An Analysis of Impact of IPv6 on QoS in LTE Networks

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Abstract **- As a network evolution goal, IPv6 will be deployed in Long Term Evolution (LTE) networks, including access network, core network, mobile carrier IP network and service-related networks. IPv6 introduction in LTE will affect he Quality of Service (QoS) mechanism. In this paper, the impact of IPv6 on LTE's end-to-end QoS is analyzed in some related aspects and some actions are proposed to improve the QoS according to the analysis results. In addition, some IPv6 transition solutions might affect QoS mechanisms in LTE are analyzed to reduce the negative impacts while IPv6 introduction.**

Keywords-LTE; QoS; TFT; PCC; flow label

I. Introduction

With the LTE evolution and the rapid development of mobile Internet and multimedia services, QoS, especially Internet Protocol (IP) QoS is becoming more and more important in mobile networks. IPv6 introduction in LTE network can impact on QoS of mobile services.

There are negative and positive impacts of IPv6. Negative impacts include more overhead, tunneling and translation caused by transition solutions, etc.. Positive impacts include the potential application of the IPv6 Flow Label field [1], no NAT required for forwarding IPv6 traffic, etc..

LTE defines a class-based QoS concept, which reduces the implementing complexity while still allowing enough differentiation of traffic handling by mobile operators. Carrier bearers can be classified into two categories based on the QoS they provide: Minimum Guaranteed Bit Rate (GBR) bearers and Non-GBR bearers. Fig. 1 shows the QoS architecture in LTE [2].

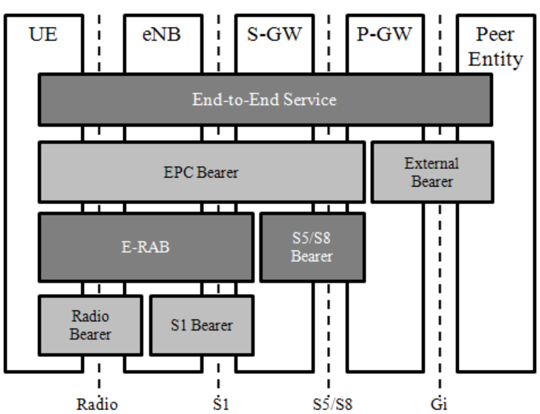

Figure 1. QoS architecture in LTE

The LTE's end-to-end QoS service consists of the external bearer service and the Evolved Packet System (EPS) bearer service. The former is used to carry out services between the LTE core network and external network nodes; and the latter is further subdivided into the EPS Radio Bearer service and the S1 Bearer service (EPS Access Bearer service) and the S5/S8 Bearer Service (Core Network Bearer Service).

The Radio Bearer service is used to transport the EPS bearer service data units between the eNodeB and the User Equipment (UE) according to the requested QoS. Moreover, it supports IP header compression and user plane encryption functions, and provides mapping and multiplexing information for UEs.

The S1 Bearer service implements the transport of EPS bearer service data units between the Serving GateWay (S-GW) and the eNodeB according to the requested QoS, and provides QoS guarantees for end-to-end IP traffic flows, while multiplexing multiple Service Data Flows (SDFs) onto the same EPS bearer.

The S5/S8 Bearer service controls and utilizes the backbone network in order to provide the transport of EPS bearer service date units among EPS Core network nodes.

Similar to the QoS mechanism adopted in Universal Mobile Telecommunications System (UMTS), Traffic Flow Template (TFT) [3] mechanism is used to provide QoS guarantee in LTE. The TFTs contain packet filter information that allows the UE and Public Data Network Gateway (P-GW) to identify the packets belonging to a certain IP packet flow aggregate. Fig. 2[1] describes the TFT architecture in LTE. The UE and the P-GW or Serving Gateway (S-GW) use packet filters to map IP traffic onto the different bearers. The TFTs are typically created when a new EPS bearer is established, and they can be modified during the lifetime of the EPS bearer.

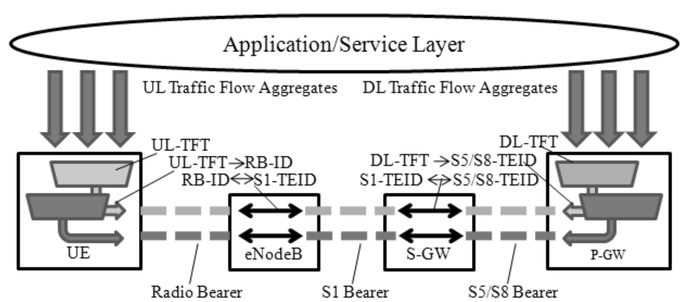

Figure 2. TFT reference network architecture

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Policy and charging control (PCC) [4] is another QoS related mechanism that provides operators with advanced tools for service-aware QoS and charging control. Different services have very different requirements of QoS, which are needed for the packet transport. PCC enables a centralized control to ensure that the service sessions are provided with the appropriate transport, for example, in terms of bandwidth and QoS treatment. The PCC architecture enables control of the media plane for both the IP Multimedia Subsystem (IMS) and non-IMS services. Furthermore, PCC also provides the means to control charging on a per-service basis. The reference network architecture for PCC in EPS is shown in Fig. 3.

In the LTE IP carrier network, Differentiated Services (Diffserv) mechanisms or the Resource Reservation Protocol (RSVP) protocol still can be used for QoS policy enforcement and resource reservation purposes now. Multiple Protocol Label Switching Virtual Private Network/Traffic Engineering (MPLS VPN/TE) also can be used to provide QoS in IP carrier network.

From the above introduction, we can conclude that the current QoS mechanism used in LTE network is based on bearers (in access and core mobile networks) and Diffserv or RSVP techniques (in IP carrier network). With the deployment of LTE and the explosion of IP-based services, such as Voice over IP (VoIP), Video on demand (VoD), etc., QoS becomes very important. After IPv6 introduction in LTE, some new scenarios are proposed and the QoS mechanisms will face new challenges. It’s necessary to analyze the impact of IPv6 on QoS in LTE networks and take some actions.

This paper is organized as follows. In Section 2, we introduce end-to-end QoS Model in LTE networks. In Section 3, impacts and actions of IPv6 on end-to-end QoS Model are provided. In Section 4, impact of IPv6 transition solutions on QoS mechanisms are analyzed. Finally, Section 5 summarizes the conclusions.

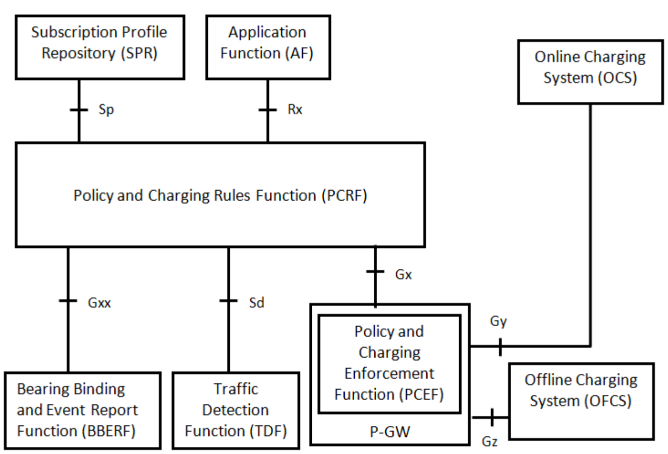

Figure 3. PCC reference network architecture

II. END-TO-END QOS MODEL

The critical factors determining QoS in mobile networks are:

- Radio network performance
- Network capacity
- Network design--delay in the system and sufficient capacity available end to end
- Application and service characteristics

The end-user performance is affected by every protocol layer and network element in the connection path, from one UE to other UE or server in the remote end of the network. As shown in Fig. 4 (only the user plane is considered), it is useful to analyze and estimate the end-user experience following a bottom-up approach, starting from the lower levels of the layer architecture and considering a cumulative degradation of the performance based on the effects of the different layers and their interactions. The ideal throughput provided by layer one (physical layer) is considered initially as the starting point, and then the performance degradation introduced by each of the upper layers in the protocol stack is estimated.

Compared with IPv4, IPv6 has some differences that may affect the QoS, such as:

- Packet header--the nominal IPv6 header is twice the size of the IPv4 header.
- Additional system messages, such as Neighbor Advertisement, Neighbor Solicitation, Router Solicitation, Router Advertisement, and Redirect.
- Network Address Translator (NAT)--Due to lack of public IPv4 addresses, NATs are deployed in some IPv4 core network; IPv6 eliminates the primary need for NATs, but translation or tunnel will be needed in a hybrid IPv4/IPv6 network without full dual-stack deployment.

Next section will discuss the impact of IPv6 on in the end-to-end QoS model showed in Fig. 4.

III. IMPACT ON END-TO-END QOS MODEL

In this section, we analyzed the impact of IPv6 on end-to-end QoS following the path from an UE to another UE or a server according to the models showed in Fig. 1 and Fig. 4.

A. UE Local Bearer Service

UE local bearer service is determined by the signaling and data processes embedded in the UE. So the processing capacity of the UE will affect the QoS.

In IPv6, there are some additional system messages and data processing compared to IPv4. For example, the interface identifier (IID) part of the IPv6 address assigned to the cellular interface of the UE may be changed periodically and randomly[5] hence making it more difficult to identify the terminal, please see next section “PDCP Layer” for details. Changing the IID of an IPv6 address randomly requires more processing capacity and resources in the UE.

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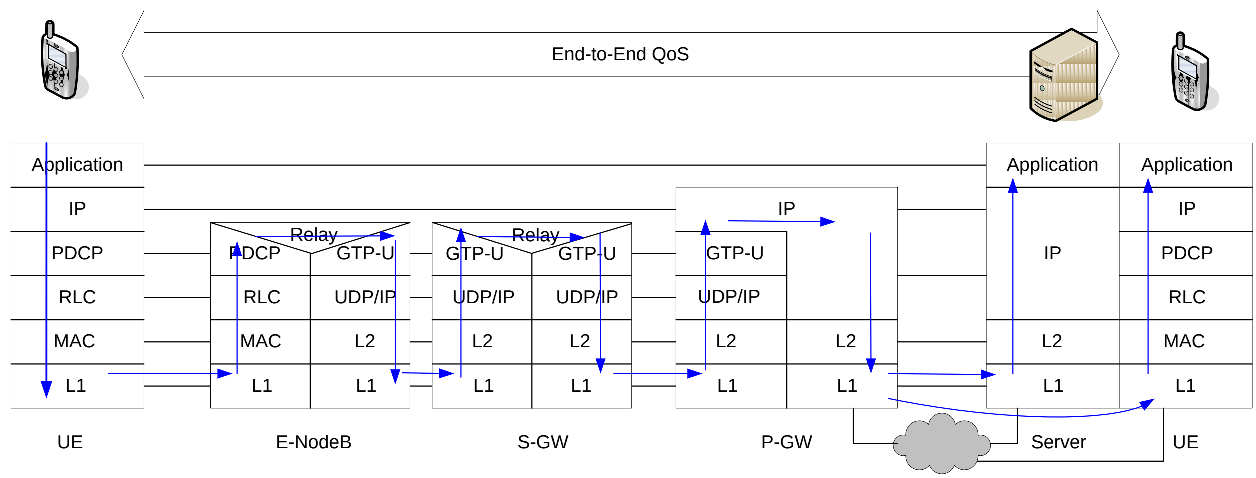

Figure 4. Layers affecting end-to-end QoS

During the transition period, the Packet Data Protocol (PDP) bearer will be dual-stack (one IPv4v6 bearer or two individual IPv4 and IPv6 bearers) or IPv6-only. If the UE sets up dual-stack bearers, more resources are required than for a single-stack bearer.

B. *Radio Bearer Service*

In the radio bearer service, the LTE Layer 2 user-plane protocol stack is composed of three layers as shown in Fig. 4, Packet Data Convergence Protocol (PDCP) layer, Radio Link Control (RLC) layer and Medium Access Control (MAC) layer.

In these layers, an important design feature is that all the Protocol Data Units (PDUs) and Service Data Unit (SDUs) are byte-aligned which means that the lengths of the PDUs and SDUs are multiples of 8 bits. This is to facilitate handling by microprocessors, which are normally defined to handle packets in units of bytes. This implies that sometimes unused padding bits are needed, and thus the cost of design for efficient processing is that a small amount of potentially-available capacity is wasted.

The size of an IPv6 packet nominal header is twice the size of an IPv4 packet header. So the padding is likely to be different and then the potentially-available capacity is different too. There may be negative and positive impacts on the QoS of the radio bearer service when IPv6 is deployed.

1) *PDCP Layer*

One of the main functions of PDCP is header compression using the RObust Header Compression (ROHC) [6] protocol defined by the IETF. In LTE, header compression is very important because there is no support for the transport of voice services via the Circuit-Switched (CS) domain. The different packet header between IPv4 and IPv6 will impact the overhead of packets, especially for small packet services, such as VoIP.

The main principle of header compression is to avoid sending fields which do not change between consecutive packets. ROHC is able to reduce a Real Time Protocol (RTP)/ User Datagram Protocol (UDP)/IPv6 header from 60 bytes to 3 or 4 bytes. This means that the 12.2 kbps AMR speech bit rate would be increased to 14.6 kbps with IPv6.

During the IPv6 address allocation process, The P-GW allocates a globally unique /64 IPv6 prefix via Router Advertisement to a given UE [5]. After the UE has received the Router Advertisement message, it constructs a full IPv6 address via IPv6 Stateless Address autoconfiguration. To ensure that the link-local address generated by the UE does not collide with the link-local address of the PDN GW, the PDN GW shall provide an IID to the UE and the UE shall use this to configure its link-local address. For stateless address autoconfiguration however, the UE can choose any interface identifier to generate IPv6 addresses, other than link-local, without involving the network.

If the same IID is used in multiple contexts, it becomes possible for that the identifier to be used to correlate seemingly unrelated activity. For example, a network sniffer placed strategically on a link across which all traffic to/from a particular host crosses could keep track of which destinations a node communicated with and at what times.

Due to privacy consideration, the UE may change its IID which is part of IPv6 address periodically and randomly. That means the IPv6 address of UE will be changed periodically and should be sent to network when ROHC applied. Then the relative overhead in ROHC will be higher when the IID changed. So for VoIP or Machine to Machine (M2M) services with small Maximum Transmission Units (MTUs) and belonging to closed services whose security can be guaranteed, a non-changing IID is suggested to be used for the sake of lower overhead.

2) *RLC Layer*

The main functions of the RLC layer are segmentation and reassembly of upper layer packets in order to adapt them to the size which can actually be transmitted over the radio interface. For radio bearers which need error-free transmission, the RLC layer also performs retransmission to recover from packet losses.

The functions of the RLC layer are performed by "RLC entities". An RLC entity is configured in one of three data transmission modes: Transparent Mode (TM), Unacknowledged Mode (UM) and Acknowledged Mode (AM).

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In AM, special functions are defined to support retransmission. When UM or AM is used, the choice between the two modes is made by the eNodeB during the RRC radio bearer setup procedure, based on the QoS requirements of the EPS bearer.

Compared with IPv4, IPv6 have some Internet Control Message Protocol version 6 (ICMPv6) messages, such as Neighbor Discovery, Auto-configuration, Multicast Listener Discovery, and Path MTU Discovery. These messages should be transmitted on a separate Radio Access Bearer using AM RLC mode for error-free transmission.

3) MAC Layer

This layer performs multiplexing of data from different radio bearers. Therefore there is only one MAC entity per UE. By deciding the amount of data that can be transmitted from each radio bearer and instructing the RLC layer as to the size of packets to provide, the MAC layer aims to achieve the negotiated QoS for each radio bearer.

In MAC layer, there are no difference between transmitting IPv4 packets and IPv6 packets.

C. S1 Bearer Service

According to LTE layer architecture defined by 3rd Generation Partnership Project (3GPP), the Radio Access Network (RAN) access bearer service between the RAN and the core network in user plane is transmitted by IP protocols. The LTE radio network is connected to the Evolved Packet Core (EPC) through the S1 interface. The S1 interface is divided into two parts:

- S1-MME carries signaling messages between the base station and the Mobility Management Entity (MME).
- S1-U carries user data between the base station and the S-GW.

There are two IP headers separated by GTP Tunnel Header and which correspond to the transport layer and the end-user IP packet respectively. If the transport layer is still IPv4 and the EPS bearer is IPv6, the overhead of IP header in S1-U is 1.5 times the overhead of the IPv4 header. If the transport layer and EPS bearer are both IPv6, the overhead of the IPv6 header in S1-U is twice the overhead of the IPv4 header. The available bandwidth at the S1-U interface will consequently be affected when IPv6 is introduced in the RAN access bearer.

Due to the greater size of the IPv6 packet header, the bandwidth between the RAN and the Core network (S1-U interface) should be dimensioned accordingly so as to limit the risk of congestion occurrences.

D. Core Network

For the General Packet Radio Service (GPRS) architecture, until Release 9, two PDP types are defined, namely IPv4 and IPv6. This means that an UE can only request one type of IP address per PDP context. With the introduction of the EPC system in Release 8, a new PDP type has been introduced called IPv4v6, and which enables the UEs to use a single Dual-stack bearer. This PDP type is available starting from Rel-9 for GPRS.

During the transition period, if the UE is dual-stack enabled, two individual IPv4 and IPv6 bearers (case where the UE doesn't support the IPv4v6 PDP type) or one IPv4v6 bearer may be set up in the S-GW and P-GW. For the S-GW and P-GW, the maximum number of simultaneous bearers that can be supported at any given time is a performance criterion. If some UEs set up two individual IPv4 and IPv6 bearers, the capacity of the S-GW and P-GW will be affected.

E. Backbone Bearer Service

The architecture of EPS bearer transport for GTP Tunnels in the backbone bearer is similar to that of S1 bearer. Obviously the problems are the same as in the S1 bearer when IPv6 is introduced.

Due to the greater size of the IPv6 packet header, the bandwidth of the core network should be dimensioned accordingly so as to limit the risk of congestion occurrences.

F. External Bearer Service

The external bearer service is related with external networks. There maybe several ways to transmit IPv6 traffic in external networks:

- If the external network is IPv6-capable or dual stack, no impacts.
- If the external network remains IPv4 and is MPLS-capable, the ideal solution is 6PE (IPv6 over MPLS)/6VPE (IPv6 over MPLS VPN). The 6PE approach allows existing IP/MPLS networks to carry the IPv6 packets using MPLS labels; hence only the PE devices need to support the IPv6 protocol and addressing. In 6PE/6VPE, the QoS of IPv6 traffic is guaranteed by MPLS.
- The IPv6 traffic can be transmitted in tunnels, if the external network is IPv4-only. Tunneling allows for the transport of the encapsulated data unit across the encapsulating protocol’s transport network. Typically, when employed as part of an IPv6 transition mechanism, the existing IPv4 transport infrastructure is used to encapsulate IPv6 packets, thereby using the existing IPv4 infrastructure to provide basic IPv6 connectivity.

The overhead of the encapsulation scheme should be considered to dimension the bandwidth used by external bearers. And the time to establish and activate the tunnels will influence the delay related to the forwarding of IPv6 traffic.

If the opposite end-points is of a different IP version or addresses need to be translated due to the deployment of a transition solution, a translation node is needed somewhere in the forwarding path. Address translation (usually with Application-Level Gateway (ALG)) is harmful to QoS, but is necessary for some transition solutions.

G. Impacts and Actions

Through the above analysis about impact of IPv6 integration on QoS, some parts in mobile network can be affected after IPv6 deployed. Fig. 5 shows the impacts on QoS for different parts of mobile networks.

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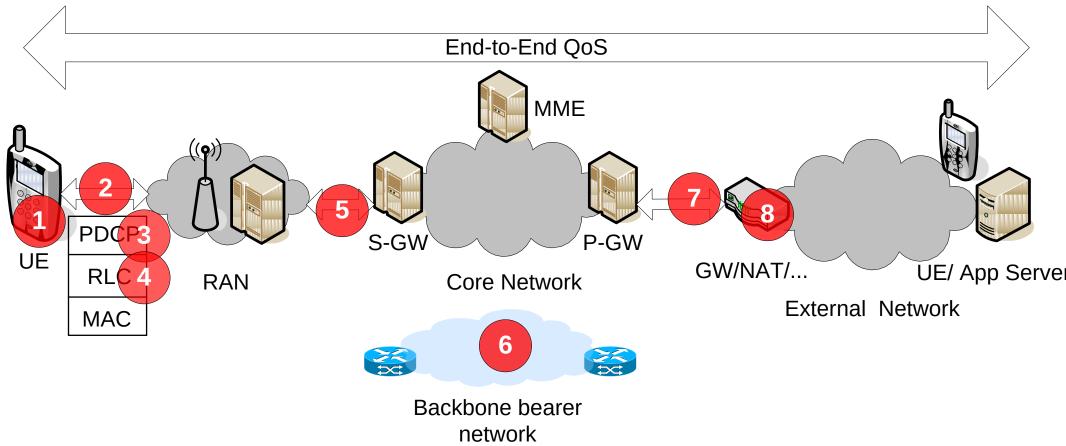

Figure 5. Localization of the impacts of IPv6 integration on QoS in LTE

Impact #1: Compared with IPv4, IPv6 and dual-stack need more processing capacity and resources in the UE.

Impact #2: When IPv6 applied to PDUs and SDUs of L2 layers, the different unused padding bits will affect the potentially-available capacity and the QoS of radio bearer services when IPv6 is deployed.

Impact #3: The overhead in ROHC will be higher when the UE's IID changes. So for VoIP or M2M services with small MTUs and belonging to closed services whose security can be guaranteed, a non-changing IID is suggested to be used for the sake of lower overhead.

Impact #4: Some ICMPv6 messages should be transmitted on a separate RAB using AM RLC mode for error-free transmission.

Impact #5: Due to longer length of packet header and additional system messages, the bandwidth between the RAN and the Core should be augmented to avoid congestion when IPv6 is introduced.

Impact #6: Due to longer length of packet header and additional system messages, the bandwidth of the core network should be augmented to avoid congestion when IPv6 is introduced.

Impact #7: The overhead of tunnels should be considered in the bandwidth of external bearers. The processing time of start and end points of tunnels will also influence the delay of IPv6 traffic.

Impact #8: Address translation (usually with ALG) is harmful to QoS, but is a necessity in some transition solutions.

The following table shows the QoS characteristics effected by above 8 impacts.

TABLE I. QoS CHARACTERISTICS AFFECTED BY IMPACTS FROM IPV6 INTRODUCTION

Impacts	1	2	3	4	5	6	7	8
Throughput/Bandwidth	√	√	√		√	√	√	
Packet Loss Rate				√				
Delay(Latency)	√	√	√				√	√

By analyzing the impacts listed above, four actions are proposed for better QoS:

Action #1: Improve the capacity and processing power of devices. Apply to Impacts #1;

Action #2: Optimize related parameters and increase resource utilization rate. Apply to Impacts #2;

Action #3: Increase bandwidth of networks. Apply to Impacts #2, #5, #6, and #7;

Action #4: Minimize the number of translating or tunneling on end-to-end path. Apply to Impacts #7, #8.

IV. IMPACT OF TRANSITION SOLUTIONS AND FLOW LABEL

Several transition solutions have been proposed to solve IPv4 public address exhaustion and to introduce IPv6 in mobile networks. These solutions employ translation and tunneling techniques and introduce some functional elements to network, which impacts on the QoS mechanisms, such as TFT, PCC.

A. *Impact on TFT*

When IPv6 is introduced in mobile network, the direct impact on TFT mechanism is that the filter information may contain the IPv6 attributes: IPv6 Next Header, Traffic class and Flow Label. That means that TFT should support IPv6 filter attribute combinations. For example, the new filter combination: Remote address and subnet mask, IPv6 traffic class and flow label. Compared with the other two combinations, this one gives us a fine-grained filter to tell different QoS flows by using IPv6 Flow Label instead of port range or IPSec Security Parameter Index (SPI) attributes.

Because the TFT mechanism works between UE and P-GW, the TFT mechanism will be impacted when a translation or a tunnel function is required in the UE for a transition solution. For tunnel-based solutions, the TFT filter attributes will be taken from the tunnel IP header instead of the internal IP header. So there should have some mechanisms to map the internal filter attributes to external filter attributes of tunnel, e.g., by copying the IPv6 Flow Label. For translation-based solutions, the filter attributes for the original IP packet should be translated to the new IP packet to ensure integrity of filters.

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Transition solutions can be cataloged two classes:

- Impact on TFT: Bump-in-the-Host (BIH) [7] (translation in UE), Address Plus Port (A+P) [8] and Dual-Stack Lite (DS-Lite) [9] (tunnel between UE and Carrier Grade NAT (CGN), except for GTP encapsulation)
- No impact: Gateway-Initiated Dual-Stack Lite (GI-DS-Lite) [10], NAT64/DNS64 [11][12], Per-Interface NAT [13], Overlapping clusters, v4 on demand

B. Impact on PCC

The PCC rules should support IPv6 IP Connectivity Access Network (CAN) sessions and service data flow filters. When the PCC architecture is used and a Policy and Charging Rules Function (PCRF) function is added, this function and the corresponding Gx interface must also support IPv6-enabled PCC rules. The Rx interface and the Application function should take into account IPv6 flows and addresses.

There are two aspects PCC mechanisms impacted by transition solutions:

Some transition solutions, such as GI-DS-Lite, overlapping clusters, Per-Interface NAT and NAT64, etc., introduce a translation function (NAT/CGN) between the P-GW and the service platforms if UEs access IPv4 services. In this case, an impact on Rx interface between the PCRF and the Application Function (AF) in the PCC architecture will need to be addressed, because the UE's address information exchanged on Rx interface stays the payload of packets. So the NAT/CGN should include an ALG which understand the protocol on the Rx Interface.

Another problem is that multiple customers share the same public IPv4 address (for most of transition solutions) or even the same private IPv4 address (for DS-Lite, GI-DS-Lite and Per-Interface NAT). In the PCC mechanism, the PCC rules including QoS parameters will be bound with IP CAN sessions. Shared IPv4 address blocks the binding process between an AF session and an IP Can session. Other identifications, such as IPv6 tunnel address or tunnel ID, are required to help to find the right bearer.

C. Impact of Flow Label

IPv6 has introduced a field named Flow Label to identify and mark a flow. General rules for the Flow Label field have been documented in [14], but how to apply this field in real-world network is still an open issue.

Under the current LTE architecture, the traffic is encapsulated in GTP tunnel and transported based upon the EPC bearer. The IPv6 Flow Label can be used to replace bearer identification to improve the current QoS mechanisms in mobile networks. In current mobile networks, the QoS granularity is based upon the bearer characteristics as defined by the PCC and TFT QoS mechanisms. The fine granularity of QoS can be implemented with the help of Flow Label [1].

In addition, the IPv6 Flow Label can be used for QoS provision in the IP backbone network carrying mobile networks. At present, the IP network can use Diffserv mechanisms or the RSVP protocol for QoS policy enforcement and resource reservation purposes. Such QoS policy and RSVP design is usually engineered in advance (e.g. configuring the actions to be performed by a router that supports the Expedited Forwarding Per-Hop Behavior). If the IP backbone network is IPv6-capable, it can perceive the bearers in mobile networks by a mapping mechanism between the bearer identification and the IPv6 Flow Label, and then provide QoS guarantee by combining Flow Label with other technology such as Diffserv. This QoS policy can be adjusted by changing the mapping between the bearer ID and the IPv6 Flow Label according to the mobile services type and traffic. When congestion is occurring, it is possible to drop the packets in same bearers for minimizing the affected bearers with the help of Flow Label.

V. CONCLUSION AND FUTURE WORK

In this paper, we provided an in-depth analysis of the end-to-end QoS impacts by IPv6 introduction in LTE networks and provide recommendations about the QoS impacts and improvement by the IPv6 introduction in mobile networks. Negative impacts should be reduced for the sake of QoS improvement by adopting appropriate actions as mentioned in section III. Positive impacts should be taken into account to improve QoS. In the future work, we consider researching on impacts of Mobile IPv6 in mobile networks.

REFERENCES

[1] T. Zheng, L. Wang, and D. Gu, A flow label based QoS scheme for end-to-end mobile services, Proc. The Eighth International Conference on Networking and Services (ICNS 2012), March 2012, pp. 169-174.

[2] D. Flore, LTE RAN architecture aspects, 3GPP IMT-Advanced Evaluation, December 2009.

[3] 3GPP TS 23.401, General Packet Radio Service (GPRS) enhancements for Evolved Universal Terrestrial Radio Access Network (E-UTRAN) access, September 2012.

[4] 3GPP TS 23.203, Policy and charging control architecture, September 2012.

[5] T. Narten, R. Draves, and S. Krishnan, Privacy Extensions for Stateless Address Autoconfiguration in IPv6, IETF RFC 4941, September 2007.

[6] K. Sandlund and G. Pelletier The RObust Header Compression (ROHC) framework, IETF RFC 5795, March 2010.

[7] B. Huang, H. Deng, and T. Savolainen, Dual-Stack hosts using "Bump-in-the-Host" (BIH), IETF RFC 6535, February 2012.

[8] R. Bush, The Address plus Port (A+P) approach to the IPv4 address shortage, IETF RFC 6346, August 2011.

[9] A. Durand, R. Droms, J. Woodyatt, and Y. Lee, Dual-Stack Lite broadband deployments following IPv4 exhaustion, IETF RFC 6333, August 2011.

[10] F. Brockners, S. Gundavelli, S. Speicher, and D. Ward, Gateway-Initiated Dual-Stack Lite deployment, IETF RFC 6674, July 2012.

[11] X. Li, C. Bao, and F. Baker, IP/ICMP translation algorithm, IETF RFC 6145, April 2011.

[12] M. Bagnulo, A. Sullivan, P. Matthews, and I. van Beijnum, DNS64: DNS extensions for network address translation from IPv6 clients to IPv4 servers, IETF RFC 6147, April 2011.

[13] J. Arkko, L. Eggert, and M. Townsley, Scalable operation of address translators with Per-Interface bindings, IETF RFC 6619, June 2012.

[14] J. Rajahalme, A. Conta, B. Carpenter, and S. Deering, IPv6 flow label specification, IETF RFC 3697, March 2004.