# THE PROSPECT OF LTE AND WI-FI SHARING UNLICENSED SPECTRUM

## Good Fences Make Good Neighbors

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On behalf of Qualcomm, Signals Research Group researched the prospect of LTE operating in unlicensed spectrum (LTE-U), specifically the 5 GHz band that is used throughout the world for Wi-Fi. We leveraged informal discussions that we've had with vendors and operators over the last several months, publicly-available information that we obtained on the Internet and conversations with Qualcomm to make sure that our understanding of the technical issues is correct.

As the sole authors of this paper, we stand fully behind the opinions that are presented in this paper. In addition to providing consulting services on wireless-related topics, including performance benchmark studies and network economic modeling, Signals Research Group is the publisher of the *Signals Ahead* research newsletter (www.signalsresearch.com).

## Executive Summary


### Key highlights from this whitepaper

*Spectrum, in particular unused spectrum, is a limited commodity. There is, however, up to 500 MHz of unlicensed spectrum around the world in the 5 GHz band that is being used for various applications and services, most notably Wi-Fi. The industry is currently pursuing the opportunity to leverage the performance characteristics of LTE to take advantage of this spectrum to address the looming capacity crunch. In many regions of the world, LTE for Unlicensed Spectrum (LTE-U) could be deployed as a pre-standard solution and offer meaningful coverage and capacity gains (2x to 4x, depending on the assumptions) over what is possible with Wi-Fi. In other regions of the world, certain regulatory requirements exist which necessitate some important changes to the LTE standard in order to leverage the unlicensed spectrum. These changes will likely get incorporated into Release 13 of the LTE standard, which could be functionally frozen by the end of 2015. With both the pre-standard and standards-based implementations of LTE-U, also referred to as LAA (Licensed Assisted Access) since it still requires the use of licensed spectrum for mobility management and other signaling-related transactions, LTE will be a good neighbor with the other occupants in the spectrum, thus preserving a key tenet of the unlicensed spectrum – namely, that all applications and services that use the spectrum must grant others fair usage of the spectrum. LTE-U will apply technology features that are comparable to what Wi-Fi uses today to ensure how multiple Wi-Fi Access Points, Wi-Fi devices, and other wireless applications, like radar, can use the unlicensed spectrum in a harmonious manner.*


As the name suggests, LTE-U involves LTE operating in unlicensed spectrum.

During the last year there has been growing interest in the concept of LTE-U (LTE for Unlicensed Spectrum), which as the name suggests involves LTE operating in unlicensed spectrum. In principle, LTE could operate in any unlicensed frequencies but the initial industry focus is on the 5 GHz band since there is up to 500 MHz of available spectrum around the world and the spectrum is relatively attractive when it comes to providing capacity, especially since LTE-U will be used primarily, if not entirely, in conjunction with small cells.

The industry seems to fully embrace the concept.

By and large the industry, including operators and vendors, seems to fully embrace the concept as evident in the numerous presentations that we reviewed which were given at a 3GPP (Third Generation Partnership Project) workshop held last summer that was dedicated to the topic. The most obvious value proposition for LTE-U is that it combines the spectral efficiency of LTE and the availability of a large amount of frequency spectrum, thus going a long way toward addressing the looming capacity crunch. Another motivating factor is that it can help create a Unified LTE network, whereby the licensed and unlicensed assets of an operator's network are more tightly integrated. However, the concept is not fully understood within the industry, not to mention by industry outsiders, so it is important to understand exactly what it is, how it might work, when it will be available, and what impact, if any, LTE-U will have on the incumbent users of the unlicensed spectrum, most notably Wi-Fi.

LTE-U will not impact the performance of the existing Wi-Fi systems.

First and foremost, LTE-U is being designed so that it will not impact or degrade the performance of the existing Wi-Fi systems or other occupants of the spectrum, such as radar. In fact, LTE-U leverages many of the same concepts used by these systems to share the same spectrum with a fair usage policy. In other words, placing an LTE-U small cell – a small cell that likely also supports Wi-Fi – next to a Wi-Fi AP (access point) would interact with the incumbent Wi-Fi AP much in the same way that two Wi-Fi APs can be deployed in close proximity to each other without having much impact on the overall system performance. In fact, simulation studies suggest that LTE-U + Wi-Fi will offer a two-fold to four-fold increase in the amount of data traffic that can be supported.

LTE doesn't abandon its licensed spectrum heritage with LTE-U since there is still a need for the concurrent use of licensed spectrum to transmit certain signaling and control channel information, such as system acquisition and mobility management. For this reason, LTE-U is also referred to as LAA (Licensed Assisted Access). Think of LTE-U/LAA as a form a carrier aggregation with the primary/anchor carrier using licensed spectrum and the secondary carrier using unlicensed spectrum. Given the unreliability of unlicensed spectrum, we believe that most operators will use the unlicensed spectrum for best effort data traffic while continuing to depend on the licensed spectrum for real-time voice and data services, such as VoLTE. There are also a few technical nuances pertaining to how the unlicensed radio carrier will operate alongside the licensed carrier, but we'll save that discussion for the main body of this paper.

In many parts of the world, LTE-U could be deployed today while in other regions LTE must support certain features that it doesn't currently support.

In many parts of the world, LTE-U could be deployed today, pending the availability of commercial devices/chipsets and infrastructure. We know vendors are working on these products and there has already been at least one announced trial but at this time we don't have a good sense for when they will be commercially available. However, in certain regions of the world, most notably Europe and Japan, there are stricter regulations regarding how the wireless systems operate in the 5 GHz band and these requirements mean that changes are required to the LTE air interface so that it can operate in the spectrum. 3GPP is currently evaluating the necessary changes that must be made and it is very likely that these changes will be included in the forthcoming Release 13. Work is just beginning on the new release and it should be finished by late 2015 or early 2016, with commercial solutions available in the following 12-18 months.

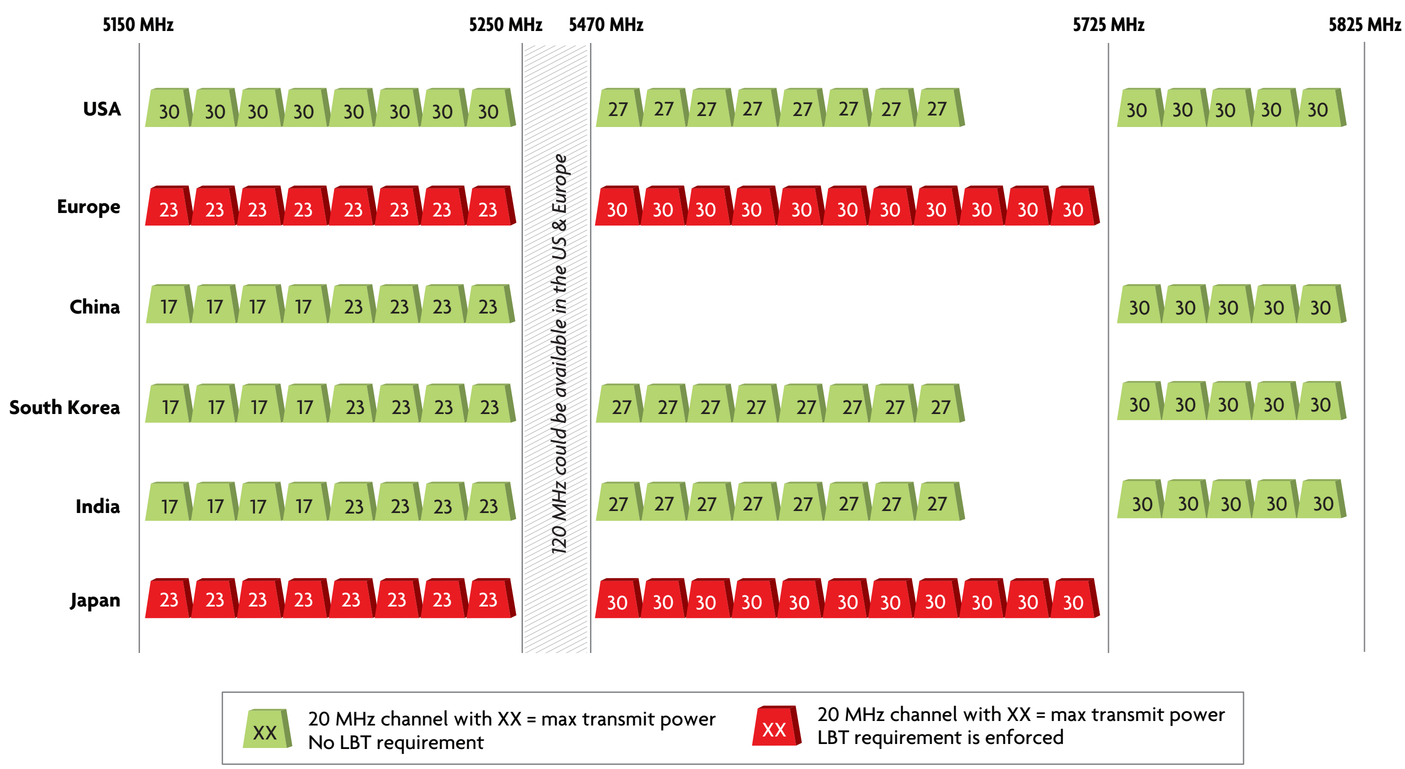
## Why deploy LTE in unlicensed frequencies?

It is no secret that spectrum, in particular unused spectrum, is a limited commodity. Throughout much of the world, most of the attractive and potentially available spectrum that is best suited for mobile data services has already been put to use or it will be put to use in the near future. All that remains are somewhat isolated slivers of spectrum. For example, in the United States regulators are preparing to auction a yet-to-be-determined amount of spectrum at 600 MHz and 65 MHz of spectrum, specifically 2 x 25 MHz of FDD spectrum and 15 MHz of TDD spectrum, that is located primarily near 1700 MHz (the AWS-3 band). Given Cisco recently forecasted that mobile data traffic will increase nearly ten fold between 2014 and 2019, utilizing this spectrum will only delay the inevitable. LTE networks will become capacity constrained, thus impacting the user experience and preventing the mobile operators from offering the mobile data plans and services that are available today.

There is up to 500 MHz of spectrum in the 5 GHz band that is available on a global basis for so-called unlicensed applications and services.

Conversely, there is up to 500 MHz of spectrum in the 5 GHz band that is available on a global basis for so-called unlicensed applications and services (reference Figure 1). Wi-Fi, specifically 802.11a, 802.11n and the burgeoning 802.11ac, is most frequently associated with using this spectrum, but other applications use it as well. For example, certain cordless phones use the spectrum as well as radar and perimeter sensors. Our point, however, is that the unlicensed 5 GHz spectrum has demonstrated that unregulated spectrum sharing can be successful and since it is unlicensed it can be used by numerous wireless applications and services, as long as those applications and services abide by certain basic principles and in some cases more well-defined regulatory guidelines. We discuss the regulatory requirements in more detail in a subsequent section of this paper.

**Figure 1. 5 GHz Unlicensed Spectrum Band Plan**




*Source: Various Sources (recreated by SRG)*

In the context of unregulated spectrum sharing, LTE-U is just another wireless application that has the ability to use/share the spectrum. From the perspective of the mobile operator, the spectrum is attractive for four primary reasons:

1. LTE Carrier Aggregation and the small cell ecosystem have matured, which allows aggregation of unlicensed carriers into LTE small cells.
2. There is a lot of unlicensed spectrum available
3. The spectrum is relatively attractive from a capacity perspective, especially when it is used in conjunction with small cell deployments
4. The spectrum is available on a global basis with very similar band plans

LTE-U gives operators the ability to integrate their disparate unlicensed and LTE networks.

LTE-U also gives operators the ability to integrate their existing disparate unlicensed and LTE networks, thus providing the opportunity to minimize cost, maximize network resources, and improve the user experience. Among other things, the so-called Unified LTE network would allow operators to use a single platform to provide authentication, security and management.

Longer term, the notion of LTE-U could extend to other unlicensed frequencies, such as those bands that reside above 10 GHz. However, the low-hanging fruit is clearly the 5GHz band and until that spectrum is used to its fullest potential there is very little need to look elsewhere for new spectrum. The 2.4 GHz band is another potential option for LTE-U, but it is highly unlikely that it will ever be used for that purpose, in part, because the success of Wi-Fi has pretty much made that band unusable for new wireless applications. With only 84.5 MHz of unlicensed spectrum at 2.4 GHz [one of the reasons why it is so congested] there is also not a lot of available bandwidth for LTE, in particular in comparison with the 500 MHz of spectrum that is available at 5 GHz. At the moment, the industry focus is on the 5 GHz band.

## Why not deploy more Wi-Fi to meet the expected growth of mobile data traffic?

Without question, mobile operators, to varying degrees, will place greater reliance on Wi-Fi to offload their mobile data traffic in the coming years. And Wi-Fi continues to evolve and improve with the fairly recent introduction of 802.11ac, not to mention other features and enhancements that are currently on its roadmap. There is also no reason that we can think of why these operators will not continue to use Wi-Fi even after they deploy LTE-U systems. However, when it comes to the performance of Wi-Fi, it just can't compare with LTE, so by leveraging LTE-U along with Wi-Fi, operators will be able to increase the efficiency of the spectrum, extend the coverage of a small cell/Wi-Fi AP beyond the range of a typical Wi-Fi AP, and still capitalize on the ubiquity of Wi-Fi-enabled devices.

LTE has certain inherent advantages over Wi-Fi that give it the ability to support more data traffic in a fixed amount of spectrum.

LTE has certain inherent advantages over Wi-Fi that give it the ability to support more data traffic in a fixed amount of spectrum (i.e., spectral efficiency) and which give it an extended range over Wi-Fi. For example, LTE offers a more robust protection of control channel elements, better link adaptation, and a more sophisticated retransmission mechanism. The link adaptation with LTE leverages CQI (channel quality indicator) reports from the mobile device, which allows the serving cell to dynamically adjust to rapid changes in channel conditions. Additionally, LTE uses a more complex HARQ (Hybrid Automatic Repeat reQuest) process, which allows it to combine the received energy of the (initial) transmission and the subsequent retransmissions of a data packet for better efficiency. With Wi-Fi, the entire data packet has to be retransmitted without combining.

The technical differences between LTE and Wi-Fi result in fairly meaningful performance differences that favor LTE.

As discussed in the next section, Wi-Fi is a contention-based protocol, which means there isn't a sophisticated scheduling process in place to allow multiple devices to seamlessly use the system in a coordinated manner. Put simply, dropping in another Wi-Fi AP doesn't offer near the amount capacity improvement compared with adding an LTE small cell in close proximity to another LTE small cell. All told, the technical differences between LTE and Wi-Fi result in fairly meaningful performance differences. Therefore, if unlicensed spectrum isn't being used by Wi-Fi, the spectrum can be used by LTE-U in a more efficient manner. The exact performance advantages that LTE has over Wi-Fi depend on the modeling assumptions, but based on presentations from multiple companies that were presented at a 3GPP workshop last June, LTE-U has a two-fold to four-fold performance advantage over Wi-Fi.

## How would LTE-U work?

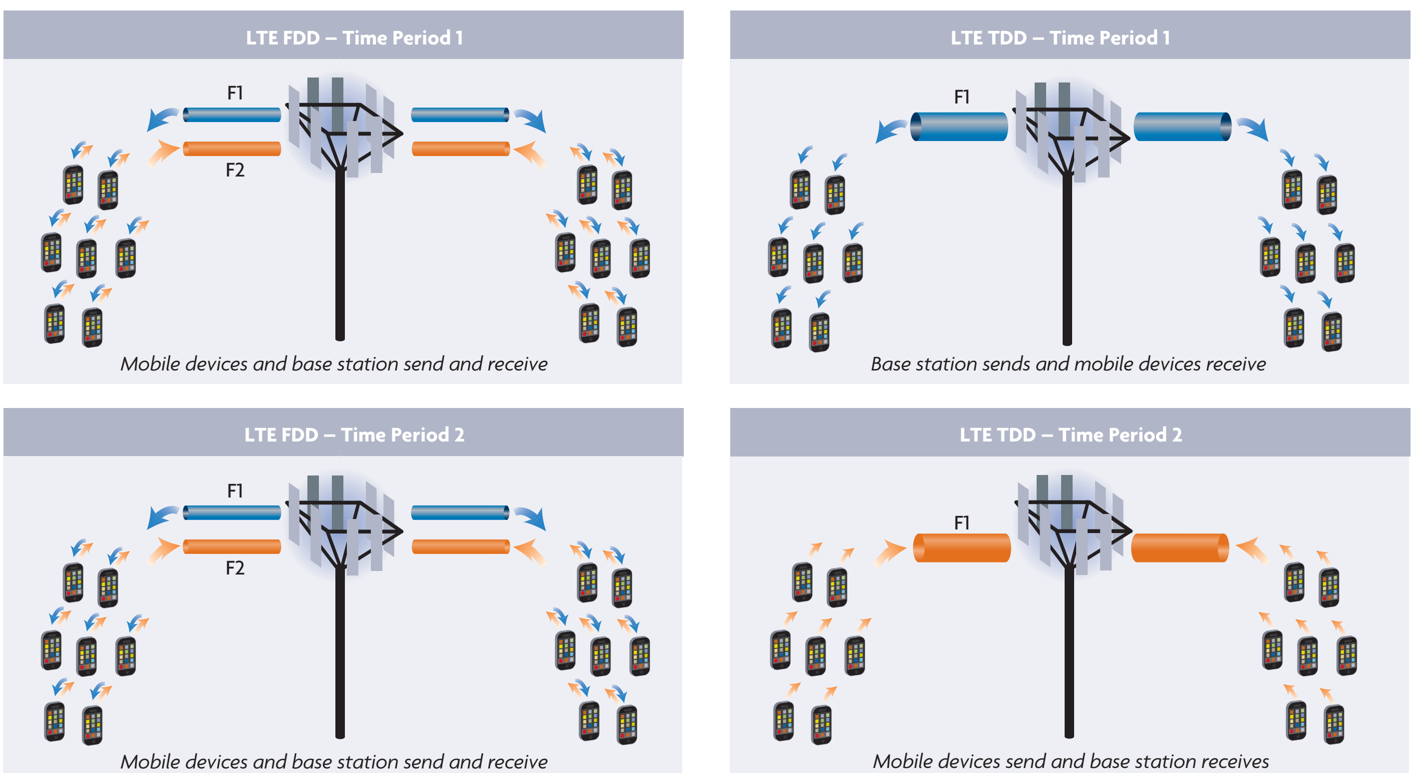
LTE-U has to conform to the varying degrees of regulatory requirements that exist around the world.

LTE-U wouldn't replace Wi-Fi, just as LTE in licensed bands doesn't currently replace the importance of Wi-Fi as a complementary offload strategy for the more ubiquitous LTE network coverage. Conversely, LTE-U wouldn't be used in the same way that LTE in licensed spectrum is used today, because LTE-U has to conform to the varying degrees of regulatory requirements that exist around the world and it would be operating in shared spectrum, which comes with its own set of challenges.

In order to understand and appreciate how LTE-U will work, it is important to first understand how the unlicensed 5 GHz spectrum is being used today and how certain features that exist today in the LTE standard could be tailored to operate in the unlicensed spectrum.

Wi-Fi uses TDD (time division duplexing). As the name suggests, with TDD, the allocation of time that is used to send data from the Wi-Fi AP to the mobile Wi-Fi client (i.e., the downlink) is orthogonal to the time used to send the data from the mobile Wi-Fi client to the Wi-Fi AP (i.e., the uplink). Part of the time the Wi-Fi AP is "talking" [and the mobile Wi-Fi client is "listening"] and part of the time the mobile Wi-Fi client is "talking" but they aren't doing it at the same time. LTE supports this concept today (called LTE TDD), but it also supports FDD (LTE FDD) in which the serving base station (eNode B in LTE vernacular) and the LTE mobile clients can communicate at the same time but they use different frequency bands to do so. Figure 2 pictorially depicts the primary differences between the FDD and TDD duplex schemes.

**Figure 2. A Comparison between LTE FDD and LTE TDD**

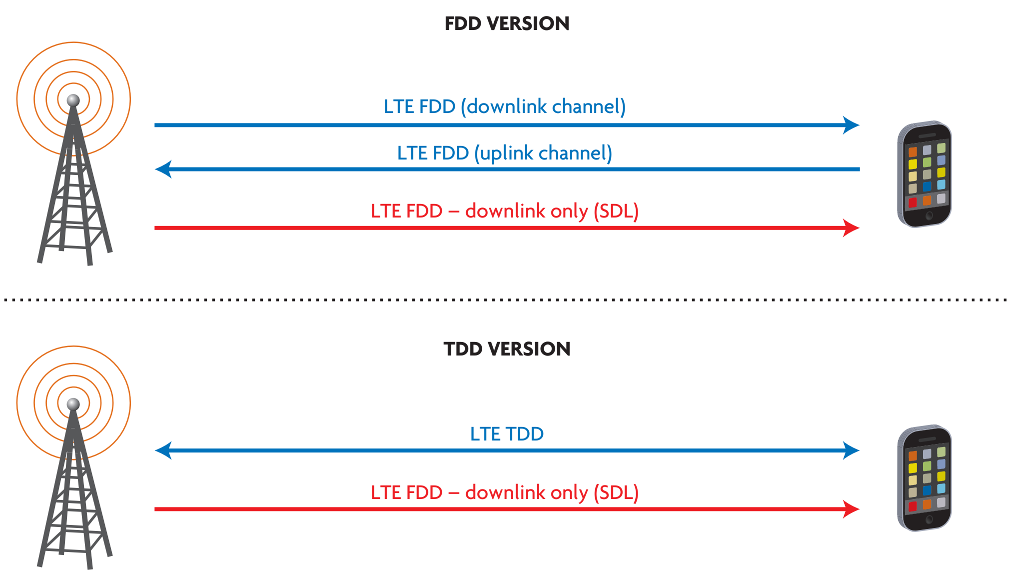



*Source: Signals Research Group*

LTE-U can accommodate the TDD nature of Wi-Fi and the 5 GHz band plan.

In order to fit in nicely alongside Wi-Fi, LTE-U can accommodate the TDD nature of Wi-Fi and the 5 GHz band plan. It can do this in one of two ways. LTE-U can use the TDD duplex scheme, in many respects similar to how LTE uses TDD in licensed spectrum. Alternatively, LTE-U can use a feature called Supplemental Downlink, which is also supported by LTE in licensed spectrum. With Supplemental Downlink, a block of spectrum is used to provide a downlink path, between the eNodeB and the mobile devices. The twist is that this spectrum typically doesn't have a dedicated uplink channel. Instead, it leverages an uplink channel that is associated with a different pairing of FDD spectrum. We note that Supplemental Downlink can also be used in combination with LTE TDD. In essence, Supplemental Downlink makes it possible to have an asymmetric allocation of downlink and uplink channel bandwidths; for example, a 20 MHz channel in the downlink and a 10 MHz channel in the uplink (reference Figure 3). Supplemental Downlink, which is a Release 10 feature, is essentially the same as LTE Downlink Carrier Aggregation from an implementation perspective. Multiple operators around the world have already deployed Carrier Aggregation.

**Figure 3. Supplemental Downlink Channel**




*Source: Signals Research Group*

The other very important concept that needs to be understood is the whole notion of an anchor carrier, or primary carrier, and a secondary carrier. LTE-Advanced uses carrier aggregation to logically combine radio channels in two different frequency bands or within the same frequency band. For example, AT&T is using 10 MHz of spectrum in Band 2 (~1900 MHz) and 10 MHz of spectrum in Band 17 (~700 MHz) to create a logical 20 MHz downlink channel to achieve the 150 Mbps maximum throughput that is possible with an LTE 20 MHz channel. In this deployment scenario one of the channels is serving as the primary carrier and the other channel is serving as the secondary carrier. The biggest distinction between the two carriers is that the primary carrier is also responsible for communicating most signaling and control information, including system acquisition, authentication, mobility management, access, paging, registration, and the signaling and control information associated with the secondary carrier.

LTE-U will leverage a primary carrier that operates in licensed spectrum while a secondary carrier will operate in the unlicensed [and unpaired] 5 GHz spectrum.

LTE-U leverages this feature, in part, because of the somewhat unreliable nature of the unlicensed spectrum. In the case of LTE-U, the primary carrier is always in the licensed spectrum and the secondary carrier is in the unlicensed spectrum. In addition to carrying the signaling information, the primary carrier can always be used to transport the mobile data traffic. Conversely, the secondary carrier in the unlicensed spectrum will be more opportunistic and only used in a way so that it shares the spectrum fairly with other systems that are using the spectrum, including Wi-Fi or other LTE-U deployments. The reliance on the primary carrier in the licensed spectrum has resulted in LTE-U being referred to as LAA (Licensed Assisted Access).

LTE-U needs a "Listen Before Talk" feature in order to use unlicensed spectrum in certain regions of the world, hence the need for a standards-based approach.

The last concept that is important to discuss is how Wi-Fi manages interference between different Wi-Fi links from the same service provider or even between different Wi-Fi deployments. Wi-Fi is a contention-based system, meaning that mutual self-destruction would happen unless the Wi-Fi APs and clients take appropriate steps to avoid interference. They do this by listening to the channel before trying to transmit data. Specifically, Wi-Fi uses the CSMA (Carrier Sense Multiple Access) protocol to achieve the so-called "Listen Before Talk" (LBT) behavior. Likewise, LTE-U needs to support LBT, which has specific requirements throughout the world. For this reason, there is a need for a standards-based approach and changes to the LTE interface in order to make LTE-U compliant with the regulatory requirements for the unlicensed spectrum in these regions. We explore this topic in more detail later in this paper.

## What are the likely deployment scenarios?

As previously discussed, for the foreseeable future LTE-U will not be autonomous from the existing LTE networks in licensed spectrum. Instead, LTE-U will need to leverage the licensed spectrum for the anchor carrier since the licensed spectrum can always be used and it is more reliable than the unlicensed spectrum where LTE-U will reside. Best effort web browsing – Yes; VoLTE – No. However, even in this context there are still a few deployment options to consider, including the distinct possibility for some deployments of LTE-U in advance of the likely standardization occurring within the 3GPP standards body.

LTE-U can be thought of as a two-phase approach.

LTE-U can be thought of as a two-phase approach. Phase 1 is a pre-R13 solution that can be deployed in certain regulatory regions as soon as the ecosystem is ready. In fact, there have already been at least a couple of announcements from operators regarding their near-term trial or long-term deployment plans for LTE-U Phase 1. Phase 2, as discussed in the next section, is the R-13-based solution that is necessary to make LTE-U a reality throughout the world, including those regions that have more stringent regulatory requirements for the 5 GHz band.

Phase 1 leverages many of the same concepts that Wi-Fi uses to avoid interference with itself.

Phase 1 is possible because it leverages existing LTE Carrier Aggregation and radio resource management features to avoid interference with itself even though it is not technically using LBT to do it. Further, any wireless application or service can use this spectrum alongside Wi-Fi and other existing incumbents, as long as the new entrant supports technical features that enable fair usage of the spectrum. There are three basic mechanisms that Phase 1 uses to keep a good fence between itself and the incumbent wireless applications, including Wi-Fi, not to mention other LTE-U deployments.

**Frequency Selection –** There is up to 500 MHz of unlicensed spectrum that is available and an LTE-U small cell can operate with only 20 MHz of it. By scanning the spectrum with a special listening module the LTE-U small cell can identify those frequencies that have the least amount of interference. In many cases there may be ample amounts of frequencies to choose from and the additional interference mitigation mechanisms discussed next will not be needed. We note that 802.11ac supports at least 80 MHz channels in 5 GHz when the channels are available, although support for 160 MHz channels is optional and it may become more common in the second wave of products. Obviously, when 802.11ac becomes more ubiquitous and it supports more Wi-Fi traffic, the relative "cleanness" of the spectrum will not be as attractive as it is today.

**Time Selection –** If the unlicensed spectrum is being occupied, LTE-U can still co-exist in the same frequencies being used by Wi-Fi if it does so in a way that does not degrade Wi-Fi performance. LTE-U supports co-existence with Wi-Fi by using something called Carrier-Sensing Adaptive Transmission (CSAT) to sense the traffic in the network, including how frequently the traffic is occurring. According to the amount of traffic and the traffic patterns, LTE-U schedules bursts of traffic during those time intervals when other traffic is not present. The shortcoming of CSAT is that the response time is on the order of 100 ms while the LBT requirement is approximately 10 ms.

It should be noted that is possible to shorten the CST On Time to facilitate the transmission of delay-sensitive Wi-Fi traffic while the LTE traffic can always be sent via the primary carrier in the licensed band. In any event, the ability of LTE to leverage the unlicensed spectrum (LTE-U) does lead to a bit of unpredictability. Therefore, LTE-U is really targeting best-effort traffic and relying on the licensed spectrum to deliver the time essential traffic, including the signaling and control information.

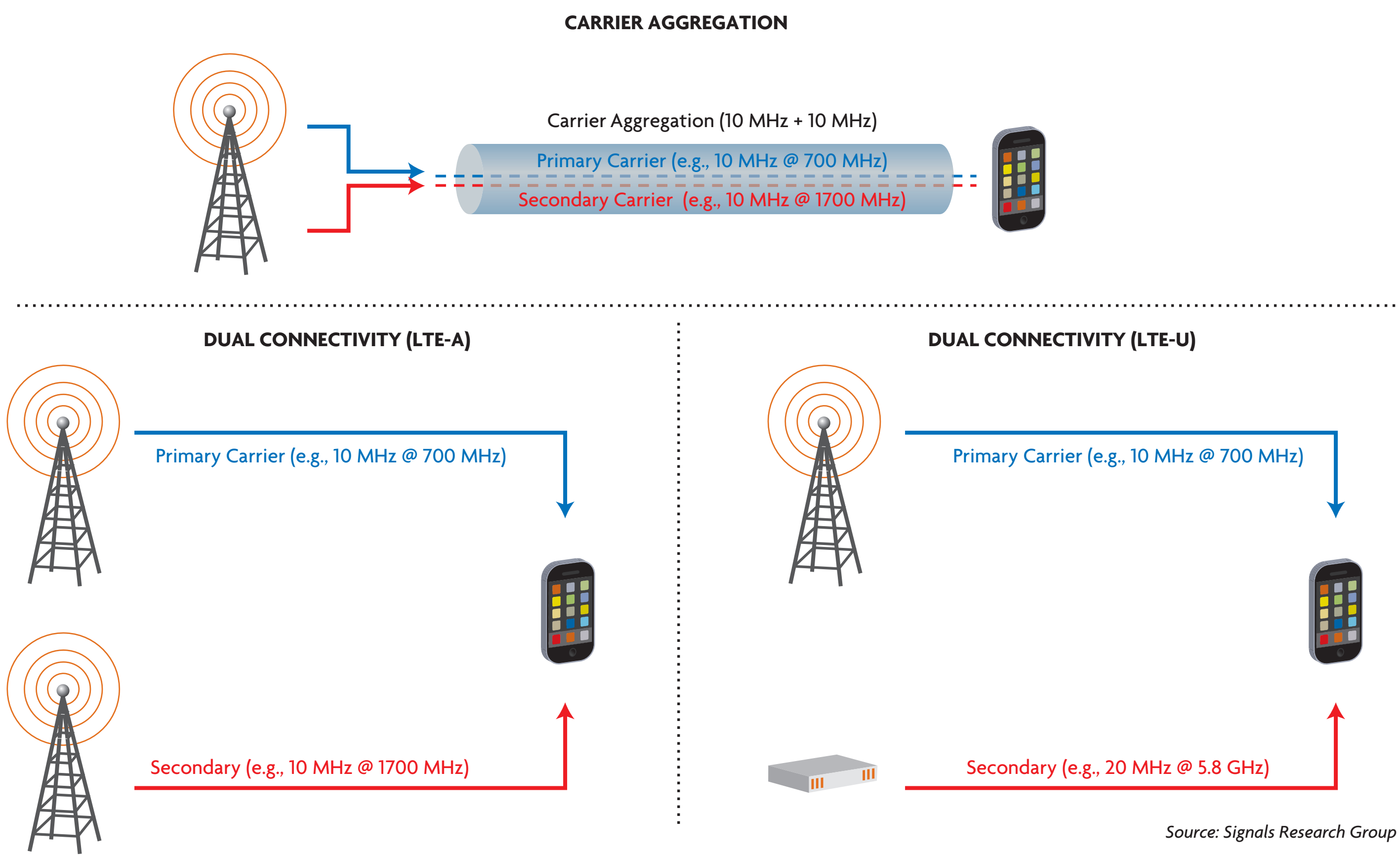
**On/Off Switch –** Since the primary/anchor carrier is responsible for transmitting the signaling and control channel information using the licensed spectrum, the secondary carrier, which uses the unlicensed spectrum, doesn't need to be activated all the time. Therefore, whenever there is not enough of data traffic to warrant using the secondary carrier it can simply stop transmitting data and radiating energy.

In Phase 1, the small cell most likely will include LTE in both licensed and unlicensed spectrum (LTE-U) since it is technically easier to have the two carriers located at the same location than having the licensed portion of LTE and LTE-U come from geographically different locations. It is also likely that the small cell will include support for Wi-Fi. This view is based entirely on the overall trends that we are seeing in the industry when it comes to the requirements for a small cell, but we recognize that Wi-Fi is more important for some operators than it is for other operators. As far as we know, incorporating Wi-Fi, LTE [licensed] and LTE-U in the same physical box is no more difficult than including just the licensed version of LTE and Wi-Fi. Further, from an economics perspective, it just makes more sense to include the Wi-Fi radio since it only adds a modest incremental cost.

Having the primary carrier and the secondary carrier (unlicensed spectrum) originate from the same location is largely identical to what is being done today with carrier aggregation.

Having the primary carrier (licensed spectrum) and the secondary carrier (LTE-U) originate from the same location is largely identical to what is being done today with carrier aggregation. In fact, it is referred to as the carrier aggregation approach to implementing LTE-U. The only difference with LTE-U is the secondary carrier is using unlicensed spectrum instead of one of the licensed bands.

**Figure 4. Carrier Aggregation versus Dual Connectivity**




*Source: Signals Research Group*

Another potential option is to have the primary carrier (licensed spectrum) and secondary (unlicensed spectrum) originate from geographically different locations. For example, the primary carrier could come from a large outdoor macro cell and the unlicensed secondary carrier could come from an indoor small cell. In Release 12 there is an LTE feature called dual connectivity which enables this capability, albeit with the primary and secondary carriers using licensed spectrum. LTE-U would simply build on this capability by using unlicensed spectrum for the secondary carrier. Since dual connectivity is an evolution of carrier aggregation, it is logical to assume that it will be supported by LTE-U, but most likely not until LTE-U Phase 2.

Although nothing is preventing mobile operators in most regions of the world from deploying LTE-U today, they still need commercially-viable solutions that support it with full interoperability.

Although nothing is preventing mobile operators in most regions of the world – for example the United States, China and Korea – from deploying LTE-U today, they still need commercially-viable solutions, including devices/chipsets and infrastructure that support it with full interoperability. Given that the major infrastructure vendors are on board and Qualcomm was one of the initial proponents of LTE-U, we know that development work is underway on both chipsets and infrastructure from all of these companies. However, we have no clear indication for when these solutions will be available. In the event that an operator moved forward with a Phase 1 strategy, we [SRG] believe that the operator will have up to a two-year advantage over its peers who elect to wait for the R-13-based solution.

Our belief is that we'll see a lot of LTE-U announcements and activities well in advance of Release 13 products becoming available. However, we are not yet convinced that there will be large-scale deployments of the Phase 1 solution. Our main concern is that the changes required to the LTE air interface could result in a less than smooth migration between LTE-U Phase 1 and LTE-U Phase 2. The initial activities will, however, be a great proving ground for the LTE-U concept since in many regards Phase 1 should be quite similar to what eventually becomes the R-13-based approach.

## What changes are required to the LTE standard to make LTE-U a reality throughout the world?

Although there are mechanisms in place for LTE-U Phase 1 that will allow LTE and Wi-Fi to co-exist in the same unlicensed spectrum, there are certain regional-specific regulatory requirements that LTE cannot support without changes to the air interface. These necessary changes explain the need for LTE-U Phase 2, which will allow LTE-U to be used in regions, including Europe, and Japan.

There seems to be general agreement regarding what needs to be changed in order for LTE-U to satisfy the regulatory requirements, which exist in some regions of the world.

At this early juncture the specific changes to the LTE air interface have not been decided within the 3GPP standards body, however, there seems to be general agreement regarding what needs to be changed in order for LTE-U to satisfy these regulatory requirements. These well-recognized changes – two changes in particular – stem from the ETSI (European Telecommunications Standards Institute) requirements for 5 GHz performance, as defined in ETSI EN 301 893.

Section 4.8 of this document defines the channel access mechanism, which basically means what a wireless system must do before using the unlicensed spectrum. To paraphrase, before starting to transmit on a channel the equipment must perform a clear channel assessment (CCA) to confirm that the channel is unoccupied. If the channel is occupied it must wait or move to another channel. If the channel is unoccupied then it can use the channel for a certain amount of time – called the Channel Occupancy Time – which is on the order of 1 ms to 10 ms in length, at which point it must repeat the process. Within this Channel Occupancy Time there is also a minimum idle period that must be at least 5% of the Channel Occupancy Time.

The wireless system must use at least 80% of the declared nominal channel bandwidth.

The other important requirement, which requires changes to the LTE standard, is defined in Section 4.3 of this document. This section defines the nominal channel bandwidth and the occupied channel bandwidth of wireless systems that use the 5 GHz band. The specified nominal channel bandwidth of 5 MHz is supported by LTE today; however, the requirement pertaining to the occupied channel bandwidth is not supported. According to this requirement, the wireless system must use at least 80% of the declared nominal channel bandwidth.

The current LTE standard, and, therefore the Phase 1 implementation of LTE-U, do not meet two ETSI requirements.

The current LTE standard, and, therefore the Phase 1 implementation of LTE-U, do not meet these two requirements. With the Phase 1 implementation of LTE-U, the secondary carrier can be activated/deactivated based on the observed interference but the response time is on the order of 100 ms, or much longer than the ETSI requirements for LBT. LTE is constantly transmitting an RF signal, so while it can still apply interference mitigation mechanisms, it is doing it while "talking" – a big No-No according to these requirements. Further, LTE uses OFDMA (Orthogonal Frequency Division Multiple Access) in the downlink and SC-FDMA (Single Carrier-Frequency Division Multiple Access) in the uplink. Without going into the gory details, it basically means that only a very modest portion of the channel may be used to send data back and forth. This mechanism violates the minimum channel bandwidth requirement.

The required changes to the LTE standard introduce some inefficiency in how LTE performs relative to how it performs in licensed spectrum.

In essence, the required changes to the LTE standard – namely, the listening period and the spreading of the data traffic over at least 80% of the channel bandwidth – introduce some inefficiency in how LTE performs relative to how it performs in licensed spectrum. This tradeoff, however, should be well worth it given that it would provide access to up to nearly 500 MHz of spectrum. There are also some other requirements regarding transmit power in certain bands/regions and the amount of emissions that can fall outside of the radiated spectrum, however, these types of requirements exist with all spectrum, included licensed spectrum, so complying with them would be less of an issue.

Adhering to the two requirements that we just mentioned has some cascading effects that impact other aspects of the LTE standard. One example is how HARQ (Hybrid Automatic Repeat reQuest) performs. With the current LTE implementation there is a 4 ms window between when a data packet is sent and when the sender of the data packet expects confirmation that the data packet was received. In the case of unlicensed spectrum there are no certainties regarding when the spectrum can be used so the recipient of the data packet may not be able to send an acknowledgement message in an orderly manner. In other words, there needs to be some built-in flexibility regarding how data packets are sent and subsequently acknowledged.

Beacon signals could be used to control interference.

There is also the notion of beacon signals that are used within Wi-Fi to communicate information about the network. In theory, the LTE-U small cell can use beacon signals to communicate their presence and to inform the Wi-Fi APs, not to mention other LTE-U small cells, that it is about to use a particular channel. Beacon signals are not a part of the LTE standard but they could be used by LTE-U to minimize interference when Wi-Fi APs or LTE-U small cells from other operators are in the immediate vicinity.

It isn't entirely clear how 3GPP will address the ETSI requirements.

At the moment it isn't entirely clear how 3GPP will address the ETSI requirements that require certain changes to the existing LTE standard. However, 3GPP has launched a study item to explore the matter in more detail, and in the coming months it will become more evident how these changes will be implemented. There may be agreement that these changes are required and that they should be incorporated into Release 13. However, the devil is in the details regarding the exact mechanisms that will be used. It is also possible that a somewhat limited set of LTE-U functionality is incorporated into Release 13 and that additional functionality gets included in subsequent releases. For example, the standards body could elect to only include carrier aggregation [or supplemental downlink] and delay the dual connectivity feature [or LTE-U TDD] until the next release.

## What happens to Wi-Fi?

The short and entirely complete answer is "nothing." One of our very initial misconceptions about LTE-U is that it would require changes to Wi-Fi in order to work. After all, from the perspective of a Wi-Fi AP, the LTE-U small cell is simply a source of unavoidable interference and it wouldn't be able to cope with it. The reality is the complete opposite.

To some extent, Wi-Fi won't even know or care that LTE-U is present.

Since LTE-U uses very similar avoidance detection mechanisms compared to what Wi-Fi uses, LTE-U can take the high road, so to speak, and leverage the spectrum across the frequency and time domains whenever Wi-Fi isn't using it. To some extent, Wi-Fi won't even know or care that LTE-U is present.

Wi-Fi has its own interference detection and avoidance system that it uses to handle interference.

Further, Wi-Fi has its own interference detection and avoidance system that it uses to handle interference from adjacent Wi-Fi APs or other unknown sources of interference. Specifically, it uses CSMA (Carrier Sense Multiple Access) to detect Wi-Fi interference on the same radio channel before transmitting in it. CSMA is one way to meet the requirement of Listen Before Talk. In addition, Wi-Fi uses energy detection mechanisms to detect unknown type of interference. It should be noted that the interference threshold for non-Wi-Fi systems is stricter than it is for other Wi-Fi systems. In the event that an LTE-U small cell is transmitting in the band the Wi-Fi AP will detect the interference [even though it doesn't recognize the source of the interference] and avoid it by delaying its transmission on the order of milliseconds or by moving to a different portion of the spectrum.

It should be noted that the Phase 1 implementation of LTE-U is intended to be less aggressive than a Wi-Fi AP when it comes to grabbing and using unoccupied spectrum, but as long as it adheres to the fair usage tenet it is entitled to use the spectrum. In a worst-case scenario, the LTE-U small cell creates no more interference than an adjacent Wi-Fi AP. The only difference is that when the LTE-U small cell is using the channel, it is making more efficient use of the spectrum.

## Is Wi-Fi still important?

We have no expectation that operators will abandon their Wi-Fi strategy.

The even shorter answer is "yes." Although some of the operators at the 3GPP workshop last June who seemed in favor of LTE-U are some of the biggest proponents of Wi-Fi today, we have no expectation that they will abandon their Wi-Fi strategy. In fact, one could argue that LTE-U creates a new market opportunity for Wi-Fi and it also encourages Wi-Fi to further enhance with innovative solutions, in 802.11ax and beyond. As an example, an operator without a strategic interest in Wi-Fi could start deploying Wi-Fi in its network when it deploys LTE-U. The concept of a Unified LTE Network is one good reason for doing so. After all, the incremental cost of the additional Wi-Fi radio is relatively modest in the big scheme of things compared to the cost associated with installing the small cell and the ongoing operational expenses (backhaul, etc.).

Wi-Fi is also very ubiquitous today in mobile devices and consumer electronics devices, and its upfront cost will always favor LTE. Wi-Fi will also be needed in those situations where LTE coverage using licensed spectrum isn't available. There will also be situations where the Wi-Fi AP owner/service provider doesn't have the rights to use the licensed LTE spectrum or the consumer with the Wi-Fi device doesn't have the right credentials (i.e., SIM card) to authenticate to the LTE network.

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