Control Plane Design and Implementation for LTE-WLAN Aggregation (LWA)

Ying-Ju Shih

Abstract **— In this paper, we introduce the LTE LWA technology. Based on 3GPP LTE Release 13, main LWA procedures are described. In addition, we implement these scenarios on a platform developed by ITRI (eNB side) and Mediatek (UE side). Peak throughput of LWA of 400 Mb/s can be achieved by aggregating a 100Mb/s LTE base station and a 300Mb/s of Wi-Fi access point. In the future, we will investigate how to use several aggregation technologies (such as CA and LWA) at the same time to gain more bandwidth.**

Index Terms **— LTE-WLAN Aggregation (LWA), Heterogeneous Network (HetNet), Multi-Radio Access Technology (Multi-RAT).**

I. Introduction

DUE to dramatically increase in mobile data traffic, telecom operators are seeking ways to provide higher bandwidth, wider coverage and better QoS (Quality of Service) with low development cost. Recently several advanced technologies have been proposed to aggregate different LTE carriers or different RATs (Radio Access Technology) to produce higher bandwidth. For example, carrier aggregation groups up to 5 discontinuous LTE component carriers to extend the bandwidth by 5 times. Apart from LTE bandwidth aggregation, Inter-RAT aggregation or offloading is another cost-effective solution to gain bandwidth. For example, LWA (LTE-WLAN aggregation) integrates LTE and WLAN radio resource [2]. Wi-Fi has the advantages of high availability and indoor coverage, which are often used by telecom operators to supplement the bandwidth need of existing mobile infrastructures (e.g., LTE). Traditionally, Wi-Fi and LTE are independently operated. Recently, LWA has been considered to provide better usage of Wi-Fi and LTE. For example, the collaboration between ASTRI (Hong Kong Applied Science and Technology Research Institute) and PCCW (Pacific Century Cyber Works) Group in Hong Kong was announced in October, 2016 [1].

Industrial Technology Research Institute (ITRI) and MediaTek (MTK) in Taiwan have collaborated to develop the LWA technology. Peak throughput of around 400Mb/s was demonstrated in Mobile World Congress (MWC) 2016 with the 100Mb/s LTE throughput and 300 Mb/s Wi-Fi throughput. In addition to providing high throughput, another great advantage of the ITRI-MTK development is to implement LWA by legacy Wi-Fi APs. By which the telecom operators can use existent infrastructure to support LWA feature with minimum capital expenditure (CAPEX). In this paper we focus on the design and implementation of LWA control plane for the ITRI-MTK development. In addition, some important design of LWA data plane is also included. The remainder of the paper is organized as follows. In Section II, we describe several LWA development issues and show how we and 3GPP standard address these issues. In Section III, the system architecture and control plane procedures for LWA implantation are introduced. In Section IV, the performance evaluation is described. Conclusion and some future works are listed in section V.

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II. LWA C-Plane: Design Overview

Figure 1 illustrates a simplified LWA network architecture consisting of the LTE base station (eNB), the Wi-Fi access point (AP) and UE. The eNB is overlapped with the Wi-Fi AP, where the radio coverage of the eNB is larger than that of the Wi-Fi AP. Consider the scenario where the UE resides in the coverage of LTE, then it moves to the coverage of the Wi-Fi AP. Without LWA, to transfer the data in the overlap coverage of eNB and Wi-Fi AP, the UE can only choose either LTE or WiFi but not both. With LWA, the UE can enjoy the aggregated bandwidth of LTE and Wi-Fi.

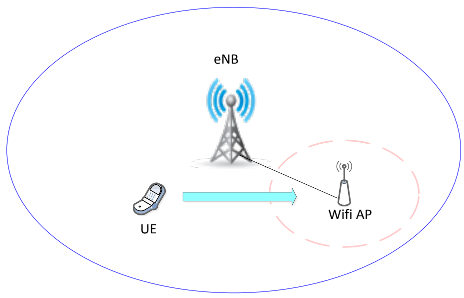

Figure 1 : LWA concept

Although the idea of LWA is simple, there were several key issues to be solved. (Note: While we were developing, the 3GPP LTE release 13 was not finalized. We need to modify earlier release to make LWA work.) Before introducing the standard solution, we describe these issues and possible solutions first and then describe LTE release 13 LWA solutions in this section.

A. Issues during development of LWA specifications

1) Issue 1: How does the eNB know a UE within Wi-Fi coverage?

This issue can be solved by adding new measurement configuration and report type for WLAN in RRC messages. The eNB sends the WLAN measurement configurations and the measurement report criteria to the LWA capable UE. The measurement configurations should include information of the Wi-Fi APs within the coverage of this eNB such as AP's SSID or Wi-Fi channels. The more APs' information a UE has, the less unnecessary measurement report is triggered; and that also saves the UE's power. As for the measurement report sent from UE to the eNB, it should contain the signal strength and identity of the detecting Wi-Fi AP for the eNB to initiate LWA related procedures.

2) Issue 2: How and when does the eNB activate or deactivate LWA?

For this issue, an easy way is to extend the original RRC Connection Reconfiguration message to have LWA configuration. The LWA configuration should include LWA target state (setup or release) and the identity of the Wi-Fi AP that the UE ought to associate with at least. Once a UE's WLAN measurement report is received, whether the eNB activates or deactivates LWA function may depend on the Wi-Fi signal strength and available resources in the eNB. Figure 2 depicts the timing to initiate LWA activation and deactivation. While the UE enters the coverage of Wi-Fi and the signal strength is larger than an activation threshold, the eNB triggers the activation procedure. On the contrary, if the signal strength is smaller than a deactivation threshold, the eNB triggers the deactivation procedure. One thing should be noticed during activation is that completing LWA configuration by using RRC connection reconfiguration procedure does not guarantee that the Wi-Fi channel is available. Only after the UE successfully associates with the target Wi-Fi AP can the eNB transfer data by Wi-Fi. For this reason, a new RRC message should be created to notify the eNB of the Wi-Fi association status. The eNB can't use LWA to transfer data until receiving a successful association result. If the status is failed, the LWA activation procedure is failed. The eNB will initiate LWA activation procedure again if another Wi-Fi AP candidate appears.

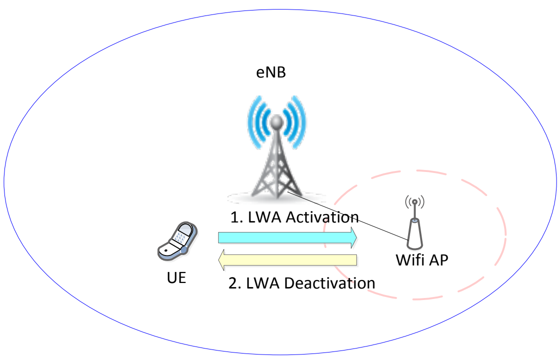

Figure 2 : LWA activation and deactivation timing diagram

3) Issue 3: How does the eNB transfer data to a UE via Wi-Fi? (DL only)

Now we want to send user data from an eNB to a UE via a Wi-Fi AP as the blue dashed line in Figure 3. For this issue, we can use L2 forwarding to achieve. The eNB connects to the Wi-Fi AP by an Ethernet cable. Therefore, the user packets can be sent to the Wi-Fi AP by Ethernet. But how does the Wi-Fi AP forward packets to the UE correctly? We can use the trick once a UE is connected to a Wi-Fi AP, this Wi-Fi AP has the UE's Wi-Fi MAC address. Hence if a packet sent from the eNB to the Wi-Fi AP via Ethernet and the destination address in the Ethernet header (the red box in Figure 4) is set as UE's Wi-Fi MAC address, the Wi-Fi AP will forward this packet to the UE.

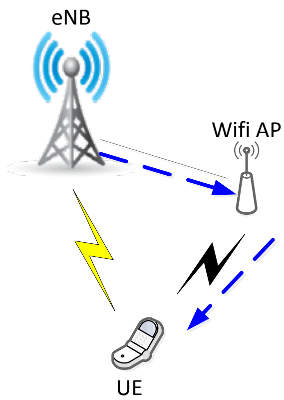

Figure 3 : Transfer LTE data via Wi-Fi

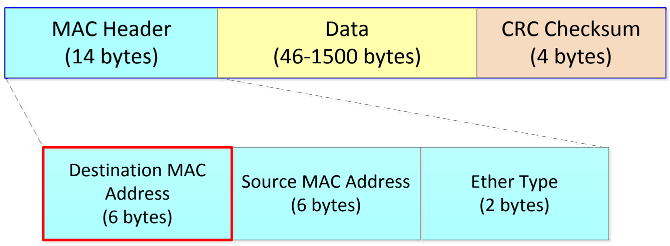

Figure 4 : Ethernet Type II MAC Frame

After solving the data transfer problem, the upcoming problem is the data format in the Ethernet packet. This problem is relevant to which protocol layer should aggregate packets from both radio links and it had been discussed in 3GPP meeting for a while. The conclusion is to aggregate in PDCP layer.

The last problem is that if there are multiple data radio bearers (DRBs) with LWA enabled, how does the UE distinguish received data from Wi-Fi between these bearers? Therefore, a new protocol layer, LWAAP, is introduced in release 13 to tag DRB info in the packets through Wi-Fi path. Owing to the main purpose of this paper is to introduce LWA control plane, the detailed packet format for the new protocol is out of the scope of is paper. The readers can refer to [2] [3][4][5] for the details.

B. LWA in 3GPP LTE Release 13

3GPP LTE release 13 published in 2016/03 includes LWA feature to provide solutions for the 3 issues in the section II.A. In release 13, 2 deployment scenarios of LWA network architecture are supported: co-located and non-collocated. The difference between these 2 scenarios is how the interface between the eNB and WLAN entity is connected. The interface in the non-collocated case is an ideal/internal backhaul and that in the collocated case is a non-ideal backhaul. Figure 5 is the overall architecture for the non-collocated LWA scenario. There are 4 components which are MME (Mobility Management Entity), S-GW (Serving Gateway), eNB and WT (WLAN terminal) in this figure. The interface between MME/S-GW and eNB is S1 interface and that between eNB and WT is Xw interface. WT and Xw are a new component and a new interface developed for LWA feature in release 13. WT is a logical representation of the WLAN system and how it implements is not described in the specification. It may be a Wi-Fi AP, or a Wi-Fi controller. Xw interface, similar to S1 interface, has control and data plane connectivity. Detailed Xw functions and protocols can refer to 3GPP TS 36.461-36.465([6]-[10]).

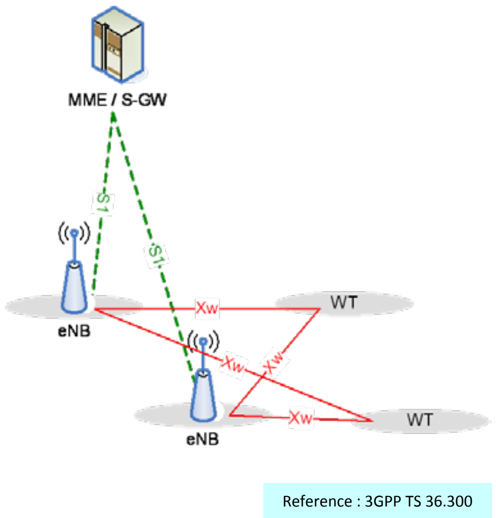

Figure 5 : Non-collocated LWA Overall Architecture

As for co-located architecture, since the connection between the eNB and WLAN entity is an ideal/internal backhaul, it's unnecessary to implement Xw interface. The radio protocol architectures for these 2 cases are as Figure 6. In release 13, it also introduces one new protocol entity, the LWAAP (orange part in Figure 6), and one new bearer type, LWA bearer, for LWA. The main functions of LWAAP are to transfer user plane data and identify the LWA bearer to which LWAAP SDU belongs (as mentioned in II.A.3). In addition, for a UE to distinguish between LWA packets and other types of Wi-Fi packets, a new EtherType "LWA" with value "0x9E65" is defined for the WT to forward data to the UE over WLAN [2]. Upon receiving a Wi-Fi packet, the UE uses the Ethertype to determine that the received Wi-Fi packet is a LWA packet and uses DRB identity to know which LWA bearer the PDU belongs to. About LWA bearers, there are 2 types of LWA bearers: split and switch. The radio protocols of both types located in both the eNB and the WLAN while split bearer can use both LTE and WLAN radio resources and switched bearer can only use WLAN radio resources. One thing should be noticed is that in release 13, LWA supports data aggregation in user-plane downlink only. The control-plane data and uplink user-plane data can only be transmitted on LTE. Therefore the LWA control messages must be exchanged between the eNB and the UE via LTE.

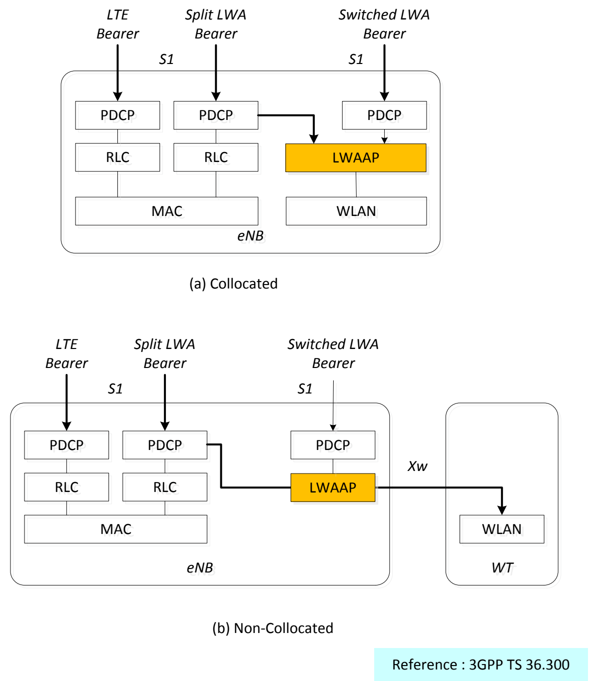

Figure 6 : LWA Radio Protocol Architecture

For existing radio protocols, major modifications for LWA feature are in RRC [3] and PDCP [4] layers. For the RRC protocol, new IEs or messages are added to support the WLAN detection, LWA activation/deactivation (Event W1, W2, W3) and WLAN association status report. In addition, a new concept "mobility set" which is a group of Wi-Fi APs (identified by WLAN identifies) is proposed to allow a UE to do mobility autonomous without informing the eNB. However, the mobility between different mobility sets is still controlled by the eNB. The design of mobility set reduces the message flows between the eNB and the UE when LWA transmission is ongoing. About PDCP, major modifications are (1) extending packet sequence number (SN) to 18 bits for better out-of-order packets detection and (2) adding a new PDCP control PDU "LWA status report" sent from a UE to notify the connecting eNB of the receiving packets status for a LWA bearer. The eNB may use the R12 PDCP status report and R13 LWA status report to decide ratio of packets transferring between LTE and Wi-Fi to have the optimal throughput.

III. LWA IMPLEMENTATION

In this section, we describe the LWA implementation of ITRI-MTK development. The overall system architecture is described first, the overview of control plane messages is in the 2^{nd} subsection, and the experiment results are in the last subsection.

A. *System Architecture*

1) *Single Wi-Fi AP*

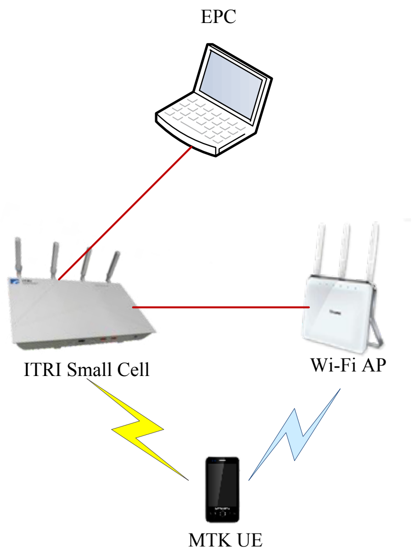

Figure 7 : System Architecture for LWA implementation – Single Wi-Fi AP

The system architecture of ITRI-MTK LWA development as Figure 7 adopts "collocated" LWA architecture. The hardware components include a commercial laptop, an ITRI small cell, a commercial Wi-Fi AP and a MTK UE. The software programs "light EPC (Evolved packet core network)" and "LTE protocol" developed by ITRI ICL (Information and Communication Research Laboratories) are executed on the laptop and ITRI small cell respectively. The interface between the EPC and small cell is internal defined interface using raw socket transmission while that between small cell and Wi-Fi AP is Ethernet. Other system specifications are listed in Table 1.

Table 1 : System specification

Hardware	Specification
Laptop	OS : Ubuntu
Small cell	TDD band 38/40
Wi-Fi AP	IEEE 802.11ac (5G) / Open System Authentication (OSA)

The single Wi-Fi AP architecture is the basic architecture for LWA implementation which is used to develop high throughput in data plane.

2) *Multiple Wi-Fi AP*

Figure 8 is the system architecture for multiple Wi-Fi APs. The architecture is similar to that of single Wi-Fi AP except for one additional Wi-Fi AP and one additional switch. The purpose of the additional switch is to transfer data from the eNB to different Wi-Fi APs. This system architecture is used for WLAN mobility development as Figure 9. In Figure 9, 2 Wi-Fi APs are connected to the same eNB and the coverage of these 2 APs is overlapping. In the beginning, the UE is in the coverage of AP 1 and LWA is activated. Then the UE moves toward AP 2; to maintain LWA connection, Wi-Fi AP change procedure should be initiated. How it works will be introduced in paragraph III.B.2).

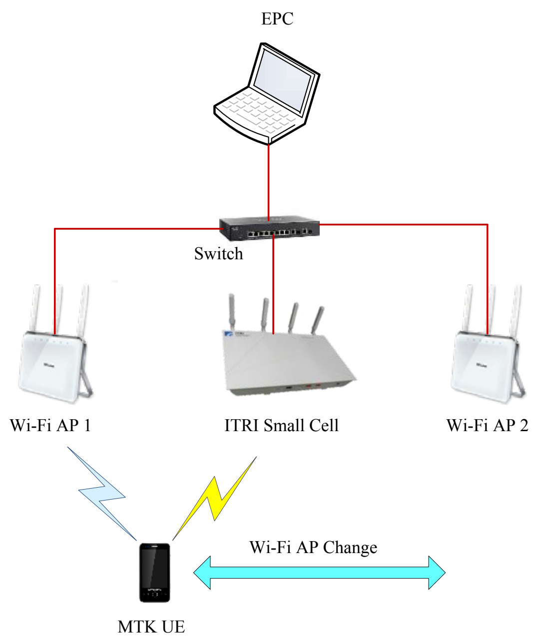

Figure 8 : System Architecture for LWA implementation – Multiple Wi-Fi APs

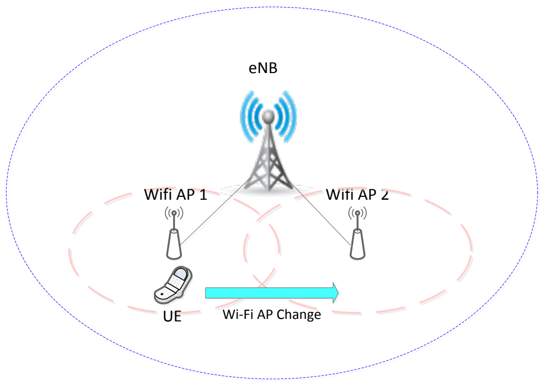

Figure 9 : WLAN mobility

B. *LWA C-Plane*

1) *Overview of the Main Procedures*

In this paragraph, we introduce the main LWA procedures in the ITRI-MTK development. The LWA procedures include UE Capability, RB configuration, measurement configuration/report, LWA activation and deactivation. As we mentioned in section II.B, the RRC messages of these procedures are transferred on LTE because they belongs to control-plane data. In our development, there is only one Wi-Fi AP in the mobility set.

Figure 10 is the overview of LWA procedures in which most messages are RRC messages between the eNB and the UE except for messages 7, 11 and 16 which describe the behavior between the UE and the Wi-Fi AP. The blue part in this figure is new IE or new RRC messages defined in release 13. There are 5 major parts in this message sequence chart (MSC): 1. UE Capability, 2. LWA type RB configuration, 3. WLAN measurement configuration and report, 4. LWA activation procedure and 5. LWA deactivation procedure. The purpose and details of each part are described in following paragraphs. After that, a small paragraph describing the data path is also given for users to get better understanding of LWA.

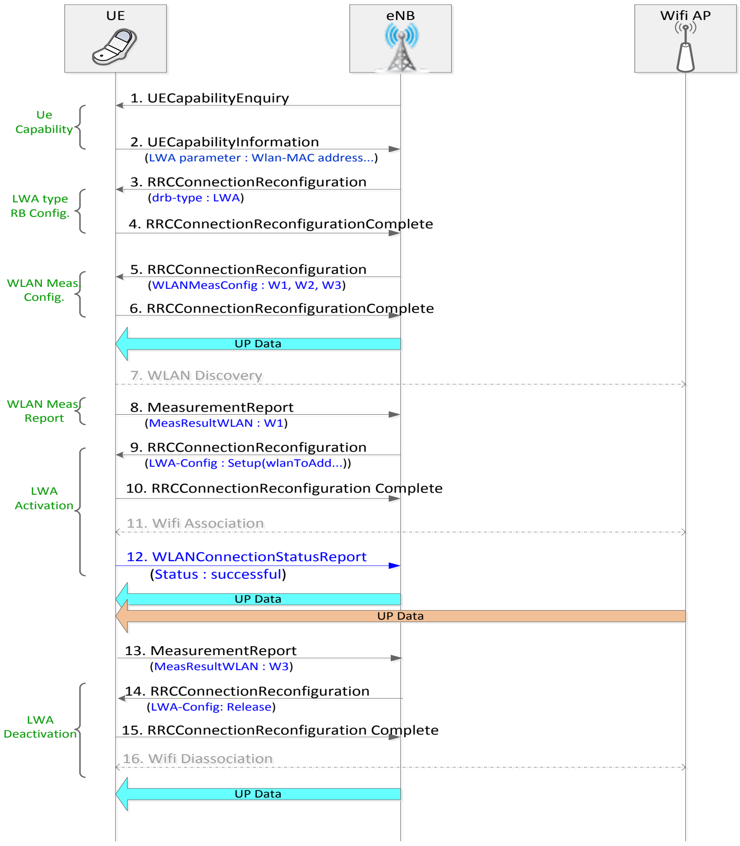

Figure 10 : Overview of LWA procedures

● **UE Capability (step 1–2)**

The eNB enquiries the UE capability after the UE initiates the attach request. Only when the UE has LWA capability does the eNB establish LWA type RB and configure WLAN measurement as steps 3~7. The LWA parameters in step 2 should contain the UE's Wi-Fi MAC address to forward LWA packets to the UE.

● **LWA RB Configuration (step 3-4)**

The eNB requests the UE to establish LWA bearer in RRCConnectionReconfiguration message. In this message, the eNB sets the DRB type as LWA and selects proper PDCP settings such as extended SN or status report for the LWA bearer.

● **WLAN Measurement configuration and report (step 5-6, 8, 13)**

The eNB configures WLAN measurement which includes WLAN measurement object and measurement report. The WLAN measurement object contains the information of the Wi-Fi AP(s) which the eNB would like a UE to monitor, such as the Wi-Fi AP's BSSID, band (2.4G or 5G) and channels. The measurement report configuration contains the report criteria and additional WLAN AP information request (e.g. channel utilization) which should be included in the measurement report if possible. There are 2 types of WLAN measurement reports: periodical and event-trigger. The former has one type and the later has 3 types: W1, W2, and W3. The description and possible uses for WLAN events is as Table 2.

Table 2 : WLAN event description

Event	Description	Possible uses
W1	WLAN becomes better than a threshold	For LWA activation
W2	All WLAN inside WLAN mobility set becomes worse than a threshold1 and a WLAN outside WLAN mobility set becomes better than a thresold2.	For mobility Set Change (or Wi-Fi AP change)
W3	All WLAN inside WLAN mobility becomes worse than a threshold	For LWA deactivation

Periodical type report was used in the prototype of the ITRI-MTK development until release 13 was approved. From then on event W1~W3 were used. The most important elements in the measurement report are the WLAN identity and its signal strength (RSSI). Those elements are used to evaluate if the eNB should initiate the LWA activation or deactivation procedure. A simple way for the eNB to make decisions is based on the received WLAN signal strength. If the identity of WLAN is valid* and the signal strength is larger (smaller) than a threshold, trigger LWA activation (deactivation) procedure. The detailed algorithm for LWA operation is described paragraph III.B.3)

* Valid means there is a connection between the eNB and the Wi-Fi AP, the eNB can transfer LWA packets to the UE via Wi-Fi AP.

● **LWA Activation (step 9-12)**

The eNB activates LWA when the UE enters WLAN coverage. The LWA-Config-r13 information element (IE) in the RRC message "RRCConnectionReconfiguration" contains the mobility set and association timer which is the maximum time for connection to WLAN. In addition, the eNB can configure the UE to send the RRC message "WALNConnectionStatusReport" after the UE successfully connects WLAN. In our system, there is only one Wi-Fi AP in the mobility set which means the UE mobility is not allowed in our system. UE's WLAN mobility is fully controlled by the eNB.

● **LWA Deactivation (step 13-15)**

The eNB deactivates LWA when the UE leaves WLAN coverage as steps 13-15. Another possible scenario to trigger LWA deactivation is that the UE reports WLAN status with failure cause (e.g. failure WLAN radio link) when LWA is activated. Because the later scenario is abnormal case, it is not shown in the MSC.

● **Data path**

The UE can receive data from both an eNB and a Wi-Fi AP after LWA is activated. Otherwise the UE receives data from LTE only as Figure 10. But this doesn't mean a UE receives data from both paths always. The eNB can decide to transfer data via either the LTE or WLAN path only, or adjust the transfer ratio between LTE and WLAN according to current available radio resource or feedback information from UE. That is, LWA activation gives an eNB the opportunity to use both radio resources, otherwise, only LTE radio resource can be used.

2) Mobility Procedure -Wi-Fi AP Change

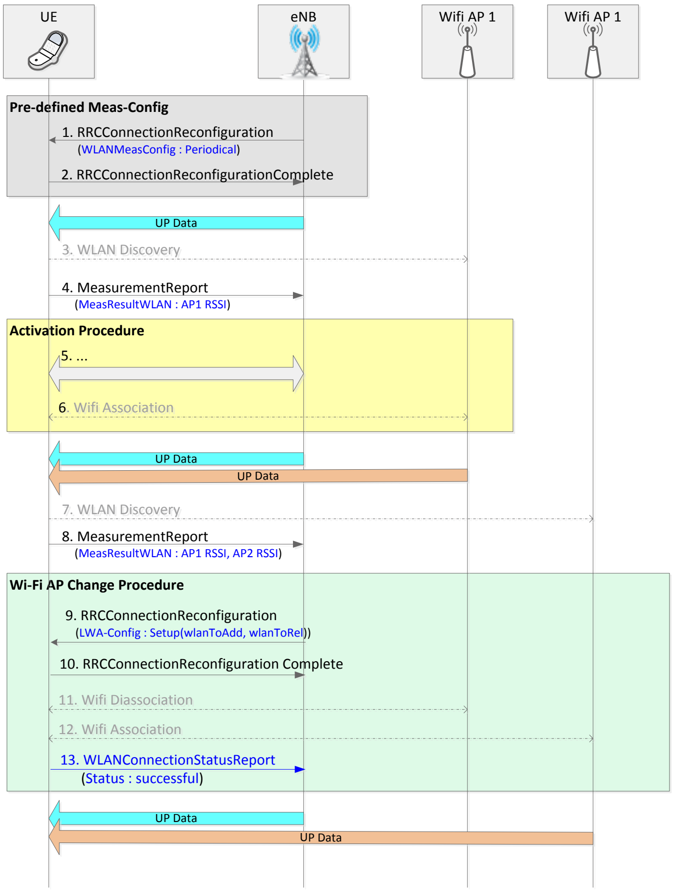

Figure 11 : LWA Wi-Fi AP Change Procedure

Figure 11 is the MSC for LWA Wi-Fi AP Change procedure and its purpose is to change UE's connecting Wi-Fi AP when UE moves from the coverage of AP1 to that of AP2 and vice versa. The MSC for the procedure in Figure 11 is used in our prototype development while the 3GPP release 13 is not finalized. In addition, the measurement configuration is predefined and the UE returns the Wi-Fi measurement report periodically in this prototype.

Steps prior to step 7 in Figure 11 is similar to that of Figure 10 except that periodical event is used. When the UE moves toward the coverage of AP2 and on detection of AP2's signal, it returns the signal strength of both APs. When AP1's signal strength is worse than a threshold_1 and AP2's signal strength is better than a threshold_2, the eNB triggers the Wi-Fi AP change procedure by using one RRC message "RRCConnectionReoconfiguration" with one wlan to release (for AP1) and one wlan to add (for AP 2) existing in LWA-config IE simultaneously. Hence, by using one RRC message accomplishments the Wi-Fi AP change procedure.

To migrate to release 13, we can configure event W2 to replace periodical setting in step 1 without affecting other sequence of this procedure.

3) LWA Control Plane Operations

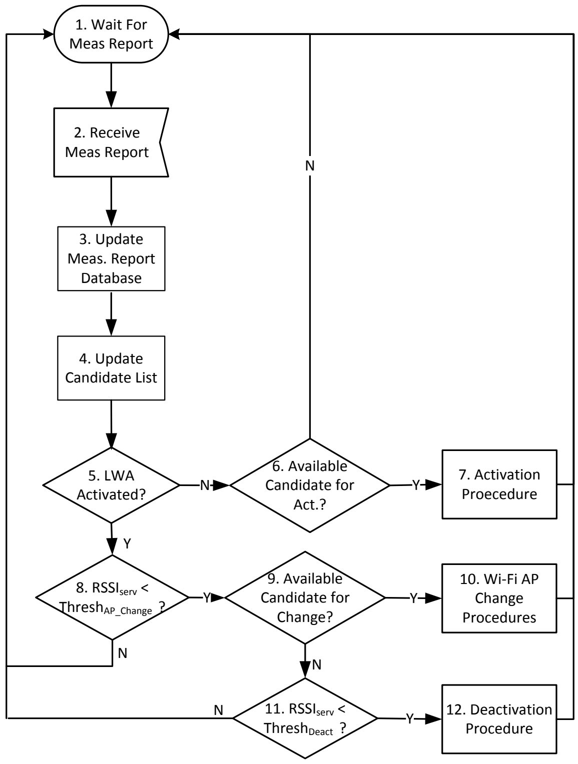

Figure 12 : LWA C-Plane Operation Flow Chart

In this paragraph, we introduce how the LWA C-Plane operates. Figure 12 is the LWA C-Plane operation flow chart. In the beginning, the eNB is waiting for the WLAN measurement report (1). After receiving a WLAN measurement report, the eNB updates its database of measurement report and candidates for activation or Wi-Fi AP change (2, 3, 4). Then it checks current LWA status. If the state is not activated, the eNB finds an available candidate for the activation procedure which is initiated immediately after (5, 6, 7). If the status of LWA has already been activated, check if the received Wi-Fi signal strength is smaller than the deactivation threshold. If so, then the eNB tries to find a candidate for Wi-Fi AP change and initiate the Wi-Fi AP change procedure once any candidate exists (8-10); otherwise, initiate the deactivation procedure (11-12). The goal of this design is to keep the LWA connection as far as possible. Hence when the signal of the associated Wi-Fi AP becomes poor, the eNB will find candidate for Wi-Fi AP change first. Unless no available candidate does the eNB initiate the LWA deactivation procedure.

IV. Performance Evaluation

The performance evaluation is composed of three parts: control plane only, data plane only, and control and data plane combined. We will discuss each part separately in the following sections.

A. Control Plane Only

The performance evaluation of the control plane focuses on the functionality and stability which includes the verification of the basic procedures, mobility procedures and error handling. An internal list of test cases which include basic functional tests and scenarios is used to verify the LWA function. Some important test items are listed in Table 3.

Table 3 : Control Plane Test Items

Procedure	Test Items
Basic Function	LWA activation, LWA deactivation
Error Handling	WLAN Radio Link failure (RLF) during LWA activation, WLAN RLF as LWA activated
Mobility	Wi-Fi AP, LTE handover procedure

Because the implementation for LWA R13 protocols in ITRI and MTK are under development, only most basic and error handling test cases are passed in the ITRI/MTK LWA IODT for R13 in Sep. 2016. The mobility related test cases were only verified in previous prototype priori to R13 in the first half of 2016.

B. Data Plane Only

The way to evaluate data plane performance is to verify the DL throughput of LWA by using a speed test tool “iperf”. There are 2 scenarios for D-Plane: max throughput measurement and dynamic LWA rate adaption. In max throughput test, around 400 Mb/s of max throughput is achieved by aggregating 100Mb/s of LTE throughput and 300Mb/s of Wi-Fi throughput. As for dynamic LWA rate adaption, the eNB adjusts the ratio between the LTE transmitting rate and that of Wi-Fi according to the current Wi-Fi signal strength.

Details of evaluation environment and scenarios are as follows.

- Test Environment
  - i) The LTE and WLAN radio antennas of the UE and those of the eNB are connected by wires where a radio attenuator is in the WLAN radio path as Figure 13
  - ii) The eNB transmits DL data to the UE by LWA after LWA is activated.
- Test Scenario and Result
  - i) Max throughput test :
    The eNB transmits 400 Mb/s DL data to the UE by aggregating 100Mb/s of LTE throughput and 300Mb/s of Wi-Fi throughput; the result is as expected and as illustrated in Figure 14.
  - ii) Dynamic LWA rate adaption :
    After LWA is activated, the eNB transmits 200Mb/s data to the UE. In the beginning, the transmitting data ratio of LTE to Wi-Fi is one to one. Then decreasing the Wi-Fi signal strength for 20s and then increasing the signal strength by adjusting the Wi-Fi attenuator. Observe the data throughput of LTE and Wi-Fi during the experiment. The result is as Figure 13; the Wi-Fi data throughput is reducing after the Wi-Fi signal strength becomes worse and start increasing after the Wi-Fi signal strength becomes better. The reason that the LTE throughput remains 100Mb/s as the Wi-Fi signal strength becomes worse is that it achieves the maximum throughput of LTE. At the end of this experiment, the throughput of LTE and Wi-Fi is about 50 Mb/s and 150 Mb/s which means the eNB forwards most data to WLAN when the Wi-Fi signal strength is good. That is just what we expect to use WLAN resource as far as possible.

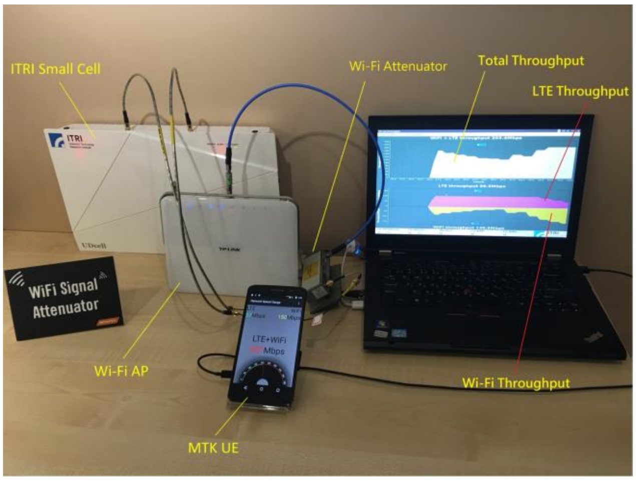

Figure 13 : ITRI LWA Display in MWC 2016 (1) – Environment and dynamic offloading

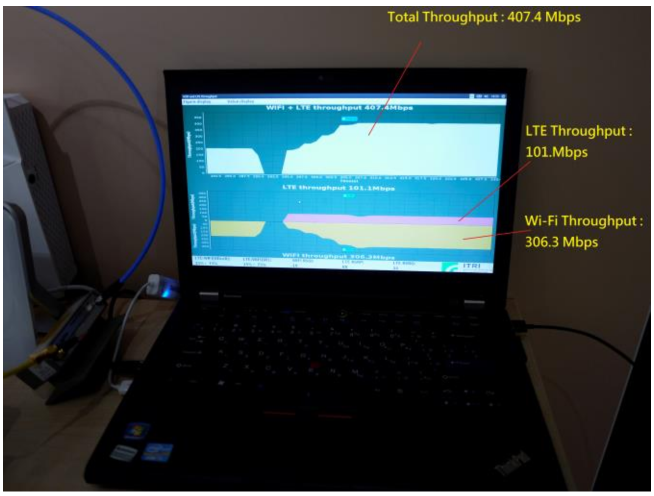

Figure 14 : ITRI LWA Display in MWC 2016 (2) – Max Throughput

C. Control Plane + Data Plane

The performance of control and data plane combined is also evaluated. In this category, the functionality and stability are the major evaluation factors as that in control plane. The scenarios in this category are to perform mobility procedures while LWA data transfer with small amount (e.g. 1Mb/s) is ongoing. The expected result is LWA data transfer resumed after successful mobility procedures. The scenarios verified in the prototype development prior to release 13 are as below.

- Wi-Fi AP change while 1Mb/s LWA data transfer.
- LTE handover while 1Mb/s LWA data transfer.

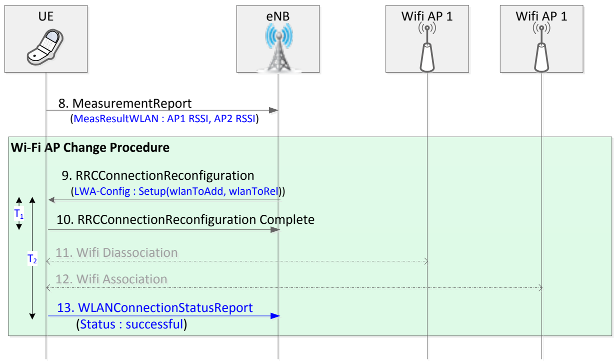

Figure 15 : Time for WLAN mobility

In addition to the functional verifications, the time for WLAN mobility is measured to evaluate the WLAN mobility performance. Figure 15 contains the small portion of Figure 11 that describes the Wi-Fi AP change procedure. In Figure 15, T_1 is the time of RRC reconfiguration message pair exchange to request the UE to perform WLAN mobility and T_2 is the total time of the WLAN mobility procedure. In the beginning of the experiment, 1Mbits/s downlink user data is transferred from the eNB to the UE via WLAN. During the duration of Wi-Fi AP change, eNB switches the user data transfer path from WLAN to LTE. The user data can be transferred via WLAN again after the UE connects to AP 2 successfully. Hence there is no data interruption as WLAN mobility though the data throughput may decrease due to smaller max bandwidth of LTE (100 Mb/s) than that of Wi-Fi (300Mb/s). The feature "seamless transmission as WLAN mobility" is one important advantage of LWA. The experiment results are as Table 4.

Table 4 : Time for WLAN mobility

Time Interval	Time
T_1	39.45 ms
T_2	39.57 ms

According to Table 4, the short period of data throughput drop is limited to 40ms when Wi-Fi AP adopts open system authentication (OSA).

V. Conclusion and Future Work

In this paper, we start from issues of existing LTE release leading to how to design control plane of LWA and introduce the LTE release 13 solutions. The collocated architecture in our LWA implementation adopting commercial Wi-Fi APs proves that LWA can be deployed without changing existing WLAN infrastructure. In addition to providing maximum 400 Mb/s capacity, we also present solutions for the WLAN mobility. By aggregating LTE and WLAN radio resources, our LWA implementation provides high data throughput and seamless data service when performing WLAN mobility. Our LWA prototype is a practical and affordable deployment for telecom operator to provide LWA service.

In future work, the research attempt is to investigate the integration of different aggregation technologies to fully utilize radio resource such as using CA (carrier aggregation) and LWA simultaneously. The more technologies are integrated, the more challenging for the eNB to manage radio resource efficiently. For example, using which technologies to transfer data from the eNB to a particular UE will have maximum throughput? How the eNB allocates radio resources from different RATs to meet various demands of multi-users? Those interesting problems will be important topics for further investigation.

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