

Unlicensed Spectrum LTE

Market Drivers and Roadmap



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EXECUTIVE SUMMARY

Global mobile data traffic will increase nearly eightfold between 2015 and 2020. Mobile data traffic will grow at a compound annual growth rate (CAGR) of 53 percent from 2015 to 2020, reaching 30.6 Exabyte per month by 2020.

Predictably, the current state-of-the-art for cellular networks (over licensed spectrum) will not support the expected traffic growth. Moreover, the extended range of Internet of Things (IoT) / Machine-to-machine (M2M) verticals currently being discussed in the industry raise several challenges defying the status quo of access infrastructure and opening a door for new technologies to rise on the license-exempt spectrum space.

Together, these market trends position license-exempt spectrum used for Wi-Fi and other wireless solutions as a platform for new technologies, innovative services and launch of innovative business models, creating some serious technical debates about coexistence which may prove to have broader value in the evolution of flexible spectrum usage.

The main goal of this project is to examine and contrast LAA, LWA and LWIP proposals, from the point of view of the business cases, the implications for operator deployments and roadmap.

At this stage several strong market drivers for LTE in unlicensed spectrum were identified:

- Increased Data Capacity
- No Spectrum Expense
- Direct Incorporation of Unlicensed Spectrum into the MNO's RAN and EPC

Technology and market landscape for LTE in unlicensed spectrum bands is continuing to evolve, and the usage scenarios and anticipated market impact are also only beginning to gel. As a result, this paper presents only a first phase view of how these technologies are progressing, and several further steps are recommended to continue to monitor and track how they mature. Especially, its interworking with Carrier Wi-Fi will unfold into several working streams in liaison with key industry forums.

As a result, the use cases and real-world deployment considerations will become more clear and targeted by vendors and operators. This, in turn, will provide more clarity about how the technology will impact the wireless market, and impact incumbent technologies (especially Wi-Fi) in nearby deployments.

WBA membership have approved a program which will focus on performance considerations and Wi-Fi coexistence impacts of LTE use of unlicensed spectrum based on commercial devices which will come to the market during 2017. Although the group's scope is still being defined, it may include end-to-end live testing, following the same approach as previous testing programs in WBA, such as the Next Generation Hotspot trial.

As part of the effort in this unlicensed LTE performance analysis program, this paper should be updated to reflect new knowledge on behaviours, features and coexistence characteristics.

1 Introduction and Goals

Global mobile data traffic will increase nearly eightfold between 2015 and 2020. Mobile data traffic will grow at a compound annual growth rate (CAGR) of 53 percent from 2015 to 2020, reaching 30.6 exabytes per month by 2020.

By 2020 there will be 1.5 mobile devices per capita. There will be 11.6 billion mobile-connected devices by 2020, including M2M modules - exceeding the world's projected population at that time (7.8 billion) [1].

Predictably, the current state-of-the-art for cellular networks (over licensed spectrum) will not support the expected traffic growth. Moreover, the extended range of Internet of Things (IoT) / Machine-to-machine (M2M) verticals currently being discussed in the industry raise several challenges defying the status quo of access infrastructure and opening a door for new technologies to rise on the unlicensed spectrum space.

Together, these market trends position unlicensed spectrum used for Wi-Fi and other wireless solutions as a platform for new technologies, innovative services and launch of innovative business models.



Figure 1. Limitless number of verticals to be addressed by Wireless Networks (source: Beecham research)

In this context, operators are looking to take advantage of unlicensed spectrum for LTE overload traffic. This has proved one of the most controversial issues in the wireless industry in 2016, but behind the politics, there have been serious technical debates about coexistence which may prove to have broader value in the evolution of flexible spectrum usage [2].

Several solutions are being developed to achieve this goal – and thus, there a number of different approaches to running LTE in unlicensed bands:

- 3GPP is developing three solutions in Release 13 and 14 [3] for unlicensed access integration using E-UTRAN as an anchor: License-Assisted Access (LAA), LTE-WLAN Aggregation (LWA), and LTE WLAN Radio Level Integration with IPsec Tunnel (LWIP)
- Additionally, 3GPP has continued to develop solutions which anchor the WLAN access in the operator's cellular network, using both trusted and untrusted access. Using these solutions an operator may route traffic over both licensed and unlicensed spectrum at different granularity levels (e.g. PDN level, IP flow level, etc.). If needed these solutions may also be complemented with other upper layer technologies (e.g. MPTCP, QUIC, etc.) to provide ever finer level of granularity for traffic routing. Contrasting with the E-UTRAN anchored solutions, a terminal device may continue to operate even in conditions in which cellular coverage is not provided, or the terminal is out of the cellular coverage
- LTE-U Forum is working on specifications for the LTE-Unlicensed (LTE-U) solution, and an initial version of the specification has been released

- Other proprietary solutions are being developed in the industry, such as MulteFire [5] for standalone LTE in unlicensed spectrum. Work is still in progress for most of these initiatives

Some of these solutions, e.g. LAA, will operate over the unlicensed spectrum which is also used by Wi-Fi, and therefore, several co-existence topics arise, such as performance, interference, quality of service & experience, and impacts to the end user. These have been studied extensively in the standards groups and necessary tests are currently being developed.

Although all the aforementioned solutions make use of unlicensed spectrum in the ISM bands, in addition to other bands, this project focuses more extensively on E-UTRAN based solutions from recognized standard bodies, in this specific case, 3GPP. Thus, the implementations addressed on this paper are the ones standardized by 3GPP in Release 13: LAA, LWA and LWIP. Standardized solutions in which WLAN access is anchored in the cellular operator core network are not covered by this paper.

For operators with some licensed spectrum, LAA, LWA and LWIP may provide increased capacity by using both licensed and unlicensed spectrum while also improving control and coverage from the macro deployment. These technologies though could potentially add to congestion challenges for Wi-Fi, weakening the competitive balance between cellular and Wi-Fi only providers. As result, industry consensus on this topic is fundamental.

As part of Vision 2020, the WBA has launched this new project to examine and contrast LAA, LWA and LWIP technologies, from the point of view of the business cases, the implications for operator deployments and roadmap.

Moreover, WBA intends to:

- Delineate and expose the market drivers for the 3GPP based unlicensed options, LAA, LWA and LWIP
- Conduct unlicensed spectrum end-to-end trials/interoperability, leveraging on past experience from Next Generation Hotspot trials underway since 2012
- Champion the development of IoT/M2M and wireless services over Unlicensed Spectrum, guaranteeing coexistence of technologies and convergence of services

2 Market Drivers for Unlicensed Spectrum use by LTE

The industry considers there are currently strong market drivers for running LTE in unlicensed spectrum, and therefore, its key dimensions are outlined on following sections.

2.1 Increased Data Capacity

Demand for data traffic have been increasing exponentially, and will continue to increase dramatically for years to come. In this context, increasing data throughput (capacity) via augmentation of the licensed LTE data path(s) with unlicensed path(s) is an effective way of coping with demand on a cost-effective basis.

2.2 No Spectrum Expense

The supply of (licensed) frequency spectrum allocated to cellular operators is very limited and operators have been feeling the crunch. Based on this, no spectrum licensing expenses and minimizing Cap-Ex increase required arise as key drivers for unlicensed solutions.

2.3 Direct Incorporation of Unlicensed Spectrum into the MNO's RAN and EPC

The new level of flexibility derives into several drivers in the perspective of the MNO:

- Seamless user experience when transitioning between Licensed-Only and Aggregated Licensed/Unlicensed operation
- Improving user mobility (coverage) while reducing/minimizing the core network signalling by integrating the unlicensed spectrum at the RAN Layer with standard LTE RAN/EPC interfaces
- Improving network-based control of the terminal through "transparent" ability for operators to add/remove unlicensed capacity to the LTE data service.

2.4 Summary of LAA, LWA and LWIP market drivers

LAA

- Utilize existing Carrier Aggregation (CA) solutions to aggregate licensed and unlicensed LTE paths
- Direct MNO management of unlicensed path(s) via LTE control mechanisms

LWA

- Utilize existing Dual Connectivity (DC) solutions to aggregate licensed LTE and unlicensed Wi-Fi paths for increased performance with limited changes to already deployed WLAN infrastructure

LWIP

- Utilize already deployed WLAN infrastructure without any changes (a Security Gateway has to be deployed between E-UTRAN and WLAN)

Joint LWA & LWIP

- Possibility for MNOs to partner with Fixed Wi-Fi Operators in non-co-located deployments (MNO - LTE RAN, Fixed Operator, Wi-Fi RAN)
- Perceived as more "coexistence friendly" to existing Wi-Fi services due to 802.11 transport

It is possible to draw the following conclusions –

- 1) Some drivers are in common to both LAA, LWA and LWIP:
 - Increasing throughput/capacity without additional licensed spectrum expense
 - Seamless user experience on licensed and unlicensed spectrum

- 2) Some aspects need more consideration from the industry and present tradeoffs
 - Enabling MNOs seamless integration with fixed Wi-Fi partners
 - Maintain MNO's ability to manage network
 - Balance the need of user input and preferences, operator policies and control;
 - Minimal impact on existing hardware (terminal, cellular network and WLAN)

3 Overview of Technologies for LTE Operation in Unlicensed Spectrum

The main objective of this section is to provide a high level overview of these technologies: who is the sponsoring body, architectural diagram, Wi-Fi coexistence mechanisms, protocol stack and other relevant information.

3.1 LTE-U

Long Term Evolution (LTE-U) is a radio access technology that has been proposed by the members of the LTE-U Forum for providing carrier-grade wireless service in the 5GHz unlicensed band. Published membership in the LTE-U Forum are: Alcatel-Lucent, Ericsson, Qualcomm Technologies Inc., Samsung Electronics & Verizon. Many of the details of the LTE-U signal and protocol can be found in published materials on the LTE-U Forum [website](#).

LTE-U operates using unlicensed spectrum as a Supplemental Downlink to primary LTE technology operation that is using licensed spectrum. LTE-U has some modifications to the normal LTE radio signal, but is predominantly a shift of the LTE signalling and protocol to the 5GHz band. As such, the primary market driver for LTE-U is the quick time to market, as a “pre-standard” technology, leading toward LAA, but with minimal changes needed to traditional LTE deployments and equipment to enable quick adoption.

Thus, architecturally, LTE-U is simply another variation of standard Supplemental Downlink LTE, except the SDL channel happens to be in the unlicensed band.

The LTE-U Forum has explicitly acknowledged the widespread use of Wi-Fi devices in the 5 GHz unlicensed spectrum, and has done a number of studies and requires certain technology behaviors to minimize coexistence interference. Specifically:

- Channel usage:
 - Initial channel selection is required to avoid channels in use by pre-existing Wi-Fi if possible. On-going channel monitoring supports changing to a more suitable channel periodically
 - If no clean channel is available, and co-channel operation is required, an “SCell DTX” algorithm is applied, to duty-cycle the LTE-U usage of the channel. This algorithm must comply with the CSAT procedure defined in “LTE-U CSAT Procedure TS Version 1.0”, published by the LTE-U Forum
- Opportunistic SCell switch off is used to quiet the use of the shared channel when SCell support is not needed. Note that LTE-U is only a supplementary, down-link service, so the primary (licensed) carrier is always available for control and lower bandwidth needs

Beyond laying out these guidelines, the LTE-U Forum documents explicitly do not specify or dictate the particular implementation or algorithms to be used. Thus, the definition of LTE-U is, in effect, created via the definition of a set of testing requirements for minimum coexistence with Wi-Fi.

To ensure LTE-U systems meet the above guidelines, a Coexistence Specification is published by the LTE-U Forum, with specific Test Cases that must be met by all LTE-U eNBs. These cover:

- Initial channel selection in the presence of an active, full-buffer Wi-Fi link
- Duty-cycle sharing of a channel with Wi-Fi that is heard by the eNB above -62 dBm. This test requires that a full-buffer Wi-Fi link results in a maximum duty cycle of 50% by the LTE-U DUT, maximum continuous “ON” duration of 20ms by the LTE-U DUT, and a minimum of 4 Mbps throughput on both the Wi-Fi and LTE-U links. Almost blank subframes are not considered to be “ON” for any of the tests

- Duty-cycle sharing in the presence of two full-buffer Wi-Fi links is similarly tested, with a maximum LTE-U duty cycle of 33%. Wi-Fi throughput is not measured in this test
- Sharing of a channel with Wi-Fi, when the Wi-Fi is carrying 4 VoIP traffic links. In this test, the voice streams must have similar measures on metrics of one-way delay, packet jitter and packet loss (including consecutive packet loss)
- Confirmation that an LTE-U eNB will switch to the “SCell OFF” state within some vendor specified time after all UEs have been removed from the coverage area. “SCell OFF” state means only periodic MIB and LDS transmissions may occur, at expected intervals of between 40ms and 160ms, with a duration in the order of milliseconds

These techniques have been analysed by the members of the LTE-U Forum, and in those studies have been shown to coexist well with Wi-Fi. However, other Wi-Fi industry players continue to have concerns about scenarios beyond those tested by the LTE-U Forum, including the protection of Wi-Fi networks detected at lower signal levels. The Wi-Fi Alliance (WFA) started a project, and held multiple public workshops, to investigate the impact of LTE-U when coexisting with Wi-Fi, in comparison to similar scenarios of coexistence between Wi-Fi networks. WFA has developed a Draft Coexistence Test Plan for LTE-U which just completed at the time of this writing.

The LTE-U Forum also continues to evolve the LTE-U specification, to both enhance the coexistence behaviour, and to move the technology closer to LAA. For example, the most recent change (as of this writing) is extensions to allow spontaneous UE detection of LTE-U transmissions, which allows more flexibility of timing of the LTE network usage of the channel.

The WBA will continue to monitor the evolution of the LTE-U technology and market penetration. However, since this is a “pre-standard” and promoted by a private organization (LTE-U Forum), this whitepaper does not explore this technology further in the next sections.

3.2 LAA

3.2.1 Introduction

Licensed Assisted Access (LAA) is a technology that enables operators that have access to licensed spectrum to complement it with unlicensed spectrum while leveraging the existing and planned investments in LTE/EPC, i.e., hardware and software in the radio and core network. The access to unlicensed spectrum is done via a Secondary Component Carrier (SCell) which is assisted by a Primary Component Carrier (Pcell) on licensed spectrum using the Carrier Aggregation Framework of LTE [6].

LAA is part of 3GPP Release-13 and the main objective is to deliver enhancements to LTE for operation in the 5 GHz band.

Fair co-existence with other technologies operating in unlicensed spectrum is a fundamental design principle for LAA.

Based on the principle of carrier aggregation, the LAA designs aim to combine the best of the licensed and unlicensed band opportunities while reducing operators’ operating costs:

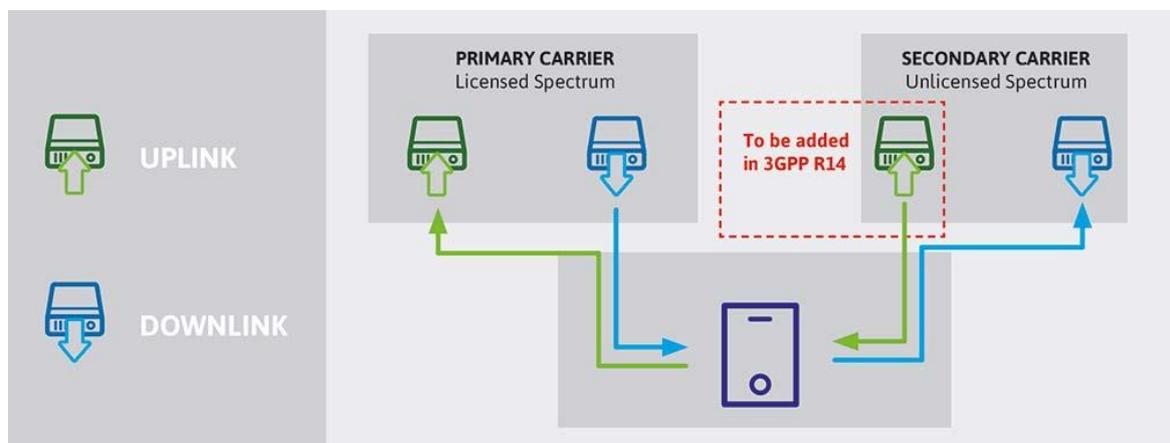


Figure 2. LAA Building Blocks

The system starts with a Primary Cell (PCell) in licensed spectrum that is used for the exchange of essential control messages. The PCell also provides a robust link over licensed spectrum that is always available for delivery of real-time or high-value traffic.

The LAA Secondary Cells (SCells) carry data transmissions in unlicensed spectrum with assistance from the PCell. With this approach, operators only need to manage and maintain one radio access network, which can be beneficial in reducing operating costs and simplify service provisioning.

3.2.2 LAA System Features

The main design guidelines of an LAA system are listed below:

- A single global solution framework that allows compliance with any regional regulatory requirements
- A single global solution framework for LAA is defined, which ensures that LAA can be operated according to any regional regulatory requirements. Furthermore, LAA provides sufficient configurability to enable efficient operation in different geographical regions
- Effective and fair co-channel coexistence with Wi-Fi
- The LAA design includes fair coexistence with existing Wi-Fi networks to not impact Wi-Fi services more than an additional Wi-Fi network on the same carrier, with respect to throughput and latency
- Effective and fair co-channel coexistence among LAA networks deployed by different operators
- The LAA design includes fair coexistence among LAA networks deployed by different operators so that the LAA networks can achieve comparable performance, with respect to throughput and latency

Based on these guidelines, the following features are required for an LAA system:

- Carrier selection
- As there is a large available bandwidth of unlicensed spectrum, carrier selection is required for LAA nodes to select the carriers with low interference and with that achieve good co-existence with other unlicensed spectrum deployments
- Listen-before-talk (Clear channel assessment)
- The listen-before-talk (LBT) procedure is defined as a mechanism by which equipment applies a clear channel assessment (CCA) check before using the channel. The CCA utilizes at least energy detection to

determine the presence or absence of other signals on a channel in order to determine if a channel is occupied or clear, respectively. European and Japanese regulations mandate the usage of LBT in the unlicensed bands. Apart from regulatory requirements, carrier sensing via LBT is one way for fair sharing of the unlicensed spectrum and hence it is considered to be a vital feature for fair and friendly operation in the unlicensed spectrum in a single global solution framework

- Discontinuous transmission on a carrier with limited maximum transmission duration
- In unlicensed spectrum, channel availability cannot always be guaranteed. In addition, certain regions such as Europe and Japan prohibit continuous transmission and impose limits on the maximum duration of a transmission burst in the unlicensed spectrum. Hence, discontinuous transmission with limited maximum transmission duration is a required functionality for LAA
- Dynamic frequency selection for radar avoidance in certain bands/regions
- Dynamic frequency selection (DFS) is a regulatory requirement for some frequency bands, e.g., to detect interference from radar systems and to avoid co-channel operation with these systems by selecting a different carrier on a relatively slow time scale
- Transmit Power Control
- Transmit Power Control (TPC) is a regulatory requirement in some regions by which the transmitting device should be able to reduce the transmit power in a proportion of 3dB or 6dB compared to the maximum nominal transmit power

3.2.3 Deployment scenarios for LAA

This section describes possible deployment scenarios for LAA. LAA deployment scenarios encompass scenarios with and without macro coverage, both outdoor and indoor small cell deployments, and both co-location and non-co-location (with ideal backhaul) between licensed and unlicensed carriers. Figure 3 shows four LAA deployment scenarios, where the number of licensed carriers and the number of unlicensed carriers can be one or more. As long as the unlicensed small cell operates in the context of the carrier aggregation, the backhaul between small cells can be ideal or non-ideal. In scenarios where carrier aggregation is operated within the small cell with carriers in both the licensed and unlicensed bands, the backhaul between macro cell and small cell can be ideal or non-ideal.

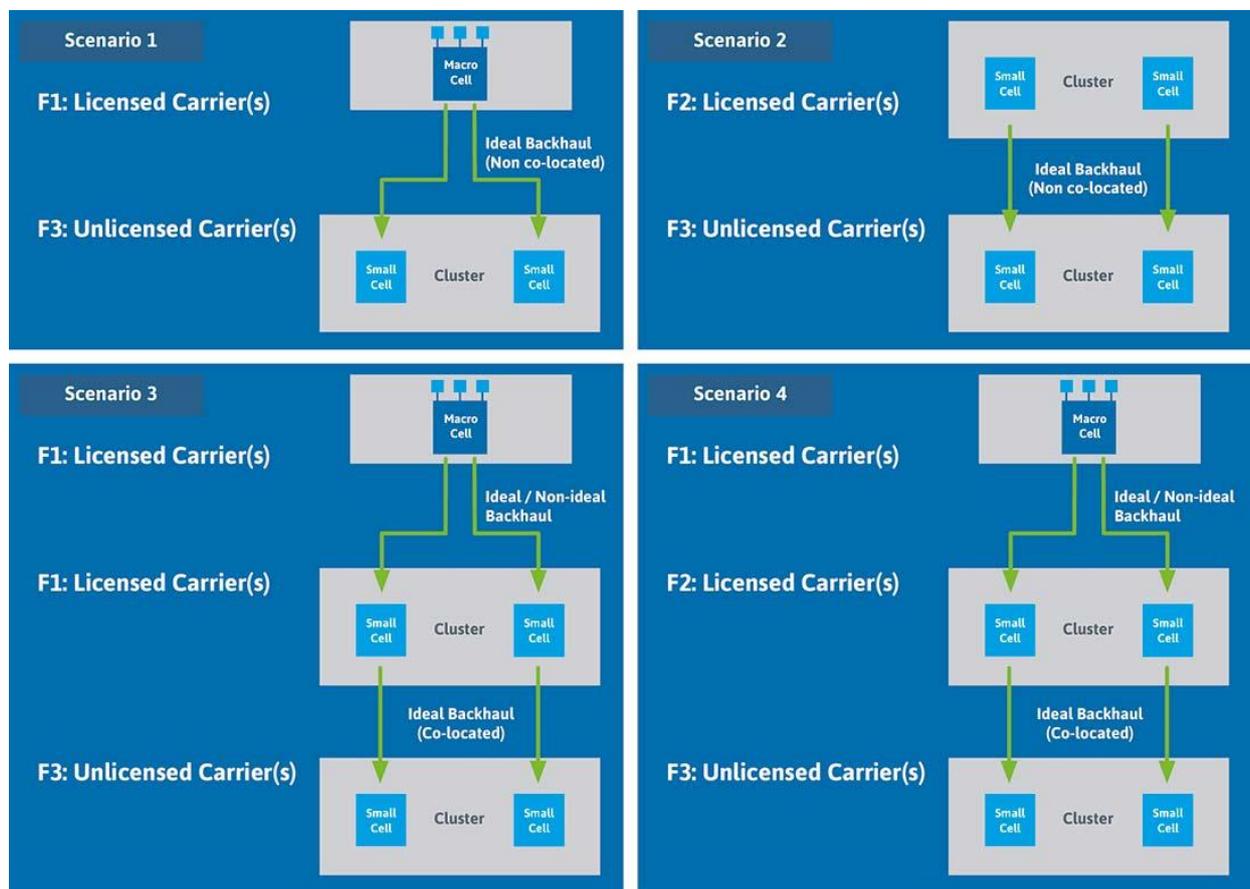


Figure 3: LAA deployment scenarios

- Scenario 1
 - Carrier aggregation between licensed macro cell (F1) and unlicensed small cell (F3)
- Scenario 2
 - Carrier aggregation between licensed small cell (F2) and unlicensed small cell (F3) without macro cell coverage
- Scenario 3
 - Licensed macro cell and small cell (F1), with carrier aggregation between licensed small cell (F1) and unlicensed small cell (F3)
- Scenario 4
 - Licensed macro cell (F1), licensed small cell (F2) and unlicensed small cell (F3)
 - Carrier aggregation between licensed small cell (F2) and unlicensed small cell (F3)
 - If there is ideal backhaul between macro cell and small cell, there can be carrier aggregation between macro cell (F1), licensed small cell (F2) and unlicensed small cell (F3)
 - If dual connectivity is enabled, there can be dual connectivity between macro cell and small cell

3.3 LWA and LWIP

3.3.1 Background

Mobile network operators (MNOs) have already had various solutions for the integration of the cellular and WLAN infrastructure through the Core Network using both trusted and untrusted WLAN deployments (3GPP TS 24.302). In all these solutions, the anchoring point of the WLAN infrastructure in the MNOs network is at the P-GW node.

Core network based solutions offer various levels at which the traffic may be seamlessly offloaded between cellular and WLAN access. This may be done at either PDN level, IP flow level, application level, etc. Finer granularity of offload, if needed, may also be achieved when such solutions are combined with application level proxies (e.g. MPTCP proxies).

MNOs may control the offload of the traffic from one access to another through ANDSF provisioned policies and/or RAN assisted WLAN interworking,

The RAN rules (i.e. access network selection and traffic steering rules) and ANDSF with RAN assistance information defined in Release 12 allow a MNO to develop offloading policies that take into account the access conditions on both cellular and WLAN as well as the load of the cellular access.

For traffic steering via RAN rules, the MME may provide information to the UE indicating which PDN Connection can be offloaded to WLAN; these decisions are not applicable to non-seamless WLAN offload.

ANDSF supports policy for WLAN access selection and policy for traffic steering between WLAN and 3GPP access network and for NSWO (Non-Seamless WLAN Offload) for both trusted and untrusted access. In Release-12 ANDSF was completely revised and extended to support: 1) inclusion of the HS2.0 parameters in network selection and traffic steering policies; 2) creation of a new WLANSF object for allowing enhanced policies for network discovery and selection; and 3) enhancement of both WLAN network selection and traffic steering rules with policies based on access condition for both cellular and WLAN through the use of RAN assistance information.

The core network based solutions offer the operator both control capabilities, at various level of granularity, and improved coverage by using both licensed as well as unlicensed spectrum. However, one of the shortcomings of these solutions may be related to the anchor point which is represented by the Core Network (P-GW). Because of this, these solutions have the overhead and latency of RAN-CN signalling for traffic routing decisions. In case of traffic offload from transitioning from one access to another is done through signalling to the core network. This may contribute to a signalling overload situation as well as impact the user experience due to higher latency while adjusting to the traffic conditions over the available accesses.

LWA and LWIP were developed in Release 13 to address these potential shortcomings. These solutions use the 3GPP E-UTRAN as an anchor point where the WLAN is connected to the eNB, thereby also eliminating any impacts on the Core Network. Furthermore, making the offloading decisions at the access network can be based on real-time user and reducing CN signalling. network conditions can allow improving system and user performance. It is assumed that an eNB is connected to WLANs that are under its coverage as LTE connectivity is required for these solutions.

LWIP was designed to minimize the impact to legacy WLAN allow fast time-to-market deployment, while LWA re-uses is based on Dual Connectivity split-bearer solution 3c for proven substantial performance gains, compared to other LTE/WLAN integration solutions.

3.3.2 LWA

3.3.2.1 Introduction

LWA (TS 36.300, section 22A.1) is built upon 3GPP Release 12 Dual Connectivity solutions, specifically options 2C (bearer switching) and 3C (bearer split), providing traffic aggregation of a single bearer (or a single IP flow/application) over both licensed (LTE) and unlicensed (WLAN). [7].

In LWA, a UE in RRC_CONNECTED is configured by the eNB to utilize radio resources of LTE and WLAN. The eNB supporting LWA is connected to WLAN via an ideal/internal backhaul in the collocated deployment scenario or a non-ideal backhaul in the non-collocated deployment scenario. For the latter UE signals its capability for LWA which also includes the supported WLAN bands. There is also a separate capability for UE support of WLAN measurements.

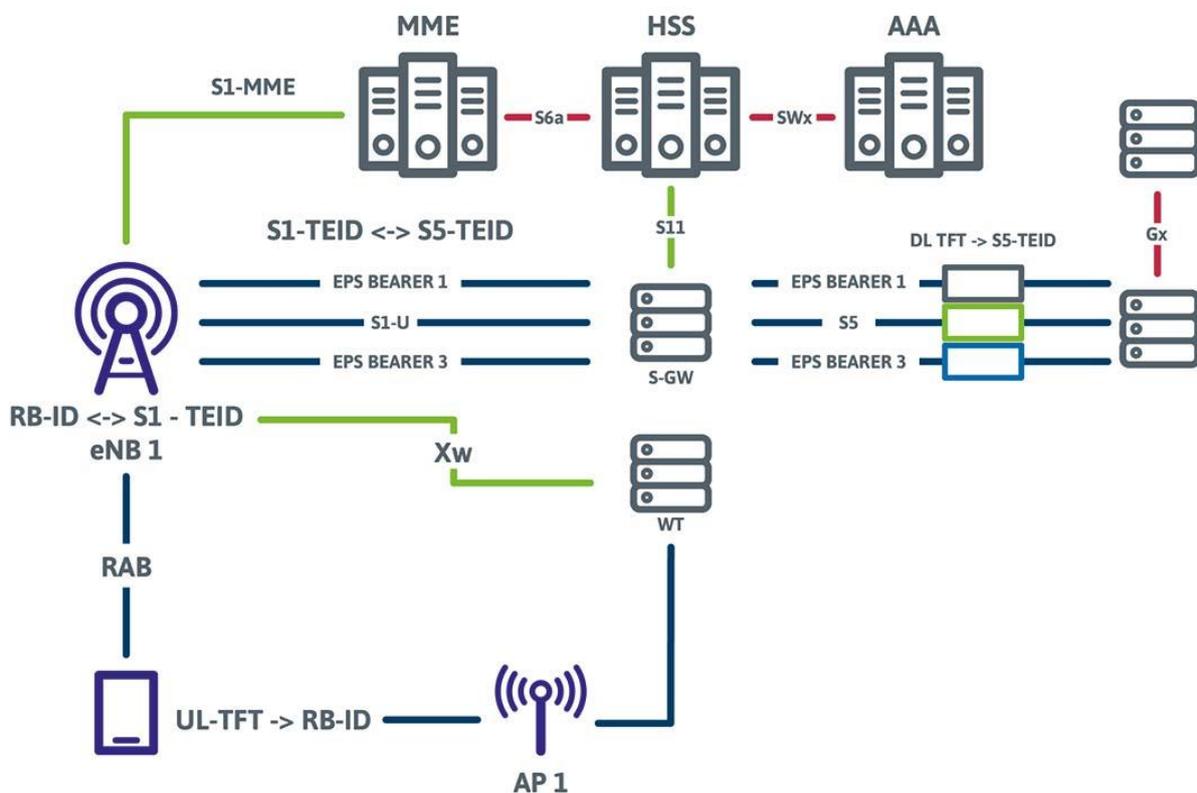


Figure 4. LWA Architecture

3.3.2.2 Radio Protocol Architecture

In LWA, downlink PDCP PDUs are generated by the eNB PDCP entity and transferred to the UE via LTE RLC/MAC and/or WLAN, as depicted in Figure 5 for the collocated deployment scenario and in Figure 6 for the non-collocated deployment scenario below.

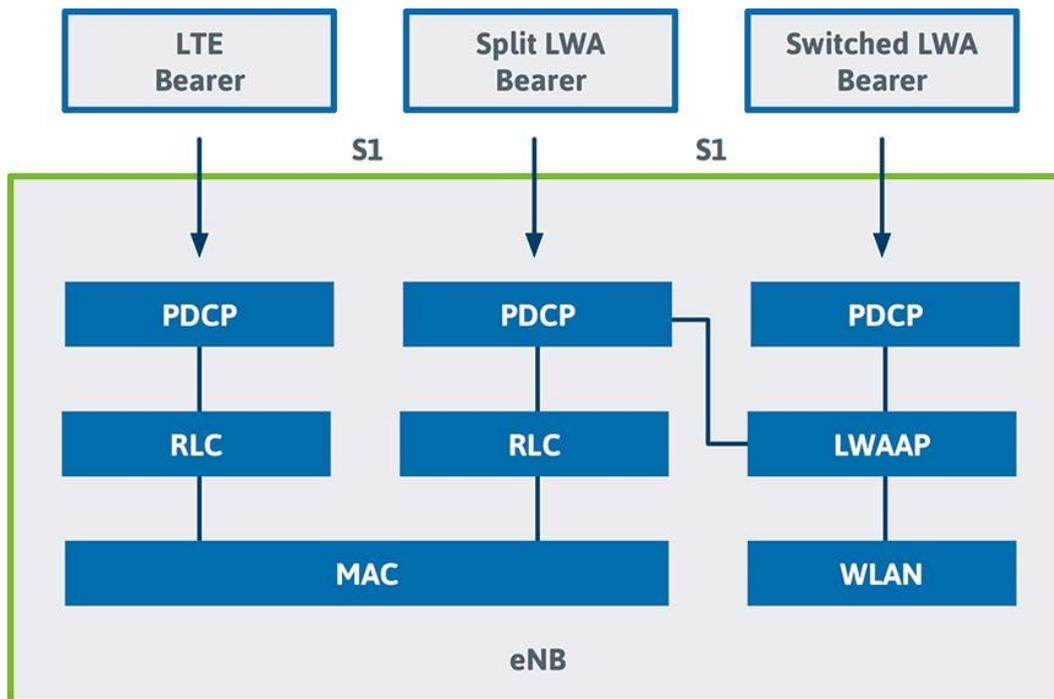


Figure 5. LWA Radio Protocol Architecture for the Collocated Scenario

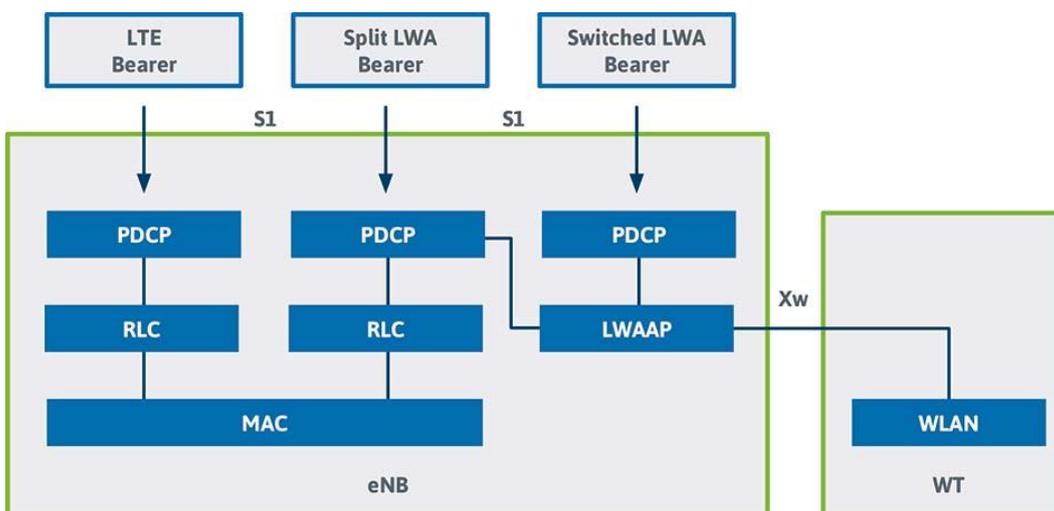


Figure 6. LWA Radio Protocol Architecture for the Non-Collocated Scenario

In LWA, the UE may be configured with multiple data radio bearers (DRBs) utilizing WLAN. There is a LWA Adaptation Layer (LWAAP) at the eNB which inserts a DRB identity to the LWA PDU, which is used by the UE to identify the bearer a PDCP PDU belongs to.

LWA supports split bearer operation on downlink in which a bearer is configured to use both eNB and WLAN resources. For split bearer operation, PDCP sublayer supports in-sequence delivery of upper layer PDUs based on Dual Connectivity reordering procedure. LWA supports transmission of uplink PDCP PDUs on LTE. In Release-14, eLWA will introduce split bearer on uplink as well.

LWA also supports switched bearer operation in which all the PDCP PDUs of the same DRB are served over one access (either LTE or WLAN). If the UE does not signal capability for split-bearer operation, the eNB may not use this option. The UE is not informed whether the eNB will use split and switched operation for a bearer and thus this is left to the eNB scheduler implementation.

The UE can be configured to report PDCP status to the eNB to inform its data reception status in the form of missing PDUs and highest sequence number received on WLAN. This information can be used by the eNB for flow control as well as possible retransmissions (e.g. use LTE link if data delivery on WLAN fails).

3.3.2.3 WLAN Measurements and Mobility

The eNB configures UE to report WLAN measurements to activate and deactivate LWA as well as assist with WLAN mobility. The measurement configuration includes WLAN identifiers and channel information and the UE report includes Wi-Fi RSSI and, if configured and can be acquired, other metrics such as STA count, admission capacity, backhaul rates, and channel utilization.

The mobility for LWA allows the flexibility to use the conventional WLAN mobility (STA driven) and LTE mobility (eNB driven). To this end, the eNB configures a WLAN mobility set in which the UE can perform WLAN mobility without signalling to the eNB. This mobility set is in the form of a set of WLAN identifiers (SSID, HESSID, or BSSID). If the UE cannot find a suitable AP within this set (WLAN RSSI is less than a configured threshold), it triggers an event and reports WLANs which it can find outside the mobility set (whose WLAN RSSI is greater than a configured threshold). The eNB can update the mobility set using this information.

3.3.2.4 LWA Security

The authentication for LWA can use the already existing 802.1x based mechanisms. However, since these methods have a large latency and require connectivity between WLAN and CN, an optional more optimized WLAN authentication procedure which is similar to 3GPP Dual Connectivity was introduced for LWA. In this method, the eNB derives a key which is delivered to the WLAN Termination (WT) to be used as the Pairwise Master Key and the UE derives the same key based on input values signalled from the eNB. In the absence of such signalling from the eNB, the UE can use the existing methods for authentication.

The user plane data for LWA is protected by PDCP ciphering; however, WLAN encryption is also used since authentication without data protection is not allowed for WLAN.

3.3.2.5 Network Interfaces

In the non-collocated scenario, the eNB is connected to one or more WT logical nodes via an Xw interface. In the collocated scenario, the interface the eNB and the WLAN is up to implementation.

User Plane

The Xw user plane interface (Xw-U) is defined between eNB and WT. The Xw-U interface provides non-guaranteed delivery of user plane PDUs. The transport layer for data over Xw-U is built on IP transport and

GTP-U over UDP over IP is used to transport the data streams. The Xw-U interface supports the flow control function based on feedback from WT.

The Flow Control function is applied when an E-RAB is configured to use WLAN and only for DL i.e. the flow control information is provided by the WT to the eNB for the eNB to control the downlink user data flow to the WT and to avoid that more than half the PDCP sequence number space is brought in flight.

Xw-U interface is used to deliver LWA PDUs between eNB and WT which contain LWA header with DRB Identity and payload of PDCP PDU. The S1-U from S-GW terminates in the eNB and if a data bearer configured for LWA, its downlink user plane data is transferred from eNB to WT using the Xw-U interface.

Control Plane

The Xw control plane interface (Xw-C) is defined between eNB and WT and the application layer signalling protocol is referred to as Xw-AP (Xw Application Protocol). There is only one S1-MME connection per LWA UE between the eNB and the MME and respective coordination between eNB and WT is performed by means of Xw-AP.

The Xw-AP protocol supports the following functions:

- Setting up the Xw and Resetting Xw
- WT Configuration Update: This function allows updating of application level data needed for the eNB and the WT to interoperate correctly on the Xw interface
- WLAN Status Reporting: This function allows the eNB to configure reporting of load-related information from the WT
- LTE-WLAN Aggregation: This function allows the eNB to request a WT to provide radio resources for a certain UE while keeping responsibility for that UE

Other

Provisions have been made to allow LWA deployment with limited WLAN infrastructure impact. To this end the network may configure the UE to provide association confirmation via RRC signalling and feedback via PDCP signalling, in case association confirmation indication and flow control on the Xw interface are not available. This feature, together with the option to use legacy EAP/AKA authentication, allows LWA deployments without any changes to the WLAN, e.g. with standalone WT deployment.

Next Steps

LWA is being enhanced in Release-14 as part of the eLWA Work Item, which adds uplink aggregation, support for 60Ghz band (WiGig) and other enhancements. With 60Ghz support in the millimetre wave spectrum, LWA can utilize unlicensed bandwidth of up to 7Gbps with 802.11ad and in the future up to 20Gbps with 802.11ay.

3.3.3 LWIP

LWIP (TS 36.300, section 22A.3) has defined a LTE/WLAN Radio Level Integration with IPsec solution with bearer switching which addresses legacy WLAN deployment scenarios.

In LWIP, the terminal device uses an IPsec tunnel over the WLAN infrastructure. For security reasons, the IPsec tunnel is terminated at a security gateway that is interfaced with the eNB. A single IPsec tunnel per terminal is used for both uplink and downlink data that is transported over WLAN. The interface between the eNB and the LWIP-SeGW has not been specified in Rel-13. However, 3GPP will specify the interface in release 14 to guarantee the needed security.

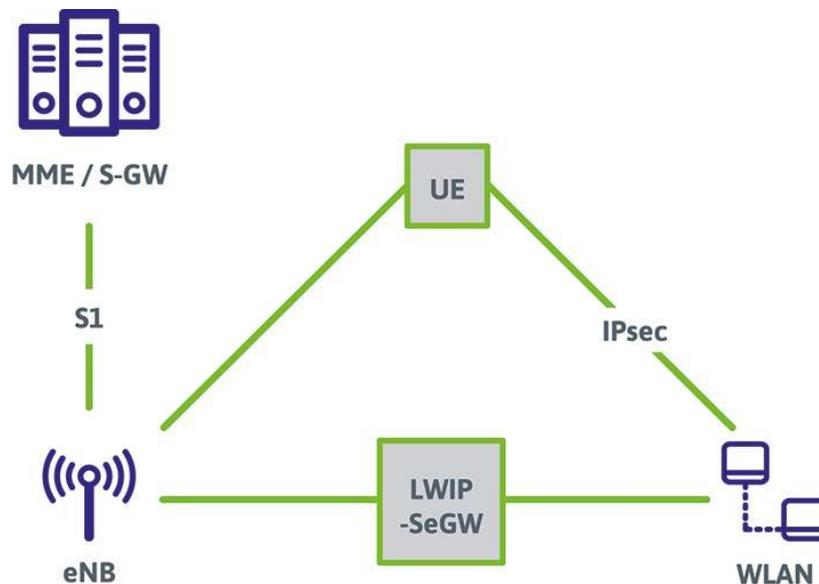


Figure 7. LWA Radio Protocol Architecture for the Collocated Scenario

LWIP Data Plane

In LWIP, both uplink and downlink data can be supported over WLAN and multiple bearers can be offloaded via the same IPsec tunnel. In uplink the PDCP SDUs, i.e. IP packets, are padded with a GRE header in order to allow carrying bearer identifier information that may need to be used at the eNB.

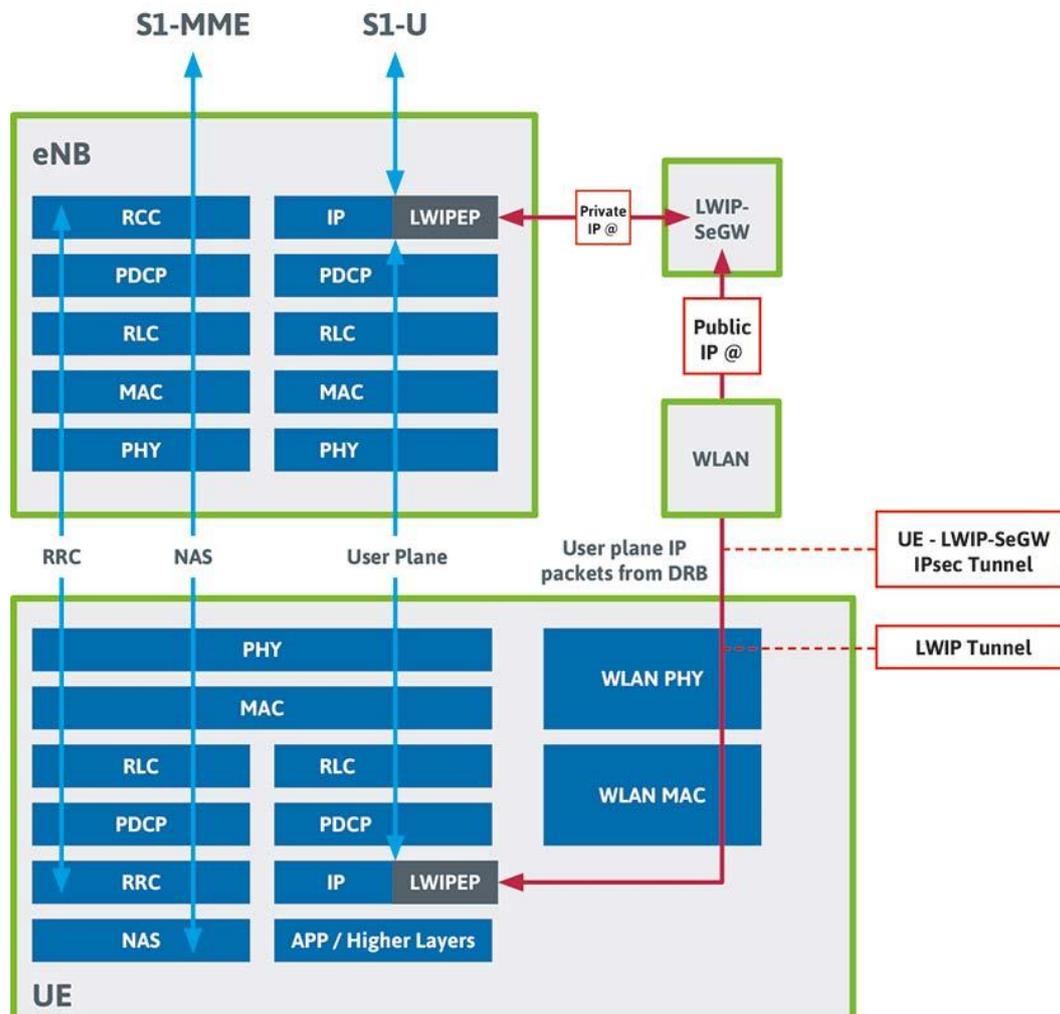


Figure 8. LWA Radio Protocol Architecture for the Collocated Scenario

LWIP Control Plane

The use of LWIP by a terminal device is entirely controlled by eNB in a similar manner as in the case of LWA. When LWIP is activated, the eNB sends a set of WLAN identifier, bearer information and LWIP SeGW IP address. This information may be used by the terminal to connect to the LWIP-SeGW through an IPsec tunnel over the WLAN identified through one of the WLAN identifiers provided by the eNB. After WLAN association and EAP/AKA authentication, the UE establishes IPsec connection with LWIP-SeGW using IKE. The IPsec keys are derived by both eNB and the UE based on the KeNB.

LWIP reuses the same WLAN measurement framework and WLAN mobility concept as LWA.

- Next Steps
- In release 14, an eLWIP (enhanced LWIP) WI will add specification of flow control, and a WLAN measurement framework.

3.4 Standalone

LTE can also be deployed in unlicensed spectrum (e.g., 3.5 GHz, 5 GHz) without being anchored with a licensed carrier. With this option, unlike LAA or LWA/LWIP, all the signalling and data are carried over the unlicensed carrier. The primary motivation for this is to combine the enhanced performance of LTE (capacity, range, and mobility) with the deployment simplicity (similar to Wi-Fi) of unlicensed spectrum. This can broaden the LTE ecosystem to more entities such as ISPs, cable operators, and enterprise/venue owners and enable both offloading and neutral host deployments.

One initiative to enable standalone unlicensed operation of LTE is the MulteFire Alliance (www.multefire.org) which announced its formation in December 2015. The Alliance is currently working on developing the MulteFire technical specifications as well as establishing a product certification program. A key principle for this design will be fair co-existence with Wi-Fi which will be based on methods used by LAA.

4 Unlicensed Spectrum LTE relationship with Carrier Wi-Fi

4.1 Carrier Wi-Fi (CWLAN) Guidelines Program

WBA develops and maintains end-to-end guidelines and best-practices for CWLAN that consolidate the views of key ecosystem players, including carriers, vendors and hubs. The main objectives of these end-to-end guidelines are:

- Bring a joint perspective from members and relevant industry bodies to define CWLAN
- Identify its components, focusing on the business perspective
- Clarify the Industry with a roadmap for operators to develop CWLAN Networks
- Identify a clear path for operators to develop a CWLAN service
- Promote a wide alignment with other industry forums on the definition of CWLAN

The program develops and publishes industry consensus regarding the characteristics of a CWLAN with features that must be supported by the infrastructure and the terminal devices, network architectures and implementation methods that support operator-managed Wi Fi services, and user-experiences and operational best-practices typical of service provider networks. The figure below depicts the overall conceptual network attributes identified for carriers when deploying CWLAN.

- Consistent User Experience
- Full End to End Integration
- Improved Network Management

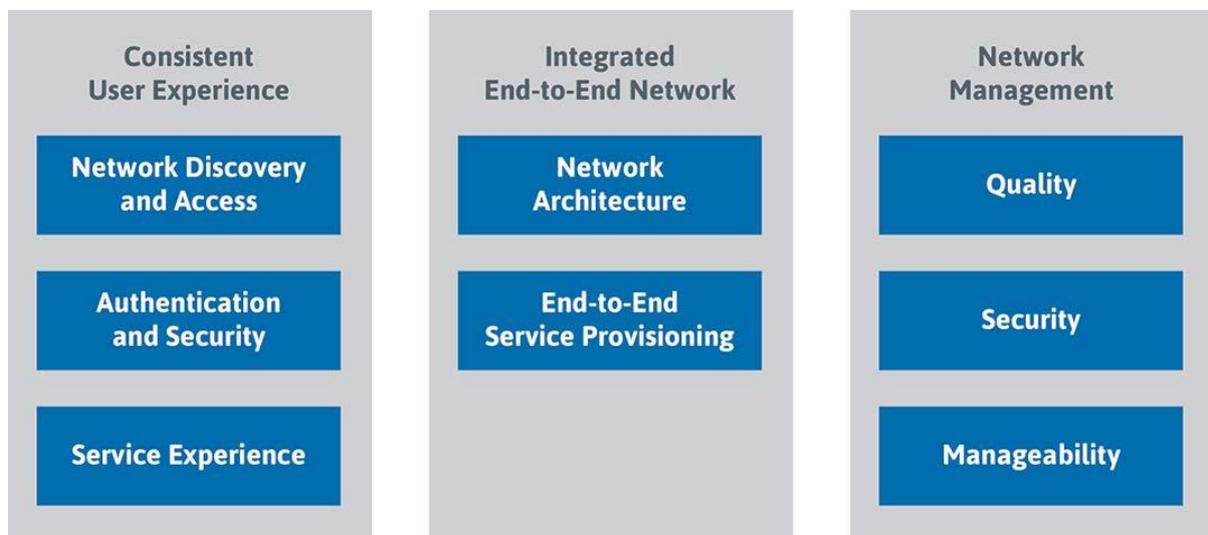


Figure 9. Carrier Wi-Fi – Network attributes

The complete document is available on the WBA extranet: “WBA Carrier Wi-Fi Guidelines v1.0 (final)” for WBA members only.

4.2 Relation of LTE/Wi-Fi RAN Interworking and Carrier Wi-Fi

Leveraging on LTE/Wi-Fi RAN Interworking development, the following considerations may be derived:

- Current requirements follow 3GPP principles and therefore they might be related/aligned with Carrier Wi-Fi principles (e.g. interworking with cellular)
- Depending on the use cases and different deployment scenarios Carrier Wi-Fi might be implied (e.g. overlapping coverage)
- Network/device configurations may impact Carrier Wi-Fi (e.g. policy)

Definition of use cases / potential scenarios to be analysed:

- Basic connection on single operator managed networks (3GPP and Wi-Fi) – Device can either use LWA/LWIP or connect directly to Wi-Fi
- Basic connection on multi operator managed networks (3GPP and Wi-Fi) – Device can use LWA/LWIP based on home LTE network and local partner Wi-Fi network (e.g. Cable Operator, Wi-Fi Operator)
- Basic connection on roaming scenarios – Device can use roaming partner LTE network and roaming partner Wi-Fi network
- Hotspot2.0 connection on roaming scenarios – Device can use roaming partner LTE network and roaming partner Wi-Fi network based on automatic Passpoint connection
- LWA/LWIP and Hotspot2.0 overlapping roaming scenarios decision – Device can either associate to LWA/LWIP or Passpoint only, based on network parameters (e.g. Backhaul bandwidth, Network loading), operator policy and others to be identified

Based on the identified use cases / scenarios, one can assume there is no standard/mechanism for the operator to control policy on LWA/LWIP related solutions

The group will monitor the technology evaluation and liaise the identified gaps to relevant organizations so further inputs can be collected once the group reconvenes. This might also constitute the basis of the test cases and a potential timeline.

4.3 Relation of LAA and Carrier Wi-Fi

At this stage the group considers there are no specific requirements for LAA in regards to Carrier Wi-Fi as this technology is developed under the scope of core 3GPP network architecture.

5 Anticipated Deployment Scenarios for Unlicensed Spectrum LTE Technologies

As the 3GPP standards have just become available, the industry and WBA operator members are first looking into the use cases and technical capabilities and plan to address and explore deployment scenarios. However, below it is presented the four dimensions where unlicensed spectrum LTE technologies are anticipated to be deployed.

5.1 Outdoor/Indoor

As the spectrum crunch issues become more and more relevant and impactful to the industry, the deployment of supporting indoor and outdoor systems in unlicensed spectrum bands becomes a priority.

Typical scenarios have been regarded as complementary to the macro cell network – now it is expected that high-density venues, such as stadiums, and high-density / high-profile locations, such as city centres, will benefit from the deployment of these technologies, turning mobile services providers more agile and increasing overall user experience.

Recently launched industry forums are looking into the technical aspects of deploying these solutions.

5.2 Macro/Small Cell

Carrier-deployed, integrated small cells can provide increased capacity for cellular operators in shopping malls, train stations, etc. This can be done by using LTE hetnets with one macro and “N” small cells. Such deployments give users improved bandwidth with seamless mobility. The small cell can be either collocated with WLAN or it may also use the unlicensed spectrum using other technologies like LAA.

For collocated small cell use case both LWIP and LWA are similar in terms of deployment impact.

5.3 Standalone Unlicensed Nodes

Standalone small cells aim at being a complete access system with no interaction with Macro cell networks, acting independently, similar to Wi-Fi. It is assumed that standalone nodes/systems can play a relevant role in future deployments, when applied to typical unlicensed access use cases (e.g. high density, indoor coverage).

5.4 Neutral Host Support

In a neutral host use case, a single eNB can enable many existing WLAN networks to become a “3GPP aggregation enabled” with zero or minimal configuration effort. Similarly, single WLAN networks can be shared by multiple operators supporting aggregation simultaneously.

The neutral host use case is an attractive feature for carriers because of a fast and low cost rollout due to no or minimal new siting requirements and no or minimal WLAN CAPEX. It may be applied to various deployment scenarios for hotels, enterprise, stadium, conference venues, etc.

LWA provides LTE–WLAN aggregation, which requires a new WT logical node at the WLAN to terminate the Xw interface. This functionality can be implemented in existing WLAN nodes (e.g. Access Controller) or at a separate node. Similarly, LWIP requires a new Security Gateway which can be implemented either at the eNB or a separate node.

6 Expected Timelines for the Various Technologies

This section intends to provide current known status for each proposal, and availability of the specifications.

SOLUTION	SOURCE	STATUS	SPECIFICATION
LAA	3GPP	Specification is ready. for downlink. 3GPP test plan for Rel-13 ongoing. Rel-14 WI for eLAA will add uplink support.	3GPP Release 13 specification
LWA	3GPP	Completed – Aggregation is supported for downlink in Rel-13 (and for uplink in Rel-14). 3GPP test plan for Rel-13 ongoing.	3GPP Release 13 specification
LWIP	3GPP	Completed. 3GPP test plan for Rel-13 ongoing. Rel-14 will add flow control and WLAN metrics.	3GPP Release 13 specification
LTE-U	LTE-U Forum	Specification developed by a set of companies and already available. Wi-Fi Alliance has developed a coexistence test plan.	Available (v1.3)
MulteFire	MulteFire Alliance	Research phase, initiating work with the ecosystem to develop industry-wide specifications for this technology. Presented current draft to 3GPP in September, 2016.	Nearly complete.

Table 6-1 Expected Timelines Overview

7 Future Actions Summary

As the technology and market landscape for LTE in unlicensed spectrum bands is continuing to evolve, the usage scenarios and anticipated market impact are also only beginning to gel. As a result, this whitepaper presents only a first phase view of how these technologies are progressing, and several further steps are recommended to continue to monitor and track how they mature.

Some suggested next steps are:

- As the technologies for LTE in unlicensed bands approach readiness for operational deployment, the use cases and real-world deployment considerations will become more clear and targeted by vendors and operators. This, in turn, will provide more clarity about how the technology will impact the wireless market, and impact incumbent technologies (especially Wi-Fi) in nearby deployments. The recommendation is to update the section in this paper outlining the anticipated deployment of unlicensed LTE/Wi-Fi RAN Interworking and Carrier Wi-Fi coverage overlapping scenarios, and discussing these impacts, in situations such as:
 - Indoor/Outdoor deployment
 - Macro and Small Cell usage and interaction
 - Integrated (into licensed nodes) or standalone unlicensed nodes
 - Neutral host support
- WBA membership will be polled (especially focusing on operators) to determine where they see the highest market demand and anticipated deployment timelines
- WBA membership have approved a program which will focus on performance considerations and Wi-Fi coexistence impacts of LTE use of unlicensed spectrum based on commercial devices which will come to the market during 2017. Although the group's scope is still being defined, it may include end-to-end live testing and interoperability, following the same approach as previous testing programs in WBA, such as the Next Generation Hotspot trial
- As part of the effort on the unlicensed LTE performance analysis and interoperability program, this paper should be updated to reflect new knowledge on behaviours, features and coexistence characteristics

The WBA Unlicensed Spectrum LTE - Market Drivers and Roadmap workgroup will reform, in 2017, to consider the above updates. WBA invites the ecosystem to join this effort driving a commercial end-to-end testing of these unlicensed technologies.

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ACRONYMS AND ABBREVIATIONS

ACRONYM / ABBREVIATION	DEFINITION
ANDSF	Access Network Discovery and Selection Function
BSSID	Basic SSID
CA	Carrier Aggregation
Cap-Ex	Capital Expense
CCA	Clear Channel Assessment
CWLAN	Carrier Wi-Fi LAN
DC	Dual Connectivity
DFS	Dynamic Frequency Selection
eLWIP	enhanced LWIP
EPC	Evolved Packet Core
E-UTRAN	Evolved Universal Terrestrial Access Network
HESSID	Homogenous Extended SSID
LAA	License-Assisted Access
LBT	Listen-Before-Talk
LWA	LTE-WLAN Aggregation
LWAAP	LWA Adaptation Layer
LWIP	LTE-WLAN Radio Level Integration with IPsec Tunnel
MME	Mobility Management Entity
MNO	Mobile Network Operators
MPTCP	Multipath TCP
NSWO	Non-Seamless WLAN Offload
Pcell	Primary Component Carrier
PDCP	Packet Data Convergence Protocol
PDN	Packet Data Network
QUIC	Quick UDP Internet Connections
RAN	Radio Access Network
RSSI	Received Signal Strength Indicator
Scell	Secondary Component Carrier
SSID	Service Set Identifier
TPC	Transmit Power Control
WLAN	Wireless Local Area Network
WT	WLAN Termination

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