

LTE-WiFi link Aggregation System Design for LTE-Unlicensed Spectrum utilization in Small-cells

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Abstract: In order to accommodate the exponentially-growing data traffic, LTE operators are considering the extension of their commercial operations by recognizing the opportunity offered both Wi-Fi technology and unlicensed spectrum for traffic offload. In a recent technical report for the third Generation Partnership Project, LTE-Wi-Fi link Aggregation (LWA) to support the unlicensed spectrum has been introduced. The report and other works in the literature reveal coexistence challenges that are raised when the LTE system coexists with other technologies such as Wi-Fi, with fairness being the primary challenge. In this work, we propose a preliminary design for a semi-distributed LTE-Unlicensed scheme where the LTE Base Station uses Wi-Fi-like carrier sense and Quality of Service facility techniques. Also describes LTE-Wi-Fi Aggregation architecture and operation that LWA can provide comparable performance to other technology innovations for the use of unlicensed bands. Concentrated focus is given to LWA deployment consideration to address operator desire to deploy the technology with minimum impact to the legacy Wi-Fi and LTE small cells infrastructure.

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I. Introduction

The exponential growth of mobile data traffic has become a serious concern for mobile network operators; particularly, it is a concern for the Long Term Evolution (LTE) systems which use a crowded licensed spectrum. Existing solutions include heterogeneous networks and small cell deployments; in addition, operators are considering the extension of the LTE operation into the unlicensed bands. This is referred to as "LTE-Unlicensed" (LTE-U), and recently the third Generation Partnership Project (3GPP) introduced the work item of "Long Term Evolution- Wi-Fi Link Aggregation" (L2A) to the unlicensed spectrum, where the unlicensed bands are aggregated with the licensed bands [1].

The extension of the LTE operation into the unlicensed bands introduces several coexistence challenges. In particular, the considered unlicensed bands are currently used by other technologies, namely 802.11 a/n (Wi-Fi), and using them for LTE will cause interference to these technologies, and consequently degrade their performance. This is mainly a concern for Wi-Fi performance, because Wi-Fi uses increasing random back-offs and inter-frame spacing to avoid collisions, while LTE uses continuous traffic generation with minimum time gaps even in the absence of mobile data traffic. As a result, the Wi-Fi stations will have minimal chances to access the medium when coexisting with the LTE system. The authors in [2] and [3] illustrate this problem by measuring the throughput degradation in LTE-Wi-Fi coexisting networks, showing a severe degradation in Wi-Fi performance (ranging between 70% and 100%) when coexisting with the LTE system. Solutions in the literature, which are surveyed in [2], include coordinated and uncoordinated techniques for solving the coexistence problem. Uncoordinated techniques include cognitive radio, least-congested channel selection, and power control; while coordinated ones typically rely on negotiating system parameters to reduce interference. One of the important solutions in the literature is the utilization of LTE Almost-Blank-Sub frames (ABSs), which are one-m time intervals during which the LTE activity is kept minimal to allow other technologies to use the medium [9].

In one of the research work [4], it is discussed the coordination challenges in the context of designing an LTE-Wi-Fi carrier aggregation scheme. In this paper, we extend our work to propose a design for a semi-distributed LTE-U-Wi-Fi scheme. In particular, we propose that the LTE base station (eNodeB) use Wi-Fi-like carrier sense, back-off, and Quality of Service (QoS) facility techniques in order to control the LTE's utilization of the unlicensed bands. Interference control is achieved by specifying ABS patterns which take both fairness and LTE cell load into consideration. In terms of scenario applicability, our scheme is useful in small cell environments, where within the coverage of the eNodeB, there may be one to very few Wi-Fi BSSs.

II. Insighton Technologies

In this section we briefly present these technologies and in-depth study of the specifications of the LTE and Wi-Fi standards, necessitated by the need to interface the two systems together.

A. Long Term Evolution

In LTE, the eNodeB connects a User Equipment (UE) to a Packet Data Network (PDN). The MAC Layer design of the eNodeB has most of the intelligence of the LTE system. The MAC functions include buffering packets from upper layers, encapsulating MAC Service Data Units (MSDUs) and vice versa, Adaptive Modulation and Coding (AMC), plus scheduling. We focus on the functions of the scheduler at the eNodeB MAC. It runs at the beginning of each 1ms sub frame, also known as Transmission Time Interval (TTI), where time-frequency Resource Blocks (RBs) are allocated to the UEs, and the scheduling decision cannot be changed until the end of the TTI. At the PHY layer, LTE adopts Orthogonal Frequency Division Multiplexing (OFDM)-based access schemes for the uplink and the downlink. These access schemes increase spectral efficiency due to their multi-carrier nature, where subcarriers from different non-adjacent frequency channels – including the Wi-Fi channels – can be used simultaneously. Six channel bandwidth configurations are defined in LTE, as illustrated in Table 1. These configurations specify the number of RBs that can be allocated to the UE from a given channel, where an RB is a $180 \text{ kHz} \times 1 \text{ slot} (0.5\text{ms})$ time-frequency resource. For example, a UE can be allocated up to 6 RBs ($180 \text{ kHz} \times 6 = 1.08 \text{ MHz}$) from a 1.4 MHz channel.

ChannelBandwidth(MHz)	1.4	3	5	10	15	20
ChannelConfiguration(RBs)	6	15	25	50	75	100

Table 1. LTE Channel Bandwidth Configurations

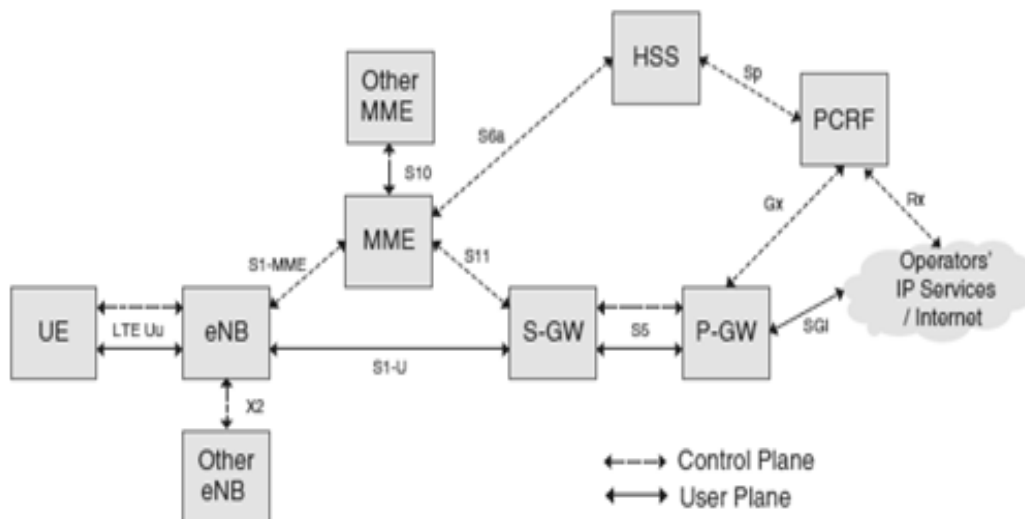


Figure: 1-The overall system architecture of Long term evolution.

There are two gateways that the IP flows must go through. In addition there is one control node. The Packet Data Network Gateway (PGW) is one of the gateway that is located between external IP networks and the LTE. For the downlink, IP flows are delivered to each destination node, which is referred to as User Equipment (UE). Next is the Serving Gateway (SGW) is another gateway that is located between PGW and eNodeB. SGW and PGW are connected via a S5 interface. In addition, SGW and eNodeB are connected via S1-U interface. Neighbour eNodeB 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 systems (EPS) bearer, security and mobility. MME and SGW are connected via S11 interface. In addition, MME and eNodeB are connected via S1-MME interface. An IP flow entering the LTE 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 radio. The maximum of EPS bearers is 11.

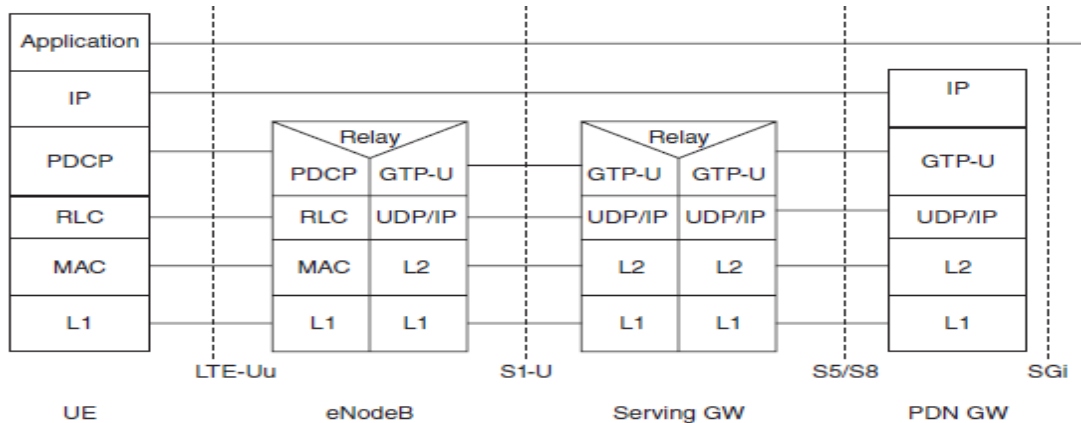


Figure: 2-Protocol stack of LTE –A User plane.

The above figure depicts overall protocol architecture of LTE. The routing mechanism of each IP flow is explained. Before starting the delivering of the IP flow, the PGW assigns an IP address to each UE and IP flow is mapped to the corresponding EPS bearer taking into the account the QoS level and delivered to each UE through General Packet Radio Service tunnel protocol (GTP) tunnel. In a particular GTP-U tunnel is established to deliver the IP flow as a user plane. The transport protocol is UDP/IP. IP flow filtering is performed the PGW and the UE for the QoS handling. For the downlink the filtering is carried 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 five-tuple(source/destination IP addresses, source/destination port numbers, and protocol types) as the result of 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 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 the necessary by the MME depending on, for example applications. The 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.

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 flowing. The 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 PDCP header is added to incoming IP packet and then it becomes as PDCP protocol data unit (PDCP-PDU), for DC there is a data split function for the downlink in eNodeB and routing function for the uplink in the UE, which enables simultaneous usage of two eNodeB. One radio bearer in the eNodeB is referred to as primary cell group bearer while one radio bearer in the secondary eNodeB is referred to as split bearer or secondary cell group bearer. For each split bearer the primary eNodeB can decide if the bearer is sent only by one of the eNodeB or sent by both the eNodeB, for each split bearer flow control function between primary eNodeB and secondary eNodeB is optionally specified in X2, where feedback indicating highest successfully delivered PDCP sequence number is informed from secondary eNodeB to primary eNodeB. To ensure in sequence delivery a PDCP packet data unit re-ordering is specified in the receiving side. A Radio link control (RLC) layer is an adaption layer for the packet transmission sent over the radio interface, the packet size is adjusted based on the latest wires lees channel quality by segmentation and concatenation of the packets. Automatic Repeat Request (ARQ) can be carried out when the packet has not been successful transited due to transmission errors over the radio. The packet is mapped to logical channel. The Media Access Control (MAC) controls radio access of the packet, the packet scheduling is performed considering Quality of service and wireless channel quality, the hybrid automatic repeat request (HARQ) must be performed when the packet has not been successfully transmitted due to transmission errors over the radio. The transmitting side added logical channel identifiers to MAC service data unit and sending the corresponding MAC-PDU to the receiving side. The receiving side finally de-maps radio bearer to EPS bearer based on the received logical channel identifier.

B. Wi-Fi

Our study of the Wi-Fi standard was based on the 802.11-2012 version of the standard [6], and the study is only concerned with the OFDM specifications. We selected OFDM Wi-Fi, first because of its similarity

to the OFDM-based access schemes of LTE, and second and more importantly because it uses the unlicensed and underutilized 5.8 GHz ISM band. The main component of the Wi-Fi architecture is the Wi-Fi Station (STA), which can be an AP-STA or a non-AP STA, where the former has additional access point capabilities. Moreover, STAs are classified as QoS and non-QoS STAs, depending on whether they support the enhanced QoS capabilities. STAs operate within what is called a Basic Service Set (BSS). A BSS is the basic building block of the Wi-Fi system, and can be thought of as a coverage area within which the member STAs may remain in communication. BSSs, are also classified into three types: Independent BSS (IBSS), also known as ad-hoc BSS, where STAs are able to communicate directly; Infrastructure BSS, controlled by an AP-STA; and Mesh BSS (MBSS), with distributed control rather than centralized control at the AP. When the AP in an infrastructure BSS is a QoS-AP, the BSS under its control is referred to as a QoS-BSS. The Wi-Fi MAC defines four channel access methods that are summarized below, where DIFS refers to the DCF Inter-Frame Space, which is one of the six inter-frame spacing (IFS) intervals defined in Wi-Fi. The fundamental channel access function in the Wi-Fi standard is the Distributed Coordination Function (DCF). It should be implemented in all Wi-Fi STAs and is based on the Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) protocol. In particular, a STA under the DCF operation tries to access the wireless medium with the following procedure: It uses a carrier sensing method to check for activity in the medium. If the medium is free, it waits for a DIFS and transmits if the medium remains free. Otherwise, it backs off for a random number of time slots. When the random duration passes, and given that the medium is still free, it transmits, and if the transmission fails due to a collision, it backs off again with a larger random window, up to a preconfigured upper limit. The Point Coordination Function (PCF), on the other hand, is required for Contention-Free services for non-QoS STAs, and is optional otherwise. It is a variation of DCF with an additional centralized priority called the Point Coordinator (PC), which is usually collocated with the AP. The QoS facility includes an additional coordination function called the Hybrid Coordination Function (HCF) that is only usable in QoS network configurations. The HCF shall be implemented in all QoS STAs except mesh STAs. The HCF offers analogous functions to the DCF and PCF, but with some enhanced QoS-specific mechanisms. These mostly concern grouping traffic into categories, and giving preference to higher priority traffic for transmission opportunities. The “replacement” functions are the Enhanced Distributed Channel Access (EDCA) mechanism for contention-based transfer, and the HCF Controlled Channel Access (HCCA) mechanism, for contention-free transfer. Finally, the Mesh Coordination Function (MCF) runs at Mesh-STAs, and is out of the scope of our study. Two carrier sense (CS) mechanisms are used to detect activity in the medium: A physical CS provided by the PHY, and a virtual CS provided by the MAC. The latter is based on setting the Network Allocation Vector (NAV), which represents a duration of time during which the STA defers from accessing the medium based on a prediction that the medium will be busy. The prediction is based on the duration information that is declared in the “Request-To-Send” and “Clear-To-Send” (RTS/CTS) frames that are sent when a STA attempts to reserve the medium before sending its actual traffic. In an LTE-Wi-Fi coexistence scenario, the PHY CS will be able to detect LTE traffic that is occurring on the Wi-Fi channels, and will cause the Wi-Fi STAs to defer from using the medium during LTE activity. On the other hand, the virtual CS cannot predict the LTE traffic, unless it is explicitly advertised. The above specifications need to be considered carefully when designing a coexistence scheme, as discussed earlier in the introduction and as it is well-elaborated in previous works.

III. Challenges of LTE Wi-Fi Aggregation

The challenges are described in the following from the transmitting side as well as receiving side point of view. From the transmitting side ciphering is applied when to an EPS bearer thus the Wi-Fi MAC layer cannot be identify the quality of service level of the EPS bearer since the PDCP packet data unit is ciphered, meaning that type of the service filed in the IP header is ciphered. The IEEE 802.11e is one of the WLAN variants supporting the quality of service aware packet handling where IP flows are classified into four quality of service levels referred to as access categories [3]. IP precedence/differentiated service code point field in the IP header or priority field in the virtual land tag are usually used so the id the IP header is ciphered, WLAN MAC cannot perform the quality of service handling of the EPS bearer. Similarly at the receiving side there is no local channel identifiers added in the WLAN packet data unit received by the WLAN, thus the receiver cannot identify the corresponding radio bearer and deliver the WLAN packet data unit to the corresponding EPS bearer. For the downlink the receiving side is the UE and it is the destination node, The UE just delivers the received data to the application layer and there may be no problem without identifying EPS bearers, however from the protocol point of view PDCP is protocol endpoint of the radio bearer so that it is better to perform the de-mapping from the AC to EPS bearer. For the uplink, the receiving side is the eNodeB but it is not the destination, the eNodeB should perform the de-mapping from the 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 logical channel identity is required.

IV. LWA - NETWORK ARCHITECTURE AND SOLUTION

The LWA network architecture supports two deployment scenarios: collocated and non-collocated. In the collocated case, the eNodeB and WLAN entities are assumed to be connected via an ideal link (e.g., they may be integrated in a common node), whereas the non-collocated scenario refers to the case when the eNodeB and WLAN entities are connected over a non-ideal backhaul.

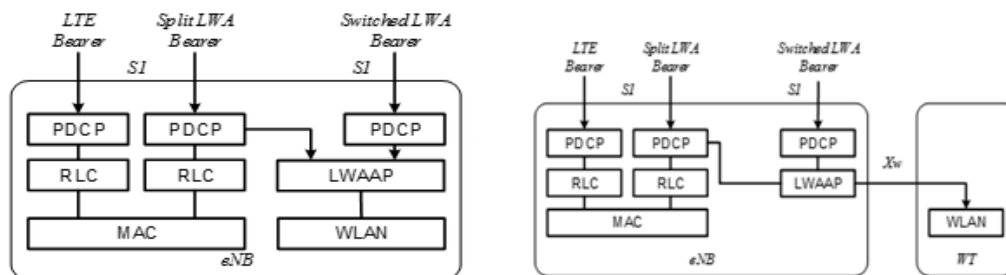


Figure: 3-An example of a collocated deployment Figure: 4-An example of a non- collocated deployment

In 3GPP developed the concept of a wireless termination (WT) node for logical representation of the WLAN system. The LWA feature does not impose any restriction on how the WT may be implemented; for example, it could be deployed as an enhancement of an existing WLAN node such as the access controller (AC) or AP, or be a separate node. An interface called Xw has been defined for control and data plane connectivity between the eNodeB and WT. In the data Xw utilizes the GPRS Tunneling Protocol for User plane using(GTP-U), and also has optional support for flow control and feedback. In the control plane, Xw supports functionality to add, modify and release WTs as well as reporting of WLAN measurements and (user equipment, UE) connection status from the WT to the eNodeB. It may be noted that the Xw interface borrows many features from the X2 interface enhanced for dual connectivity, developed by 3GPP. In LWA supports aggregation in downlink only, with the assumption that uplink transmissions are always on LTE. The LWA solution supports two kinds of data bearers: split and switched bearers. As the names suggest, packets belonging to a switched LWA bearer are always scheduled over Wi-Fi by the eNodeB, whereas packets belonging to split LWA bearers can be scheduled over either Wi-Fi or LTE. The LWA Adaptation Protocol layer (LWAAP) [6] serves as the interface between the PDCP layer and the Wi-Fi MAC layer. The LWAAP entity at the LTE eNodeB appends a one-byte header to each PDCP PDU to identify the data radio bearer (DRB) associated with the PDCP entity, allowing LWA to support transport of multiple DRBs. In order to allow the UE to de-multiplex Wi-Fi frames carrying LWA PDUs from other kinds of packets, a new Ether Type (a field in the 802.11 MAC header) was allocated by the IEEE Registration Authority Committee. The LWA feature contains new features for WLAN mobility management, measurements, and security. The LWA mobility function was designed to achieve a good balance between network control and UE flexibility based on the concept of a WLAN mobility set. The eNodeB configures the UE with a single mobility set that consists of a group of Wi-Fi APs. The mobility set can be specified by any combination of WLAN identifiers (SSIDs, HESSIDs, and/or BSSIDs). Within a mobility set, WLAN network selection is controlled by the UE, and mobility outside of the WLAN network mobility set is controlled by the eNodeB. A new WLAN measurement framework was developed to assist the eNodeB in LWA configuration (e.g., activating/deactivating LWA and mobility). The eNodeB can configure measurements for specific Wi-Fi identifiers (e.g., SSID) and frequencies (channel and/ or band). The WLAN measurement report includes WLAN received signal strength indicator (RSSI), and can optionally include other WLAN measurement metrics, based on the Hotspot 2.0 specification, such as admission capacity, uplink and downlink backhaul rates, channel utilization, and/or station count. 3GPP also decided to devise an eNodeB-based WLAN security mechanism as an alternative to the existing WLAN security mechanism based on EAP/AKA 802.1X-based authentication. It was felt that the existing WLAN security mechanism may be time consuming, and also not be available when the WLAN AP is not connected to the core network (and may not be able to access, say, an authentication, authorization, and accounting [AAA] server). The new security mechanism involves the eNodeB and the UE deriving a common key based on a counter sent by the eNodeB over LTE radio resource control (RRC) signaling. The eNodeB communicates the key to the WT over the Xw interface, and the WT in turn is supposed to distribute the key to the Wi-Fi APs/ ACs to which the UE may connect. It should be noted that the new security mechanism is optional, and LWA can be supported fully with the current WLAN security framework. It was felt that in some deployments, the user plane functionality for flow control and feedback supported by Xw may be unavailable. In fact, even the Xw interface may not be present. For such cases, 3GPP has developed a UE-based feedback mechanism for flow control. In this mechanism, the eNodeB can configure the UE's PDCP layer to report legacy PDCP status reports that contain the first missing PDCP SN (FMS) and a

bitmap indicating the reception status of PDCP packets with sequence number greater than FMS. Since the bitmap can potentially be large (especially when large sequence number lengths such as 15 and 18 bits are used), it was also decided to devise an enhanced status report called the LWA status report that contains the FMS, number of missing PDCP packets, and the SN of the highest received PDCP packet over WLAN.

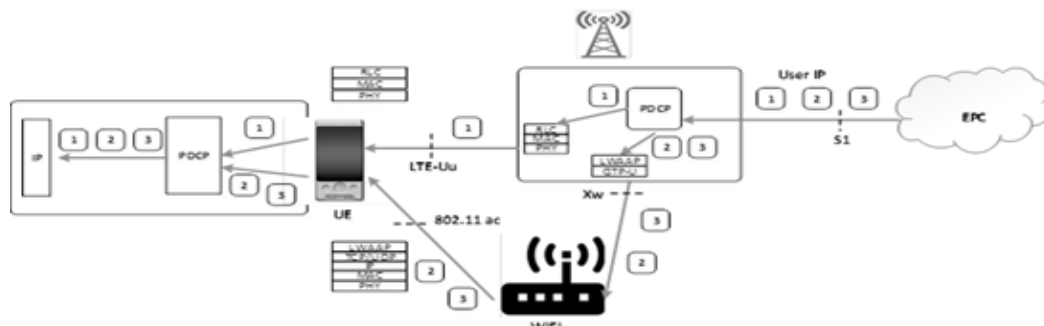


Figure: 5- PDCP level data aggregation

In the downlink data is split in eNodeB across LTE-Uu and Xw-U interfaces in PDCP layer. In this architecture, WT (Wireless Termination) is co-located with the Wi-Fi AP. In the above diagram, eNodeB receives packets 1, 2, and 3 from SGW (EPC) over S1 interface. PDCP layer of eNodeB splits the packets based on local policy, sends packet 1 on LTE-Uu interface and sends packets 2 and 3 over Xw interface. WT functional component of Wi-Fi AP receives the packets, removes GTP-U header and sends the packets to UE over WLAN/802.11ac interface. LWAAP layer of the UE removes LWAAP header and forwards the packets 2 and 3 to appropriate PDCP instance based on DRBID. Similarly RLC layer of the UE forwards the packet 1 to appropriate PDCP instance. PDCP layer of the UE aggregates the packets 1, 2 and 3 in proper sequence and send them to IP layer.

V. Conclusion

In this paper, LWA architecture and operation design has been explained and provided a simple analysis to study the impact of employing LWA technology, through the aggregation of unlicensed spectrum with licensed spectrum, allows communications service providers to add capacity and coverage to their networks. It also looks at LWA deployment options to demonstrate how a non-collated LWA can be deployed with minimum impact to the existing infrastructure which is limited to a software upgrade and without any changes required for the deployed legacy nodes. The Unlicensed spectrum and Wi-Fi interworking in particular will continue to be important to the operators in the coming 5G era. Additionally the IEEE community is currently evaluating the role in 5G with LWA/eLWA being one of the preferred options and allowing for IEEE to play a role in 5G development. The 3GPP NR (New RAT) study item includes requirements for tight interworking with Wi-Fi and licensed assisted operation. Unlicensed technologies are going to play an important role in responding to the growing demands from mobile operators and the Wi-Fi community. In conclusion deployment recommendations are provided based on potential operator service requirements and deployment constraints LWA provides technical and market advantages for considerations and tighter convergence through the building out of the network of access points and integrated small cell infrastructure is an approach that may prove to be attractive for the mobile operators that have well established Wi-Fi services and are aiming to operate in both the cellular and Wi-Fi markets.

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