Traffic Offload Enhancements for eUTRAN

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***Abstract*—Local IP Access (LIPA) and Selected IP Traffic Offload (SIPTO) are two topics currently of high interest to mobile network operators. They enable data traffic offload at appropriate points in the Radio Access Network in a highly cost-efficient manner. These technologies also have the potential to greatly increase system scalability and offer operators the flexibility to cope with the growing community of smart phone users and the associated increase of mobile data traffic. This paper first introduces the main concepts behind LIPA/SIPTO and discusses the main requirements to support them. Different architecture solutions, proposed for home, enterprise and macro-cellular networks, are presented. The paper also elaborates on LIPA/SIPTO traffic handling. A DNS-based approach, offering operators a fine-grained control of LIPA/SIPTO traffic handling, is introduced. The paper then discusses different other issues pertaining to LIPA/SIPTO traffic management, SIPTO QoS support, data offload gateway selection, and service planning and deployment. Finally, the paper concentrates on recent efforts towards the support of LIPA/SIPTO service continuity.**

***Index Terms*—Data Offload, LIPA, SIPTO, eUTRAN.**

I. INTRODUCTION

DUE TO THE increasing popularity of smart-phones and other mobile broadband enabled devices, mobile data is expected to continuously increase with an annual rate above 100% [1]. Operators are therefore in urgent need of means to cope with such increase in data volumes with minimal additional capital expenditures on existing mobile infrastructures. The challenge is even more significant given the fact that the Average Revenues per User (ARPU) is getting lower due to the trendy flat rate business models [2].

A large portion of macro-cellular traffic originates from local environments, such as home and enterprise networks, as well as from a disproportionate set of users that use bandwidth intensive applications [3]. Therefore, solutions that focus on network capacity scaling/optimization are not really addressing the root of the problem, not to mention how expensive and complex they are [4]. Offloading selective mobile data traffic via low-cost fixed access networks and the Internet, bypassing the operator core network, represents indeed a promising solution and thus constitutes a key requirement for future mobile network infrastructures [5]. Mobile network vendors as well as operators are already showing tremendous interest in the standardization of these solutions within the 3rd Generation Partnership Project (3GPP). The solution is expected to cost-efficiently support the data traffic growth by optimizing network usage and lowering network congestion, reducing therefore the necessary Capital Expenditure (CAPEX) investments.

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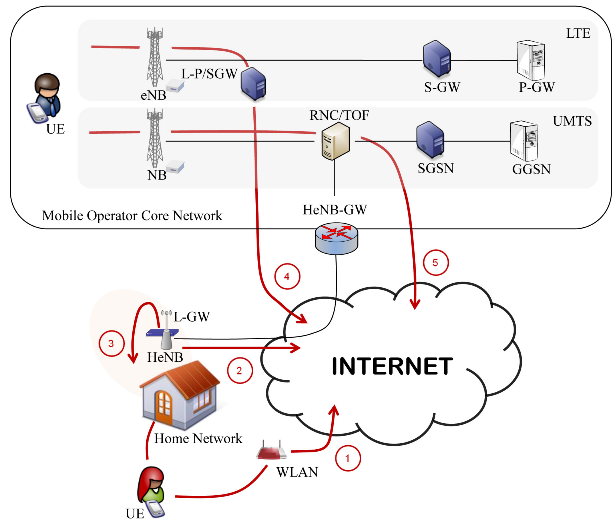

Fig. 1. Mobile data offloading options.

Data offloading points are typically located at the edge of the network - close to the radio access. Operators selectively breakout IP traffic; important traffic, for which the operator provides value added service, is carried over the core network, whereas "dump" traffic, for which the operators acts merely as a "bit-pipe", is offloaded to the Internet as efficiently as possible. By reducing the core network load, the SIPTO solution also ensures that operators remain with sufficient network capacity for their value added services without necessarily investing in costly upgrades of their core network infrastructure.

The LIPA solution enables direct communication with other devices within a local network, resulting in higher quality and security. SIPTO may serve to offload indoors data, accounting 81% of the data usage, from home, offices, public places, reducing the cost of per GB of data delivered by four times [3]. Wireless LAN (WLAN) has also been identified as a promising technology capable to offload 65% of the total mobile data, while saving 55% of the terminal battery [6]. Data offloading solutions can be quickly realized in existing network infrastructure, especially for local environment usage, via the installation of femtocells (Home (e)NodeBs), providing more cost-efficient and time-efficient solutions in comparison to macro-network upgrades. An overview of data offloading solutions is available in [7].

Different data offloading techniques are illustrated in Fig.1. WLAN solutions allow data offload directly to the Internet without utilizing service provider's resources (path 1). Femtocells or H(e)NBs permit data offload via a Local Gateway (L-GW) (path 2), while maintaining home/enterprise related traffic local, via LIPA (path 3). WLAN and H(e)NB data offload solutions may be blended with the current 3G UMTS and emerging eUTRAN - LTE as well as with WiMax networks. Considering macro-cellular network technologies, data offload points may be positioned at or above particular eNBs for eUTRAN, or at or above the Radio Network Controller (RNC) for UTRAN, redirecting selected traffic via path 4 and path 5 respectively.

Each solution is applied at a different location having a distinct effect on the core network performance and offering different control capabilities to the network operators. It should be noted that WLAN-offloading based solutions require enhanced vertical handover mechanisms as described in [8]. This paper concentrates on the 3GPP eUTRAN - LTE architecture, whereby the following solutions are envisioned:

- **Local IP Access (LIPA)**: a data offload solution towards a local network, either home or enterprise. LIPA functionality is provided by a Local GW co-located with the HeNB.
- **Selected IP Traffic Offload (SIPTO)**: an Internet data offload solution provided either to a local network in a similar way like LIPA or at/above certain eNBs in the macro network.
- **IP Flow Mobility**: a solution that offloads data traffic towards a WLAN, ensuring seamless movement of selected traffic.

The objectives of this paper is to initially overview the existing LIPA/SIPTO architectures within 3GPP and beyond, and to identify the key requirements, before exploring the network management perspective taking into account QoS, load balancing and gateway selection. The main contribution is to provide a comprehensive survey on the current state of the art, presenting insights on LIPA/SIPTO network management aspects and highlighting the fundamental principles behind LIPA/SIPTO service continuity, which is currently evolving, considering local, enterprise and macro-cellular network scenarios.

The remainder of this paper is organized as follows. Section II presents the 3GPP LIPA/SIPTO architectures and enlists the service requirements. Section III analyzes the management aspects, including the management architecture, QoS, load balancing and deployment issues. Section IV discusses issues on LIPA/SIPTO service continuity. Finally, Section V summarizes our study and provides further research directions.

II. LIPA/SIPTO Architectures

This section presents first an overview of the main LIPA/SIPTO challenges and requirements. It then analyzes the existing 3GPP LIPA/SIPTO architectures with respect to eUTRAN, before illustrating an enterprise network specific solution. Finally, it presents a solution for flexible offload control based on DNS extensions, which offers operators fine-grained control of whether a new IP connection should be offloaded or provided via the core network.

A. Concepts and Requirements

Two data offload solutions are currently discussed in 3GPP's System Architecture 2 (SA2) working group, namely LIPA and SIPTO [9]. LIPA is applied in residential or corporate deployments enabling local network access as elaborated in [10] [11]. It allows an IP-enabled mobile terminal, connected via a H(e)NB, to directly connect to other IP-capable devices and services in the local network without detour via the mobile operator's core network. SIPTO offloads selective IP traffic to the Internet at home and enterprise environments as well as at macro-cellular access networks. An overview of LIPA/SIPTO solutions is illustrated in Fig.2.

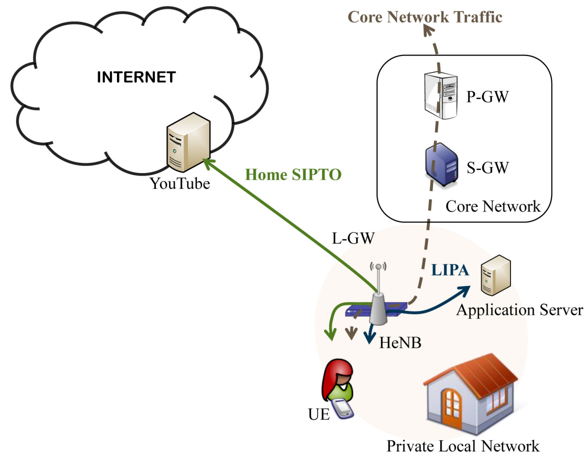

Fig. 2. LIPA/SIPTO breakout at a private local network.

LIPA breakout takes always place at the Local GW (L-GW) in the local/home or enterprise femtocell network, while SIPTO-based offload for femtocell can take place at L-GW similar to LIPA or above H(e)NB, such as at H(e)NB gateway [9]. Considering macro-cellular networks, macro SIPTO offload takes place at or above the RAN. By breaking out selected traffic closer to the edge of the network, operators may avoid overloading their scarce resources, i.e. PDN (Packet Data Network) gateways and Serving gateways (S-GW), as well as avoid inefficient routing in the mobile backhaul network.

According to 3GPP specifications related to H(e)NB subsystems [12], LIPA and SIPTO solutions should fulfill the following requirements:

(a) **LIPA**:

- UEs (User Equipments) shall be able to communicate with other network entities within the local network via H(e)NB.
- LIPA traffic is expected to remain local, i.e. not traverse the operator's network except H(e)NB, offloaded before HNB-GW, located in the operator's premises.
- UEs shall be able to access both the operator's core network and local IP access network at the same time.
- LIPA is subject to subscription. Subject to roaming agreements, UEs may be able to use LIPA in a visited network.
- Service continuity for a UE moving among different H(e)NBs within the same local/enterprise femtocell network is desirable [1].

[1]Note that in 3GPP Rel-10, service continuity for LIPA is not yet supported.

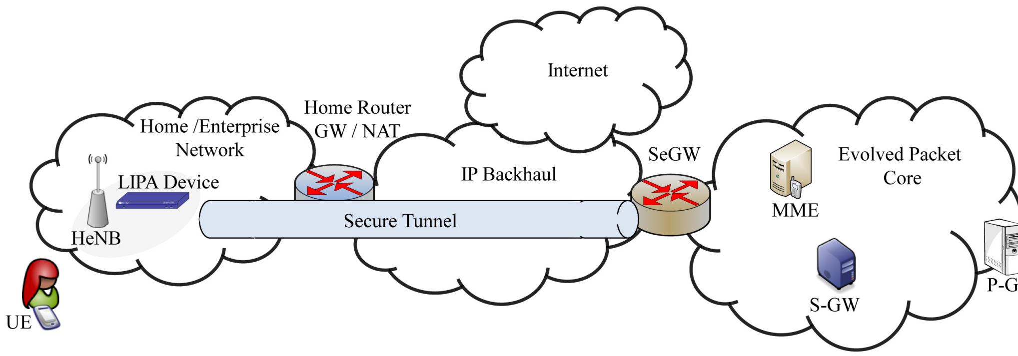

Fig. 3. Overview of Home/Enterprise LIPA/SIPTO architecture.

(b) **SIPTO**:

- SIPTO applies to both macro-cellular access networks and H(e)NB subsystems.
- Possibility for an operator to enable/disable SIPTO per UE and per IP network, i.e. Access Point Name (APN)
- No impact on supporting simultaneous services.
- Service transparency to UE, i.e., no user interaction is required.
- Possibility to support mobility between macro-cellular networks and H(e)NB and among H(e)NBs [2].

Effectively, operators are interested in controlling traffic, i.e., routing of IP traffic of particular users, depending on the traffic type and the destination IP network/address. With such control, operators can flexibly regulate which IP traffic flows to offload by SIPTO and which not, enabling:

- Lawful intercept,
- Access optimization to specific Internet services, and
- Value-added services provided by the operator (e.g., content filtering).

Currently, the location of Legal Interception (LI) functionalities is under discussion at 3GPP System Architecture working group 1 (SA1) and at the Femto Forum [13]. H(e)NB subsystem may perform LI for LIPA, while the location of LI for SIPTO is not clear since user traffic may need to travel inside the operator's core network, which is against the main objective of SIPTO.

For LIPA/SIPTO solutions, UEs shall be able to handle communications via both data offload points and core network nodes, which correspond to different PDN connections. Such a process may be supported by the following two different UE types:

- UEs configured with one single/common PDN connection for both LIPA/SIPTO and non-LIPA/SIPTO traffic.
- UEs configured with multiple/separate PDN connections, with at least one dedicated for LIPA/SIPTO.

When accessing a local/home or enterprise network, a user is preferred to have control on selecting the available LIPA service, while SIPTO usage should be transparent to the users. Handling separate dedicated PDN connections is only applicable to UEs with the capability to support such feature, i.e., multiple PDN connections, and may not be the case for certain legacy UEs. For UEs with a single common PDN connection, there is need for a Network Address Translation (NAT) function at H(e)NBs, HNB-GWs, and eNBs that translates the address of the UE into an IP address exclusively used for LIPA/SIPTO. Intuitively, such feature requires packet inspection, introducing high processing load. Additional requirements on LIPA/SIPTO solutions are as listed below:

- Mobility management signaling is handled by the operator's core network.
- Session management signaling, such as bearer setup for both LIPA/SIPTO and core network traffic, terminates at the operator's network.
- Reselection of UE's SIPTO offloading point is desirable during idle mode mobility once a significantly better offload point becomes available.
- UEs attaching to the network need to be authenticated, authorized and registered by the core network before being able to establish a LIPA/SIPTO session.

B. Architectures

In LIPA/SIPTO solutions for home and enterprise networks, the breakout point, i.e. the L-GW, is assumed to be either collocated with the H(e)NB subsystem or is a standalone entity connected directly to the H(e)NB. The home/enterprise LIPA/SIPTO architecture is depicted in Fig.3.

Connectivity towards the operator's core network is established via the IP backhaul through a secure tunnel between the HeNB and a Security Gateway (SeGW) in the operator network. Traffic from the home/enterprise femtocell network is tunneled through the Home Router and IP backhaul towards the SeGW. Such tunnel ensures security, which is vital particularly in case the IP backhaul is owned by a different operator. It should be noted that such a SeGW could also address the need of data aggregation from heterogeneous sources as pointed out in [14]. The following two main different LIPA/SIPTO approaches are currently considered:

- **LIPA/SIPTO solution based on a dedicated offload PDN connection**, whereby separate PDN connections are used for LIPA/SIPTO and non-LIPA/SIPTO traffic.

[2]Note that in 3GPP Rel-10, service continuity for SIPTO is not yet supported for offload at the residential/enterprise femtocell network

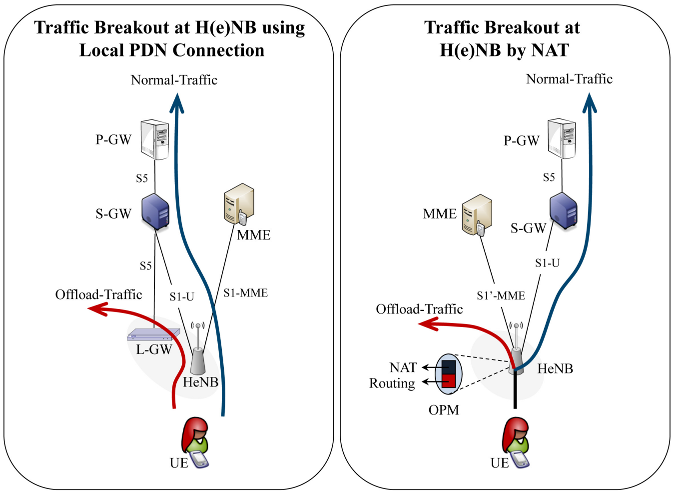

Fig. 4. LIPA/SIPTO solution with breakout at the H(e)NB.

- **LIPA/ SIPTO solution based on a Traffic Offload Function (TOF) and NAT**, whereby a common/single PDN connection is used for both LIPA/SIPTO and non-LIPA/SIPTO traffic, and the breakout functionality including NAT is collocated in the H(e)NB.

A LIPA/SIPTO solution based on a dedicated offload PDN connection targets UEs supporting multiple PDN connections. In the NAT-based solution, UEs use a single IP address assigned by the operator's core network, which is translated into a routable address in the local network. Such NATing and offload functionality is provided by the Offload Processing Module (OPM) at the HeNB, which inspects packets applying a set of offload policies (Fig.4), provisioned by the H(e)NB Management System (HMS). For the local PDN connection based LIPA/SIPTO solution [9], the L-GW is connected to the S-GW via a S5 interface, functioning as a P-GW. When the UE communicates (i.e. is active), the direct path between HeNB and L-GW is used. The S5 interface is only used in case the UE is idle, to initiate the normal paging process via the core network. In the TOF-based approach, the H(e)NB maintains a S1-MME interface with the associated MME, which requires certain upgrades to support paging for LIPA/SIPTO related traffic, depicted as S1'-MME in Fig.4.

The official 3GPP LIPA/SIPTO solution for home/enterprise networks is the L-GW variant with the local PDN connection-based solution. This solution variant introduces minimal standardization effort compared to the second variant, i.e. no interface modifications, and avoiding the need for packet inspection and NAT. The PDN connectivity establishment is initiated by a request message from the UE towards the MME. Such message contains a well defined APN and the address of L-GW. The MME performs the appropriate authorization and forwards a create session request towards the S-GW and L-GW. Upon completion of the create session procedure, the MME initializes the bearer setup among the UE and serving H(e)NB, which completes the process [9]. As for paging, the first downlink packet is duplicated and sent on the S5 towards S-GW, while buffering the subsequent packets at the L-GW. The paging procedure follows the normal paging process [15].

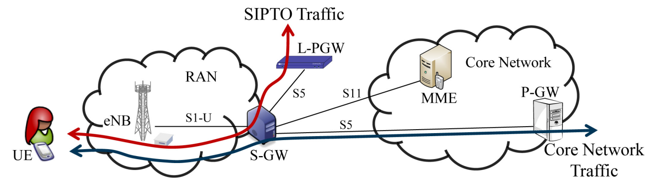

Fig. 5. SIPTO solution with one S-GW for SIPTO and Core Network traffic.

Once the UE is active, the L-GW forwards the buffered packets.

The NAT based solution though not documented in the 3GPP standards - could also be an alternative variant. For the NAT based approach, if H(e)NB receives a LIPA/SIPTO packet while the UE is idle, it can simply perform local paging - only at the HeNB where the packet arrived. Alternatively, the HeNB can also perform the appropriate NATing operations and send a dummy packet to the PDN-GW in the operator's core network in order to trigger the default paging process. Again, once the UE active, the HeNB would deliver the buffered data.

For macro-cellular networks, SIPTO is enabled at breakout points located at or above the RAN. UEs are supposed to be able to establish multiple PDN connections to different APNs, with at least one APN dedicated for SIPTO traffic. Selected data offloading services are supported at a local P-GW (L-PGW), which constitutes the breakout point towards the Internet via an external IP network (Fig.5). For optimal SIPTO, both L-PGW and S-GW need to be collocated nearby the RAN. The L-PGW selection process performed by MMEs is mainly based on the geographical location of UEs with respect to the established PDN connection. To regulate the SIPTO availability with respect to particular UEs or PDN connections, a SIPTO flag may be employed. Otherwise, local configuration methods and APNs dedicated for SIPTO may be envisioned.

For the enterprise environment, an efficient LIPA/SIPTO architecture is proposed in [16]. This solution assumes an Enterprise Femto Gateway (EFGW), with traffic offload capabilities and containing a proxy MME and proxy S-GW (Fig.6). As shown in Fig.6, the offloading decision function (ODF) can be implemented in the proxy S-GW or alternative a dedicated offload PDN connection can be used, which is terminated by the L-GW function located in the EFGW. The L-GW is responsible for data routing, NATing or IP address allocation depending on the offload model. A similar proposal is also included in [17] where the notion of Femto Private Branch Exchange (FPBX) is introduced with the objective to offload local traffic among the attached femtocells.

The L-GW supports an extension tunnel towards the P-GW as depicted in Fig.6. The tunnel extension is used to forward packets towards the P-GW when UEs are in idle mode or when active UEs are connected to a different eNB from the one where the L-GW is located. Such tunnel extension provides the means to support LIPA/SIPTO service continuity even among non-3GPP access, i.e. WLAN or among different 3G technologies, i.e. UMTS. The reason behind such flexibility is the use of the P-GW and the establishment of the extension

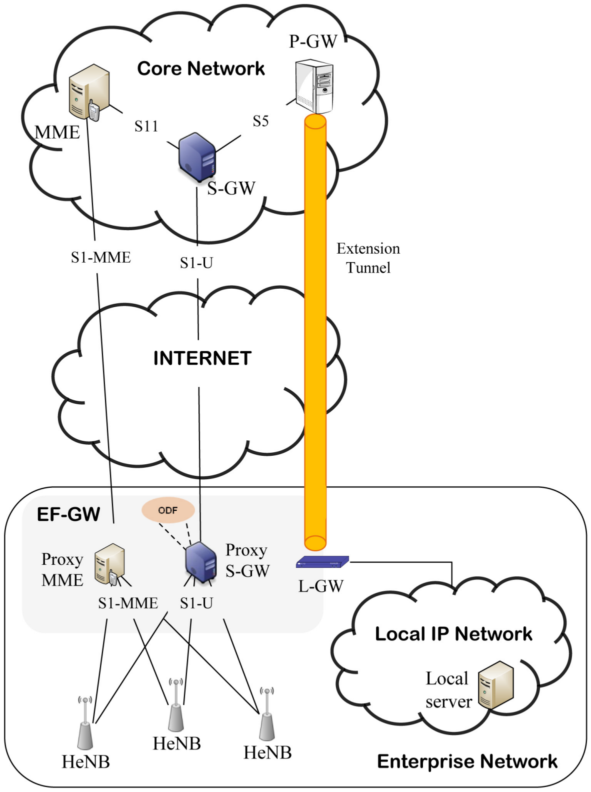

Fig. 6. LIPA/SIPTO architecture for enterprise networks.

tunnel. It should be noted that this solution requires state maintenance for mapping LIPA/SIPTO traffic into tunnels at L-GW and a routing decision mechanism.

III. LIPA/SIPTO Management Aspects

This section presents the main LIPA/SIPTO management aspects taking into account specific architecture solutions. First, a flexible solution for traffic offload control based on DNS is presented. QoS issues are then discussed before the different gateway selection options are identified and compared. Finally, the impact of LIPA/SIPTO on network planning and deployment is examined.

A. LIPA/SIPTO Management Requirements

The management of LIPA/SIPTO primarily depends on the way of determining the offloading decision and communicating them. Particularly significant is the location of the breakout point and the scheme used to communicate the related information. LIPA is provided within the H(e)NB domain below the RAN. It is expected to be regulated by specific operator controls and UE service profiles located in the same node where other management functions are being handled for H(e)NB. On the contrary, SIPTO breakout points are located at or above the RAN in the operator's core network and may employ other means to determine the offloading decision. So far 3GPP System Architecture 5 (SA5) have identified the following LIPA related management requirements, which are solution independent:

- Mobile operators shall be able to enable/disable LIPA per H(e)NB and per UE.
- H(e)NB Hosting Party, within the limits set by the mobile operator, shall be able to enable/disable LIPA per H(e)NB.
- H(e)NB subsystem shall allow the mobile operator to make traffic and signaling performance measurements related to LIPA for each user and for the H(e)NB.
- H(e)NB subsystem shall allow the mobile operator to collect fault management information related to LIPA for each H(e)NB.

H(e)NBs should be able to enable/disable operations on demand as well as being able to communicate alarm related information to HMS according to the configured policy. The mobile operator should be able to retrieve performance specific information from H(e)NBs. Regarding SIPTO, no impact on the existing H(e)NB management interface is expected since its positions is inside the operator's core network or H(e)NB-GW.

LIPA enables an IP capable UE to gain connectivity via a H(e)NB with other network entities inside the same residential/enterprise network, while SIPTO provides data offloading based on the following traffic granularities:

- **APN-basis**, where all traffic of a certain APN is subject to offload.
- **Application protocol**, where traffic associated with certain application protocols (e.g., identified based on traffic protocol type and port number) is subject to offload.
- **Destination IP address**, where traffic is offloaded based on the destination IP address.

Besides the granularity of LIPA/SIPTO, the communication necessary to establish data offload on selected network elements is equally important. In principle, there are the following three main ways to regulate LIPA/SIPTO:

- **LIPA/SIPTO flag**, which regulates each flow or APN. Besides the DNS based approach (see Section III B), such flag may also be associated with the user subscription to specify whether certain network elements, i.e. MMEs, should use LIPA/SIPTO PDN for particular APNs.
- **Local configuration**, where the LIPA/SIPTO related information is pre-configured in certain network elements such as MMEs via OAM procedures.
- **Well defined APN**, where dedicated APNs are solely used for LIPA or SIPTO.

The LIPA/SIPTO flag is highly flexible providing solutions per UE and per APN basis, but its use in association with subscription data may prove complex requiring upgrades on the HSS. The local pre-configuration is relatively simple but not flexible, while the well defined APN requires terminal configuration to provide a dedicated APN for LIPA/SIPTO traffic.

LIPA/SIPTO solutions regulate the offload decisions for specific IP traffic, an activity that requires network management processes to provide and maintain the decision information consistent. Currently, the following two distinct management options exist for controlling the LIPA/SIPTO offload:

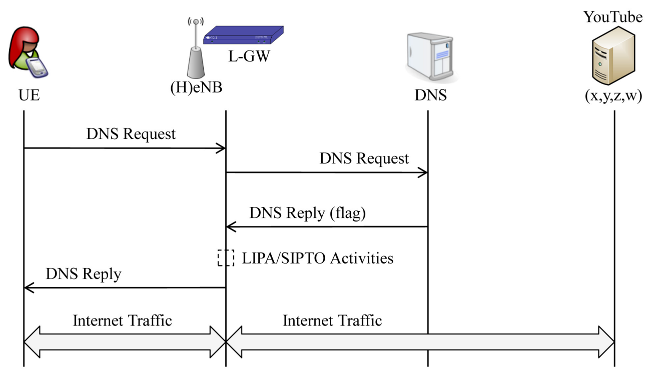

Fig. 7. SIPTO traffic handling by Operator DNS.

- **IP flow filters**: A policy based offloading decision, which is installed at particular HeNBs based on the regulation of a centralized management entity.
- **DNS-based**: A centralized offloading approach where a DNS server is accessed to provide offloading related information on per UE or per APN connection basis.

For LIPA/SIPTO traffic control, a basic solution can be performed by enforcing IP flow based routing/offload policies at HeNB. In this solution, the HMS dynamically updates the HeNBs with IP flow filters for policy based offloading. To accommodate the HeNB management interface (TR69 [18]) needs to be extended and the notion of IP flow-based routing/offload policies for LIPA/SIPTO should be established in HMS. IP flow-based filters take into account source/destination IP address/port number (or sub-network address), protocol version, and optionally the transport protocol type. Routing policies define which traffic is subject to LIPA/SIPTO based on these routing policies, while (H)eNBs decide how to route an IP flow.

A major concern with this solution is the complexity of provisioning these IP-flow filters dynamically to HeNBs or proactively providing LIPA/SIPTO IP flow filters to HeNBs. This incurs high signaling cost and management complexity. Besides, the absence of collective intelligence may cause no comprehensive solutions with evident problems on service continuity. A solution whereby the routing decision is taken centrally in the operator core (e.g., at DNS) and routing policies are explicitly provided to HeNBs during IP flow setup may be preferred.

B. DNS-based LIPA/SIPTO Traffic Handling

Generally speaking, operators want to have full control of SIPTO traffic handling, making decisions on which traffic is to be handled via the macro cellular network and which one to be offloaded. This feature can be achieved with the help of the core network DNS. Fig.7 shows how DNS is involved in the LIPA/SIPTO traffic control considering a scenario whereby a UE desires to connect to a YouTube server while being at home via a H(e)NB.

Initially, the UE issues a DNS request to the core DNS server requesting the IP address of the YouTube server. A local DNS proxy at the L-GW intercepts the DNS request and forwards it to the operator DNS server. In response to the DNS request, the Operator DNS server sends a DNS reply with the IP address of the peer along with additional information that indicates how the traffic should be handled. Following the DNS reply from the Core DNS, the L-GW applies the appropriate action in case the reply indicates LIPA/SIPTO traffic and sends a DNS reply with particular information towards the UE.

Depending on H(e)NB functionalities and UE capabilities with respect to multiple APNs support, four different options can be envisioned.

1) Simple Source NATing Solution: Solution In a simple "DNS-based LIPA/SIPTO control" solution, referred to as Simple Source NATing, we consider UEs supporting one single APN for both LIPA/SIPTO and non- LIPA/SIPTO traffic. In this solution, the L-GW provides NAT services for LIPA/SIPTO traffic by translating the IP address of the UE into a local IP address and adds it as an entry into its NAT table.

The LIPA/SIPTO service is indicated by a flag in the DNS reply message that specifies the offload decision for the related IP traffic flow. In case of offload, the IP address of the peer provided in the DNS reply is stored at the H(e)NB and is used for the traffic offload enforcement. It is worth noting that applications that do not work through NAT cannot be offloaded using this solution.

2) Twice-NATing Solution: In this solution, both source and destination addresses are translated as offload traffic crosses the L-GW. For non-SIPTO traffic a UE uses the IP of the peer, i.e. YouTube server, while for LIPA/SIPTO traffic it uses an IP address of the local GW, referred to as destination NAT (DestNAT). The local GW performs twice-NATing on LIPA/SIPTO traffic by translating the destination NAT address to the IP address of the peer and the UE global IP address into the local GW or external NAT address (Source NAT).

In this variant, the traffic offload is again triggered by a flag in the DNS reply message. The IP address of the peer is stored in the local GW and is associated with the local DestNAT. The address space for DestNAT is subject to certain limitations, since DestNAT should be routable in the operator network. IPv6 support or solutions based on the combination of source/destination port numbers in conjunction with the UE's IPv4 address as described in [19] provide a solution. It should be noted that the Twice-NATing solution also suffers from the same limitations as conventional NAT-based solutions.

3) Simple-Tunneling Solution: In the simple-tunneling approach, UEs forward LIPA/SIPTO traffic by establishing a tunnel towards the L-GW, which performs simple source address translation. Non- LIPA/SIPTO traffic is again routed through the operator core network using the UE's global IP address. To enable the simple tunneling approach, the UE is supplied, in the DNS reply message, with the L-GW's IP address, routable within the macro network, in addition to the IP address of the peer. Upon receipt of the offload traffic, the L-GW "untunnels" the packets and performs simple source address translation.

In this variant, the traffic offload is also triggered by a SIPTO flag in the DNS reply. The L-GW, upon receipt of the flag, adds its IP address to the DNS response towards the UE. The UE realizes that a particular connection is subject to LIPA/SIPTO by the additional tunnel end-point addresses provided in the DNS reply and tunnels the uplink traffic to the local GW address. An alternative approach to tunneling could be source routing based on the IPv6 header options. UEs maintain per flow state information to decide how to route a flow. Such information is kept at the network-layer and is completely transparent to the application layer.

4) Multiple-APNs UEs-oriented Solution: In this solution we consider UEs that can support multiple PDN connections to different APNs, with at least one APN dedicated for SIPTO. In this variant, the operator DNS indicates to the UE which APN to use for a given IP flow. The DNS server must be aware of the configured APNs. UEs may inform the DNS server of their available APNs as part of the DNS request. The DNS server may also recommend a list of APNs in order of priority that is defined based on different parameters.

Alternatively, the operator DNS can again employ a flag in the DNS reply to indicate that this IP flow should be offloaded. In this case, the UE must be able to autonomously identify the adequate APN for LIPA/SIPTO. In response to the DNS reply, the UE binds the new IP flow to the UE's IP address associated with the recommended PDN connection/APN. It is worth noting that the UE requires only simple network-level functionality for the binding process, which is anyway supported by UEs supporting concurrent PDN connections.

C. Quality of Service for SIPTO Traffic

Although SIPTO traffic is of low priority for an operator, SIPTO QoS is desirable from the customer satisfaction perspective. Potential QoS solutions for SIPTO traffic, in both macro-cellular networks and H(e)NB subsystems, depend on the control an operator has on the SIPTO-enabled domain or IP backhaul as illustrated in Fig.8. In other words, SIPTO QoS depends on the relation between mobile and fixed network operators. The following three different relation arrangements currently exist:

- **Same operator** provides the mobile and IP backhaul and/or SIPTO enabled domain.
- **Separate operators with Service Level Agreement (SLA)**, where the IP backhaul or the SIPTO enabled domain is managed by a different operator but a SLA between them ensures a minimum QoS assurance for SIPTO traffic.
- **Separate operators with no SLA**, where there is no QoS assurance for SIPTO traffic, which is handled as a best effort service.

Managing both the Evolved Packet Core (EPC) network and the IP backhaul/SIPTO enabled domain, an operator is in full control, providing the necessary level of QoS for specific SIPTO traffic, while at the same time being flexible in the overall network resource usage. A similar QoS assurance is also provided when SLA exists between the mobile and fixed network operators. In case no SLA exists, the QoS provision depends on the overall network load and application type. In particular, under low load conditions, even best effort services receive adequate QoS, while at peak hours with high traffic demand, some QoS degradation may be experienced, particularly for QoS-sensitive applications.

To compensate for high QoS degradation in the absence of SLA between different operators, a QoS monitoring mechanism as the one described in [20] may be employed to keep track of key performance parameters and influence the selection decision. Specifically, such QoS monitor may suggest disabling SIPTO during particular time intervals or applications until QoS in the IP backhaul or SIPTO enabled domain reaches acceptable levels.

Another issue that is indirectly related though critical to QoS is the gateway (GW) selection process, which is currently defined in [21] based on DNS with TAC/RAC (Tracking Area/Routing Area Code) as the selection criterion. For LIPA/SIPTO the following two different methods are proposed in [9] to perform the GW selection, based on the geographical location of UEs:

- **GW selection as suggested by a RAN node**, an approach that may select a GW above the RAN or collocated with the RAN node based on the UE location. Its simplicity forms its main advantage but the fact that deviates from the current DNS based GW selection [21] may give rise to an operational burden. In addition, it may require RAN enhancements at selected eNBs, which is a further limitation.
- **DNS based GW selection** scheme may have the same outcome as the previous approach but its main advantage is the fact that it is aligned with the current GW selection DNS based specification [21]. Therefore, it introduces minor modifications and could operate even with legacy nodes without the need for any enhancements. Such flexibility may compensate network upgrades and emerging requirements.

Once a GW is selected, there is the option to re-select a geographically closer GW in order to optimize future usage. Such process is typically carried out during idle mode periods and may be performed either by the MME, which detects the GW sub-optimality or by the GW itself. Further enhancements that consider load information in terms of network capacity or GW processing are highly desirable to improve the GW selection procedure.

D. LIPA/SIPTO Planning & Deployment Issues

The introduction of LIPA/SIPTO data offload solution has a significant impact on the CAPEX and OPEX of a mobile core network providing several benefits. LIPA/SIPTO may prove essential in urban areas with high traffic concentration, like popular shopping areas or train stations. A study concentrated on the specific requirements and challenges on deploying femtocells and data offload is available in [22]. Considering the location of traffic offload nodes in the macro-cellular networks, conventional network planning tools may be used for optimization purposes, identifying optimal positions.

Regarding indoor environments, certain connections are subject to most attenuation and are expensive in terms of macro-cell radio resources according to [23]. Therefore, the aim is to serve such connections using H(e)NB and SIPTO in order to improve resource usage of the macro cellular network

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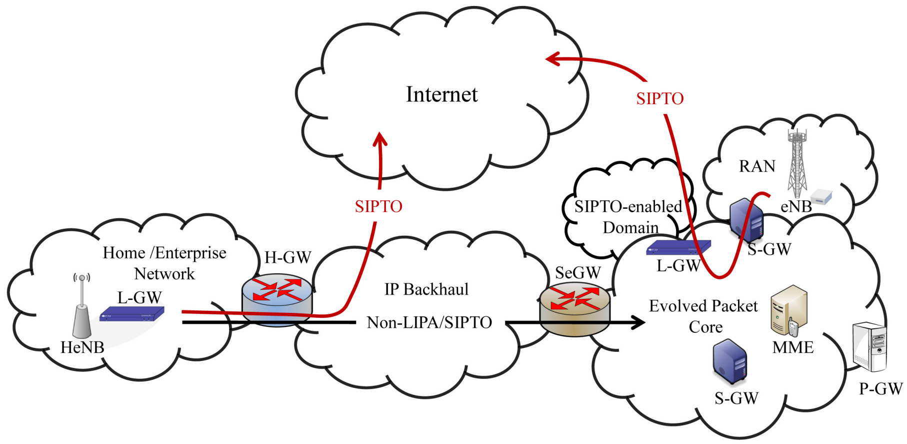

Fig. 8. Applicable QoS solutions for SIPTO traffic in macro networks or H(e)NB subsystems.

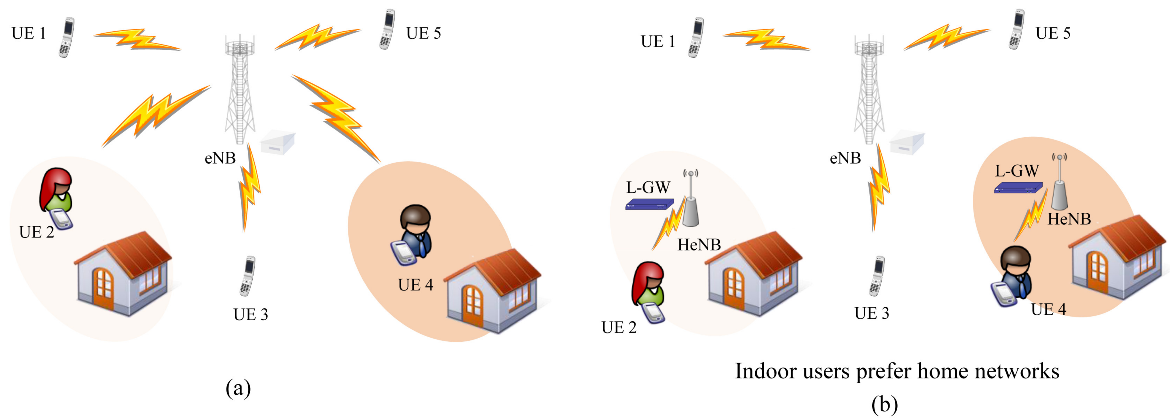

Fig. 9. (a) Conventional macro-cell, (b) combined femto-macro cellular networks.

in terms of both radio and network resources as illustrated in Fig.9. In [23], a study centered on UMTS presents results that demonstrate the benefits of SIPTO offloading in increasing the operator's macro-cellular network capacity up to 100%. However, such results vary depending on the interference among macro and home-local cells, which requires attention because of the likely use of the same radio spectrum. The deployment of femtocells in conjunction with macro-cellular networks has tremendous impact on the savings of the total energy expenditure, especially in urban environments, as illustrated in the simulation study of [24]. Based on the assumption that main network resource consumption is performed indoor at home and enterprise networks, femtocells may be used to offload high traffic volumes associated with macro-cellular networks, permitting:

- Reduced deployment of macro cellular base stations since indoor coverage is provided by femtocells, even when a relatively small fraction of femtocell is deployed.
- Higher quality radio conditions, producing less retransmission and more effective scheduling.
- Selected macro-cellular base stations to adapt their energy consumption to actual demand by switching off local functions, including radio carriers, power amplifiers or air condition units at off-peak times as described in [25].

In these ways, femtocells and data offloading nodes may enable some energy savings for the mobile core network. When public access is available for specific indoor environments, femtocells may optimize even further the capacity of macro-cellular networks.

Another study, focusing on femtocell interference [26], examines the correlation between coverage and capacity, where increased co-channel interference on femtocell deployments may also reduce the outdoor coverage. Therefore, as suggested in [22], femtocells should employ self-organizing functions, such as radio resource management. In open deployment cases, where femtocells may be accessed and used by any device in their coverage space, additional admission control and QoS policy measures may be essential in order to favor certain users according to applications or emergency services [22].

IV. LIPA/SIPTO Service Continuity

This section analyzes the mobility and service continuity issues related with LIPA/SIPTO traffic. Initially, we present an approach that supports LIPA/SIPTO service continuity in enterprise network scenarios. Then a SIPTO mobility scheme is presented based on the DNS-based solution, qualitatively comparing the earlier-mentioned alternatives, (i) Simple Source

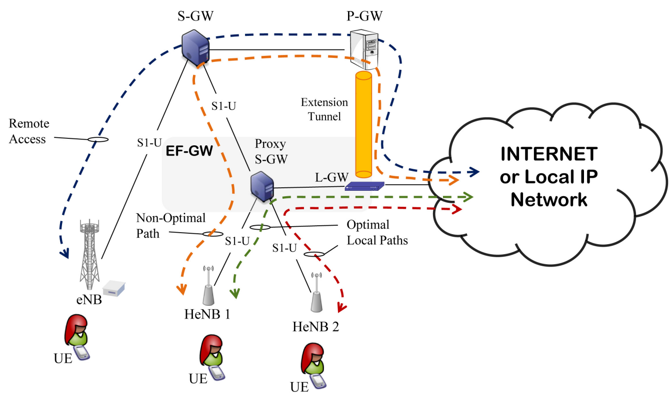

Fig. 10. Data paths for LIPA/SIPTO before and after handovers.

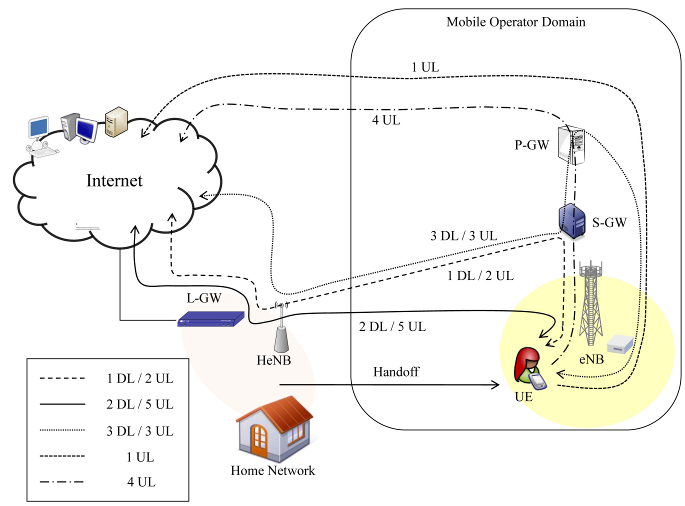

Fig. 11. DL/UL potential paths after handoff.

NAT, (ii) Twice NAT, (iii) Simple Tunneling and (iv) Multiple APN. The envisioned SIPTO service continuity share some similarity with IP flow mobility [27] and the distributed IP flow mobility considered in [28] [29], though the means of achieving mobility are different. The fundamental principles of distributed and dynamic mobility management and the notion of a flat architecture are also investigated in [30] [31], adopting the concept of data offload.

A. LIPA Mobility in Enterprise Networks

This subsection analyzes the LIPA/SIPTO service continuity in enterprise networks based on the EFGW-based architecture. The following three types of LIPA/SIPTO handovers are supported. The corresponding paths before, during, and after the handover process are shown in Fig.10:

- **Inter-H(e)NB Handover**, among H(e)NBs within the same enterprise domain, where the mobility signaling is handled locally by the proxy MME/S-GW. UEs are connected to the local network or Internet via the H(e)NB, Proxy S-GW, and L-GW. Upon moving to another H(e)NB within the same domain, UEs are still able to receive offloaded traffic via EFGW, i.e. from H(e)NB 1 (green session) to H(e)NB 2 (red session) in Fig.10. Such process reduces the signaling as well as the user plane data that would otherwise be routed via the backhaul, increasing also the QoS by avoiding long round trip delays.
- **Macro-cellular to H(e)NB Handover**, involves a UE movement from an eNB within the operator's core network towards a H(e)NB located inside an enterprise network assuming that the UE has a remote connection to the enterprise network, i.e. from eNB (blue session) to the H(e)NB 1 (orange session) in Fig.10. User data is routed through the backhaul, the operator's core network, and then to the enterprise network. A step that would optimize such routing scheme consists in having the ODF decide to route locally traffic related to the enterprise network, utilizing the green session in Fig. 10.
- **H(e)NB to Macro-cellular Handover**, involves a UE movement from the H(e)NB within the enterprise network to an eNB located in the operator's core network, i.e., from H(e)NB 1 (green session) to eNB (blue session). Such activity assumes that the UE has established an extension tunnel, which is not used since its traffic has been locally offloaded.

It should be noted that the described enterprise LIPA mobility is applicable for UEs that support both single/common PDN connection for all traffic as well as for UEs that support multiple APNs.

B. SIPTO Mobility for Home and Macro Cellular Networks

This section analyzes the feature of the DNS-based LIPA/SIPTO traffic handling approach, described in section III A, in terms of service continuity support. A qualitative comparison among the different variants is also presented. Fig.11 depicts all potential paths for both uplink (UL) and downlink (DL) traffic upon the handoff of a UE . There are two possible paths for downlink traffic, namely 1DL - 3DL, and five possible paths for uplink traffic namely, 1UL - 5UL.

In case SIPTO is handled via IP flow filters, the uplink traffic breaks-out at the target (H)eNB using 1UL in Fig.11 without providing service continuity support in case of handover. Similarly, in the DNS-based Simple Source NATing solution, service continuity cannot be supported since the correspondent peer will, upon a handover, receive the UE traffic with a different source IP address, namely the UE's global IP address. Service continuity for ongoing SIPTO traffic can be supported only if the break-out point for ongoing connections remains the same, at the L-GW of the source (H)eNB. This implies a L-GW must remain as anchor point employing novel mechanisms to forward/route the uplink traffic from the UE to the L-GW.

The traffic may traverse the core network before reaching the new location of the UE, a process that may need some further functionality on selected network elements. Paths that transverse the S-GW, like 2UL in Fig.11, require some extra functionality at S-GW to distinguish SIPTO from non-SIPTO traffic, break it out and route it to the L-GW at the source (H)eNB. Paths connecting directly the Local GWs at the source and target (H)eNBs as 2DL and 5UL and/or support data forwarding over the X2 interface are optimal but may

TABLE I
SUMMARY OF THE QUALITATIVE ANALYSIS ON THE SERVICE CONTINUITY SUPPORT FOR DIFFERENT DNS-BASED SIPTO TRAFFIC HANDLING VARIANTS.

	Single APN				**Multiple APN DNS based**
	IP flow filter	**DNS based**			
		Simple NATing	**Twice NATing**	**IP-in-IP Tunneling**	
System complexity & Cost	High	Low	Moderate	Moderate	Low
Transparency to UE	Yes	Yes	Yes	Transparent to application layer but network layer involved	Transparent to application layer but network layer involved
Service continuity support	No	No	Yes	Yes	Yes
Changes to DNS resolution	None	SIPTO flag	SIPTO flag & DestNAT	SIPTO flag & L-GW address	SIPTO flag or APN
Flushing of DNS caching at UE	No impact	Requires DNS cache flush upon (H)eNB change	Caching not possible (unless IPv6/IPv4 NAPT supported)	Requires DNS cache flush upon (H)eNB change	No impact
Packet inspection processing	Yes	Yes	Yes	Yes	No
Further issues	-	-	IP address space of LP-GW	-	APN priorization

need some (H)eNB/L-GW enhancements, which are outside the scope of this paper.

In case of the Twice-NATing solution, using the DestNAT, which is routable within the operator network and Source NAT, service continuity of the SIPTO traffic can be guaranteed by enforcing the downlink and uplink traffic to follow paths 1DL or 3DL and 2UL or 3UL as shown in Fig.11, respectively. In the uplink, path 3UL can be easily established as this requires merely the Twice-NATing functionality in the L-GW, which needs to intercept packets sent to the DestNAT address. The use of the alternative path 2UL requires some extra functionality in the S-GW to detect traffic targeted to the L-GW based on the DestNAT address range. Considering the downlink, path 3DL follows the conventional standardized path, while the optimized 1 DL requires functionality alternations at the S-GW.

In the Simple-Tunneling based solution, the IP address of the L-GW, used for the IP-in-IP tunnel, is routable within the operator network towards the source (H)eNB, and therefore service continuity of SIPTO traffic can be supported by enforcing the downlink and uplink traffic to follow paths 1DL or 3 DL and 2UL or 3UL as in Fig.11, respectively. In the uplink, path 3UL can be easily established as this requires merely the Simple Tunneling functionality in the L-GW, which needs to terminate the tunnel and route the traffic towards the destination. Path 2UL requires some extra functionality in the S-GW to detect traffic targeted to the L-GW based on the L-GW address range, while the downlink Path 3DL follows the conventional standardized path. Again the optimized 1 DL is also supported but requires S-GW functionality alternations.

In the multiple APNs UE-oriented solution, service continuity for SIPTO traffic is supported as the standard mobility procedures ensure that the PDN connections are maintained during handover. The downlink and uplink traffic follow paths 1DL and 2UL as shown in Fig.11, respectively. It should be noted that unlike the other schemes the multiple APN approach avoids the cashing problems related with DNS results and peer addressing in service continuation process. A qualitative comparison among all introduced solutions is presented in Table 1. A simulation study that compares among the performance of the described variants in terms of session blocking and dropping percentage is available in [32]. In summary, the proposed solutions achieve the following:

- Enabling operators to dynamically/flexibly control whether a particular traffic to or from a particular UE should be routed via SIPTO or macro core network (as discussed in Section III A)
- Supporting service continuity of SIPTO traffic
- Not supporting service continuity of SIPTO traffic if that is the wish of the operator (for the purpose of applying different charging schemes)
- Depending on the variant, transparency to UEs
- Depending on the variant, partial or full involvement of UEs in the decision on traffic handling
- Minimal or no additional complexity to the Core network
- Minimal or no modifications at the UEs

C. Gateway Selection and SIPTO Service Continuity

For an efficient SIPTO service, the selection of optimal offloading points is of vital importance. The main challenge is the fact that the selected gateway may not be optimal when a UE changes its point of attachment while being active, while the process of re-selecting another gateway is typically performed when a UE is in idle mode. In addition, a UE cannot have multiple IP sessions via different PDN connections to the same APN over the same access. Therefore, new IP sessions are established via the old Local PDN-GW (LP-GW).

An example that demonstrates such limitation is illustrated in Fig.12, where a UE initially establishes a PDN connection via eNB 1 and after a handover to eNB 2 it maintains such PDN connection and establishes a new one via the LP-GW 1. This is clearly not an optimal decision given the fact that another more optimal LP-GW (LP-GW 2) is available in the visited area. The optimality of the new PDN gateway can be assessed based on geographical proximity and expected load.

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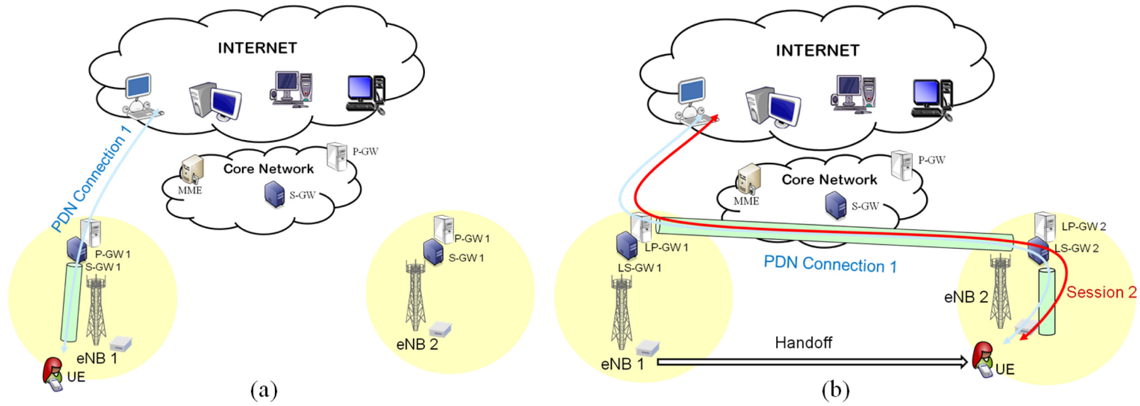

Fig. 12. Limitation of the GW re-selection: (a) PDN connection 1 initiated when UE is attached to eNB 1, (b) After performing a handoff to eNB 2, UE establish a new session via the old GW.

A radical solution to this issue could be setting up the new IP sessions via the optimal gateway and migrating the existing sessions to the new gateway. This solution would not only have significant impact on the user experience due to service disruption, but would also require massive modifications to current standards. As an alternative, UE may keep the old IP sessions via the old LP-GWs but sets up new IP sessions (to the same APN) via the currently optimal gateways as illustrated in Fig.13. Such optimal gateway re-selection solution may be applied even when the UE remains in the same area, i.e., cell, and its serving LP-GW is no longer optimal due to experience of overload conditions or another optimal LP-GW is available. A critical issue in the gateway re-selection is to identify the means of triggering such process at the UE considering the network element that provides such decision and the way of communicating it towards the UE. To cope with this issue, the following three different ways can be considered:

- **MME-initiated**: MMEs may check whether a more optimal LP-GW is available using Tracking Area Update (TAU) procedure, S5/S11 interfaces for exchange of load information, etc., and indicate this to the UE via Non-Access Stratum (NAS) protocol. Thus, when the UE establishes new IP sessions, it will re-establish the existing PDN connection or establish an additional PDN connection to the optimal LP-GW.
- **UE-initiated**: When the UE initiates a new IP session to an APN with which it has an ongoing PDN connection, it queries the associated MME regarding the used PDN connection, i.e. continue using the existing one or considering an alternative.
- **LP-GW initiated**: When the serving LP-GW realizes that a specific UE is better served by another LP-GW, it simply rejects requests for new IP sessions providing an appropriate new error message towards the UE. Alternatively, when a LP-GW starts experiencing certain load conditions, it notifies a selected set of UEs to establish new PDN connections with other less loaded P-GWs.

In order to establish a new PDN connection, UEs need to be able to bind the potential new IP sessions with the

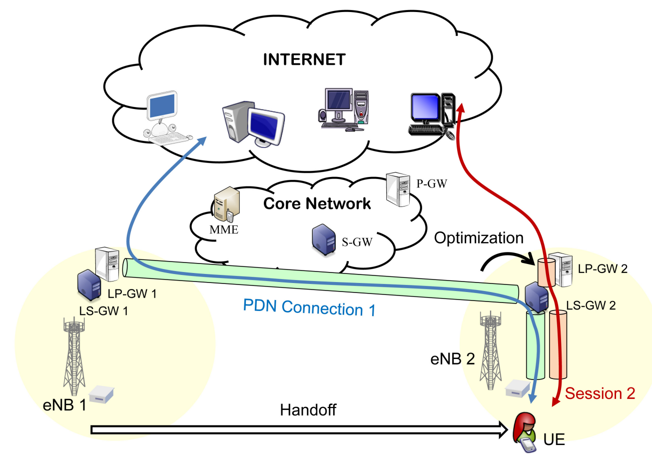

Fig. 13. Optimal GW re-selection: Setting up a new IP Session via the optimal GW while maintaining the old one using the established PDN connection.

corresponding LP-GWs. A conventional solution is to map the IP address of the destination peer, application type and protocol type with the LP-GW. In this way UEs efficiently keep track of the association of IP flow/sessions with particular PDN connections. A simulation study that demonstrates the performance benefits and the significance of load balancing in gateway selection process is available in [33].

V. Lessons Learned and Open Issues

LIPA and SIPTO are key solutions to help operators overcome the increased load crunch, being provided either via a local PDN or NATing. Different architectures are envisioned depending on the particular implementation with home, macro cellular and enterprise networks.

Considering the management perspective the main focus is on enabling the means for operators to control offloading. In particular, the management activities mainly concern the means of determining the offloading decision and the way such decision is communicated among specified network elements. Two fundamental distinct methods are described in this paper, one using local filters, which suits static scenarios and another, the DNS-based that may efficiently enable more dynamic decisions.

In terms of QoS provision, the most significant element is the relation among the mobile and fixed network operators and the offloading gateway selection process. In case a certain QoS should be guaranteed, a SLA between mobile and fixed operator is essential, otherwise offloading traffic may be best effort. It should be noted that conventionally offloading traffic is treated as best effort, but future offloading scenarios may raise different requirements. Such scenarios may include load balancing, energy saving and resiliency, thus ensuring QoS for offloaded traffic may be desired.

From the deployment perspective data offloading is the means to reduced OPEX and CAPEX, especially considering scenarios combining home and macro cellular networks. In particular, data offloading may increase the capacity of macro cellular networks and provide the means for energy saving at off peak times, while at the same time having shorter transmission links may increase the radio quality minimizing also interference.

Mobility and service continuity is a critical component for the data offloading solutions. A common characteristic among all solutions is the maintenance of the initial offloading point when a user of an offloaded session changes his point of attachment. Considering the enterprise network scenario, mobility is supported within the enterprise network as well as from or towards the macro network, where the key component is the intelligence within the enterprise femtocell gateway. For SIPTO mobility between home and the macro cellular network, different scenarios were analyzed depending on the UE capability and the routing of UL/DL sessions.

An additional issue with mobility solutions pertains to the selection of optimal offloading points, which is critical for both the network performance and user perceived quality. Initiating a new IP session via the optimal offloading point and balancing the sessions traffic among offloading points are critical issues for network stability. Whilst there have been many achievements in this particular area of research, the following lists up some elements that deserve further studies:

- **Mobility**: Current SIPTO service continuity methods do not take advantage of the X2 interface linking neighboring eNBs. Further research is needed to identify possible enhancements to the X2 interface to support SIPTO mobility. Furthermore, a critical issue regarding mobility and service continuity of LIPA/SIPTO is the stability of the handover decision, where mobility prediction techniques may prove valuable. Finally, admission control of handing over LIPA/SIPTO traffic towards another cell or even home network is an another research topic that deserves further investigation to ensure the required level of QoS for SIPTO traffic.
- **Charging**: SIPTO services are expected to complement the pricing paradigm for traffic routing, inspection and charging by operators, supporting the trend towards flat rates and differentiation into “dumb”, bit-pipe and value-added services [34]. Defining new approaches for charging and accounting of LIPA/SIPTO traffic (e.g. based on data volumes) will be of interest.
- **Energy Saving**: As discussed earlier, LIPA/SIPTO may help mobile operators to achieve energy savings. It will be interesting to understand the impact of offloading policies on the energy savings of the operator’s core network on one hand, and on the energy consumption of the fixed network operator on the other hand. A comprehensive solution considering offloading as a parameter into energy saving algorithms needs further research.
- **Admission Control**: Existing HeNBs are equipped with a single interface offering a single breakout point where LIPA/SIPTO functionality is realized. Future HeNBs are envisioned with multiple interfaces as described in [35] where the SIPTO functionality may be available either via the local breakout point or via the macro network with the HeNB acting as a relay node. In such a case enhanced admission control is desired to enhance the QoS provision taking into account the different offloading options.
- **Access Control**: Current HeNBs offer typically restricted access to particular users, but also further access models are investigated in [36] from a technical and business perspective. It would be interesting to explore further models considering also the option of LIPA/SIPTO functionality in relation with different QoS provision options.

VI. Conclusions

Data offloading is currently an important topic that interests operators. It has been discussed within different standardization bodies (e.g., 3GPP and Broadband Forum). Efforts to align the adoption of data offloading solutions are hence highly desirable. This paper investigated the concept of data offloading focusing on 3GPP LIPA/SIPTO solutions, identifying the main service requirements and architectures considering home, enterprise and macro cellular networks. In particular, the paper addressed different aspects of the service, focusing on network management, where specific operator requirements in relation with traffic handling were analyzed. Data offloading issues in relation with network deployment were further investigated focusing on capacity, energy efficiency and improvement of radio propagation conditions. Service continuity support was also considered where different solutions were investigated taking in account the selection of the optimal offloading point for load balancing and improved quality of experience. The adopted LIPA/SIPTO solution depends on the UE capabilities, while the management of the offloading decision, either fixed or DNS-based, depends on the dynamics of the network. SLAs among fixed and mobile operators are desirable to maintain QoS also for offloaded traffic, but they are not essential as offloaded traffic is considered to be only best-effort traffic for the time being. Finally, the selection of optimal offloading points is critical for both QoS and service continuity support.

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