Routing Enhancements for Selectively Offloaded IP Traffic in the Evolved Packet System (EPS)

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***Abstract*-In an effort to optimize the network for IP traffic, the third generation partnership project (3GPP) recently introduced several offload solutions which included Selective IP traffic offload (SIPTO). SIPTO facilitates offloading of selected traffic (e.g. internet or access to a corporate network) at appropriate points in the radio access network through distributed core network nodes. This allows optimization of backhaul and central core network resources. The use of SIPTO technology has the potential to greatly increase system scalability and flexibility to cope with the increase in mobile data traffic. Within the framework of the suggested SIPTO architecture, mobility for SIPTO traffic results in nonoptimal paths which fall back on the use of central core network resources defeating the purpose of SIPTO. Furthermore, in a scenario where a user equipment (UE) has multiple packet data network (PDN) connections active, there is a high likelihood of the occurrence of nonoptimal paths for SIPTO traffic. The problem becomes further significant because such nonoptimal paths may result in degradation of quality of service for delay sensitive applications. This paper proposes a SIPTO optimized PDN connection and handoff procedure to ensure break out of SIPTO traffic as locally as possible to the UE even under the identified scenarios and hence maintain an optimal route at all times.**

***Index Terms*—EPS, SIPTO, Routing**

I. INTRODUCTION

In the past few years, numerous surveys have been done on mobile data traffic forecasts and the challenges data traffic may cause for mobile network operators (MNOs) and most of the findings of these surveys are in agreement. The surveys show that mobile networks are becoming dominated by data traffic due to an increase in the use of smart phones, air cards for notebook computers, netbooks and tablet PCs running bandwidth intensive applications such as video streaming, interactive gaming, and mobile TV. The surveys also show that mobile data has changed from generating disproportionately high revenues in relation to network resources consumed when it was mainly SMS, to generating only 35 percent of the revenues while consuming 54 percent of the resources today [1]. The average revenue per user (ARPU) from data services may not be enough to offset the requirements for capacity and the associated capital and operational expenditure to meet this projected mobile data traffic growth.

Mobile network operators (MNOs) should therefore seek means to maintain profitability through new revenue sources (e.g. in-house applications), reduced operational costs (e.g. internet offload) and enhanced service delivery (e.g. 3 screen experience). All options that can help in relieving pressure on the mobile infrastructure should be considered. Approaches to this challenge can be directed towards three distinct areas of the mobile data network infrastructure i.e. the radio access network (RAN), backhaul network and the data core network. A solution is required that will balance customer satisfaction with extracting as much mileage as possible from the existing mobile infrastructure before triggering significant capacity upgrades.

A. 3GPP recommendations for optimized network use

In line with the need to reduce operational costs for MNOs, 3GPP recommended several mechanisms for optimizing the network for IP traffic which included selective IP traffic offload (SIPTO), an internet data offload solution provided either to a local network (femtocell) or at/above an evolved node B (eNB) in the macro network to facilitate offload of both RAN and core networks if deployed in the local network or to enable core network offload if deployed in a macro network environment [2]. The primary focus was to introduce mechanisms which would enable operators to move traffic to its destination at the lowest possible cost.

The SIPTO service enables an operator to offload selected traffic herein referred to as SIPTO traffic (e.g. internet or corporate network traffic) towards a defined IP network close to the user equipment (UE) point of attachment to the access network as shown in Fig. 1. It is based on an enhanced gateway selection function that has the capability to select a mobile core network gateway close to a RAN node [3]. When a user requests to access a service that the operator has defined to be offloaded locally through SIPTO offload, the packet data network (PDN) connection will therefore be established through a local PDN gateway (LPGW) defined for SIPTO traffic offload.

B. Key drivers for SIPTO adoption

The implementation of SIPTO functionality can be beneficial to operators in a number of ways. The following are some of the potential benefits that drive SIPTO adoption:-

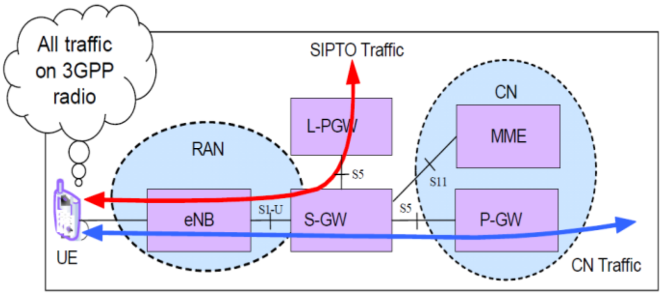

Figure 1. SIPTO architecture (3GPP) for macro networks

- Reduction of core network load

  The capability to offload specific traffic types as early as possible in the backhaul infrastructure ensuring that operators remain with sufficient network capacity for value added services without necessarily investing in costly upgrades of their core network infrastructure.
- Reduction of IP backhaul costs

  The bandwidth increases to be introduced in LTE will massively increase the backhaul and core bandwidth requirements. The ability to offload internet traffic to a less costly transport network or for users to access content from locally deployed servers can lead to significant operator transport cost reductions.
- Support for content distribution networks (CDNs)

  Distributed architecture introduced by SIPTO mechanism can be leveraged to push content caches closer to the end user resulting in better user experience and reduced operator core transport costs. Most operators carry large amounts of unicast video, and this accounts for a high percentage of their total traffic. Employing a content distribution network approach coupled with SIPTO offload targeting the locally deployed content servers can lead to significant internet peering and transport cost reductions for operators.
- Lower capital expenditure (CAPEX)

  Locally deployed gateway nodes are envisioned to have less functionality and therefore be less expensive. Deploying SIPTO gateways may therefore lead to less investment costs as compared to increasing the capacity of centrally located core networks.

The focus of our work is on SIPTO functionality in an evolved packet system (EPS) based macro cellular network environment. The EPS includes long term evolution (LTE) radio access and the evolved packet core (EPC). In as much as the femtocell based SIPTO solution can offer more benefits in terms of relieving the operators network through both RAN and core network offload, it comes with a dependency on the level of femtocell adoption [4]. It would therefore be more desirable in the short term to concentrate on leveraging SIPTO functionality in macro networks to enable offload of the operators' core network resources until such a time when femtocells get a more widespread adoption.

In this paper, we describe the routing of SIPTO traffic (IP traffic that is selectively offloaded through a LPGW) in the EPS and identify a need for optimization in certain scenarios. To this effect, we propose new serving gateway relocation mechanisms and give a preliminary evaluation of the algorithms. We further lay down the roadmap for our testbed evaluation of the proposed algorithms.

The remainder of the paper is organized as follows: Section II contains a review of the current status in terms of 3GPP standardization and SIPTO traffic routing within the standardized EPS framework. This is followed by Section III which discusses related works. Section IV proposes enhancements in this area and a preliminary evaluation is given in Section V. The paper is concluded by Section VI.

II. SIPTO TRAFFIC ROUTING WITHIN STANDARDISED EPS FRAMEWORK

According to a technical report by the 3GPP two deployment approaches were defined i.e. SIPTO for H(e)NB subsystems (femtocells) and SIPTO for macro networks [5]. The main objective of the technical study was to analyze architectural aspects needed to achieve the defined deployment approaches and to gather technical content to include in relevant technical specifications. Some of the key issues of the study included quality of service (QoS) aspects, support for both single and multiple PDN capable UEs and operator control of SIPTO.

According to the technical study, the SIPTO architecture shown in the previous figure (Fig. 1) was recommended for an EPS network supporting SIPTO functionality (i.e. for macro networks). The recommended architecture shows that the gateways i.e. local PDN gateway (LPGW) and local serving gateway (LSGW) should preferably be located at or close to the RAN edge in order to allow an efficient offloading of SIPTO traffic i.e. IP traffic that is selectively offloaded through a LPGW. A per UE per access point name (APN) configuration was recommended such that when a user requests for a service (defined by the APN in a PDN connection request) which is defined by the operator to be offloaded through a LPGW, the mobility management entity (MME) queries the home subscriber server (HSS) for possible gateways for this service and selects one that is close to the UEs point of attachment.

In a separate report focused on session continuity (mobility) for local IP access (LIPA) and SIPTO, 3GPP specified that for SIPTO implementations above the RAN with mobility within the macro network, session continuity for offloaded traffic should be supported within the standardized mobility procedures for macro networks as specified in release 10 [6]. These mobility procedures however do not put into consideration the SIPTO context when executing mobility functions in the MME.

A scenario based evaluation of the routing of SIPTO traffic led to an identification of potential nonoptimal paths which result in sub-optimal use of network resources and may consequently lead to degraded QoS for delay sensitive applications thereby defeating the purpose of SIPTO.

A. Scenario 1 – Multiple PDN connections

According to specified requirements for SIPTO, it should be possible to support both SIPTO and nonSIPTO IP traffic on a UE at the same time and offloading of SIPTO traffic for a UE should not affect services running in parallel for the same UE [7]. It is assumed for this requirement that the UE supports multiple APNs. The requirements further state that for traffic going through the mobile operators' core network, the serving gateway (SGW) user plane functions should be located within the operators' core network. In this paper, by nonSIPTO traffic we refer to IP traffic that traverses centrally located core entities.

When a UE attaches to the network, it is allocated a default PDN connection which is typically for operator services e.g. IMS location or presence services. This therefore results in the selection of a centrally located core SGW for the UE. If the UE later initiates a PDN connection request for a service subject to SIPTO offload, only a new packet data network gateway (PGW) can be allocated since there is no mobility trigger for SGW relocation. This results in a non optimal path as the SIPTO traffic will have to traverse the central core SGW which is undesirable. This is shown in Fig. 2.

A possible solution to this could be to relocate the SGW during the SIPTO PDN connection procedure and consequently achieve an optimal route for both SIPTO and nonSIPTO traffic as shown in Fig. 3, but the PDN connection procedure has no provision for triggering a SGW relocation. SGW relocation is only triggered during UE active mode mobility when the MME receives a new tracking area identity (TAI) for the UE or during idle mode tracking area updates (TAU). It would therefore be desirable to enhance the PDN connection procedure to take into account if the PDN connection request is for a SIPTO session and then trigger the SGW relocation procedure for such a request to allow the reselection of a more optimal LSGW for the UE.

B. Scenario 2 – Session continuity

Even if we were to achieve an optimal path as shown in the previous scenario, at handoff to a new cell assigned to a different LS/PGW (i.e. whose tracking area ID is not on the UEs current LSGWs tracking area list), SIPTO traffic would have to be forwarded to the UEs current cell by using a path through the central core network SGW as shown in Fig. 4.

If an operator was to provide IP connectivity between the local gateways (LGWs) of neighboring cells, it would be possible to forward SIPTO traffic directly between the source and target LGWs during mobility scenarios as shown in Fig. 5, but according to 3GPP recommendations, in situations where SGW service area overlap occurs (in this case LSGW and central core SGW), it is recommended to select a SGW that will give less probability of SGW change and in this case the central core SGW would be selected.

If the criteria for SGW selection was to be changed by placing more priority to a LSGW during such scenarios, this would lead to unnecessary SGW changes even for UEs not carrying SIPTO traffic (as LSGW has smaller service area) consequently increasing signaling load in the network. This is due to the fact that current mobility procedures do not have a mechanism of distinguishing between UEs with SIPTO sessions and those without so that for UEs with SIPTO sessions a location (geographical/topological) based SGW selection criteria could be used and for UEs without SIPTO sessions, the recommended SGW selection criteria could be used.

In an effort to resolve the nonoptimal path in this scenario, 3GPP recommended that reselection of an offload point that is geographically close to the user shall be possible during idle mode mobility procedures [6]. This solution however does not mitigate this problem completely as it does not cater for active sessions [8] [9]. A solution is required that will take into account the session context of a UE during handoff and determine if it is carrying SIPTO traffic for which there is a LSGW assigned in the new cell and thereafter perform SGW selection based on the appropriate criteria for that context.

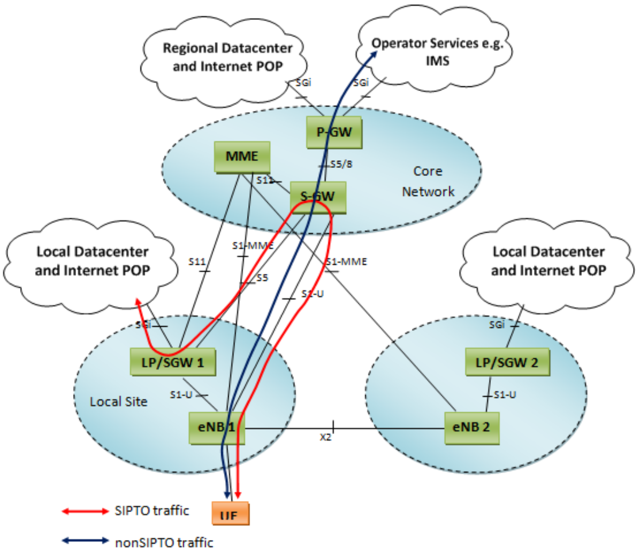

Figure 2. Default PDN connection (nonSIPTO session) and subsequent nonoptimal SIPTO PDN connection

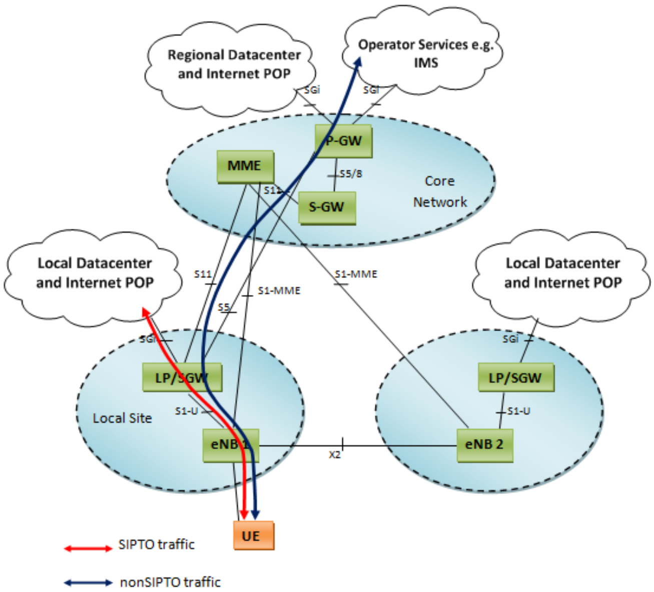

Figure 3. Optimization for scenario one

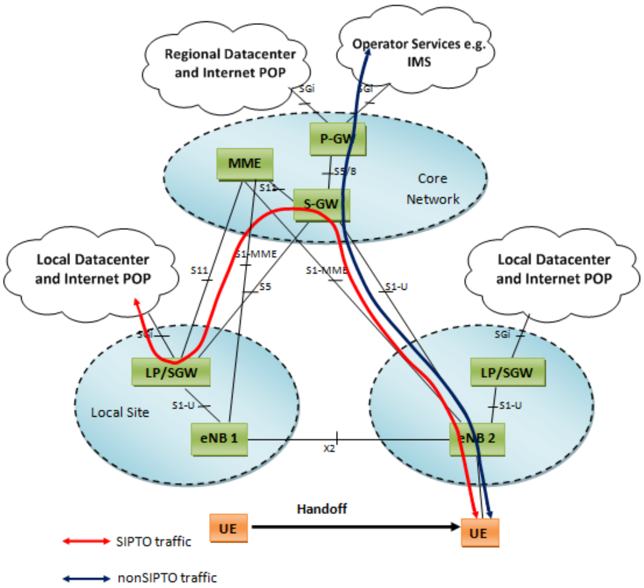

Figure 4. Nonoptimal SIPTO traffic path during mobility

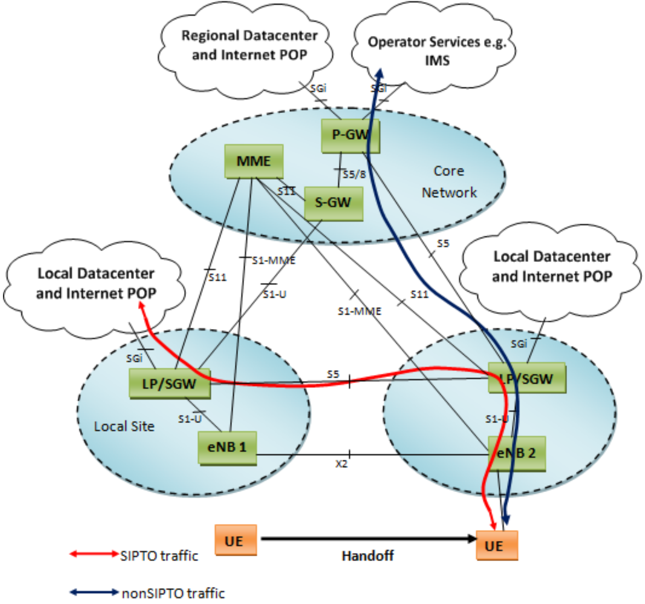

Figure 5. Optimization for scenario two

III. RELATED WORK

There have been minimal papers written on this subject as the SIPTO concept is still very recent. However, key papers which relate to the two nonoptimal routing scenarios presented earlier are discussed in this section. The important features of these papers (in terms of their aim, recommended enhancements, merits/demerits) are presented.

W. Hahn discusses the requirement for an optimized PDN connection procedure in order to avoid nonoptimal routing in a distributed evolved packet core (EPC) architecture with multiple PDN connections [10]. The paper recommends the incorporation of a TAU based SGW relocation procedure to the PDN connection procedure. The enhancement is to be implemented at the MME to allow SGW reselection during a standalone PDN connection request if the request is for a SIPTO session.

The proposed scheme ensures that an optimal SGW is always selected for SIPTO traffic even when the session is setup after a nonSIPTO session has already been established and is active on a UE. However, their integration of the TAU based SGW reselection with the PDN connection procedure is nonoptimal and may lead to unnecessary delays in creating a new SIPTO session. Their solution is such that an MME would only send a create session request for the requested SIPTO session to the target SGW after nonSIPTO sessions active on a UE have been relocated to the target SGW i.e. SGW assigned to target eNB. This is not necessary as the MME can process both the relocation of the old nonSIPTO session and the creation of a new SIPTO session concurrently without affecting the active nonSIPTO session on the UE.

T. Taleb et al. discuss a method for routing traffic within a network in order to allow an efficient offloading of SIPTO traffic from the core network even upon handoff of a UE to a new cell [11]. They recommend the implementation of a table of inbound SIPTO sessions at the original LGW i.e. a gateway from which a SIPTO session was first established. This table is used to maintain information about UEs with ongoing SIPTO traffic and the IP addresses of LGWs of H(e)NBs they are currently connected to. A table of outbound SIPTO sessions is recommended for the target LGW as well. The table is used to maintain a mapping of SIPTO sessions and the original LGWs. A list of original LGWs for each UE with ongoing SIPTO sessions is also recommended to be implemented at the MME.

Their proposed scheme enables direct forwarding of SIPTO traffic from the original to target LGW during/after handover thereby preserving backhaul and core network resources. In as much as the solution enables optimal routing of SIPTO traffic during/after handoff, non standard mechanisms (in relation to the evolved packet core) are not kept to a minimum i.e. tables at the LGWs and MME, new signaling between MME - LGW and source - target LGW, and the need for the original LGW to inform the MME about a UE SIPTO context. They also do not take into account the possibility of having both SIPTO and nonSIPTO traffic on a UE and how nonSIPTO traffic will be affected by their solution.

In as much as the authors of the papers discussed above state that their proposed solutions would enable optimal routing of SIPTO traffic during the scenarios under consideration, they neither show results of an evaluation (analytical or experimental) of their proposed schemes nor do they state any future plans to validate their algorithms. It would therefore be desirable to add to their contributions by carrying out investigations in an experimental setup.

IV. PROPOSED SOLUTION

Following the identification of nonoptimal routing scenarios for SIPTO traffic within the standardized EPS framework and the evaluation of related literature, our work aims to devise solutions that will facilitate optimal routing and consequently reduce network resource usage by SIPTO traffic during the described scenarios. We further aim to optimize routing in order to improve end to end delay for traffic subject to SIPTO offload under the identified scenarios and consequently improve quality of experience (QoE) for users particularly those running delay sensitive applications. A solution is therefore sought that will ensure that SIPTO traffic is maintained as locally as possible to the UE even when the UE has an already established nonSIPTO session or upon handoff of the UE from one eNB to another.

We propose a SIPTO optimized PDN connection and handoff procedure. The key requirements we considered in our approach to resolving the identified problems include the following:-

- There should be support for multiple APNs but no modifications at the UE.
- The enhanced mechanisms should put into consideration the need to support both SIPTO and nonSIPTO traffic simultaneously.
- Where possible, SIPTO traffic should not traverse the central core network entities.
- The architecture should be such that there is IP connectivity between the gateways assigned to neighboring cells to enable direct GTP based tunneling of SIPTO traffic between neighboring local gateways (i.e. between LPGW and LSGW).

A. *SIPTO optimized PDN connection procedure*

In our optimised PDN connection procedure, a SGW reselection function is incorporated to the stand alone PDN connection request. This requires an enhancement at the MME so that when it receives a PDN connection request it will first check if the PDN connection is for a SIPTO session or not and perform subsequent functions based on the context. A SGW reselection function will only be triggered if it is established that the request is for a SIPTO session.

When a user initiates a service that the operator has defined to be offloaded through a LPGW, a standalone PDN connection request as per standard procedures will be sent to the MME. When it is established that the request is for a SIPTO session, the MME will send create session requests to the target LSGW for relocation of already established sessions running on the UE and for allocation of resources for the new request at the gateways. After the required resources are allocated at the target LSGW and LPGW, downlink traffic for the UE can be forwarded from both the PGW for the old session and the LPGW for the new SIPTO session to the target LSGW. This is illustrated in Fig. 6. A GTP based EPS system is used to illustrate our solution.

Once the MME gets responses for the create session requests, it will send bearer setup requests to the eNB which will enable the allocation of resources for the SIPTO session at the eNB. The bearer setup requests will also communicate information about the allocated resources (at LSGW) for all the sessions to the eNB to enable transfer of uplink traffic.

The downlink traffic for the UE will be forwarded from the LSGW to the eNB once the LSGW gets information about the allocated resources at the eNB through the modify bearer request from the MME. The solution therefore enables a more optimal path for SIPTO traffic in a scenario

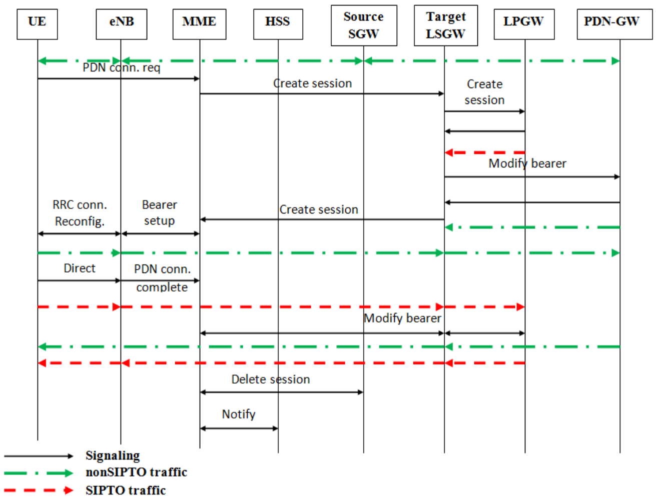

Figure 6. Enhanced PDN connection procedure with SGW relocation

in which the UE already has a PDN connection for nonSIPTO traffic and utilizing a core based SGW.

B. SIPTO optimized handover procedure

The enhanced handover procedure incorporates the ability to distinguish at the MME if a UE has SIPTO traffic during mobility events so that different criteria should be applied for SGW relocation depending on the SIPTO context. If we take for instance an X2 based handver with SGW relocation as shown below, the only enhancements will be done at the MME. When a UE establishes a SIPTO based PDN connection, the MME will store information about the UEs SIPTO context through a flag. The flag will simply indicate if a UE has SIPTO traffic or not.

During handoff of a UE from one eNB to another, the handover preparation and execution stages will take place according to standardized procedures [12]. When the target eNB sends a path switch request to the MME during the handover completion stage, the MME will first check if the TAI is on the tracking area list for the UEs current SGW. If the TAI is not on the tracking area list, the MME will then check the SIPTO context for the UE under consideration. If it is established that the UE currently has a SIPTO session active, the MME will perform a SGW relocation procedure with a SGW selection criteria based on geographical/ topological closeness to the UE and therefore select the SGW close to the UEs current location (i.e. LSGW collocated with LPGW assigned to the UEs current eNB) as illustrated in Fig. 7. If the SIPTO context indicates that the flag is off for this UE, the criteria will favor a SGW with less probability of SGW change and therefore select a central core based SGW.

In a situation where the TAI is on the current SGWs tracking area list, a LSGW relocation will not be triggered and traffic will therefore be maintained on the same LSGW and only new GTP tunnels will be established between the LSGW and the target eNB to which the UE is currently attached.

V. EVALUATION

To evaluate the performance of our proposed solutions, a preliminary (analytical) evaluation was carried out. The evaluation was focused on finding out if our proposed algorithms could lead to a more optimal use of network resources in a typical deployment scenario. Furthermore, the evaluation sought to establish if our proposed solutions could improve the end to end delay for SIPTO traffic in the scenarios under consideration.

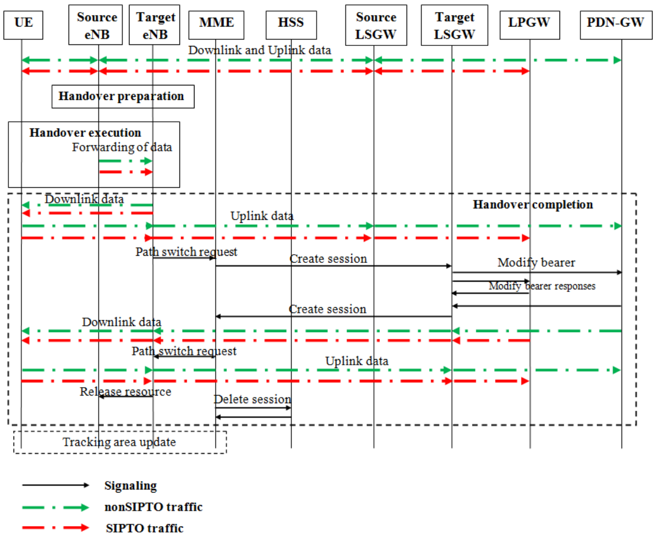

Figure 7. Enhanced X2 based handover with SGW relocation

The cost of network resources used by a service was compared between our proposed solution and the standard mechanism in the two scenarios under consideration. The metrics used included *bandwidth* allocated to a service and the *hop count* (data plane nodes) for the path taken by the bearers for the service. These metrics were used to estimate the *network cost* through a bandwidth – hop count product [13][14]. The network cost of a service represents the network resources consumed by the service.

Let $P = \{p_1, p_2, \ldots, p_k\}$ be the path followed by the EPS bearer allocated to a service (k). The hop count (HC_i) and bandwidth (BW_i) denote the number of hops and the average value of the bandwidth for the path (p_i) followed by the EPS bearer for the service, respectively. The cost of network resources used for various services can be defined as:-

$$\text{Network Cost } (NC) = \sum_{p_i \in P} HC_i \text{ x } BW_i \qquad (1)$$

If we assume that a service is a real time gaming application with a QoS class indicator (QCI) equal to 3, the bandwidth component in the equation can be replaced by the minimum amount of bandwidth that is reserved by the network for the guaranteed bit rate (GBR_{min}) bearer for that service. We further assume that the network consists of extra underlying data plane entities (additional routers) apart from the mobile specific ones (SGWs and PGWs) as shown in Fig. 8.

On the other hand, the delay experienced by a service in the operators' network includes the delays (D_{nodes}) at the data plane nodes and the delays (D_{links}) through the links between the data plane entities. This can be represented as:-

$$D_{total} = D_{nodes} + D_{links} \qquad (2)$$

This representation does not include the delays associated with processing at the UE end and through the air interface.

For scenario one

The *network cost* for a SIPTO real-time gaming (*rtg*) session is given by:-

$$NC_{rtg,\ standard\ procedure} = HC_{rtg} \text{ x } BW_{rtg}$$
$$= 6 \text{ x } GBR_{min} \qquad (3)$$

Note:- Hop count - hops from eNB to central core SGW then back to LPGW.

$$NC_{rtg,\ proposed\ procedure} = 2 \text{ x } GBR_{min} \qquad (4)$$

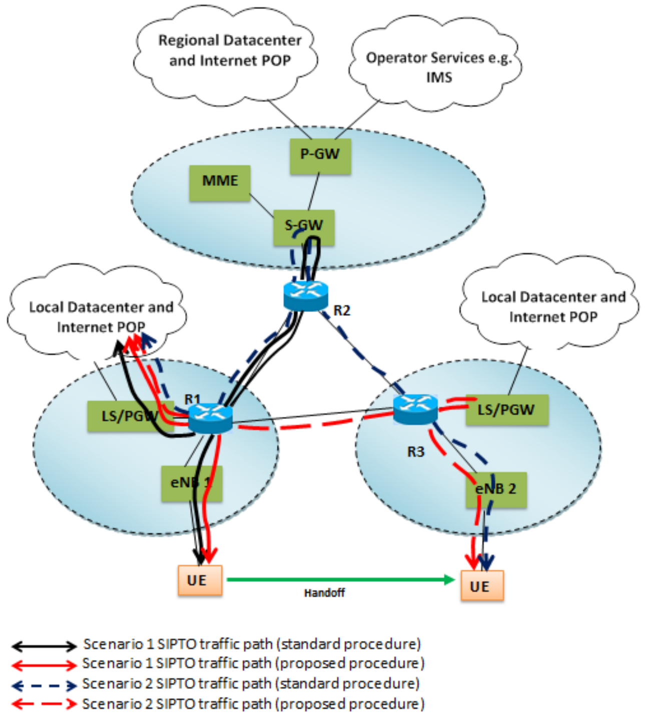

Figure 8. Evaluation architecture

Note:- Hop count - hops from eNB to LSGW collocated with LPGW.

The *delay* experienced by a SIPTO real-time gaming session is given by:-

$$D_{total,\ standard\ procedure} = D_{nodes(eNB,2xR1,2xR2,S,LP)} + D_{links(eNB\_R1,2xR1\_R2,2xR2\_S,R1\_LP)} \tag{5}$$

$$D_{total,\ proposed\ procedure} = D_{nodes(eNB,R1,LS,LP)} + D_{links(eNB\_R1,R1\_LS/P)} \tag{6}$$

For scenario two

The *network cost* for a SIPTO real time gaming session after handoff is given by:-

$$NC_{rtg,\ standard\ procedure} = 6 \text{ x } GBR_{min} \tag{7}$$

Note:- Hop count - hops from target eNB to central core SGW then to source LPGW.

$$NC_{rtg,\ proposed\ procedure} = 5 \text{ x } GBR_{min} \tag{8}$$

Note:- Hop count - hops from target eNB to target LSGW then to source LPGW.

The *delay* experienced by a SIPTO real-time gaming session is given by:-

$$D_{total,\ standard\ procedure} = D_{nodes(eNB,R1,2xR2,R3,LS/P)} + D_{links(eNB\_R3,R3\_R2,2xR2\_S,R2\_R1,R1\_LS/P)} \tag{9}$$

$$D_{total,\ proposed\ procedure} = D_{nodes(eNB,R1,2xR2,R3,LS/P)} + D_{links(eNB\_R1,R1\_LS/P)} \tag{10}$$

Note:- D_{nodes} *represents the queuing, processing and transmission delay experienced at the nodes given in (the brackets) and* D_{links} *represents the propagation delay experienced through the links between the entities given in (the brackets).*

Equations (4) and (8) show that our proposed solutions can enable significant resource preservation by reducing the network cost. Equations (6) and (10) also show that the delay is likely to be lower in our proposed solutions as both the nodes and the links to be traversed are less for both scenarios. This evaluation is however an estimation and there is therefore need for a more accurate evaluation in an experimental setup.

A proof of concept implementation is underway in the University of Cape Town (UCT) OpenEPC testbed. This is aimed at further evaluating our proposed mechanisms in a close to real world deployment environment. Tests will include comparison of the backhaul *link utilization* and central core serving *gateway utilization* for our scheme against the standard procedures. This will highlight the potential benefits to the network operator. Further tests to investigate the potential benefits to the end users will include measuring the *session setup delay* and *packet end to end delay*.

VI. CONCLUSION

This paper has reviewed the current state of art regarding SIPTO in the EPS framework. It has concluded that while SIPTO presents a good opportunity for operators to optimize their networks for IP traffic, more research is needed to enhance routing in certain scenarios. It has been determined that there is need for an enhanced PDN connection and handoff procedure that will ensure that SIPTO traffic is maintained as locally as possible to the UE at all times. Future work will involve an evaluation of the proposed schemes in a testbed setup to determine the suitability of the discussed solutions for real world deployment.

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