Link Layer Structure for LTE-WLAN aggregation in LTE-Advanced and 5G network

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***Abstract*—In LTE-Advanced (LTE-A), system enhancements have been studied in the 3GPP (3rd Generation Partnership Project) for standardizing integrated wireless communications using multiple radio access technologies (RATs) toward 5th generation (5G) mobile communications. One of study topics is LTE-WLAN (Wireless LAN) aggregation, aiming at enabling simultaneous usage of LTE radio access and WLAN radio access. An important technical challenge is the existing layer 2 structure. Specifically, the layer 2 structure for LTE-WLAN aggregation should be designed so that the Quality of Service (QoS) level of Evolved Packet System (EPS) bearers is kept even when each EPS bearer is sent over the WLAN radio. Requirements should include: (1) the layer 2 structure must be backward compatible to existing LTE-A specifications, and (2) the layer 2 structure must not have any impacts to existing WLAN specifications. In order to meet these requirements, in this paper, three layer 2 structures are proposed. The characteristics of proposed layer 2 structures are clarified, the pros and cons are discussed, and then one of proposed layer 2 structures is selected as a desirable structure to be standardized in 3GPP for LTE-WLAN aggregation.**

Keywords—LTE-A; 5G; LTE-WLAN aggregation; EPS bearer; QoS

I. INTRODUCTION

3rd Generation Partnership Project (3GPP) [1] standardizes cellular mobile communications systems referred to as LTE-Advanced (LTE-A) [2-4]. One of major discussion topics in LTE-A Release 13 is the system enhancements for integrated radio communications using multiple radio access technologies (RATs). The target is to enable simultaneous usage of LTE-A radio access and another radio access technology in order to improve the user experience and deal with explosive amount of data traffic as part of the motivation for the 5th generation (5G) mobile communications. In particular, the rapid spread of Wireless LAN (WLAN), for example, it is widely deployed and used in home, office, and smartphones, has motivated the standardization of radio level integration and aggregation of LTE-A and WLAN.

There are some relevant existing and standardized methods for increasing data throughput in current 3GPP specifications. In LTE Release-8, network level traffic offloading from LTE to WLAN was standardized [5–6]. Until LTE-A Release-12, the method was enhanced so that the traffic offloading is carried out by taking the channel utilization rate of WLAN and the user preference of the traffic offloading into account [7]. In LTE-A Release-12, Dual Connectivity (DC) was standardized. It allows Carrier Aggregation (CA) among base stations (eNBs: evolved NodeBs). In LTE-A Release-13, a study item called Licensed Assisted Access (LAA) has been newly established, targeting CA between licensed carriers and unlicensed carriers within one eNB [9]. DC and LAA can be categorized as inter-eNB CA and intra-eNB CA, respectively.

The radio level integration and aggregation of LTE-A and WLAN is another technology direction, for which a new work item called LTE-WLAN aggregation was established in LTE-A Release-13 [10–11]. It has couple of benefits compared to the above techniques. Firstly, the above mentioned network level traffic offloading is not able to take radio aspects (e.g. wireless channel quality) into account since the core network does not have any information on LTE-A radio due to the functional separation between the core network and the access network. In addition, control signaling needs to be exchanged between the core network and the mobile terminal for handling the traffic offloading, which increases signaling overhead. Secondly, the above mentioned LAA can overcome the drawbacks of the network level traffic offloading, but inter-eNB CA cannot be performed. LTE-WLAN aggregation can overcome these drawbacks: radio aspects can be taken into account, control signaling to the core network is not needed, and inter-eNB CA feature enables CA with already deployed WLAN Access Points (APs) and Access Controllers (ACs).

The standardization of LTE-WLAN aggregation is ongoing and the layer 2 structure is still under discussions. One of key challenges is traffic classification when incoming data traffic to LTE-A is offloaded to WLAN since traffic classification methods are different. Specifically, data traffic in LTE-A is classified into *bearer* based on QoS level defined in LTE-A, while traffic in WLAN is classified into *access category* based on QoS level defined in WLAN. Therefore, it is important that the QoS level of traffic is transparent between LTE-A and WLAN, so that the QoS level in LTE-A can be guaranteed in WLAN. Key requirements of LTE-WLAN aggregation should include that (1) it must be backward compatible to existing 3GPP specifications to minimize specification impacts, and (2) it must not have any impacts to existing IEEE 802.11x specifications to enable the aggregation between LTE-A and already deployed APs/ACs. There is related work in [12]. It is

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proposed that GRE (Generic Routing Encapsulation) protocol is used for the traffic offloading. However, the proposal does not consider the case when traffic with different QoS levels in LTE is offloaded to WLAN. In addition, implementing GRE on top of LTE layer 2 increases the GRE header overhead.

The objective of this paper is to tackle the challenge: layer 2 structure that enables the traffic classification. Three layer 2 structures are proposed. The characteristics of each structure are clarified, the pros and cons are discussed, and then one of proposed layer 2 structures is suggested as a desirable layer 2 structure to be standardized for LTE-WLAN aggregation.

II. IP Flow transmission in LTE-A network

This section describes the system architecture of LTE-A (II-A) and the layer 2 structure (II-B) of LTE-A.

A. System Architecture of LTE-A

Fig. 1 depicts the overall system architecture of LTE-A. There are two gateways that IP flows must go through. In addition, there is one control node.

- The Packet Data Network Gateway (PGW) is one of the gateways that is located between external IP networks and the LTE-A network. For the downlink, IP flows are delivered to each destination node, which is referred to as Use Equipment (UE).
- The Serving Gateway (SGW) is another gateway that is located between PGW and eNB. SGW and PGW are connected via S5 interface. In addition, SGW and eNB are connected via S1-U interface. Neighbor eNBs are connected with each other via X2 interface.
- The Mobility Management Entity (MME) is a control node which is responsible for the overall control of UE, for example, the configuration of Evolved Packet System (EPS) bearer, security, and mobility. MME and SGW are connected via S11 interface. In addition, MME and eNB are connected via S1-MME interface.

An IP flow entering the LTE-A network is delivered from the PGW to the UE as an EPS bearer. It is uniquely mapped to the corresponding Radio Bearer (RB) when transmitted over LTE-A radio. The maximum number of EPS bearers is eleven.

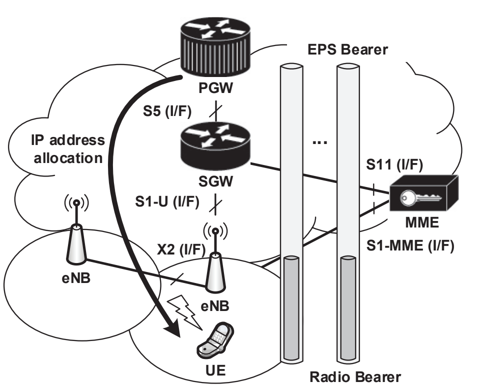

Fig. 1: Overall system architecture

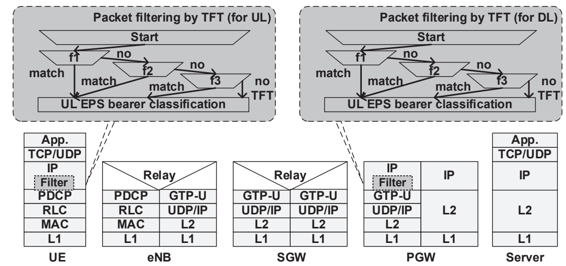

Fig. 2: Protocol stack of LTE-A user plane

Fig. 2 depicts overall protocol architecture of LTE-A. The routing mechanism of each IP flow is explained.

- Before starting the delivery of the IP flow, the PGW assigns an IP address to each UE. An IP flow is mapped to the corresponding EPS bearer taking into account the QoS level and delivered to each UE through General Packet Radio Service Tunnel Protocol (GTP) tunnel. In particular, GTP-U tunnel is established to deliver the IP flow as user plane. The transport protocol is UDP/IP.
- IP flow filtering is performed in the PGW and the UE for QoS handling. For the downlink, the filtering is carried out in the PGW and then each IP flow can be mapped to an EPS bearer with the same QoS level. For the uplink, the filtering is carried out in the UE and then each IP flow can also be mapped to an EPS bearer with the same QoS level. For that purpose, a packet filtering rule is configured by the PGW. This rule is referred to as Traffic Flow Template (TFT) and typically defined by using 5-tuple (source/destination IP addresses, source/destination port numbers, and protocol type).
- As a result of the filtering, each IP flow is mapped to a corresponding EPS bearer. One of EPS bearers is referred to as default bearer. The default bearer is established at the time when the IP address of the UE is assigned and it is kept until the IP address of the UE is released. Other EPS bearers are referred to as dedicated bearers. The dedicated bearers are freely established and released as necessary by the MME depending on, for example, applications.
- QoS aware routing of EPS bearers in the core network is performed. Each EPS bearer is delivered to each destination by IP based routing. PGW (downlink) and UE (uplink) set the QoS level of each IP flow to the Type of Service (ToS) field in the IP header.

B. Layer 2 Structure of LTE-A

Fig. 3 depicts overall layer 2 structure of LTE-A user plane. Three layers are defined: Packet Data Convergence Protocol (PDCP) layer, Radio Link Control (RLC) layer, and Media Access Control (MAC) layer. The functions of each layers are briefly explained in the following.

- Packet Data Convergence Protocol (PDCP) layer is responsible for the header compression (ROHC: Robust Header Compression) and security (ciphering for user plane and integrity protection for control plane). The

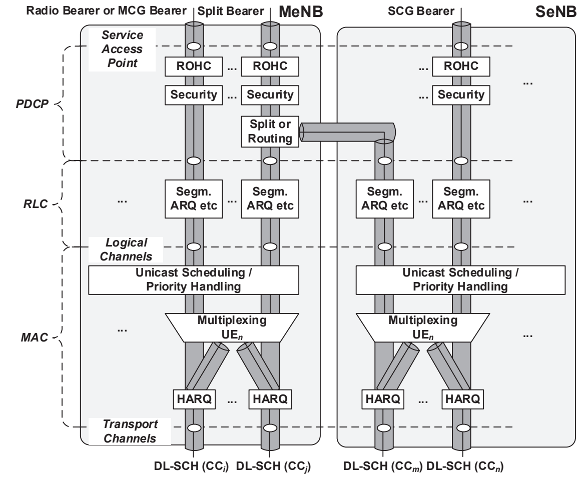

Fig. 3: Protocol stack of LTE-A user plane

PDCP header is added to incoming IP packet and then it becomes a PDCP Protocol Data Unit (PDCP PDU). For DC, there is a data split function (for downlink in the master eNB (MeNB)) and a routing function (for uplink in the UE), which enables simultaneous usage of two eNBs. One RB in the MeNB is referred to as Master Cell Group Bearer (MCG bearer), while one RB in the secondary eNB (SeNB) is referred to as split bearer or Secondary Cell Group Bearer (SCG bearer). For each split bearer, the MeNB can decide if bearer is sent only by one of eNBs or sent by both eNBs. For each split bearer, flow control function between MeNB and SeNB is optionally specified in X2, where feedback indicating highest successfully delivered PDCP SN is informed from SeNB to MeNB. To ensure in sequence delivery, PDCP PDU reordering is specified in the receiving side.

- Radio Link Control (RLC) layer is an adaptation layer for packet transmission sent over the radio interface. The packet size is adjusted based on the latest wireless channel quality by segmentation and concatenation of the packet. Automatic Repeat Request (ARQ) can be carried out when the packet has not been successfully transmitted due to transmission errors over the radio. The packet is mapped to Logical Channel (LCH).
- Media Access Control (MAC) controls radio access of the packet. Packet scheduling is performed considering QoS and wireless channel quality. Hybrid ARQ (HARQ) must be performed when the packet has not been successfully transmitted due to transmission errors over the radio. The transmitting side adds Logical Channel Identifier (LCID) to MAC Service Data Unit (MAC SDU) and sends the corresponding MAC PDU to the receiving side. The receiving side finally de-maps RB to EPS bearer based on the received LCID.

III. CHALLENGES OF LTE-WLAN AGGREGATION

The layer 2 structure of LTE-WLAN aggregation should be based on the layer 2 structure as described in Fig. 3. Then, the challenges are described in the following from the transmitting side or receiving side point of view.

Challenge 1: In the transmitting side, ciphering is applied to an EPS bearer. Thus, the WLAN MAC cannot identify the QoS level of the EPS bearer since the PDCP PDU is ciphered, meaning that Type of Service (ToS) field in the IP header is ciphered. IEEE802.11e is one of WLAN variants supporting QoS aware packet handling, where IP flows are classified into four QoS levels referred to as Access Categories (AC) [13]. IP precedence/DSCP (Differentiated Service Code Point) field in the IP header, or Priority field in Virtual LAN (VLAN) tag are usually used. Therefore, if the IP header is ciphered, WLAN MAC cannot perform the QoS handling of the EPS bearer.

Challenge 2: In the receiving side, there is no LCID added to WLAN PDU received by WLAN. Thus, the receiver cannot identify the corresponding RB and deliver WLAN PDU to the corresponding EPS bearer. For the downlink, the receiving side is UE and it is the destination node. The UE just delivers the received data to the application layer. Thus, there may be no problem without identifying EPS bearers. However, from a protocol point of view, PDCP is the protocol endpoint of the radio bearer, so that it is better to perform the de-mapping from AC to EPS bearer. For the uplink, the receiving side is the eNB but it is not the destination. Thus, the eNB should perform the de-mapping from AC to EPS bearer and then deliver each EPS bearer to the core network over the GTP tunnel with which each EPS bearer is associated. Therefore, a method of AC to EPS bearer de-mapping without LCID is required.

IV. PROPOSED LAYER 2 STRUCTURE

We propose three layer 2 structures to support LTE-WLAN aggregation. In this section, the details are explained. The first two proposed structures (categorized as Alt. 1) have a simple PDCP function in order to adapt to IP packet transmission. The last proposal (categorized as Alt. 2) keeps the current LTE-A layer 2 structure but an adaptation function is introduced for the purpose of EPS bearer to AC mapping and de-mapping.

Fig. 4 depicts common parts of proposed structures. As an example, eleven EPS bearers are offloaded to the SeNB deploying WLAN. Note that the SeNB could be Access Point (AP) or Access Controller (AC). From here, the SeNB is referred to as the WLAN Termination point (WT).

Alt. 1: The IP packet is not ciphered. Therefore, the IP header and ToS field are exposed to WLAN MAC, so that the QoS provisioning in WLAN becomes possible. Specifically, instead of using normal PDCP as specified in LTE-A, PDCP

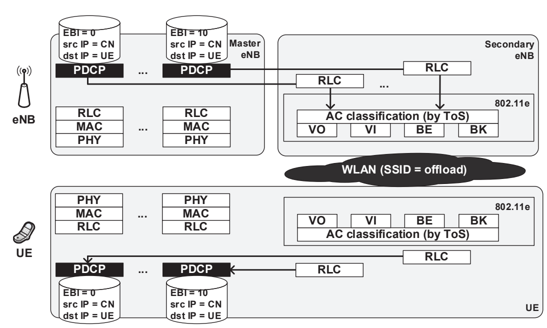

Fig. 4: Common structure of each proposal

layer is configured with PDCP Transparent Mode (PDCP TM). In this mode, the IP packet is directly offloaded to the WT without any processing in the PDCP layer. It is offloaded to the WT through the interface between the MeNB and the WT. There are two feasible deployments for the interface. The first one is 3GPP based interface, which is the Xw interface [14]. Another one is non 3GPP based interface. RLC layer is configured with RLC TM to enter the IP packets into WLAN MAC, by which WLAN MAC can process the IP headers.

<u>**Alt. 2:**</u> PDCP layer is configured with normal PDCP. The IP packet is ciphered, a PDCP header is added to the IP packet, and then offloaded to the WT as a PDCP PDU. In order to enable QoS provisioning in WLAN, an adaptation function is required in the WT. A PDCP PDU is forwarded to the WT via the Xw interface. The receiving side can receive PDCP PDUs from both LTE-A and WLAN. To ensure in-sequence delivery of PDCP PDUs to the application layer, PDCP PDU reordering based on the Sequence Number (SN) is performed. Therefore, high throughput is expected compared to Alt. 1.

A. Alternative 1

There are two variants of Alt. 1 described in this section. For the sake of simplicity, only the downlink is described here.

<u>Alternative 1–1: Bearer classification based on TFT</u>

The details of the transmitting side are described. The WT maps each EPS bearer to the corresponding AC. An example is depicted in Fig. 5. In LTE-A, the QoS class of each EPS bearer is identified by QoS Class Identifier (QCI) [15]. The WT classifies each QCI into 4 categories: Video (VI), Voice (VO), Best Effort (BE) and Background (BK). The QCI information to which each EPS bearer belongs is informed from the MeNB to the WT. Based on the informed QCI value, the WT performs the AC classification.

In the receiving side the UE is configured with EPS bearers to be offloaded to the WT. The configuration includes the EPS bearer identifier and QCI. Based on the configuration, the receiver tries to de-map each AC to the corresponding EPS bearer. However, a limitation must be specified. Specifically, EPS bearers with the same QoS level cannot be offloaded at the same time since those EPS bearers are mapped to the same AC. Otherwise, each EPS bearer cannot be uniquely identified in the receiving side. For example, if an EPS bearer with (ID, QCI) = (n, x) and another EPS bearer with (ID, QCI) = (m, x) are mapped to the same AC in WLAN, then the UE cannot uniquely identify the EPS bearer after the AC de-mapping.

QCI	Type	Priority	Example	AC
1	GBR (Guaranteed Bit Rate)	2	Conversational Voice	VO
2		4	Conversational Video (Live Streaming)	VI
3		3	Real Time Gaming	VI
4		5	Non-conventional Video (Buffered Streaming)	VI
65		0.7	Mission critical P to T voice	VO
66		2	Non mission critical P to T voice	VO
5	Non GBR (Non Guaranteed Bit Rate)	1	IMS signaling	VO
6		6	Video (Buffered Stream), TCP based applications	BE
7		7	Voice, Video (Live Streaming), Interactive Gaming	BE
8		8	Video (Buffered Stream), TCP based applications	BK
9		9		
69		0.5	Mission critical delay sensitive signaling	VO
70		5.5	Mission critical Data	VO

Fig. 5: An example of QoS classification and mapping

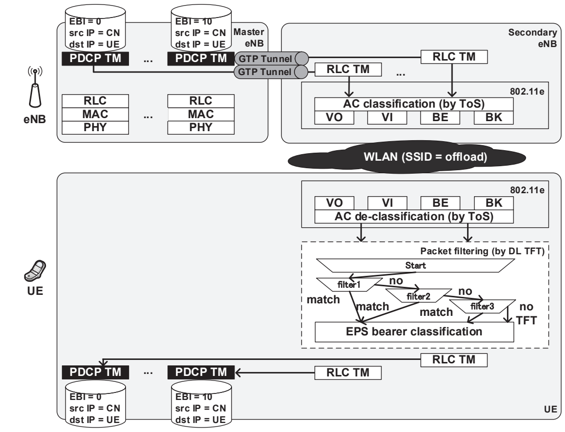

Fig .6: TFT based QoS de-mapping

Fig. 6 shows the architecture to solve this above issue. For the downlink, the UE performs the packet filtering based on DL TFT. For the uplink, the eNB performs the packet filtering based on UL TFT. As mentioned in Section II-A, TFT-based EPS classification is the method that IP flows are mapped to each EPS bearer. Therefore, the UE can uniquely identify the EPS bearer after the AC de-mapping. However, the drawback is that the filtering based on TFT increases the processing load.

<u>Alternative 1–2: Bearer classification based on Virtual GW</u>

Fig. 7 depicts the details of Alt. 1–2 for downlink. The difference from Alt. 1–1 is that Virtual Gateway (VGW) is deployed between the PDCP layer and WLAM MAC to setup a virtual network, by which the receiving side can de-map the received AC to the corresponding EPS bearer. There are two variants of how the VGW is realized. The details are described in the following.

The first variant is that the transmitting side maps each EPS bearer to the corresponding VLAN and then transmits each MAC frame associated with VLAN ID via WLAN. After AC classification, the QoS level is set to the Priority field in the VLAN tag. The receiver refers to the VLAN tag in each MAC frame and classifies each AC into the corresponding EPS

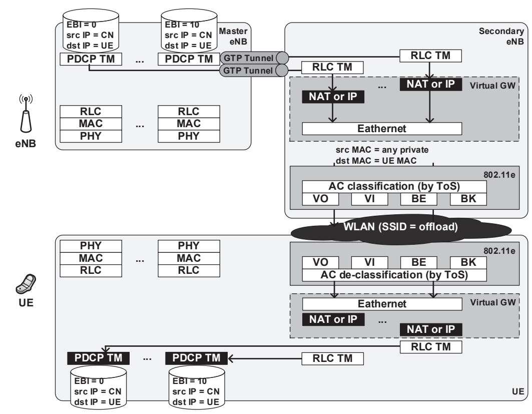

Fig. 7: Virtual network based on VLAN

bearer. For the MAC addresses, the source MAC address is the private MAC address of VGW obtained by setting the most significant bit to xxxxxx10, and the destination MAC address is set to the MAC address of the destination UE. The VLAN tag length is 12 bit, so that the maximum number of supported VLAN is 4096. Assuming that each UE establishes eleven EPS bearers at the same time and all EPS bearers are offloaded to the WT, the number of possible accommodated UEs per the WT is limited to 372. However, this assumption is not so realistic. Therefore, the limitation of the number of VLANs is not major problem.

In the second variant, the transmitting side sends each EPS bearer through the corresponding private IP network to the receiving side. For that purpose, Network Address Translation (NAT) is deployed in VGW. The source IP address is replaced with the private IP address of VGW and the destination IP address is replaced with a private IP address as the destination IP address represents each EPS bearer. After NAT, IP flows are delivered to Ethernet and transmitted to each destination IP address representing the EPS bearer via WLAN. The receiver refers to each destination IP address and delivers the received data to the corresponding EPS bearer. The private destination IP address assigned to each EPS bearer must be preconfigured. Here, an example of the IP address is described as follows. In LTE-A standards, the UE is configured with a unique address of LTE-A, which is Cell-Radio Network Temporary Identifier (C-RNTI) with a 16 bit length. By using C-RNTI, each IP address is generated by combining the EPS bearer ID and C-RNTI together. This can avoid IP address collision among UEs.

Note that RLC TM entity and VGW can be deployed in the MeNB. If this is the case, non 3GPP based interfaces can be used between the MeNB and the WT. For the uplink layer-2 structure, the same discussion as the downlink is applied.

B. Alternative 2

The last alternative solution Alt. 2 is described. In the MeNB, PDCP layer is configured with normal PDCP. The IP packet in the PDCP layer is offloaded to the WT via Xw interface as PDCP PDU. It arrives at the corresponding RLC layer in the WT and delivered to VGW. The key point here is that (private) IP layer is deployed in the ingress layer of the VGW. The QoS provisioning in WLAN MAC is carried out by using the ToS field in the IP header.

Fig. 8 depicts the layer 2 structure of Alt. 2. The structure is similar with that of Alt. 1–2. The differences are that IP layer is deployed in the VGW for IP encapsulation to the incoming PDCP PDU. The values in the IP header are configured by VGW based on parameters informed from the MeNB. The details of the configuration are explained by using Fig. 9. It depicts a typical procedure based on DC [7] for the parameter configuration and the data flow in LTE-WLAN aggregation.

0) UE capability: The UE informs the MeNB of the capability e.g. if LTE-WLAN aggregation is supported.

1-2) WT Addition Procedure: In this signaling, parameters e.g. EPS bearer information (e.g. QoS attributes) and WLAN information (e.g. MAC address of the UE) are included. The WT sends the response if the request is accepted.

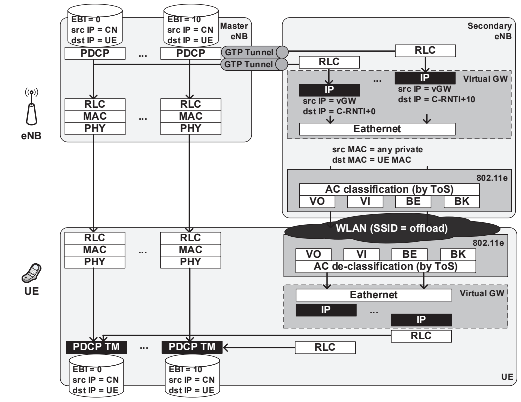

Fig. 8: Virtual network based on IP

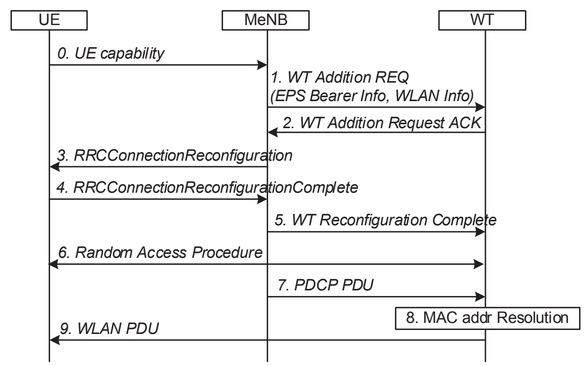

Fig. 9: Sequence of the transmission of IP flows over WLAN

3-5) RRC Connection Reconfiguration Procedure: The MeNB informs the UE of the parameters. The UE informs the MeNB of the completion of the configuration.

6) Random Access Procedure: The UE performs the random access procedure for the uplink timing synchronization.

7-9) Offloading: PDCP PDU sent by the MeNB is delivered to the UE as WLAN PDU after the MAC address resolution.

Here, WT Addition Request is the important signaling. The WT identifies the QoS class of each EPS bearer and the QCI value as in Fig. 5 by receiving this signaling. Accordingly, WT can set the ToS field to the IP header. The setting of IP addresses is same with that in Alt. 1–2. The other fields in the IP header are left to the VGW implementation.

C. Observations: 3GPP Standardization Direction

We have proposed three layer 2 structures. Tab. I shows a summary of supported functions of each alternative. Based on Tab. I, the pros and cons are discussed and one of proposed layer 2 structures is selected as a desirable structure to be standardized in 3GPP for LTE-WLAN aggregation.

Interface between MeNB and WT: In all alternatives, Xw interface and GTU tunnel can be deployed between MeNB and WT since PDCP and RLC are termination points, respectively. In addition, as mentioned in Subsection IV-A, a non 3GPP based interface can be used between the MeNB and the WT for

TABLE I. FUNCTIONAL SUPPORT

Function	Alt. 1-1	Alt. 1-2	Alt. 2
Interface between MeNB and WT:			
(a) 3GPP based interface (e.g. Xw)	✓	✓	✓
(b) Non 3GPP interface	✓	✓	
De-mapping from AC to EPS bearer			
(a) TFT (Traffic Flow Template)	✓		
(b) QCI (QoS Class Identifier)		✓	✓
Flow control between MeNB and WT			✓
Simultaneous usage of both radios			✓

Alt. 1. Thus, it is observed that there is freedom for deploying different backhauls between the MeNB and the WT by using Alt. 1, which is an important factor for network operators.

De-mapping from AC to EPS bearer: In Alt. 1–1, IP packet filtering is required in the UE (for downlink) and the WT (for uplink) for the de-mapping from AC to EPS bearer. It is observed that this scheme has negative impact on processing load due to the TFT based filtering. Especially, the processing load is increased as the number of the packet filtering rules increases. On the other hand, in Alts 1–2 and 2, the VGW needs to be newly setup for the EPS bearer delivery over WLAN. So the impact of VGW is expected to be less than the TFT based filtering since the amount of processing due to NAT or VLAN is limited compared to the TFT based filtering.

Flow control between MeNB and WT: MeNB and WT are configured with PDCP TM and RLC TM, respectively, in Alt. 1. As described in Subsection II–B, the flow control is based on the highest successfully delivered PDCP SN in WT. Thus, DC based flow control cannot be supported in Alt. 1, which may cause throughput degradation in the case when the packet loss rate becomes high due to the buffer overflow in WT. Instead, it could be possible that a new flow control scheme is standardized. However, it is not desirable since the flow control scheme is simpler if it is common between DC and LTE-WLAN aggregation. On the other hand, in Alt. 2, if the MeNB and the WT are configured with normal PDCP and normal RLC, respectively, then the flow control function already specified in DC can also be supported.

Simultaneous usage of both radios: In Alt. 1, incoming IP packet to MeNB is offloaded to the WT and transmitted to UE over WLAN. On the other hand, in Alt. 2, simultaneous usage of LTE-A and WLAN at the same time is possible. Therefore, Alt. 2 shows higher throughput than Alt 1.

A desirable scheme can be selected from these qualitative observations and findings. The advantage in Alt 1 is that there is freedom of the interface selection and network deployment. However, the drawback is that high throughput may not be achievable without simultaneous usage of LTE-A and WLAN. In addition, the drawback of Alt. 1–1 is the increase of packet processing load in the UE. Implementing the TFT filtering in the UE also increases the UE complexity. Toward 5G, low complexity and high throughput are indispensable requirements, therefore, it is suggested that Alt. 2 be standardized in 3GPP.

Finally, note that quantitate analisys is planned to be studied. Therefore, performance metrics, for example, the percentage of the data traffic whose QoS level has been guaranteed, the processing load, and throughput will be investigated.

V. CONCLUSIONS

For LTE-WLAN aggregation, this paper proposes three layer 2 structures for enabling QoS handling of EPS bearers in WLAN MAC according to the IEEE802.11e standard. Two of proposals have a common structure, where PDCP Transparent Mode is configured in the transmitting side (MeNB for downlink and UE for uplink) so that incoming IP packets are directly delivered to the WLAN MAC. The WLAN MAC then carries out AC classification based on ToS field in the IP header. The receiving side (UE for downlink and WT for uplink) identifies each EPS bearer from the AC based on packet filtering (Alt. 1–1). Alternatively, WLAN MAC carries out the AC classification based on VLAN tag or using a private IP address (Alt. 1–2). The last proposal (Alt. 2) has a different structure from Alt. 1, where the transmitting side performs normal PDCP operation to incoming IP packets. The WLAN MAC performs IP encapsulation to a PDCP PDU and carries out AC classification. The receiving side identifies each EPS bearer from the AC based on the IP address in the IP header.

It is observed that the final scheme selection should take requirements of 5G into account. Specifically, the requirements are low complexity and high throughput, therefore, it is suggested that Alt. 2 be the standardization direction.

REFERENCES

[1] URL of 3rd Generation Partnership Project: http://www.3gpp.org/

[2] 3GPP Technical Report, “Requirements for further advancements for Evolved Universal Terrestrial Radio Access (E-UTRA) (LTE-Advanced),” *TR36.913*, V12.0.0, September 2014.

[3] 3GPP Technical Report, “Further Advancements for E-UTRA (LTE-Advanced),” *TR36.912*, V12.0.0, September 2014.

[4] 3GPP Technical Report, “Evolved Universal Terrestrial Radio Access (E-UTRA); Further advancements for E-UTRA physical layer aspects,” *TR36.814*, V9.0.0, March 2010.

[5] 3GPP Technical Specification, “Architecture enhancements for non-3GPP accesses,” *TS23.402*, V13.2.0, June 2015.

[6] D. Roeland and S. Rommer, “Advanced WLAN integration with the 3GPP evolved packet core,” *IEEE communications magazine – communications standards supplement*, December 2014.

[7] 3GPP Technical Specification, “Evolved Universal Terrestrial Radio Access (E-UTRA) and Evolved Universal Terrestrial Radio Access Network (E-UTRAN); Overall description,” *TS36.300*, V13.0.0, June 2015.

[8] 3GPP Technical Report, “Study on Small Cell Enhancements for E-UTRA and E-UTRAN – Higher layer aspects,” *TR36.842*, V12.0.0, December 2013.

[9] 3GPP Technical Report, “Study on Licensed-Assisted Access to Unlicensed Spectrum,” *TR36.889*, V13.0.0, June 2015.

[10] 3GPP Contribution, “Motivation for new SI proposal: LTE-WLAN Radio Level Integration,” *RP-150180*, RAN#67, Shanghai, March 2015.

[11] 3GPP Contribution, “Revised: LTE-WLAN Radio Level Integration and Interworking Enhancement,” *RP-151114*, RAN#68, June 2015.

[12] Y. Kojima, J, Suga, T. Kawasaki, M. Okuda and R. Takechi, “LTE-WiFi link aggregation at femtocell base station,” *Proceedings of WTC2014*, pp. 1– 6, San Francisco, June 2014.

[13] IEEE Standard, “Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications,” *IEEE Std 802,11TM – 2012*, March 2012.

[14] 3GPP Technical Report, “Study on Muti-RAT joint corrdination,” *TR37.870*, V13.0.0, June 2015.

[15] 3GPP Technical Specification, “Policy and charging control architecture,” *TS23.203*, V13.4.0, Section 6.1.7, June 2015.