QUALCOMM

Qualcomm Incorporated

Extending LTE Advanced to unlicensed spectrum

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1 Executive summary

Thanks to the onslaught of smartphones combined with the popularity of mobile data, 3G/4G operators around the world are bracing for the continued phenomenal growth of mobile data. A holistic approach is needed to address this formidable challenge, encompassing dense deployment of small cells, intelligently utilizing spectrum, increasing end-to-end efficiency, and more.

Extending LTE Advanced to unlicensed spectrum is the latest in a series of ground-breaking innovations to address the mobile data challenge. This paper examines the benefits of this approach, challenges involved in bringing it to fruition, and shows how it can co-exist with existing technologies such as Wi-Fi.

Spectrum is life-blood of wireless networks. Licensed spectrum is operators' first choice, as it provides reliability, and predictable performance. Hence the industry is hard at work to make best use of existing spectrum and looking for more licensed spectrum via traditional auctions and innovative paradigms such as authorized/licensed shared access (ASA/LSA). At the same time, to support the insatiable data demand, operators will also have to leverage readily available unlicensed spectrum. Brining LTE Advanced to unlicensed spectrum is the most efficient option to achieve that.

Bringing LTE Advanced to unlicensed spectrum is really a simple idea with immense benefits. It involves leveraging the large number of small cells that operators are planning to deploy and aggregating unlicensed spectrum with the licensed spectrum for LTE Advanced. The existing core network can be used as is. In essence, the whole system works as a unified LTE network to efficiently leverage both licensed and unlicensed spectrum bands.

LTE Advanced in the unlicensed bands can provide better coverage and capacity than Wi-Fi deployed by network operators (also referred to as Carrier Wi-Fi), while allowing for seamless flow of data between licensed and unlicensed spectrum through a single core network. This means operators can augment the capacity of their networks by utilizing the unlicensed spectrum more efficiently, while also providing the tightest possible interworking between the licensed and unlicensed bands. From the user perspective, this means an enhanced broadband experience—higher data rates, seamless use of both licensed and unlicensed bands, higher reliability, better mobility, and more. LTE Advanced in unlicensed bands is carefully designed to harmoniously co-exist with Wi-Fi. There are many features to avoid and mitigate interference, as well as to share the resources proportionately and fairly, when using the same channel, all-in-all to be a "good-neighbor" to Wi-Fi.

The primary use case for bringing LTE Advanced to unlicensed spectrum is for LTE operators to augment their network capacity. It targets the bandwidth-rich 5 GHz spectrum, which potentially has up to 500 MHz of available spectrum. Commercial deployments in the United States, South Korea, and China can be fast-tracked using the existing standard (3GPP Rel 10) supporting carrier aggregation, whereas other countries need standards modifications (candidate for Rel. 13) to meet region-specific regulatory requirements.

Qualcomm, being a wireless pioneer, is at the forefront of the development of all the major wireless technologies, including LTE Advanced, Wi-Fi and their evolutions, and now LTE Advanced in the unlicensed spectrum. Along with 3G/4G, we are fully committed to the strong evolution of Wi-Fi. The 802.11ac expanded product portfolio (from Qualcomm Atheros, Inc.) continues to enable robust end-to-end ecosystem. Qualcomm not only excels in envisioning the impossible, but also in inventing, developing and commercializing and bringing our vision to fruition.

2 Bringing the benefits of LTE to unlicensed spectrum

The explosive increase in mobile data consumption is a global phenomenon. There is a strong trend of media consumption moving toward smartphones, tablets, and other mobile computing devices. The content on the Internet is increasingly getting richer and of higher quality. The industry is constantly on the hunt for solutions that can meet this insatiable data demand, while continually providing higher-levels of user experience to their customers. We call this the "1000x mobile data challenge," the effort to increase data capacity of mobile networks by a thousand times over the next ten years. As detailed in our previous white paper, titled "Rising to Meet the 1000x Mobile Data Challenge," operators will have to adopt a holistic strategy to address it. At the top of their agenda are two initiatives: 1) many densely deployed small cells; and 2) intelligently utilizing existing spectrum and getting access to more. Bringing LTE Advanced to unlicensed spectrum fits perfectly with these initiatives, as it exploits the deployment of small cells to achieve the best possible performance for opportunistically using the unlicensed spectrum, while mitigating and managing the interference.

Licensed spectrum is of paramount importance to operators. The rights of exclusive use allow them to deploy a fully coordinated network and efficiently manage it. Such coordination provides ensured Quality of Service (QoS), seamless mobility, and predictable performance, and becomes the foundation of their offerings. Hence getting access to more licensed spectrum is their top priority. While industry is hard at work in that respect, to address phenomenal growth in data demand, it is worthwhile for operators to also take advantage of unlicensed spectrum, when readily available. In fact many operators are already doing it by deploying Wi-Fi networks. Extending LTE Advanced to unlicensed spectrum offers operators a more efficient and seamless option to achieve that goal.

2.1 Unified network for both licensed and unlicensed spectrum

Operators are increasingly leveraging unlicensed spectrum to opportunistically offload the "best-effort" class of data from their 3G/4G networks.

Many operators have their own Wi-Fi networks, sometime referred to as "Carrier Wi-Fi." In the last couple of years the wireless industry has been working hard to establish more seamless interworking

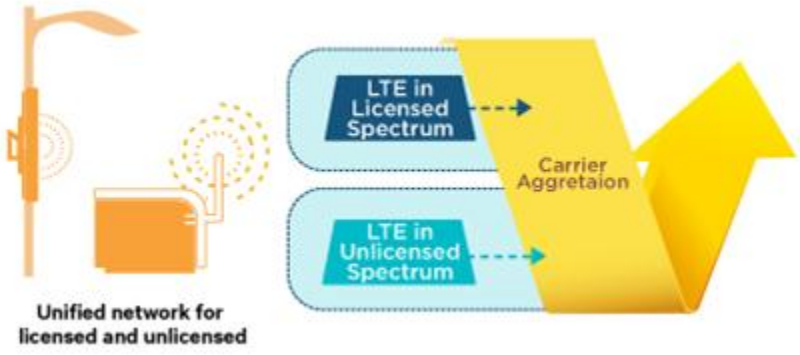

Fig. 2.1: Unified LTE Advanced network for both licensed and unlicensed spectrum

between such Carrier Wi-Fi and 3G/4G, especially with LTE. Bringing LTE Advanced into unlicensed spectrum takes this effort to the extreme, by using the same technology and network for all spectrum types. This not only achieves the tightest possible integration, it also offers the most seamless user experience.

In this approach, the same small cells that offer LTE Advanced on licensed spectrum, will also offer it on the 5 GHz unlicensed spectrum. Both bands are aggregated together, in exactly the same way that licensed bands are treated in standard LTE Advanced carrier aggregation, which launched in June 2013. Since it is the same system using both spectrum types, it has a number of benefits.

From the operator's perspective, the primary benefit is having a unified network for both licensed and unlicensed spectrum—using the same:

- core network
- small cells
- spectrum bands
- authentication systems
- operations and management systems
- Acquisition, access, registration, paging and mobility procedures
- and more

For operators who embrace the concept of extending LTE Advanced to unlicensed spectrum, deploying and managing the resulting unified network is a simple and cost-effective process.

2.1.1 Two deployment options – Supplemental downlink or TDD

There are two main deployment options for aggregating unlicensed spectrum: Supplemental Downlink (SDL) and TDD.

In the **SDL mode**, as illustrated in Fig 2.2, unlicensed spectrum will only be used for the downlink, so that the data rates and capacity are greatly increased only in the downlink, keeping the uplink as is. This is beneficial, especially to address the typically heavy traffic in the downlink.

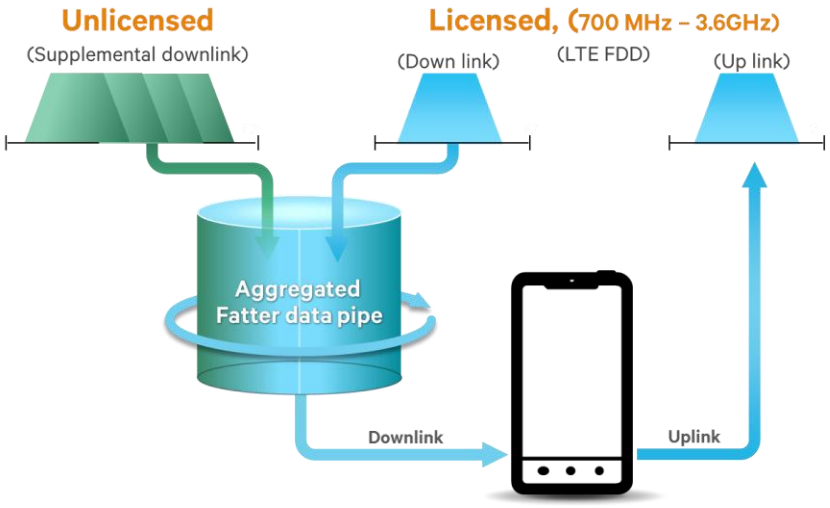

Fig. 2.2, In SDL mode unlicensed spectrum is combined only with the downlink

In the **TDD mode**, the unlicensed spectrum will have both downlink and uplink, just like a typical LTE TDD system, and it works like a typical LTE TDD carrier aggregation. The advantage here is the flexibility to adjust the

amount of resources between the uplink and downlink. In both options unlicensed spectrum is used only for the data plane, and all the control plane is handled through licensed spectrum. No matter which option is used, both operators and users benefit.

2.2 Enhanced user experience

Although combining LTE in licensed and unlicensed spectrum is transparent to the user, it has many perceivable and compelling user benefits. Some of which are discussed below.

2.2.1 Wider data pipe for better data rates through carrier aggregation

Just like any other aggregation scenario, combining the licensed and unlicensed bands creates a much wider data pipe, which results in very high data rates for users. Higher data rates mean faster downloads, and more responsive apps and services.

2.2.2 Reliable and predictable performance with an anchor in licensed spectrum

The hallmarks of any network utilizing licensed spectrum, such as LTE, are reliable and predictable performance. This is achieved through a coordinated and managed network, where-in the resource allocation is always tightly managed. The effort to offer LTE Advanced using unlicensed spectrum relies on the same time-tested philosophy. However, because of the nature of unlicensed spectrum, this may not be possible all the time. That's where the concept of "anchoring" on licensed spectrum comes in.

As noted in section 2.1.1, through aggregation, the connectivity on the unlicensed spectrum always comes with the connectivity on the licensed spectrum. The control signaling always happens on the licensed band, where the QoS is ensured, which means no matter what the channel condition in the unlicensed band is, the crucial signaling information is always communicated properly between the network and device. And since service on both of the bands is offered using the same integrated small cell, it is always in control, and knows about the condition of the connectivity. This ensures that the unlicensed bands are opportunistically added to maximize performance.

2.2.3 Seamless user experience

From a user perspective, the best measure of seamless mobility service is to not notice the impact of mobility at all. The users need not worry about selecting one or the other (or both) radios, or worse, experiencing interruption in the service. Since it is the same LTE network using both licensed and unlicensed bands, the interworking between the two is seamless as it can get. One way to better appreciate this is to contrast it with the interworking between, LTE and carrier Wi-Fi. These are two different technologies and systems, so by definition, the interworking is more complex.

In an LTE Advanced network, using both licensed and unlicensed bands, the network and devices work in tandem, always looking for the availability of an unlicensed spectrum and aggregating it whenever it is available. Users will have a better mobile experience, thanks to the increase in data rates brought about by the aggregation.

2.3 Better coverage and increased capacity

For operators, the unified network, and the seamless and enhanced user experience provide significant advantages compared to the current Carrier Wi-Fi option. As can be expected from a coordinated and managed architecture, LTE in the unlicensed spectrum offers higher performance than Wi-Fi for the same transmit power. This improvement is derived from multiple aspects of LTE. For example, LTE has a better and more robust air link structure designed specifically for mobility. LTE's coordinated and synchronized architecture makes the best use of resources by managing and mitigating the interference. The mandatory anchor in the licensed spectrum ensures that control signaling is always efficiently delivered and, above all, seamless mobility is achieved. Also, using a common set of signaling for both licensed and unlicensed spectrum reduces the overall overhead.

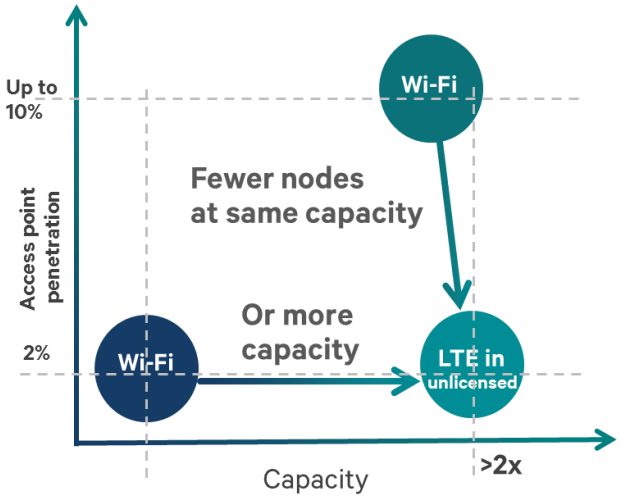

Fig. 2.3, LTE Advanced in unlicensed offers better coverage or more capacity

Our initial studies indicate a two-fold or more increase in performance as compared to Wi-Fi. As shown in Fig. 2.3 one can get twice the capacity with the same amount of LTE Advanced nodes using unlicensed spectrum as compared to Wi-Fi. On the other hand, the same capacity can be provided with fewer nodes. The example in Fig. 2.3, assumes a typical "inside-out" type of deployment, where-in small cells, deployed indoors, not only provide indoor coverage and capacity, but also serve the outdoor traffic.

3 Harmonious co-existence with Wi-Fi

Since bringing LTE Advanced to unlicensed spectrum is an alternative option to carrier Wi-Fi, the first question asked is "How will this affect existing Wi-Fi networks?" To address this, it has been designed to harmoniously co-exist with Wi-Fi, and in many cases it can be a better neighbor than Wi-Fi itself. Utmost care was taken during development to ensure that Wi-Fi is protected, and that LTE is a "good neighbor" in unlicensed bands. The result is a harmonious co-existence of both technologies, while conforming to all the regulatory requirements of the spectrum bands.

There are numerous safeguards put in place to protect Wi-Fi, as shown in Fig. 3.1

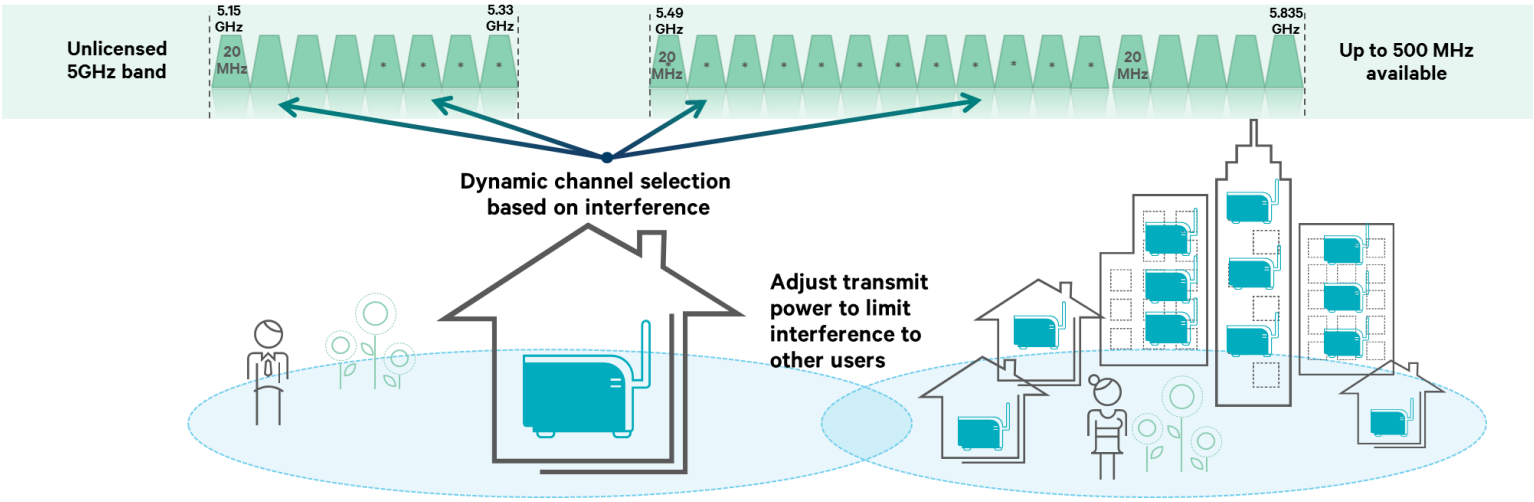

Fig. 3.1, LTE Advanced in unlicensed has many safe guards to protect Wi-Fi

LTE in unlicensed spectrum targets the 5 GHz band, which potentially has up to 500 MHz of spectrum. The band is typically divided into more than 20 channels of 20 MHz bandwidth. When LTE Advanced small cells are searching for unlicensed spectrum, they select the channel with the least interference, and they dynamically adjust for continued interference avoidance. This ensures that there is no interference between the two systems, if enough unused channels are available. In the case where the same channels have to be used, the interference is minimized.

It should be emphasized that this is different process than the mandatory regulatory requirements of Dynamic Frequency Selection and Transmit Power Control (DFS/TPC) needed to protect radars using the 5 GHz spectrum. In addition, the unlicensed spectrum is used on an “on demand” basis, meaning that only the small cells that have *active* users are able transmit in the unlicensed band, and don’t transmit at all in other times.
This is possible because of a mandatory “anchor” in the licensed band. Even during transmission, the transmit power is continuously adjusted to minimize the interference.

The design also exploits the full benefits of coordinated and managed architecture. For example, since the small cells know what channel their neighbors are using, they avoid using the same or any nearby channels. This results in minimizing the

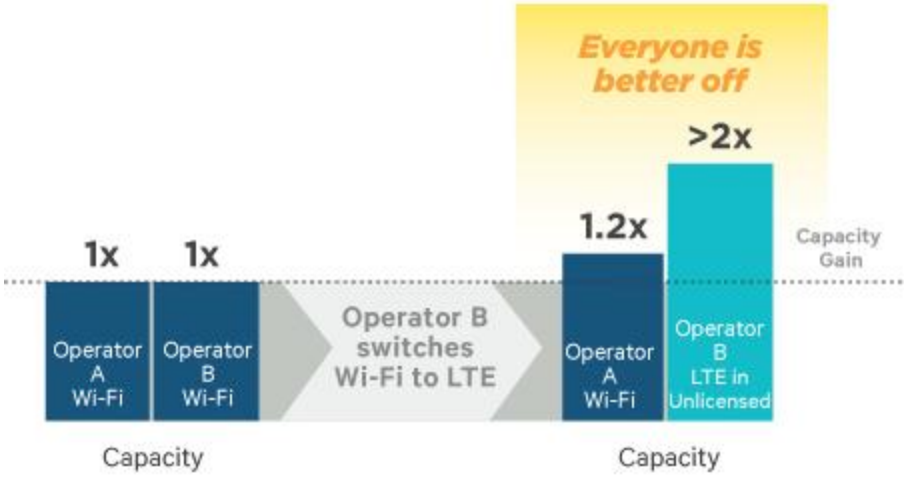

Fig. 3.2, LTE Advanced in unlicensed co-exists with Wi-Fi and benefits all users

interference at cell edges and significantly improving the data rates for users in those regions, as well as increasing overall network performance.

In addition to the safeguards discussed above, there are many more enhancements envisioned, especially for Rel. 13 that allow for a much more dynamic spectrum and resource sharing between unlicensed transmitters. An example of such enhancement is co-channel, co-existence, where LTE Advanced in unlicensed node monitors the amount of activity in the channel and shares the channel in proportion to the activity of other users (i.e. Wi-Fi) on that channel. Further, given there are also specific co-channel usage requirements referred to as “Listen Before Talk ” (also based on time sharing but on a finer scale on the order of milliseconds) mandated by regulations in some countries, modifications are being made to the LTE PHY and MAC structure. These modifications are targeted for Rel. 13.

The result of all these techniques is that LTE Advanced in unlicensed spectrum can harmoniously co-exist with Wi-Fi, providing good overall performance. See Fig 3.2.

4 Early commercialization with existing standard

How soon it can be brought to market?

Bringing LTE Advanced to unlicensed spectrum can be commercially realized in the near future, especially, in countries such as the United States, South Korea, and China. In these countries, operators can launch LTE Advanced (Rel. 10/11) in both licensed and unlicensed 5 GHz band with small cells that support carefully designed co-existence mechanisms and UEs that supports 5 GHz band for LTE.”

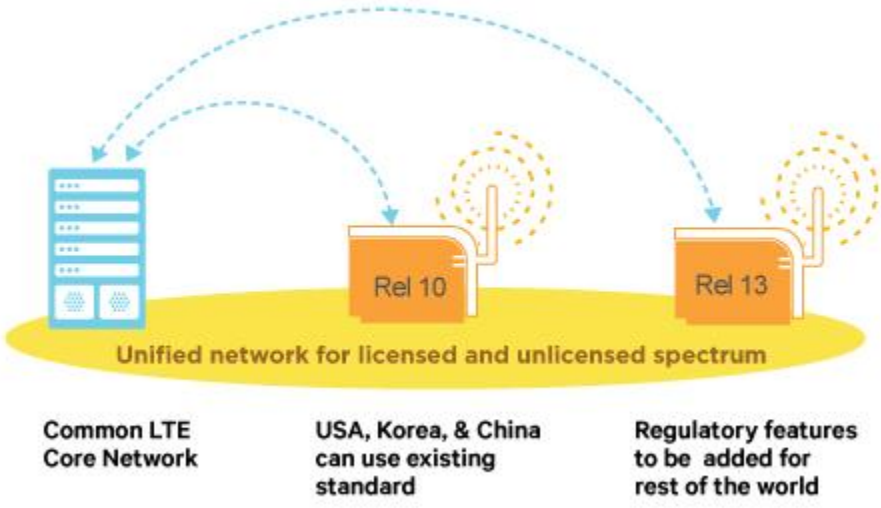

Fig. 4.1, early commercialization with existing standards and core network

The path to commercialization in other countries involves modification of the standard to support certain “specific waveforms” mandated by regulatory requirements for co-channel existence (LBT features). These features are proposed to be standardized in Rel. 13 timeframe.

5 Qualcomm – a leader in providing best solutions for unlicensed spectrum

As a pioneer and leader in wireless, Qualcomm, with its subsidiaries, plays a key role in the development and evolution of all leading wireless technologies, including 3G, 4G, and Wi-Fi. The

company is focused on offering the best solutions for all types of spectrum, maximizing the use of this finite resource, be it traditional licensed spectrum, unlicensed spectrum, or Authorized Shared Access (ASA). ASA is a new method to access *underutilized* spectrum wherein it is shared on an exclusive basis between incumbent holders (e.g., the military) and 3G/4G operators.

Qualcomm is an established leader in both 3G/4G and (with Qualcomm Atheros, Inc.) Wi-Fi technologies. Qualcomm Atheros' expansive Wi-Fi product portfolio addresses mobile, connected home, automotive, energy, and many other sectors. Such end-to-end approach continues to enable a robust 802.11ac ecosystem. It is committed to the strong evolution of Wi-Fi into 11ad, 11ah and beyond.

Thus far, cellular 3G/4G technologies have been deployed in licensed spectrum and deployments are planned in licensed ASA spectrum as well. Meanwhile, Wi-Fi has been used extensively in the unlicensed spectrum for private, residential, and enterprise wireless broadband connectivity. Of late, mobile operators also have been leveraging this spectrum to opportunistically offload traffic from their 3G/4G networks (Carrier Wi-Fi). LTE Advanced in the unlicensed spectrum offers an additional option for these (LTE) mobile operators to use the 5 GHz band. Qualcomm is strongly committed to both of these options. In fact, it is envisioned that the future small cells will integrate all of these technologies—3G/4G, LTE Advanced for both licensed and unlicensed spectrum, and Wi-Fi— in a single box, so that operators have the flexibility to choose the options that suit them best.

Qualcomm, with its demonstrated ability to foresee and solve seemingly impossible wireless challenges, is at the forefront of evolution of all of these technologies.

6 Conclusion

In a world where mobile operators are striving to increase the capacity of their networks to address phenomenal traffic growth, spectrum is an essential component. Getting access to more licensed spectrum is a top priority for the industry as it offers reliability and predictable performance. While industry is hard at work to get more licensed spectrum via traditional auctions and innovative paradigms such as authorized/licensed shared access (ASA/LSA), extending LTE Advanced to unlicensed spectrum is a very effective tool for operators to utilize readily available unlicensed spectrum. It involves offering LTE Advanced, using small cells that not only use licensed bands, but also use the 5 GHz unlicensed band, and then aggregating those bands together to offer an enhanced broadband experience to users.

Bringing LTE Advanced to unlicensed spectrum has profound benefits for both operators and end users. For operators, it provides a cost-effective, unified network for both licensed and unlicensed spectrum—using the same core network; the same small cells will use both the spectrum bands; the same authentication, operations, and management systems; and more. For consumers and enterprises, it means an enhanced user experience—higher data rates through a wider data pipe.

And since it has an anchor in licensed spectrum, it provides reliable and predictable performance, and a seamless broadband experience.

LTE Advanced in unlicensed spectrum will harmoniously co-exist with Wi-Fi. The design not only has many techniques to mitigate and minimize interference but also to share channels proportionally and fairly. LTE Advanced in unlicensed will be a “good-neighbor” to Wi-Fi, and in many cases can be a better neighbor than Wi-Fi itself.

Unlike many new technologies, bringing LTE Advanced to unlicensed spectrum is easier as it utilizes the existing core network. In countries such as the United States, South Korea and China, the existing standards (Rel. 10/11) could be utilized.

Qualcomm is leading the development of all the major wireless technologies, including LTE Advanced, Wi-Fi, and now LTE Advanced in the unlicensed spectrum. Along with 3G/4G, we are fully committed to the strong evolution of Wi-Fi. The 802.11ac technology expertise and expansive product portfolio (from Qualcomm Atheros, Inc.) continues to enable a robust end-to-end ecosystem. At Qualcomm, we are steadfastly focused on bring the best value of all spectrum types, licensed, unlicensed and ASA, for the benefit of the entire industry.