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A Local IP Access Mechanism for VoIP Service in LTE Home eNodeB Systems

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***Abstract*— The need for multimedia communication through wireless media brings development of 4G cellular wireless networks. Long Term Evolution (LTE) is one of 4G standards and specified in 3GPP. In an LTE system, home base station (HeNB) is designed for indoor usage. Since packets are always routed back to the core network before to destination, if two user equipments (UEs) stay in the same HeNB, the routing path is detour and results in longer packet delivery delay, jitters and thus lower data throughput. As a result, the idea of local IP Access (LIPA) was drawn and two solutions have been proposed. However, the two solutions would suffer from poor voice quality in a VoIP application. We propose a novel solution which establishes an additional data radio bearer (DRB) between UE and HeNB to detect local packets. Once local packets are detected, the data radio bearer is then responsible for local packet delivery. Simulation results show that our method outperforms the other two solutions in terms of packet delivery delay and mean opinion score (MOS).**

Keywords-component; LTE; UE; HeNB; LIPA; Data Raio Bearer

I. INTRODUCTION

The development of mobile communication networks has been steered to a high speed wireless system for multimedia communications. Many standardization bodies are working on the related issues, such as Third Generation Partnership Project Long Term Evolution (3GPP-LTE) [1], Wireless World Initiative New Radio (WINNER) [2] and Worldwide Interoperability for Microwave Access (WiMAX) [3]. These standardization bodies all focus on achieving higher peak data rate, lower packet delivery latency, larger system capacity, and flexible bandwidth allocation operations.

To enhance capacity and coverage of a mobile communication system in home and office environments [5], Home eNodeB (HeNB) has been defined in 3GPP. HeNB or 'home base station' is a low-power access point with an output power level, typically less than 50mW [4] and thus of a coverage up to 30 - 50 meters for indoor usage. Due to its high capacity, an HeNB is able to provide users both voice and broadband services, such as real-time multimedia streaming. Usually, a single HeNB supports at most four to eight simultaneous voice connections in an indoor environment, thus guaranteeing the quality of broadband services.

However, voice service may be held between two user equipments (UEs) both staying in the network. Since all packets are first routed back to P-GW (Packet data network gateway) before to destination, packets of such voice services flow along with a detour route. It implies broadband services whose packets are destined for the Internet through the P-GW impact the quality of the voice services. As a result, Local IP Access (LIPA) [6] is a solution to the detour route. As shown in Figure 1, LIPA offloads the traffic of a local voice service without passing through the P-GW. Specifically, LIPA allows an IP-enabled device to access the local area network under a HeNB and simultaneously the broader Internet through the HeNB. This can improve the quality of both broadband services and voice services. Enabling LIPA in a network benefits the mobile operator, subscribers and Internet Service Providers (ISPs). Mobile operators supporting LIPA via HeNBs will foresee higher revenues since they need not to upgrade network infrastructure for a higher core network (i.e., Evolved Packet Core, EPC in Figure 1) speed that such services would demand. In addition, subscribers perceive quality voice service since routing packets locally promises a faster and more efficient data transmission.

Currently, there are two LIPA solutions having been proposed in the literature [6][7][8]. One of them use a well-defined access point name (APN) to establish a dedicated routing path for LIPA. This method is workable when either the UE supports multiple APN configurations or the HeNB serves the VoIP flow of the UE only which supports single APN configuration. The other implements LIPA by way of deep packet inspection (DPI) techniques. This method may suffer from long packet process delay, thus resulting in poor voice quality. We thus propose a novel solution for LIPA support at the home base station level.

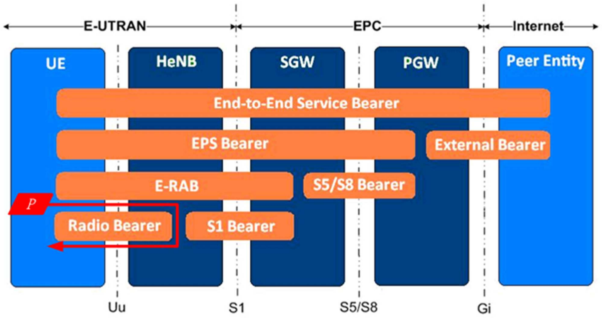

Figure 1. Example of Local Packet with Local IP Access

The remainder of this paper is organized as follows. Section 2 describes the two LIPA schemes, one using well-defined APNs and the other using Network Address Translation (NAT) with Deep Packet Inspection (DPI). With the discussion on their pros and cons, section 3 illustrates the

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proposed Local IP Access Mechanism. The simulation and results are described and discussed in Section 4. Finally, Section 5 concludes the paper.

II. RELATED WORK

A. *LIPA through well-defined APN*

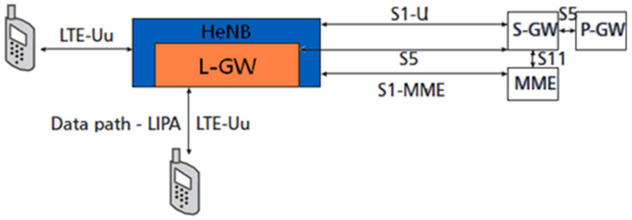

Figure 2. Example of Local IP Access through Well-defined APN

Figure 2 illustrates the first solution. The UE would be configured an additional APN which is well-defined for LIPA. Once the well-defined APN is identified, a collocated or standalone Local Gateway (L-GW) in a HeNB acts as a local DHCP server, allocating an IP address for local routing. Data packets sent by the UE using the IP address would be sent to the L-GW. L-GW is a new function and essentially it is a PDN-GW, thus implementing such as IP address allocation for the UE, tunneling, and packet filtering. It is logically located in the HeNB and connects to the private network devices and public network directly. It also connects to the S-GW (Serving Gateway) through S5 interface. The core network still handles the signaling for the registration and session management procedures to setup the LIPA PDN connection. When it setups, the L-GW takes over to implement the data path. The UE can continue to have data sessions with the core network using separate PDN connections while the LIPA connection is established.

For a specific LIPA APN, MME (Mobility Management Entity) selects an L-GW, which is topologically, geographically close to the UE's attachment point, to establish the PDN connection. It controls the LIPA in a PDN connection granularity. L-GW selection is similar to the PDN-GW selection function in the core network, which additionally takes LIPA subscriptions into consideration. The HeNB generally sends the IP address of the L-GW (derived from the IPSec tunnel established on the S1-MME interface) to the MME during the PDN connection establishment procedure. The MME checks with the HSS whether or not the particular L-GW can be selected for the UE. If it is, the L-GW address is passed on to the S-GW. The HeNB should provide the APN address if the LIPA permissions of the L-GW in the HSS say “LIPA only.” In case of “LIPA conditional”, LIPA is only supported on a certain APN. If there is no APN address provided by the HeNB, the MME is free to choose another PDN-GW for a non-LIPA PDN connection. With this solution, the UE should be able to support multi-APN configurations.

B. *LIPA through Deep Packet Inspection*

The second solution enhances the HeNB with network address translation (NAT) function and routing function. It uses DPI techniques to inspect data packets and forwards them directly from the HeNB. The forwarding destination depends on the pre-configured traffic offload policy and inspection results. With this solution, the UE would be configured with only one APN. It is not aware of the distinction between LIPA and P-GW and it would be aware of only one IP address. This address would be allocated by the core network in the Activate PDN Connection Accept message and this signal message would be read by the HeNB to derive the IP address allocated to the UE. The HeNB would then request a local subnet IP address from the local DHCP server and map this IP address to the core network allocated IP address. The HeNB then is able to route packets either to the normal PDN gateway or to the local router in the HeNB. The HeNB decides the route based upon the source and destination IP addresses of the packets. In addition, the HeNB should be able to sniff and decode NAS signal messages being exchanged between UEs and MMEs. Thus, no S-GW or P-GW like functionality is required. However, the HeNB needs to equip with sufficient DPI capability to inspect the IP headers of packets for correct routing decisions.

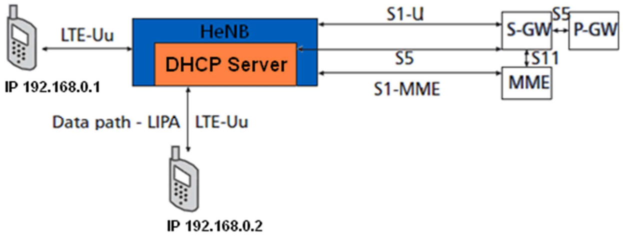

Figure 3. Example of NAT with DPI Local IP Access

As show in Figure 3, the core network (P-GW) allocates an IP address 10.10.0.1 to the UE and the local DHCP server allocates 192.168.0.1 to the UE. When the UE initiates a data packet with source IP = 10.10.0.1 and destination IP = 192.168.0.2 for a node within the local subnet (e.g., a local UE with IP address 192.168.0.2), the HeNB changes the source IP address of the packet to 192.168.0.1 before forwarding the packet. The packet is correctly routed over the local subnet. Similarly, for an IP packet originated from 192.168.0.2 and destined for 192.168.0.1, the HeNB changes the destination IP address to 10.10.0.1 before delivering it to the UE. As for packets destined for 202.202.6.10 or for downlink packets received from the core network, the HeNB does not modify the IP packets.

Although the two LIPA solutions above are workable, they may still impact the quality of voice service in some situations, especially with respect to mean opinion score (MOS) and packet delivery delay. The first solution support only multi-APN capable UEs. If a single-APN capable UE sets up more than one voice call, LIPA cannot correctly work. As for the second solution, high packet delay is expected in packet inspections. Therefore, we propose a solution described as follows.

III. LIPA THROUGH DETECTION RATIO-BEARER

We propose a LIPA solution in which an additional data radio-bearer (DRB) is established for local routing. We first introduce a new role, Home MME module, which plays an important role on setting up the DRB. We then detail how the proposed solution is designed.

A. Home MME Module

As shown in Figure 4, Home MME (H_{MME}) within the local area network of the HeNB provides following functions.

- Intercept/Modify NAS messages from MME and UE
- Generate NAS messages to UE
- Use S6a interface to get K_{ASME} from HSS
- Generate K_{NASenc} and K_{NASint} from K_{ASME}
- Manage Detection Radio-Bearer & Local Data Radio-Bearer
- Maintain DRB-ID (DRB identification) table and Group Mapping table

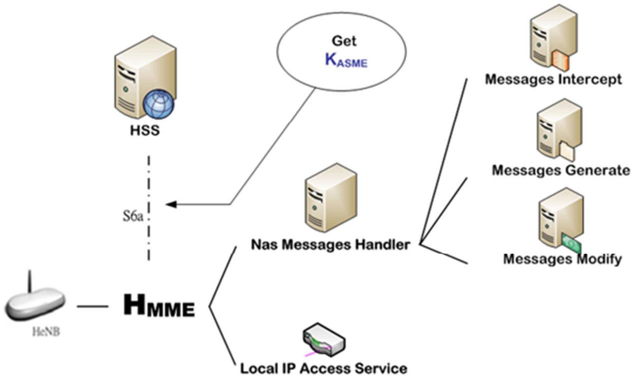

Figure 4. The architecture of H_{MME} module

H_{MME} is transparent to MME and HeNB which communicate with each other through S1 interface. H_{MME} sniffs (intercepts) NAS messages between a pair of MME and HeNB so as to collect information for later detection radio-bearer establishment.

B. Detection Radio-Bearer

Detection Radio-Bearer is a special dedicated data radio bearer which is used to detect local data packets. We utilize the existing QoS mechanism in the LTE network to enable the packet detection, described as follows.

To deliver packets with guaranteed QoS, data radio bearers can be established with different levels of QoS. Packets mapped to the same DRB receive the same bearer-level packet forwarding treatment. As a result, packets must be filtered into the appropriate radio bearers.

Packet filtering into DRBs is based on Traffic Filtering Templates (TFTs). The TFTs use IP header information such as source and destination IP addresses and Transmission Control Protocol (TCP) port numbers to filter packets so that each packet can be sent down to the respective bearers with appropriate QoS. An Uplink TFT (UL TFT) associated with each bearer in the UE filters IP packets to EPS bearers in the uplink direction. A Downlink TFT (DL TFT) in the P-GW is a similar set of downlink packet filters. Using the information of the TFT filters, we can obtain the bearer attribute without requiring any DPI operations and decide whether to route them locally or not. Therefore, we utilize a data radio-bearer for local packet detection. Once the detection radio-bearer detects local data packets, the detection radio-bearer is changed to Local Data Radio-Bearer for local data packet transmission.

C. LIPA Setup Procedure

Figure 5 describes the detailed LIPA setup procedure. When UE attaches to the core network, H_{MME} is sniffing NAS messages exchanged between UE and MME. Once H_{MME} sniffs NAS messages for the IMSI of the UE, the MME_ID and authentication and security related information during the Attach procedure, H_{MME} requests HSS for K_{ASME}. After that, H_{MME} initiates a dedicated data radio bearer by transmitting the *Dedicated Bearer Setup Request* [9] message to UE.

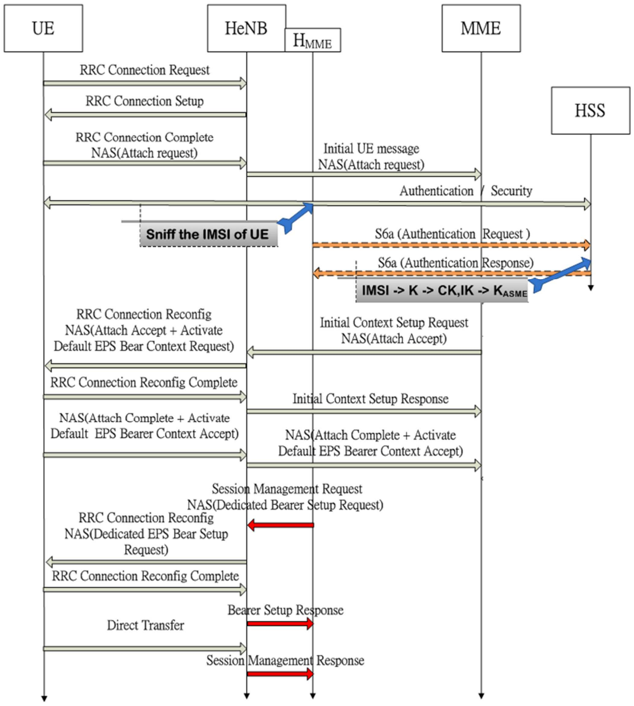

Figure 5. LIPA Setup Procedure

As shown in Figure 6, after the LIPA setup procedure, UE1 creates not only default bearer but also a dedicated data radio bearer. The uplink data radio-bearer of the UE is called Detection Radio-Bearer. The TFT of the bearer only allows packets of destination IP addresses of UEs which register to the same HeNB or D-class IP addresses for multicast routing. When a number of packets are received from the Detection Radio-Bearer, the H_{MME} inspects the first packet for the destination IP address and then adds one entry to the DRB-ID Directing table and the Group Mapping table.

H_{MME} modifies the dedicated IP address in the packet filter of the detection radio-bearer in order to transmit packets with source UE1 and destination UE2. After the modification, the data radio-bearer is then called a Local Data Radio-Bearer.

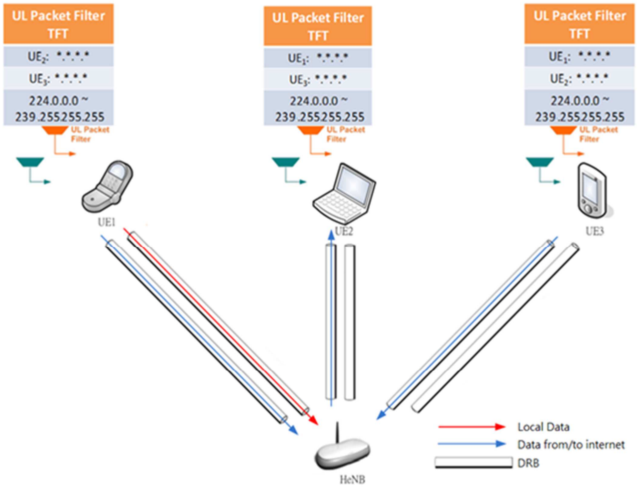

Figure 6. Detection Radio Bearer being Setup after UE1 Attach

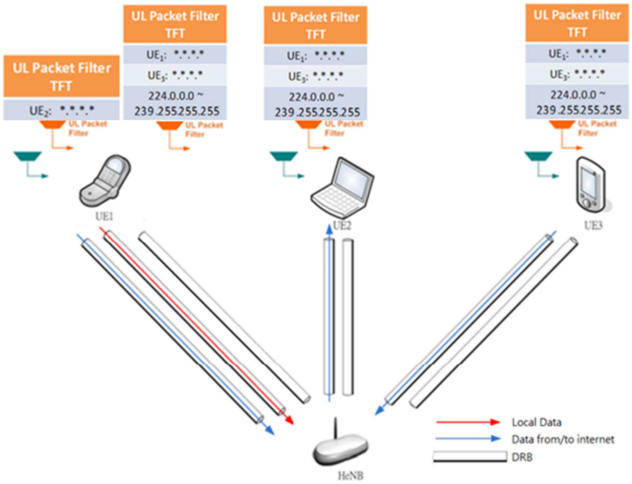

Figure 7. Local Data Radio-Bearer and New Detection Radio-Bearer in UE1

As shown in Figure 7, to accept further local IP access service, H_{MME} creates a new Detection Radio-Bearer to UE1 for detecting other local packets connection. After this step, H_{MME} can provide the dedicated services for the packet flow which is from UE1 to UE2. By leveraging TFTs, instead of deep packet inspection, to detect packets, providing Local IP Access service does not introduce a significant amount of loading to HeNB. In addition, less inspection processing time is expected, and thus less delay for local packet routing.

D. Local Packet Routing

To correctly route local packets, H_{MME} needs to configure two important tables: the DRB-ID Directing table and the Group Mapping table. To this end, two pieces of information are required: DRB_ID (Data Traffic Channel, DTCH) and C-RNTI (Cell Radio Network Temporary Identifier). DRB_ID is a 5-bit DTCH ID, DTCH is a point-to-point channel, dedicated to one UE for user information transfer. A DTCH exists in both uplink and downlink. The C-RNTI is an unique 16-bit UE identification identifying an RRC connection at cell level. UE obtains C-RNTI during the Random Access procedure [10].

TABLE 1. DRB-ID Directing Table and Group Mapping Table

DRB-ID Directing table

From		To
UE (C-RNTI)	DRB (DTCH)	Group
1(16bits)	***2(5bits)***	***B***
2(16bits)	2(5bits)	D

Group Mapping table

Group	Member [UE(C-RNTI) , DRB(DTCH)]
A	[1(16bits) , 1(5bits)]
B	***[2(16bits) , 1(5bits)]***
D	[1(16bits) , 1(5bits)] [3(16bits) , 1(5bits)]

Table 1 shows an example of DRB-ID Direction Table and Group Mapping Table. H_{MME} uses a pair of C-RNTI and DRB_ID in the DRB-ID Directing Table to identify a local IP access connection. The Group Mapping Table is used to identify destination UEs and corresponding data radio bearers for LIPA. Figure 8 shows a local packet routing instance. H_{MME} receives packets from UE1's detection radio bearer. By consulting the DRB-ID Directing Table, H_{MME} then finds the destination (UE2, DRB 1) for the local packets.

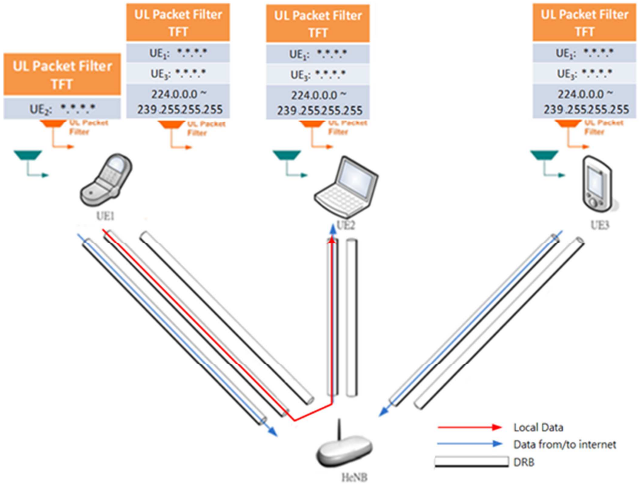

Figure 8. Local Packet Routing

When the session using LIPA ends, H_{MME} deletes the bridge entry in the DRB-ID Directing Table and the Local Data Radio-Bearer for this session by using normal *Dedicated Bearer Deactivate* messages [9]. All LIPA sessions of a UE neither affect PDN Connections of the same UE nor use any resources of the core network.

IV. SIMULATION

We use the Simulating LTE Cellular Systems to build our simulation environment [11]. In order to ensure modularity, polymorphism, flexibility, and high performance, *LTE-Sim* has been written in C++, using the object-oriented paradigm, as an event-driven simulator.

We built and ran a prototype system to analyze the LIPA performance of the proposed solution and the other two solutions discussed in the Related Work section. The traffic for LIPA was simulated as a *VoIP* application which generates G.729 voice flows. Another traffic being simulated is a flow of high-quality video Environment and simulation parameter settings are listed in Table 3.

TABLE 3. Environment simulation parameters

Parameter	Setting
System bandwidth	3 MHz
RB bandwidth	180 kHz
Number of RBs	15
Number of active UEs	1 ~ 4
Per VOIP Packet	8KB
Simulation time	100s
UE support capacity	Single/Multiple PDN
Local Data flow	1 VOIP ,0~4 Video
Number of Radio Bearer	1 ~ 5

The performance metrics used in our simulation are packet delay and the MOS value of VoIP. The meanings of MOS numbers are listed as follows.

1. Perfect. Like face-to-face conversation or radio reception.
2. Fair. Imperfections can be perceived, but sound still clear. This is (supposedly) the range for cell phones.
3. Annoying.
4. Very annoying. - Nearly impossible to communicate.
5. Impossible to communicate

MOS values need not to be integers. Some thresholds are often expressed in decimal values from the MOS spectrum for voice quality interpretation. For instance, a value in the interval from 4.0 to 4.5 is referred to as toll-quality and causes complete satisfaction. Values dropping below 3.5 are termed unacceptable by many users.

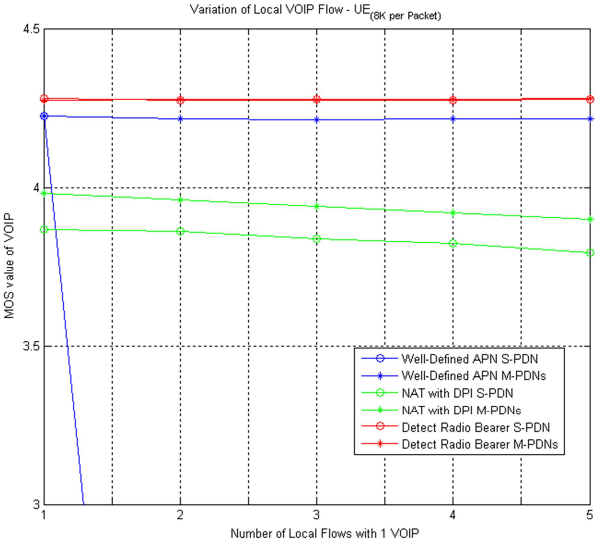

Figure 9. Number of Local Video Flows with one VoIP Flow against MOS

Figure 9 shows the MOS values of VoIP service. Here, one local VoIP flow is definitely established. We further introduced and varied the number of local video flows. Obviously, the proposed method has the highest MOS values among others, regardless of the number of local flows. Since the LIPA solution through well-defined APN does not support multiple-PDN UE in this simulation, it has the worst MOS value. The solution through DPI has a decreasing MOS curve as the number of local flow increases. This is because the additional video packet traffic prolongs the waiting time for DPI and thus introduces more delay to local packet routing.

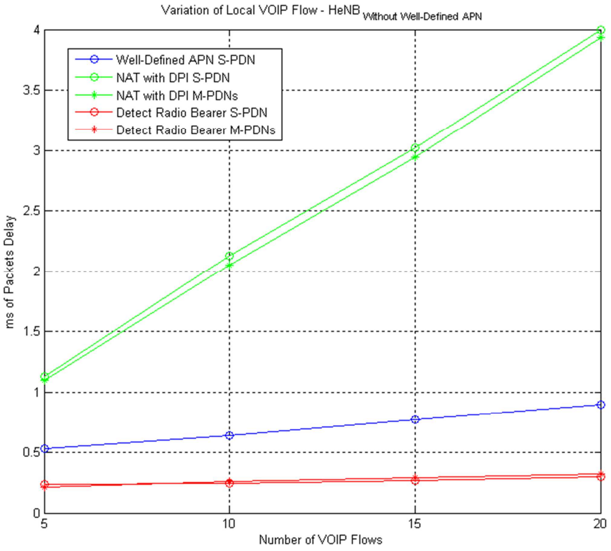

Figure 10. Local VoIP Flows – HeNB Delay.

Another simulation was conducted in which we varied the number of local VoIP flows. Figure 10 shows the average local VoIP packet delay. Since the well-defined APN solution does not support multi-PDN UEs, we does not compare with this case. The proposed method has the shortest delay since the loading in HeNB and the core network is low. As a result, the delay of the proposed method increases with the smallest amplitude when the number of local flows rises. In contrast, the DPI solution has a longer packet delivery delay due to its time-consuming inspection process.

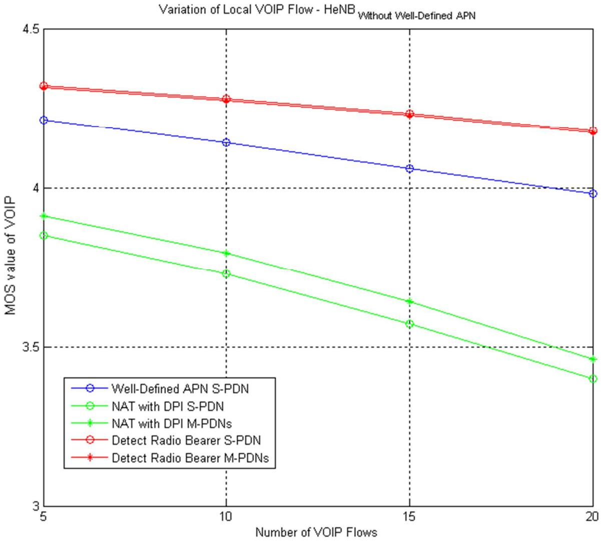

Figure 11. Local Video Flow with one VoIP Flow – MOS.

Figure 11 shows the MOS values in this simulation, which coincides with the curves of packet delivery delays. As the number of local VoIP flows increases, the MOS values decrease. However, the proposed method is of the lowest dropping rate, thus outperforming the other two solutions.

V. CONCLUSION AND FUTURE WORK

In this paper, we propose a LIPA solution which only sets up an additional normal data radio bearer and uses the existing packet filtering mechanism in the LTE network to realize LIPA. A new role, Home MME is introduced to conduct local packet routing. Compared to the existing works, the proposed method reduces the packet transmission delay and maintains the voice quality to a satisfactory level, even in the case that many LIPA connections take place simultaneously. In other words, the simulation results show that our approach has the shortest delay and the highest MOS value.

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