach location, and a default bearer is created between the UE and the designated P-GW. Figure 2 shows how a static IP address is allocated in the two-city model.
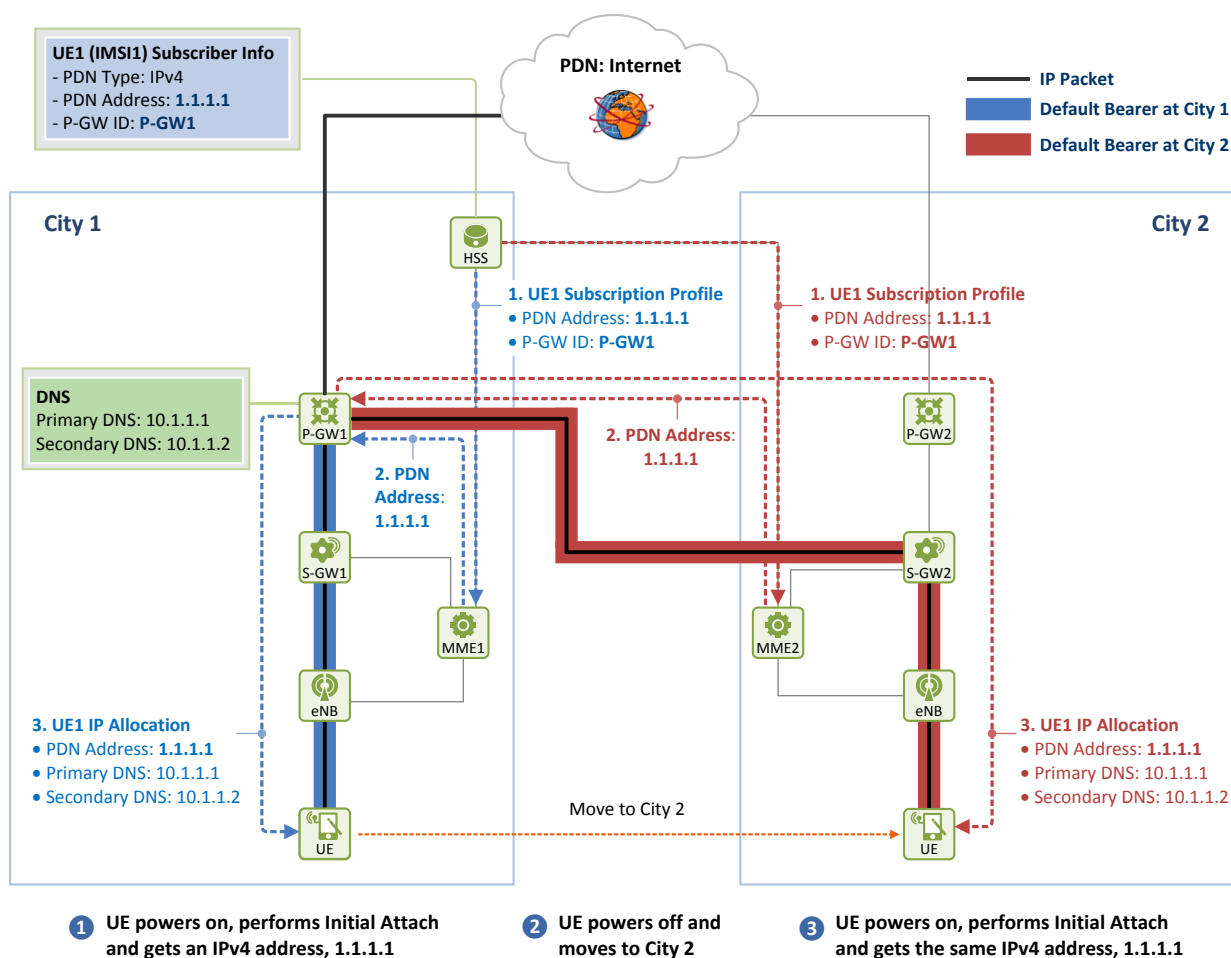
Figure 2. Static IP Address Allocation

IP Provisioning at HSS

At HSS, subscription profiles are provisioned for each user. Each subscription profile includes a PDN type to be used for PDN connection, PDN address (IP address) and P-GW ID.

> **HSS**
> - UE1: PDN type: IPv4, PDN address: 1.1.1.1, P-GW ID: P-GW1
> - UE2: PDN type: IPv4, PDN address: 1.1.1.2, P-GW ID: P-GW2
> - …

IP Provisioning at P-GW

At P-GW, DNS server IP addresses to be assigned to UE are provisioned.

> **P-GW1**
> - DNS server IP addresses: Primary DNS: 10.1.1.1
>   Secondary DNS: 10.1.1.2
>
> **P-GW2**
> - DNS server IP addresses: Primary DNS: 10.1.1.1
>   Secondary DNS: 10.1.1.2

IP Address (PDN Address) Acquisition and PDN Connection

After powered on, UE1 requests the local MME for a PDN connection. The MME then downloads the UE's subscription profile from HSS, and confirms the UE has a static IP address and a designated P-GW. Based on this information, the MME starts procedure for creating an EPS session (PDN connection) and establishing an EPS bearer.

This way, no matter where UE1 is accessing the LTE network from, i) the same static IP address is allocated, ii) a default bearer route is established connecting to the designated P-GW, **P-GW1**, and iii) UE1 gets to connect to a PDN (Internet) through P-GW1. The default bearer routes in each city are:

- City 1: UE1 - eNB - S-GW1 - **P-GW1**
- City 2: UE1 - eNB - S-GW2 - **P-GW1**

Procedure for Static IP Address Allocation

Figure 3 illustrates the procedure for allocating a static IP address in the two-city model.

City 1

UE1   eNB   MME1   S-GW1   P-GW1   HSS

UE powers on at City 1

1) Attach Request (PDN Connectivity Request)
IMSI, PDN Type=IPv4, PCO=DNS Server IPv4
Address Request

2) Update Location Request
IMSI, MME ID=MME1

3) Update Location Answer
IMSI, PDN Type=IPv4, **PDN Address=Static UE IP(1.1.1.1), P-GW ID=P-GW1**

P-GW Selection at MME1:
Static P-GW(P-GW1) from HSS

4) Create Session Request
IMSI, PDN Type=IPv4, PDN Address=Static UE IP(1.1.1.1),
P-GW ID=P-GW1, PCO=DNS Server IPv4 Address Request

5) Create Session Request
IMSI, PDN Type=IPv4, PDN Address=Static UE IP(1.1.1.1),
PCO=DNS Server IPv4 Address Request

IP Allocation: Staic IP Addr (1.1.1.1) from HSS
Deliver DNS IP

6) Create Session Response
PDN Type=IPv4, PDN Address=Static UE IP(1.1.1.1),
PCO={Primary DNS IP, Secondary DNS IP}

7) Create Session Response
PDN Type=IPv4, PDN Address=Static UE IP(1.1.1.1),
PCO={Primary DNS IP, Secondary DNS IP}

8) Attach Accept (Activate Default EPS Bearer Context Request)
PDN Type=IPv4, PDN Address=Static UE IP(1.1.1.1),
PCO {Primary DNS IP, Secondary DNS IP}

9) UE gets UE IP and DNS IP

EPS Default Bearer (UE1 – eNB – S-GW1 – P-GW1)

PDN: Internet

IP Packet

City 2

UE1   eNB   MME2   S-GW2

UE powers on at City 2

10) Attach Request (PDN Connectivity Request)
IMSI, PDN Type=IPv4, PCO=DNS Server IPv4
Address Request

11) Update Location Request
IMSI, MME ID=MME2

12) Update Location Answer
IMSI, PDN Type=IPv4, **PDN Address=Static UE IP(1.1.1.1), P-GW ID=P-GW1**

P-GW Selection at MME2:
Static P-GW(P-GW1) from HSS

13) Create Session Request
IMSI, PDN Type=IPv4, PDN Address=Static UE IP(1.1.1.1),
P-GW ID=P-GW1, PCO=DNS Server IPv4 Address Request

14) Create Session Request
IMSI, PDN Type=IPv4, PDN Address=Static UE IP(1.1.1.1),
PCO=DNS Server IPv4 Address Request

IP Allocation: Staic IP Addr (1.1.1.1) from HSS
Deliver DNS IP

15) Create Session Response
PDN Type=IPv4, PDN Address=Static UE IP(1.1.1.1),
PCO={Primary DNS IP, Secondary DNS IP}

16) Create Session Response
PDN Type=IPv4, PDN Address=Static UE IP(1.1.1.1),
PCO={Primary DNS IP, Secondary DNS IP}

17) Attach Accept (Activate Default EPS Bearer Context Request)
PDN Type=IPv4, PDN Address=Static UE IP(1.1.1.1),
PCO {Primary DNS IP, Secondary DNS IP}

18) UE gets UE IP and DNS IP

EPS Default Bearer (UE1 – eNB – S-GW2 – P-GW1)
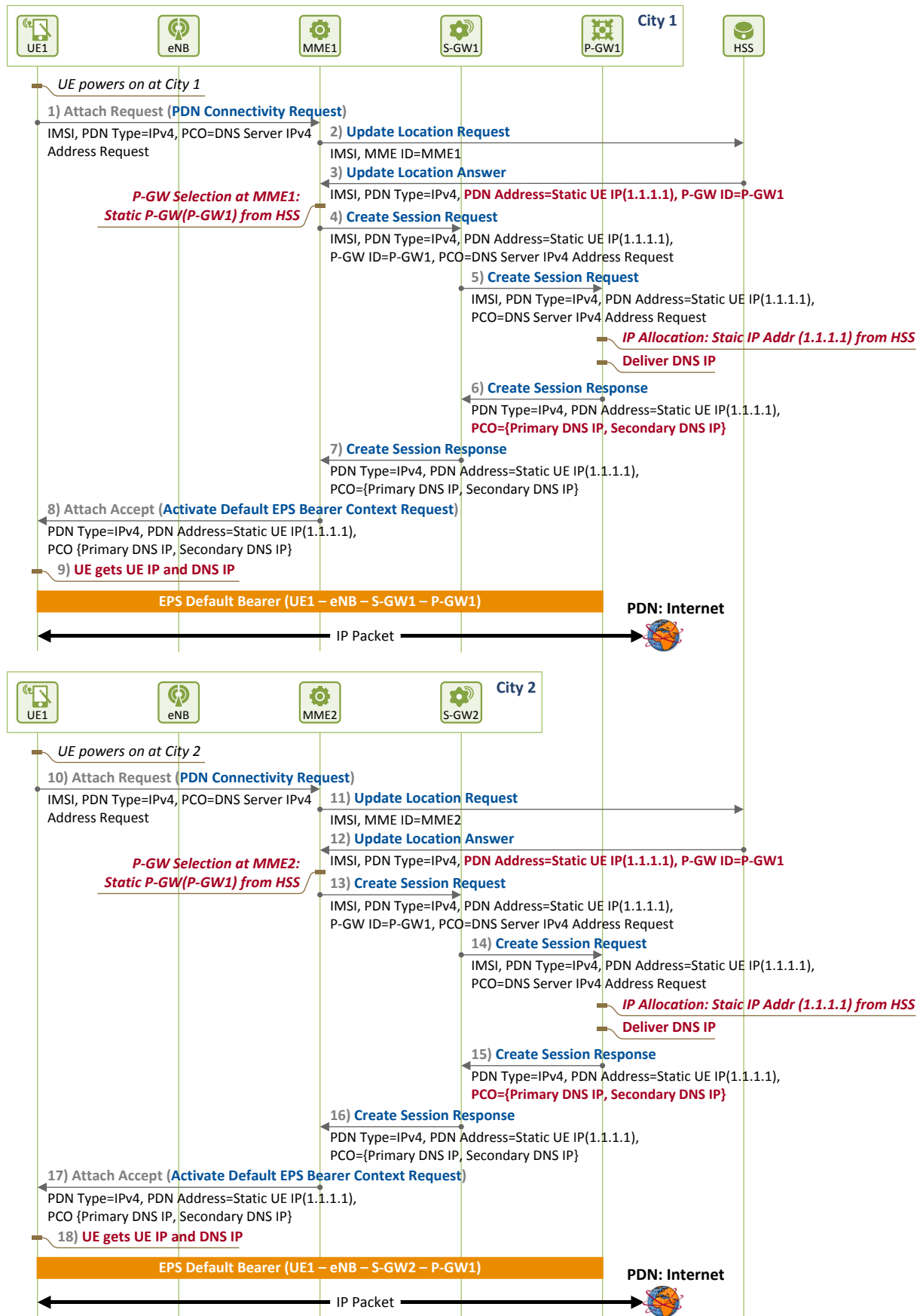
PDN: Internet

IP Packet

Figure 3. Procedure for Static IP Address Allocation

- **In City 1**

1) **[UE1 → MME1] Requesting for PDN (Internet) Connectivity**

   In City 1, after powered on, UE1 requests MME1 for a PDN connection by sending **PDN Connectivity Request (PDN Type=IPv4, PCO=DNS Server IPv4 Address Request)** message. At this time, in addition to an IPv4 address for the UE, IP addresses for DNS servers (by PCO field) are requested as well.

2) **[MME1 → HSS] Requesting the LTE Network for Registration**

   MME1 informs HSS that UE1 is under its control by sending **Update Location Request** message, and registers UE1 at the network.

3) **[MME1 ← HSS] Forwarding Subscription Profile**

   The HSS, recognizing UE1 is registered at MME1, forwards the UE's subscription profile to MME1 by sending **Update Location Response (IMSI, PDN Type=IPv4, PDN Address=Static UE IP(1.1.1.1), P-GW ID=P-GW1)** message. This subscription profile includes the static IP address and the P-GW ID provisioned for UE1.

4) **~ 5) [MME1 → S-GW1 → P-GW1] Requesting for Session Creation**

   After receiving UE1's subscription profile from the HSS, MME1 knows UE1 has a static IP address (1.1.1.1) and a designated P-GW ID (P-GW1). MME1 prepares **Create Session Request (IMSI, PDN Type=IPv4, PDN Address=Static UE IP(1.1.1.1), PCO=DNS Server IPv4 Address Request)** message and sends it to P-GW1. At this time the message contains the static IP address received from the HSS and PCO information received from UE1.

6) **~ 7) [MME1 ← S-GW1 ← P-GW1] Responding to Create Session Request**

   P-GW1 sends **Create Session Response (IMSI, PDN Type=IPv4, PDN Address=Static UE IP(1.1.1.1), PCO={Primary DNS IP, Secondary DNS IP})** message to MME1. This message contains the UE's static IP address and the DNS server IP addresses.

8) **[UE1 ← MME1] Requesting for Activation of Default Bearer Context**

   MME1 requests for activation of the default bearer context by sending UE1 **Activate Default EPS Bearer Context Request (PDN Type=IPv4, PDN Address=Static UE IP(1.1.1.1), PCO={Primary DNS IP, Secondary DNS IP})** message. This ESM message contains the UE's static IP address (1.1.1.1) and DNS server IP addresses, and is embedded in **Attach Accept** message, an EMM message, when delivered.

9) **[UE1] Obtaining Static IP Address for Using PDN Service**

   UE1 obtains the static IP address (1.1.1.1) and DNS server IP addresses. A default bearer is created between UE1 and P-GW1 (UE1 – eNB – S-GW1 – P-GW1). UE1, now connected to a PDN (Internet) in City 1, can use the Internet with its static IP address at any time.

After done using the Internet service, the user powers off UE1, having it detached from the LTE network. Once in City 2, the user powers on UE1 again.

- **In City 2**

10) [UE1 → MME2] Requesting for PDN (Internet) Connectivity

UE1 requests for a PDN connection by sending **PDN Connectivity Request (PDN Type=IPv4, PCO=DNS Server IPv4 Address Request)** message to MME2. At this time, in addition to an IPv4 address for the UE, IP addresses for DNS servers (by PCO field) are requested as well.

11) [MME2 → HSS] Requesting the LTE Network for Registration

MME2 informs the HSS that the UE is under its control by sending **Update Location Request** message, and registers the UE at the network.

12) [MME2 ← HSS] Forwarding Subscription Profile

The HSS, recognizing UE1 is registered at MME2, deletes the UE's context in MME1 and forwards the UE's subscription profile to MME2 by sending **Update Location Response (IMSI, PDN Type=IPv4, PDN Address=Static UE IP(1.1.1.1), P-GW ID=P-GW1)** message.

13) ~ 14) [MME2 → S-GW2 → P-GW1] Requesting for Session Creation

After receiving UE1's subscription profile from the HSS, MME2 knows the UE has a static IP address (1.1.1.1) and a designated P-GW ID (P-GW1). MME2 prepares **Create Session Request (IMSI, PDN Type=IPv4, PDN Address=Static UE IP(1.1.1.1), PCO=DNS Server IPv4 Address Request)** message and sends it to P-GW1. At this time the message contains the static IP address received from the HSS, and PCO information received from the UE. The message is delivered to P-GW1 in City 1 through S-GW2.

15) ~ 16) [MME2 ← S-GW2 ← P-GW1] Responding to Create Session Request

P-GW1 sends **Create Session Response (IMSI, PDN Type=IPv4, PDN Address=Static UE IP(1.1.1.1), PCO={Primary DNS IP, Secondary DNS IP})** message to MME2. This message contains the static IP address and the DNS server IP addresses to be used by UE1.

17) [UE1 ← MME2] Requesting for Activation of Default Bearer Context

MME2 requests for activation of the default bearer context by sending UE1 **Activate Default EPS Bearer Context Request (PDN Type=IPv4, PDN Address=Static UE IP(1.1.1.1), PCO={Primary DNS IP, Secondary DNS IP})** message. This ESM message is embedded in **Attach Accept** message when delivered.

18) [UE1] Obtaining Static IP Address for Using PDN Service

UE1 obtains the static IP address (1.1.1.1) and DNS server IP addresses. A default bearer is created between UE1 and P-GW1 (UE1 – eNB – S-GW2 – P-GW1). UE, now connected to a PDN (Internet) in City 2, can use the Internet at any time.

V. Closing

When a user attempts initial attach to the LTE network, the LTE network provides the user with PDN connectivity (IP connectivity) according to the service that the user is subscribing to (e.g. Internet, IMS, etc.). Once connected, the network has the connectivity maintained until the user is detached from the network, ensuring for "always-on IP connectivity". This means the network allocates an IP address for UE to use in the PDN. PDN connectivity is provided for each PDN, and hence IP addresses are assigned to every PDN that the UE is accessing.

We have so far learned how an LTE network allocates an IP address in the two-city model presented in one of our EMM scenarios [2]. In case of dynamic allocation, no matter where UE is initially attaching to the network from, a P-GW selected by the local MME dynamically allocates an IP address. And every time the UE accesses the network, a new IP address is given. In case of static allocation, a permanent address determined based on the subscription profile provisioned at HSS (i.e. static IP address and designated P-GW ID) is allocated, and UE is connected to a PDN through a designated P-GW at all time.

References

[1] Netmanias Technical Document, "LTE IP Address Allocation Schemes I: Basic", February 2015, http://www.netmanias.com/en/?m=view&id=techdocs&no=7246

[2] Netmanias Technical Document, "EMM Procedure 1. Initial Attach - Part 1. Cases of Initial Attach", December 2013, http://www.netmanias.com/en/?m=view&id=techdocs&no=6098

[3] 3GPP TS 23.401, "General Packet Radio Service (GPRS) enhancements for Evolved Universal Terrestrial Radio Access Network (E-UTRAN) access"

[4] NMC Consulting Group Confidential Internal Report, "E2E LTE Network Design", August 2010

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