LTE unlicensed and Wi-Fi: Moving beyond coexistence

By Monica Paolini, Senza Fili

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I. Market report

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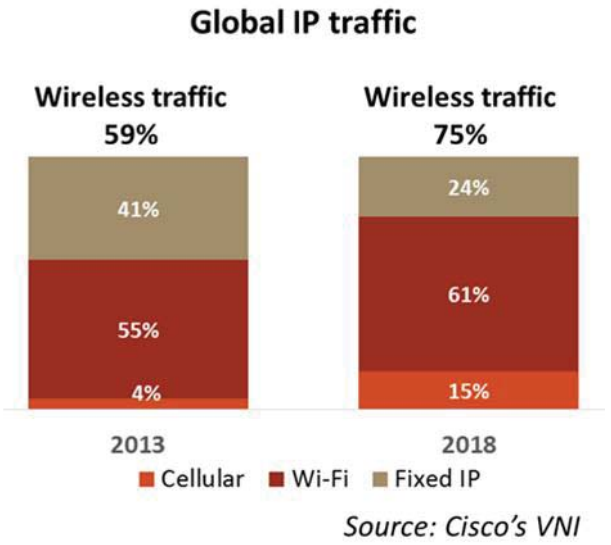
1. Introduction.
Why LTE unlicensed?

The increase in mobile traffic grabs most of the attention in the industry today, but even more remarkable is the massive shift from wireline to wireless IP traffic over the last decade. Today, wireless traffic accounts for more than half of IP traffic, and most of that is not cellular but Wi-Fi, as Cisco VNI's data on the right shows – and transported over unlicensed spectrum, mostly still in the 2.4 GHz band.

In this context, it is difficult to overestimate the relevance and value of unlicensed spectrum. Initially allocated for niche applications, it has become a key enabler of wireless consumption worldwide, driven by the success of Wi-Fi.

Traditionally mobile operators have been wary of using unlicensed spectrum. In the last few years, though, they have started to warm to its use as they developed an appreciation of unlicensed spectrum's versatility and potential in serving their subscribers, especially indoors. While estimates vary across regions, in most markets Wi-Fi accounts for more than half of traffic from mobile devices. Offloading cellular traffic into Wi-Fi networks – residential, enterprise or hotspot – has been a vital approach for mobile operators under pressure to meet subscriber demand and retain control over profit margins.



Source: Cisco's VNI

Mobile operators' recent interest in extending LTE to operations in the unlicensed 5 GHz band is the natural extension of those efforts. Wi-Fi offload was the first foray into the unlicensed bands. It paid off handsomely, and now mobile operators want to expand their use of unlicensed spectrum and bring it closer to home – using the same technology they use for licensed access, LTE, so that licensed and unlicensed transmission can be natively integrated.

With LTE in the unlicensed 5 GHz band, mobile operators can expand their network capacity in a way that is at once cost effective and easy to implement. To be clear, this is not an alternative to Wi-Fi, but a complement to it. Not even the most committed LTE unlicensed supporters question the dominance of Wi-Fi in residential and enterprise settings, or the role it will continue to play for mobile operators. The reason to adopt LTE unlicensed is not to unseat Wi-Fi, but to increase the spectral efficiency and capacity of the 5 GHz band, and to do so with a technology that is fully integrated within the mobile operators' networks.

The efficient use of unlicensed spectrum is all the more important because, although traffic load has been on the rise, ARPUs have been stagnant. That combination forces operators to find cost-effective means to increase capacity – which translates into improving per-bit economics by using available resources and assets more intensively. The efficient use of unlicensed spectrum plays a crucial role in increasing resource utilization.

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But there is more to it. Mobile operators have moved away from a single service (e.g., voice) and a single air interface (e.g., GSM) for each subscriber. Instead, they are embracing multi-RAT networks in which they can leverage the specific advantages of each technology for different services. Like Titian's painting on the cover of this report, mobile networks are multi-faceted, with older and more mature technologies coexisting with new ones. The key challenge is to seamlessly integrate multiple network interfaces, technologies and bands to optimize resource utilization and improve subscriber experience.

Mobile operators are not the only – nor the primary – users of unlicensed spectrum. Most unlicensed use comes from Wi-Fi networks installed in residential and enterprise environments. Service providers such as WISPs and cable operators also use Wi-Fi, to provide fixed or mobile broadband services to their customers. Mobile operators may rely on this infrastructure for offload, but in most cases they do not own it or control it. The introduction of LTE unlicensed proposals has met with deep concern from Wi-Fi vendors and service providers, which have used the 5 GHz band for a long time and want to continue to do so without being unfairly penalized by the introduction of LTE.

The addition of LTE unlicensed in the 5 GHz band will unquestionably increase the traffic load in the band, the contention for spectrum resources, and, eventually, the congestion. The 5 GHz band has hundreds of MHz of spectrum, and in most places it is not heavily congested today. But utilization of the band is growing quickly, and it is only a matter of time before different Wi-Fi networks and different technologies will have to compete to transmit.

A fair coexistence of multiple technologies – primarily, but not exclusively, Wi-Fi and LTE unlicensed – is essential to preserving equilibrium in the 5 GHz band as new tenants, namely mobile operators, join in with a new technology and as the traffic load increases. Wi-Fi was designed from the ground up to support fair coexistence through listen-before-talk (LBT) mechanisms that restrict AP transmission to the times when no neighboring APs are transmitting. In contrast, LTE uses a scheduled-transmission model designed to operate in licensed bands over which it has exclusive access. Extending this transmission approach to the 5 GHz band has a detrimental impact on Wi-Fi, and virtually everybody agrees that this is not acceptable even if regulation allows it.

Modifications to LTE are necessary for coexistence with Wi-Fi and other technologies in the 5 GHz band. What these modifications should be and how they should be incorporated into the 3GPP standards is at the center of the debate on LTE unlicensed today. As of mid-2015, multiple proposals are under consideration and the 3GPP standardization process is ongoing. This is a crucial moment: the standards specifications will determine whether LTE unlicensed will provide guarantees of fair coexistence with Wi-Fi and high spectral efficiency sufficient to garner the necessary support from both the Wi-Fi stakeholders and the LTE stakeholders.

With this report, we strive to present an overview of LTE unlicensed and how it can coexist with Wi-Fi. We discuss central issues such as performance, standardization, business models, and deployment costs. The debate on LTE unlicensed is a heated one in which parties have often taken antagonistic views. In the interviews in this report, we have tried to present multiple perspectives from players deeply involved in the Wi-Fi and LTE ecosystems, and discuss how to best develop a coexistence regimen for LTE unlicensed that expands the overall use of the unlicensed spectrum in the 5 GHz band and benefits all the stakeholders.

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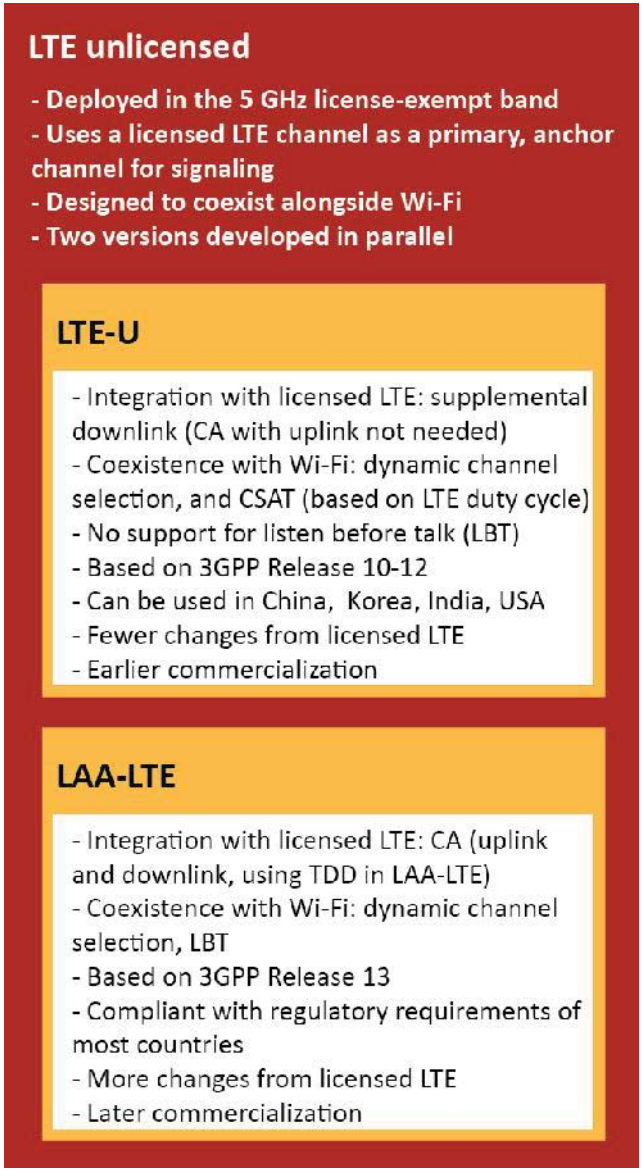
2. Terminology.
LTE unlicensed, LTE-U, LAA-LTE and more

There are different proposals on how to use LTE in unlicensed bands, and this has created confusion in the terminology. In this report, we use "LTE unlicensed" as the umbrella term that covers all implementations of LTE in the 5 GHz unlicensed band that use a licensed channel – referred to as a primary channel or anchor – for signaling to coordinate transmission among different channels. Regardless of how LTE unlicensed is implemented, it is fully integrated within LTE networks and it acts as a secondary channel that relies on carrier aggregation (CA).

There are two types of LTE unlicensed: LTE-U and LAA-LTE.

LTE-U is the version of LTE unlicensed that was proposed in 2013 by Qualcomm and Ericsson. LTE-U relies on 3GPP Release 10-12 functionality, with specifications defined by the LTE-U Forum, an organization established by Verizon in collaboration with Alcatel-Lucent, Ericsson, Qualcomm Technologies, Inc., a subsidiary of Qualcomm Incorporated, and Samsung. Because it requires few modifications from licensed LTE, LTE-U will be the first version of LTE unlicensed to be available in commercial deployments. However, because it does not implement listen-before-talk mechanisms, LTE-U can only be used in markets where regulation does not require LBT, such as China, Korea, India and the USA.

LAA-LTE is the version of LTE unlicensed that 3GPP plans to standardize in Release 13 and that supports LBT in addition to CA. LAA-LTE is set to become a global standard as it strives to meet regulatory requirements worldwide. However, because the standardization work is not completed yet, commercialization will take longer than for LTE-U. In the long term, we expect operators and vendors worldwide to support LAA-LTE because it provides a globally harmonized solution that leads to better scalability and choice among equipment and device vendors.



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3. LTE unlicensed integration with LTE licensed.
A special case of carrier aggregation

LTE unlicensed is fundamentally a special case of carrier aggregation in which the primary carrier – also referred to as the anchor – uses licensed spectrum, and the secondary carrier is in the 5 GHz band.

The primary carrier manages the control plane for both carriers, and hence is crucial for the allocation of traffic between carriers. It is also used for data traffic in the uplink and downlink. The secondary carrier is limited to the data plane, with downlink required, but uplink optional in LTE-U. The secondary carrier uses TDD, while the primary may use FDD or TDD.

To maximize the contribution of the combined carriers, the primary carrier is preferred for voice and uplink traffic, while the secondary carrier transports more downlink traffic. The primary carrier is better suited to supporting mobility. The operator may choose to use the secondary channel on an opportunistic basis – i.e., only when the primary carrier is at capacity or overloaded.

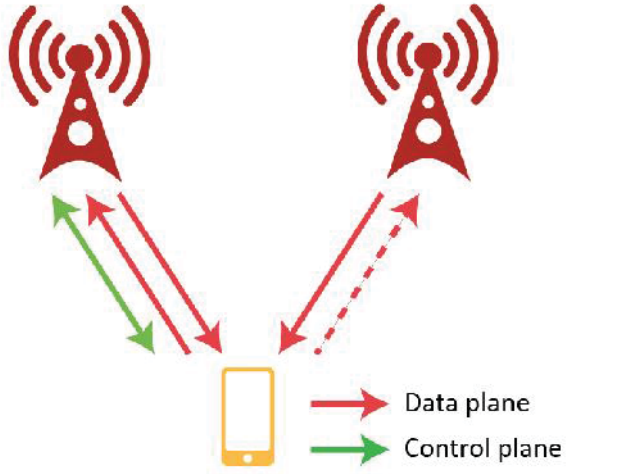
The secondary carrier operates in a high-capacity wide channel, but the capacity is not guaranteed because the channel may be shared with other LTE unlicensed cells or with Wi-Fi APs. For an efficient traffic allocation, the operator has to take into account the traffic volume and real-time traffic condition in the second carrier and use policy for load-balancing.

LTE unlicensed will be deployed mostly in small-cell topologies, often in indoor locations. It can be co-located with macro cells, but this is an unlikely deployment scenario because of the propagation characteristics of the 5 GHz spectrum. In a small-cell deployment, multiple scenarios are possible.

The scenarios that 3GPP envisages are shown below, and all include an LAA-LTE small cell. In the first scenario, the primary cell is the macro, and the LAA-LTE small-

Integration of LTE licensed and LTE unlicensed

LTE licensed	LTE unlicensed
Primary carrier, anchor	**Secondary carrier**
Control plane for both licensed and unlicensed	Data plane only
FDD/TDD	Uplink optional in LTE-U
Preferred for voice, uplink	TDD
Mobility support	Preferred for downlink traffic
	Opportunistic use



Source: Senza Fili

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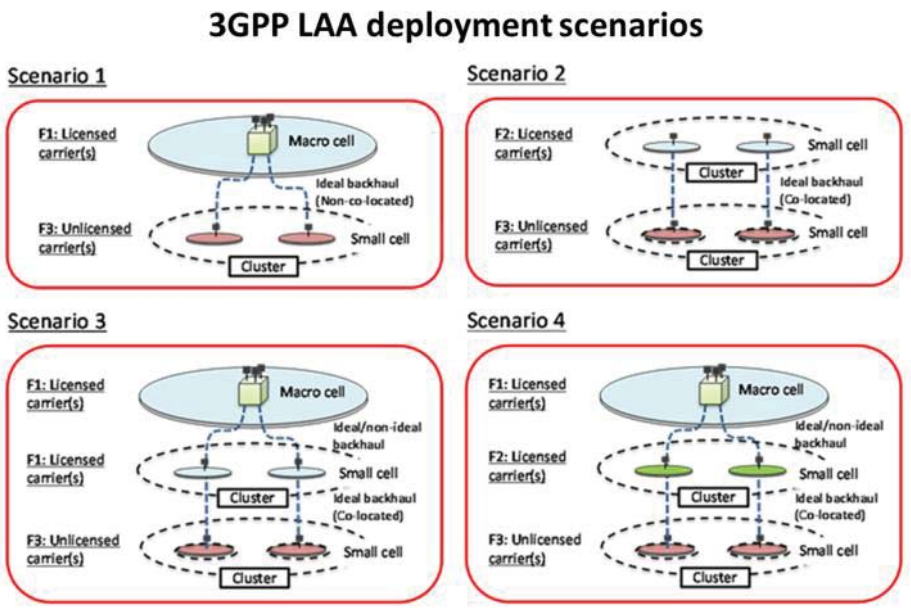
cell is not co-located, but linked to the macro cell with ideal backhaul (i.e., with less than 2.5 µs one-way latency and 10 Gbps throughput, most commonly fiber). In the other three scenarios, the LTE unlicensed cell is always co-located with a licensed small cell, with the small cell or the macro cell acting as the primary carrier. The second scenario is most likely used in indoor environments. The choice of deployment scenario depends on the operator's strategy for small cells and the availability of ideal backhaul.

A stand-alone version of LTE unlicensed that does not require aggregation with a licensed band has also been proposed, but so far it has not gained industry-wide support. It is a solution that may be attractive to cable operators, WISPs or hotspot network operators that lack licensed spectrum. For an operator without licensed spectrum, the cost and complexity of operating an LTE unlicensed only network is likely to overshadow the performance advantages of LTE unlicensed over Wi-Fi.

Operators supporting LTE unlicensed
Verizon
China Mobile
T-Mobile (USA)
NTT DOCOMO
Deutsche Telekom
China Unicom
TeliaSonera



Source: 3GPP

Scenario 1: CA between licensed macro cell (F1) and unlicensed small cell (F3).

Scenario 2: CA between licensed small cell (F2) and unlicensed small cell (F3), no macro coverage (e.g., indoor deployment).

Scenario 3: CA between licensed small cell (F1) and unlicensed small cell (F3), with macro coverage.

Scenario 4: CA between licensed small cell (F2) and unlicensed small cell (F3), with macro coverage (F1). With ideal backhaul between macro and small cell, CA among F1, F2 and F3 is possible. Dual connectivity between macro cell and small cell can be enabled.

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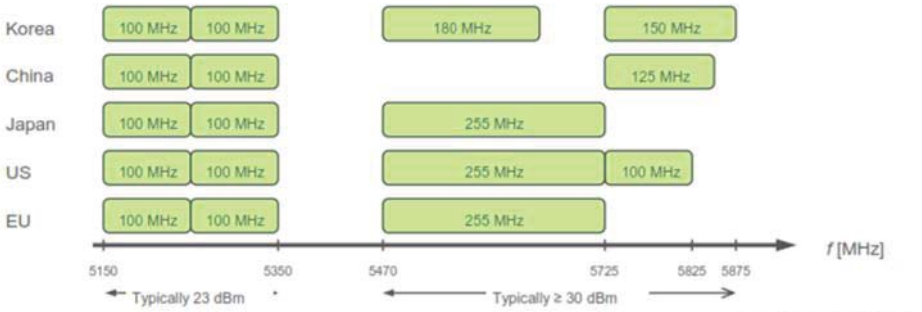
4. The 5 GHz unlicensed band.
What's so special about it?

The 2.4 GHz band has for a long time carried most of the world's unlicensed wireless traffic the 100 MHz allocated to it. Initially established as an ISM band by the ITU in 1947, it has been an extremely powerful success story that has proved the benefits of unlicensed spectrum – in terms of high spectral efficiency, wide broadband access, and low costs. No longer considered a harmless giveaway, unlicensed spectrum has become a major driver of technical innovation, broadband connectivity and economic growth.

As the use (and congestion) in the 2.4 GHz band has grown over the last decade, the 5 GHz band has become the new star in unlicensed spectrum. Wi-Fi traffic is rapidly expanding in the 5 GHz band, with the latest version, Wi-Fi ac, working exclusively in that band. Like the 2.4 GHz band, the 5 GHz band is available virtually worldwide, even though regulation and band boundaries change country by country. The 5 GHz band has a major advantage over the 2.4 GHz band: a wider spectrum allocation, with at least 300 MHz in most markets. In the US, the 5 GHz band has 580 MHz, in Europe 455–605 MHz, and in China 325 MHz.

Spectrum in the 5 GHz band by country



Source: Ericsson

In the USA, the FCC allocated the first 300 MHz in the 5 GHz U-NII band in 1997; it added spectrum in 2003 and 2014, along with the DFS requirement to manage interference with radars that share access to the band. The band is split into 20 and 40 MHz TDD channels, and transmission is subject to power limitations that restrict the coverage range and make the 5 GHz band well suited for Wi-Fi or small cells, mostly in indoor environments. In addition to Wi-Fi and, in the future, LTE unlicensed, the 5 GHz band is used by other wireless technologies, including proprietary ones for point-to-point and point-to-multipoint links, cordless phones, and medical, scientific and other IoT devices.

The 5 GHz U-NII band in the US

Source: FCC, Senza Fili

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5. Why do we need listen before talk (LBT)?

Fair coexistence is a requirement for success, not an option

In many countries, transmission in the 5 GHz band requires that the equipment implement a listen-before-talk mechanism that enables the peaceful coexistence of multiple technologies and the adoption of dynamic frequency selection (DFS) to protect radar transmissions in the band. Countries like China, India, South Korea and the USA do not mandate the implementation of listen-before-talk mechanisms. Coexistence with other technologies is required, but no specific mechanism to support it is required.

LBT requirements in Europe and Japan have been instrumental in driving LAA-LTE standardization, but the need to support LBT in LAA-LTE goes well beyond regulation. The fair coexistence with Wi-Fi that LBT provides is so crucial to the success of LTE unlicensed that most vendors and operators are keen to introduce it across all markets, including those that do not require it, to address concerns from Wi-Fi stakeholders.

With LBT enabled, each cell or access point operating at a location scans the environment to detect activity, and transmits only when the channel is free. This allows different technologies and devices to operate in the same spectrum channel. There are different ways to implement LBT. For instance, how the backoff time – i.e., the period between scans of network activity – is defined in LAA-LTE plays an important role in how the traffic will be split between Wi-Fi and LAA-LTE and, hence, is a factor in how fair the coexistence will be. For this reason, there is a growing consensus that LAA-LTE specs may have to go beyond regulatory requirements to meet the levels of fairness that stakeholders expect – namely that the impact of an LTE small cell is not greater than that of a Wi-Fi access point.

3GPP LAA-LTE study item take on LBT

"In some regions in the world, unlicensed technologies need to abide to certain regulations, e.g. Listen-Before-Talk (LBT). Fair coexistence between LTE and other technologies such as Wi-Fi as well as between LTE operators is seen necessary. Even in countries without LBT, regulatory requirements exist to attempt to minimize interference with other users of the unlicensed spectrum. However, it is not enough to minimize interference simply for regulatory aspects. It is also essential to insure that a deployed system will operate as a 'good neighbour', and not significantly impact legacy systems.

Therefore a study is required to determine a single global solution which enhances LTE to enable licensed-assisted access to unlicensed spectrum while coexisting with other technologies and fulfilling the regulatory requirements. When looking at such enhancements, current LTE physical-layer design should be reused as much as possible. To ensure holistic solutions are considered, in-device, co-channel, and adjacent channel intra and inter RAT coexistence scenarios should be included in the study." (3GPP R-141817)

FCC on coexistence in the 5 GHz U-NII band

"Typically, unlicensed devices operate at very low power over relatively short distances, and often employ various techniques, such as dynamic spectrum access or listen-before-talk protocols, to reduce the interference risk to others as well as themselves. The primary operating condition for unlicensed devices is that the operator must accept whatever interference is received and must not cause harmful interference. Should harmful interference occur, the operator is required to immediately correct the interference problem or to cease operation." (FCC 14-30)

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6. LTE-U, ahead of inclusion of LBT in 3GPP standards.
The solution for operators ready to deploy

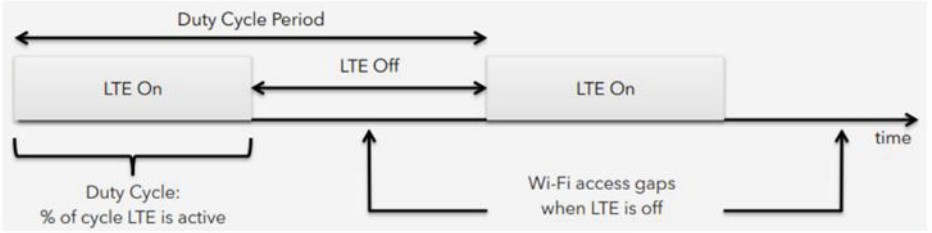
LTE-U is the first version of LTE unlicensed, initially proposed by Ericsson and Qualcomm in 2013. It is the version that is easier to deploy, because it requires fewer changes from LTE in licensed bands and does not require an ad-hoc standardization effort. While LTE-U relies on 3GPP Release 10-12, it does not have to support functionality such as LBT, which is not yet included in 3GPP standards. That means LTE-U can be used only in countries such as China, India, South Korea and the USA, where LBT is not required.

The advantage of LTE-U is that it can be deployed sooner than LAA-LTE, because all the standardization work has been done and the specifications for the implementation of LTE-U have been published by the LTE-U Forum. The availability is attractive to operators that need to increase capacity in the short term, especially if they plan to deploy LTE-U in environments where there are free channels and hence fair coexistence with Wi-Fi is easy to achieve.

In such a setting, LTE-U can identify and use channels that co-located Wi-Fi does not use, as shown as the first step in the figure below. LTE-U and Wi-Fi coexist side by side, and LTE-U does not impact Wi-Fi performance. Because LTE-U can transmit continuously, the operator can expect performance comparable to licensed LTE in a 20 MHz channel. Because the 5 GHz band is still not heavily used in many environments, this is a solution that is especially attractive in the short term, as operators wait for standardization and commercialization of LAA-LTE.

If there are no free channels in the 5 GHz band, the operator has to share the channel with Wi-Fi. LAA-LTE will use LBT for coexistence. LTE-U uses adaptive duty cycles. In the duty-cycle approach, LTE-U transmits only during part of the cycle, leaving Wi-Fi to transmit for the rest of the cycle, as the figure on the right illustrates.

Using duty cycles for LTE and Wi-Fi coexistence



Source: CableLabs

In the duty-cycle approach, LTE transmits only during the on period. The duty cycle is the percentage of the time during which LTE can transmit. With a 50% duty cycle with a 100 ms period, both LTE and Wi-Fi can transmit for 50 ms.

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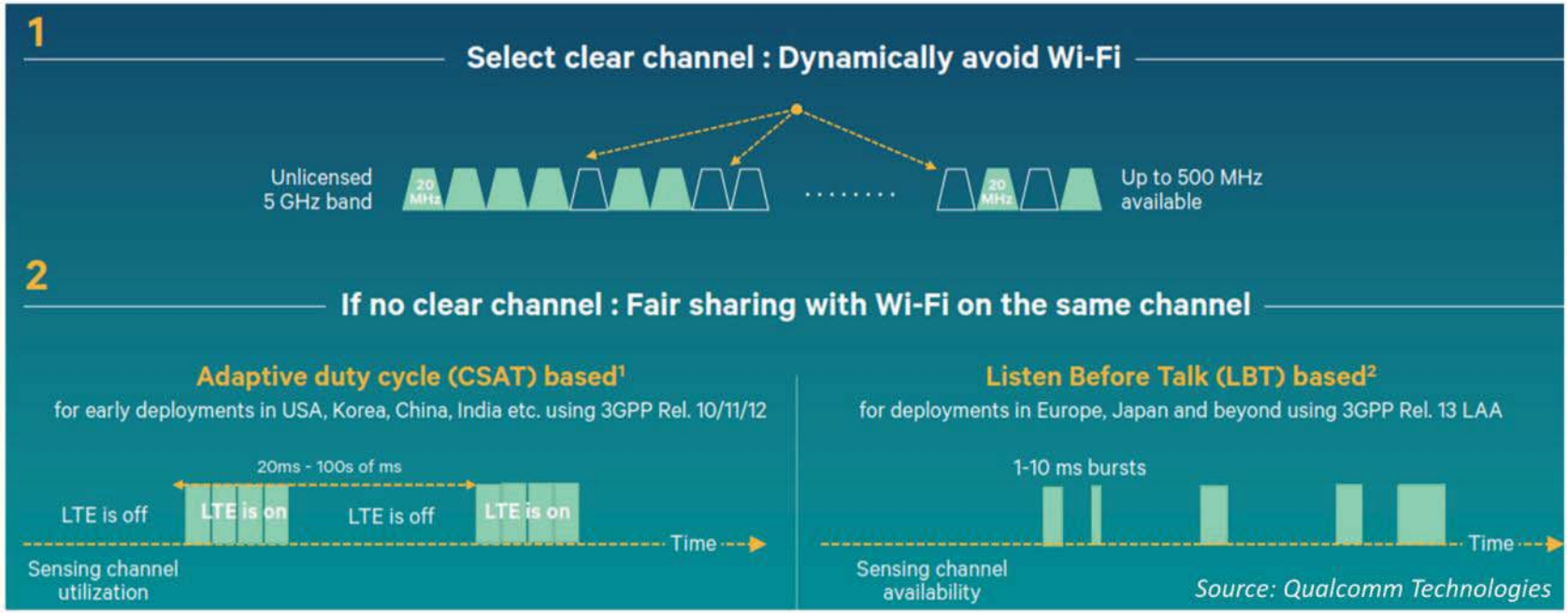
Duty cycles can support fair coexistence with Wi-Fi when appropriately set up (e.g., when the duty-cycle duration is set in such a way that the existing Wi-Fi APs using the same channel are affected in the same way they would be by a new Wi-Fi AP). However, it is the LTE-U cell that decides how much fairness to allow – and Wi-Fi networks can only adapt to the rules set by LTE-U. In this context, it is easy to see why some Wi-Fi players are nervous about the introduction of LTE-U, especially because some (incorrectly) consider 5 GHz to be the "Wi-Fi band."

LTE unlicensed operations in the 5 GHz band



In selecting the 5 GHz channel for transmission, LTU unlicensed looks first for empty channels and selects them if available. If not, a coexistence mechanism is necessary. LTE-U uses a CSAT approach that relies on the adaptive duty cycle that senses channel utilization to set the duty cycle parameters. LAA-LTE uses mechanisms based on LBT that sense channel availability.

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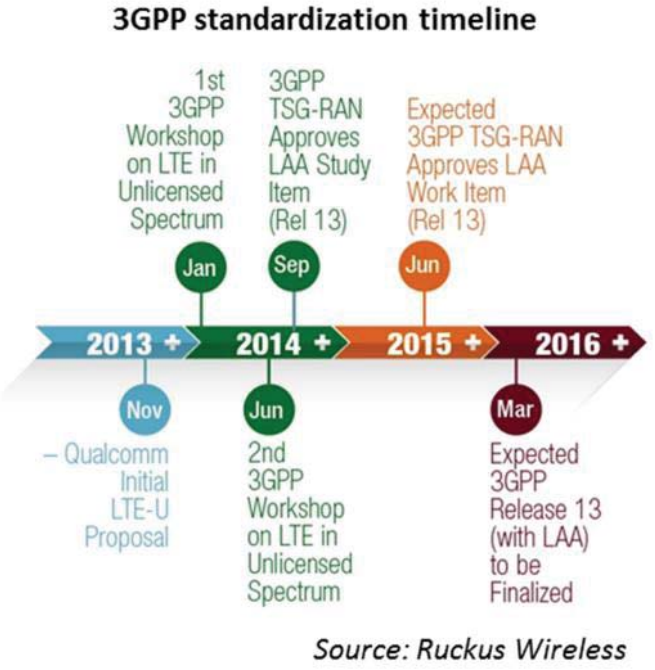
7. The LAA-LTE standardization process in 3GPP. Enshrining fairness in the standards

To be deployable worldwide, LTE unlicensed has to implement LBT, and this requires the introduction of LBT in the 3GPP standards. 3GPP is working on this, having created a study item in 2014; finalization is expected in Release 13, projected for March 2016.

The main features of LAA-LTE have been largely defined and the commitment to fair coexistence with Wi-Fi reiterated. The focus of the current work is to find an industry-wide consensus as to what is required for fair coexistence. This is a difficult process, because fairness does not come for free: the price is reduced performance. Part of the reason Wi-Fi is less spectrally efficient than LTE in licensed bands is, in fact, that it implements mechanisms like LBT to ensure fair coexistence with other Wi-Fi networks. When adding LBT to LTE unlicensed, we should expect a degradation in performance – and that degradation will vary depending on how LBT is implemented.

As the standards body for LTE, 3GPP represents the mobile operator and vendor ecosystem and only indirectly the Wi-Fi ecosystem (through operators and vendors that have a presence in both). As a result, there have been concerns in the industry that the LAA-LTE standardization process may be more favorable to LTE than to Wi-Fi.

An LAA-LTE standard that does not guarantee fair coexistence to Wi-Fi – or does not do so to the satisfaction of the main Wi-Fi stakeholders – would be a destructive outcome for the prospects of LTE unlicensed. Regardless of regulatory requirements, if LAA-LTE does not gain a sufficient level of industry-wide support, it is unlikely to succeed – i.e., gain the scale it needs to motivate mobile device vendors to support the technology in new devices. Wi-Fi is a technology so widely used – it carries more traffic than LTE – and loved that it would be unwise to engage in an aggressive



Source: Ruckus Wireless

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confrontation. These considerations are not lost on either vendors or operators, and seem to be guiding the work being done at 3GPP. There is a growing commitment to finding a robust solution to coexistence in environments where Wi-Fi will continue to dominate.

Progress in LTE unlicensed standardization	
December 2013	Qualcomm and Ericsson presentation of the initial proposal for LTE-U at a 3GPP meeting in Busan, South Korea.
January 2014	A 3GPP unofficial meeting in Paris, with companies and operators presenting their perspectives on the use of LTE in unlicensed bands.
March 2014	Discussion at the 3GPP plenary meeting in Fukuoka, Japan.
June 2014	Workshop in Sophia Antipolis, France. Outcomes included ▪ A plan to set up a study item in September 2014 ▪ Adoption of LAA-LTE designation ▪ Agreement to focus on the 5 GHz band ▪ Commitment to finding a global solution ▪ Establishment of fair coexistence with Wi-Fi and among LTE operators
September 2014	3GPP TSG-RAN approved LAA-LTE as a study item for Release 13. The main goal is to determine the changes needed for fair coexistence of LAA-LTE and Wi-Fi. Release 13 covers ▪ Regulatory requirements ▪ Deployment scenarios, including multiple operators, and coexistence with both Wi-Fi and other LAA-LTE networks ▪ Design targets and functionalities ▪ Coexistence evaluation and methodology Required functionalities include ▪ LBT, with maximum transmission duration ▪ Dynamic frequency selection for radar avoidance in certain bands and regions ▪ Carrier selection ▪ Transmit power control The primary focus is on the downlink, although uplink is also under consideration.
March 2016	3GPP work item specs to be finalized. They will define the LBT coexistence mechanisms to be implemented, and the pairing of unlicensed transmission with licensed bands. Release 13 will also include LTE and Wi-Fi aggregation (LWA) and new functionality to improve mobility management and eNB management in integrated LTE and Wi-Fi networks.

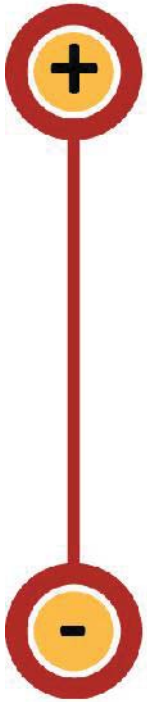
8. Wi-Fi or LTE unlicensed in small-cell deployments?
A look at the tradeoffs

LTE unlicensed is squarely aimed at mobile operators because it requires an LTE licensed spectrum allocation that can be used as a primary carrier. Residential and enterprise Wi-Fi users, as well as WISPs, MSOs and other service providers using Wi-Fi, may become involved by hosting or sharing access in LTE unlicensed deployments, but we expect that these deployments will be driven (although not necessarily funded) by mobile operators.

Mobile operators are assessing LTE unlicensed – running trials, participating in the 3GPP standardization, or announcing deployment plans as Verizon and T-Mobile in the USA have done. At the same time, mobile operators also rely on Wi-Fi for residential and enterprise offload, hotspot access, or carrier Wi-Fi, and their use of the technology is expanding as they become more comfortable using unlicensed spectrum for opportunistic access.

The choice they face is not between Wi-Fi and LTE. Mobile operators will continue to rely on Wi-Fi access for offload – or, at a bare minimum if they do not want to engage directly with Wi-Fi, they have to accept the fact that most of the data traffic their subscribers generate goes through Wi-Fi. But even the operators that deploy LTE unlicensed are likely to use Wi-Fi and, increasingly, carrier Wi-Fi in the same types of locations where LTE unlicensed is used, and likely to step up their efforts to integrate Wi-Fi within their LTE networks.

Instead, the place where mobile operators face a complex decision of choosing between Wi-Fi and LTE unlicensed is mostly in indoor environments where they plan for a small-cell LTE deployment and must decide whether to invest in Wi-Fi, in LTE unlicensed, or in a mix of both.



Wi-Fi	LTE unlicensed
- Ubiquitous in mobile devices - Large installed footprint - Robust standardization - Trusted certification process for devices and infrastucture - Mature technology - Established ecosystem - Strong indoor presence - LTE and Wi-Fi aggregation (LWA) as an alternative to LTE unlicensed - Carrier Wi-Fi facilitating integration in mobile networks - Lower equipment costs - Need to integrate with LTE for mobile operators	- Higher spectral efficency - Better device management - More robust performance under heavy traffic load and high number of devices - Easy integration within mobile RAN and core - LTE-U available soon, but does not implement LBT - LAA-LTE not yet commercially avaiable - LBT to reduce performance advantage over Wi-Fi - Standardization still ongoing - Access to venues depends on enterprise and real estate owners' acceptance - New devices required

Among all the factors we list in the graph, two have the heaviest weight:

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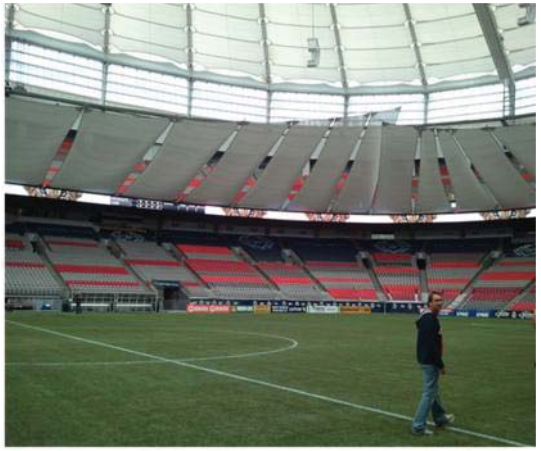
- LTE unlicensed has greater spectral efficiency and better performance than Wi-Fi – although it is unclear how much that difference will be retained with the introduction of LBT.

- Virtually all mobile devices have Wi-Fi, making the integration of Wi-Fi in LTE networks possible today. The inclusion of LTE unlicensed in mobile devices requires support from device vendors. Commercial availability will require a couple of years, and then wide adoption a few more years. At the same time, the marginal cost of adding LTE unlicensed in mobile devices is not high, and cost is not seen as a substantial challenge to adoption.

One additional advantage of Wi-Fi that is rarely mentioned is its wide AP footprint – in the enterprise and in public venues. This installed base can be used as a springboard for small-cell deployments. In the deployment of small cells, acquiring locations and backhaul connections to them for the equipment can be challenging for mobile operators –almost invariably time consuming and complex, and often downright expensive. Being able to co-locate small cells where Wi-Fi APs already exist can speed up deployments and reduce cost and complexity in enterprise locations and public venues.

With a combined licensed and unlicensed LTE small-cell strategy, a mobile operator may find it more complex to gain access to these premises, because enterprises, real estate owners, city agencies, and public venue managers often have their own Wi-Fi networks and, reasonably, they want to protect their investment, retain the performance level of their networks, and be able to expand them as needed. An operator wanting to install LTE unlicensed in the real estate they control might be seen as an aggressive competitor, especially if those in charge of the property do not trust the fair coexistence that LTE-U and LAA-LTE promise.



A valuable Wi-Fi footprint can become the springboard for co-located small-cell deployments

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9. Quantifying the LTE unlicensed performance benefits. The challenges in generalizing simulation and trial results

If a key driver for LTE unlicensed adoption is its performance advantage over Wi-Fi, we need to quantify the size of this advantage to assess whether mobile operators stand to benefit from it, and whether there is a solid business case to support adoption.

Vendors and operators have run many simulations and trials, and we have listed some in the references. It is difficult, however, to generalize the performance differences that have been observed and how they will translate in commercial deployments, because many factors (see table on the right) affect performance. The assumptions made for the two technologies and the scenarios considered vary from study to study to study, because the goal of each study is different. In addition, most of the published data focus on throughput, but other metrics – e.g., latency – are important to characterizing performance and quality of experience.

The high-level drivers of performance differences between the two technologies and their directionality are, however, becoming established, even though the results from individual trials and simulations are somewhat varied. The table below summarizes the high-level findings to date, but interested readers should consult the referenced documents for a detailed assessment of the results. As an example of the results obtained in LTE unlicensed and Wi-Fi simulations, we show below the results from NTT DOCOMO.

Multiple factors are responsible for the improved spectral efficiency of LTE unlicensed over Wi-Fi:

- Robust FEC
- Hybrid ARQ

Factors affecting relative performance of Wi-Fi and LTE unlicensed

- LTE unlicensed specifications (3GPP LAA-LTE specifications are not yet finalized, so current simulations and trials have to make assumptions about what the specifications will be). Performance differences should be expected between LTE-U and LAA-LTE
- LTE-U: CSAT implementation (e.g., duty cycle duration, percentage of time LTE is active, and how they change as a function of Wi-Fi activity) and parameters that operators can choose or that are fixed
- LAA-LTE: LBT implementation (e.g., fixed or exponential backoff, defer period, CAA protocol)
- Physical environment and deployment topology (including indoor versus indoor locations)
- Features and versions of the technologies
- Hardware vendor, equipment specifications
- Channel size; TDD or FDD modulation; inclusion of uplink; frequency reuse
- Spatial distribution of UEs and infrastructure nodes (macro and small cells, Wi-Fi AP); co-located/non–co-located equipment
- Synchronization
- Traffic model, including assumptions about traffic mix (e.g., voice and video as a percentage of traffic)
- Other simulation parameters

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- Effective interference coordination and avoidance
- Better mobility support and device scheduling
- CA to manage traffic across licensed and unlicensed channels
- Inter-operator and intra-operator RAN synchronization.

In an environment in which LTE unlicensed has complete access to a channel because there is no competing network (either Wi-Fi or LTE unlicensed), LTE unlicensed performance reaps all these benefits to the maximum, and we can expect it to be much better than Wi-Fi. This is because in unlicensed spectrum, LTE uses the same scheduled transmission mechanisms that it uses in licensed bands, giving it a higher spectral efficiency than Wi-Fi, which is subject to the overhead exacted by fair coexistence mechanisms that are in place even if the channel is uncontended.

In contrast, when operating in a channel shared with Wi-Fi or another LTE unlicensed network, LTE's performance advantages are reduced by interference or by the introduction of coexistence mechanisms.

In LTE-U, the duty cycle approach reduces the percentage of time the LTE-U cell transmits and this affects the throughput. In a lightly loaded network, this may have a limited impact on throughput, but as traffic load increases, so does the impact on throughput. If the duty cycle is set as a function of the number of Wi-Fi or LTE-U networks active in the same channel, we could expect a duty cycle of 50% for one competing network, and 25% for three competing networks. So performance in this case is tied to environmental constraints. If LTE-U were to use a duty cycle of 50% regardless of the number of networks present, it would appropriate an unfair portion of network resources.

The addition of LBT in LAA-LTE will degrade performance and hence reduce the benefits of LTE unlicensed over Wi-Fi and, by improving coexistence with Wi-Fi (as well as with other LTE unlicensed networks), it will improve Wi-Fi throughput. However, the LBT penalty critically depends on the implementation. CableLabs argued that an implementation of LBT meant to only meet European regulation would greatly penalize Wi-Fi, with the impact becoming more severe as the number of devices increases. An implementation of LBT according to the 3GPP target – of not

Performance comparison:
LTE unlicensed versus Wi-Fi, stand-alone configuration

- LTE has better spectral efficiency:
  - Transmission
  - Interference management
  - Coverage
- LTE performance is more robust than Wi-Fi with:
  - Increased traffic load
  - Increased number of users

How listen before talk works

1. Listen for ongoing transmission in the selected channel.
2. If channel is idle, start transmission for a fixed amount of time, then release traffic for a backoff period and start with step 1 again.
3. If the channel is busy, don't transmit, and go back to step 1. If the channel continues to be busy after multiple attempts, change channel.

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degrading Wi-Fi performance any more than another Wi-Fi access point would – is expected to degrade LAA-LTE performance more (simulations by Intel and Nokia indicated a reduction in throughput by 30% or more – but this is also associated with an increase in Wi-Fi throughput of 50%) and reduce the combined Wi-Fi and LAA-LTE channel throughput over the case in which LTE unlicensed does not use LBT. This is to be expected because of the network resources needed by LBT's overhead.

The impact on Wi-Fi, too, varies depending on how LBT is implemented. For instance, 3GPP is considering the use of a fixed backoff period, whereas Wi-Fi uses a variable backoff period. Because Wi-Fi performance benefits from a variable backoff period, Wi-Fi players are increasingly requesting that LAA-LTE use a variable backoff period as Wi-Fi does.

LBT allows for a distribution of spectrum resources that takes into account the traffic load of each coexisting network. However, coexistence mechanisms that maximize fairness in the allocation of network resources to competing networks necessarily have a negative effect on performance, so the tradeoffs have to be assessed to avoid a situation where fairness leads to a severe reduction in spectral efficiency in which served users are collectively worse off – i.e., there is a decrease in both channel capacity and average per-device throughput.

One way to address this issue is to replicate within LAA-LTE a level of fairness that closely mimics the one that is common in Wi-Fi networks. This approach makes sense, because Wi-Fi is the prevalent technology using 5 GHz spectrum, and LAA-LTE is the newcomer. There seems to be a growing consensus that this is the way to go, but it is not clear yet what it takes to achieve this goal and how this will affect the performance of LAA-LTE.

Performance comparison:
LTE unlicensed with Wi-Fi, coexistence

- Combined Wi-Fi and LTE capacity can be higher than Wi-Fi only.
  - Stronger improvements in sparse deployments, with LAA-LTE having a stronger impact on Wi-Fi performance in congested environments (see NTT DOCOMO simulation results below).
- Wi-Fi performance may increase with LTE as neighbor (instead of Wi-Fi) (see NTT DOCOMO simulation results below).
- LTE-U duty-cycle parameters affect Wi-Fi performance. For instance longer periods increase Wi-Fi throughput stability but also latency (CableLabs).
- LBT more onerous to implement that duty cycle, but leads to better overall throughput for 50% duty cycle (Intel and InterDigital).
- Impact of LBT and fair coexistence mechanisms.
  - Standardization still in progress, so it is difficult to assess impact.
  - Degradation in LTE unlicensed performance due to LBT may reduce throughput by 30% or more (Intel and Nokia). Wi-Fi throughput may increase by 50% (Nokia).

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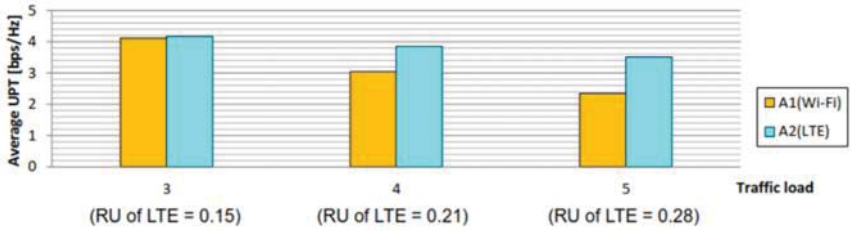
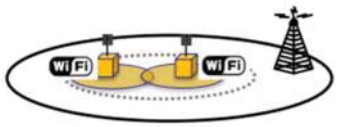
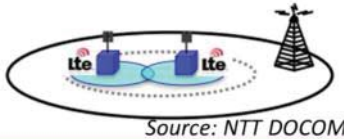
Wi-Fi and LTE performance comparison: single operator



A1: two Wi-Fi APs per cluster



A2: two LTE small cells per cluster

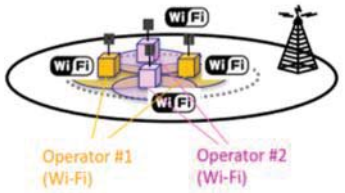


Source: NTT DOCOMO

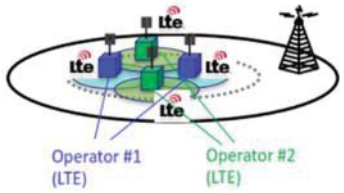
In NTT DOCOMO's simulation, as the traffic load increases, LTE unlicensed spectral efficiency decreases more slowly than for Wi-Fi, making LTE unlicensed better in high-traffic environments.

Wi-Fi and LTE performance comparison: coexistence scenario, two operators

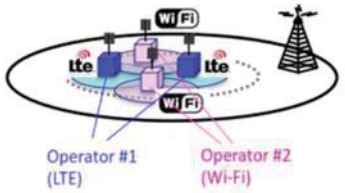
B1: two Wi-Fi APs per cluster per operator (total four APs)

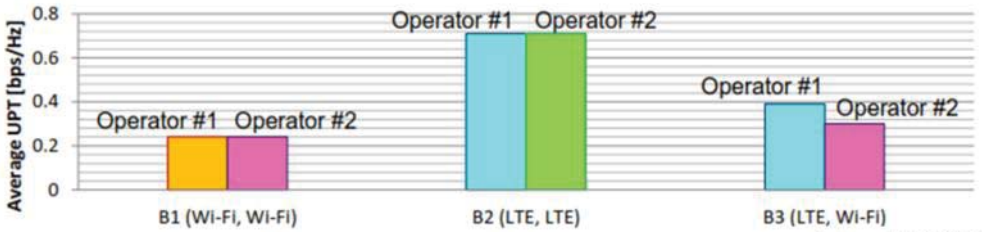


B2: two LTE small cells per cluster per operator (total four small cells)



B3: two LTE small cells and two Wi-Fi APs per cluster





Source: NTT DOCOMO

In NTT DOCOMO's simulation, under medium traffic load assumptions, LTE is more spectrally efficient than Wi-Fi and, when combined with Wi-Fi, lead to an overall increase in spectral efficiency.

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Beyond LTE unlicensed

What are the alternatives to LTE unlicensed – or solutions complementary to it – that give mobile operators a way to leverage spectrum assets beyond the cellular bands they already use?

- **Carrier Wi-Fi.** Today mobile operators mostly use Wi-Fi as an offload technology that enables them to reduce network congestion and give their subscribers a better experience. Even when they own the Wi-Fi infrastructure, operators do not usually integrate it with their cellular networks, and Wi-Fi access is managed as a separate access channel (and a special case of offload). With carrier Wi-Fi, operators can use their Wi-Fi infrastructure, and that of their wholesale or roaming partners, as an integral part of their cellular network, and rely it on opportunistically – when available, and when needed. Because with carrier Wi-Fi, cellular and Wi-Fi are integrated in the core, mobile operators can present a consistent set of services, policy, and pricing across Wi-Fi and cellular. This solution allows operators to use the 5 GHz band right away, using the mobile devices already in the market, but they do have to integrate their cellular and Wi-Fi networks. Many vendors and operators are working on Wi-Fi and cellular integration, but there is still work ahead before achieving full integration.

- **LTE and Wi-Fi aggregation (LWA).** Complementary to carrier Wi-Fi and to LAA-LTE, LWA enables operators to integrate Wi-Fi and cellular traffic (see section below). As carrier Wi-Fi does, LWA leverages the same 5 GHz band as LTE unlicensed, but, unlike LTE unlicensed, it does so without requiring new handsets. 3GPP is working on LWA standardization, and it is expected that the specs will be included in Release 13, along with LAA-LTU. In the meantime, interest in LWA is rapidly expanding.

- **LTE unlicensed in other bands.** 3GPP has decided to focus initially on the 5 GHz band, but LTE unlicensed could easily expand to other unlicensed bands. An obvious one is the 2.4 GHz band, but that is already congested, and hence unlikely to attract mobile operators because in such an environment, they cannot protect their LTE unlicensed investment. The 60 GHz band is another possible target, but the range is too limited to be used in the enterprise or in public venues, with few possible exceptions – and there, operators will be able to use Wi-Fi instead, if they need to add capacity to their small cells.

- **LTE in other (licensed) bands.** LTE unlicensed's attraction for mobile operators is that it gives them access to a new band. However, there are other bands available that can be used to add capacity to cellular networks. The 3.5 GHz band is an attractive option, because it is underutilized in most markets. It is also an excellent solution for small-cell deployments. Because of its short coverage radius, the 3.5 GHz band is well suited for macro deployments, but it works well as an under-layer for small cells that, unlike co-channel deployments, does not create interference with the macro layers.

- **LSA/ASA.** Pending regulatory support, mobile operators will be able to use LSA/ASA in bands that can be shared with the primary spectrum holder (e.g., military entities). As in the LTE unlicensed case, LSA/ASA provides an opportunistic access channel that, where available, can provide a reliable capacity boost.

10. One step further with LWA.
Alternative or complement?

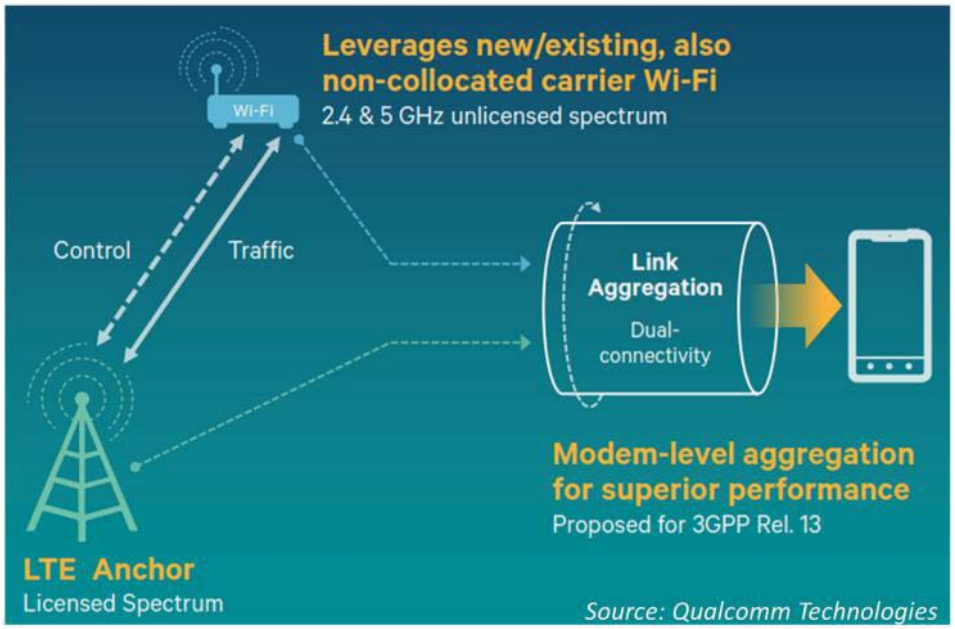
Alongside LTE unlicensed, LWA has started to gain traction, and it presents some advantages over LTE unlicensed. Like the latter, LWA is being standardized by 3GPP and gives mobile operators a way to use unlicensed bands that is well integrated within their network. Because LWA uses Wi-Fi and not LTE for unlicensed access, it can use not only the 5 GHz band, but also the 2.4 GHz one. Because the 2.4 GHz is already crowded, mobile operators' interest in it is limited, but the marginal cost of adding 2.4 GHz in LWA is small.

With LWA, mobile operators use Wi-Fi for access, with Wi-Fi transmission integrated in the cellular RAN. The RAN manages the traffic, and all signaling goes through LTE in a licensed channel (as is the case in LTE unlicensed).

The main advantage of LWA is that it requires little intervention in existing networks (only a software upgrade or a new Wi-Fi access point) and in devices (an OS update should suffice; the existing Wi-Fi handsets do not have to be replaced). Because it uses ubiquitous Wi-Fi and LTE wireless interfaces, it can become commercially available in the short term. The downside of LWA is that it lacks the performance benefits of LTE unlicensed (although, as discussed, we do not yet have a way to quantify them, especially if we include the LBT implementation).

LWA delivers, however, important benefits over Wi-Fi offload and increases the attractiveness of carrier Wi-Fi when the two are combined. In LWA, Wi-Fi is used only for the downlink, with LTE carrying all the uplink traffic and, optionally, downlink traffic as well. This combination can increase the spectral efficiency, because Wi-Fi is well suited to carry downlink traffic, but less so for uplink traffic – and on the opposite side, LTE uplink is better than Wi-Fi uplink.

LTE and Wi-Fi aggregation



Licensed LTE provides the anchor for Wi-Fi and is responsible for signaling. Data traffic is transmitted through both LTE and Wi-Fi (dual connectivity). LWA can be combined with LAA-LTE, or deployed as an alternative to it.

In addition, RAN integration makes it possible to use real-time traffic conditions and interference levels to allocate traffic to the most appropriate interface, and to manage mobility more efficiently than in a Wi-Fi offload environment. Because the RAN sends all traffic to the mobile core, all traffic – Wi-Fi and LTE – is treated in the same way, and no further integration of Wi-Fi traffic in the core is necessary.

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11. Is LTE unlicensed worth the investment?
A look at the business case

Ultimately, a new technology is adopted only if there is a business case that supports it. For LTE unlicensed, a solid business case is not sufficient – because adoption will largely depend on the availability of new devices that support the technology, but it is still nevertheless necessary. Assuming that lack of devices will not be an obstacle to adoption, we need to understand whether there is a business case that justifies LTE unlicensed adoption in small-cell deployments.

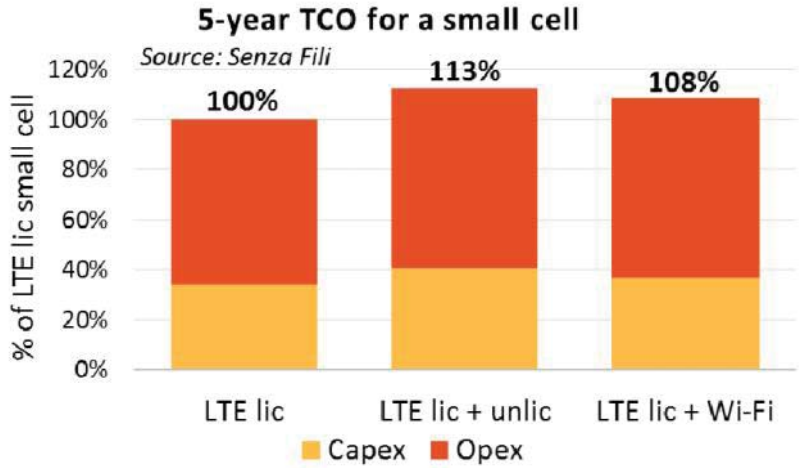
Mobile operators assessing the LTE unlicensed business case face two preliminary questions:

- To increase capacity, is it cost effective to add LTE unlicensed to LTE licensed small cells?
- To leverage the 5 GHz band, it is more cost effective to use LTE unlicensed or Wi-Fi?

Depending on their strategy and environment, mobile operators are likely to include in their assessment additional deployment scenarios – e.g., stand-alone LTE unlicensed deployments in which a macro cell that is not co-located is the primary carrier for an LTE unlicensed small cell, or where the LTE licensed small cell integrates LTE unlicensed and Wi-Fi (all co-located at one location).

In this section, we explore these two preliminary questions to understand the basic economics behind LTE unlicensed adoption. We do so by looking at the per-bit TCO (i.e., the 5-year TCO divided by capacity) of a small cell in three cases:

- **LTE lic**: a small cell with only LTE licensed



- **LTE lic + unlic**: a small cell with both LTE licensed and unlicensed (we assume the adoption of LAA-LTE)
- **LTE lic + Wi-Fi**: a small cell with both LTE licensed and Wi-Fi

To facilitate the comparison, our model assumes the same channel width for each technology and reports the results as a percentage of the LTE lic throughput. We chose this approach because the cost to deploy small cells varies considerably across geographies, deployment locations (e.g., indoors vs. outdoors), operators and other factors, but we expect that the marginal costs to add LTE unlicensed or Wi-Fi – measured as a percentage of the cost of the small cell using only LTE licensed – are comparable within each deployment.

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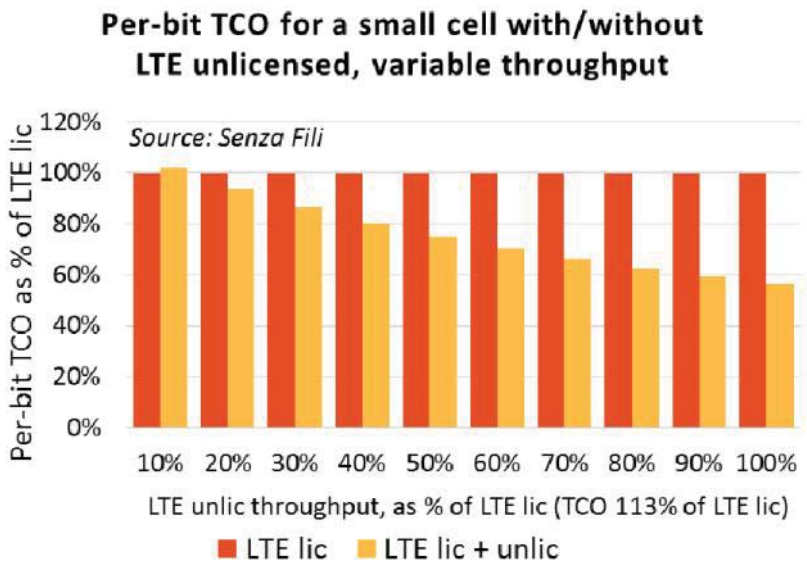
The cost of installing and operating a small cell in an airport in India may be very different from that of an outdoor high-street small cell in the UK, but the marginal cost of adding Wi-Fi or LTE unlicensed as a percentage of small-cell costs is comparable.

The main obstacle in examining the business case for LTE unlicensed is that we do not know yet how well LAA-LTE will perform and what impact LAA-LTE will have on Wi-Fi. Furthermore, because the 5 GHz band is unlicensed, the contention for spectrum resources from other networks is unknown and cannot be controlled; hence, the impact of congestion and interference on performance is variable.

So instead of looking at the per-bit TCO after making assumptions about throughput, we look at the impact that performance has on the per-bit TCO. This approach tells us at what performance thresholds LTE unlicensed is more cost-effective than Wi-Fi, or Wi-Fi more cost effective than LTE unlicensed, as a function of small-cell capacity.

The graph on the previous page shows our baseline 5-year TCO. We assume that capex accounts for 34% of the TCO and equipment for about a third of the capex. We estimate the incremental TCO contribution from the addition of LAA-LTE to be limited to double the equipment costs, an increase of 15% in operating costs, and an increase of 20% in backhaul. Overall the TCO for a small cell with LAA-LTE is 113% of the TCO for an LTE licensed small cell alone. A small cell with Wi-Fi is less expensive (108% of the TCO for an LTE licensed small cell) because of the lower equipment costs, but we assume that operating costs will be the same as for a small cell with LAA-LTE.

The graph on this page shows the impact of adding LTE unlic to an LTE lic small cell using the per-bit TCO (TCO divided by capacity, shown as a percentage of the LTE lic base case) as the throughput of LTE unlic grows. The higher the LTE unlic throughput, the lower the per-bit TCO, as expected. If LTE unlic has half the capacity of LTE lic, the overall (lic and unlic) per-bit TCO is 25% lower than in the LTE lic-only case. Because the incremental cost of adding LTE unlic is low, it



becomes cost-effective to add LTE unlic with an incremental throughput of only 20%.

To address the second question, we kept the Wi-Fi throughput fixed, and looked at the impact on the business case from changes in throughput that may be due to congestion or from the different overhead costs that specific implementations of LBT have. To look at the sensitivity of this analysis, we show the results from four cases that assume a fixed Wi-Fi throughput of 20%, 30%, 40% and 50% of LTE lic. Changes in Wi-Fi throughput may result from varying congestion and interference levels, and from different LBT implementations.

We show the total throughput of the small cell (i.e., LTE lic + Wi-Fi, or LTE lic + LTE unlic) as a percentage of the throughput for the LTE lic base case, and the per-bit TCO as a percentage of the LTE lic per-bit TCO. In the graphs on the right, LTE lic and Wi-Fi throughput stay constant and hence the LTE lic and Wi-Fi per-bit TCO does not change. In the 10% to 20% range, the LTE unlic throughput is lower than that of Wi-Fi, because in this graph, we assume a Wi-Fi throughput of 20% of LTE lic or higher.

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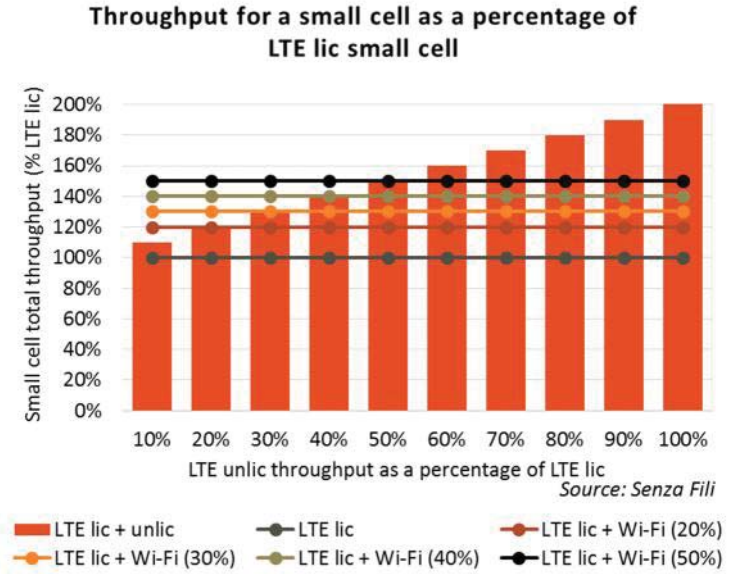
The per-bit TCO for LTE lic + unlic decreases as the throughput grows, as expected. Wi-Fi installed in LTE lic small cells has a lower per-bit TCO than LTE lic + unlic if LTE unlic throughput is higher or comparable to LTE unlicensed. As LTE unlicensed is expected to have a higher performance than Wi-Fi, the per-bit TCO is better to LTE unlic than Wi-Fi in most environments. This is due to the fact that the deployment and operation costs of the two solutions – LTE unlic and Wi-Fi – are similar.

A better per-bit TCO for LTE unlic does not imply that LTE unlicensed should be preferred to Wi-Fi, as there are many other considerations to take into account, such as time-to-market, device availability and cost, business models, integration options, alternative solutions and so on. The per-bit TCO spread between Wi-Fi and LTE unlicensed should be assessed within the context of these considerations. As it is always the case for financial analysis, a TCO analysis does not give a go/no go answer, but it is a key took to assess the tradeoffs between these two technologies.

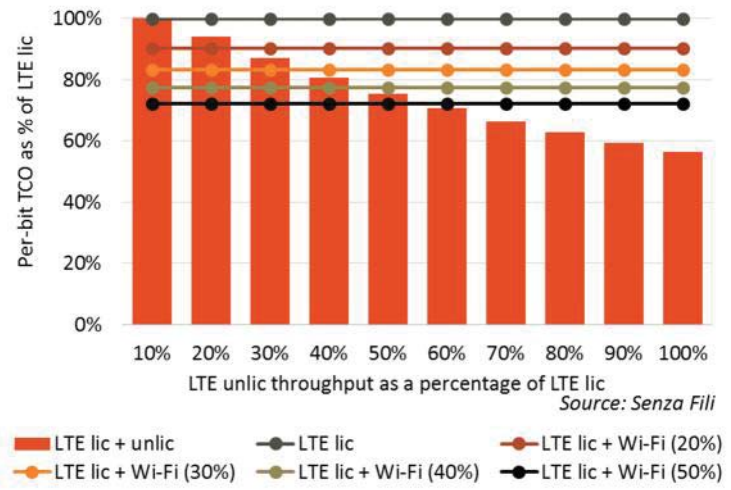
The results of the per-bit TCO sensitivity analysis show that even in the face of heavy use of the 5 GHz band, it is still cost-effective to add LTE unlicensed or Wi-Fi to small cells using LTE in licensed bands, because their addition lowers the per-bit TCO. At the same time, the cost tradeoffs between LTE unlicensed and Wi-Fi crucially depend on the relative performance of the two technologies – and this is what gives the upcoming 3GPP specs a central role in determining the breadth of LAA-LTE adoption and market success.

What is peculiar in the LTE unlicensed and Wi-Fi comparison is the fact that the performance of each technology is tied to that of the other: a stricter implementation of LBT stands to degrade LAA-LTE performance more and improve Wi-Fi performance. Conversely, an implementation of LBT that is friendlier to LAA-LTE may result in less degradation of LAA-LTE and worse Wi-Fi performance. The per-bit TCO analysis shows that finding the right balance in drawing the specs for LAA-LTE has implications that go beyond meeting regulatory requirements or ensuring basic fairness in coexistence with Wi-Fi.

Fixed Wi-Fi throughput, variable LTE unlic throughput



Per-bit TCO for a small cell with LTE unlic, compared to LTE lic and Wi-Fi



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12. Summary.

Growing value and usage of unlicensed spectrum: LTE unlicensed expands utilization of the 5 GHz band, with high spectral efficiency.

Two versions of LTE unlicensed: LTE-U (3GPP Release 10-12; only for China, India, South Korea, and USA; shorter time to market) and LAA-LTE (Release 13, a global standard that will include listen-before-talk mechanisms to meet regulatory requirements and ensure fair coexistence).

Commitment to fair coexistence: With Wi-Fi dominating in the 5 GHz band, LTE unlicensed proponents realize that fair coexistence mechanisms must in place to ensure acceptance of the technology – especially in the enterprise. Wireless ecosystem acceptance is necessary to LTE unlicensed success.

LTE unlicensed strengths: High throughput, full integration in LTE network (it is a special case of CA, with one band using unlicensed spectrum).

Wi-Fi strengths: Ubiquitous in devices, widely deployed, can be integrated in LTE networks today with fair coexistence with other networks.

LTE unlicensed or Wi-Fi? LTE unlicensed requires new mobile devices. The deciding factor may be device availability within an acceptable timeline and at an acceptable price.

LBT does not come for free: There is a growing consensus that listen before talk is necessary and an overall positive, but it will degrade LTE unlicensed performance – and the impact on performance is still uncertain, because it depends on the LBT implementation that 3GPP selects.

LWA as an alternative: LTE and Wi-Fi aggregation is emerging as an alternative (and possibly a complement) to LAA-LTE. It gives mobile operators another solution to leverage the 5 GHz band better than with Wi-Fi offload.

Business case: The choice between LTE unlicensed and Wi-Fi hinges on the relative performance of the two technologies, and this is dependent on the ongoing 3GPP standardization process.

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II. Vendor profiles and interviews

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Alcatel-Lucent: LTE unlicensed and Wi-Fi

At Alcatel-Lucent, increasing wireless network capacity goes hand in hand with an improvement in the quality of experience. The goal is for wireless networks' performance to match that of wireline networks in terms of reliability, speed, and quality of voice and video. Densification of the network infrastructure with small cells and Wi-Fi is one path that Alcatel-Lucent has pursued over recent years.

With the newly announced Wireless Unified Networks, Alcatel-Lucent has moved two steps further, by adding what it calls Cellular Boost with LTE unlicensed, and adding Wi-Fi Boost by closely tying Wi-Fi and cellular transmission.

The motivation to do so is that each technology has different strengths. Alcatel-Lucent intends to leverage these differences to optimize the allocation of network resources. LTE provides good uplink but can benefit from additional downlink throughput, while Wi-Fi is strongest in the downlink but can benefit from better scheduling and uplink at the cell edge. Alcatel-Lucent proposes that, where both technologies are available, Wi-Fi provides the downlink, and LTE the uplink as part of a blended service.

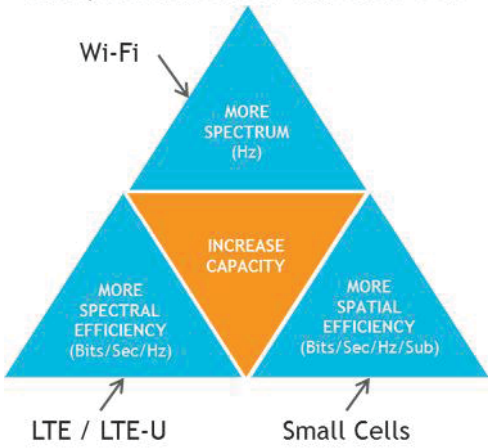
Wi-Fi Boost goes beyond Wi-Fi offload or solutions like Passpoint and Hotspot 2.0, which improve access of mobile devices to Wi-Fi with improved authentication and network selection. In its simplest implementation, best effort traffic is transmitted down over Wi-Fi and up over LTE. In advanced versions, it will use dual connectivity for simultaneous Wi-Fi and LTE according to 3GPP's LWA. As an IP-layer solution, Wi-Fi Boost works with 3G too, where the capacity gains of Wi-Fi over 3G are higher than those of Wi-Fi over 4G.

Alcatel-Lucent reports that the Wi-Fi Boost approach provides a 20% to 30% increase in downlink throughput to a single device, a tenfold increase in the user's uplink at cell edge, and a 2x improvement in Wi-Fi range. With LWA, the downlink is a summation of the available Wi-Fi and LTE capacity. The link to the cellular network improves performance reliability when Wi-Fi is congested or not available. This is a solution that can be deployed in the short term, because it does not require new devices or new infrastructure.

Cellular Boost aims to improve the user experience by increasing the capability of LTE through the addition of unlicensed spectrum. With Cellular Boost, devices transmit and receive LTE signals as they do today, but aggregate carriers that operate in unlicensed bands, and that coexist with other traffic (e.g., Wi-Fi) within the same band. Cellular Boost is complementary to Wi-Fi Boost; it enables LTE to be added as an additional channel in the 5 GHz band to increase download capacity and optimize end-user experience.

Alcatel-Lucent expects Wi-Fi Boost to be fully commercial soon, as it builds on current Wi-Fi and LTE deployments. Cellular Boost will take longer as it requires new devices and new infrastructure. Hence, Alcatel-Lucent sees Wi-Fi Boost as the initial step for mobile operators, one that is independent of the Cellular Boost. This gives mobile operators a short-term path to increase capacity by leveraging existing deployed network components while the industry agrees on LTE unlicensed standardization and gets ready for that technology's commercialization.

Adding capacity with a mix of Wi-Fi, LTE unlicensed and small cells



Source: Alcatel-Lucent

The joint connectivity across technologies raises the issue of how mobile operators charge for the traffic – whether they want to treat traffic over LTE differently from traffic over Wi-Fi, or over licensed versus unlicensed bands (i.e., LTE licensed and LTE unlicensed). From a technical viewpoint, the operator has full visibility into all these networks, so it can charge differently, and enable Wi-Fi Boost and Cellular Boost as and when desired. From a subscriber perspective, the difference may eventually become irrelevant as subscribers learn to trust interface selection to the network, so no longer actively choose Wi-Fi or LTE.

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A performance boost from combining Wi-Fi and LTE unlicensed

A conversation with Mike Schabel, VP of Small Cells, Alcatel-Lucent

Monica Paolini: Welcome to our conversation today with Mike Schabel, the VP of Small Cells at Alcatel-Lucent. This conversation is part of our report on LTE unlicensed and its coexistence with Wi-Fi from Senza Fili and in collaboration with RCR Wireless news. Mike, thanks for taking the time to talk to us today.

Mike Schabel: Thanks for having me, Monica.

Monica: Mike, can you tell us what you do on small cells at Alcatel-Lucent?

Mike: I'm fortunate enough to run the small cell business at Alcatel-Lucent, focusing on the over 70 operators that we do business with around the world, in 53 countries, helping to commercially deploy cellular in the home, in the indoor enterprise, and in outdoor environments. Fifty-three countries means I'm on a lot of airplanes.

Monica: A lot of flights and a lot of technologies. The list of technologies keeps growing by the day. Instead of getting smaller, it expands. This is what is happening with LTE unlicensed. We had Wi-Fi. We had LTE. LTE unlicensed is a little of Wi-Fi, a little of LTE.

How does LTE unlicensed fit in this ecosystem of wireless technologies?

Mike: It's a great question, because it can get very confusing when we're talking about all of these different technologies. To simplify it for myself, I often think about what's the problem we're trying to solve.

I think you have to look no further than some of the recent spectrum auctions to recognize that the spectrum that we transmit wireless cellular signals over is going to be challenged in a variety of ways.

First of all, when you have more users doing more things on this spectrum, then you're capacity limited. People want to continue growing their ability to send more traffic. You need more network capacity.

When you try to go after more network capacity, you need more spectrum. That spectrum is limited. Therefore, operators have said, "Why don't we go use some of the unlicensed spectrum to complement what we do with our licensed spectrum?"

They can already do some pretty cool things – such as dual connectivity or carrier aggregation. Why not aggregate that unlicensed traffic and unlicensed spectrum? But there's a small issue: there are other technologies and devices that use that unlicensed spectrum.

Wi-Fi is a great example, but not the only one. In fact there are other technologies. In white spaces, as an example, you have other technologies that run and use some of that unlicensed spectrum.

The real challenge here is: if you're going to go use that unlicensed spectrum, how do you do it in a way that's 1) fair; 2) standardized in a way that everybody can go use it; and 3) doesn't really change the nature or the behavior of the other technologies that are already there? It requires a tremendous amount of collaboration and careful study to get that done properly.

Monica: This is a concern that some of the people have with LTE unlicensed. Some see it as a newcomer intruding in a territory that is already occupied – even though, obviously, the unlicensed band is for everybody to use. There is a question of fairness. How do you define fairness?

Mike: Unlicensed spectrum is unlicensed spectrum. Anybody is allowed to use it for certain purposes. "Fair" is probably not a term I need to try to define.

What I can say is it's important to accommodate the other technologies that are already there, and existing and working in a particular way. There may be a specific regulation or standard for which they're working and have agreed on. Or even behaviorally, they may have agreed to work with each other to use that space.

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I believe that you shouldn't go confuse that or mess that up. You should accommodate it. You should recognize it. You should appreciate it and work collaboratively with those other users in order to become yet an additional user in their space. These technologies have carved off their space. You have to respect that.

LTE-U has to properly accommodate any other technology, whether it's Wi-Fi, white space, or another one. It has to accommodate what's there, and do it in a collaborative way.

Monica: You can also make the argument that using LTE unlicensed increases the spectrum utilization, because the 5 GHz band is often not used to maximum potential. Do you think that with LTE unlicensed, we can get a better utilization of the spectrum assets that are available?

Mike: Whenever you have your own slice of spectrum, you can do some cool things within that and get some very high performance schemes. But then Wi-Fi says, "You don't have your own slice."

Therefore, you have to spend more time in a nonscheduled environment, because you have so many different players. When you have so many players, you can't guarantee what anybody else could do. You effectively have to listen before somebody else engages.

What is really clever in LTE-U is to say, "How can I take the coding and spectrum efficiencies, and blend them into the concept of being a good partner and player in the use of that spectrum by listening to everybody, and then speaking when it's an appropriate time to do so?" I'm using voice analogies here, but it's the same type of concept. You have a conversation. Let's not ruin it.

Monica: Today, Wi-Fi is in all smartphones, laptops and tablets. And it's relatively inexpensive. Do we need another technology? What are the benefits that an operator can gain from LTE unlicensed?

Mike: We're thinking about LTE-U as a different technology. It's not. It's cellular. It is LTE. It is LTE running over a different piece of spectrum. If I look in any operator's LTE network today, generally speaking, they're operating over many different pieces of spectrum down and up, as well as by region – multiple pieces of spectrum that they're aggregating together, so it's unified.

Many consider this unlicensed piece something new. It's not new. It's LTE carrier aggregation over a piece of spectrum that we carved out. You need to take one small step, technically, to figure out when you can carve it out, when it's not being used – and consume it when it's not being used. Or if everybody is using it, use it in a way that respects what other people are doing.

LTE-U is the same technology, applied in another piece of spectrum that's also being used in other ways. An operator who has access to more spectrum can deliver a higher-capacity network.

As a consumer, why would I care? If my operator is spending all of its capital on buying more spectrum to give me what I want as a user experience, ultimately it's going to come back to me: I've got to help them pay for that. If there is available spectrum, the operator can go and deliver the type of experience that I want. Because the operator can lower its cost, that doesn't come back to me and I can (in theory) lower my cost as well.

Monica: At the same time, it's not Wi-Fi versus LTE unlicensed. Operators will not only use both technologies in different places, but they might also use them in the same place. So in the same location, they may use LTE licensed, LTE unlicensed, and Wi-Fi.

Mike: Wi-Fi is really interesting from a cellular operator perspective because it has mobility capabilities, but it was developed to serve nomadic data usage. It's well tuned for that.

Some operators have decided to roll out an extension of their wireline network to provide a wireless solution. I've seen cable operators and wireline ISPs do that. I see a lot of that wireline or wireless service provide that last meter's access and mobility with Wi-Fi. That's going to continue.

It gets a little confusing when you see service providers that actually have both, that they have both carrier-grade Wi-Fi and cellular, and use load balancing across the two networks.

They say, "I'm going to put you on Wi-Fi or cellular." It's an either-or technology. The cool thing about Hotspot 2.0 and ANDSF was to enable that type of switching capability. LTE-U absolutely fits right into that paradigm. It's not changing that paradigm. I don't know that it fundamentally

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enhances Wi-Fi or LTE-U. It's just making LTE-U available to use more spectrum. It's as simple as that.

Monica: Alcatel-Lucent's solution is interesting because what you're trying to do is to actually increase the integration between the Wi-Fi and LTE. By doing that, you can have a better utilization of all the resources that are available.

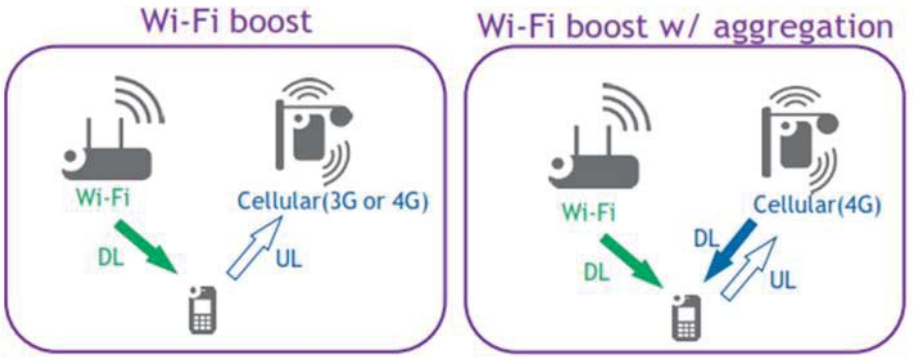
Mike: LTE-U is a great technology, but let's park it for a minute. We're introducing something that is very different. We think that Wi-Fi is a great technology. Wi-Fi in itself is a fantastic solution. It's in our homes, in our enterprises. It's going to be a very important part of the internet of things as that moves forward in the wireless home and the wireless enterprise. There's no question about that.

What we recognized, though, is that as you put more demands on Wi-Fi, you're going to expose the challenges that that technology has. It has a lot of spectrum, and so a lot of capacity. But what we also saw is that the uplink is challenged. That network can be better served by using a cellular solution. What we've come up with is a technology called Wireless Unified Networks.

We're saying it's not Wi-Fi or cellular, but it's Wi-Fi *and* cellular operating at the same time using their inherent strengths to deliver a unified experience to users.

What's the value? Who cares? Here's yet another technology that's going to drive everybody crazy, right? The value is now we can build a unified

Alcatel-Lucent's Wi-Fi boost, with and without carrier aggregation



Source: Alcatel-Lucent

wireless network, instead of Wi-Fi or cellular. And it's an extremely high-performance network.

With one of our partners, Qualcomm, we were showing an instantiation of this by taking the cellular and putting it together with Wi-Fi. At Mobile World Congress, we were providing download speeds of 450 Mbps down, using standard, off-the-shelf gear that exists today. 450 Mbps down on wireless is pretty interesting. We have 700 Mbps going in the labs, and we have a pathway to greater than 1 Gbps down.

What we realize is that hitting those types of rates with standalone technologies is going to get harder over time. We just realized if we put the two together, as simple as that, now all of a sudden, you can get some extremely great horsepower out of it. It changes our thinking about what wireless networks actually should be on a go-forward basis.

Monica: It's not just putting them together, it's putting them together to leverage the relative advantages of them. This is the first act, to get Wi-Fi and cellular together. How does LTE unlicensed come into that picture?

Mike: We're blending Wi-Fi and cellular. I can do it with standard cellular today and standard Wi-Fi today. We blend those, and we end up with a very high-performance network.

For example, if I were trying to do a Wi-Fi video uplink, that can put a lot of load on the Wi-Fi network. But when I blend Wi-Fi and cellular, I can more easily handle synchronous traffic and a lot of that synchronous uplink traffic. This doesn't congest the Wi-Fi network as much as it otherwise would, so the network can handle it well.

What about LTE-U? Remember, these are two completely separate technologies. LTE-U is just more spectrum for LTE. Wireless Unified Networks are about blending technologies to get a better overall user experience. We can actually take LTE-U as the cellular piece. Remember, I'm just taking Wi-Fi and cellular and I'm putting them

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together. I can also take Wi-Fi and LTE-U and put them together. It's exactly the same. These are coexisting concepts, not competitive concepts in any way.

Monica: A mobile operator can decide on which interfaces the uplink/downlink traffic goes – both for the data plane. Do you expect that the control-plane traffic to be over LTE?

Mike: Our first example of this is what we call Wi-Fi Boost, because we're just boosting the performance of Wi-Fi. I take the Wi-Fi downlink exactly as it is, no change. But instead of taking the uplink on Wi-Fi, we can move the uplink over to cellular. That's the simplest form. When you do that, you really free it.

You get two times more range out of the existing Wi-Fi AP, you get about a 20% to 70% improvement on the downlink, and you get 10X to 50X improvement on the uplink, depending on the cellular technology you're using. Great horsepower out of existing technology, just by doing these simple things.

From a control perspective, we're still using the typical WLAN access controller that's in the loop. Nothing gets changed. We do move the session, though, to be handled by the mobile core.

When you do that, what's really cool is that, when you're talking about having simultaneous Wi-Fi and cellular, you can make a very quick and easy decision on moving your voice traffic, for example, from VoWi-Fi over to, let's say, VoLTE – where you get to leverage the inherent spectrum advantages of how LTE manages those voice packets.

You can use VoWi-Fi, but, if you have the option, you can just flip it over to cellular because it's an efficient use of cellular spectrum, and you can avoid to unnecessarily congest the Wi-Fi.

Monica: You mentioned the importance of collaborating with the different players in the industry to make sure that Wi-Fi keeps working well and that LTE unlicensed doesn't get disrupted. Who are you working with to get the end-to-end LTE unlicensed solution ready?

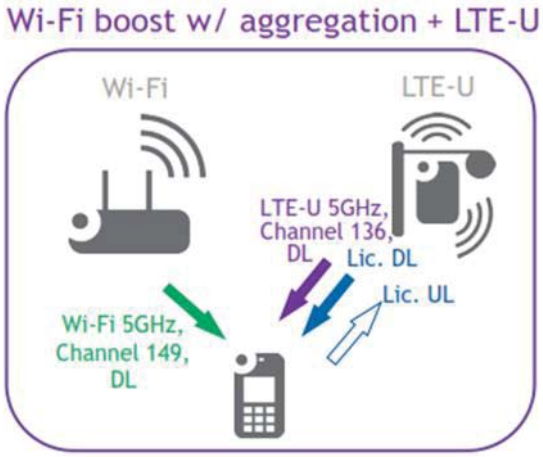
Mike: We have two major initiatives happening in parallel. One is our LTE-U initiative, the Cellular Boost. The other one is our Wi-Fi Boost. They're separate entities and they are both part of the Wireless Unified Networks initiative.

Let me talk about Wireless Unified Networks first. We introduced a great partner, Ruckus, that we'll go to market with on these Wi-Fi enhancement technologies, where we bring cellular and augment the Wi-Fi. We'll do that very soon.

What's great about that is that it's a Wi-Fi company who's going to their Wi-Fi deployments to say, "Look, we can build a better wireless network for you by using cellular." That's the key aspect. Ruckus is a great commercial partner for us, and we're expanding to others.

We're also working with Accenture with a joint go-to-market business relationship. Accenture, of course, serves many, many enterprises.

Alcatel-Lucent Wi-Fi boost working with LTE unlicensed



Source: Alcatel-Lucent

On the LTE-U side, we're working with all the players within standards bodies, with Wi-Fi Alliance, with the handset providers and the silicon providers.

In Wireless Unified Networks, it's all pretty much leveraging what exists, and now it's about going to market.

On the LTE-U side, we're talking about new technology. It's the same thing as LTE, but repeated into new spectrum. New spectrum means new handsets. New spectrum means new eNBs – whether they're big or small, it's still new. We've got to spend a lot of time to make sure that the silicon and the transceivers that go into the devices are done really, really well and properly. That's all new.

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Monica: As you said, we need infrastructure and new devices. How long is it going to take to get to market?

Mike: We'll have LTE-U prototypes and proofs of concept for operators that are commercial grade by the end of this year, in Q3 and Q4. From an operator perspective, I see this potentially happening in the first quarter of 2016, but there are a lot of dependencies that I don't control that we're counting on, such as standards finalization, and deep collaboration and demonstration of the technology between the Wi-Fi community and the cellular community.

LTE-U requires new handsets and new silicon in the baseband, before rolling all of that out. By the end of this year, we're going to be in a good proof-of-concept phase. I'll be prepared to go, but I think we would have to work through the other dependencies and make sure that everybody else is ready for commercial adoption.

Monica: You work with many operators. What is it you hear from them?

Mike: On LTE-U, operators are absolutely attracted to it, in general. The planned use of unlicensed spectrum is different for each operator, because it depends on how much they have to pay for more spectrum. They're certainly interested in that opportunity to augment their position, no question.

Operators are acutely aware of the dependencies and the challenges, in particular with Wi-Fi Alliance and in making sure that LTE-U works well with Wi-Fi. If you're making an investment in new silicon, new handsets, new baseband and new base stations, it's really important that it's done in a way that has wide-scale deployment capabilities. That's why the standards are so important, and the industry recognizes that.

Monica: In closing, what should we expect from Alcatel-Lucent in the next two or three years on this front?

Mike: On this front, we're definitely going to participate in LTE-U, there's no question.

We're really going to explore the segment of converting the enterprise and the home to the wireless enterprise and the wireless home.

I firmly believe that we're going to move the enterprise today from wires – the huge body of traffic on the wires in the enterprise – onto the wireless network. This transformation is going to happen over the next couple of years.

We're going to have to invent a lot of new technology and services, and go to market with partners in order to enable that, and we'll continue to do that. That's a big industry shift that I see happening. We're going to be behind that, trying to make that big shift happen and work well.

Watch the video of the interview.

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About Alcatel-Lucent

Alcatel-Lucent is the leading IP networking, ultra-broadband access and cloud technology specialist. We are dedicated to making global communications more innovative, sustainable and accessible for people, businesses and governments worldwide. Our mission is to invent and deliver trusted networks to help our customers unleash their value. Every success has its network. For more information, visit Alcatel-Lucent on http://www.alcatel-lucent.com, read the latest posts on the Alcatel-Lucent blog http://www.alcatel-lucent.com/blog and follow the Company on Twitter: http://twitter.com/Alcatel_Lucent.

About Mike Schabel

As the vice president in charge of Alcatel-Lucent's Small Cells Division, Mike Schabel is responsible for establishing a leadership position in this new market, from articulating a compelling industry vision, to working with partners to build small cell networks for wireless operators, to creating an industrialized product portfolio and solution. Mike earned his doctorate in chemical engineering at the University of Arizona, specializing in plasma chemistry, and also received degrees in materials science and aerospace engineering. Starting his career with Alcatel-Lucent as a Bell Labs researcher in 2000, Mike soon recognized that he enjoyed commercializing technology as well as trying to invent it. Mike quickly established a track record of successfully creating and scaling new businesses, cutting his teeth on the Alcatel-Lucent 9900 Wireless Network Guardian.

Mike regularly runs marathons and frequently trains around the world while travelling to meet with customers.

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InterDigital: LTE unlicensed and Wi-Fi

With its focus on enhancing wireless technologies and expanding wireless access and usage, InterDigital has had a keen interest in the development of LTE unlicensed from the beginning, because the technology naturally fits within InterDigital's core areas of expertise – including cellular infrastructure, Wi-Fi and small cells. One of the major areas of work at InterDigital today is 5G, and there LAA-LTE is one of the emerging technologies.

Like much of the work on 5G today, most of the activities on LTE unlicensed still revolve around standardization. InterDigital regards LAA-LTE standardization as a prerequisite to commercial rollouts and product availability. As a result, its main efforts today are to ensure a robust LAA-LTE standardization, with good coexistence with Wi-Fi and a wide industry consensus that spans both the Wi-Fi and the LTE vendors and service providers.

The standardization efforts at InterDigital are focused on 3GPP and, specifically, on proposed standards for LAA-LTE that require a listen-before-talk foundation to ensure coexistence. According to InterDigital, not only does this approach allow for an LAA-LTE standard that can be deployed globally, it is required to establish a fair coexistence with existing and new Wi-Fi networks.

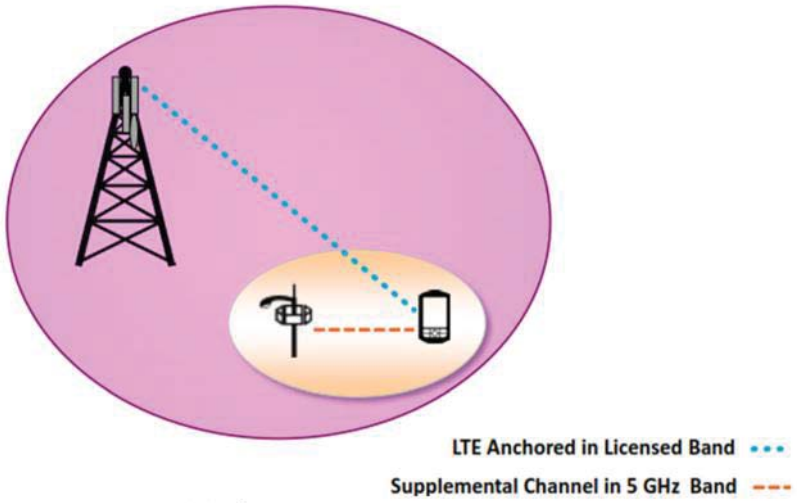
We can expect LAA-LTE solutions from InterDigital to be available after the 3GPP standardization process is completed.

In the meantime, InterDigital offers solutions that optimize the use and performance of network resources in existing networks while aiming at improving the user experience and operators' revenues. Within this area, InterDigital has worked extensively on the integration and coexistence of Wi-Fi and cellular networks. This gives InterDigital a good vantage point to assess the potential of LAA-LTE, and a good platform to develop solutions to manage the joint transmission in the LTE licensed and unlicensed bands, and in Wi-Fi.

InterDigital's Smart Access Manager product is designed to improve users' QoE, and improve traffic management across cellular and Wi-Fi. Because most operators have limited or no visibility into the real-time traffic load and resource availability of the Wi-Fi infrastructure, the Smart Access Manager works from the mobile device end to select the network that provides the best connectivity seamlessly. It bases the selection on multiple factors, such as traffic load of the network, link quality and capacity, battery level, location, and time of day. Network selection can be tied to a policy server (based on ANDSF) to implement the operator's policy and enable revenue-generating services.

Specifications like Hotspot 2.0 use real-time load metrics to provide QoS and address the current needs of operators to improve traffic management in Wi-Fi networks. However, many network equipment providers have not yet implemented these features. Mobile operators prefer to manage traffic from the network, using mechanisms that supports resource management for both licensed and unlicensed spectrum. LAA-LTE can address this need, because it gives operators ability to jointly manage both licensed and unlicensed spectrum.

The aggregation of licensed and unlicensed channels in LAA-LTE



Source: InterDigital

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Fairness to Wi-Fi is crucial to LTE unlicensed's success

A conversation with Jim Miller, Director, Radio Standards, InterDigital

Monica Paolini: Good afternoon, and welcome to our conversation on LTE unlicensed systems with Wi-Fi. Today, I am talking to Jim Miller, Director of Radio Standards at InterDigital. Jim, welcome and thanks for talking to us today.

Jim Miller: Yes, thanks for having me to discuss this important topic.

Monica: Can you tell us, what is your role at InterDigital?

Jim: I coordinate all of our 3GPP RAN activities, and am heavily involved in our IEEE activities as well. My goal is to develop a coherent strategy for all of our radio work in both IEEE and 3GPP.

Monica: That's excellent, because you're seeing both the Wi-Fi side and the LTE unlicensed side. How do you approach both technologies at InterDigital?

Jim: We take a technology-agnostic position, because we feel that, even though unlicensed spectrum is free to use, we want LAA-LTE to use it fairly. If it is not fair to Wi-Fi, LAA-LTE will end up occupying a niche market, where it can only be used in certain spectrum where Wi-Fi isn't. That would not be good for it, and would make it a fringe technology that we wouldn't necessarily need to be further involved in.

We're working strongly in that direction, to progress both on the Wi-Fi side and the LAA-LTE side for some cooperation, and in particular on the LAA-LTE side, making sure it's defined so it treats Wi-Fi and anything else in the spectrum fairly.

Monica: There has been a lot of debate back and forth, and a lot of changes over the last year or so, in terms of the evolution of the role of LTE unlicensed, Wi-Fi and how they coexist.

Can you provide some background about how we are moving forward?

Jim: I'll start briefly at the beginning of this, when it came into the picture on the 3GPP side in December 2013, within some initial proposals. Though we were interested in LTE unlicensed, we could not support those proposals at that time, because they were not addressing fairness. These proposals were more or less trying to put Wi-Fi in one of the spectrum blocks still to be allocated.

We were not alone in that aspect. It took LAA-LTE the following 9 to 12 months before it became agreeable to everybody in 3GPP to go forward, and fairness was a large part of that, and a large addition to that.

Monica: How do you define "fair" and "nice"? They are appealing terms, but they're not trivial to define, are they?

Jim: That's going to be the sticking point going forward, as we try to come to a solution on the LTE side.

Coming to that solution is to define fairness. At InterDigital, we define fairness as an LAA-LTE node being brought into an existing system not causing any more interference or degradation to a Wi-Fi cell than adding another Wi-Fi cell.

Right now, anybody can come in and add a Wi-Fi cell anywhere, and that's part of the appeal of Wi-Fi to begin with. So there's no reason why an LAA-LTE cell couldn't go in there and have the same basic effect on the existing Wi-Fi cell, and that's what we're striving to get to. In certain environments, that's easier to define than in others.

Monica: Do you think the existing regulation good is enough or sufficient to ensure this kind of coexistence?

Jim: At InterDigital we look at some of the regulations worldwide – for instance, at DFS requirements here in the US, LBT in Europe and other places, and the various power control requirements. They're all different.

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The 5 GHz spectrum is splintered, with radar and other things in some of the blocks. We were looking for a solution that is a superset to all of those. We didn't want a solution that would work, for instance, in certain bands only in the US, or that would not be allowed in Europe, or that would need some different features to work in Europe.

We wanted, basically, a worldwide standard that could be deployed in any unlicensed spectrum band. The initial targets, of course, and the initial studies are in the 5 GHz range.

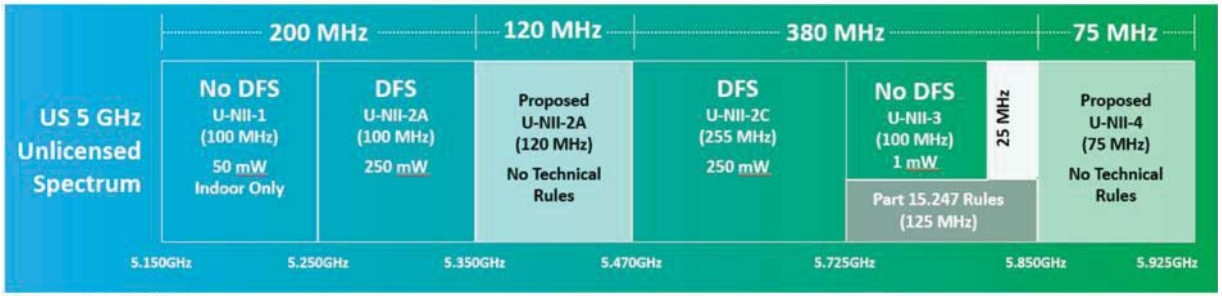
Monica: You need to have a solution that meets the requirements of all the regulations in major countries worldwide so that you can have a global product. Do you think that's achievable?

Jim: I think it's achievable. Fairness is probably going to be the biggest sticking point, because there are varying views on that, but I see a great deal of similarity, and fundamentally the issue is the same.

For LAA-LTE to be deployed in an area, for example, and have the potential to bring down somebody's home Wi-Fi, or a company's Wi-Fi or a conference center's Wi-Fi, based on conflicts or hogging the spectrum – that is going to attract attention, and thus, trigger the regulators to get involved.

I would anticipate that we will be able to have an industry consensus on this, hopefully get to a point where the number of issues in front of regulators is small and they can rule in those particular areas.

The 5 GHz band in the US



Source: InterDigital

I've talked to people on both sides. Neither side is interested in having a big fistfight in front of regulators. The idea is to define this, and get some initial indications of how each side feels about it, try to come to some consensus, and then bring it out to the regulators. And hopefully, get to a point where they're answering a small number of questions, and they handle a small number of cases.

And thus, the regulators should not have to be put in their referee perspective of saying you can't be here, or you can be here. We've have witnessed in the past – for instance in the 3GPP world, with satellite conflicts, and it gets very messy.

That's something that everybody I work with on both the LTE side and the Wi-Fi side wants to avoid, even though they're in positions to possibly have a good argument. The regulators are the court of last resort, and we want to try to avoid that as much as possible.

Monica: This is something that's emerging in the last few months. No matter where the operators and the vendors are coming from, they all agree that coexistence with Wi-Fi is crucial for LTE unlicensed to succeed.

Everybody is willing to cooperate, and I think that this cooperation within the industry is crucial to success. Do you think this a foundation for the standardization efforts?

Jim: Yes. In our perspective, definitely. We are pushing strongly to have everybody involved, and have an open discussion and an open forum as much as possible, because right now, the discussions go on both in the Wi-Fi and 3GPP camp in separate meetings.

While there's overlap in the company positions, in each paradigm (3GPP/Wi-Fi), the differences in how each standards body looks at the same issue cause more disconnects between Wi-Fi and 3GPP than is actually present.

Everybody has some strategy here on this. A strong discussion is going on in both realms, each using a different perspective, because the Wi-Fi world is different than the LTE world. The difference between the two technologies is at work continuously in the unlicensed spectrum

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versus working in licensed spectrum: two different viewpoints, and two different ways of even doing simulations.

The whole point of the effort right now, and what we're trying to contribute to it, is to get the 3GPP design decisions– initially for instance, the 3GPP models of the channels – to a point where we can judge fairness for both Wi-Fi and LTE.

People can point to certain aspects of Wi-Fi that could cause more damage to LTE than the other way around. And vice versa: LTE has a potential, if the fairness algorithm is not written correctly, to take over the whole band.

We're working that battle from both ends to try to get to a point where we have some intergroup agreement on a system as being relatively fair. But there may still be some sticking points, and we may have to get some regulatory ruling on them.

But if that's necessary, we hope that's minimal, as opposed to saying, "Here's the whole mess" and throwing it in the regulators' lap.

Monica: There's a lot of work being done, and hopefully over the next few months, we will get to some good standardization approach that satisfies the industry. The question at that point, though, is, how do we make sure the adopted standard is followed in practice?

For instance, for Wi-Fi you do have a certification program, and that ensures coexistence of different Wi-Fi systems with each other. But here, we have a different problem. Here you have two different technologies and they both have to be fair to each other.

Right now, there is no way to ensure that. Do we need to, or don't we even need to do that? How can we know that the vendors and operators are complying with the standards?

Jim: Yes, that comes into play, and that will be a further discussion. We anticipate that LAA-LTE terminals will go through a rigorous conformance testing, also. In fact, one could argue it's even stronger than the Wi-Fi one, because it's normally used in licensed networks.

But LAA-LTE will be, at the very least, on par with Wi-Fi. The struggle once it's defined will be to find ways to test the terminal, to ensure that it is not transmitting when it's not supposed to be and that it's acting like it should be so it does not interrupt the Wi-Fi.

Monica: You work with a lot of mobile operators, obviously, and I'm sure this is a topic that comes up all the time these days. What do you hear from the operators?

Jim: We get a large range of inputs from operators. The issue is, right now Wi-Fi is used to offload traffic. A lot of operators do have separate Wi-Fi networks, or somewhat interrelated, where if you subscribe to a carrier, you can get on their Wi-Fi also.

The same thing with cable companies: they have their own Wi-Fi, and if you use their internet, you can use their Wi-Fi.

There are multiple ways that the operators can do offload right now.

The problem is, the Wi-Fi operations system is completely separate from the 3G one, and it requires a whole different set of tools for operations, maintenance, etc.

Another problem is that, right now, the control of the Wi-Fi offload is more in the terminal, not in the networks. The operator has less control over Wi-Fi offload from the network side.

At InterDigital, we have many operators looking at our Smart Access Manager product, which is a UE-based application that allows the selection of the network that provides the best-quality service to users.

Our solution works very well in environments where the operator owns or has ready access to a Wi-Fi network – it is an obvious solution in those environments. This type of solution isn't as effective in environments where an operator doesn't have access to a Wi-Fi network to offload traffic. LAA-LTE would be a solution in those cases.

LAA-LTE will allow the 5 GHz band to be treated as the licensed spectrum already is – to be controlled from the licensed side, and getting a better guarantee of quality of service than with the Wi-Fi offload.

When people go to Wi-Fi it is because there is a good Wi-Fi signal there but the Wi-Fi network may be or become congested. Thus they get worse

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service if they stay on Wi-Fi than they would in the 3G or LTE systems.

There are various operators that have existing Wi-Fi, so they are moving at a different speed than some of the other operators that just want to utilize the spectrum and deploy it separately. Once an operator has a large Wi-Fi deployment, it isn't necessarily looking to run out and replace the Wi-Fi network with LAA-LTE.

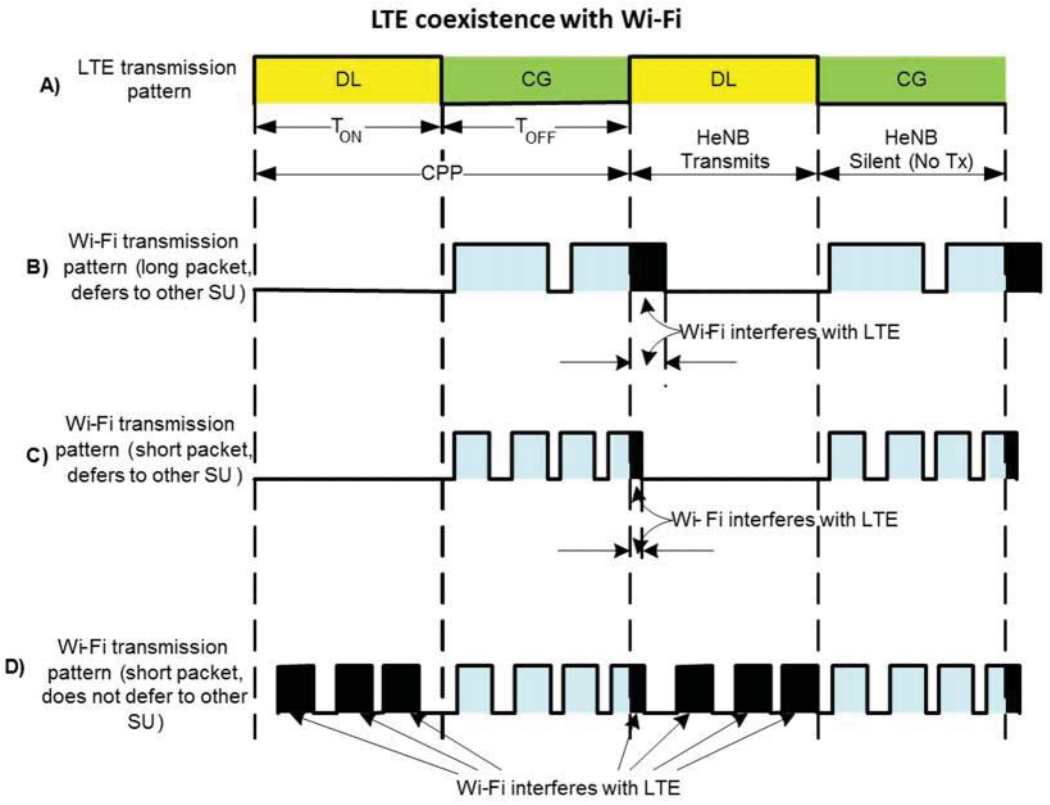
The current version of LAA-LTE involves all the signal scheduling from the macro – the LTE station – with the Wi-Fi being part of the macro and connected directly to the macro with no real latency.

LTE base stations in the unlicensed spectrum are either co-located with a macro cell or at very short distances away from one, so that can they be controlled, more or less simultaneously– this is called "no latency backhaul." Scheduling can be done at a single location, which is the macro at the LTE site.

Monica: This is quite interesting, because LTE unlicensed gives operators more control from the network side over Wi-Fi.

At the same time, there is a lot of work being done also on the Wi-Fi side that will make it easier to integrate Wi-Fi with LTE. Does that reduce the appeal of LTE unlicensed?

Jim: The LTE unlicensed is a somewhat separate use case than the typical Wi-Fi offload.



LTE with listen before talk (LBT) and properly designed coexistence gaps (CG) can do as well or better in managing interference

Source: InterDigital

If you're traveling in a car, for example, you're probably not doing Wi-Fi offload that much. Even if it's tightly controlled – and there is work going on in LTE to make Wi-Fi even more tightly controlled and somewhat network based – Wi-Fi offload still involves a connection with 3G or LTE. To add Wi-Fi to it, you have to attach to a Wi-Fi base station. But Wi-Fi was not necessarily built for mobility. So if you're moving fast, by the time you associate with the Wi-Fi station and start transmitting, you could need to be at the next Wi-Fi station, and have to start the process over again.

In LAA-LTE, you're going to be registered in the LTE spectrum, and all the control signaling is on the LTE licensed band. You're just using it to transmit data on the spare parts of the unlicensed 5 GHz band, because of fairness mechanisms. You just transmit there in that spectrum when the Wi-Fi is not using it. But then you can come back and still

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have your connection through your macro cell that's based on LTE.

Monica: Do you envisage operators having both Wi-Fi and LTE unlicensed in the same location, as well?

Jim: Potentially that could be done, and it is dependent on the use cases and how much focus an operator is putting on a particular use case. For example, right now certain operators have complete Wi-Fi networks and others don't.

If you talked to five different operators, you are going to have five different levels of Wi-Fi support in a particular area. So Wi-Fi and LAA-LTE could be used, at the same time.

Thus, if you have fairness with LAA-LTE, it's just like another Wi-Fi base station. It creates interference in the spectrum that they share, but it's still part of the normal management that Wi-Fi networks have for that, and thus, doesn't create any more headaches.

It still allows the operator to control their LAA-LTE transmission in the unlicensed band, in the same way they do with the licensed band, as far as the quality of service and similar things. But even in networks with LAA-LTE, LTE allows stationary users to offload most or even all of the air traffic to a Wi-Fi hotspot using Wi-Fi that's nearby, as it does today. It could theoretically be in the same area.

Monica: What are your plans at InterDigital in terms of helping operators with LAA-LTE?

Jim: We have our Smart Access Manager to work with the current UE-based offload. To enhance that, we're working with operators, and on the standards, for improving that Wi-Fi offload even more in the current release.

Simultaneously we are working on LAA-LTE to make it as easy as possible for them to use their licensed spectrum and the unlicensed spectrum. For instance, they want to be able to come in and out of LAA-LTE and at the same time retain the guaranteed quality of service. Additionally we work with the operators to help them use our gateway products and expertise to leverage that even more in the access to unlicensed spectrum.

But a lot of our work will be to enable the operators to expand what they currently have with LTE in licensed bands into the unlicensed band and, thus, to have a single point of management that includes an enhanced quality of service for handling the traffic that goes over the unlicensed spectrum.

Monica: In closing, when do you think we will be able to see the first commercial deployments of LAA-LTE?

Jim: That's a tricky question, because some operators have already publicly announced plans to do some pre-standard trials. That's going to happen pretty shortly.

That's similar to what happens in the Wi-Fi environment. Whenever a new standard comes out, there's always pre-standard equipment out there to try to enhance performance.

They are doing initial LTE-U trials which utilize pre-standards concepts which are being discussed while standardizing LAA-LTE. These trials are in particular spectrum blocks to minimize the effect on Wi-Fi, because they'll pick a spectrum channel that's outside of current Wi-Fi usage. And thus, they will be able to test and see how the integration goes.

The standardization of LAA-LTE through the first couple of evolutions will probably take place over the next couple years. The first version of this will probably be finished at the end of the year or early next year, thus fully standards-compliant LAA-LTE will probably be available at the end of next year, or the year after. But pre-standardization versions of LAA-LTE will be available earlier.

Watch the video of this interview.

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About InterDigital

InterDigital develops technologies that are at the core of mobile devices, networks, and services worldwide. We solve many of the industry's most critical and complex technical challenges, inventing solutions for more efficient broadband networks and a richer multimedia experience years ahead of market deployment. InterDigital has licenses and strategic relationships with many of the world's leading wireless companies. Founded in 1972, InterDigital is listed on NASDAQ and is included in the S&P MidCap 400® index.

About Jim Miller

As a Director in InterDigital's Standards department, Jim Miller has been an active participant in the development of wireless technology related standards. Currently, he leads the InterDigital 3GPP RAN delegation and participates in the standardization of the IEEE 802. Prior to this, Jim spent 8 years as the Vice Chair of 3GPP TSG RAN WG3 (the organization that standardizes Radio Network Architecture) from 2001 to 2009. Jim has been with InterDigital for 19 years, and holds a Bachelor's degree in computer science from Rensselaer Polytechnic Institute.

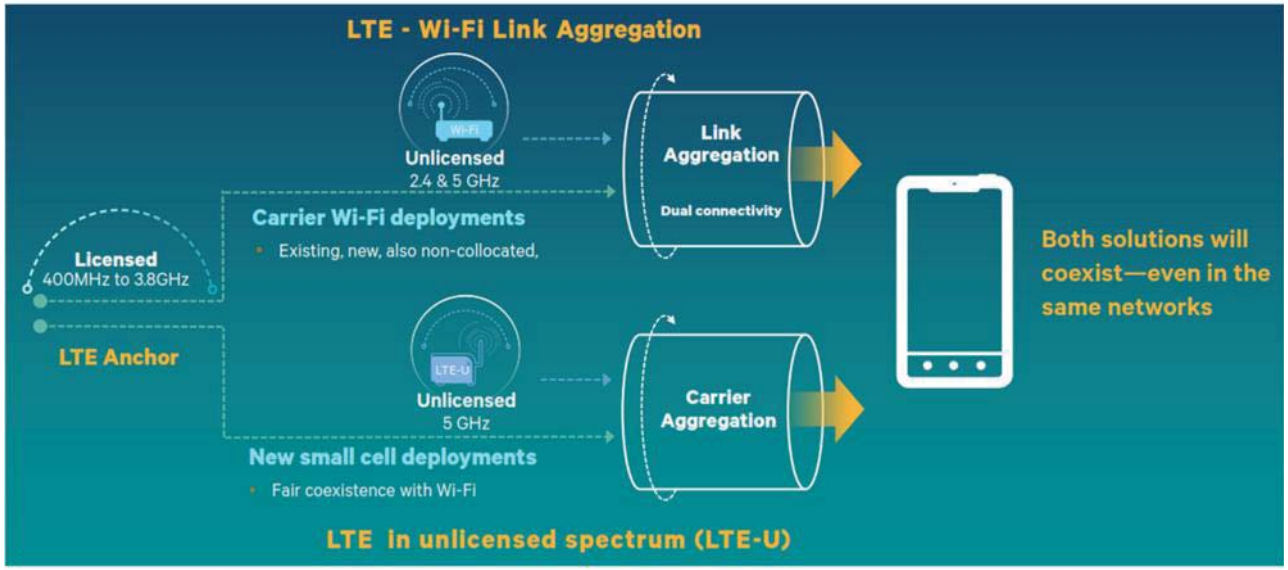
Qualcomm: LTE unlicensed and Wi-Fi

Qualcomm Incorporated's wholly owned subsidiary, Qualcomm Technologies, Inc. (QTI) was one of the initial proponents of LTE unlicensed, along with vendors such as Ericsson and operators such as Verizon. LTE unlicensed fits well within QTI' 1000x vision – preparing for a thousand-fold increase in mobile data usage. LTE-U complements parallel efforts to increase wireless capacity with small cells, shared access, and the multiple flavors of Wi-Fi – residential, community, hotspot, enterprise, and carrier.

From QTI' perspective, LTE unlicensed is a tool to maximize the use of the 5 GHz band, and to increase the attractiveness of unlicensed spectrum to mobile operators. It complements the ongoing work to expand and improve carrier Wi-Fi. For example, QTI has contributed to the development of LTE and Wi-Fi link aggregation feature, which enables devices to transmit concurrently over Wi-Fi and LTE links. The dual connectivity enables the operator to provide robust mobility and uplink performance with the LTE anchor (i.e., a licensed channel for LTE), and high downlink capacity with Wi-Fi in the 2.4 GHz and 5 GHz bands. LWA is part of an industry-wide effort to integrate Wi-Fi and LTE, with 3GPP working on its standardization.

On the LTE unlicensed side, QTI is working on two development tracks. The first addresses the LTE-U opportunity in countries, such as the US, South

Qualcomm's vision for increasing spectral efficiency in the 5 GHz band



Source: Qualcomm Technologies

Korea, India and China, where the restrictive the regulation regime does not require the adoption listen-before-talk mechanisms, and LTE-U can use existing LTE 3GPP standards (Release 10, 11 and 12) along with CSAT based co-existence mechanisms in 5GHz.

These countries are likely to see the first LTE unlicensed deployments, using dynamic channel selection and CSAT to ensure fair coexistence with Wi-Fi.

The second LTE unlicensed solution is for markets where LBT is required, and this is tied to the ongoing LAA-LTE standardization efforts at 3GPP to be included in Release 13. Because the standardization process is not yet complete, LAA-LTE will become commercial after LTE-U products do.

LAA-LTE not only will meet the power, emission levels and LBT requirements set by regulators, it will go beyond the regulations to ensure coexistence with Wi-Fi and to optimize LAA-LTE's performance. This includes conformance testing to ensure that LTE unlicensed is implemented according to the published specs.

QTI has announced products to support LTE-U, to be available in the second half of 2015, with plans to introduce LAA-LTE products after the 3GPP specs are finalized. QTI has announced the integration of LTE-U in its FSM99xx SoC, and the availability of the FTR8950 RF transceiver for small cells. On the UE side, QTI has announced the WTR3950 RF transceiver, which supports LTE Advanced CA with support for up to 40 MHz channels.

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Improving spectrum efficiency with LTE unlicensed

A conversation with Puneet Sethi, Director of Product Management, Qualcomm Atheros Inc.

Monica Paolini: Good afternoon, and welcome to our conversation on LTE unlicensed and Wi-Fi, which is part of a report from Senza Fili in collaboration with RCR Wireless News.

Today, our guest is Puneet Sethi, the Director of Product Management at Qualcomm Atheros Inc. Puneet, thank you for taking the time to talk to us today.

Puneet Sethi: Thank you, Monica.

Monica: To get started, can you tell us what prompted QTI to get into this business, exploring the use of LTE technology that was only used for licensed spectrum and moving into the unlicensed band?

Puneet: Monica, you know about the 1000x Challenge. That's something that began almost three years back. LTE-U came out of that initiative, as did several other things.

You go back three years, we started this initiative to drive solutions from within QTI and also across the industry, to meet the challenges of exponential growth in data demand, which was almost doubling every year.

You really needed some innovative solutions to meet that kind of challenge. Several solutions under the 1000x Challenge initiative were brought from conception to commercialization, and they include hyper-dense mobile networks, UltraSON solutions for LTE inside to out coverage, and licensed shared access.

Now, LTE unlicensed is part of that tool set, as well, which allows operators to pair unlicensed spectrum with their licensed anchor, and deliver higher throughput and better user experience to their subscribers.

Monica: What is the advantage that specifically LTE unlicensed brings, when you can already use Wi-Fi in the 5 GHz band? What is the value proposition for a mobile operator?

Puneet: Yes, you're correct: Wi-Fi has been there in 5 GHz, and also, previous to that in 2.4 GHz.

Before we get into that, let me just say that both LTE and Wi-Fi are technologies that have been there for quite some time, and have seen multiple layers of evolution. They will continue to evolve and will be there to meet the different sets of use cases we see out there in the real world, which include diverse sets of devices, diverse sets of applications, and diverse sets of QoS requirements.

LTE-U brings a certain set of unique advantages to operators that have already deployed an LTE network, to provide additional capacity by leveraging unlicensed spectrum paired with a licensed anchor, and delivering higher throughput, as I mentioned earlier.

Additionally, it enables them to spread the capital expenditure on the core network across both licensed and unlicensed spectrum. It's a more efficient use of the investment that they made in the core network.

It also enables them to use the same security, mobility and signaling framework that is core to the LTE protocol itself across both licensed and unlicensed spectrum, thereby enabling seamless mobility to their subscribers.

Monica: LTE unlicensed fits better with the mobile operator network, but if you look at it from the point of view of the users, will they notice the difference? Does it make any difference to them if they connect to Wi-Fi or LTE unlicensed?

Puneet: It really depends on the use case and the requirements, and there are different sets of users out there, including enterprise and residential users.

For a local area use case, I think Wi-Fi has been there and has been serving that market well.

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For use cases that require increased mobility and where you have a licensed anchor that you can rely on for control and signaling, that's where I think LTE unlicensed provides certain benefits.

LTE also is inherently spectrally more efficient. For the same amount of spectrum, it can deliver 2x more capacity than Wi-Fi.

It also works better alongside Wi-Fi. What we say is it's a better neighbor to Wi-Fi than Wi-Fi is to itself. If you have two Wi-Fi nodes right next to each other and you replace one of them with LTE unlicensed, not only would you see the gains from the LTE unlicensed node, but also you will see the improvement on the neighboring Wi-Fi's performance.

Again, the two technologies are very complementary, and, depending on the use case and the requirements, either one or the other would meet the subscriber needs.

Monica: If you can pack more throughput, more capacity and demand, that's to the collective advantage of everybody involved – service providers, enterprises and subscribers.

Another important stakeholder here is the enterprise. Many Wi-Fi networks are managed and owned by the enterprise – including public venues. There, the owners of the Wi-Fi networks are going to be very protective about their Wi-Fi networks, and they want to control the unlicensed spectrum as much as they can. What are you seeing in terms of the reaction of the enterprise to LTE unlicensed?

Puneet: Enterprise, again, represents a very unique set of subscribers with their unique requirements.

In today's enterprise, mobility is a key requirement. Enterprises are becoming increasingly mobile, with employees moving across the enterprise, in and out of buildings, and within the enterprise building itself.

LTE unlicensed satisfies those requirements, because mobility, as I said, is inherent to the LTE technology itself. If you pair unlicensed spectrum with the licensed anchor, you get the mobility that's needed, and you are also able to meet the coverage and capacity needs of enterprises.

The challenge there is typically around indoor coverage, which is where LTE unlicensed is more relevant. This technology is more applicable to small cells because of the higher-frequency band that's used in the LTE-U product. You're able to deploy those small cells inside the building for indoor coverage and capacity.

Monica: You mentioned the fact that these technologies have to coexist, but there is just so much spectrum out there. You need to find a good way to allocate spectrum resources to support both technologies.

A term frequently used is "nice." What does "nice" mean? What does it mean for technologies to be nice to each other?

Puneet: At the basic level, it really means that the radio technology is able to detect the presence of other users of the transmission medium, and thereby adapt its own behavior and share the transmission medium with the other users.

There are ways to ensure that technologies are nice to each other. There are different layers to that.

The first layer is the regulatory side. There are regulations in every country as to how to utilize the unlicensed spectrum; those regulations may define a spectrum mask, transmit power and other requirements. Every radio technology has to comply with that.

There are certain differences as you go from one country to another in terms of regulations that apply to the unlicensed spectrum. For example, if you look at Europe and Japan, and some of the other markets that have what we call a listen before talk, or LBT, requirement, that forces changes on the waveform in order to meet those regulatory requirements of listen before talk. Then there are other countries – the US, South Korea and China – where you don't have those requirements, and those are the non-LBT regions.

Regardless of whether it is an LBT region or not, the first layer is that radio technology has comply with the regulatory requirements.

That is not enough from the perspective of being nice, or standardizing coexistence procedures. You have to go beyond regulatory requirements, and actually define and standardize coexistence procedures that define how technologies coexist.

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That requires industry consensus. For LTE unlicensed in the LBT regions, that work is happening in 3GPP, as a Release 13 study item supported by various operators and vendors.

For non-LBT regions, you have the opportunity to use the existing Release 10, Release 11, Release 12 LTE waveform with an adaptive duty-cycle mechanism, which we call CSAT, to ensure coexistence.

That has also been standardized. LTE-U Forum, as you know, has published specs that are publicly available for everybody to review and see what coexistence procedures and aspects are defined for that space.

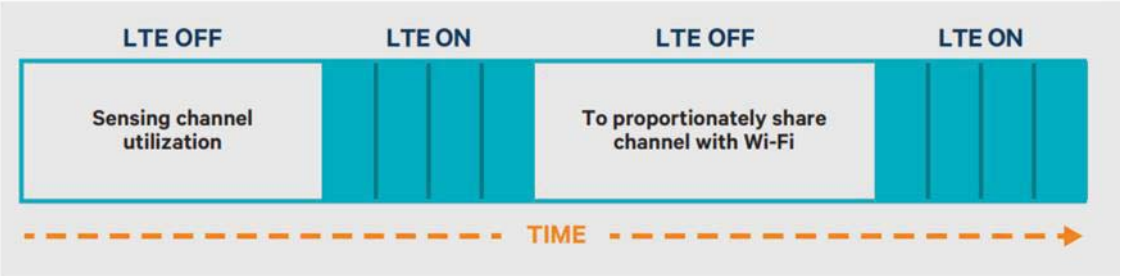
Monica: Right. There is a lot of ongoing work right now. There is a lot of activity on the organization side.

As you say, we need to have industry consensus. How close are we to getting that consensus? Knowing that not everybody has the same goals, how close are we to finding a solution that makes everybody reasonably happy?

Puneet: I think we are pretty close. Fortunately LTE unlicensed has seen a lot of industry support. There's a lot of ecosystem support building for this technology.

For LBT regions, that work is ongoing in 3GPP. That work is supported by the major operators and vendors, and is going to be part of Release 13 discussions as they play out within 3GPP.

LTE unlicensed based on 3GPP Release 10 with CSAT for the US, Korea, China and India



Source: Qualcomm Technologies

For non-LBT regions such as the US, LTE-U Forum published the specs. That work was done over the past several months by leading operators, including Verizon, and infrastructure vendors such as Ericsson. QTI was also a founding member of the Forum. That work has resulted in these coexistence specs that are available for anybody to review.

If somebody wants to create an LTE-U product, they can look at the specs and see what coexistence procedures they have to implement, and what test they would have to pass.

The work ahead in those regions is to take those specs and drive those products – solutions for LTE unlicensed products – into those markets. I think, in short, we're pretty close. There's a lot of ecosystem momentum behind LTE unlicensed.

Monica: For most vendors, there is both a Wi-Fi component and an LTE component within their own business, and they have to manage both; there is no choice between the two of them.

QTI is one such vendor, because at QTI you have both the Wi-Fi business and the LTE business.

Puneet: Both technologies have been around for some time. We've participated in the evolution of both these technologies.

A few weeks back, I was at an event in the Bay Area with our team that is responsible for the Wi-Fi infrastructure. Organizationally, small cells fit closely with the Wi-Fi infrastructure team, as well. We were all in the same room, brainstorming future-generation products for both LTE unlicensed and Wi-Fi. As you've seen, even on the Wi-Fi side, we have driven the leadership in Wi-Fi 11ac and multiuser wave 2 MIMO.

We are the leader in that space and we are driving that evolution further with 11ax and however Wi-Fi technology will evolve going forward.

Similarly, for LTE unlicensed, we're working for the LBT regions, supporting the industry and the 3GPP discussions. For non-LBT regions, we're now working on our productization plans based on the LTE-U Forum spec.

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In short, both technologies are here to stay. They're going to be required to meet a diverse set of use cases, and devices and applications.

We just want to make sure we drive both technologies really hard, and have best-in-class solutions on both sides. Whatever our customers end up selecting based on their own requirements, we would have something to offer to them.

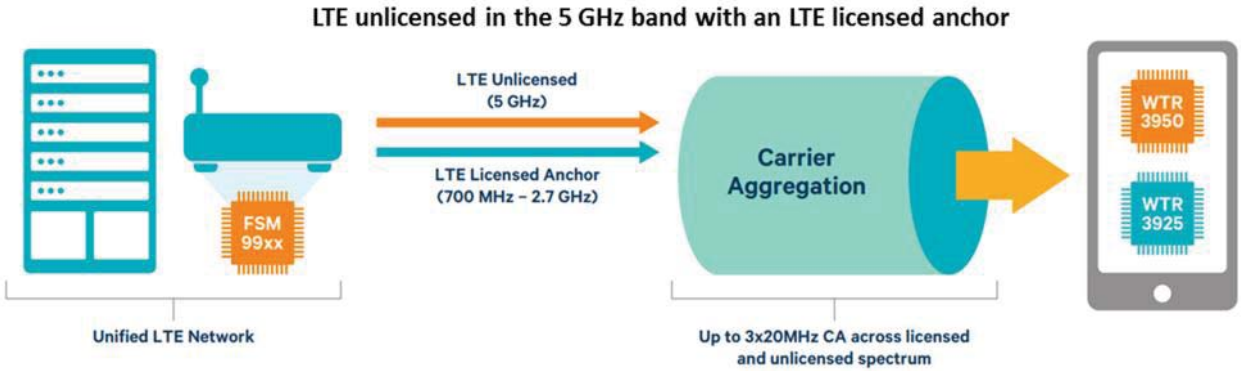
Monica: There is a lot of work that you are doing, moving forward in terms of technology and thought leadership.

If a mobile operator comes to you and says, "We're interested in LTE unlicensed," how can you specifically help them? How can you help them move to where they're deploying the technology?

Puneet: Earlier this year, we announced support for LTE-U in non-LBT regions for both small-cell and UE products.

We're driving those products towards commercialization and early trials later this year. That's the way we're going to help mobile operators in the non-LBT regions to get to products in the field faster. North American mobile operators have already expressed support for LTE unlicensed trials, and we're working with them.

For the LBT regions, we will continue to work with the industry and within the 3GPP forum to drive that technology through the standards. And then, when the standards firm up, we're going to drive technology through our product plans, both on the small cells and on the UE side.



Source: Qualcomm Technologies

Monica: If a mobile operator wants to deploy LTE unlicensed today, say in a non-LBT region, what upgrade do they need to then move to LAA-LTE, if they decide to do that?

Puneet: The answer depends on several factors, including what sort of investment the mobile operator would have already made in LTE unlicensed, or is going to make.

There're a lot of architectural details that would have to get into there. In short, the platforms that we're looking at have features that would enable software upgradability from along the LTE unlicensed track.

That is designed to enable operators to upgrade from one phase of LTE unlicensed to another phase, depending on the product architecture, of course, and also, depending on the core network architecture, as well.

Monica: And I guess it depends on what the standards will be.

Puneet: Yes, there are some moving parts there, too, as the standards are not set. A lot will depend on what actually comes out of 3GPP.

Monica: One crucial element to determine the success of LTE unlicensed is the handset, because you need to have handsets that support it, you need to have the device vendors that will make those handsets and subscribers that will buy them. What are you doing in that area, specifically?

Puneet: On the handset, we announced our WTR 3950, which is a companion chip that supports the 5 GHz band. It will be commercially available later this year; that's part of the LTE unlicensed support on the handset side.

For the LBT regions, we will have productization plans to meet the 3GPP specs for LAA-LTE.

There is work being done both on the handset and on the small-cell side to drive the solutions to market, both for LBT and non-LBT regions.

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Monica: What do you have specifically on the small-cell side for LTE access?

Puneet: On the small-cell side, we already have commercially available the FSM9955 solution. We're able to software-upgrade that solution to support LTE unlicensed. We then pair that baseband solution with our new RFIC FTR8950, and that will support the 5 GHz band with FTR8950. Both of those solutions will line up with the UE availability in the latter half of 2015.

Monica: Can you give a bit of a sense of how difficult it is and how expensive it is to add LTE unlicensed to the current devices and small cells?

Puneet: There are different aspects of that, Monica.

One aspect is the product cost. You really need to add 5 GHz band support to the product, and that would be the additional cost.

And then additionally, depending on how the operator decides to deploy this, LTE unlicensed may require some software upgrades to the other elements of the network, as well.

Monica: When will the devices be available?

Puneet: We're targeting our chipset solutions for both small cells and handsets to the latter half of this year, and expect commercial solutions three to six months after that, depending on the OEM trials and schedules.

Monica: Within the 1000x vision, Qualcomm Technologies has been very vocal on the use of the 3.5 GHz band as a spectrum resource that can be used to increase capacity.

How does the availability of the 3.5 GHz relate to LTE unlicensed? Is it in addition to that, or an alternative?

Puneet: I think it complements very well the LTE unlicensed model. The LTE unlicensed initial focus is on the 5 GHz band, which is sort of a global band. The 3.5 GHz band is different, because there are different regulations depending on the country. Outside of the US, in some markets – Europe and Japan – it's mainly a licensed band.

For those markets, it really becomes licensed LTE in 3.5 GHz. In the US, the FCC is still working on how to regulate this. There are proposals on the table about a tiered approach. Depending on what finally comes out of that, we can potentially see LTE unlicensed deployment in the 3.5 GHz band, as well.

Monica: Let me ask you a final question. What should we expect in the next year or two in terms of the priorities of what needs to be done to make sure that LTE unlicensed succeeds, and of what other major challenges are there?

Puneet: The work ahead of us is for the LBT regions. I think the big chunk of work that's ahead of the industry is to drive the item through the 3GPP process.

There's a lot of support there. A lot of operators, equipment manufacturers, mobile manufacturers, silicon manufacturers are working on this together. We've got to make sure that this gets standardized through 3GPP Release 13.

For the non-LBT regions, the specs are already out there for everybody's review and feedback. Now we have to take those specs and implement products, and drive those products through early trials, and then launch in the early part of next year.

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About Qualcomm, Inc.

Qualcomm Incorporated is a world leader in 3G, 4G and next-generation wireless technologies. Qualcomm Incorporated includes Qualcomm's licensing business, QTL, and the vast majority of its patent portfolio. Qualcomm Technologies, Inc., a wholly-owned subsidiary of Qualcomm Incorporated, operates, along with its subsidiaries, substantially all of Qualcomm's engineering, research and development functions, and substantially all of its products and services businesses, including its semiconductor business, QCT. For more than 25 years, Qualcomm ideas and inventions have driven the evolution of digital communications, linking people everywhere more closely to information, entertainment and each other.

About Puneet Sethi

Puneet Sethi is a Director of Product Management at Qualcomm Atheros. At Qualcomm Atheros, he drives roadmap and strategy for small cell SoC solutions, UltraSON and other related products. He is instrumental in defining software strategies and managing relationships with various eco-system partners including software providers. He works with Qualcomm Atheros's `global sales organization to market Qualcomm Atheros's portfolio of small cell solutions to operators and OEMs around the world. Puneet also drove the LTE PHY enhancements for the LTE-Advanced project at Qualcomm Atheros. Prior to that, Puneet provided consulting services to Ixonos for its entry in to the US market and, before that, he held engineering positions at Radioframe Networks, Comneon and Ubinetics. Puneet earned his MBA with concentrations in Finance and Marketing from the Anderson School of Management at UCLA and has a B.S. in computer science and engineering from the Indian Institute of Technology at Guwahati.

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Ruckus Wireless: LTE unlicensed and Wi-Fi

There are two dimensions that are crucial to the deployment and success of LTE in the 5 GHz unlicensed band: spectrum and site acquisition.

Spectrum in the 5 GHz band is license-exempt virtually everywhere, but LTE unlicensed can realistically use that band only if it coexists with Wi-Fi fairly.

Site acquisition is equally crucial as LTE unlicensed is going to be tied to small-cell deployments, which will mostly occur in indoor locations. Operators will need easy and affordable access to these indoor venues to be able to successfully deploy LTE unlicensed.

Through its background in Wi-Fi, Ruckus Wireless is very familiar with both unlicensed spectrum and the needs of businesses and venues and intends to leverage this expertise to ensure that spectrum utilization in the 5 GHz band is fair to current and future tenants.

As a provider of high-performance Wi-Fi equipment for operator and enterprises, Ruckus understands the challenges that come from having large numbers of collocated Wi-Fi networks contending for access to spectrum.

A robust listen-before-talk mechanism is required to ensure coexistence. To retain a similarly fair environment in the 5 GHz band, Ruckus believes that LTE unlicensed has to adopt listen before talk as well, even though this represents a departure from the way LTE normally operates.

The listen-before-talk approach is required to ensure fairness but is also crucial for operators to gain access to venues -- especially indoor venues.

Operators need to get consent and support of the entities that control these venues. That consent may be hard to come by if the venues' managers worry that LTE unlicensed may affect the performance of existing Wi-Fi networks, which are often mission critical to their operations.

Ruckus has experience in working with public venues and private enterprise in developing a wireless strategy that helps them meet their business needs.

Wi-Fi has a crucial role to play here as do LTE small cells. Increasing the performance of LTE small cells by using the unlicensed bands can make for an even better user experience in venues or businesses, provided it is done properly. In most cases this means supporting listen before talk to ensure fair access the spectrum.

This flexible approach makes it possible to support a variety of business models, which may be driven by capex commitments from the service providers, enterprises, or neutral-host parties.

While much of the debate today revolves around the role of LBT in deployments of LTE unlicensed, LTE Wi-Fi Link Aggregation, or LWA, has emerged as a new option. With this approach LTE traffic is simultaneously sent over both LTE and Wi-Fi radios. A separate SSID is configured on the Wi-Fi access point for this purpose.

LWA gives Ruckus an opportunity to expand its solution portfolio by allowing traffic that currently uses LTE to transit its commercially deployed Wi-Fi networks.

LWA's objective is similar to that of LTE unlicensed, but its focus is on leveraging the advantages of Wi-Fi in the 5 GHz band and of LTE in the licensed spectrum.

Ruckus believes this approach leads to a more efficient use of the 5 GHz band, because Wi-Fi is designed for this environment, and LTE is optimized for licensed bands. Each will be allowed to do what they do best.

Convergence of Wi-Fi and LTE

Source: Ruckus Wireless

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Beyond LTE unlicensed, with LTE plus Wi-Fi link aggregation

A conversation with Steve Hratko, Director of Service Provider Marketing, Ruckus Wireless

Monica Paolini: Good afternoon, and welcome to our conversation on LTE unlicensed and its coexistence with Wi-Fi. Today, we are talking to Steve Hratko, the director of service provider marketing at Ruckus Wireless.

Steve, thanks for talking to us today.

Steve Hratko: It's always a pleasure, Monica.

Monica: Steve, how do you rationalize your involvement with both Wi-Fi and LTE unlicensed?

Steve: Ruckus Wireless has been in the Wi-Fi business for more than a decade, and we specialize in two primary markets.

We have a pretty significant enterprise business that focuses on venues like airports, train stations, hotels, et cetera. We also have a large service provider business, and the service provider business focuses on the needs of both mobile operators and cable operators, along with wireless ISPs and managed service providers.

As part of our focus on service providers, we've been taking a long, hard look at LTE in the unlicensed band. At Ruckus, we use these bands for Wi-Fi, which has been an enormously successful business, largely because of its ability to share unlicensed spectrum. The unlicensed bands are free for anyone to use, for any purpose.

Now, with the arrival of LTE-U, we've been taking a look at what impact this will have on the unlicensed bands. We certainly understand the driver for LTE-U, which is how best to use this spectrum to provide a more compelling, higher-performance LTE service. At Ruckus, we want to understand how LTE-U is going to impact Wi-Fi services, which are broadly deployed and very successful.

Monica: As you said, Wi-Fi has been very successful. It has also taught us a lot about how different networks can coexist in the same frequency band. Can we expand to other technologies, like LTE unlicensed, what we learned with Wi-Fi? What is necessary for the two technologies to coexist?

Steve: There's an established mechanism for Wi-Fi networks to share spectrum, called listen before talk. With listen before talk, the Wi-Fi device waits for the channel to be clear, and when it is, it transmits. Typically, an AP would transmit for up to 10 milliseconds, then it would release the channel and the process repeats. This works extremely well for the sharing of the unlicensed bands.

This isn't terribly efficient – and certainly not as efficient as LTE, which uses a scheduled MAC process – but it works extremely well for sharing unlicensed spectrum.

The big debate within 3GPP right now about LTE-U is just exactly how LTE might implement listen before talk, or will it implement something different? A lot of the early work around LTE-U is not focused on using listen before talk per the IEEE, but is instead focused on looking at other approaches that might be a better fit for LTE.

We're advocating, along with the whole Wi-Fi industry, that 3GPP come forward in Release 13 with an approach that supports listen before talk. This is going to make LTE-U and, more specifically, LAA-LTE much more successful.

Monica: Do you think there is enough consensus in the industry – not just from the Wi-Fi side, but from all the LTE players – to support listen before talk?

Steve: I think the consensus in the industry is to move towards implementing listen before talk for LTE-U. We think this will be done by 3GPP in Release 13 as LAA-LTE.

There are a number of reasons for this.

The first reason is that in some jurisdictions, specifically in the European Union, it's required by regulation. It's not required by regulation in the US

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and some other markets, but in the interest of having a solution that works worldwide, it makes sense to implement listen before talk. I think it's going to make everything run a lot smoother.

The second reason is that there is a huge installed base of Wi-Fi equipment, and it is in everyone's best interest for LTE-U to work with that installed base and to share spectrum fairly.

A third factor, which doesn't get enough attention in the listen-before-talk debate, is that LTE-U and LAA-LTE are small-cell technologies. LTE-U and LAA-LTE operate on the unlicensed band, so you have the same power limitations that Wi-Fi has and they are ideally suited to high-capacity-density venues.

Those are locations where Ruckus has a lot of expertise. Stadiums, train stations, convention centers, airports, downtown city centers, areas where you have huge numbers of people aggregating in close proximity, and they are all using data. One of the challenges with addressing this opportunity is that in almost all cases, to deploy any radio technology will require the permission of the venue.

If it's a downtown city center, you've got to go through a large number of municipal commissions and committees. It's going to be easier to get permission to deploy LTE small cells if they don't impact the Wi-Fi networks already deployed.

An operator proposing to install LAA-LTE-enabled small cells with listen before talk will have a much easier time passing muster with that stadium, with that convention center, with that airport.

In many cases, these venues have people whose job it is to keep an eye on how the unlicensed bands are being used, because Wi-Fi services are so important to the venue -- in many cases are mission critical. Any solution that's not IEEE compatible is going to get a lot of scrutiny.

Monica: Is the enterprise going to allow somebody else to come and use the same spectrum?

Steve: At these very high-capacity-density venues, it's very important to make sure that you meet the needs of the venue. This applies whether you're deploying Wi-Fi in that venue, or LTE small cells, or LTE small cells using LTE-U. In all cases you have to understand the needs of the venue.

Many of us pick venues based on how good the Wi-Fi is. People who enter these venues expect high-quality Wi-Fi, so anything that potentially impacts the Wi-Fi networks is going to get looked at very closely by the venue.

Now, it's possible that even if you implement LAA-LTE with listen before talk, the venue still may not like that. They still may prefer that the LTE stay in the licensed band, and the Wi-Fi stay in the unlicensed bands.

It's going to be their choice, because they control access to the facility. Again, they are an important constituent in this debate, and I think we need to hear more from them going forward.

This convergence of service providers and public venues is the sweet spot for Ruckus, in that we build very high-end Wi-Fi gear that's designed for these sorts of installations, and so we have a good sense of what venues are looking for, what's important to them, what the industry needs to do.

Monica: Now, from a mobile operator point of view, there is the opportunity not only to use LTE unlicensed, but also LTE unlicensed and Wi-Fi in a much more tightly integrated way.

Steve: There is a focus in the industry on combining LTE small cells with Wi-Fi access points – putting both radios into the same box. We're already working with major RAN vendors that are looking to add Wi-Fi to their small-cell products.

Part of the challenge is that site acquisition is difficult when deploying any kind of a small radio in a high-density venue. Once you get permission to deploy, you might as well deploy a box that does more things. If you have Wi-Fi in the box, add an LTE small cell. It makes a lot of sense to combine them, and we expect to see a lot of that going forward.

But it introduces some interesting problems that have not gotten enough attention in the industry.

If you have a single node with both a Wi-Fi access point and an LTE-U small cell, you end up in a situation where that node has two 5 GHz radios operating at the same time. Running the Wi-Fi and LTE-U radios together in the same box with antennas in very close proximity requires very sophisticated filtering.

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People haven't been spending enough time figuring out how that's going to work. And these challenges bring us to LWA. I have a feeling we're heading in this direction.

Monica: What's happening with LWA?

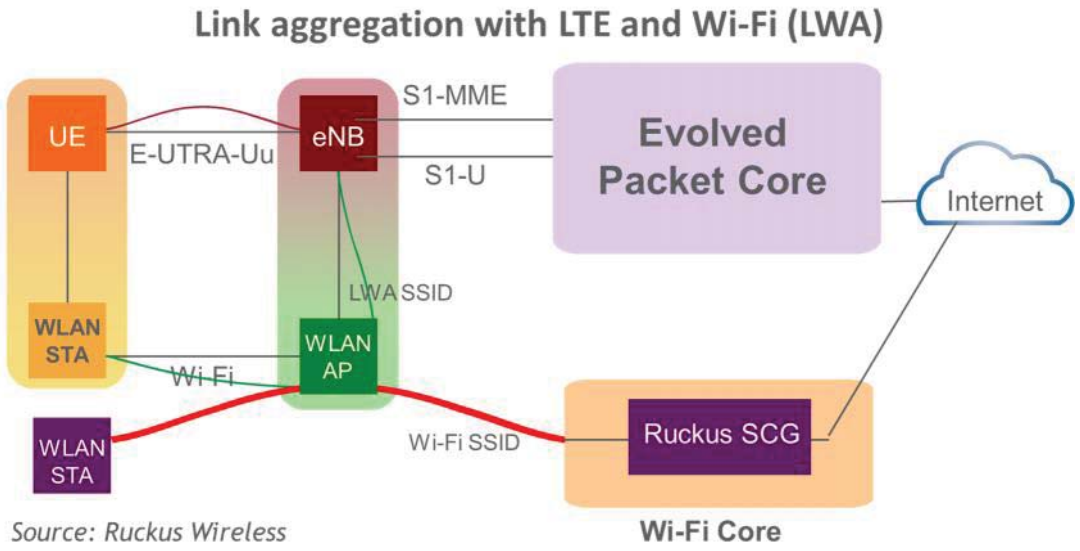
Steve: LWA is LTE plus Wi-Fi link aggregation. It is another proposal coming from our friends at Qualcomm. It builds on the original LTE-U concept.

As with all things, with each iteration the technology gets better and the solutions get better. At Ruckus, we're big fans of LWA. In the end, it will prove to be a stronger solution than running LTE directly over the unlicensed band.

The theory here is that rather than try to put a 5 GHz unlicensed radio inside an LTE small cell, you'll have Wi-Fi access points running in the unlicensed band, and you'll have LTE small cells running in the licensed band. You let each of them do what they do best.

The smartphone would turn on both of its radios and send some of the data natively over LTE, and the rest as a tunnel over Wi-Fi.

You're running LTE in the unlicensed band, but you're using the Wi-Fi MAC and PHY. You don't have any of the issues with listen before talk and fair sharing that come with LTE-U. When the LWA signal arrives at the Wi-Fi access point, it is peeled off and tunneled back to the eNB, where the Wi-Fi and LTE signals are combined and sent back to the mobile core.



Source: Ruckus Wireless

This is a really nice solution, because it gets us out of that debate over running LTE in an unlicensed band, something it was never designed to do.

By recombining the Wi-Fi data at the eNB, you can bring it all back into the mobile core without having to go through any 3GPP S2A, S2B, or S2C interfaces, which are normally used to bring Wi-Fi data into the mobile core. It's just going to be a straight S1 interface through a Serving Gateway

There's a lot of value in this approach. It is the right way to give cellular service a boost, by letting it tap into that enormous pool of bandwidth we have in the unlicensed bands. In the US, there is close to 700 MHz. This varies by geography, but there is a significant amount of unlicensed bandwidth, and it can be shared.

Monica: LWA is also something that 3GPP is working on – it's not a proprietary solution.

Steve: The industry has been trying to understand how to do Wi-Fi and cellular convergence now for close to a decade. There have been a number of different approaches that have been queued up, and I think everybody agrees that Wi-Fi and cellular technologies can be combined to offer a truly compelling user experience.

We have to figure out how to make them converge so that the user is always best connected. Sometimes cellular is the better connection. Sometimes Wi-Fi is the better connection. But regardless of which one's better, how do we combine them?

Monica: From the operational and business model point of view, how will the LTE-U and LWA models work? That's an even a bigger challenge than working out the technology issues, How will this get deployed in venues and who will pay?

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Steve: I think that's a fascinating question, and I think we are well-positioned to answer it.

Many of the technical issues around deploying LTE small cells have been worked out by the RAN industry. Now we're going down the path of trying to understand how to use LTE in the unlicensed band.

As we start looking to deploy small cells, whether it's just a straight LTE small cell or an LTE small cell using the unlicensed band, what does the business model look like?

In a convention center or an airport, mobile operators are going to want to deploy LTE small-cell networks. Each operator will negotiate with the venue, put in its own network, and pay the venue whatever site rental fee is required.

But once you get past the high-capacity-density venues, you're looking at smaller venues, like the tens of thousands of hotel chains in the United States and around the world. You're also looking at hospitals, shopping malls and universities.

We've learned a couple of lessons from deploying Wi-Fi in public venues of various types.

Number one, once you're past the high-capacity-density venues, the enterprise or venue has to pay. For almost any radio deployment, whether it's Wi-Fi or LTE, you've got to come up with a model where the venue will pay to deploy the equipment.

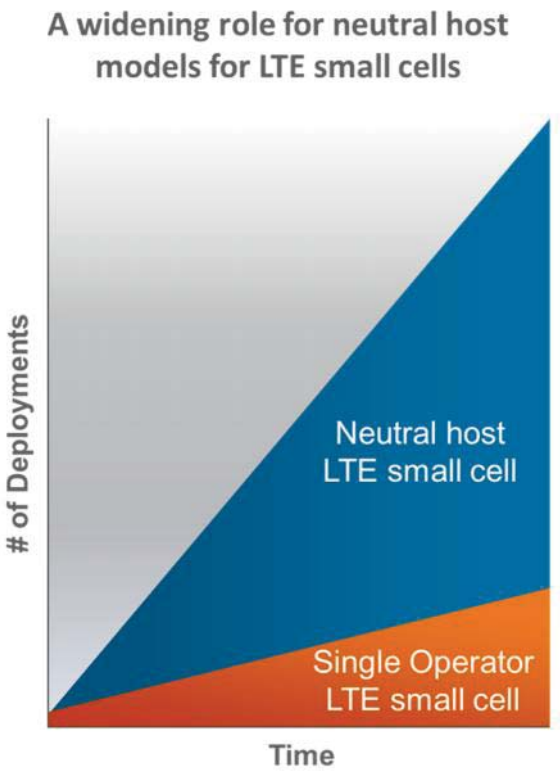
Number two, it should be deployable by a value-added reseller, or VAR. If radio engineers are required, things can get really expensive. Obviously, you need to make the deployment as easy as possible, and have that equipment be as cost effective as possible.

We've seen a lot of projections from analysts talking about the LTE small-cell market being worth upwards of $10 billion in five years. But to get there, we've got some business model challenges we need to address.

Monica: As you move to smaller venues, you still want multiple operators, but it becomes increasingly difficult to have multiple operators deployed side by side. So you need a DAS-like neutral-host model. Do you think it will work for indoor LTE-U or LTE licensed small cells?

Steve: To get the venue to pay for the deployment, it has to be a neutral-host model. Everyone who walks into that venue has to be able to access that network. Venues don't want to put in three or four networks, they want just one. That's why Wi-Fi has been so successful. A single Wi-Fi network is a perfect neutral-host solution, because everybody who walks into the venue can connect.

We need to do the same with LTE. We need to find a way to make the neutral-host model work with LTE. The venue will pay to deploy the network, and anyone who walks into the building will be able to use that small-cell network. Venues won't pay for two, three or even four networks, but they will pay for one.



Source: Ruckus Wireless

To make the small-cell LTE market really explode, we've got to solve the neutral-host problem.

Monica: Is there a difference in terms of geography? In the US, there is much less of an infrastructure-sharing mentality than in places like Europe, for instance.

Steve: Yeah, RAN sharing tends to be much more popular overseas.

The neutral-host model is now becoming a top-of-mind issue for the LTE small-cell industry, especially, as we start looking at potentially

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running LTE in the unlicensed band. The industry needs to better understand the business model and better understand how to neutral-host the technology.

Monica: What do you see in the short- to mid-term for the coexistence of Wi-Fi and LTE unlicensed?

Steve: I think the key right now is what's going to happen at 3GPP. They've taken on the challenge of looking at LTE-U and trying to understand how to standardize it.

I think everybody wants to see a standard come out of 3GPP, and that's targeted for Release 13 in the summer of 2016. We believe that at that time, 3GPP will come up with a mechanism that supports listen before talk per the IEEE. There are so many reasons to go down that path that we expect that to happen.

Separately, we also have LWA, and that's being worked by 3GPP, also, for Release 13. We should see something big coming out in the summer of 2016. There's going to be a great deal of interest in terms of understanding what 3GPP is doing there.

Certainly, a lot of the Wi-Fi standards organizations are also plugging themselves in to the 3GPP process. I think we'll come out with a solution that's going to be a win-win for the entire industry.

Monica: Is this going to make the small-cell market bigger, or is it just going to have a larger benefit for Wi-Fi?

Steve: These approaches accelerate the convergence, which is good for everyone. We've been working to converge Wi-Fi and cellular for some time now, and approaches like LTE-U and especially LWA accelerate that convergence, as do things like Hotspot 2.0 and Wi-Fi Calling.

Anything that helps to accelerate this convergence makes a more compelling user experience for people using wireless services, and I think it's going to be a plus for the entire industry.

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About Ruckus Wireless

Headquartered in Sunnyvale, CA, Ruckus Wireless, Inc. (NYSE: RKUS) is a global supplier of advanced wireless systems for the rapidly expanding mobile Internet infrastructure market. The company offers a wide range of indoor and outdoor "Smart Wi-Fi" products to mobile carriers, broadband service providers, and corporate enterprises, and has over 40,000 end-customers worldwide. Ruckus technology addresses Wi-Fi capacity and coverage challenges caused by the ever-increasing amount of traffic on wireless networks due to accelerated adoption of mobile devices such as smartphones and tablets. Ruckus invented and has patented state-of-the-art wireless voice, video, and data technology innovations, such as adaptive antenna arrays that extend signal range, increase client data rates, and avoid interference, providing consistent and reliable distribution of delay-sensitive multimedia content and services over standard 802.11 Wi-Fi. For more information, visit http://www.ruckuswireless.com.

About Steve Hratko

Steve Hratko is the Director of Service Provider Marketing at Ruckus Wireless. Steve is responsible for the marketing of all service provider class products worldwide. The primary markets for Ruckus solutions include MNOs, MSOs, WISPs, managed services providers and wireline providers. Steve's specific areas of expertise include Wi-Fi technology, licensed radio technology (specifically small cells), mobile packet core and related systems. Steve has worked with service providers of all types and in all geographies. He has also been quoted extensively in industry press, written extensively on the wireless market, and spoken at a wide variety of wireless industry events. Prior to joining Ruckus in the spring of 2012, Steve served in a variety of product marketing positions at Juniper Networks and Cisco.

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Wi-Fi Alliance: LTE unlicensed and Wi-Fi

Managing the coexistence of multiple networks in unlicensed spectrum is something with which Wi-Fi Alliance has unmatched experience, gained through its certification programs. Certification ensures that multiple Wi-Fi devices meet standards requirements and behave nicely toward each other. Wi-Fi Alliance is eager to use this experience to ensure a successful coexistence of Wi-Fi and LTE in the 5 GHz band, through a consensus-based process that includes all the stakeholders – service providers, users and enterprises.

In parallel with the standardization efforts for LAA-LTE, Wi-Fi Alliance continues its work on the integration of Wi-Fi and cellular networks. Many programs have already been established to improve the performance of Wi-Fi in mobile devices and to facilitate its integration with cellular interfaces. The growing adoption of VoWi-Fi is the latest example of how Wi-Fi and cellular, each with its own strengths, complement each other to improve the end-user experience.

More work lies ahead at Wi-Fi Alliance to promote carrier Wi-Fi, which will require increasingly tight coordination of Wi-Fi and cellular to enable operators to flexibly allocate traffic between the two interfaces.

Wi-Fi Alliance recognizes that LTE in 5GHz requires the industry to collaborate to find a satisfactory solution for sharing the 5 GHz band. Currently Wi-Fi Alliance is tracking both the LTE-U and LAA-LTE closely, and actively trying to facilitate strong collaboration between the Wi-Fi and cellular ecosystems.

Certification and testing programs that facilitate Wi-Fi and cellular integration	
Passpoint™	Providing seamless authentication and government-grade security in public Wi-Fi networks, with users no longer required to repeatedly enter credentials. Based on Wi-Fi Alliance Hotspot 2.0 Technical Specification, Passpoint enables SIM and non-SIM mobile devices to discover, select and connect to Wi-Fi networks without user intervention. Passpoint devices "see behind" the SSID that designates the network identity, to make a network selection based on ownership, services and performance characteristics. The technology behind Passpoint is foundational to Wi-Fi roaming and has been specified by both Wireless Broadband Alliance and the GSMA Terminal Steering Group.
Wi-Fi CERTIFIED™ ac, Wi-Fi CERTIFIED™ n	Encouraging use of the 5 GHz band via high-performance Wi-Fi networking. With ac, Wi-Fi can reach Gbps throughput rates.
WPA2™ Personal and Enterprise, EAP	Supporting Wi-Fi wireless network security in both personal and enterprise environments.
WMM®	Providing support for multimedia traffic by enabling QoS to improve real-time traffic (e.g., voice and video streaming).
WMM Power Save	Extending battery life of mobile devices by managing the time the devices spend in sleep mode.
Voice Personal, Voice Enterprise	Testing the performance of Wi-Fi devices in a network loaded with both voice and data traffic streams, in multiple network configurations, to support good voice call quality over a Wi-Fi link, with VoWi-Fi technologies, including Wi-Fi Calling.
CWG-RF	Testing for Wi-Fi and cellular devices that provides detailed information about the Wi-Fi performance in the mobile device, and about the interaction between Wi-Fi and cellular. Although this test program – developed with CTIA – is not an element of Wi-Fi certification, completion of the testing is mandatory for Wi-Fi handsets seeking CTIA certification.

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Learning from Wi-Fi, working toward coexistence with LTE in unlicensed 5GHz

A conversation with Edgar Figueroa, President and CEO, Wi-Fi Alliance

Monica Paolini: Good afternoon and welcome to our conversation today. This is part of a Senza Fili report, in collaboration with RCR Wireless News, on LTE unlicensed and its coexistence with Wi-Fi. Today I am talking to Edgar Figueroa, the CEO and president of the Wi-Fi Alliance.

Edgar, thanks for taking the time to talk with us.

Edgar Figueroa: Thanks for having me, Monica. It is nice to be here.

Monica: Wi-Fi has been using the 5 GHz band that LTE unlicensed is planning to use for a long time. In the 5 GHz band, Wi-Fi is the incumbent. At the same time, there are many other technologies that use the 5 GHz band and the 2.4 GHz unlicensed band.

In a way, it's nothing new but there is a lot of discussion going on with LTE unlicensed.

Edgar: We shouldn't be surprised that there is interest in doing more with 5 GHz, because Wi-Fi has been so successful there. Last year we shipped over a billion devices that operate in 5 GHz. We've been absolutely successful with that. Wi-Fi CERTIFIED ac is the first version of Wi-Fi that delivers gigabit per second speed.

We have been tremendously successful operating in unlicensed. I would say we are the model of success in unlicensed. The conversation is shifting quickly toward how to ensure that whatever happens in 5 GHz does not unduly impair the current tenants in that band.

Monica: This is a major issue because the 5 GHz band is unlicensed, so everybody can use it. How can all the different tenants with the different technologies in that band coexist nicely?

Edgar: At a very high level, coexistence will require extreme collaboration. Wi-Fi Alliance stands ready to collaborate on this front. We have a history of being able to collaborate successfully, particularly with operators. You probably know that one of our early programs, which ushered in the era of equipment that has both Wi-Fi and cellular, came about through collaboration between Wi-Fi Alliance and CTIA. Together we made sure devices that have Wi-Fi and cellular can operate radios concurrently without one unduly impacting the other. That has been terrifically successful. We can do that again in this area. That is our hope.

Monica: This is really an important precedent, because it made technologies collaborate. With mobile devices, each device works with multiple technologies and networks. Integration across technologies becomes important because you can't really mandate something on a unilateral basis. How do you see the willingness in the industry to collaborate on technology coexistence?

Edgar: Collaboration is hard work, there is absolutely no doubt. We know a lot about collaboration. And even within Wi-Fi, the solutions we have brought about have required a lot of collaboration.

I would say that the complexity in unlicensed LTE is one order of magnitude bigger than what we've ever had up to now in dealing with licensed LTE. A good solution will require collaboration, etiquette across different spectrum domains, across different technologies, across licensed and unlicensed bands, and across equipment that supports primarily one technology or another.

It will definitely require a lot of collaboration. That is something that we are eager to get involved with.

Monica: Nice coexistence among networks started within Wi-Fi because you often have multiple networks sharing the same band. These networks have to be nice to each other. How is Wi-Fi nice to itself?

Edgar: I would say probably the testaments to our success with Wi-Fi etiquette protocols, the good-neighbor protocols that we have in all versions of Wi-Fi, are that the density of the networks has continued to increase, the speed of the data transfer has continued to increase, and Wi-Fi

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networks continue to work well with other Wi-Fi networks.

There are a number of parameters that need to be considered in assessing how well a technology shares the medium. Probably the ultimate testament is, as I said, that the technology continues to advance, gain popularity, and increase in density. Wi-Fi has been able to do that. We have mechanisms in the protocol that address this.

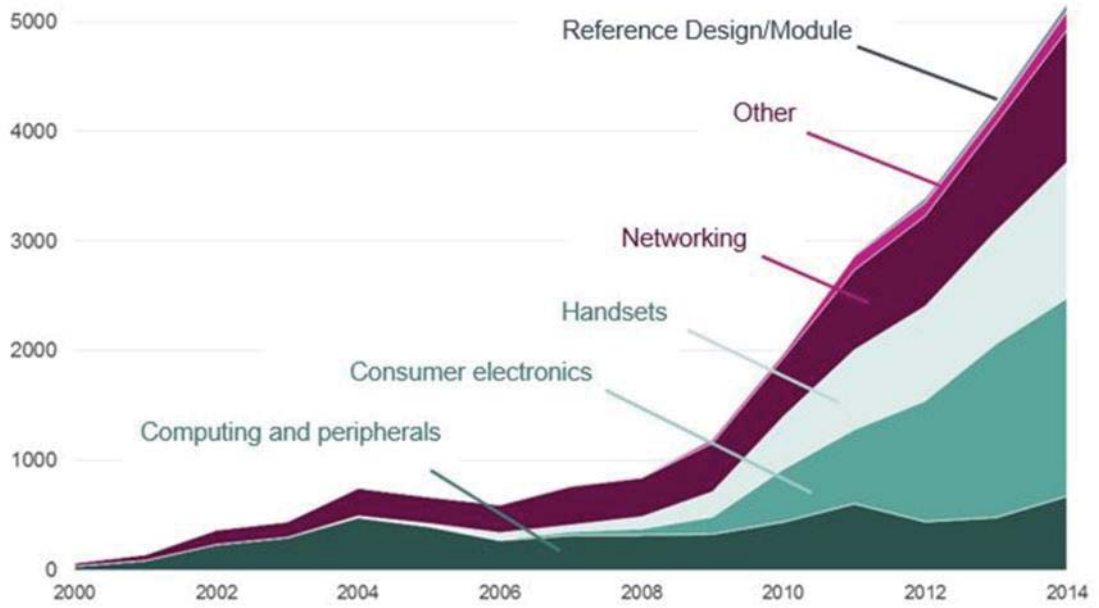
With unlicensed LTE, the challenge is going to be to make sure the medium is shared so that all tenants in unlicensed operate in a way that doesn't unduly impair the operation of other tenants.

Monica: What is the status of LTE unlicensed right now? There's a lot of work in terms of standardization, and a lot of discussion.

Edgar: We are far from a solution for sharing the band that is broadly accepted as addressing the issues of coexistence and fair sharing. It is still very early. The standardization work has just started. Only a handful of solutions have been demonstrated, and no commercial solutions exist that we can go pull off the shelf today and test.

A solution that is harmonized, that is broadly understood, and that is recognized for having all these proper etiquette techniques within it requires peer evaluations. It requires implementation across different bands. It requires collaboration across industry segments.

Wi-Fi Certified products by device type



Source: Wi-Fi Alliance

A lot of that is nascent. We are just starting with all of this. The good news is that it could be a seminal moment for unlicensed in general. It might require a very close working collaboration across the different segments to make sure we continue to evolve on this terrific path of innovation that we've been on.

Monica: In addition to the standardization work, there's also regulation to take into account. Unlicensed bands are regulated in a very different way in different countries.

Do you think we need stronger regulation to enforce nice behaviors of different technologies?

Edgar: Our philosophy that less regulation is better has served us well up to now. That, of course, is a philosophy that can only be upheld if there is proper self-policing, if we are all operating from the principle of sharing the spectrum in the best possible way – in a way that is respectful toward other tenants in unlicensed.

When you have lighter regulation, you leave the door open for even more innovation. Our hope is that we can continue to cooperate with those basic principles set in place. These are principles that have allowed unlicensed to continue to be the model of innovation in the last 15 years or so.

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I hope that, in working with the stakeholders in unlicensed LTE we can continue on that path, and that we will not need heavy-handed regulation, and certainly no more regulation than we currently have.

Now, there is also the possibility that we will not be able to continue to operate in that mode. So long as devices and solutions are operating within current regulations, then they're operating legally, but they may do so in ways that impair current users.

I'll give you a very quick example. Within Wi-Fi Alliance, we have policies just for Wi-Fi operation with other Wi-Fi gear, to ensure that devices do not operate in a way that impairs other Wi-Fi gear. When that doesn't happen, we recognize that it hurts everybody. We operate in a very open and transparent way based on self-policing. We have policies like that in place to ensure no undue interference.

With unlicensed LTE we need to take that to the next level and ensure that these self-policing rules are taken into account in this new era of, potentially, many different technologies operating in licensed and unlicensed.

Monica: You have a good model to ensure the implementation of self-policing rules in your certification program. You can test the ability of Wi-Fi gear to coexist. When it comes to LTE unlicensed, however, there is no obvious way to do that yet.

The standards are excellent in providing a framework. But within a standard, multiple things are allowed; different vendors interpret standards differently. At some point, somebody needs to make sure that the implementation of the standard follows the specs. It could be the operators, it could be vendors, it could be an association similar to the Wi-Fi Alliance.

Edgar: Ideally there could be some third-party validation ensuring that the gear is properly configured or developed, not only within the standards and within the regulations, but beyond that. We need a higher bar in unlicensed.

That higher bar is to ensure proper coexistence, so that the medium is not impaired and end users are not unduly harmed. My hope is that that will eventually be put in place.

The good news is we are ready to participate in that if there is interest in Wi-Fi Alliance participating. If it is needed, we will take on the work. Beyond that, there are enough of our members interested in this. We already have a task group that is focused on looking at coexistence. We will have to monitor this space.

Monica: You brought up the issue of the users. Oftentimes in our discussions about LTE unlicensed, we focus on the mobile operators. But actually the enterprises and residential consumers are the major users of Wi-Fi.

What is the best way to protect their access to the band? How do we maximize it for everybody involved – not just the Wi-Fi users, not just the LTE users, but everybody out there?

Edgar: You're absolutely right that you have to start with a focus on the end user. And you have to start with a focus on getting it right, instead of getting it right now.

This is terrifically important in order to come out with the best possible solution that continues not only to honor that legacy of making sure that we are getting the most value out of unlicensed.

It requires an awful lot of collaboration and discussion among the different stakeholders.

The key thing here is that now the interest in 5 GHz is expanding beyond just Wi-Fi and other tenants of the 5 GHz spectrum that we have had up to now. The stakeholders now include new use cases with an operator focus and new bands.

Monica: Right now, often the 5 GHz band is not used heavily, so it is possible to split up the channels across technologies. Each technology could take a different channel, and that's fine. That's a very simple solution.

But when you have to share a channel, how do you go about it? Because you can allocate more or less capacity to different technologies depending on the usage. What do you think is a fair framework to do that?

Edgar: A framework is fair when it is not self-centered. When it takes into account all the different energy that is being emitted by all the

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folks using that spectrum at that time. There is a lot of discussion that needs to happen about how we take into account the different sharing mechanisms that are going to be employed by different industries.

It is not necessarily the case that one size is going to fit all here, but what we need are solutions that take into account everyone else. In the case of Wi-Fi, it has been mechanisms like listen before talk, and algorithmic back-off that have been used and proven effective.

That may need to evolve, but certainly Wi-Fi would need to be taken into account when new solutions come into the 5 GHz and other unlicensed spectrum domains, because Wi-Fi has been very successful. You can be sure the solutions with Wi-Fi using 5 GHz today will be there for a very long time. It is something that you do not do in a vacuum, I suppose is the short answer.

Monica: We've been talking about LTE unlicensed, but Wi-Fi is also evolving in a direction that will make it easier for Wi-Fi to be integrated with the mobile cellular networks and help mobile operators to leverage unlicensed spectrum.

Can you tell us what plans Wi-Fi Alliance has for the future in this area? What should we expect in terms of commitment to get Wi-Fi to work more extensively with the cellular?

Edgar: This is very much aligned with our commitment to continue to make Wi-Fi better for all stakeholders. But, certainly, operators have been making their interest known within Wi-Fi Alliance.

We are working on things such as multiband operations to ensure that there is a similar way to go from one spectrum band to the other – for instance, between the 2.4 GHz and 5 GHz bands — and to make that seamless to the end user and easy to manage for the operator.

We are working to continue to improve power efficiency and manage the network layer by improving Passpoint, with its third generation being developed right now.

Most of the solutions that we are working on should be of keen interest to operators. The reality is that Wi-Fi has become integral to operators in their own services.

It should not be surprising that we are working hard to continue to make Wi-Fi better for operators, as we are continuing to make it better for a number of the other vertical segments that we serve.

Monica: And VoWi-Fi has become a hot topic that comes up the most when we talk about LTE unlicensed. It's also another direction in which Wi-Fi becomes closer to LTE.

Edgar: It is the topic du jour, but the reality is that Wi-Fi Alliance worked on enabling voice within Wi-Fi many years ago. Again, it is a testament to the efficacy of Wi-Fi, the reliability of Wi-Fi, the confidence that operators have in Wi-Fi and in the core services with Wi-Fi. It is here today. It is a terrific testament now.

We are evolving toward a world where, as a part of the operator HetNets, Wi-Fi would just fit in the background. Users will just be connected the best possible way, whether it is on cellular or unlicensed network.

I am encouraged by this progression toward bringing that about, because users want the best experience. We are working to try to make that come about.

Monica: In closing, can you tell me what you expect over the next several years in terms of the coexistence of Wi-Fi and LTE unlicensed?

Edgar: The biggest thing we need to do is to work very closely together to make sure we come out with the best solutions in 5 GHz – solutions that do not impair either the experiences that folks might have with any 5 GHz solution today, but also that set us on the path toward a positive future for unlicensed well into the future.

This is a pivotal moment. It requires different industries that have operated very independently to get intensely close to each other and to work very well together, because our interests are joined. To the extent that we can evolve toward successful solutions in sharing 5 GHz we will have a bright future together.

Watch the video of this interview.

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About Wi-Fi Alliance

Wi-Fi Alliance® is a global non-profit industry association – our members are the worldwide network of companies that brings you Wi-Fi®. The members of our collaboration forum come from across the Wi-Fi ecosystem and share a common vision of connecting everyone and everything, everywhere. Since 2000, the Wi-Fi CERTIFIED™ seal of approval designates products with proven interoperability, industry-standard security protections, and the latest technology. Wi-Fi Alliance has certified more than 25,000 products, delivering the best user experience and encouraging the expanded use of Wi-Fi products and services in new and established markets. Today, billions of Wi-Fi products carry a significant portion of the world's data traffic in an ever-expanding variety of applications.

About Edgar Figueroa

As president and CEO of Wi-Fi Alliance, Edgar has led an unprecedented period of growth for Wi-Fi®, with more than two and a half billion devices shipped in 2014 alone. Under Edgar's leadership, Wi-Fi Alliance has grown to more than 600 member companies, maintained an aggressive development roadmap, and adopted a vision of "Connecting everyone and everything, everywhere." Edgar forged numerous strategic partnerships to facilitate penetration of Wi-Fi into established and emerging markets. Edgar also defined the Wi-Fi Alliance Wi-Fi CERTIFIED™ program development framework, and guided the launch of several generations of interoperable Wi-Fi programs that have proliferated Wi-Fi into mass markets such as mobile and consumer electronics.

XCellAir: LTE unlicensed and Wi-Fi

XCellAir, a spinoff from InterDigital announced in February 2015, provides a shared solution with which operators can manage large-scale LTE and Wi-Fi networks within a HetNet framework.

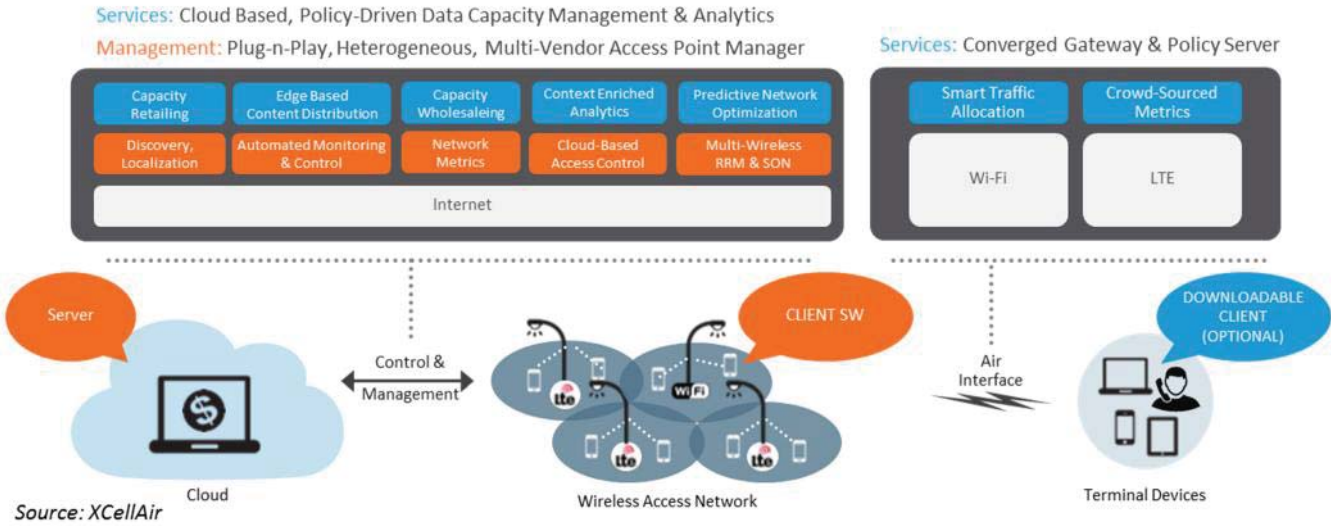
To address the surge in data traffic, mobile operators have to move beyond the limited small-cell deployments that dominate in their networks today, to large-scale densification deployments that will involve multiple access technologies (Wi-Fi and LTE), multiple bands (licensed and unlicensed), and multiple vendors. A denser and more complex network infrastructure will increase operators' need for scalability, reliability and resiliency. At the core of the XCellAir solution is SON functionality to address the requirements of operators managing – or preparing to manage – these multi-access, multivendor networks.

XCellAir aims to go beyond coexistence of network elements, and to maximize resource utilization and revenue generation. XCellAir's is a shared platform that takes into account real-time RAN performance data, policy, and application and traffic information.

The unified management system includes

- Radio resource management (RRM)
- SON

XCellAir's solution integrating LTE and Wi-Fi management



Source: XCellAir

- Capacity optimization
- Analytics

Deploying and managing a network with multiple access technologies makes it possible for an operator to benefit from the specific strengths of each technology – e.g., using higher frequencies for indoor coverage and lower, licensed frequencies for outdoor hot spots and wide area coverage. In turn, the improved network utilization can reduce per-bit costs and improve coverage.

In line with the trend toward virtualization, XCellAir takes a cloud-based approach designed to provide the flexibility and scalability that operators require as they build out and expand dense, large-scale HetNets. The cloud-based architecture supports SaaS business models geared toward a shift from a capex-intensive business model to a cost model more tightly linked to the pace of network growth.

The integrated LTE and Wi-Fi network management solution leverages development work previously done at InterDigital and contributions from two ecosystem partners:

- GoNet, for the management of in outdoor and indoor deployments, with high-performance Wi-Fi access points with MIMO and beamforming
- AirHop, for SON functionality supporting LTE-A features in LTE-TDD and LTE-FDD networks

In this context, LTE unlicensed is treated as another air channel. Mobile operators can use traffic steering and load balancing to decide how to allocate traffic across technologies, depending on network loading, user preferences, subscription plans, location, time of day, and RAN conditions.

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A shared solution to manage Wi-Fi and LTE unlicensed traffic

A conversation with Narayan Menon, CTO and EVP of Engineering, XCellAir

Monica Paolini: Welcome to our conversation with Narayan Menon. He is the CTO and EVP of Engineering at XCellAir, and one of the company's founders. Today's conversation is part of our report on LTE unlicensed.

Narayan, thanks a lot for taking the time to talk to us today.

Narayan Menon: It's my pleasure to talk to you about these topics.

Monica: XCellAir is a new company that just came out of stealth mode. Can you tell us what is it you do at XCellAir?

Narayan: At XCellAir, we are developing network management and optimization solutions for HetNets, and particularly for LTE small cells and Wi-Fi networks. The company was formally launched a few weeks ago. It's a spin-out of InterDigital and folks who were at InterDigital in its early years, like I and the rest of the team were. The technology was initially incubated and developed starting in late 2013 in InterDigital.

A few weeks back, the team and the technology were transitioned over to XCellAir, which was launched just before the Mobile World Congress in Barcelona. Our solution includes both management and optimization of mobile traffic. We cover things like provisioning, configuration management, fault management, and optimization techniques like SON, applied to both Wi-Fi and cellular.

We also deal with optimization aspects – like traffic management, capacity management, and traffic steering – that apply to both Wi-Fi and cellular. It's a cloud-based, scalable, multivendor, multi-technology solution.

Monica: This is a brand new solution, but you have a lot of experience and substantial work already done. You start off in a very good position. It's really a very hot topic right now because all operators are working with both Wi-Fi and cellular. Obviously they face a big challenge in how to combine the two.

To date, mobile operators have used a basic offload type of environment in which, whenever there is Wi-Fi, you use it. There is not much coordinating and integrating of the two sources of traffic.

With LTE unlicensed, there will be an additional layer of complexity, integration, and opportunity at the same time. How will LTE unlicensed fit in with both Wi-Fi, on one end, and licensed LTE on the other end?

Narayan: LTE unlicensed, the way we see it, is going to be a nice complement to LTE the way it is today. It will help augment the capacity and bandwidth available to LTE systems by being able to take channels in the unlicensed band and aggregate them with channels in the licensed band. It serves as a bandwidth boost for the LTE solutions.

Most of the scenarios you're talking about involve both the macro cells and small cells, and aim to give this bandwidth boost. They also segregate traffic intelligently between licensed or unlicensed spectrum, based on quality-of-service requirements.

Wi-Fi is a very key aspect to consider, because when LTE operates in these bands, in the 5 GHz band, it will need to coexist with Wi-Fi, as well as with other LTE systems that are operating in the same band, following the channel access etiquette. This etiquette and the rules that apply within the band become very important. It is crucial that one network doesn't trample on the others. The LTE system should not trample on or interfere with the Wi-Fi solutions.

The coexistence of the two systems, Wi-Fi and LTE unlicensed, will become very, very critical. That's the way they would relate to each other. One would not necessarily displace the other. Wi-Fi will have its own place and continue to have its place in the sun. What this enables is for the LTE

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solutions to expand and reach out on the unlicensed spectrum and gain more bandwidth.

Monica: There are going to be locations where there is only Wi-Fi or only LTE unlicensed. That's relatively easy to manage. The challenge for the operator is to operate in locations with a combination of Wi-Fi, LTE unlicensed, and LTE. How can you help an operator steer different types of traffic to the different interfaces?

Narayan: A very interesting, very relevant question. There are multiple ways to do traffic steering, or traffic segregation as we call it.

It could be done based upon policy – policy as it relates to the user's SLA, as it relates to the user's quality-of-service requirements, as it relates to the type of application. The policy could end up placing some applications on one system and other applications on the other system.

For example, the operator might prefer to keep applications that require a high level of quality of service and reliability on the licensed band – whereas best-effort traffic, for example, might be placed on the unlicensed band. Or it could be the other way around, depending on the scenario.

The operator could also leverage this to provide wholesaling capabilities to in-house customers and third parties. The bandwidth that is wholesaled to the third party might come out of the unlicensed band, or it could be the other way around. The operator may prefer to place that on the licensed band. LTE-U gives the operator the flexibility to choose.

Network conditions are another angle. As conditions change, the system has to be adroit enough, nimble enough, to be able to move things around. If a particular application is on the unlicensed band and things start to get flaky because there's too much contention there, the system might move that piece of traffic back to the licensed band.

Those kinds of mechanisms – based on awareness of the network conditions, based on awareness of latency, throughput, packet loss rates, etc. – have to come into play to make this work really well.

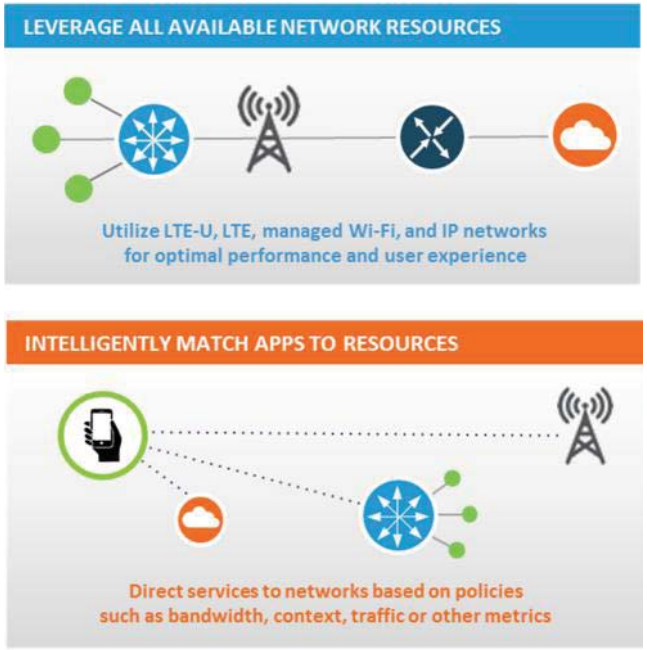
Monica: This level of complexity is difficult to manage. But if you manage it correctly, it brings a lot of value to the operator because it can use the resources more efficiently. You're combining the real-time network information from the RAN with policy.

Narayan: A third element that comes into play is user preferences. On top of all of these requirements, the user might have certain preferences – for example, not to use the unlicensed band at all, or in certain scenarios or locations.

Monica: Voice is a special case. How can an operator manage voice where you have three different interfaces?

Narayan: Voice will be treated as one of the applications. It's obviously a key application. Especially as we move more and more to VoIP and away from the circuit switch world, network quality, link quality and quality of service become

XCellAir's optimization of network resources



Source: XCellAir

more and more important. In the case of voice, the default preference is to keep that on the licensed side. If you're using VoIP, there's no reason why you couldn't be on either side.

This would be subject to the actual network conditions. If the voice call is on the unlicensed band and the conditions start to get bad, the operator needs to be able to hand the voice call back over to the licensed band. That capability becomes very important. In a sense, VoIP, video and other applications could be associated to a per-user policy.

There would be a per-user, per-application policy that really depends on what the user has signed up

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for and paid for. Based on that policy, the application might be placed in one place or the other. Then if network conditions change, the application can be moved back and forth. If the user has some preferences applied on top of that, those preferences would need to be respected as well.

Monica: The same flexibility can be used when an operator has to manage IoT applications, for which you have different types of devices and different requirements.

Narayan: Absolutely. IoT is such a diverse world. There are tons and tons of applications in the IoT space. Some of them, such as health care applications, will require higher reliability.

You may want to keep those on the band you consider to be more secure, more safe – perhaps on the licensed side. Some applications within the IoT space that may be best effort or may be possible to do after hours have more flexibility in terms of placing them on the unlicensed side.

Monica: Mobile operators today use unlicensed spectrum through Wi-Fi offload, but they don't really manage it. With LTE unlicensed, they face a new challenge because they have to manage traffic both in licensed and unlicensed bands, using the same air interface.

Narayan: The management of mobile traffic with respect to LTE-U has to happen at two levels. At one level, there have to be mechanisms in place to make sure that the LTE system, when it operates on the unlicensed band, is following the rules and etiquette that apply on that channel and on that spectrum, to ensure that it doesn't cause any kind of damage to Wi-Fi services.

LTE-U should not impact Wi-Fi any more than another Wi-Fi system on the same branch of the system. That's where listen before talk and similar mechanisms come into play. And on top of that is the traffic steering, traffic management capability we talked about: being able to place traffic intelligently on one or the other band, based on these factors that we outlined previously.

There's a challenge in terms of how effectively that gets done, but it's also a huge opportunity for operators.

It is two levels. One is fundamentally making sure that the mobile traffic is not impacting or impeding other types of traffic in the unlicensed band. The second aspect is once you've conquered that, you try to make best use of that bandwidth with the right things in the right place.

Monica: Let's go back a little bit. Wi-Fi is widely available. Every handset has Wi-Fi. Why does an operator need LTE unlicensed? What is he going to gain from it that Wi-Fi cannot deliver?

Narayan: That's a great question as well. Wi-Fi is there today. As you mentioned earlier, it exists in a somewhat disparate fashion. Today, when you go home, the iPhone switches to Wi-Fi no matter what. There's no real control. Like you said, Monica, there's no real management, there's no control of that. There's no ability to put certain types of traffic on Wi-Fi, some types of traffic on cellular. Those elements are missing now.

Cellular standards have tried to foster more integration of Wi-Fi networks into the cellular core. They haven't yet come into play on a large scale in the cellular network.

LTE-U provides another, and in some ways more interesting, more tightly coupled way to combine transmission in the two types of bands, without forcing the integration of Wi-Fi with LTE.

You're not trying to integrate your Wi-Fi solution with LTE. LTE-U is another way of tapping into, or leveraging, the unlicensed band without necessarily trying to couple Wi-Fi with cellular or integrate Wi-Fi with cellular in a very tight fashion. That's the opportunity here – to be able to use LTE-U to provide bandwidth aggregation and bandwidth segregation.

It could be used either to segregate traffic, like we discussed before, or to aggregate bandwidth, or to provide more bandwidth to an application when it needs it. When a single application needs more bandwidth, you reach out on the unlicensed band, grab a couple of channels, aggregate them, and you get this boost.

This ties in nicely with the LTE architecture. Some of these mechanisms, such as listen before talk and radio resource management schemes, will get built into the LTE architecture. It becomes a much more holistic solution that happens to be on the unlicensed band.

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Monica: For an operator, LTE unlicensed is a way to leverage unlicensed spectrum in a more efficient way, and that's good.

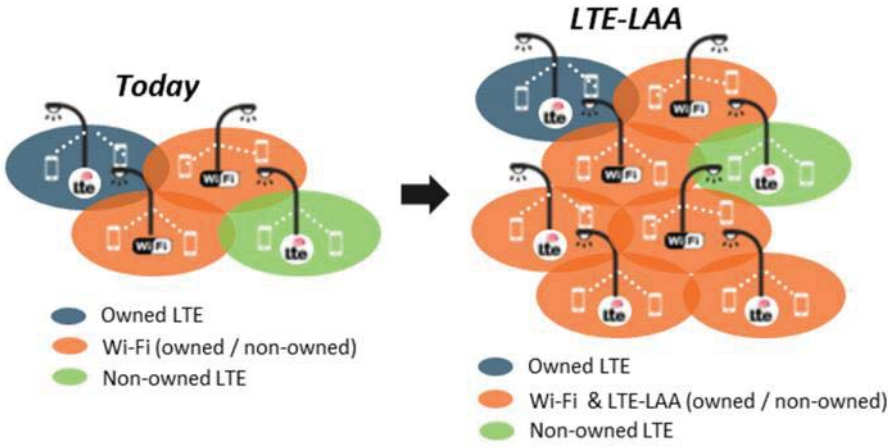
But what about Wi-Fi? Is LTE unlicensed going to be nice enough to the existing Wi-Fi infrastructure there? Should we worry about it? There are a lot of worries that it's going to create a lot of disruption in Wi-Fi networks. Do you think that challenge is being addressed right now?

Narayan: That challenge is being addressed quite adequately, in my opinion. There was a study item that 3GPP started a while back to study LTE-U and the impact on Wi-Fi, to come up with requirements and recommendations for what needs to be done to ensure that the LTE systems don't disrupt the Wi-Fi systems in place. The end of that study item resulted in a technical report which outlines several recommendations.

One of those recommendations, one of the key ones, is listen before talk (LBT). That's essentially making the LTE system do a channel check to see if there's any activity on the channel, via energy sensing or energy detection on the channel, before trying to access and use that channel. It's essentially making LTE behave almost like Wi-Fi. That's what Wi-Fi does with the collision detection in that band.

There are other things as well. They recommended the use of dynamic frequency selection (DFS) to prevent interference with radar and other systems that operate on the 5 GHz band in some countries.

XCellAir's solution to manage LAA-LTE interference



BS ID	Type	Owned	Channel	SS
SSID: XCellAir	W-Fi	N	3	-60dbm
Operator A	LTE-U	Y	7	-80dbm
Operator A	LTE-U	Y	7	-80dbm
SSID: Guest	Wi-Fi	N	6	-102dbm
SSID: Free-Wi-Fi	Wi-Fi	N	7	-60dbm
Operator A	LTE-U	Y	7	-80dbm
Operator B	LTE-U	N	8	-72dbm
SSID: Carrier Wi-Fi A	Wi-Fi	Y	5	-80dbm
SSID: Carrier Wi-Fi B	Wi-Fi	N	3	-102dbm
Operator C	LTE-U	N	11	-80dbm
SSID: Carrier Wi-Fi A	Wi-Fi	Y	10	-60dbm

Source: XCellAir

One other recommendation is to use discontinuous transmission to ensure that you don't hog the channel and increase the probability of collision due to an existing Wi-Fi system trying to access the channel. In 3GPP, we've discussed things like radio resource management schemes that will come into play.

For Wi-Fi and LTE systems to coexist, we believe that some of the SON schemes will have to evolve to incorporate awareness of other systems. Today's SON solutions are LTE-specific. Or in some cases, there's limited SON functionality in some Wi-Fi systems. One technology is not cognizant of the other.

We believe SON has to evolve significantly to create this multi cross-technology awareness. That's an area we can have at XCellAir. Our solutions address the whole network management

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with multi-technology access designed into our solution from the beginning. Extending our SON's schemes to provide this kind of multi-technology coordination in the unlicensed band would not be difficult at all for us to do.

Monica: What's special about what you do at XCellAir, in terms of how you help operators deal with this challenge?

Narayan: A big part of our solution is network management and optimization. We provide the ability to configure, provision and fault-manage small cells and Wi-Fi access points. Also, we combine that with optimization and SON capabilities, such as optimal channel allocation and interference mitigation schemes.

The nice thing is that these are all tied into one solution. Traditionally, network management and SON tended to be uncoordinated. We combine these into one end-to-end solution. To that, we are adding other capabilities, like traffic management, traffic steering, and bandwidth management, into one holistic solution.

We help the operator accelerate the rollout of small-cell networks. Today, one of the impediments for small-cell network adoption is the lack of plug-and-play automated procedures to bring up small cells quickly. If you want to bring these up in large numbers, you need much-more-automated procedures than what the macro-cell network procedures support today.

With our solution, we help operators to manage millions of units in a hands-free, zero-touch fashion. We enable the operator to get the small cells up and running fast, and to be able to manage them easily and scale the network easily. Then, we enable the operator to extract value out of the network by adding other aspects, such as capacity band and the bandwidth optimization.

One aspect is acceleration of deployment. Other ones are ease of management, and value extraction from the access technology the operator deploys.

There are three key attributes that make our solution unique.

One is that it is access technology independent. From the outset, we have designed it to be unified across LTE and Wi-Fi – and LTE-U can be easily added to that. We have developed the system with reusable components that enable us to go from Wi-Fi to LTE very quickly.

This enables us to support the two systems with a unified visual interface, a common set of algorithmic tools, a common set of database components, etc. This is unique, because a lot of systems start with one technology and then try to move to the other. They're breaking concrete to do that.

The second key aspect is our multivendor approach. One of the issues that operators will have with large-scale small-cell deployments is that they will inherently end up going multivendor. Today, each vendor solution comes with its own native management capability, its own EMS. What we provide here is a multivendor solution that easily works across multiple vendors' access points.

The way we do it is that the vendor specificities are isolated or confined to a small part of our system. Large parts of our system that deal, for instance, with the algorithms, the databases and the virtualized tools do not get impacted when we move from one technology to the other. This enables us to adapt to each vendor's specifications very quickly and flexibly.

The third piece is the scalability. Our solution is virtualized today in the cloud. It makes the network bandwidth solution very scalable for the operator. As opposed to buying big controller boxes upfront, the operator can scale the solution very granularly as the network grows and as it adds more access points. Resources on the cloud side – such as processing, memory and storage – can be scaled very gradually, very granularly. Operators are able to scale as they grow. They pay for those resources as they scale. That gives them a lot of flexibility.

Monica: In closing, can you tell us what we should expect next from XCellAir? This is all new ground. What's coming next?

Narayan: On one hand, we are working very promisingly towards taking our technology to market. We are dialoguing with operators, we are dialoguing with vendors to integrate our solution with different vendors' access points. In our near-term roadmap, our goal is to get the ecosystem dialogs going, get the IoTs, get to the lab trials,

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pretrials in the next few months, and get this to market very quickly.

In the longer term, we will focus on the capacity and bandwidth management capabilities and on analytics. We collect, store and analyze a lot of information from the access points within our system – attributes, metrics that relate to network performance, subscriber data that we get from the access points. All of that data can be analyzed and made available to the carrier or service provider, via either well-defined APIs or analytics capabilities that we will provide in the future.

Of course, support of LTE-U is on our roadmap, as well as supporting community Wi-Fi networks and enabling coordinated management of community Wi-Fi networks.

Watch the video of this interview.

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About XCellAir

XCellAir enables wireless service providers to efficiently manage, optimize and monetize their wireless access networks. Heterogenous Networks (HetNets) consisting of Wi-Fi and/or cellular small cells can deliver massive increases in capacity, extended coverage and a lower cost-per-bit for wireless service providers, but – to date – their potential remains largely unrealized. This untapped potential is why XCellAir exists. XCellAir provides the industry's first cloud-based, multi-vendor, multi-technology mobile network management and optimization solution.

About Narayan Menon

At XCellAir, Narayan develops and evangelizes the technology strategy and roadmap, and leads product development. Prior to XCellAir, Narayan drove research and development for InterDigital, leading elite teams to innovate and implement next-generation wireless solutions – including the inception and early development of the XCellAir product. Narayan has over 25 years of experience in the wireless field, holding leadership roles at Siemens Mobile Networks, Omnipoint Technologies and Hughes Network Systems in the development of TDMA, GSM/GPRS and 3G systems. Narayan holds Engineering degrees from the Indian Institute of Technology, New Delhi and an Executive MBA from Hofstra University.

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III. Operator interviews

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Ooredoo: Spectrum efficiency and business case with Wi-Fi and LTE unlicensed

A conversation with Ziemowit Neyman, RAN Assistant Director, and Seppo Hämäläinen, RAN and SON Tools Assistant Director, Ooredoo

Monica Paolini: Good afternoon. Welcome to our conversation on LTE unlicensed and its coexistence with Wi-Fi, with Ooredoo Group in Qatar. I have here with me Ziemowit Neyman, who's the assistant director in RAN, and Seppo Hämäläinen, assistant director in RAN and SON tools.

Good afternoon, Ziemowit and Seppo.

Ziemowit: Good afternoon.

Monica: First, can you tell me what you do at Ooredoo?

Ziemowit: I'm involved in the discovery and promotion of new technologies waiting out there for the RAN. This year, two of the topics we are focusing on is the investigation of VoLTE and Wi-Fi Calling.

I'm also involved in the selection, evaluation, specification of antennas and near base station antenna devices.

Seppo: And I am focusing on planning and performance tools for planning, geolocation, and self-organizing networks. In addition to that, I'm also looking at spectrum matters, and as part of that, Ooredoo Group am looking at LTE unlicensed – collecting information and knowledge about LTE-U, so that we can create a position and a strategy for its introduction if we think it is the right way to go.

Monica: Let's start with Wi-Fi. How do you use Wi-Fi in your networks today, and what are the short-term plans for Wi-Fi?

Ziemowit: At the moment our strategy to support Wi-Fi is actually limited, because we haven't seen good solutions to control the flow of the traffic between Wi-Fi and RAN. From this perspective, we haven't seen good use cases for Wi-Fi – although Wi-Fi does provide a lot of spectrum, and this can be a way of addressing future data growth in the networks.

We need to find out a new way of integrating Wi-Fi. We think that with Wi-Fi Calling, the new application being recently deployed in terminals, has a lot of potential.

Basically, every Wi-Fi AP now becomes the operator's base station. Operators can extend their coverage beyond places they covered before. If you imagine, you spend 80% of your life indoors and you have a Wi-Fi AP around you, then you now have potentially additional coverage.

This, together with macro cell layer coverage, gives mobile networks a way to provide a seamless service to customers anywhere they are.

Monica: What does LTE unlicensed add to this? If Wi-Fi is becoming a better tool to use in unlicensed bands, what is the further advantage that LTE unlicensed will bring you?

Seppo: I wouldn't see them as competing. They are used in different ways, or different areas. I would see that Wi-Fi, including Wi-Fi Calling, will be used at homes, and maybe in offices and corporate venues.

Then the LTE unlicensed would provide additional spectrum in public hotspots, perhaps also in some corporate venues. I see that there is a different demand, or different use cases, for Wi-Fi and LTE unlicensed.

Monica: In terms of the use cases, it's going to be mostly indoors, in the enterprise or public venues. Do you see other use cases?

Seppo: The main use cases for LTE unlicensed are hotspots, mainly indoors and corporate venues, and possibly also outdoors. Anyway, it will be in a small-cell environment.

Ziemowit: Access to the Wi-Fi spectrum is available for free. So everyone can use it. In turn,

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this causes another problem – there is a year-by-year rise in the background noise in Wi-Fi spectrum, due to increased traffic.

If you can control your RF environment in an indoor location, then, definitely, any Wi-Fi or LTE-U usage is possible and can deliver offload. A problem however may arise in open hotspots, where you have many different Wi-Fi access points that may cause interference to an operator's Wi-Fi or LTE-U AP. So I see the application of any Wi-Fi or LTE-U limited to specific scenarios.

From this perspective, any corporate venue or any home office is suitable to support traffic within of Wi-Fi spectrum where the number of different operator's APs is limited. On the contrary in a public space, there is need for dedicated spectrum to provide dedicated service. You always can compete for the Wi-Fi spectrum, but you might see limitations, as the traffic is increasing leading to higher soft-congestion due to higher background noise.

We have also heard from other mobile operators, for example in Japan, that Wi-Fi traffic in public places increases background noise yearly by 10 dB. By the time LTE-U is commercially available, in some areas it could be that there may not be spectrum left for LTE-U applications in the 5 GHz spectrum, because it will be simply jammed by existing Wi-Fi APs.

Monica: Obviously the spectrum limitations apply to both Wi-Fi and LTE-U. In a situation where there is too much traffic, at some point you run out of capacity. Which brings the question of how the two technologies can coexist. If there is space for both, not a problem; but if there is contention, how do you deal with that?

Are you happy with what you are seeing from a standardization point of view, in terms of the two technologies being able to coexist, not just in the same band, but also in the same channel?

Seppo: Yes. What standardization is working on just now is mechanisms for listen before talk. You can use LTE-U if there are free channels. The key is that LTE unlicensed should not harm Wi-Fi users. This is the way it should go.

LTE unlicensed could be used wherever there is still spectrum available, or where the spectrum is not fully congested. Again, LTE-U and Wi-Fi should not be seen as competing, but rather as complementary technologies.

Monica: There is a lot of talk about using listen before talk and other mechanisms to make sure that if you have the two technologies side by side, they can be nice to each other. Do you think that that's possible? Or will the Wi-Fi users feel impacted by LTE unlicensed?

Ziemowit: This is possible, because any newer technology needs to coexist with the predecessor. You always fix a system specification and agree on a testing process to verify if it is working. If proved, then the deployment may proceed.

It's not only relevant to LTE-U working in the 5 GHz band. It also applies to the networks deployed in the lower frequencies in the co-existence with legacy systems as well, or in spectrum which is not widely used in a specific area. This is the typical way to utilize this spectrum in which legacy systems are still in place.

But let me also mention another point, which is quite important, although not taken much into account yet. Any Wi-Fi access point operating in the same spectrum band as LTE-U is actually in the price range of hundreds of dollars, while any LTE-U small cell, working in the same spectrum, are expected to be in the price range of thousands of dollars. There is a huge price point difference, and the question is whether operators will be willing to spend more resources for the LTE-U capabilities, instead of using Wi-Fi access points. I cannot answer this question for you right now but it is definitely one the LTE-U vendors will need to address.

Definitely, studies show that spectrum utilization for LTE-U is more efficient than for Wi-Fi. Wi-Fi is not stopping LTE-U specification and possible deployments, and LTE-U may further increase the Wi-Fi competitiveness, in terms of the spectrum efficiency if the Wi-Fi community wants to respond. Let's see.

Monica: You raise an important point, because LTE unlicensed is going to be in the price range of LTE, and Wi-Fi has a lower cost. At the same time, you can argue that LTE unlicensed can be integrated better within the networks.

You can decide which application's traffic goes to which spectrum band in an easier way than you can do with Wi-Fi. But there's also a lot of work

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being done in integrating Wi-Fi with cellular. Can you achieve the same with Wi-Fi alone?

Seppo: At least in the past, it has been really difficult to make the cellular networks and Wi-Fi cooperate. We have ANDSF and so on, but still, the cooperation between cellular and Wi-Fi has been not as good as one could expect. You don't have this challenge with the integration between LTE and LTE unlicensed.

Ziemowit: Also there is a lot of work ongoing in the core networks. For example, technology is being developed to allow the data to be transmitted using a dual stream. If the coverage is provided by both LTE and Wi-Fi, then the data can be forwarded using both access technologies, through Wi-Fi and through LTE. This may improve spectrum efficiency, average user and peak data rates even further.

Definitely LTE-U is very interesting, that's no question, but we still do not know if and when it will be deployed, and how. To do this we will need to see the whole picture. There is need to evaluate what are the other complementary technologies available today, or being developed in parallel. The situation of today will definitely be different tomorrow.

Monica: Talking about alternatives, you want to use your licensed spectrum, too, to increase capacity. One way to go is to increase use of the 5 GHz band, but there's already Wi-Fi. Or you can go to other bands like 3.5 GHz. How does use of the 3.5 GHz band relate to LTE unlicensed? Is that a potential alternative, or a complementary solution?

Seppo: Of course, the LTE unlicensed could be used in those bands, but there's also LTE-TDD. I see, at the moment at least, a preference to use TDD as the main solution in the 3.5 GHz band.

Ziemowit: It's a very good spectrum band to be used indoors, in small-cell deployments. If you need capacity, the 3.5 GHz will be good for indoor small cells. But again, the question will be the cost of an LTE small cell versus a Wi-Fi AP.

If you are able to control the Wi-Fi coverage quality indoors, as well as the number of operators there, then the cheapest solution is currently Wi-Fi. If you are not able to control this quality, then definitely, the deployment of a clean layer in a new frequency band is the better technical solution.

Monica: How do you go about it in Ooredoo, in terms of evaluating the technology? Because from a technology point of view, LTE unlicensed is not too different from licensed LTE, but there are all other business case and spectrum availability issues.

Ziemowit: We started evaluating the strategy for LTE-U recently. We'll see how the industry evolves, and we'll be watching what's happening with the technology and what is the initial industry assessment. On the basis of these factors, we will make our decisions regarding how we move forward, although we definitely see, as well, the potential of Wi-Fi.

Monica: In terms of timeline, what is it that you expect? Let's say you decide to go ahead with LTE unlicensed; how long would it be before you can actually have it commercial?

Seppo: It will take a couple of years, because first we have to wait until standardization is ready, and before the terminals and the base stations are available. It will take a couple of years before we will see any deployment.

Monica: How about the device side? You need to have a deployment on the RAN side, but also you need to have LTE unlicensed in the handsets. Is that something that could become a challenge?

Ziemowit: It will be. We had, recently, discussions with chipset vendors. They stated that you cannot always provide any software upgrade over the air to support LTE-U in the 5GHz band. Even if you have, right now, the 5 GHz band supported for Wi-Fi in the terminal, the terminal cannot support LTE-U, because LTE-U will requires support for the new protocol. I'm not sure about the other hardware, but you require new chipsets for the terminals. Once the chipsets are available in the market, then the LTE-U capability in the real products will be available half a year later, at least.

My guess is it will be two-plus years at a minimum to have LTE-U commercially deployed.

Monica: When and if you get to the deployment of LTE unlicensed, do you expect to do any infrastructure sharing? Every mobile operator could be using the same band with LTE unlicensed. So there are some advantages to having some

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infrastructure sharing there. Is that something you'll be considering?

Seppo: For LTE unlicensed, I'm not sure if we have an opinion on that yet. Generally speaking, this is what we would do. I'm not quite sure yet what will be the case for LTE unlicensed.

Monica: You'd be open to doing infrastructure sharing on the small cells as well?

Ziemowit: If it is a viable option, why not? Any operator will be looking to minimize the cost of the deployments. You can simply turn the question back to the situation in the market. What is your position in the specific market? As with most operators our general aim is to share the networks where it makes commercial sense.

Monica: Granted that voice traffic is not the main source of traffic, it's still an important and valuable traffic source. Is the availability of VoWi-Fi going to weaken the case for LTE unlicensed?

Seppo: I will say that there is no impact, because LTE unlicensed is primarily to cope with data demand.

Monica: You'll be using LTE unlicensed to basically do the downlink, and you just select whatever application. Will it be at the application level, the policy level? How would you do the traffic steering for LTE unlicensed?

Ziemowit: I see LTE unlicensed as providing just more LTE component carriers, nothing else therefore I don't think we will necessarily be steering different services between LTE and LTE-U.

Monica: In closing, what should we expect to see over the next two, three years? What's going to be the focus of activities for the LTE unlicensed?

Ziemowit: First, finalize the specification. Second, find how to use the 5 GHz spectrum with LTE unlicensed in conjunction with the existing Wi-Fi networks. And then, definitely, there has to be the field trials and results, as well as a compelling small cell business case – which is still the most important thing to be sorted out.

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About Ooredoo

Ooredoo is a leading international communications company delivering mobile, fixed, broadband internet and corporate managed services tailored to the needs of consumers and businesses across markets in the Middle East, North Africa and Southeast Asia. As a community-focused company, Ooredoo is guided by its vision of enriching people's lives and its belief that it can stimulate human growth by leveraging communications to help people achieve their full potential. Ooredoo has a presence in markets such as Qatar, Kuwait, Oman, Algeria, Tunisia, Iraq, Palestine, the Maldives, Myanmar and Indonesia. The company was named "Best Mobile Operator of the Year" at the World Communication Awards 2013. The company reported revenues of US$ 9.1 billion in 2014 and had a consolidated global customer base of more than 107 million people as of 31 December 2014. Ooredoo's shares are listed on the Qatar Exchange and the Abu Dhabi Securities Exchange.

About Ziemowit Neyman

Ziemowit Neyman is currently employed at Ooredoo Qatar as Assistant Director RAN. He has over 20 year experience in the wireless industry and has had exposure to several positions at other leading operators and vendors. He holds an M.Sc. Electrical Engineering from University of Dresden, Germany.

About Seppo Hämäläinen

Seppo Hämäläinen received his M.Sc. degree in Electrical Engineering from Lappeenranta University of Technology, Finland in 1994 and a Ph.D. degree in Electrical Engineering from Jyväskylä University, Finland in 2003. He joined Nokia in 1993, where he worked in various research and research management positions until 2013. In 2013 he joined Ooredoo Group, Qatar, as Assistant Director SON and Tools. He is author or co-author of 50 scientific journal papers, conference papers, book chapters, and 19 independent patents.

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Tele2: Maximizing the use of unlicensed spectrum with Wi-Fi today, LTE later

A conversation with Joachim Horn, EVP and Group CTO, Tele2

Monica Paolini: Good morning. Welcome to our conversation with Joachim Horn, at the mobile operator Tele2. He is its EVP and group CTO. Today we're going to talk about LTE unlicensed, and the role it plays within the ecosystem and services of a mobile operator.

Joachim, thanks for taking the time to talk to us today.

Joachim Horn: It's a pleasure.

Monica: Joachim, what is your role at Tele2, especially with respect to different radio interfaces such as Wi-Fi, 3G and LTE?

Joachim: Tele2 is an operator in Scandinavia, based in Sweden. We are operating in nine countries in northeastern Europe, and also in Kazakhstan. We are a low-cost operator.

We are a fast mover and a challenger. Our tagline is "We deliver what you need, but for less." We are always looking for how can we get more efficient in order to give our customers a better service. In this context, you also need to see how we approach the strategy for radio interfaces.

Also, we are a fast mover on LTE. We're already rolling out LTE in six countries. In Sweden, we have 99% population coverage over the past year. The experience is outstanding.

LTE brings together exactly what we want – superior user experience and low production cost. This is the reason why, strategically, we see LTE as the future standard for cellular for the years to come. We see customers migrating from 2G and 3G, to LTE relatively quickly.

When it comes to spectrum on the unlicensed band, it's mainly Wi-Fi. We are a big fan of Wi-Fi. Actually, we are selling hotspots that are LTE on the one side and Wi-Fi on the other, and it's being used in Sweden in more than 100,000 cases. There are many Wi-Fi hotspots out there which use LTE from Tele2 as a backup.

Wi-Fi is extremely important for our customers. More than 70% of data today goes over Wi-Fi. We are very interested in whatever comes in the future in this unlicensed band, and we want to make sure it does not harm our customers, as they need to be able to use Wi-Fi.

There is a lot of spectrum out there, in particular in the 5 GHz band, for unlicensed use. Today it's mainly used with Wi-Fi. With LTE unlicensed we have to answer the question of whether we should use LTE also in the unlicensed band.

The benefit for that would be that LTE unlicensed will be much more efficient in terms of coordination with the licensed bands, and generate a much better user experience.

Why do we need that? Because 70% to 80% of usage happens indoors, in particular when it comes to broadband.

Now, indoor coverage, in particular with high capacity, is not easy to get. Today operators try to do it from outside, building big base stations and blast through the wall to reach inside, but it doesn't work when it comes to high capacities. Then there is a need for indoor coverage with indoor antenna systems, or pico cells and so on, which is an extremely costly game.

The question is, how can we approach this in a more cost-efficient way? The number one step would be actually to make more use of Wi-Fi, to coordinate the use of Wi-Fi with LTE in a much better way.

In the long run it's very attractive to think about in parallel to Wi-Fi, without jeopardizing the Wi-Fi quality, to also put LTE into the unlicensed band and combine it with the licensed band, and by doing that get much better coverage and also capacity, deep indoors, which will lead to a much better user experience for our customers.

Monica: We often think about LTE unlicensed as a competitor to Wi-Fi, but at the same time it's a fact

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of life that pretty much all mobile operators rely on Wi-Fi in one way or another.

LTE unlicensed and Wi-Fi can coexist in the same location, so it's not residential Wi-Fi and LTE unlicensed.

Joachim: Yes. There would not be any benefit for operators if we would mess with the Wi-Fi camp. Wi-Fi is a consumer, noncellular wireless standard, which has extremely high value to our customers and also to our operators. We have no interest in endangering that situation or even getting into a political fight about what's right.

I think an unlicensed LTE standard will only have a chance if it is ensured that it has no impact on Wi-Fi. That's what's happening currently in the discussions with operators in the standardization process. We look for technologies that are available and make sure that they can coexist.

The first performance measurements I've seen from different companies show we can get an excellent LTE performance without a major impact on the existing Wi-Fi. It's using technologies that we all know now in Wi-Fi – for example, listen before talk. It is using the same low power, so there is not a strong LTE signal and weak Wi-Fi signal. They are working on the same power levels.

There are other methods, like dynamic frequency selection, that help to avoid conflicts between a Wi-Fi transmission and LTE transmission.

Monica: You said the LTE unlicensed shouldn't create any major impact on the Wi-Fi. What impact do you consider to be acceptable?

Joachim: In the 5 GHz band, there is 300 to 400 MHz of bandwidth. The Wi-Fi channel is typically 20 MHz to 40 MHz wide, maybe 80 MHz. The LTE channel is typically 20 MHz, maybe 40 MHz.

Wi-Fi and LTE will compete with each other over this spectrum. But it's not like LTE takes the spectrum and holds it for all time. The spectrum is only allocated during transmission. Then it's being given back.

It's random access. It's like Ethernet: many people can use the same cable, and there are methods to avoid collisions, to detect if somebody else is sending and receiving.

From a Wi-Fi perspective, it's as if another Wi-Fi station would enter the scene. From an LTE perspective, I have additional spectrum I can use with the LTE technology and interface, which is a little bit more efficient than Wi-Fi. We expect 50% more efficiency here.

Monica: As long as it behaves like Wi-Fi, that's good enough. Do you think the listen-before-talk regulation, which is prevalent in Europe and Asia, is sufficient to ensure this?

Joachim: I think we have not dug down to all the details of coexistence. I think this is still in the research. I obviously cannot speak for the regulator, but I think there must be an intent to make sure each of the technologies and services can coexist without endangering the other side.

I'm sure that the regulators will look to that. Listen before talk is a good technology. It's definitely a good start to prevent LTE from taking it all and then there's nothing left for Wi-Fi. The first trials have shown us that this is a good way to progress; whether it's sufficient or not, difficult to say.

Monica: You said that with LTE unlicensed you get a better user experience. Where is the improvement coming from?

Joachim: Wi-Fi is a relatively old standard. It has been developed further and further, with MIMO, beamforming, and Wi-Fi ac and Wi-Fi ad coming in. LTE is much younger. LTE is more robust. It's built from a telco-grade perspective, whereas Wi-Fi comes from a totally other area, more a best-effort area.

I think also that the experience on LTE is related to how to deal with radio and spectrum. It's very sophisticated, was not built for consumers originally. But now, with LTE unlicensed, there's a chance to go more into that space for consumers.

Monica: Now, when you have to allocate, you're going to have the same indoor location venue, where you have licensed and unlicensed LTE, and Wi-Fi. How do you split the traffic? How do you decide which subscriber or which application is allocated to which radio interface?

Joachim: First of all, if you are an operator, that's the part of the design which needs to happen still.

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But it's all about the control plane and the control mechanisms behind it.

Unlicensed LTE will be just an extension to licensed LTE. You will never leave the licensed LTE for unlicensed LTE.

The phone detects there is an unlicensed band, and it will add that band. This means increased capacity, and probably also coverage, compared to if you just stick with the licensed band.

It is not intended to only roam on the unlicensed band. Of course, a user can always decide to switch to the phone to the normal Wi-Fi mode. That's in the user's hands.

Monica: Do you have any plans to manage traffic depending on the applications – for instance, to keep voice on licensed, or video on Wi-Fi?

Joachim: The idea is to keep the real-time services in the licensed band, because the conditions will be more predictable and reliable, and because the unlicensed band has an undefined interference situation. For video streaming, downloads and internet access, you would move to the unlicensed band.

LTE unlicensed is obviously a very interesting technology. It will not be available any time soon. We need to be realistic. Standardization just has started.

It will take two years to develop the equipment. Then it will take a while until we have devices supporting that. My estimation is that before three to four, or maybe five years, LTE unlicensed will not play a major role.

As an operator, we are looking at the question "How can we make more use of Wi-Fi?" Improving the combination of Wi-Fi and LTE – both existing technologies – does not need a new phone or a new chipset to be developed.

One of the first things we are looking at is, obviously, VoWi-Fi. Today, at least in densely populated areas, there is Wi-Fi practically in all buildings. Then, even if you have a coverage issue with your micro-network, you could continue a voice call on Wi-Fi.

We all have seen that the iPhone is now supporting VoWi-Fi, giving the technology a new dynamic. We are now starting a trial to see how we can integrate that, and how big the value would be for us.

I see a big benefit, before moving even to use LTE unlicensed when it's available. Today it's already a big benefit to add the capacity of Wi-Fi to what you have in 3G and 4G for both voice and data, before we move to LTE unlicensed for data.

Monica: You were talking about the timeline, and one of the concerns that I hear is about the availability of devices, because, as you say, you cannot use your current phone to use LTE unlicensed. Do you think that's going to be an issue down the line?

Joachim: GSM was named "God send mobiles," because the standard was there but it took years until the mobile devices were there. We had the same in 3G.

With 4G, it was not so bad – we had the devices. Now, when it comes to LTE Advanced, with carrier aggregation announced one or two years ago, still there are only a few phones supporting it, although CA is a very good feature.

I expect the same to happen with LTE unlicensed. We need to add to the phone another frequency band, the 5 GHz one, which phones don't have for the cellular yet.

A new chipset is required. We need to be able to run 5 GHz in parallel to other bands, because LTE unlicensed will be used together with LTE licensed.

That's a number of requirements which need to be developed and also put into the phone in a very power-efficient manner. At the same time, once you need to deploy base stations, is LTE unlicensed built into the macro base station?

It makes not too much sense, because the output power is a fraction of that in a macro cell. You need separate base stations to deploy indoors, instead of Wi-Fi or in a combination with Wi-Fi, so we are talking about pico-, femto-cell technologies.

There is the question still about economics, because what LTE unlicensed does not do is change the economics of small cells. It is only interesting if this can be deployed in the way we deploy to the Wi-Fi.

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Actually, we don't deploy Wi-Fi. In the consumer case, typically, the end user deploys the Wi-Fi hotspot because he has a cable connection with the Wi-Fi there, and it works.

That's a very cost-efficient way to deploy Wi-Fi. If we, as operators, go to private houses, that's very unrealistic. Of course, in public buildings, we do indoor coverage anyway. Then it's relatively easy to add this kind of technology.

It is very interesting to expand the use also to the private houses – in particular, big houses – and the new buildings, with the thermal glazed windows, where it's very difficult to cover from outside.

Monica: In the case of residential, could you have a model like the one for femto cells, where the cost is sufficiently low that subscribers buy the Wi-Fi access points that support LTE unlicensed?

Joachim: Yeah, I think the economics and the dynamics should be the same. The question is, why did that not work for femto cells? Why did femto cells not get much greater traction? Because the price point of femto cells is now reasonably low.

I remember the first discussions, four of five years ago, where the discussion was "Let's put the femto cells into the shop next to the Wi-Fi router, or integrate into the Wi-Fi router, and just sell it to the customer or give it away subsidized, and then by that make sure we can improve coverage."

It has been done. We did it in some countries, on a very small scale, more in the B2B environment, but the big deployment never happened.

One of the reasons was that we had a lot of interference issues with femto cells, because they used the same band as micro cells.

With unlicensed LTE that could be better. Still, the economics need to be solved. How do we distribute that? How do we make the price point low enough in order to make it attractive?

Monica: How much would residential users gain from having LTE unlicensed in their home, when the bottleneck is the broadband connection?

Joachim: That's a fair point. At the end of the day what LTE unlicensed would bring is definitely much-more-reliable services, in terms of robustness against interference. Wi-Fi is much more sensitive against interference from the surroundings.

Here in my house, for example, if I check Wi-Fi ac, I find 50 Wi-Fi hotspots using the same band. It makes it very difficult to get good performance. The LTE unlicensed technology is more robust against this kind of interference.

With LTE unlicensed there will better service for the end user. But how to make sure this is attractive to users needs to be found. It is very much dependent on the economics, and on the cost of such devices.

Monica: Can you tell us about what you have done so far in terms of testing the technology, looking at how it performs, and what are your plans for the future?

Joachim: We have not yet started to test LTE unlicensed; we are a low-cost operator and we are relatively lean. But we engage in the discussion with vendors and fellow operators. Also, we think a lot about how to solve the indoor coverage problem, and also the potential capacity problem.

Everybody is talking about 1,000x more data by 2020, and of course all of us need to think about how we get this done if we don't get more spectrum. Then these technologies are very attractive, because all you need to deploy them is a hotspot.

You don't need to build wide coverage, but wherever you have a high density of traffic you could use that technology to offload.

I have no doubt that LTE unlicensed will perform well, because it is the same technology we use in the licensed band; it is just a different band with some adjustments, lower power and compatibility with Wi-Fi.

There is no reason to believe that it wouldn't work. The trial does not need to show whether it works or not. It is more about the economics. What are the deployment scenarios? What's the business case behind it?

Monica: When deploying it indoors, you are dealing with enterprise or real estate owners that might have their own Wi-Fi network, and then are going to be very protective of your Wi-Fi network.

You expect them to visit this and say, "Hold on, before you come in and you use the same

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frequency that I use, I want to be really sure, or I might not want you because you might create interference with me." Do you expect that to become an issue?

Joachim: It may become an issue. Today we have cases where some landlords do not want anything else to be deployed beyond what they have deployed. Therefore, I'm coming back to what I said earlier: it's very important that we are flexible, and we can also work with Wi-Fi.

This is a much lower-hanging fruit. It is easier to get a combination of the normal Wi-Fi consumers have at home, with tighter integration or collaboration with the cellular standard.

There are a number of features coming on the Wi-Fi side with automatic sign-on, and much faster registration procedures and so on, with Hotspot 2.0. There are a lot of things coming which will make it more attractive to operate.

The benefit is that you don't need new chipsets. It's not a new frequency. The things are there and probably easier also to get around when the landlord insists on deploying their old technology, which is their right.

Monica: In closing, can you tell me what you think are the challenges for LTE unlicensed to succeed?

Joachim: It's very important to think about the use cases, because we should not do LTE unlicensed just because we can do it. We should be very conscious about exactly some of the discussions we've just had.

What are the deployment scenarios? What is the business case behind them? Is the economic model of such a technology better than any other small-cell technology? If not, the likelihood that it succeeds is as big as any other small-cell technology we have seen today. It's another spectrum band.

I believe there are good opportunities in it, and by working today already with Wi-Fi and VoWi-Fi, we take a first step in this direction. The use of the unlicensed band will probably play a much bigger role in the upcoming 5G networks.

Watch the video of this interview.

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About Tele2

Tele2 is one of Europe's fastest growing telecom operators, with 14 million customers in 9 countries. Tele2 offers mobile communication services, fixed broadband and telephony, data network services and content services. Ever since Jan Stenbeck founded the company in 1993, Tele2 has been a tough challenger to former government monopolies and other established providers. Tele2 has been listed on the NASDAQ OMX Stockholm since 1996. In 2014, Tele2 had net sales of SEK 26 billion and reported an operating profit (EBITDA) of SEK 5.9 billion.

About Joachim Horn

Joachim Horn is Executive Vice President and the Group Chief Technology and Information Officer of the Tele2 Group headquartered in Stockholm, Sweden. He also serves as a chairman of the board of two affiliate companies to Tele2, ProcureItRight, a leading procurement management consultancy in the Nordic region, and Net4Mobility, a joint venture between Telenor Sweden and Tele2, operating the world's first shared 2G/4G radio network in Sweden. Joachim has over thirty years of global experience in the telecommunications market both from an infrastructure vendor and telecom operator perspective. He has worked and lived in emerging as well as developed markets. Joachim Horn also served as a GSMA board member and was the chairman of the GSMA strategy committee.

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Further reading

3GPP (2013) Technical Specification Group Radio Access Network; Scenarios and requirements for small cell enhancements for E-UTRA and E-UTRAN (Release 12).

3GPP (2014) Study on Licensed-Assisted Access to Unlicensed Spectrum, 3GPP RP-141817.

Alcatel-Lucent (2015) Wireless Unified Networks blending Wi-Fi and cellular technologies.

FCC (2014) Revision of Part 15 of the Commission's Rules to Permit Unlicensed National Information Infrastructure (U-NII) Devices in the 5 GHz Band, FCC 14-30.

FCC (2014) Revision of Part 15 of the Commission's Rules to Permit Unlicensed National Information Infrastructure (U-NII) Devices in the 5 GHz Band. First Report and Order, ET Docket No. 13-49.

FCC (2015) Office of Engineering and Technology and Wireless Telecommunications Bureau Seek Information on Current Trends in LTE-U and LAA Technology, ET Docket No. 15-105.

Flore, Dino (2015) 3GPP and the unlicensed spectrum.

Hratko, Steve (2015) Getting engaged: LTE and Wi-Fi fall in love, The Ruckus Room.

Huawei (2014) U-LTE: Unlicensed spectrum utilization of LTE.

Intel (2014) LTE System Deployment and Performance in Unlicensed Bands.

LTE-U Forum (2015) LTE-U SDL Coexistence Specifications.

LTE-U Forum (2015) LTE-U Technical Report. Coexistence Study for LTE-U SDL.

McKibben, Bernie; Kyung Mun; and Rob Alderfer (2014) LTE-Unlicensed: Augmenting mobile data capacity, but coexistence needs consideration, Cable Television Laboratories, Inc.

Murias, Ron (2014) LTE-U Coexistence Mechanisms, InterDigital.

Nguyen, Tho (2014) New Rules for Unlicensed National Information Infrastructure (U-NII) Bands KDB 789033, KDB 644545, FCC.

Nielsen, Sari, and Antti Toskala (2014) LTE in unlicensed spectrum: European regulation and co-existence considerations, Nokia.

Nokia (2014) LTE for unlicensed spectrum.

NTT DOCOMO (2014) NTT DOCOMO's views on LAA for unlicensed spectrum: scenarios and initial evaluation results.

NTT DOCOMO (2014) NTT DOCOMO's views on LTE unlicensed.

Padden, Joey (2015) Wi-Fi vs. EU LBT: Houston, we have a problem, Cable Television Laboratories, Inc.

Qualcomm (2013) Extending LTE Advanced to unlicensed spectrum.

Qualcomm (2013) Introducing LTE in unlicensed spectrum.

Qualcomm Research (2014) LTE in unlicensed spectrum: Harmonious coexistence with Wi-Fi.

Ruckus Wireless (2015) Making sense of convergence: LTE-U, LAA-LTE, and LWA.

Wright, Dave (2015) When worlds collide, and When worlds collide: digging deeper, The Ruckus Room.

Glossary

3G	Third generation
3GPP	Third Generation Partnership Project
4G	Fourth generation
ANDSF	Access network discovery and selection function
AP	Access point
API	Application programming interface
ARPU	Average revenue per user
ARQ	Automatic Repeat-reQuest
ASA	Authorized Shared Access
BS	Base station
CA	Carrier aggregation
CCA	Clear channel assessment
CG	Coexistence gap
CPP	Coexistence pattern period
CQI	Channel quality information
CSAT	Carrier Sensing and Adaptive Transmission
CWG-RF	Converged Wireless Group–Radio Frequency
DAS	Distributed antenna system
DFS	Dynamic frequency selection
DL	Downlink
EAP	Extensible Authentication Protocol
EMS	Element management system
eNB	Evolved NodeB
E-UTRA	Evolved Universal Terrestrial Radio Access
FCC	Federal Communications Commission
FDD	Frequency division duplex
FEC	Forward error correction
GSM	Global System for Mobile Communications
GSMA	GSM Association
HeNB	Home eNodeB
HetNet	Heterogeneous network
IEEE	Institute of Electrical and Electronics Engineers
IOT	Interoperability testing
IoT	Internet of things
IP	Internet Protocol
ISM	Industrial, scientific and medical
ISP	Internet service provider
ITU	International Telecommunication Union
LAA	Licensed-assisted access
LAA-LTE	Licensed-assisted access Long Term Evolution
LBT	Listen before talk
LSA	Licensed Shared Access
LTE	Long Term Evolution
LTE-FDD	LTE frequency-division duplex
LTE-TDD	LTE time-division duplex
LTE-U	LTE Unlicensed (LTE-U Forum specs)
LWA	LTE Wi-Fi Aggregation
MAC	Media Access Control [layer]
MIMO	Multiple input, multiple output
MNO	Mobile network operator
MSO	Multiple-system operator
OEM	Original equipment manufacturer
PCRF	Policy and charging rules function
PHY	Physical (layer)
QoS	Quality of service
RAN	Radio access network
RAT	Radio access technology
RF	Radio frequency
RFIC	Radio frequency integrated circuit
RRM	Radio resource management
SaaS	Software as a service
SCG	Small-cell gateway
SDL	Supplemental Downlink
SIM	Subscriber Identity Module
SLA	Service-level agreement
SoC	System on a chip
SON	Self-organizing network
SSID	Service Set Identifier
STA	Station
SU	Secondary user
SW	Software
TCO	Total cost of ownership
TDD	Time-division duplex
Toff	Transmission off
Ton	Transmission on
TPC	Transmit power control
TSG-RAN	Radio Access Network Technical Specification Group
Tx	Transmission
UE	User equipment
UL	Uplink
U-NII	Unlicensed National Information Infrastructure
VAR	Value-added reseller
VoIP	Voice over Internet Protocol
VoLTE	Voice over LTE
VoWi-Fi	Voice over Wi-Fi
WISP	Wireless internet service provider
WLAN	Wireless local area network
WMM	Wi-Fi Multimedia
WPA	Wi-Fi Protected Access

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We provide a bridge between technologies and services, helping our clients assess established and emerging technologies, leverage these technologies to support new or existing services, and build solid, profitable business models. Independent advice, a strong quantitative orientation, and an international perspective are the hallmarks of our work. For additional information, visit www.senzafiliconsulting.com or contact us at info@senzafiliconsulting.com or +1 425 657 4991.

About the interviewer

Monica Paolini, PhD, is the founder and president of Senza Fili. She is an expert in wireless technologies and has helped clients worldwide to understand technology and customer requirements, evaluate business plan opportunities, market their services and products, and estimate the market size and revenue opportunity of new and established wireless technologies. She has frequently been invited to give presentations at conferences and has written several reports and articles on wireless broadband technologies. She has a PhD in cognitive science from the University of California, San Diego (US), an MBA from the University of Oxford (UK), and a BA/MA in philosophy from the University of Bologna (Italy). She can be contacted at monica.paolini@senzafiliconsulting.com.

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