Keysight Technologies

4G LTE-A in Unlicensed Band – Use Cases and Test Implications

Application Note

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1. Why is 4G LTE-A expanding to the unlicensed band?

On the path to 5G, the current standard, 4G LTE-A continues to rapidly evolve, providing even faster data rates and supporting more mobile devices. With very little spectrum available in the licensed band, network operators are working on ways to support growing demand for voice and data connectivity. Possible collaboration with wireless technologies such as WLAN, and expansion of the 3GPP network's spectrum domain to the unlicensed band are two approaches which have been topics of discussion within the 3GPP standardization body. This application note will cover LTE unlicensed band features that have been defined by the 3GPP along with major use cases and practical examples to help you address test challenges.
Smart phones and access to higher data rates have changed the way we communicate. Because devices need to be constantly connected while sharing data with the Internet, network operators are challenged to find new ways to improve throughput and make their networks more cost efficient.

1.1 What is Unlicensed Spectrum?

The International Telecommunication Union (ITU) is responsible for defining ISM bands which are portions of spectrum reserved internationally for Industrial, Scientific and Medical purposes. Unlicensed operators are typically permitted, which means that devices operating within these bands must accept interference from equipment such as the microwave ovens used in homes. In recent years, short range communication technologies such as Bluetooth, ZigBee and WLAN have been used in this band for communication services without paying a licensing fee, as long as they were in compliance with specific regulatory rules. The exact frequency of unlicensed bands is country dependent which determines the type of technology operators are willing to use within designated parts of the spectrum.

1.2 Unlicensed Spectrum Opportunity

Operators seek sustainable ways to leverage indoor connectivity and provide access to more users in smaller areas at faster data rates. A possible solution is traffic offload to unlicensed spectrum such as a more controlled collaboration between WLAN and cellular to take advantage of WLAN's ubiquity and low-cost infrastructure. Because of the absence of licensing requirements, operators can more cost effectively deploy cellular in this spectrum. This results in the need for new capabilities in LTE to comply with the regulatory rules of a shared communications channel.

2. Offloading Traffic to Unlicensed Spectrum

Since release 12, 3GPP has focused on two ways to help operators offload traffic to the unlicensed spectrum.

2.1 WLAN via LTE/WLAN Interworking

One method pursued by the 3GPP establishes interworking LTE and WLAN networks. WLAN and cellular technologies have traditionally been completely independent with the user equipment switching from one technology to the other without applying any logical intelligence. This results in a poor user experience when a mobile device switches to a slow WLAN network while in range of a faster cellular connection. WLAN interworking has been defined using two different models: cellular traffic offload to WLAN and simultaneous use of LTE/WLAN with link aggregation. Delivery of mobile cellular traffic over WLAN reduces congestion of the network by taking advantage of WLAN functions built into most mobile devices, as well as the substantial number of readily available WLAN networks. While the concept of WLAN offload is not new, the quality of the user's experience can be improved by logical decision making such as:

- Receipt and placement of calls through IMS (IP Multimedia Subsystem) in areas with poor cellular coverage,
- Selection of LTE or WLAN based on environment and network conditions, and
- Seamless offload for higher quality transitions when entering or exiting LTE or WLAN coverage.

Let's imagine a scenario with poor cellular coverage with access to a WLAN router connected to the Internet in an end user's home. How might this user place and receive calls through their operator's SIM card? WLAN calling is a proposed technique which creates an entry point into the 3GPP network so user equipment (UE) becomes visible on the operator's infrastructure. The two solutions proposed depend on the nature and ownership of the WLAN access point. The first one assumes the use of a trusted access point normally deployed by WLAN operators, with an infrastructure in place for encryption and authentication so that the subscriber can be unambiguously identified. The second scenario addresses an untrusted access point like a public hotspot or WLAN at home where the operator has no control over the access point. Most operators have deployed the untrusted model because of the pervasive use of WLAN networks in homes and offices. In this case, the solution requires no change in the wireless access point for use of legacy devices; however, alterations will be required for the UE and network.

When a UE connects to an untrusted network, a secured connection must be established between the UE and the entry point of the network. This entry point is called the evolved Packet Data Gateway (ePDG), a new element of the 3GPP network. Inside the network itself, the ePDG connects to the Packet Data Network (PDN) gateway. Then each user session is transported through a secure tunnel to various PDNs, such as IMS, the network commonly used for 3GPP operator communications. In this case the ePDG acts as a proxy between the network and the access point, and to secure the path between them, an IPSec tunnel is established. The device is then authenticated for WLAN calling through a secure USIM authentication using Extensible Authentication Protocol - Authentication and Key Agreement (EAP - AKA) algorithms. Once the IPSec tunnel is created and the SIM is authenticated, the UE has visibility into the operators IMS infrastructure and can register into the IMS to receive and place calls through its SIM. It behaves as if it was connected in cellular, but in this case, it is just connected to a WLAN.

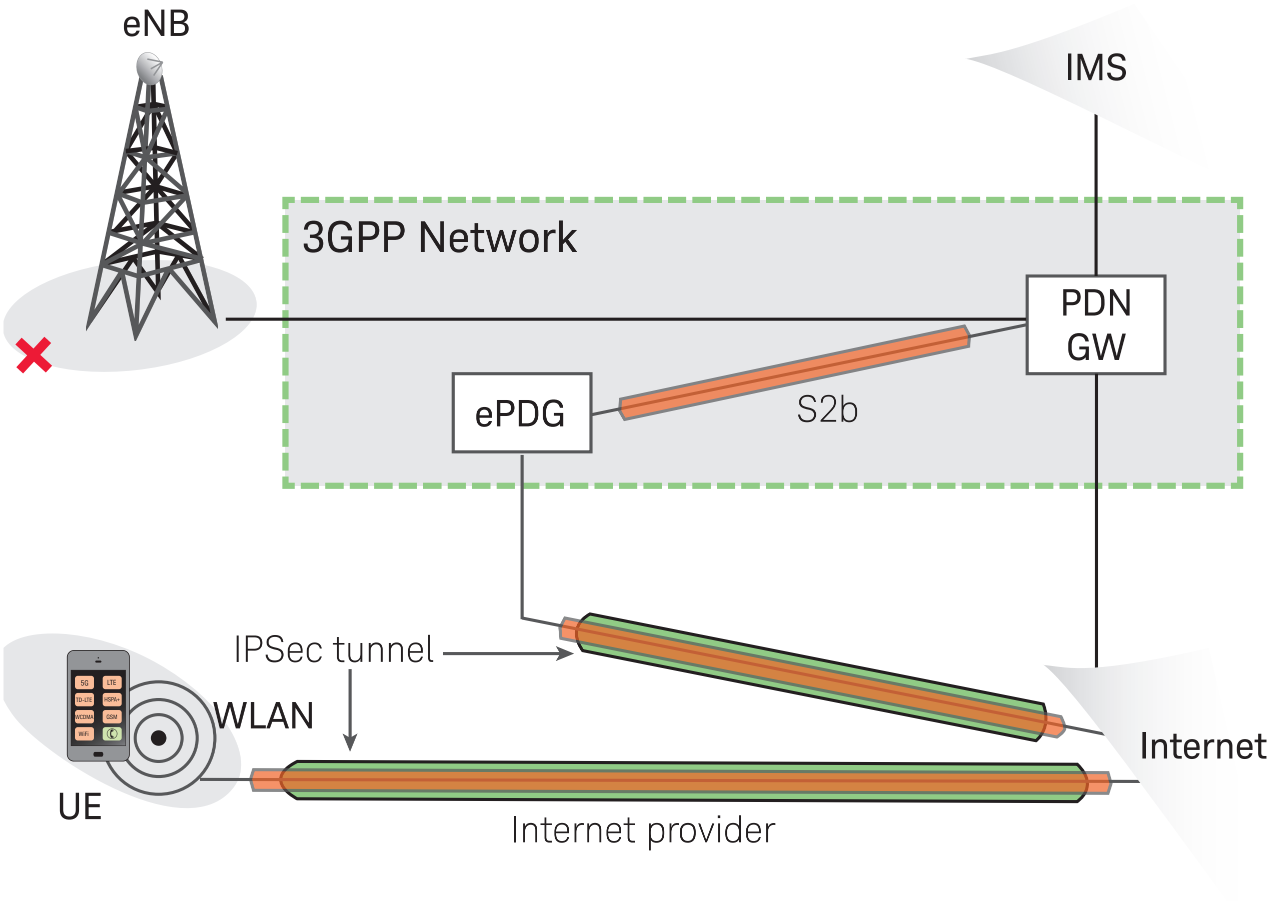


Figure 1. UE visibility to 3GPP network through WLAN.

2.2 LTE Over Unlicensed Spectrum

The second model of interest, deployment of LTE over the unlicensed spectrum, comes with new regulations and challenges to allow coexistence with other devices using the same channel. Because the goal is to achieve higher data throughput while leveraging the functionality of LTE, deployment of LTE in the unlicensed band is a good option. LTE was originally designed to only operate in cellular bands. Interference only came from neighboring bands and there was no need to share the channel with other devices. Deploying LTE in unlicensed bands presents coexistence issues which will be addressed by the 3GPP by creating support for new capabilities. The 3GPP already proposed several solutions for different scenarios. For example, one of the solutions addresses ideal back haul connection of collocated cells and the use of aggregated LTE cells in the unlicensed spectrum which are assisted by a licensed primary cell. This is generally described in LAA or Licensed Assisted Access which is a release 13 feature.

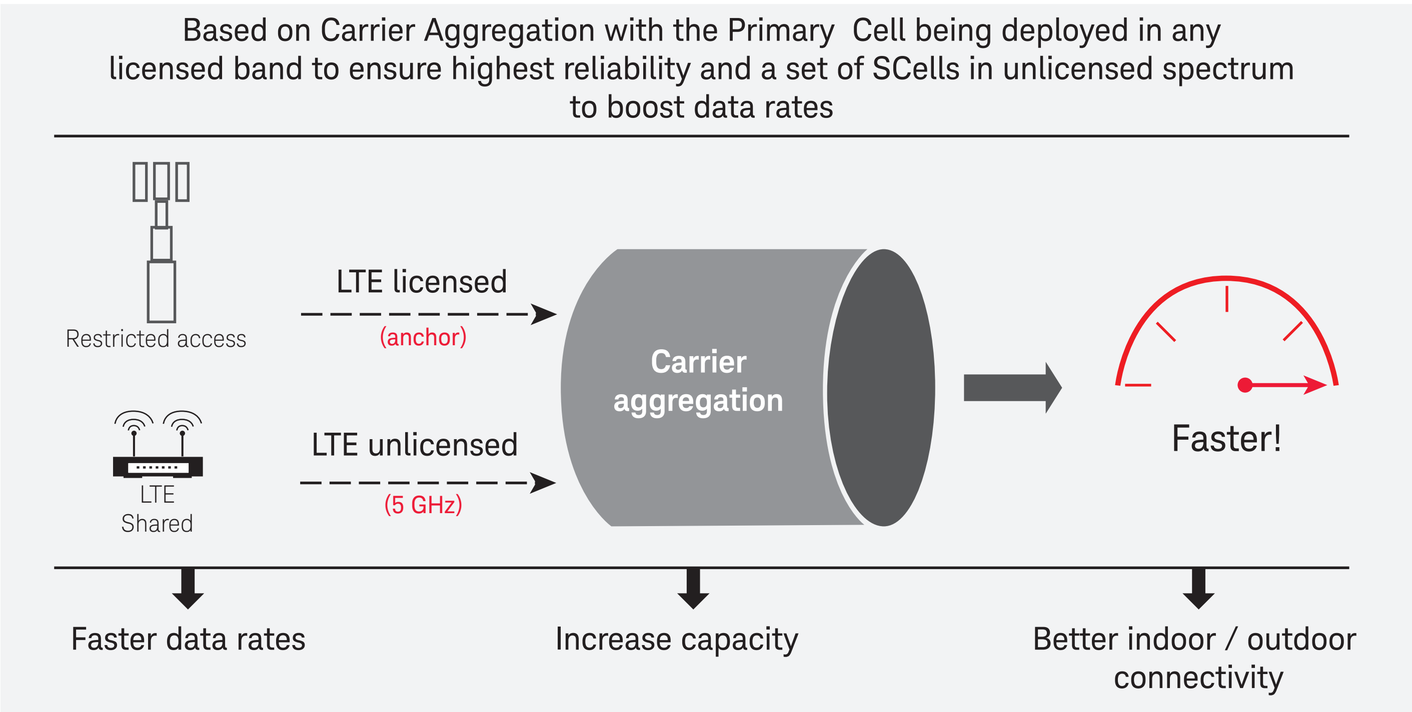


Figure 2. Simple illustration of LAA and its benefits.

2.3 LTE-LAA (Licensed Assisted Access) Overview

Licensed Assisted Access (LAA) was introduced in 3GPP release 13 as part of LTE Advanced Pro. It uses Carrier Aggregation in the downlink to combine LTE in the unlicensed spectrum (5 GHz) with LTE in the licensed band. This aggregation of spectrum provides a fatter pipe with faster data rates, increasing indoor connectivity and network capacity. For example, a mobile operator using LAA can provide better data rates than LTE to end users with as little as 20 MHz of licensed spectrum. This is done by maintaining a persistent anchor in the licensed spectrum that carries the control and signaling information and combining it with one or more carriers from the unlicensed spectrum. LAA has been designed as a single global solution that can adapt to unique regional requirements, and allows for fair co-existence with WLAN and other operator's LAA deployments.

For regulatory compliance and co-existence with other devices operating in the unlicensed band, devices supporting LAA must utilize Listen-Before-Talk (LBT) which is mandated in Europe and Japan. LBT is similar to the method used by WLAN nodes. A new frame structure (type 3) defined exclusively for LAA cells, enables support for discontinuous time limited transmissions to ensure that e node B (eNB) does not monopolize the channel. It also enables the use of incomplete subframes below 1 ms for more flexible adaptation to transmission opportunities after listen before talk. While eLAA (enhanced LAA) for release 14 is being developed, LAA cells will continue to be downlink only and will not send the broadcast channel assuming that the information is transmitted by the primary cell. To enable detection, synchronization and RRM reporting, even when the cells are in an "off" state, the proposal uses discovery signals as defined in release 12.

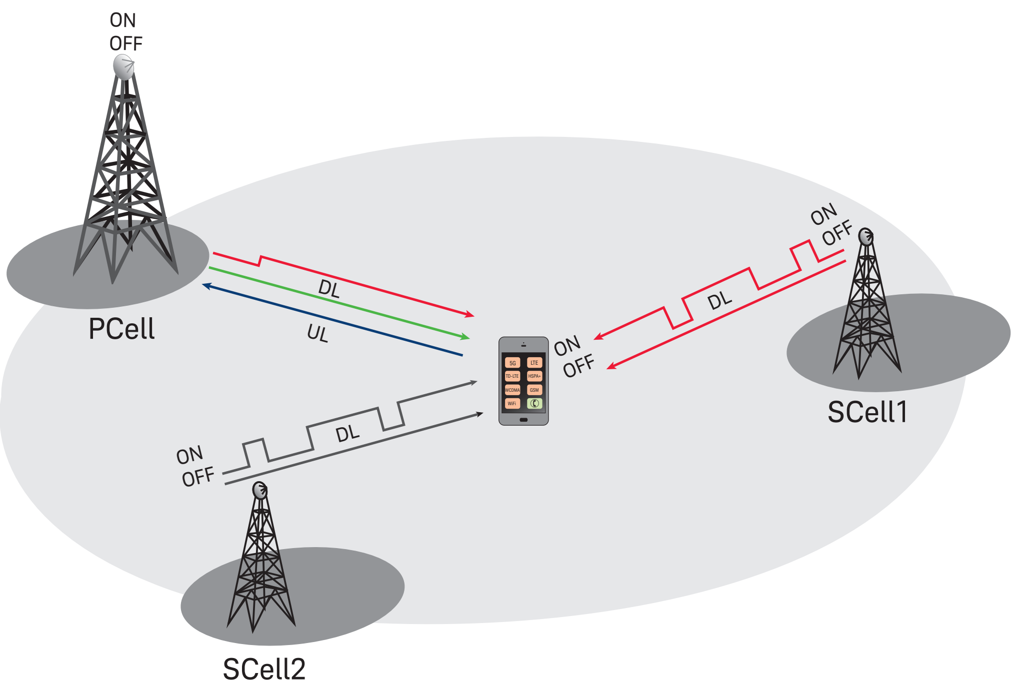


Figure 3. Shows how SCell1 and SCell2 transmits when no transmissions are detected in the same channel.

2.3.1 LAA: Listen Before Talk (LBT)

Listen Before Talk (LBT) is a mechanism used by devices to determine the presence of signals in the channel before using it, to avoid collisions with other transmissions. This protocol allows many users and different technologies to use the same channel without pre-coordination. In LAA, the LBT procedure initializes when the secondary cell has data to transmit. Prior to that, the cell is shut off completely to all transmissions, including cell reference signals. Then, the LAA cell will initiate a Clear Channel Assessment (CCA) to determine whether the channel is idle or not. If there are no signals detected within the channel, then the transmission can proceed. This is described graphically in Figure 4.

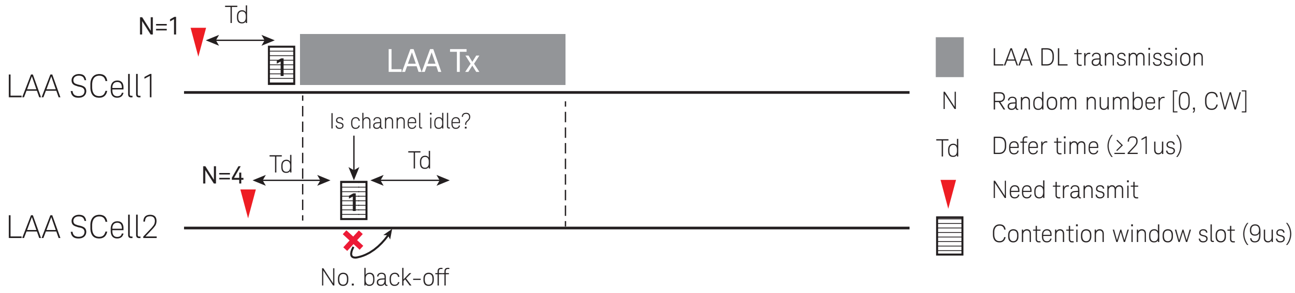


Figure 4. Monitoring channel before transmission.

If the channel is not idle, the device performs a slotted random back off procedure, in which a random number of slots is withdrawn from the Contention Window Slot (CWS). This increases exponentially with the occurrence of collisions, and then gets reset to the minimum value once the transmission succeeds. Given the random nature of the back off procedure, different devices will have different back off intervals allowing for improved channel adaptation.

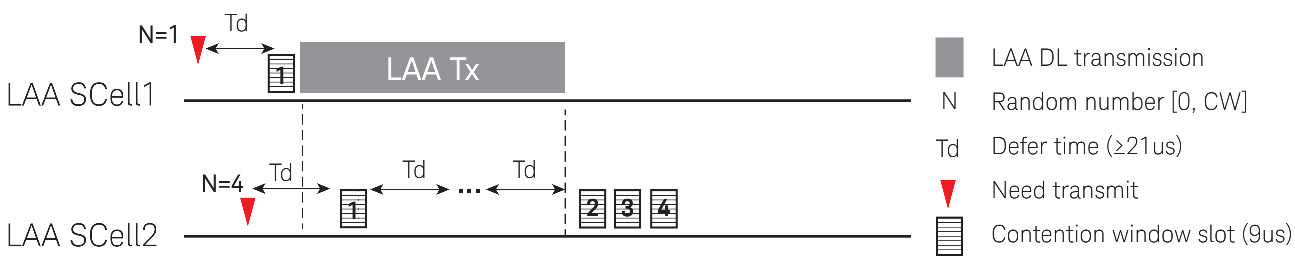


Figure 5. Sensing a transmission, LAA SCell2 waits until the channel is free.

This is very similar to the Carrier Sense Multiple Access (CSMA) procedure currently employed by WLAN. The LBT algorithm developed by the 3GPP was based on the feedback from the community on CSMA.

2.3.2 LAA: Discontinuous Transmission

Once LAA gains access to the channel, it can transmit for a limited time so that other devices can share the channel. To provide fair access, multiple LBT channel access priority classes have been defined by the standard. The priority class (p) determines the interval of the contention window as well as the maximum duration of the transmission burst. The Maximum Channel Occupancy Time (MCOT) ranges between 2 ms for p = 1 (highest priority) and 10 ms for p = 4 (lowest priority).

		Contention Window		MCOT	
Channel access priority class (ρ)	**m_ρ**	**$CW_{min,\rho}$**	**$CW_{max,\rho}$**	**$T_{mcot,\rho}$**	**Allowed CW_ρ sizes**
1	1	3	7	2 ms	{3,7}
2	1	7	15	3 ms	{7,15}
3	3	15	63	8 or 10 ms	{15,31,63}
4	7	15	1023	8 or 10 ms	{15,31,63,127,255,511,1023}

Figure 6. Maximum Channel Occupancy Times based on access priority.

After the on period, the eNB ceases transmission. If there is more data to transmit, the device starts the LBT process again.

To create more availability in the channel, it is also possible to use incomplete subframes. The first subframe in a burst can last the full duration of 1 ms or it could start at OFDM symbol 7 and its duration would only be 0.5 ms. The duration of the last subframe is also flexible. It can be 1 ms or the duration of a special subframe with normal cyclic prefix. This would allow the eNB to stop transmitting when there is no data remaining, or in the case of clear channels, start the next transmission earlier.

2.3.3 LAA: Discovery Signals

LAA requires methods for UEs in the LAA Secondary Cell (SCell) coverage range to enable Radio Resource Management (RRM) measurements and reporting, even when SCells are not aggregated. Release 12 Discovery Signals (DS), initially designed for small cells, is being used with certain modifications for LAA SCells:

1. RRC signaling (DMTC) allows DS periodicity of 40ms, 80ms and 160ms
2. ≥12 OFDM symbols subframe with only CRS, PSS and SS
3. DS transmission can occur in any of the 6 first subframes of the period

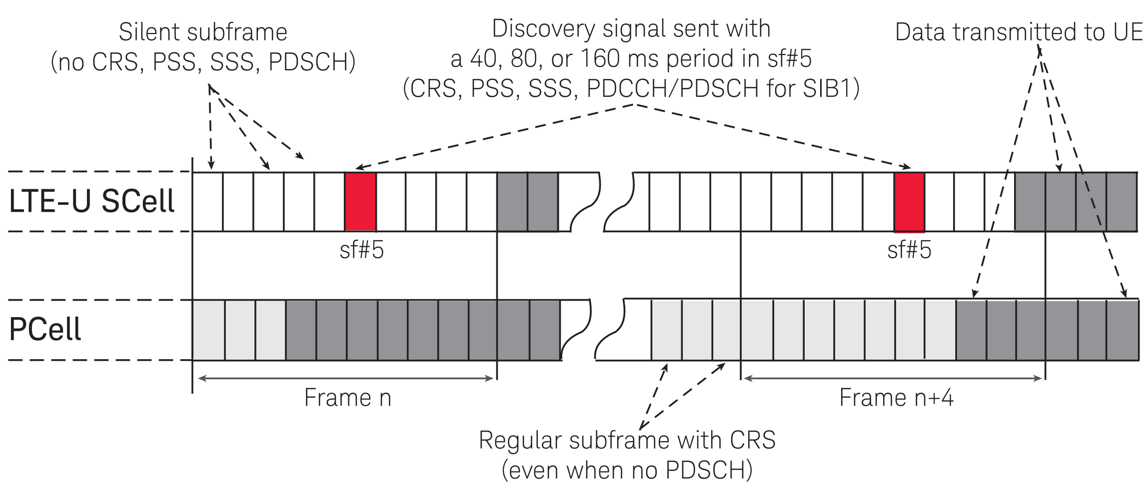


Figure 7. Discovery signals in the LAA secondary cell.

In addition, CSAT (Carrier Sensing Adaptive Transmission) appears as a variation of LAA, and provides fair coexistence with WLAN and other LTE-U deployments. Although the concept is the same, some slight differences apply to CSAT, as compared with LAA, such as:

- Based on duty cycle (ON/OFF) with no collision mechanism (LBT).
- No special DCI 1C required.
- Maximum burst duration (ON) of 20ms.
- Minimum OFF duration of 1ms.
- Subframes of partial duration not allowed.
- MIB must be transmitted at least once every 160ms.
- DRS occasion is a subframe #5 carring SIB1.
- No CSI-RS as part of DRS.
- No E-PDCCH.
- Only FDD bands 252 and 255.
- Only CRS based TM2, TM3 and TM4 allowed (LAA also allows beamforming transmission modes TM8, TM9 and TM10).
- No periodic CSI reporting.
- No cross-scheduling.

2.3.4 LTE-U vs. LTE-LAA and Other Methods

In 2014, a group of companies formed the LTE-U forum to develop technical specifications for LTE in the 5 GHz band. LTE-U, designed to comply with US regulations, targets regions without LBT requirements. However, it does not necessarily meet the needs of other regions, such as Europe and Japan. Both LTE-U and LAA are possible LTE unlicensed band solutions, but with differences in regulatory requirements. LTE-U is well suited for regions that do not require LBT and address coexistence issues with WLAN using CSAT in the eNB. CSAT, an algorithm utilized in LTE-U eNB, is based on the use of duty cycle that adapts the duration of the on period by sensing the average power in the channel. LTE-U also limits the duration of the on period to 20 ms so that low latency applications can coexist. On the other hand, LAA is a more broadly used global solution and includes support for LBT and a more flexible frame structure to better adapt to channel availability. LAA is generally preferred by operators since it is the only method that provides full cellular capabilities. WLAN Calling is also extensively deployed to provide coverage extension in rural or remote access areas where no cellular coverage is available. Other methods like LWA or LWIP are less frequently used because it requires either a WLAN network or partnership with a WLAN operator.

3. LTE-A in Unlicensed Band: Design and Test Challenges

When higher data rates and excellent signal quality are needed in indoor environments, WLAN calling is a good solution.

WLAN calling allows to use a WLAN network to make and receive phone calls, rather than using the traditional mobile network. End users in poor signal areas, such as rural villages and underground stations, can harness the power of available WLAN networks to stay connected. This new solution may also be deployed without additional cost for end user (depending on the data plan contracted), since the calls will be charged as normal calls, based on the current plan signed by end customer.

In case of WLAN offload, congested mobile data networks “offload” to additional capacity from unlicensed WLAN spectrum. As both subscribers and devices tend to connect to WLAN whenever it is in reach, mobile operators need to follow their subscribers into the WLAN environment. This is why mobile operators are starting to integrate WLAN simply as another radio network to their 3GPP mobile core. ePDG is a core network entity which allows access to the mobile core network from untrusted networks. This will permit IMS voice calling over WLAN using operators IMS server.

One test challenge for devices supporting LAA and LTE is to ensure realistic end to end IP data throughput. This is one of the strengths of Keysight Technologies’E7515A UXM wireless test set. It tests the complete device top to bottom and can uncover problems with the integration of the different components as well as bottlenecks in the system. This type of testing stresses the phone or device as much as possible to test its robustness. When these tests are executed over a long period of time, sporadic issues may be discovered, such as those related to memory leaks. The importance of test setup and environment should be considered, as bottlenecks may occur in the tester, especially when using complex configurations involving multiple boxes and vendors. In the past, custom designed tests have been used, but more recently, standards organizations have created standardized test scenarios for end to end data throughput (3GPP 37.901 test specification for application layer data throughput testing).

The UXM was architected for extensibility: multiple UXMs can be interconnected, enabling numerous synchronized cells and component carriers. You can connect 2 UXMs in an “array” to add component carriers (e.g. for 4CC downlink cat 11/12) and perform handover/mobility testing between multiple cells (up to 4 LTE cells with 2 UXMs). When connected in an array, the “main” UXM completely controls the auxiliary (aux) UXM through an integrated, easy-to-use interface present on the main unit’s screen. The integrated interface allows you to quickly and individually set up both units’ cells/component carriers (set up each cell as PCC or SCC, set duplex mode, cell on/off, DL CA or DL/UL CA), and initiate handovers between the units, etc. The aux UXM merely provides the extra RF hardware required. However, upon separating the units the aux UXM can then be used stand-alone based on whatever licensing it includes. The 2 UXMs are connected through the interconnectivity hardware kit (option E7515A-AC1) which includes 1 SRIO, 2 SYNCH, 1 LAN cable. Both UXMs require their own frequency range and fading platform options. A E7515A-L01 (logging) license is only required for one UXM, which may be installed on main or aux.

Depending on the number of carriers that you want to allocate to the DUT (from 1CC to 5CC) you may need to set up an array using 2 UXMs. Two UXMs require the following physical connections between the main and auxiliary UXMs.

3.1 Data Throughput Performance

You may create more realistic simulations, such as devices located at unequal distances from a cell tower, using the UXM. Configure cell power by selecting the desired band as well as bandwidth for each cell individually. Once you set a SCC band as TDD Band 46, the graphical user interface automatically adapts itself based on the band selected. Because band 46 was selected, the operation mode is automatically set to LAA, as shown in Figure 8.

Number	Item Name	Description
1	Ethernet GbE 1 and GbE 2	Connected to the ICM's Ethernet switch. Used to connect UXM arrays requiring either the GbE 1 or GbE 2 connector on the main UXM to be connected to either GbE 1 or GbE 2 on the auxiliary UXM. The Ethernet traffic local to a UXM is isolated from these connectors precluding Ethernet traffic between units
2	RIO I/O 1 and I/O 2	RIO ports are connected to the ICM's RIO switch: UXM arrays require the I/O 2 connector on the main UXM to be connected to the I/O 1 connector on the auxiliary UXM.
3	Synchronization ports	SYCNH 1, SYNCH 2 and SYNCH 3 UXM arryas require: -SYCNH 1 connector on the main UXM to be connected to SYNCH 3 connector on the auxiliary UXM. -SYNCH 2 connector on the mian UXM to be connected to SYNCH 3 connector on the main UXM.

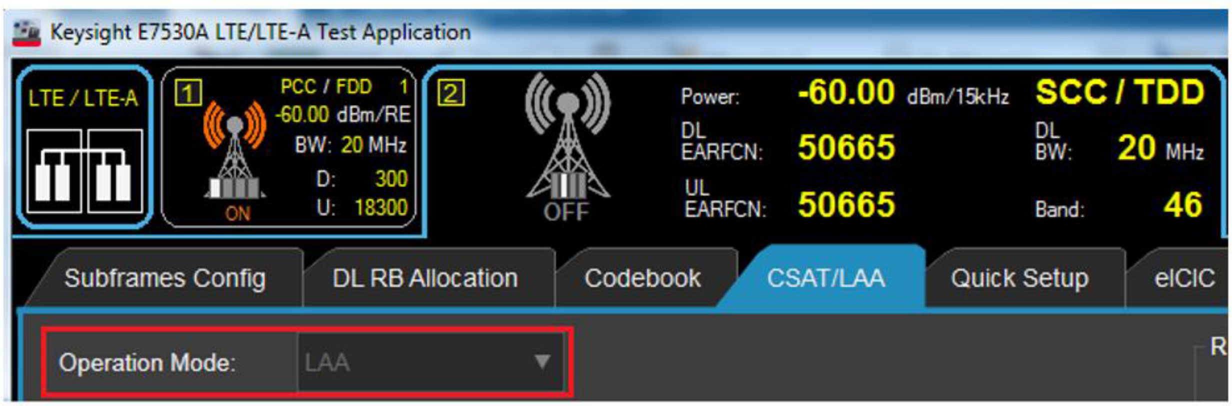


Figure 8. Operation mode is automatically set to LAA.

You can modify burst configurations for discontinuous transmissions, set the subframe starting positions, modify the transmission of discovery signals while in OFF and set a customized policy to send downlink control information per subframe. Configuring the transmission of DCI 1C per subframe allows you to send only partial subframes from either once (from previous) or twice (from current and previous) depending on the number of times setting (Figures 9a and 9b).

Number of Times: Once (from previous)

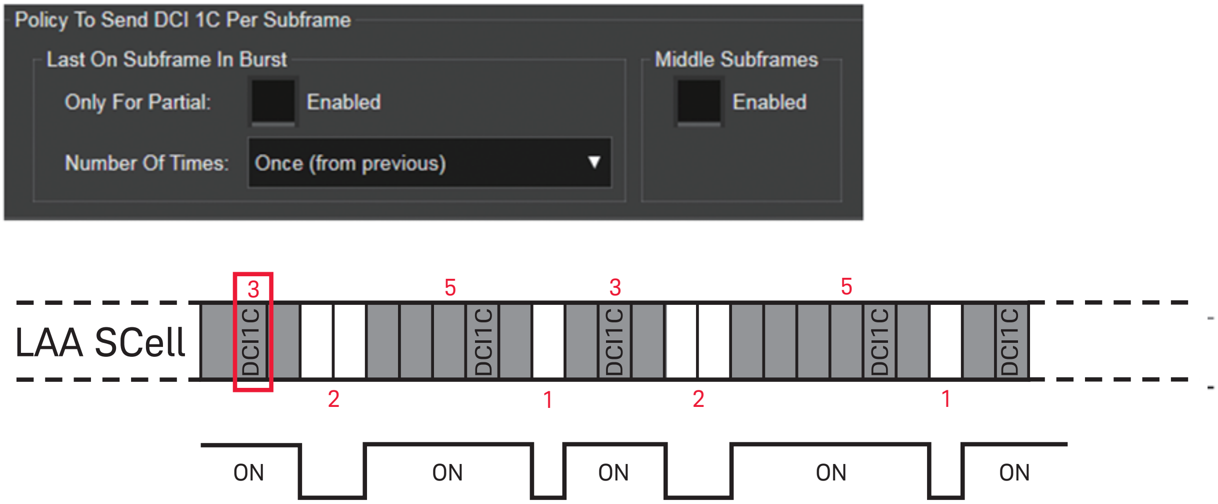


Figure 9a. Previous DCI 1C message shows that the next subframe is the last one.

Number of Times: Once (from previous) and Only For Partial: Enabled

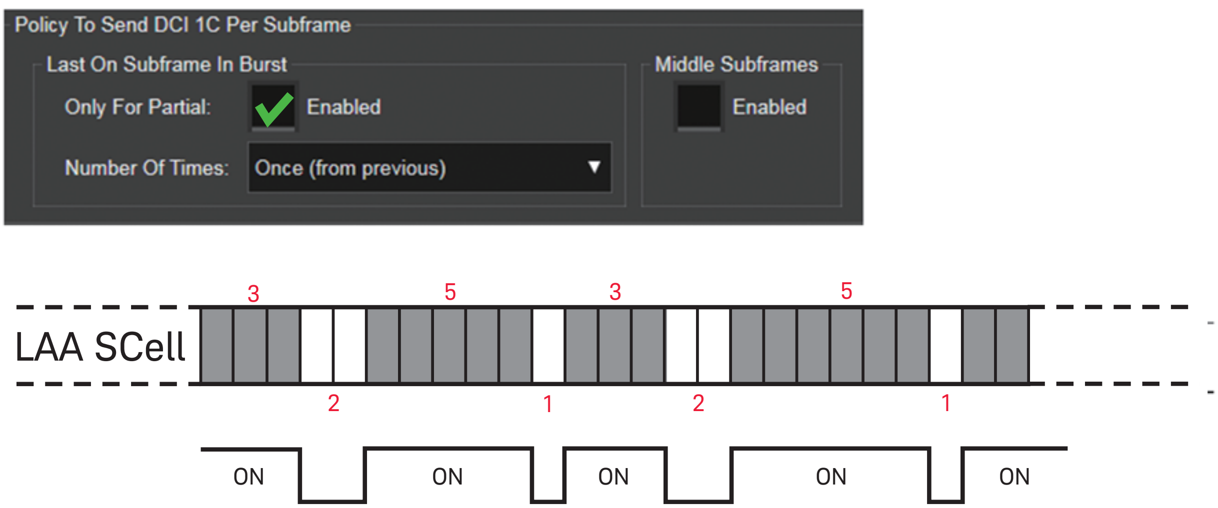


Figure 9b. Previous DCI 1C message indicates that the next SF is the last one. This DCI 1C message is only going to be sent when partial SFs are sent. In this example, as not partial sub-frames are being sent, DCI 1C messages are neither being sent.

3.1.2 Channel Impairments

LTE networks are designed to adapt to a wide range of real-world operating conditions. Depending on the quality of the downlink channel, the eNB will adjust the modulation type, coding scheme, and resource block allocation to optimize for the best performance. This results in thousands of potential mobile device performance scenarios that need to be tested. Figure 10 shows reduced throughput resulting from channel impairments (fading) and recovery in throughput when the impairment is removed. With just a click of the mouse (or touch of your finger) you can quickly and easily add and remove fading and AWGN to either or both component carriers, completely independently (or set different fading profile on each CC), and evaluate the resulting changes to throughput. Having this complex test capability readily available in the UXM lets you easily perform tests that previously were very tedious to set up, unreliable, or just not available.

Figure 10. Reduced throughput resulting from channel impairments (fading) and recovery in throughput when the impairment is removed.

3.1.3 LTE-LAA LBT Testing Using the UXM

The UXM allows you to easily demonstrate how the data throughput varies under LBT conditions.

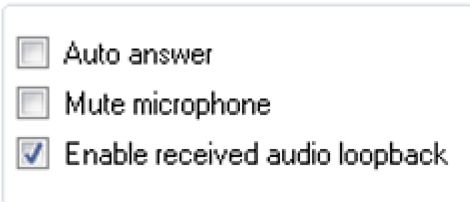
Figure 11. Data throughput with Burst Order #1 enabled.

Figure 11 displays the data throughput with only Burst Order #1 enabled. When enabling a second burst order transmission, data throughput measurements convey a decrease in throughput when a base station (carrying unlicensed band) implements an LBT protocol to avoid collisions with a neighbor wireless system as shown in Figure 12.

Figure 12. Base station carrying unlicensed band implements an LBT protocol to avoid collisions with a neighbor wireless system.

3.2 WLAN Calling and Offload

The UXM allows you to test IPv4 and IPv6 WLAN calling both with and without server side certificate authentication. It supports the ability to alter the security algorithms and even simulate scenarios that allow testing of the UE for IPv4 WLAN offload. Once you perform the test setup for IPv4 on the UXM, power on your WLAN calling and offload supporting DUT, modify the ePDG configuration file settings and then open an SSH session to the ePDG virtual machine. You can start a call for the IMS client and verify bi-directional audio assuming "enable received audio loopback" is checked.



Terminate your call from the IMS client and verify that the UE cleanly drops the call, now initiate a call from the UE to IMS client and again verify bi-directional audio. Terminating the call from the UE, you should now be able to verify the code 200 OK (bye) messages.

Here is the view from the LTE application:

sip:001012345678901@ims.mnc001.mcc001.3g…	200 OK [REGISTER]
sip:001012345678901@ims.mnc001.mcc001.3g…	INVITE
IMS-SIP Server	100 Trying [INVITE]
IMS-SIP Server	180 Ringing [INVITE]
IMS-SIP Server	200 OK [INVITE]
sip:001012345678901@ims.mnc001.mcc001.3g…	ACK
sip:001012345678901@ims.mnc001.mcc001.3g…	BYE
IMS-SIP Server	200 OK [BYE]

And the view from the IMS server:

IMS-SIP Server	BYE
tel:001012345678901	BYE
IMS-SIP Server	200 OK [BYE]
tel:+10000000001	200 OK [BYE]

3.3 Carrier Aggregation Requirements Supported by the UXM

The UXM's powerful architecture supports modern carrier aggregation and modulation test requirements. It also has the capabilities to handle today's carrier aggregation and modulation requirements while being ready for tomorrow's advancements.

	Feature Option (TA*)	Min. HW	Notes
Downlink 2CC	E7530A-AFP-xDD	1 UXM (with TRX sets)	300 Mbps DL
Downlink 3CC	E7530A-AFP/DFP-xDD	1 UXM (2 TRX)	450 Mbps DL
Downlink 4CC	E7530AA-AFP/DFP/EFP-xDD	1 UXM (2 TRX)	600 Mbps DL
Downlink 5CC	E7530A-AFP/DFP/EFP-xDD/EFP-xD5	Main (2 TRX), Aux (1 TRX)	750 Mbps DL
DL 3CC + 256 QAM	E7530A-AFP/DFP-xDD, E7530A-FFP-0M2	1 UXM (2 TRX)	587 Mbps DL
FDD-TDD mixed CA	E7530A-AFP/DFP/EFP -FDD amd -TDD/ efp-FD5 and TD5	2CC: 1 UXM, 3CC/4CC/5CC: 1 or 2 UXMs	Requires both FDD and TDD, PCC must be FDD
LTE-U/LAA	E7530A-AFP/DFP/EFP-FDD/EFT-xD5, E7530A-FFP-0L1	2CC: 1 UXM, 3CC/4CC/5CC: 1 or 2 UXMs	Requires E7515A-506 for unlicensed CC
Uplink 64 QAM	E7530A-FFP-0M1	1 UXM	75 Mbps UL
Uplink 2CC	E7530A-AFP/CFP-xDD	1 UXM (with 2 TRX sets)	100 Mbps UL

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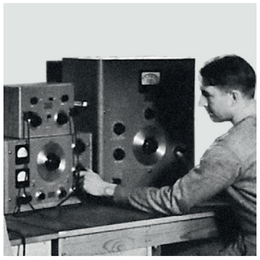
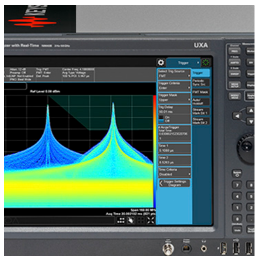


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